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The efficiency of microbial preparations in different systems of fertilizing crops

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Goal. To investigate the efficiency of microbial preparations in the cultivation of crops in crop rotation with different fertilizer systems. **Methods.** A field experiment, statistical. **Results.** The use of microbial preparations for pre-sowing inoculation of seeds of crops contributed to the growth of productivity of agricultural lands, however, the effectiveness of such measures depended on fertilizer systems. Bacterization increased the yield of potato, barley and pea at the cultivation of the crops on the background of low and medium mineral soil fertility, and especially for the combination of fertilizer with the effect and after-effect of use of 5 t/ha of wheat straw, and lupin as intermediate green manure. Preplant bacterization of winter wheat was effective in all studied doses of fertilizers and intensified on the background of the after-effect of straw and green manure. With the organic fertilizer system, the efficiency of microbial preparations depended on the kind of organic fertilizer. The low stimulating effect of the preparations was provided on the background of 5 t/ha of straw. In the year of the direct action of 40 t/ha of bedding manure of cattle, the efficiency of bacterization was leveled. In subsequent years (for the after-effect of fertilizers) the growth of yields was reliable, but the smallest among the studied agricultural backgrounds. A high stimulating effect was observed when growing bacterized plants on green manure agricultural background and for the combination of straw with green manure biomass. **Conclusions.** The use of microbial preparations for pre-sowing bacterization of seeds is an effective agricultural measure in the techniques of cultivation of crops, but their influence on the productivity of agrocenoses depends on the fertilizer system.

Key words: *biological products, mineral fertilizers, straw, green manure crops, manure, crop rotation, potato, barley, pea, wheat.*
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In the soil-microorganisms-plant system the soil bacteria and microscopic fungi play essential and an integral role. The plant backed up with a full complex of microorganisms, actively develops roots, receives from the soil nutrients in easily digestible form and physiologically active compounds, that positively influence its production process. However, due to unjustified use of mineral fertilizers, pesticides, failures of follow crop rotation, etc. most soils in modern agrocenosis have distorted composition of microorganisms, requiring urgent correction [1 – 8]. The optimum solution of this problem is the use of microbial preparations, created on the basis of selected active strains of microorganisms.

Analysis of recent researches and publications. Various scientific centers have developed biological preparations for most crop types, including non-legumes [9 – 18]. Numerous field and production experiments, lysimeter installations, ^{15}N research studies etc. have proved that effect of biologicals on the production process of crops may be equivalent to 30 – 60 kg/ha of mineral nitrogen and 15 – 30 kg/ha of phosphorus [12]. This is due to the increasing absorption level of the active substances from fertilizers and the improvement of constructive metabolism of crops, when plant mineral compounds actively being used in the synthesis of organic substances [19 – 21]. However, quite often the production does not note the positive effects of inoculation. This can be explained by different factors, case wise, but with systems of crops fertilizing playing an important part.

The goal of research is to study the efficacy of microbial preparations on crops cultivation in rotation under the use of different fertilizing systems.

Materials and methods. The research was conducted during 2016 – 2018 in a stationary (started in 2009) experimental field of the Institute of Agricultural Microbiology and Agroindustrial Manufacture, NAAS, on leached chernozem, under short crop rotations scheme (potato – spring barley – pea – winter wheat).

The agrochemical characteristics of soil were as follows: pH_{salt} – 5.3; humus content – 3.03 %; easily hydrolysable nitrogen – 95 mg/kg of soil; mobile phosphorus compounds (P_2O_5) – 150 mg/kg of soil (by Kirsanov); exchangeable potassium (K_2O) content (by Kirsanov) – 108 mg/kg of soil.

The crops were grown in the two blocks – with and without the inoculation with the selected microbial preparations. Crops inoculation was performed with the following biologicals: Biohran, for potato (TU U 24.1-00497360-006:2009) Microhumin, for spring barley (TU U 24.1-00497360-007:2009), Rhizohumin, for pea (TU U 24.1-00497360-003:2007) and Polymyxobacterin, for winter wheat (TU U 24.1-00497360-004:2009). All biological preparations are registered in the Ministry of Environmental Protection of Ukraine and permitted for use in agriculture.

Potatoes of Skarbnytsia variety were grown by the following scheme: 1 – without fertilizers; 2 – straw; 3 – green manure; 4 – manure; 5 – straw + green manure; 6 – manure + green manure; 7 – $N_{40}P_{40}K_{40}$; 8 – $N_{40}P_{40}K_{40}$ + straw + green manure; 9 – $N_{80}P_{80}K_{80}$; 10 – $N_{80}P_{80}K_{80}$ + straw + green manure; 11 – $N_{120}P_{120}K_{120}$; 12 – $N_{120}P_{120}K_{120}$ + straw + green manure; 13 – manure + $N_{40}P_{40}K_{40}$; 14 – manure + green manure + $N_{40}P_{40}K_{40}$.

Spring barley of Hosia variety was grown by the following scheme: 1 – without fertilizers; 2 – straw*; 3 – green manure*; 4 – manure*; 5 – straw* + green manure*; 6 – manure* + green manure*; 7 – $N_{30}P_{30}K_{30}$; 8 – straw* + green manure* + $N_{30}P_{30}K_{30}$; 9 – $N_{60}P_{60}K_{60}$; 10 – straw* + green manure* + $N_{60}P_{60}K_{60}$; 11 – $N_{90}P_{90}K_{90}$; 12 – straw* + green manure* + $N_{90}P_{90}K_{90}$;13 – manure* + $N_{60}P_{60}K_{60}$; 14 – manure* + green manure* +$N_{60}P_{60}K_{60}$ (note: * – first year after-effect of organic matter).

Pea plants of Hotivskyi variety were cultivated following by the following scheme: 1 – without fertilizers; 2 – straw**; 3 – green manure**; 4 – manure**; 5 – straw** + green manure**; 6 – manure** + green manure**; 7 – $N_{30}P_{30}K_{30}$; 8 – straw** + green manure** + $N_{30}P_{30}K_{30}$; 9 – $N_{60}P_{60}K_{60}$; 10 – straw** + green manure** + $N_{60}P_{60}K_{60}$; 11 – $N_{90}P_{90}K_{90}$; 12 – straw** + green manure** + $N_{90}P_{90}K_{90}$; 13 – manure** + $N_{30}P_{30}K_{30}$; 14 – manure** + green manure** + $N_{30}P_{30}K_{30}$ (note: ** – second year after-effect of organic matter).

Winter wheat of Poliska 90 variety was grown by the following scheme: 1 – without fertilizers; 2 – straw***; 3 – green manure***; 4 – manure***; 5 – straw*** + green manure***; 6 – manure*** + green manure***; 7 – $N_{30}P_{30}K_{30}$; 8 – straw*** + green manure*** + $N_{30}P_{30}K_{30}$; 9 – $N_{60}P_{60}K_{60}$; 10 – straw*** + green manure *** + $N_{60}P_{60}K_{60}$; 11 – $N_{90}P_{90}K_{90}$; 12 – Straw * * * + green manure*** + $N_{90}P_{90}K_{90}$; 13 – manure*** + $N_{30}P_{30}K_{30}$; 14 – manure*** + green manure*** + $N_{30}P_{30}K_{30}$ (note: *** – third year after-effect of organic matter).

Raw fresh organic matter was introduced prior to the planting of potatoes. The chopped straw in the amount of 5 t/ha was incorporated into the soil immediately after harvesting of winter wheat (in the crop rotation — the predecessor of potatoes) using disks, followed by the intermediate green manure crop *Lupinus angustifolia* (where applicable). The raw green mass of lupine (13 – 15 t/ha depending on the years of the study) was incorporated into the soil through disking and shallow (15 cm) ploughing in late fall (end of November). At the same time, the bedding cattle manure was incorporated into the soil on the appropriate variants at the rate of 40 t/ha.

The area of the research site is 43.2 m^2 (7.2 × 6.0), 4-fold repetition. Experiments planning and conducting were carried out following B. Dospekhov [22]. The statistical processing of the experimental data was performed using the dispersing analysis method in Microsoft Office Excel 2003 – 2007 software.

Research results. The yield of potatoes has increased under the crop cultivation in all studied fertilizing systems (table. 1). However, it was noticed that the efficiency of microbial preparation Biohran was subject to fertilizing background.

Cultivation of inoculated potatoes with mineral fertilizers have resulted in some of the largest yield gains throughout the experiment. At the same time, it should be emphasized, that the effectiveness of the Biohran preparation has reduced with the increasing norm of mineral fertilizers. In part, this negativity trend was neutralized through the application of complex mineral fertilizers on the background of the combined use of straw and lupine green manure, which is likely due to the prolonged action of mineral nitrogen by its temporary immobilization with a fresh organic substance with a wide C/N ratio.

Potatoes cultivation on the wheat straw background has not resulted in reliable yield increase. In contrast, a significant increase in the productivity of agrocenosis from the use of Biohran was observed in the variant with green manure. Especially high efficiency of biological was observed on the “straw + green manure” background, leading to the largest yield increase noticed in the experiment – 3.5 t/ha.

Over the study years, no yields increase from bacterization was observed in the tests with potatoes grown on the background of 40 t/ha cattle manure. Low, if any, effectiveness of biopreparation can be explained by high pool of microorganisms introduced into the soil with the manure. Thus, the attempts to introduction the selected bacteria into the agrocenosis under these circumstances can have a strong competition, which will prevent the formation of the plant-bacteria associations. Through the manure application the soil was inoculated for the centuries making the additional inoculation means ineffective.

Even in the late XIX century. V. Dokuchaev wrote that a large number of microorganisms are introduced into the soil with the manure, playing an equally important role with fertilizers [23].

1. Effect of fertilizing and inoculation on potato crop yield

Variants	Yield, t/ha (average for three years)	Increase from fertilizer and inoculation, t/ha	Increase from inoculation, t/ha
Without inoculation			
Without fertilizers, control	13,0	–	–
Straw	13,4	0,4	–
Green manure	14,6	1,6	–
Manure	22,8	9,8	–
Straw + green manure	16,2	3,2	–
Manure + green manure	24,0	11,0	–
$N_{40}P_{40}K_{40}$	15,7	2,7	–
$N_{40}P_{40}K_{40}$+ green manure	21,1	8,1	–
$N_{80}P_{80}K_{80}$	24,6	11,6	–
$N_{80}P_{80}K_{80}$+ green manure	29,1	16,1	–
$N_{120}P_{120}K_{120}$	29,2	16,2	–
$N_{120}P_{120}K_{120}$+ green manure	34,2	21,2	–
Manure + $N_{40}P_{40}K_{40}$	29,4	16,4	–
Manure + $N_{40}P_{40}K_{40}$+ green manure	31,6	18,6	–
With Biohran			
Without fertilizers	14,7	–	1,7
Straw	14,3	1,3	0,9
Green manure	16,5	3,5	1,9
Manure	23,1	10,1	0,3
Straw + green manure	19,7	6,7	3,5
Manure + green manure	25,9	12,9	1,9
$N_{40}P_{40}K_{40}$	18,1	5,1	2,4
$N_{40}P_{40}K_{40}$+ green manure	23,8	10,8	2,7
$N_{80}P_{80}K_{80}$	26,1	13,1	1,5
$N_{80}P_{80}K_{80}$+ green manure	30,8	17,8	1,7
$N_{120}P_{120}K_{120}$	30,5	17,5	1,3
$N_{120}P_{120}K_{120}$+ green manure	35,8	22,8	1,6
Manure + $N_{40}P_{40}K_{40}$	30,1	17,1	0,7
Manure + $N_{40}P_{40}K_{40}$+ green manure	33,0	20,0	1,4
LSD_{05}	1,1		

The combination of manure with a low norm of fertilizers in the experiment also has not ensured the performance of biopreparation. Only its combination with the green manure contributed to the reliable increase in potatoes yield (see Table 1).

The effectiveness of microbial preparation Microhumin was observed in all studied variants (Table 2) with spring barley cultivation after the first year of aftereffect of organic and direct action of mineral fertilizers. However, the observed yield increase was one of the smallest in the experiment for the cattle manure after effect.

2. Influence of fertilizing and inoculation on yield of spring barley

Variants	Yield, t/ha (average for three years)	Increase from fertilizer and inoculation, t/ha	Increase from noculation, t/ha
Without inoculation			
Without fertilizers, control	2,07	–	–
Straw*	2,21	0,14	–
Green manure*	2,41	0,34	–
Manure*	3,40	1,33	–
Straw* + green manure*	2,67	0,60	–
Manure* + green manure*	3,64	1,57	–
$N_{40}P_{40}K_{40}$	2,56	0,49	–
$N_{40}P_{40}K_{40}$+ green manure*	3,26	1,19	–
$N_{80}P_{80}K_{80}$	2,94	0,87	–
$N_{80}P_{80}K_{80}$+ green manure*	3,56	1,49	–
$N_{120}P_{120}K_{120}$	3,57	1,50	–
$N_{120}P_{120}K_{120}$+ green manure*	3,89	1,82	–
Manure + $N_{40}P_{40}K_{40}$	4,02	1,95	–
Manure + $N_{40}P_{40}K_{40}$+ green manure*	4,17	2,10	–
With Microhumin			
Without fertilizers	2,53	0,46	0,46
Straw*	2,69	0,62	0,48
Green manure*	2,90	0,83	0,49
Manure*	3,64	1,57	0,24
Straw + green manure*	3,25	1,18	0,58
Manure + green manure*	4,02	1,95	0,38
$N_{40}P_{40}K_{40}$	3,06	0,99	0,50
$N_{40}P_{40}K_{40}$+ green manure*	3,75	1,68	0,49
$N_{80}P_{80}K_{80}$	3,40	1,33	0,46
$N_{80}P_{80}K_{80}$+ green manure*	3,99	1,92	0,43
$N_{120}P_{120}K_{120}$	3,80	1,73	0,23
$N_{120}P_{120}K_{120}$+ green manure*	4,10	2,03	0,21
Manure* + $N_{40}P_{40}K_{40}$	4,26	2,19	0,24
Manure* + $N_{40}P_{40}K_{40}$+ green manure*	4,46	2,39	0,29
LSD_{05}	0,21		

*) first year aftereffect of organic fertilizers

High efficiency of pre-sowing inoculation of barley seeds was noted in the test plots with the aftereffect of all other types of organic fertilizers, and especially lupine green manure. Low and medium norms of mineral fertilizers also provided significant increments of crop yield – 0.46 – 0.50 t/ha. Whilst high norm of mineral fertilizers has significantly decreased the efficiency of Microhumin.

Peas cultivation on the second-year after-effects of organic fertilizers with the microbial preparation Rhizohumin has significantly increase the crop yield by 0.30 – 0.35 t/ha (Table 3). Also, the preparation action was not masked with the action of the cattle manure after-effect.

3. The effect of fertilizing and inoculation on the yield of peas

Variants	Yield, t/ha (average for three years)	Increase from fertilizer and inoculation, t/ha	Increase from inoculation, t/ha
Without inoculation			
Without fertilizers, control	2,16	–	–
Straw**	2,33	0,17	–
Green manure**	2,38	0,22	–
Manure**	2,44	0,28	–
Straw** + green manure**	2,38	0,22	–
Manure** + green manure**	2,58	0,42	–
$N_{40}P_{40}K_{40}$	2,70	0,54	–
$N_{40}P_{40}K_{40}$+ green manure**	2,87	0,71	–
$N_{80}P_{80}K_{80}$	2,95	0,79	–
$N_{80}P_{80}K_{80}$+ green manure**	3,15	0,99	–
$N_{120}P_{120}K_{120}$	3,19	1,03	–
$N_{120}P_{120}K_{120}$+ green manure**	3,32	1,16	–
Manure** + $N_{40}P_{40}K_{40}$	2,99	0,83	–
Manure** + $N_{40}P_{40}K_{40}$+ green manure**	3,10	0,94	–
With Ryzohumin			
Without fertilizers	2,48	0,32	0,32
Straw**	2,63	0,47	0,30
Green manure**	2,73	0,57	0,35
Manure**	2,78	0,62	0,34
Straw** + green manure**	2,77	0,61	0,39
Manure** + green manure**	2,94	0,78	0,36
$N_{40}P_{40}K_{40}$	3,19	1,03	0,49
$N_{40}P_{40}K_{40}$+ green manure**	3,38	1,22	0,51
$N_{80}P_{80}K_{80}$	3,28	1,12	0,33
$N_{80}P_{80}K_{80}$+ green manure**	3,50	1,34	0,35
$N_{120}P_{120}K_{120}$	3,35	1,19	0,16
$N_{120}P_{120}K_{120}$+ green manure**	3,61	1,45	0,29
Manure** + $N_{40}P_{40}K_{40}$	3,28	1,12	0,29
Manure** + $N_{40}P_{40}K_{40}$+ green manure**	3,41	1,25	0,31
LSD_{05}	0,16		

**) second year aftereffect of organic fertilizers

The largest yield increase from inoculation on peas was observed in the variants with the crop cultivation on a low mineral fertilizing background. With the increase of norms of mineral fertilizers in the technology of pea cultivation, the efficiency of Rhizohumin was decreasing.

The application of the microbial preparation Polymyxobacterin in the technologies of winter wheat cultivation has positively affected the crop yields (Table 4). The biological preparation has provided yield increments on all investigated fertilizing backgrounds. However, it should be noted the highest values were observed in the tests with the use of mineral fertilizers. Thus, whilst the yield gains from bacterization at wheat cultivation with the organic fertilizing systems were within 0.30 – 0.49 t/ha, the use of mineral fertilizers has ensured yield increase of 0.80 – 0.95 t/ha.

The smallest, though still reliable, yield gain from inoculation was observed for the wheat cultivation on the background of the aftereffect of manure. As with the cultivation of other crops (see the discussion above), the direct action and aftereffect of the intermediate lupine green manure appeared to have the have the best action on the performance of microbial preparations among the studied organic agricultural backgrounds.

To assess the impact of microbial preparations on the performance of agrocenosis in the crop rotation, the crop yield values were recalculated in grain units, used to compare the effectiveness of agricultural means upon the cultivation of different crop types [24]. The results obtained have confirmed the above made conclusions about the effectiveness of biotechnologies subject to the individual crop fertilizing system.

4. Influence of fertilizing and inoculation on the yield of wheat

Experiment variants	Yield, t/ha (average for three years)	Increase from fertilizer and inoculation, t/ha	Increase from inoculation, t/ha
Without inoculation			
Without fertilizers, control	3,92	–	–
Straw***	3,95	0,03	–
Green manure***	4,04	0,12	–
Manure***	4,12	0,20	–
Straw*** + green manure***	4,03	0,11	–
Manure*** + green manure***	4,20	0,28	–
$N_{40}P_{40}K_{40}$	4,25	0,33	–
$N_{40}P_{40}K_{40}$+ green manure***	4,35	0,43	–
$N_{80}P_{80}K_{80}$	4,42	0,50	–
$N_{80}P_{80}K_{80}$+ green manure***	4,50	0,58	–
$N_{120}P_{120}K_{120}$	4,64	0,72	–
$N_{120}P_{120}K_{120}$+ green manure***	4,75	0,83	–
Manure*** + $N_{40}P_{40}K_{40}$	4,60	0,68	–
Manure*** + $N_{40}P_{40}K_{40}$+ green manure***	4,61	0,69	–
With Polymyxobacterin			
Without fertilizers	4,24	0,32	0,32
Straw***	4,35	0,43	0,40
Green manure***	4,53	0,61	0,49
Manure***	4,42	0,50	0,30
Straw*** + green manure***	4,43	0,51	0,40
Manure*** + green manure***	4,62	0,70	0,42
$N_{40}P_{40}K_{40}$	5,10	1,18	0,85
$N_{40}P_{40}K_{40}$+ green manure***	5,22	1,30	0,87
$N_{80}P_{80}K_{80}$	5,30	1,38	0,88
$N_{80}P_{80}K_{80}$+ green manure***	5,40	1,48	0,90
$N_{120}P_{120}K_{120}$	5,51	1,59	0,87
$N_{120}P_{120}K_{120}$+ green manure***	5,70	1,78	0,95
Manure*** + $N_{40}P_{40}K_{40}$	5,40	1,48	0,80
Manure*** + $N_{40}P_{40}K_{40}$+ green manure***	5,53	1,61	0,92
LSD_{05}	0,21		

***) third year aftereffect of organic fertilizers

The largest yield increments were obtained for the systemic use of biological preparations in crops growing on the low and medium mineral agricultural backgrounds (Table 5). Under the use of intensive mineral fertilization system, the effectiveness of microbial preparations has reduced. In part, it was restored in the variants with the combined use of straw and green manure on a mineral fertilizers background.

Under the use of solely organic fertilizing systems, the smallest increments from inoculation were observed for crops cultivated on the background of cattle manure, whilst the largest – under the use of intermediate lupin green manure.

5. Average performance crop rotation for various systems of fertilizing and exposure of microbial drugs

Fertilizing Systems	Grain units, t/ha/year	Increase from inoculation, t/ha
Without inoculation		
Without fertilizers, control	13,13	–
Straw	13,70	–
Green manure	14,38	–
Manure	17,61	–
Straw + green manure	15,03	–
Manure + green manure	18,48	–
Mineral low	15,60	–
Mineral low + straw + green manure	18,06	–
Mineral average	18,82	–
Mineral average + straw + green manure	21,01	–
Mineral intense	21,25	–
Mineral intense + straw + green manure	23,17	–
Organic + inorganic №1 (manure + NPK)	21,35	–
Organic + inorganic №2 (manure + green manure + NPK)	22,26	–
With microbial preparations		
Without fertilizers	14,91	1,78
Straw	15,35	1,65
Green manure	16,47	2,09
Manure	18,84	1,23
Straw + green manure	17,60	2,57
Manure + green manure	20,41	1,93
Mineral low	18,43	2,83
Mineral low + straw + green manure	21,00	2,94
Mineral average	21,13	2,31
Mineral average + straw + green manure	23,39	2,38
Mineral intense	22,97	1,72
Mineral intense + straw + green manure	25,25	2,08
Organic + inorganic №1 (manure + NPK)	23,09	1,74
Organic + inorganic №2 (manure + green manure + NPK)	24,38	2,12

It should be noted that intermediate green manure is a significant supplement for other organic fertilizing systems and promotes the effectiveness of biopreparations. Even in the combination with cattle manure, the green fertilizer significantly improves the situation and ensures yield increase under the use of biopreparations.

Experiment results lead to the preliminary conclusion on the formation of the best conditions for the performance of microbial preparations for systemic cultivation of crops on mineral fertilizers background. This corresponds to the logic of the microorganisms' behavior while capturing free niches in the absence of a competitive environment. That is, under such conditions soil diminishes of the agronomic useful microorganisms, which promotes the development of an introduced bacteria and the formation of productive plant- microbial associations.

The introduction of cattle manure reduces the efficiency of the microbial preparations due to the formation of highly competitive environment in the soil, which prevents the establishment of close relationships between the plant and the introduced bacteria.

The positive effect of the interim lupine green manure is probably caused by the fact that the biomass of lupin green manure is faintly contaminated by microorganisms and is quickly mineralized. In addition, it is possible that the products of its mineralization are used as an additional nutritional source by the introduced bacteria. However, this assumption requires additional research.

Conclusions

The effectiveness of microbial preparations upon their application for pre-sowing inoculation of seed material is high when crops are cultivated on the direct and/or post-effect background of lupine green manure and upon the combination of green fertilizer with straw. Under the introduction of cattle manure, the influence of pre-sowing seeds inoculation is largely leveled, but can be restored by the combination of cattle manure with lupine green manure.

The significant influence of inoculation on the yield of potatoes, spring barley and peas was observed on the background of low and medium norms of mineral fertilizers. Inoculation of winter wheat seeds have contributed to a significant growth in crop yields in all studied variants, particularly in the tests with the intensive mineral fertilizing ($N_{90}P_{90}K_{90}$) system. The effectiveness of biologic preparations is increased in the organic-mineral systems of crops was fertilizing (mineral fertilizers + straw + lupine green manure).

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