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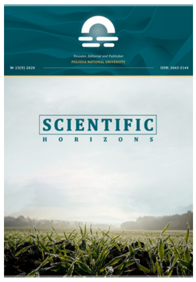

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Optimisation of dosages and application methods for Agrobion granulated soil improver in combination with mineral fertilisers for grain crops on southern chornozems in Northern Kazakhstan

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Abstract. The study aimed to identify effective ratios of the biological product and mineral fertilisers to increase yields and soil activity. The study presented the results of a comprehensive study of the effect of the granular preparation "Agrobion" and different doses of mineral fertilisers (NP) on the agrobiological parameters of oats and spring wheat in the southern black soil of Northern Kazakhstan. The experiment covered 18 variants of fertiliser combinations, including an absolute control, a standard dose of NP, as well as different doses of Agrobion (100-300 kg/ha) and their combinations with ¼, ½, ¾ and full NP norms in the main and pre-sowing methods of application. The highest biological activity of the soil was observed in

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the variant with 200 kg/ha of "preparation" and ½ NP, which was accompanied by a fivefold increase in the number of nitrogen fixers, actinomycetes and cellulose-degrading bacteria compared to the control. The yield of oats in the earing phase reached 49.52 g/vessel with this combination, and the maximum field germination (72.14%) was recorded at the pre-sowing application of 100 kg/ha of Agrobion with a full dose of NP. Analysis of the chemical properties of the soil showed a decrease in electrical conductivity and maintenance of optimal pH with a moderate reduction in NP and the use of the product. The results demonstrated that the optimal doses of Agrobion (100-200 kg/ha) in combination with ½ or ¾ of the calculated NP rate provide the highest yield, microbiological activity and germination. Excessive doses (300 kg/ha) or a sharp decrease in NP led to a decrease in efficiency. A correlation was found between the dose of Agrobion, yields and soil fertility indicators. The recommended combination to increase agroecological efficiency is 200 kg/ha of "granular preparation" with ½ NP at the main application. The practical value of this study is the substantiation of the optimal doses of Agrobion and NP, which reduces the mineral load without loss of yield, which contributes to resource conservation and environmental protection of agriculture

Keywords: soil microorganisms; yield; soil acidity; methods of application; bioactivity

INTRODUCTION

The research relevance is determined by the need to increase the efficiency of mineral nutrition of grain crops on the chornozems of Northern Kazakhstan while reducing the environmental and economic burden on agroecosystems. Given the shortage of high-quality fertilisers and rising agricultural production costs, the use of biological products capable of increasing the availability of nutrients and stabilising agrobiological processes in the soil is of particular importance. The granular forms of such products, particularly Agrobion, demonstrate the potential to be integrated into traditional fertilisation schemes, providing a more uniform distribution of the active ingredient and the ability to adapt doses to specific conditions (Mohylevska, 2025). The problem of this study is caused by the lack of scientifically based recommendations on dose regulation and the choice of the method of applying biological products in combination with mineral fertilisers when growing grain crops on chornozems. Insufficient knowledge of the joint impact on soil microbiota, plant germination and productivity of oats and spring wheat limits the widespread adoption of such technologies in agricultural practice (Drobitko & Kachanova, 2023). In addition, the impact of different fertiliser combinations on agrochemical and microbiological soil parameters requires systematic analysis to develop optimal solutions for sustainable agriculture (Tonkha *et al.*, 2024).

According to the results presented by A.T. Khusainov *et al.* (2021), the use of a "granular biological product" on black soil contributed to an increase in agroecological sustainability and soil microflora activity in barley cultivation. The study recorded a positive effect of the preparation on crop yields even with reduced doses of mineral nutrition. As noted by S. Turebayeva *et al.* (2022), the introduction of no-till tillage in combination with biologically active agents ensured sustainable winter wheat production in the conditions of Southern Kazakhstan. According to the authors, the combination of biological and technological factors increased the biological activity of the soil and improved its water regime on chornozem plots.

According to the observations described by S.B. Kenenbaev *et al.* (2023), the agricultural sector of Kazakhstan continues to employ an irrational approach to the use of mineral fertilisers, which is exacerbated by insufficient microbiological activity of soils. The researchers emphasised the need to combine mineral components with biological products to compensate for agrochemical degradation, especially in arid regions. As demonstrated by M. Dugalić *et al.* (2025), the systematic application of mineral fertilisers in combination with organic matter and corrective agents such as lime improved the agrophysical and chemical properties of the soil under maize cultivation. The results obtained indicate a high sensitivity of yields to an integrated approach including biological regulation.

Based on the analysis performed by K. Pycia *et al.* (2024), the study determined that changes in the composition of fertilisers used on different soil types directly affect the structural and heat-resistant properties of cereal starch. The study emphasised the importance of considering the specifics of soil nutrition when using organic and mineral compounds, especially against the backdrop of growing interest in biomass by-products. According to Ch. Srinivasarao *et al.* (2024), organomineral fertilisers help restore microbial balance in the soil, improving agrochemical parameters and increasing nutrient availability. The study emphasises the potential of such systems as an element of sustainable agriculture in regions with a high level of agro-environmental risk. As confirmed by V. Kavvadias *et al.* (2023), the use of chemical fertilisers, compost and zeolite has different effects on yields, nutrient composition and soil properties in the short term. The study determined that the integration of organic and mineral components stabilises soil acidity (pH) and increases the utilisation of macronutrients. According to the analysis by M. Kulhánek *et al.* (2023), modern approaches to plant nutrition should incorporate the historically accumulated knowledge of the interaction of fertilisers with agroecosystems. The study emphasised the importance of returning to combined nutrition models in which organic and mineral elements are used synergistically.

As demonstrated by F. Cheţan *et al.* (2022), the response of soils and maize yields to tillage systems is significantly modified by climatic factors and the type of fertiliser applied. The study determined that crop sustainability is enhanced using gentle tillage technologies in combination with biostimulants and mineral additives. According to the observations of E.G. Magnucka *et al.* (2023), different forms of sulphur have a complex effect on the composition of organic matter and microbiota activity in models of vegetation experience. The authors noted that the use of available forms of macronutrients activates the growth of symbiotic bacteria and promotes the biotransformation of carbon fractions in the soil. According to M. Knežević *et al.* (2021), automated databases and tools are substantial in processing and systematising soil profiles, especially when analysing the dynamics of indicators under the influence of fertilisers. The authors emphasised the importance of digitalisation and structural interpretation of soil data when conducting comprehensive agrochemical research. According to the trials by M. Kozłowski *et al.* (2023), the use of agrarian reclamation with the alternation of wheat and rapeseed crops on techno-soils in Central Poland helps improve the water and physical properties of disturbed soils. The authors recorded an increase in water-holding capacity and a decrease in soil density with the systematic use of organomineral fertilisers.

The study aimed to substantiate the optimal rates and methods of applying Agrobion with mineral fertilisers to increase grain yields and improve the properties of the black soil of Northern Kazakhstan. The objective of the study was to identify the agrobiological effects of the combined use of different doses of the "granular biological product" and mineral fertilisers, as well as to determine the impact on the productivity of crops, the state of microflora and changes in the agrochemical parameters of black soils.

MATERIALS AND METHODS

The study was conducted between May and September 2024 on the territory of the Limited Liability Partnership "Kokshetau Experimental Production Farm" (Zereninsky District, Akmola Region, Republic of Kazakhstan) on southern chornozems with a neutral reaction (pH 7.24-7.75). The experiment included field and vegetation parts, corresponding to the agrotechnical requirements for the cultivation of grain crops. Oats (*Avena sativa* L.) and spring wheat (*Triticum aestivum* L.) were used as test objects. The meliorative preparation "Agrobionov" was applied in the conditions of the vegetation experiment in doses of 0, 100, 120, 200, 240 and 300 kilograms per hectare (kg/ha) in combination with mineral fertilizers (NP) in full and fractional doses of ¾, ½ and ¼ of the calculated rate (denoted as NPcalc, ¾ NPcalc, ½ NPcalc, ¼ NPcalc). Vegetation experiments were conducted in plastic cylindrical vessels of 5 litres, 28 cm high and 19 cm in diameter, filled with 4 kg of air-dry soil, and placed in a climate chamber at a temperature of +20…+25 °C and humidity of 60-65%.

The yield of the green mass of oats at the end of tillering and the earing stage was determined in vegetative vessels by cutting the aboveground mass and weighing it on analytical scales Sartorius CPA225D (Germany) with an accuracy of ±0.01 g. The yield of the green mass of spring wheat in the tube stage was determined in the field on an area of 1 m^2 in triplicate with the subsequent weighing of the biomass on an Ohaus Scout Pro Balance (USA). In the field experiment, fertilisers and the preparation were applied in two ways: main (in autumn before sowing) and pre-sowing (simultaneously with sowing). A total of 18 experimental variants were laid out, including an absolute control (without fertiliser and preparation) and a control with a full rate of NP without ameliorative preparation. Field plots of 21×2.1 m, or 44.1 m^2, were laid out in triplicate. Soil samples for determining the microbiological activity of the soil were taken with a soil drill in the phase of spring wheat emergence in the root zone at a depth of 0-20 cm.

To determine the number of soil microorganisms, the seeding method was applied using selective nutrient media. The number of bacteria consuming organic nitrogen was determined on meat-peptone agar, bacteria using inorganic nitrogen on starch-ammonium agar; actinomycetes on Gauze medium; aerobic nitrogen fixers on Ashby medium; cellulose-degrading bacteria on Hutchinson medium; and microscopic fungi on Chapek medium. Samples were taken from the rhizosphere of plants at a depth of 0-10 cm, soil suspensions were prepared in sterile saline, and 0.1 ml was applied to Petri dishes. Incubation was conducted at +28°C for 5-7 days. The colonies were counted manually under a Nikon SMZ745 binocular microscope (Japan), expressing the results in colony forming units per 1 g of dry soil. In 2024, meteorological conditions in Shagalaly village, Zerendy district, Akmola region, were characterised by increased precipitation rates in May and August 2024, and during the critical phase of the growing season, precipitation and moisture reserves were optimal. In general, the year was favourable for grain cultivation in Northern Kazakhstan (Table 1).

***Table 1**. Meteorological conditions for the growing season of 2024 on the territory of Kokshetau Experimental Production Farm Limited Liability Company, Shagalaly of Zerendy District, Akmola Region*

Parameters	20-31 May	June	July	August	September	Sum
The sum of precipitation, mm	65.1	65	67.5	56	21.8	
Annual average, mm	30.7	44.2	63.9	39.7	27	
Average monthly temperature in 2024, t °C	9	20.9	19.5	17.1	10.5	
Average annual t °C	11.7	17	18.8	17.1	12	
The average annual sum of active temperatures, t °C	18.7	210	272.8	220.1	60	781.6
Total active temperatures in 2024, t °C		327	294.5	220.1	15.5	857.1

***Source:** compiled by the authors*

In the third decade of September 2024, harvesting was carried out, and wheat yield data were obtained for 18 experimental variants. The harvesting was conducted using a continuous method with a WinterSteiger grain selection combine, the accounting area of the plot was 21×1.6 m. The yield of spring wheat in tonnes per hectare (t/ha) was recorded based on the results of harvesting plots with a selection combine, converted to hectares and adjusted for standard moisture according to ISO 712:2009 (2009). The effectiveness of fertilisers in combination with Agrobion 120 kg/ha was assessed by a set of parameters: yield of dry vegetative mass of oats for haylage), soil pH, electrical conductivity (EC), content of available forms of nitrogen (N), phosphorus (P) and potassium (K) in the soil-plant system. The pH was measured with a portable pH meter Hanna HI98103 (Italy), and the electrical conductivity with a conductivity meter Mettler Toledo FiveEasy (Switzerland). The concentration of N, P, and K in the soil and plant mass was determined by the method of wet mineralisation followed by spectrophotometric analysis using a Shimadzu UV-1800 (Japan). The results were statistically processed using Statistica 12 (StatSoft, USA). To assess the reliability of differences between the variants, one-factor analysis of variance (ANOVA) was used at a significance level of $p < 0.05$. The least significant difference ($LSD_{0.05}$) was calculated for each indicator. To evaluate the strength of the relationship between Agrobion doses and the resulting traits, Pearson's correlation coefficient (R) was calculated. The authors adhered to the standards of the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

The application of Agrobiones at a dose of 100 kg/ha in combination with a full dose of NP (options 2 and 3) did not result in a significant increase in the number of microbial communities compared to option 1. In the control variant (variant 1), the number of actinomycetes was 54.66×10, and aerobic nitrogen fixers were 1×10. In variant 2 (basic application), the number of actinomycetes was 46.3×10, and nitrogen fixers 2×10; in variant 3 (pre-sowing application), 40.67×10^4 and 2.33×10, respectively. Thus, in both cases, the increase compared to the control was insignificant and did not exceed the statistical error, which indicated weak biological activity. This confirms that a dose of 100 kg/ha in the presence of complete mineral fertilisation does not have a pronounced stimulating effect on the development of key functional groups of microorganisms.

The most significant changes were observed in variant 10, which combined 200 kg/ha of "granulated biopreparation" (basic application) and ½ of the NP norm. In this variant, the number of bacteria consuming organic nitrogen reached 12.33; bacteria using inorganic nitrogen 14.3×10; actinomycetes 108.67×10; aerobic nitrogen fixers 17×10^6; cellulose-degrading bacteria 39.3×10; microscopic fungi 2.33×10. These indicators significantly exceeded the values of control variant 1: the number of bacteria consuming organic nitrogen was 3.4 times higher (12.33 vs. 3.66); bacteria using inorganic nitrogen was 7.15 times higher (14.3×10 vs. 2×10); actinomycetes was 99 times higher (108.67×10 vs. 54.66×10); aerobic nitrogen fixers were 17 times higher (17×10 vs. 1×10).99 times (108.67×10 vs. 54.66×10); aerobic nitrogen fixers 17 times (17×10 vs. 1×10); microscopic fungi 3.5 times (2.33×10 vs. 0.66×10).

The variants with a dose of 300 kg/ha of the "preparation" (variants 14-16) did indeed demonstrate contradictory results in terms of microbiological indicators. The contradiction was that at high doses of Agrobion, there was an increase in the activity of certain functional groups (e.g., bacteria that use mineral nitrogen), but at the same time, other important groups of actinomycetes and nitrogen fixers, which play a key role in the formation of a stable and balanced microbial community. Thus, in variant 14 (at full NP rate), the number of bacteria using inorganic nitrogen reached 28×10^6, which is 14 times higher than in the control (2×10^6). However, at the same time, the number of actinomycetes decreased to 71.67×10^4 compared to 108.67×10^4 in variant 10, and aerobic nitrogen fixers decreased to 8×10^6 compared to 17×10^6. Variant 15 (½ NP) showed an even more dramatic decrease: actinomycetes 69.67×10^4, aerobic nitrogen fixers 2.1×10^7, and cellulose-degrading bacteria only 4.3×10^4, which is significantly lower than 39.3×10^4 in variant 10. Option 16 (¼ NP) yielded an extremely high number of bacteria utilising inorganic nitrogen (153×10^6), but the number of actinomycetes (33.3×10^4) and aerobic nitrogen fixers (12.3×10^6) was below optimal values.

Variants 12 and 13 (200 kg/ha of "granular biopreparation" at ¼ NP, applied by the main and pre-sowing methods, respectively) demonstrated pronounced differences in microbiological indicators depending on the method of application. In variant 12, the number of aerobic nitrogen fixers reached 10.3×10^6, which was significantly higher than in variant 13 (6.67×10^6). At the same time, in both variants, the number of bacteria using inorganic nitrogen remained high (22.3×10^6 and 17×10^6, respectively), and actinomycetes 104.3×10^4 and 46.3×10^4. This confirmed the importance of the application method for the activation of certain microbial groups, in particular spore-forming forms. The absolute control (variant 17) demonstrated the lowest number of most groups of microorganisms: organotrophic bacteria 0.33; aerobic nitrogen fixers 0.67×10^6; actinomycetes 66×10^4. However, the number of bacteria using inorganic nitrogen reached an abnormally high level (153×10^6), which is possibly determined by the accumulation of mineral residues from previous seasons and the lack of competition from active microflora.

Variant 18, which included only Agrobion at a dose of 100 kg/ha, without mineral fertilisers, showed a sharp surge in organotrophic bacteria (217), but other groups, including actinomycetes and nitrogen fixers, remained at a low level. This indicates a short-term stimulating effect, not accompanied by structural changes in microbial communities. A comparison of the main and pre-sowing applications showed that the first method often provided a higher number of microorganisms. For instance, at a dose of 200 kg/ha and full NP (variants 8 and 9), the total number of bacteria using organic nitrogen was 4.33 (main) versus 10.0 (pre-sowing), but the number of actinomycetes and fungi was higher in the main method, 76.3×10^4 and 0.33×10^4, respectively (Table 2).

***Table 2**. Quantitative indicators of microorganisms in 18 variants of the experiment to study the doses and timing of application of the granular preparation Agrobion on different nutrient media*

	Variant	Microorganisms that consume organic nitrogen	For the detection of actinomycetes and bacteria that consume inorganic nitrogen	Number of actinomycetes	Number of aerobic nitrogen fixers	For aerobic bacteria that use cellulose	Number of microscopic fungi
		MPA	**SAA**	**Gauze**	**Ashby**	**Hutchinson**	**Chapeka**
NPcalc control	1	3.66×10^6	2×10^6	54.66×10^4	1×10^6	45×10^4	0.66×10^4
A100base+NPcalc	2	2.33	6.3×10^6	46.3×10^4	2×10^6	40.67×10^4	0.66×10^4
A100prep+NPcalc	3	1	1×10^6	40.67×10^4	2.33×10^6	46×10^4	0.66×10^4
A100base+1/2NPcalc	4	1	1.67×10^6	32×10^4	1.33×10^6	30×10^4	0.66×10^4
A100prep+1/2 NPcalc	5	3	6.3×10^1	28.67×10^4	1×10^6	25×10^4	0.33×10^4
A100base+1/4 NPcalc	6	5	3.67×10^6	27.3×10^4	2×10^6	38.3×10^4	0.66×10^4
A100prep+1/4 NPcalc	7	3	1.67×10^6	80.67×10^4	1×10^6	42.67×10^4	0.33×10^4
A200base+NPcalc	8	4.33	3×10^6	76.3×10^4	6.3×10^1	52.3×10^4	0.33×10^4
A200prep+NPcalc	9	10	3.67×10^6	35.3×10^4	6.3×10^0	44.67×10^4	1.33×10^4
A200base+1/2 NPcalc	10	12.33	6.3×10^{14}	108.67×10^4	17×10^6	39.3×10^4	2.33×10^4
A200prep +1/2NPcalc	11	7	7.67×10^6	78.67×10^4	6.3×10^{10}	18.67×10^4	0.33×10^4
A200base+1/4 NPcalc	12	17.66	6.3×10^{22}	104.3×10^4	6.3×10^{10}	26.67×10^4	0.66×10^4
A200prep+1/2NPcalc	13	11.66	17×10^6	46.3×10^4	16×10^6	26.67×10^4	1×10^4
A300base+NPcalc	14	27	28×10^6	71.67×10^4	8×10^6	34×10^4	2×10^4
A300base+1/2 NPcalc	15	67.33	7.67×10^6	69.67×10^4	21×10^6	4.3×10^4	0.33×10^4
A300base+1/2NPcalc	16	57.33	153×10^6	4.3×10^{33}	6.3×10^{12}	26×10^4	0.66×10^4
abs control	17	0.33	153×10^6	66×10^4	0.67×10^6	35.67×10^4	4×10^4
A100 kg/ha	18	217	153×10^6	45×10^4	1×10^6	36.67×10^4	2×10^4

***Note:** MPA – meat-peptone agar; SAA – starch-ammonium agar*
***Source:** compiled by the authors*

Thus, the greatest microbiological effect was recorded in variant 10 (200 kg/ha of "granular biological product" + ½ NP, main application). A moderate decrease in the mineral load with active biostimulation ensured a balanced development of microbial groups. Exceeding the dose (300 kg/ha) or excessive reduction of NPs led to a decrease in biological activity. The obtained data recommended variant 10 as the most effective from the agrobiological point of view for use in the conditions of southern chornozems of Northern Kazakhstan. The control variant (NP calculated, variant 1), which used the full calculated dose of mineral fertilisers without biological additives, provided an average yield of green mass of oats at the level of 6.13 g/vessel.

This indicator was taken as the base for the comparative analysis of the other variants. The variants involving a reduction in the dose of mineral fertilisers to ¾ of the calculated dose and the simultaneous application of the "preparation" at a dose of 120 kg/ha showed a moderate decrease in yield. Thus, the average value for variant 2 was 5.76 g/vessel, which is 0.37 g less than in the control case. Even though the result was lower than the baseline, the difference was within the error margin ($LSD_{0.05}$ = 0.99 g/vessel), and therefore not statistically significant. This fact indicated that part of the mineral fertilisation could be effectively replaced by a biological preparation without significant yield loss.

The variant with half the dose of NP and the same amount of Agrobion (variant 3) gave an even lower yield of 5.31 g/vessel, which was 0.82 g less than the control. At the same time, the result was closer to the limit of statistical significance. Consequently, when NP was reduced by 50%, the potential of the biological preparation became insufficient to fully compensate for the missing mineral elements. The most pronounced decrease in yield was observed when ¼ NP was applied together with 120 kg/ha of "granular biopreparation" (variant 4). The average value was only 4.45 g/vessel, which is 1.68 g lower than in the control variant. The difference was significantly higher than the $LSD_{0.05}$, and therefore statistically significant. This indicates that excessive reduction of mineral load, even in the presence of a biological stimulant, negatively affected the productivity of oats in the early stages of vegetation. Probably, under these conditions, the plants experienced a deficiency of key macronutrients (nitrogen and phosphorus), especially during the period of active growth of vegetative mass (Romanchuck *et al.*, 2017). Comparison of the data between the experimental variants revealed a clear correlation between the level of yield and the degree of NP reduction. When 75% of the calculated dose was preserved, yield losses were not statistically confirmed, but when reduced to 50% and below, the losses became pronounced. This concludes that there is a threshold dependence below which the effect of the biological product cannot provide full compensation for the missing mineral elements. Notably, the use of the "biopreparation", even with a significant reduction in NP, still provided a significant yield of green mass (Yeraliyeva *et al.*, 2017) In practical farming conditions, this may indicate the high agronomic flexibility of the biopreparation, which can be used to adapt the nutrition technology to specific economic and climatic conditions (Table 3).

***Table 3**. Yield of green mass of oats in the phase of the end of tillering in the conditions of vegetation experience with the application of different doses of fertilizers in combination with Agrobion at a dose of 120 kg/ha (g/vessel)*

Variants	1	2	3	4	average	Difference from control
Ncalc control	5.34	7.18	6.40	5.58	6.13	
3/4 NPcalc+A120	6.52	5.40	6.14	4.98	5.76	-0.37
1/2 NPcalc+A120	6.83	3.35	5.52	5.52	5.31	-0.82
1/4 NPcalc+A120	5.51	3.40	4.68	4.21	4.45	-1.68
$LSD_{0.05}$, g/vessel					0.99	

***Source:** compiled by the authors*

Thus, according to the results of the tillering phase, the best option in terms of efficiency and resource consumption was the variant with a ¾ dose of mineral fertilisers in combination with 120 kg/ha of Agrobion. It provided yields that were statistically indistinguishable from the control at lower mineral inputs. Therefore, it is possible to consider this combination as an economically and environmentally feasible alternative to full mineral fertilisation in oat cultivation on the black soil of Northern Kazakhstan. In the control variant with the full calculated dose of NP without the addition of the "preparation" (NP calculation, variant 1), the pH value was 7.24, which corresponded to a slightly alkaline reaction. The electrical conductivity of the soil reached 306 μS/cm, reflecting the presence of a standard level of salts in the soil solution for chornozem conditions. At the same time, the yield of the green mass of oats was 6.13 g/vessel. The balance of the elements was as follows: nitrogen 181.02 milligrams per kilogram (mg/kg), phosphorus 18.30 mg/kg, and potassium 382.51 mg/kg.

Reducing the dose of mineral fertilisers to ¾ of the calculated rate in combination with 120 kg/ha of "granulated biopreparation" (variant 2) resulted in an increase in soil pH to 7.6. Electrical conductivity decreased to 167.9 μS/cm, indicating a decrease in the total dissolved salt content. Yield decreased slightly to 5.76 g/vessel. Nitrogen content decreased to 171.93 mg/kg and potassium to 263.74 mg/kg, while phosphorus content increased to 20.79 mg/kg. This indicated more active nitrogen uptake by plants and stabilisation of phosphorus availability under the influence of Agrobion. In the variant with ½ of the calculated dose of NP and the same dose of "preparation" (variant 3), the pH increased to 7.71, which corresponded to the tendency of mild alkalisation of the soil. The electrical conductivity was 202 μS/cm, which remained within the normal range. Yields decreased to 5.31 g/vessel and nitrogen content was 162.01 mg/kg. The potassium content was 302.52 mg/kg, indicating a more economical use of potassium resources with a reduced mineral load. The phosphorus content remained at 18.19 mg/kg, which almost correlated with the benchmark.

The most significant decrease was recorded in the variant with ¼ of the calculated dose of NP with the addition of 120 kg/ha of Agrobion (variant 4). The yield in this variant was 4.45 g/vessel, which was significantly lower than the control level. The pH value increased to 7.75, but the electrical conductivity decreased to 158.3 μS/cm. Nitrogen concentration in the soil decreased to 142.94 mg/kg, potassium to 263.53 mg/kg, and phosphorus remained at 18.23 mg/kg. These data indicated a lack of mineral nutrition with a too strong reduction in the dose of NP, despite the presence of biostimulation. Correlation analysis revealed a negative relationship between yield and soil electrical conductivity (correlation coefficient R = -0.90), indicating that a decrease in salt pressure had a favourable effect on plant development. At the same time, a moderately negative relationship between soil pH and yield (R = -0.78) was found, which reflected the optimal weakly alkaline reaction in the range of 7.2-7.6 for oat growth (Table 4).

***Table 4**. Efficiency of fertiliser application in combination with Agrobion 120 kg/ha*

Variant	pH	Electrical conductivity (EC)	Yield, g/vessel	Nutrient balance of oats, mg/kg in the soil-plant system at the end of the tillering phase		
				N	P	C
NPcalc (control)	7.24	306	6.13	181.02	18.30	382.51
¾ NPcalc+A120 kg/ha	7.6	167.9	5.76	171.93	20.79	263.74
½ NPcalc+A120 kg/ha	7.71	202	5.31	162.01	18.19	302.52
¼ NPcalc+A120 kg/ha	7.75	158.3	4.45	142.94	18.23	263.53
Correlation coefficient, R	-0.78	-0.9	$LSD_{0.05}$=0.99 g/vessel	0.98		

***Source:** compiled by the authors*

Thus, an increase in the dose of “preparations” combined with a moderate decrease in mineral fertilisation contributed to an improvement in the balance of macroelements in the soil without salt accumulation, which was confirmed by a decrease in electrical conductivity. The best balance between the level of available nitrogen, phosphorus and potassium, as well as the optimal yield, was recorded when using ¾ dose of mineral fertilisers in combination with 120 kg/ha of “granular biological product” (variant 2). With a further reduction of the NP dose to ½ and even more so to ¼, the effectiveness of the biostimulant decreased, especially concerning the nitrogen supply of plants. The yield of oats in the earing phase varied depending on the combination of doses of the “preparation” and mineral fertiliser rates. In the control variant with the full calculated dose of NP, the yield was 26.4 g/vessel. With a reduction in the rate of mineral fertilisers to ½ NP and the application of 100 kg/ha of Agrobion, the yield reached 38.23 g/vessel, which exceeded the control value. When 120 kg/ha was applied, the yield decreased to 30.24 g/vessel, remaining above the baseline. A dose of 200 kg/ha at ½ NP provided a yield of 35.23 g/vessel. The highest rate was recorded at a dose of Agrobion 300 kg/ha in combination with ½ NP, where the yield was 49.52 g/vessel.

When applying ¾ NP, the yield of oats also varied depending on the dose of the “granular biopreparation”. When 100 kg/ha was applied, the yield was 22.7 g/vessel, which was below the control level. When the dose was increased to 120 kg/ha, the yield increased to 29.16 g/vessel. At 200 kg/ha, the yield was 24.6 g/vessel. The variant with a dose of 300 kg/ha provided a yield of 35.41 g/vessel, which exceeded the control indicator. The differences between the variants at ½ NP were more pronounced than at ¾ NP. At a dose of 100 kg/ha of Agrobion, the yield increased by 11.83 g/vessel compared to the control. At a dose of 120 kg/ha, the difference was 3.84 g/vessel. The application of 200 kg/ha provided a yield increase of 8.83 g/vessel. The dose of 300 kg/ha contributed to an increase in yield by 23.12 g/vessel compared to the control variant. At ¾ NP, the application of 100 kg/ha of the “preparation” was accompanied by a decrease in yield by 3.7 g/vessel compared to the control. The variant with a dose of 120 kg/ha gave a yield increase of 2.76 g/vessel. At 200 kg/ha, the yield remained at the control level. A dose of 300 kg/ha provided a yield increase over the control by 9.01 g/vessel.

The analysis demonstrated that at ½ NP, the application of 300 kg/ha of the “granular biopreparation” provided a significant increase in yield, exceeding the $LSD_{0.05}$ of 10.2 g/vessel. The differences between the 100 kg/ha and 200 kg/ha doses also exceeded the significance threshold. The variant with 120 kg/ha at ½ NP showed an increase but within the statistical error. At ¾ NP, a significant difference in yield was recorded only at 300 kg/ha of Agrobion. At a dose of ½ NP, an increase in the dose of Agrobion from 100 to 300 kg/ha was accompanied by an increase in yield from 38.23 to 49.52 g/vessel. At a dose of ¾ NP, a similar increase in yield was observed from 22.7 to 35.41 g/vessel. The lowest yields at ¾ NP were recorded at 100 and 200 kg/ha of the “preparation”. The correlation coefficient between the dose of Agrobion and yield at ½ NP was 0.70, reflecting a strong positive relationship. At ¾

NP, the correlation coefficient was 0.5, indicating a less pronounced dependence between the level of biostimulation and yield. The highest yield in the experiment was recorded in the variant with the introduction of 300 kg/ha of "granular biopreparation" and ½ of the calculated dose of NP (Table 5).

***Table 5**. Yield of green mass of oats in the conditions of vegetation experience in the eating phase*

Agrobions, kg/ha	0.00	100	120.00	200	240.00	300	R
Fertiliser rates							
½NPcalc		38.23	30.24	35.23	35.86	49.52	0.70
¾NPcalc		22.7	29.16	24.6	35.41	28.5	0.5
$N_{22}P_{100}$calc average	26.4	$LSD_{0.05}$=10.2 g/vessel					

***Source:** compiled by the authors*

The obtained data on the yield of oats in the earing phase showed that the maximum values were recorded when the dose of mineral fertilisers was reduced to ½ NP and the dose of the "biopreparation" was increased to 300 kg/ha. At ¾ NP, the best results were also observed at a dose of 300 kg/ha, but the overall yield level remained lower than at ½ NP. Field germination at the main application of the full calculated dose of NP (1 NP) without Agrobion was 61.07%. With the addition of 100 kg/ha of Agrobion, germination increased to 62.19%, and at 200 kg/ha to 64.82%, indicating a positive effect of the preparation. However, with a further increase in the dose of Agrobion to 300 kg/ha, germination decreased to 56.43%, which was lower than the control (61.07%). When using ½ NPcalc, the field germination rate without "preparations" was 59.64%. The application of 100 kg/ha of Agrobion increased the index to 70.36%, which was the maximum value for the main application at this NP rate. A dose of 200 kg/ha of the "granular biopreparation" gave a germination rate of 60.71%, which was slightly higher than the control. At ¼ NPcalc, the germination rate without Agrobion was 58.93%, increasing to 64.82% at 100 kg/ha and 67.14% at 200 kg/ha of the "granular biopreparation", which demonstrated a stable positive effect of the preparation at low NP doses. In the variant without fertilisers and "preparations" (absolute control), the field germination rate was 67.50%, which was higher than the number of variants with low doses of NPs, probably due to natural soil fertility.

At pre-sowing application, the full rate of NP (1 NP) without "selected preparation": provided germination of 61.07%, identical to the main application. The application of 100 kg/ha of "Agrobion" increased the indicator to 72.14%, which was the maximum value in the entire experiment, indicating the high efficiency of the pre-sowing application. A dose of 200 kg/ha of the "selected preparation" gave a germination rate of 67.86%, which also exceeded the control. For ½ NPcalc, germination without the "selected product" was 54.46%, which was lower than all other variants. The application of 100 kg/ha of Agrobion increased the index to 61.96%, demonstrating the restoration of germination to the control level. At ¼ NPcalc, germination without "preparation" was 61.79%, and with 100 kg/ha of "preparation" – 64.82%, which corresponded to the data of the main application for this dose. The analysis demonstrated that the smallest significant difference ($LSD_{0.05}$) was 5.6%, therefore it is possible to define the differences between the variants as significant when this threshold was exceeded. The correlation coefficient (R) for the main application was 0.73 and for the pre-sowing application 0.67, indicating a moderate relationship between the doses of the "granular biopreparation" and field germination. The greatest increase in germination was observed at the pre-sowing application of 100 kg/ha of the "granular biopreparation" with the full rate of NP (+11.07% compared to the control), while the dose of 300 kg/ha at the main application reduced germination by 4.64% compared to the control. Variants with ½ and ¼ NPcalc showed less stability, especially at pre-sowing application, where low doses of NP without "granular biopreparation" reduced germination to the lowest values (54.46%) (Table 6).

***Table 6**. Field germination depends on the timing and doses of mineral fertilisers and Agrobion*

	Main				**Pre-sowing**		
Agrobions, kg/ha / NPcalc	0	100	200	300	0	100	200
1 NP	61.07	62.19	64.82	56.43	61.07	72.14	67.86
1/2.NPcalc		59.64	70.36	60.71		54.46	61.96
¼NPcalc		58.93	64.82	67.14		61.79	64.82
0		67.50					
$LSD_{0.05}$=5.6%		Correlation coefficient R				0.73	0.67

***Source:** compiled by the authors*

The data obtained showed that pre-sowing application of Agrobion at a dose of 100 kg/ha with the full rate of NP provided the highest field germination (72.14%), while high doses of the preparation (300 kg/ha) at the main application reduced the indicator. Moderate doses of Agrobion (100-200 kg/ha) stably increased germination at both application rates, especially at low NP doses, which emphasised the role of optimising germination conditions on southern black soil. With the main application of the full design dose of NP (1 NP) without the "granular biopreparation", the yield of green mass was 510 grams per square metre (g/m²). The application of 100 kg/ha of the "granular biopreparation" increased the indicator to 560 g/m², and a dose of 200 kg/ha provided the maximum yield for this variant of 664 g/m². However, with a further increase in the dose to 300 kg/ha, the yield decreased to 566 g/m², indicating possible growth inhibition at high concentrations of the product. For the ½ NPcalc, the yield without the "preparation" was 565 g/m², which was higher than the control with the full rate of NP. The application of 100 kg/ha of "preparations" increased the yield to 587 g/m², and 200 kg/ha to 566 g/m², which was below the maximum. A dose of 300 kg/ha of "biopreparations" yielded 676 g/m², which was the highest for ½ NPcalc with the main application. At ¼ NPcalc, the yield without the "granular biopreparation" reached 728 g/m², which was the highest value among all variants of the main application. However, the addition of 100 kg/ha of the "granular biopreparation" reduced the figure to 499 g/m², 200 kg/ha to 425 g/m², and 300 kg/ha to 702 g/m², indicating an unstable effect of the preparation at low NP doses. The variant without fertilisers and "biological products" (absolute control) showed a yield of 319 g/m², which was the minimum value for the main application.

At the pre-sowing application, the full rate of NP (1 NP) with 100 kg/ha of Agrobion provided a yield of 733 g/m², which was the maximum value in the entire experiment. The dose of 200 kg/ha of Agrobion yielded 664 g/m², which corresponded to the maximum of the main application for this NP rate. For ½ NPcalc, the yield with 100 kg/ha of Agrobion was 676 g/m², and with 200 kg/ha 555 g/m², which was below the maximum. At ¼ NPcalc, 100 kg/ha of Agrobion provided a yield of 702 g/m², while 200 kg/ha reduced the yield to 402 g/m², which was the minimum value for pre-sowing application. The variant without "preparations", but with pre-sowing application (0 kg/ha), showed a yield of 646 g/m², which exceeded the control of the main application. The analysis revealed the smallest significant difference ($LSD_{0.05}$) at 98 g/m², which confirmed the significance of differences between the variants when this threshold was exceeded. The correlation coefficient (R) for the main application was 0.85, indicating a strong relationship between Agrobion doses and yield. The greatest increase in yield was observed at the pre-sowing application of 100 kg/ha of "biopreparations" with the full rate of NP (+223 g/m² compared to the control of the main application). At the same time, high doses of "preparations" (200-300 kg/ha) at ¼ NPcalc reduced the yield, especially when applied at pre-sowing (-326 g/m² at 200 kg/ha compared to ¼ NPcalc without "granular biological product") (Table 7).

***Table 7**. Influence of doses and timing of "Agrobion" application in combination with mineral fertilisers (NP) on the yield of spring wheat green mass in the critical phase of heading (g/m²)*

Method of application	Main				Pre-sowing	
Agrobions, kg/ha / Full norm $N_{40}P_{45}$	0	100	200	300	100	200
1 NP	510.00	560.00	664.00	566.00	733.00	664.00
1/2.NPcalc		565.00	587.00	566.00	676.00	555.00
¼NPcalc		728.00	499.00	425.00	702.00	402.00
0	319				646.00	
	($LSD_{0.05}$ = 98 g)				R 0.85	

***Source:** compiled by the authors*

The obtained data showed that the pre-sowing application of 100 kg/ha of Agrobion with full NP rate provided the highest yield of spring wheat green mass (733 g/m²). Moderate doses of the "granular biopreparation" (100-200 kg/ha) stably increased the yield at full and half NP rates, while at low NP doses (¼ NPcalc) the preparation more often reduced the indicators, especially when applied at pre-sowing. With the main application of the full calculated dose of NP (1 NP) without "selected preparations", the yield was 2.40 t/ha. The application of 100 kg/ha of the "preparation" increased the yield to 2.57 t/ha, which was the maximum value for the main application at this NP rate. A dose of 200 kg/ha of "selected preparations" reduced the yield to 2.36 t/ha, and 300 kg/ha to 1.98 t/ha, indicating a negative effect of high doses of the preparation. For ½ NPcalc, the yield with 100 kg/ha of "preparation" was 2.23 t/ha, with 200 kg/ha 2.10 t/ha, and with 300 kg/ha 1.45 t/ha, which demonstrated a consistent decrease in yield with increasing dose of the preparation. At ¼ NPcalc, 100 kg/ha of the "granular biopreparation" yielded 1.93 t/ha, 200 kg/ha 1.67 t/ha, and 300 kg/ha 1.25 t/ha, which was the lowest value among the fertiliser variants at the main application. The absolute control (no fertiliser and "biopreparation") yielded 2.09 t/ha, which was higher than several variants with low NP rates and high doses of the "preparation".

At the pre-sowing application, the full rate of NP (1 NP) with 100 kg/ha of the "granular biopreparation" provided a yield of 2.76 t/ha, which was the maximum value in the entire experiment. A dose of 200 kg/ha of the "biopreparation" yielded 2.44 t/ha, which also exceeded the control of the main application (2.40 t/ha). For ½ NPcalc, the yield with 100 kg/ha of Agrobion was 2.24 t/ha, and with 200 kg/ha 2.17 t/ha, which was comparable to the results of the main application for this NP rate. At ¼ NPcalc, 100 kg/ha of Agrobion provided a yield of 1.96 t/ha, and 200 kg/ha 1.67 t/ha, which corresponded to the data of the main application for this dose of the preparation. Statistical analysis revealed the smallest significant difference ($LSD_{0.05}$) at the level of 0.2 t/ha, which confirmed the significance of differences between the variants when this threshold was exceeded. The correlation coefficient (R) for the main application was -0.99 for the full NP rate, -0.9 for ½ NPcalc and -0.99 for ¼ NPcalc, indicating a strong negative relationship between increasing doses of the "granular biopreparation" and yield. For pre-sowing application, R was 0.91 for 100 kg/ha and 0.94 for 200 kg/ha, showing a positive correlation at moderate doses of the product. The highest yield increase was observed at 100 kg/ha of the "granular biopreparation" with the full rate of NP (+0.36 t/ha compared to the control of the main application). At the same time, high doses of "Agrobion" (300 kg/ha) at the main application reduced the yield by 0.42 t/ha for 1 NP and by 0.84 t/ha for ½ NPcalc compared to the control (Table 8).

***Table 8**. Influence of doses and timing of Agrobion application in combination with NP fertilisers on the yield (t/ha) of spring wheat*

		Main contribution					**Pre-sowing**	
NPcalc (total calculated dose)	**Agrobions, kg/ha**	**0**	**100**	**200**	**300**	**Correlation coefficient R**	**100**	**200**
1 NP	1	2.40	2.57	2.36	1.98	-0.99	2.76	2.44
1/2.NPcalc	0.5		2.23	2.1	1.45	- 0.9	2.24	2.17
¼NPcalc	0.25		1.93	1.67	1.25	-0.99	1.96	1.67
0	0						2.09	
($LSD_{0.05}$=0.2 t/ha)						Correlation coefficient R	0.91	0.94
1 NP	1	2.40	2.57	2.36	1.98	-0.99	2.76	2.44

***Source:** compiled by the authors*

The obtained data showed that the pre-sowing application of 100 kg/ha of Agrobion with full NP rate provided the highest yield of spring wheat (2.76 t/ha). Moderate doses (100-200 kg/ha) steadily increased the yield at full NP rate, while high doses (300 kg/ha) and low NP rates (¼ NPcalc) reduced the yield, especially at the main application. The effectiveness of the product depended on the method of application and dosage, with the advantage of pre-sowing application (Shuvar *et al.*, 2022). The results obtained confirmed that the effectiveness of the granular preparation Agrobion in combination with mineral fertilisers (NP) depends on their doses and method of application. At full NP rate (variant 1) without biostimulation, moderate biological activity and average yield levels were maintained, while absolute control (variant 17) showed degradation of the microbiota and a decrease in productivity. The addition of Agrobion at a dose of 100 kg/ha at full NP rate (variants 2 and 3) did not provide a noticeable increase in microbiological activity, indicating the low efficacy of the preparation in the presence of excess mineral nutrition. The maximum indicators of microorganism activity and oat yield in the tillering phase were recorded in variant 10 (200 kg/ha of "granulated biopreparation" + ½ NP, main application), where a synergistic effect of biological and mineral stimulation was observed. Variants with 300 kg/ha of the preparation showed a tendency to suppress certain microbial groups, especially actinomycetes and nitrogen fixers, which may be associated with substrate oversaturation. Similar patterns were observed in the analysis of spring wheat yield: the highest values were recorded with a pre-sowing application of 100 kg/ha of Agrobion with a full NP rate. Thus, the effectiveness of the preparation depends significantly on the dosage and application technology.

Furthermore, S.V. Nallanthighal (2024) and C.O. Adetunji *et al.* (2024) considered approaches to increasing crop yields using organic compounds and nanotechnology. S.V. Nallanthighal demonstrated that humanite can improve plant nutrition, but the study was limited to two crops and did not consider microbiological changes in the soil. The review by C.O. Adetunji *et al.* addressed nanobiofertilisers, the structure and potential benefits, but lacked information on dosages, application methods and practical results in real agricultural systems. In contrast, the present study is based on a vegetation and field experiment with 18 normalised variants, including Agrobion doses, fractional NP rates and different application methods. It covers not only oat and wheat yields but also the dynamics of microbial groups (actinomycetes, nitrogen fixers, fungal microflora), as well as agrochemical parameters (pH, EC, NPK content), making it more applicable and representative of the conditions of the black soils of Northern Kazakhstan.

According to the results of M. Aguiar *et al.* (2023) and M. Liu *et al.* (2025), biological processes in the rhizosphere directly affect nutritional efficiency and crop productivity. M. Liu *et al.* found a correlation between phosphorus-sensitive bacteria and canola growth, but the study was limited to molecular analysis without the use of fertilisers or agronomic practices. M. Aguiar *et al.* studied the impact of agroecosystem edge zones on microbial community structure, but the study addressed spatial gradients rather than managed agronomic practices. In contrast, the present study is based on targeted variation of doses and methods of application of a "granular biopreparation" with mineral fertilisers and enables a direct impact on the abundance of key microbial groups. It was found that the combination of 200 kg/ha of Agrobionts and ½ NP (variant 10) provides a multiple increase in microbiological activity and balanced nutrition, which is not covered by M. Liu *et al*. and M. Aguiar *et al*. Thus, the study offers not just monitoring of the microbiota, but specific ways of its targeted regulation.

Moreover, the studies by A. Botero (2021) and F.C. Schilt (2023) considered aspects indirectly related to soil fertility but in a different context. F.C. Schilt conducted geoarchaeological research aimed at reconstructing the Late Pleistocene environment and anthropogenic impact but without agronomic objectives and evaluation of soil processes in modern systems. A. Botero addressed phytopathological aspects and plant resistance to the keel pathogen, without considering soil microbiota, mineral nutrition and agrochemical parameters. In contrast to these studies, the present work combines agrochemical, microbiological and yield approaches. It presents data on the impact of "biological products" and mineral fertilisers on grain yields, microbial numbers, and soil chemistry, and establishes threshold dose levels beyond which a decrease in efficiency is observed. Such complexity and experimental representativeness distinguish this study from theoretical reconstructive and specialised phytopathological works.

Furthermore, R. Siuda *et al.* (2021) and G. Izydorczyk *et al.* (2022) addressed the technological aspects of fertiliser pelletisation. R. Siuda *et al.* developed and verified the method of lime-gypsum granulation, confirming its industrial applicability, but did not conduct agrobiological tests in the field. G. Izydorczyk *et al.* emphasised the importance of granulation to increase the efficiency of fertiliser application, including reducing losses and leaching, but the work was limited to laboratory analysis of the physical properties of the granules. In contrast to these technological approaches, the present study combines the granular form of Agrobion with graded doses of NPs, recording both chemical (pH, conductivity), biological (microbiota population) and yield parameters. This comprehensiveness not only confirms the suitability of the granules but also determines the biologically and economically optimal schemes of the use, which was not presented by R. Siuda *et al.* and G. Izydorczyk *et al.*

In addition, studies by A. Lisowska *et al.* (2022) and M. Ferrari *et al.* (2025) addressed alternative forms of macronutrient application. A. Lisowska *et al.* investigated granular sulphur fertilisers and their effect on sandy soils, finding an increase in sulphur content and improved substrate structure, but did not assess yield or soil biological activity. M. Ferrari *et al.* compared foliar fertilisation with traditional nitrogen application and concluded that gradual foliar application can be effective in conditions of moisture deficiency. In contrast to thematically narrow studies, the present paper covers several crops (oats and wheat), different doses of "granulated biopreparation" and NP, and includes an assessment of germination, yield and microbiological parameters. This can be used for the development of specific fertilisation schemes adapted to chornozems, in contrast to the studies by A. Lisowska *et al.* and M. Ferrari *et al.*, which were limited to certain nutrient forms.

In this context, studies by B.R. Sahoo *et al.* (2024) and C.O. Asadu *et al.* (2024) addressed promising approaches to improving fertilizer efficiency. B.R. Sahoo *et al.* showed that nanoforms of fertilisers have a positive effect on rice yield and soil health, but the study was mainly laboratory-based and did not address interactions with mineral fertilisation. C.O. Asadu *et al.* presented an overview of slow-release fertilisers, emphasising mechanisms and potential benefits, but without specific dose gradations or analysis of application methods. In contrast, the present study is based on field and vegetation experiments with clear variations in fertiliser rates, which identified threshold values at which a sharp decline in biological activity or yield occurs. Thus, the results obtained not only complement but also expand the understanding of the rational use of fertilisers in practice, offering reproducible solutions for the conditions of Northern Kazakhstan.

In addition, J. Hou *et al.* (2025) and A.R.S. Viana *et al.* (2025) investigated the effectiveness of alternative types of organo-mineral fertilisers. J. Hou *et al.* demonstrated that the application of mixed straw-chemical fertiliser increases nitrogen nutrition in sweet corn; however, the study was limited to a single crop and did not evaluate soil microbiological parameters. A.R.S. Viana *et al.* studied the effect of wastewater sludge-based fertilisers on chickpea yield and soil properties, recording increased yields and higher available phosphorus content. In contrast to the mentioned study, the present paper covered several crops (oats, wheat), uses combinations of "biopreparations" and mineral fertilisers that differ in method and dose, and evaluates not only productivity but also the state of the microbiota (actinomycetes, nitrogen fixers, fungi) and agrochemical indicators. This provides grounds for a comprehensive assessment of the interactions between "preparation-fertiliser-soil-plant", which was not conducted in the studies. The experiment must establish threshold doses and application methods.

Furthermore, D. Shanmugavel *et al.* (2023) and A. Jasińska *et al.* (2023) addressed promising strategies for sustainable fertilisation. D. Shanmugavel *et al.* presented a synthesis review of smart fertilisers, focusing on controlled release and new carriers, but practical data in field crops was minimal. A. Jasińska *et al.* analysed the use of digestate from anaerobic digestion as a fertiliser, identifying agronomic potential but not considering microbiological activity and interaction with mineral components. In contrast to these approaches, the present study provides experimentally confirmed data on the combination of a "biological product" and NPs, quantifying the response of microbial communities and yields at different doses. This not only theoretically substantiates the effectiveness of the combined approach but also proposes specific practical solutions for the chornozems of Northern Kazakhstan, including in conditions of limited use of mineral components.

In turn, the studies by T. Srisawat *et al.* (2024) considered alternative models of agriculture and biowaste conversion. T. Srisawat *et al.* demonstrated that natural (subsistence) agriculture can reduce vegetative mass but does not affect the yield and quality of rice, while not studying microbiological processes and agrochemical changes in the soil. K. Chojnacka *et al.* (2024) presented the practical aspects of converting biological waste into fertilisers, emphasising the technological value of the raw material, but the efficiency in terms of soil microbiota and agrocenosis productivity was not assessed. In contrast to the mentioned studies, the present paper addressed the granular biopreparation not only in terms of form and source but also in an agro-functional context: how it affects growth, nutrition, microbial composition and yield. This makes it possible to adapt Agrobion doses depending on the goal (increasing yield, activating microbiota, saving NPs), which makes the study highly applicable.

CONCLUSIONS

A comprehensive assessment of the effectiveness of the granular biological product Agrobion in combination with nitrogen-phosphorus mineral fertilisers (NP) in different doses and methods of application was made in a vegetation and field experiment on the southern black soil of Northern Kazakhstan. The study covered 18 experimental variants, including absolute control (no fertiliser), control with full NP rate, and combinations of biological products at doses of 100, 200 and 300 kg/ha with mineral fertilisers applied at doses of ¼, ½, ¾ and 1.0 of the calculated rates. Based on microbiological analyses, the study determined that the most favourable option for activating the rhizosphere microbiota was a combination of 200 kg/ha of the "granular biological product" with a ½ dose of NP at the main application (variant 10). In this variant, the maximum values of the number of actinomycetes, aerobic nitrogen fixers, and organotrophic and cellulose-degrading bacteria were recorded. This confirms that a moderate reduction in the mineral load during biostimulation can achieve a synergistic effect and activate the soil microbiota. On the contrary, high doses of the "granular biological product" (300 kg/ha) at the full dose of NP caused inhibition of certain microbial groups, probably due to substrate oversaturation.

The analysis of oat yields in the tillering and earing phases showed that at a dose of 300 kg/ha and a reduction of NP to ½, the yield reached maximum values (49.52 g/vessel), exceeding the control values by more than 20 g/vessel. At ¾ NP, a similar ratio also had a positive effect, but the yield level was slightly lower than at ½ NP. When the dose of NP was reduced to ¼, the compensating effect of the "preparations" became less pronounced, especially at a dose of 120 kg/ha. The field germination of oats and spring wheat also responded positively to moderate doses of the "preparation". The highest values of germination (72.14%) and yield (733 g/m²) of wheat green mass were achieved at the pre-sowing application of 100 kg/ha of the "granular biopreparation" with the full dose of NP. For the grain productivity of spring wheat (t/ha), the same variant provided a yield of 2.76 t/ha, the maximum among all experimental combinations. At the same time, an increase in the dose of the "selected preparation" to 300 kg/ha at low NP rates led to a decrease in yield, which indicates a possible stressful effect of excessive biological load. In the future, it is planned to expand the tests on different soil types and under-production crops to assess the stability of the effect of the "preparations".

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CONFLICT OF INTEREST

None.

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Оптимізація дозувань та методів внесення гранульованого меліоративного препарату Агробіонів у поєднанні з мінеральними добривами для зернових культур на південних чорноземах Північного Казахстану

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Анотація. Метою дослідження було визначення ефективних співвідношень біопрепарату та мінеральних добрив для підвищення врожайності та активності ґрунту. У дослідженні представлені результати комплексного вивчення впливу гранульованого препарату «Агробіон» та різних доз мінеральних добрив (МД) на агробіологічні показники вівса та ярої пшениці на південному чорноземі Північного Казахстану. Дослід охоплював 18 варіантів комбінацій добрив, включаючи абсолютний контроль, стандартну дозу МД, а також різні дози Агробіону (100-300 кг/га) та їх комбінації з ¼, ½, ¾ та повною нормою МД за основного та передпосівного способів внесення. Найвища біологічна активність ґрунту спостерігалася у варіанті з 200 кг/га «препарату» та ½ МД, що супроводжувалося п'ятикратним збільшенням кількості азотфіксаторів, актиноміцетів та целюлозорозкладаючих бактерій порівняно з контролем. Урожайність вівса у фазі колосіння за цієї комбінації досягла 49,52 г/посудину, а максимальна польова схожість (72,14 %) зафіксована при передпосівному внесенні 100 кг/га Агробіону з повною дозою МД. Аналіз хімічних властивостей ґрунту показав зниження електропровідності та підтримку оптимального pH при помірному зниженні МД та використанні препарату. Результати демонструють, що оптимальні дози Агробіону (100-200 кг/га) у поєднанні з ½ або ¾ розрахункової норми NP забезпечують найвищу врожайність, мікробіологічну активність та схожість. Надмірні дози (300 кг/га) або різке зниження NP призвели до зниження ефективності. Виявлено кореляцію між дозою Агробіону, врожайністю та показниками родючості ґрунту. Рекомендована комбінація для підвищення агроекологічної ефективності – 200 кг/га «гранульованого препарату» з ½ МД при основному внесенні. Практична цінність цього дослідження полягає в обґрунтуванні оптимальних доз Агробіону та МД, що зменшує мінеральне навантаження без втрати врожайності, що сприяє ресурсозбереженню та захисту навколишнього середовища сільського господарства

Ключові слова: ґрунтові мікроорганізми; врожайність; кислотність ґрунту; способи внесення; біоактивність