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FORMATION OF SOYBEAN NODULES DEPENDING ON MINERAL NUTRITION AND BIOPREPARATIONS IN THE FOREST-STEPPE OF UKRAINE

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Soybean plays a key role in global nutrition and industry as a high-protein crop with unique nitrogen-fixing ability, improving soils and reducing the need for synthetic fertilizers. On a global scale, it dominates in exports and processing into food products, biofuels, and feeds, with a focus on adaptation to regional conditions. In Ukraine, soybean is gaining strategic importance for diversifying the agricultural sector; optimizing crop rotations, and enhancing agroecosystem resilience. As a versatile raw material, soybean is used in pharmaceuticals and cosmetics for producing extracts and oils, underscoring its multifaceted industrial significance. At the same time, the growth of soybean production stimulates innovations in organic farming, contributing to the sustainable development of global food security.

The study was conducted in the conditions of the Forest-Steppe of Ukraine. An early-maturing Ukrainian-bred soybean variety Titan was grown in the experiment. Seed inoculation before sowing was performed with the Atuva preparation, and mineral fertilizers in the form of ammonium nitrate were applied at rates of 20 kg/ha, 40 kg/ha, and 60 kg/ha of active substance during spring cultivation.

On early developmental stages of soybean, seed inoculation with the biopreparation increased the number of nodules per plant, with a maximum of 26.4 at the N₄₀ rate of mineral fertilizer; higher (N₆₀) or lower (N₂₀) rates reduced this indicator. Without inoculation, the number of nodules increased under N₂₀ and N₄₀ (19.2–24.2), decreasing to 22.5 at N₆₀. The mass of nodule without inoculation was also highest at N₄₀; a positive effect of the biopreparation on nodule development was observed without fertilizers and at N₄₀. Before soybean flowering, the number of nodules increased with the use of the biopreparation, especially under natural nutrition, with positive dynamics in all variants except N₄₀ where fertilizers inhibited bacterial activity. The maximum mass of nodule in the study was recorded with the interaction of the biopreparation and N₂₀ application – 0.81 g. With increasing rates of ammonium nitrate application, especially in combination with the biopreparation, the mass of nodule decreased. Without seed inoculation with the biopreparation, soybean yield ranged from 33.77–34.90 t/ha, with the maximum at N₆₀. The use of the biopreparation increased soybean yield, and in combination with N₆₀ the highest harvest was obtained – 35.23 t/ha. Thus, the application of the Atuva biopreparation in combination with moderate rates of ammonium nitrate is an effective measure to increase soybean yield, optimizing plant nitrogen nutrition, reducing stress impacts, and improving production economic efficiency.

Key words: soybean, soybean nodules, biopreparation, mineral fertilizers, soybean yield.

Жарко Д.А., Соколовська І.М. Формування бульбочок сої залежно від мінерального живлення та біопрепарату в Лісостепу України

Соя відіграє ключову роль у глобальному харчуванні та промисловості як високобілкова культура з унікальною азотфіксуючою здатністю, що покращує ґрунти та зменшує

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потребу в синтетичних добривах. У світовому масштабі вона домінує в експорті та переробці на продукти харчування, біопаливо та корми, з фокусом на адаптацію до регіональних умов. В Україні соя набуває стратегічного значення для диверсифікації аграрного сектору, оптимізуючи сівозміни та стійкість агроєкосистем. Як універсальна сировина, соя використовується в фармацевтиці та косметичці для виробництва екстрактів і олій, що підкреслює її багатогранне промислове значення. Водночас, зростання виробництва сої стимулює інновації в органічному землеробстві, сприяючи сталому розвитку глобальної продовольчої безпеки.

Дослідження проводили в умовах Лісостепу України. В досліді вирощували ранньостиглий сорт сої Титан української селекції. Інокуляцію насіння перед сівою проводили препаратом Атува, мінеральні добрива в формі аміачної селітри вносили нормою 20 кг/га, 40 кг/га, 60 кг/га діючої речовини під весняну культивуацію

На ранніх фазах розвитку сої інокуляція насіння біопрепаратом підвищувала кількість бульбочок на рослині, з максимумом 26,4 шт. при внесенні мінерального добрива нормою N_{40} вищі (N_{60}) або нижчі (N_{20}) норми знижували цей показник. Без інокуляції кількість бульбочок збільшувалася на фоні N_{20} та N_{40} (19,2-24,2 шт.), при N_{60} – зменшувалася до 22,5 шт. Маса бульбочок без інокуляції також була найбільшою при внесенні N_{40} на фоні без добрив та N_{40} спостерігали позитивний ефект дії біопрепарату на розвиток ризобіїв. Перед цвітінням сої кількість бульбочок зростала при використанні біопрепарату, особливо на фоні природного живлення з позитивною динамікою в усіх варіантах, крім N_{40} де добрива пригнічували активність бактерій. Максимальну в досліді масу бульбочкових бактерій відмічали при взаємодії біопрепарату з внесення N_{20} – 0,81 г. Із збільшенням норми внесення аміачної селітри, особливо при комплексній дії з біопрепаратом маса бульбочок зменшувалася. Без інокуляції насіння біопрепаратом урожайність сої коливалася у межах 33,77–34,90 т/га, з максимальним значенням при внесенні N_{60} . Використання біопрепарату сприяло підвищенню врожайності сої, в комплексі з N_{60} отримали найбільший врожай – 35,23 т/га. Таким чином, застосування біопрепарату Атува у поєднанні з помірними нормами аміачної селітри є ефективним заходом для підвищення урожайності сої, що дозволяє оптимізувати азотне живлення рослин, знизити рівень стресових впливів і покращити економічну ефективність виробництва.

Ключові слова: соя, бульбочкові бактерії, біопрепарат, мінеральні добрива, урожайність сої.

Formulation of the problem. The formation of soybean nodules is a key component of the nitrogen-fixing symbiosis, which largely determines the level of nitrogen supply to plants and their productivity under various soil and climatic conditions. In the Forest-Steppe zone of Ukraine, the combination of intensive cultivation technologies with climate-related stresses (fluctuations in moisture and temperature) requires clarification of the optimal fertilization parameters and the use of biological products.

The effects of different levels of mineral nutrition and the application of biological products on nodule formation, their number, mass and activity, as well as on the realization of the symbiotic potential of soybean under Forest-Steppe conditions of Ukraine, are still insufficiently substantiated. This complicates the development of scientifically grounded fertilization and inoculation systems capable of ensuring stable nitrogen fixation, rational use of fertilizers and increased soybean yield without excessive pressure on agroecosystems.

Analysis of recent research and publications. Soybean (*Glycine max* (L.) Merr.) is one of the most important legume crops in the global agribusiness, serving as a primary source of protein, oil, and feed resources. According to FAO data, global soybean production in 2023 exceeded 390 million tons, with leading producers such as the USA, Brazil, and Argentina, where sown areas surpass 100 million ha [3].

Soybean forms the basis of the food, feed, and industrial sectors: its seeds contain 35-45 % protein, 18-25 % oil, and significant amounts of essential amino acids, making it indispensable for producing soy milk, tofu, biodiesel, and livestock feeds. On

a global scale, soybean contributes to food security by providing high-quality plant-based protein for the population and improves soil fertility through biological nitrogen fixation [1, 2].

In Ukraine, soybean is gaining strategic importance: according to State Statistics Service data, in 2024, the sown area under soybean increased to 1.8 million ha, with yields reaching 2.5-3 t/ha, making it one of the most relevant crops. Ukraine is a significant soybean exporter (over 2 million tons annually), which stimulates the development of the processing industry and contributes to the diversification of the agricultural sector, especially amid climate change and GMO use restrictions [4, 5].

Soybean cultivation in Ukraine and worldwide depends on optimizing agrotechnologies, where fertilizers and biopreparations adapted to the crop's biological characteristics play a key role. The most important feature of soybean is its symbiosis with nodule of the genus *Rhizobium*, which ensures atmospheric nitrogen fixation (up to 100-200 kg/ha), making soybean less dependent on nitrogen fertilizers compared to other crops. However, soybean is sensitive to phosphorus and potassium deficiencies, especially in early stages (germination at 15-20 °C, flowering at 20-25 °C), when the root system develops intensively, and nutrient shortages lead to flower drop and reduced yields [6, 12, 9].

Mineral fertilizers enhance nutrient availability, but their excessive use can suppress symbiosis and pollute soils. Biopreparations boost nitrogen fixation, improve phosphorus uptake from poorly available forms, and increase resistance to drought and diseases, which is particularly relevant for Ukrainian chernozems with pH 6.0-7.5. Integrating these tools not only increases yields by 15-30 % (up to 3-4 t/ha) but also ensures production ecological sustainability by reducing on synthetic fertilizers [7, 8, 10, 11, 13, 14].

It should be noted that soybean is also an important component of crop rotations due to its ability to fix atmospheric nitrogen, which improves soil fertility. It serves as a good predecessor for many crops, as it helps reduce the risk of disease and pest development. Including soybean in crop rotations helps decrease the need for chemical fertilizers, positively impacting the ecological situation. Additionally, soybean increases the organic matter content in the soil, contributing to improved structure and water-holding capacity. Using soybean in crop rotations also ensures crop diversity, which is crucial for agroecosystem sustainability. Thanks to these advantages, soybean becomes a key element in modern agriculture, promoting sustainable development of the agricultural sector [17, 18, 15, 16].

Thus, the article addresses current issues of optimizing soybean agrotechnology in the conditions of the Forest-Steppe of Ukraine, presenting the results of a study on the impact of combined application of mineral fertilizers (ammonium nitrate) and a biopreparation on soybean yield and productivity.

Research task. To determine the level of impact of mineral fertilizer application rates and biopreparation on the formation of nodule and soybean yield in the conditions of the Forest-Steppe of Ukraine.

Materials and methods of research. The study was conducted in the conditions of the Forest-Steppe of Ukraine on dark gray forest heavy loamy soils. An early-maturing Ukrainian-bred soybean variety Titan was grown in the experiment.

The soybean cultivation technology was standard for the zone, except for the treatments under study. Soybean was sown at a rate of 450 thousand plants/ha using wide-row method (row spacing 45 cm) after spring wheat as a predecessor.

Seed inoculation before sowing was performed with the Atuva preparation – a biological inoculant for soybean containing *Bradyrhizobium japonicum* bacteria, which fix atmospheric nitrogen and form nodule on roots (2.0 l/t + biological protector Premax 0.5

l/t) (factor A). Mineral fertilizers in the form of ammonium nitrate were applied at rates of 20 kg/ha, 40 kg/ha, 60 kg/ha of active substance during spring cultivation (factor B).

The territory of the field experiment is characterized by a moderately continental climate with sufficient moisture but a tendency toward summer drought. The average precipitation sum for the period is 300–400 mm, with risks of uneven rains and temperature fluctuations affecting emergence and flowering. Overall, conditions were favorable for soybean during the study period, but 2024 proved stressful due to drought.

The year 2023 was favorable for soybean – a warm spring (May: +15...+20 °C, precipitation 50–70 mm) with even rains promoted rapid emergence; summer was moderately warm (June–July: +20...+25°C, 70–90 mm precipitation), without severe droughts but with thunderstorms; August–September were cooler (+15...+22 °C, 40–60 mm), with sufficient moisture for maturation.

The year 2024 was characterized as unfavorable due to sharp weather fluctuations – a warm April (+12...+18 °C) led to early sowing, but May cooling (+8...+15 °C, cold rains 60–80 mm) caused uneven emergence and diseases; July was hot and dry (+25...+30 °C, precipitation <50 mm, dry winds), weakening flowering and pod setting; June and August had thunderstorms (60–70 mm), but overall moisture deficit led to reduced crop yield.

The year 2025 was close to normal, with moderate warming – May was warm (+14...+22 °C, 50–60 mm precipitation) for emergence; summer had rains (June–July: +18...+26 °C, 70–80 mm), but short droughts in August (+17...+25°C, 50 mm); September was cool (+12...+20 °C, 40 mm), with fogs that aided soybean yield formation.

Results and discussion. Nodules, as symbiotic structures, play a key role in providing plants with essential nutrients, particularly nitrogen. Studying the conditions that promote or inhibit their development is crucial for optimizing agronomic practices and increasing soybean yields. Analysis of factors such as moisture, temperature, soil type, and agronomic measures will help better understand the mechanisms of nodule formation and their significance for plant health.

We established that at different developmental stages of soybean plants, the rates of ammonium nitrate application and seed treatment with the Atuva biopreparation had varying impacts on the development of the plants' symbiotic apparatus. Thus, in the three true leaf stage, seed inoculation before sowing significantly enhanced the activity of nitrogen-fixing bacteria in variants without mineral fertilizer application: we counted 21.7 nodule, whereas without the biopreparation, their number was 19.2. The maximum number of nodules formed under N_{40} application, 26.4 per plant, but the rhizobial intensity was slightly lower than under natural plant nutrition – seed inoculation provided a significant difference, +2.2 per plant (Fig. 1).

At N_{60} application, nitrogen suppressed microbial activity, and the preparation's effect was insignificant, +0.7 nodules. Under N_{20} , the plant and rhizobial bacteria likely received a sufficiently low level of soil nitrogen, but enough for the plant to stimulate symbiotic bacteria development less. As a result, the biopreparation did not provide a noticeable increase in the number of nodules, as the plant and soil were already supplied with nitrogen at a basic level. Thus, the optimal combination was mineral nutrition at N_{40} , where nitrogen stimulated roots, and the biopreparation, where Atuva enhanced symbiosis.

It should be noted that a greater number of nodules formed at the optimal fertilizer application rate in the study – N_{40} , both with seed inoculation (26.4 nodules) and without the biopreparation (24.2 nodules), with this fertilizer rate being more effective without the biopreparation – the number of nodules increased by 5.0 compared to the control.

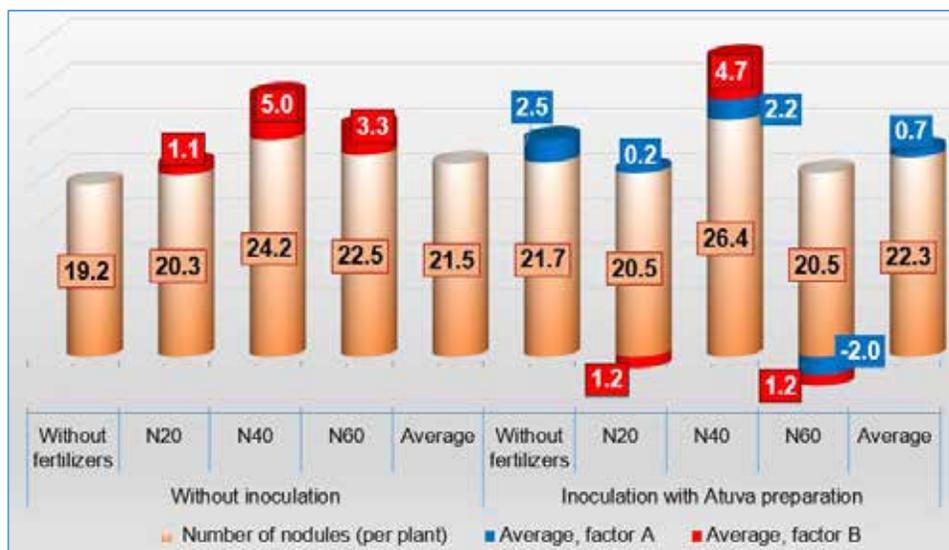


Fig. 1. Impact of the biopreparation and ammonium nitrate application rates on the number of nodules in the three true leaf stage, nodules per plant (2023-2025).

$LSD_{0.5}$: factor A = 2.2, factor B = 4.6, factors AB = 5.4.

During the growth and development of soybean plants, we observed dynamic changes in the number of nodules, as well as changes in the role of the biopreparation and mineral fertilizer rate in regulating this indicator. Thus, we noted a positive dynamic in the number of nodules under seed inoculation in all fertilization variants (Fig. 2), except for N_{40} application (in early developmental stages of plants, this variant provided the greatest increase in the symbiotic apparatus).

It should be noted that the activity of the biopreparation was enhanced, especially under natural plant nutrition: the number of rhizobial bacteria was the highest, 67.5 per plant, with the greatest positive dynamics, +24.1. Mineral fertilizer application suppressed the activity of nitrogen-fixing bacteria, particularly at the N_{40} rate, where a negative dynamic was observed, -3.2, and moreover, the difference from the control (without inoculation) was significant.

At the initial stages of soybean vegetation, we observed a greater positive impact of mineral fertilizer on the formation of rhizobial bacteria without the use of the biopreparation, whereas at the onset of plant flowering, there was a tendency toward increased combined action of ammonium nitrate and inoculation on rhizobial activity, and moreover, the dynamics was negative.

Without seed inoculation with the biopreparation, a decrease in the number of nodules was observed from 43.4 to 35.9 per plant, with N_{60} application most strongly suppressing the formation of the symbiotic apparatus. Under N_{40} application, although a significant decrease in the number of nodules was noted, the difference from the control was the smallest, -2.9.

Seed treatment before sowing with the biopreparation intensified the negative trend of decreasing nodule number, and particular attention is drawn to soybean fertilization at the N_{40} rate: under this mineral nutrition background, an almost twofold decrease

in nodule number was observed compared to the control without fertilizers – 37.3 per plant (-30.2).

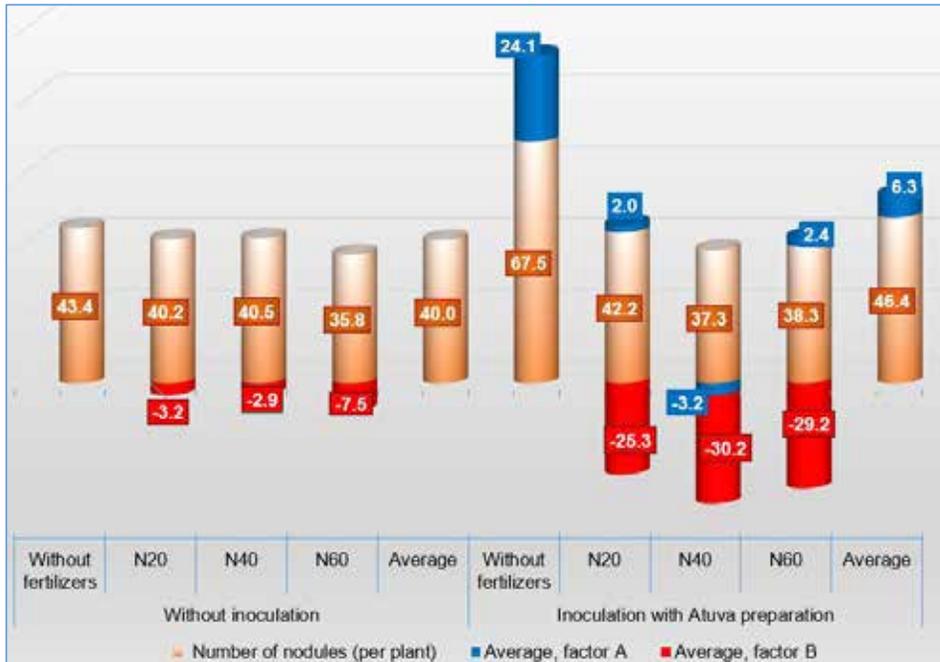


Fig. 2. Impact of the biopreparation and ammonium nitrate application rates on the number of nodules at the onset of flowering, nodules per plant (2023-2025)
*LSD*_{0.5}: factor A = 2.0, factor B = 3.0, factors AB = 4.3.

The mass of nodules per plant is a key indicator of symbiotic activity, determined by a complex of factors. At early developmental stages of soybean plants, the mass of rhizobia increases (from vegetative stage to the onset of flowering). The use of the biopreparation stimulates root system activity, activates nitrogen fixation, and ensures an increase in nodule mass. Therefore, the greatest effect of the biopreparation was observed in the variant without mineral fertilizers, where nodule mass at the three true leaf stage was 0.32 g per plant, increasing by 0.08 g compared to the control. Under N₄₀ application, the mass of rhizobial bacteria was also at the level of 0.32 g, but it formed due to soil nitrogen, which suppressed bacterial activity (Fig. 3).

Ammonium nitrate has a dual effect – it stimulates plant growth but suppresses symbiosis because soybean primarily uses soil nitrogen. In our experiments without the biopreparation, the optimal rate was N₄₀, with nodule mass at 0.31 g and an increase of 0.08 g compared to the control. Increasing or decreasing the fertilizer rate led to a reduction in the mass of the soybean plants' symbiotic apparatus.

With combined use of the biopreparation and ammonium nitrate, the same trend persisted, but the negative dynamics were intensified. Under N₆₀ and seed inoculation, the mass of rhizobial bacteria was the lowest in the study, at 0.20 g.

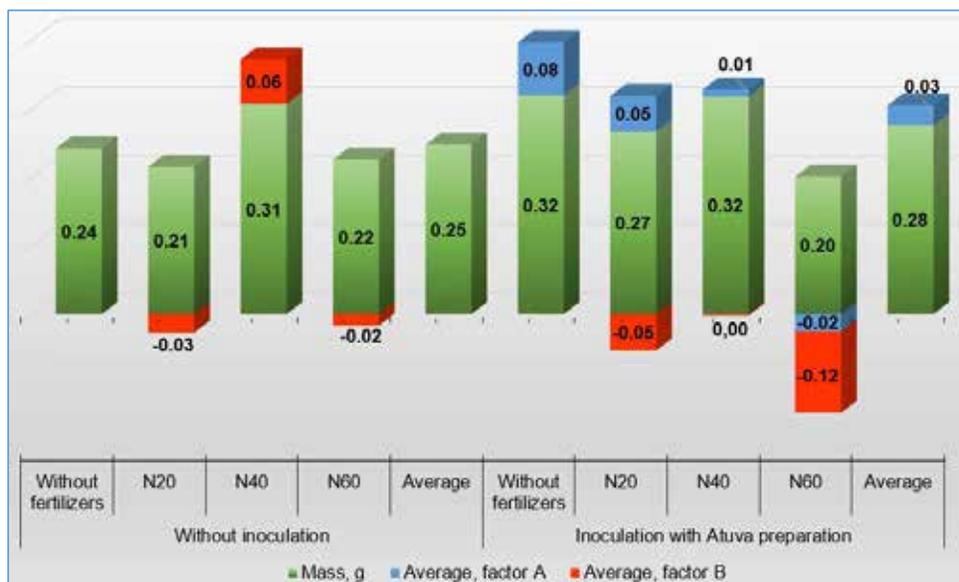


Fig. 3. Influence of the biopreparation and ammonium nitrate application rates on nodules mass at the three true leaf stage, gram from one plant (2023-2025)

$LSD_{0.05}$: A = 0.03; B = 0.05; AB = 0.07.

The mass of nodules peaked before soybean flowering. In our study, values ranged from 0.54 g to 0.81 g. Similar to early developmental stages, the greatest significant increase in rhizobial mass was observed under the influence of the biopreparation, an increase of +0.26 g compared to the absolute control, with mass reaching 0.79 g. The highest nodules mass was noted with the interaction of the biopreparation and minimal fertilizer application rate N_{20} – 0.81 g, with a significant increase of +0.09 g. It should be noted that without seed inoculation, this fertilizer variant also provided a higher nodules mass value of 0.72 g per plant (Fig. 4)

According to our research results, without seed inoculation with the biopreparation, soybean yield ranged from 33.77 to 34.90 t/ha, with the maximum value at N_{60} application. This indicates that nitrogen fertilizers alone had a moderate stimulating effect, but at the intermediate N_{40} rate, yield did not increase, possibly due to suppression of rhizobial symbiosis by NH_4^+ (Table 1).

The use of the Atuva biopreparation stabilized and increased yield: without fertilizers, yield was 33.66 t/ha, and with N_{60} application – 35.23 t/ha, exceeding the corresponding value without inoculation by 0.33 t/ha. This indicates that inoculation enhanced rhizobial activity, stimulating nodules formation, improving nitrogen fixation, and thus plant development even at higher nitrogen application rates.

The interaction of the biopreparation and mineral fertilizer in our study demonstrated a synergistic effect, where the optimal ratio between soil nutrition and symbiosis ensured the highest yield. The highest values were observed with seed inoculation using the biopreparation and N_{60} application, which contributed to a 4-5 % increase in soybean yield compared to the control without fertilizers and inoculation.

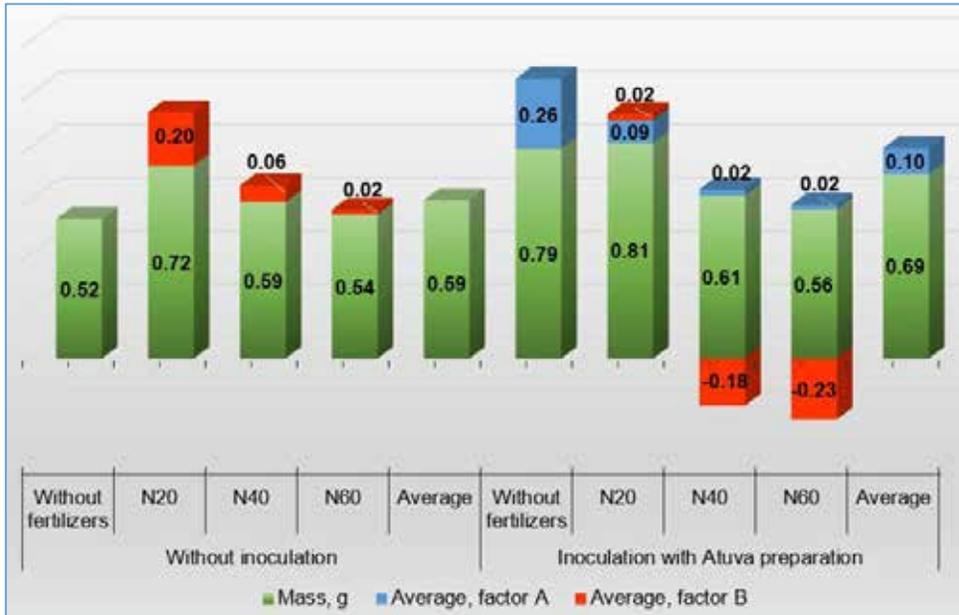


Fig. 4. Influence of the biopreparation and ammonium nitrate application rates on nodules mass at the onset of flowering. gram from one plant (2023-2025)

LSD_{0.05}: A = 0.05; B = 0.08; AB = 0.11.

Table 1

Influence of the biopreparation and ammonium nitrate application rates on soybean yield (2023-2025)

Seed inoculation (factor A)	Fertilizer application rate, (factor B)	Yield, t/ha	Average, factor A	Average, factor B	Difference, factor A	Difference, factor B
Without inoculation	Without fertilizers	33.77	34.18	33.72		
	N ₂₀	34.27		34.27		0.50
	N ₄₀	33.78		33.97		0.01
	N ₆₀	34.90		35.07		1.13
Inoculation with Atuva preparation	Without fertilizers	33.66	34.33		-0.11	
	N ₂₀	34.27			0.00	0.61
	N ₄₀	34.15			0.37	0.49
	N ₆₀	35.23			0.33	1.57
LSD _{0.05} : A=0.36 t/ha; B=0.54 t/ha; AB=0.79 t/ha.						

Conclusions. The results of our study allow us to draw the following conclusions:

1. At early developmental stages of soybean plants, seed inoculation before sowing with the Atuva preparation increased the average number of nodules per plant, with a maximum of 26.4 at N₄₀ application; increasing the rate to N₆₀ or decreasing to N₂₀ reduced the number of nodules. Without inoculation, the number of nodules increased

from 19.2 (without fertilizers) to 24.2 (N_{40}) and decreased at N_{60} to 22.5, indicating stimulation of symbiosis by moderate nitrogen fertilizer rates and partial suppression by high rates.

2. Nodules mass at early developmental stages without inoculation increased from 0.21 g (N_{20}) to 0.31 g (N_{40}) and decreased to 0.22 g at N_{60} application. The use of the biopreparation contributed to an increase in nodule mass to 0.32 g, both without fertilizers and at the N_{40} rate.

3. During the growth and development of soybean plants, changes in nodules number were observed: positive dynamics in nodules number under seed inoculation in all fertilization variants except N_{40} ; enhanced biopreparation activity under natural plant nutrition – the number of rhizobial bacteria was the highest at 67.5 per plant, with the greatest positive dynamics of +24.1; mineral fertilizer application, especially at N_{40} , suppressed the activity of nitrogen-fixing bacteria.

4. The mass of nodules peaked before soybean flowering. The most significant increase in rhizobial mass was observed under the influence of the biopreparation, reaching 0.79 g, which is an increase of +0.26 g compared to the absolute control. The maximum nodules mass in the study was noted with the interaction of the biopreparation and N_{20} application – 0.81 g. With increasing ammonium nitrate rates, especially in combination with the biopreparation, nodule mass decreased. Excess mineral nitrogen suppressed the symbiosis development between the plant and rhizobial bacteria, reducing nitrogen fixation activity.

5. Without seed inoculation with the biopreparation, soybean yield ranged from 33.77 to 34.90 t/ha, with the maximum value at the N_{60} rate; under N_{40} , yield did not increase, possibly due to suppression of the rhizobial symbiosis. The use of the Atuva biopreparation contributed to increased soybean yield, with the highest yield of 35.23 t/ha obtained at the N_{60} application rate.

Thus, the use of the Atuva biopreparation in combination with moderate ammonium nitrate rates is an effective measure to enhance soybean yield, optimizing plant nitrogen nutrition, reducing stress factors, and improving economic production efficiency.

REFERENCES:

1. Shea Z., Singer W. M., Zhang B. Soybean Production, Versatility, and Improvement. *In book: Legume Crops [Working Title]*. 2020. <https://doi.org/10.5772/intechopen.91778>
2. Terzić D., Popovic V. M., Tatić M., Vasileva V. Soybean area, yield and production in world. *International Eco Conference*. 2018. P. 135-144. file:///C:/Users/User/Downloads/TerzicPopovicTaticetal.Soybean-Eco2018.pdf
3. FAO. World Food and Agriculture – Statistical Yearbook 2024. Food and Agriculture Organization of the United Nations. 2024. <http://www.fao.org/3/cc8020en/cc8020en.pdf>
4. Мізерник Д. В. Сучасний стан та перспективи вирощування сої в світі і Україні. *Передгірне та гірське землеробство і тваринництво*. 2024. Вип. 76(1). P. 36-47. [https://doi.org/10.32636/01308521.2024-\(76\)-1-4](https://doi.org/10.32636/01308521.2024-(76)-1-4)
5. Романько А. Ю. Стан вирощування сої в Україні та Сумській області. Вісник Сумського національного аграрного університету. Серія: Агрономія і біологія. 2017. № 9. С. 73–76. <https://repo.snau.edu.ua/xmlui/handle/123456789/5776>
6. Губенко Л. В., Голодна А. В., Ремез Г. Г. Вплив мінеральних добрив та бактеріальних препаратів на урожайність та якість насіння сої. *Науково-технічний бюлетень Інституту олійних культур НААН*. № 27, 2019: 89-96. https://bulletin.imk.zp.ua/pdf/2019/27/Hubenko_27.pdf

7. Федорук І. В., Колодій В. А., Хмелянчишин Ю. В. Вплив елементів живлення на продуктивність сої. *Таврійський науковий вісник*. № 128. С. 221-228. <https://doi.org/10.32851/2226-0099.2022.128.30>
8. Душко П. М., Шумигай І. В. Вплив систем удобрення на продуктивність рослин сої (*Glycine max* L.). *Агроекологічний журнал*. 2023. № 4. С. 175-180. <https://doi.org/10.33730/2077-4893.4.2023.293796>
9. Książak J., Wojarszczuk J. The Effect of Mineral N Fertilization and Bradyrhizobium japonicum Seed Inoculation on Productivity of Soybean (*Glycine max* (L.) Merrill). *Agriculture*. 2022, 12(1), 110. <https://doi.org/10.3390/agriculture12010110>
10. Бараболя О. В., Найдон М. Й., Кононенко С. М., Коровніченко С. Х. Вплив мінерального живлення на продуктивність сої. *Науковий прогрес та інновації*. 2020. № 4, 35–44. <https://doi.org/10.31210/visnyk2020.04.04>
11. Nematova Feruzakhon Jamol kizi. The effect of mineral fertilizers on the yield and oil content of soybean grains of the arleta variety. *American journal of agriculture and horticulture innovations*. 2022. 02(05):19-24. <https://doi.org/10.37547/ajahi/Volume02Issue05-04>
12. Фурман В. Вплив мінеральних добрив та інокуляції на формування індивідуальної та насінневої продуктивності сої в умовах Лісостепу Правобережного. *Корми і кормовиробництво*. 2021. Випуск 91. С. 82-92. <https://doi.org/10.31073/kormovyrobnytstvo202191-07>
13. Mashchenko Yu. V. Sokolovska I. M. Productivity of soybean depends on predecessors and fertilizer systems in short-rotation crop rotations of the steppe zone of Ukraine. *Аграрні інновації*. 2023. № 20. 50-55. <https://doi.org/10.32848/agra.innov.2023.20.8>
14. Sokolovska I. M., Mashchenko Yu. V., Zharko D. A. Productivity of soybean depending on the predecessor and fertilization system in the conditions of the steppe of Ukraine. *Таврійський науковий вісник*. 2024. № 136. Частина 2. С. 142-151. <https://doi.org/10.32782/2226-0099.2024.136.2.18>
15. Mashchenko Yu. V., Sokolovska I. M., Zvezdun O. M. Yield and economic efficiency of soybean cultivation in different models of short-rotation crop rotations. *Науково-технічний бюлетень Інституту олійних культур НААН*. 2024, № 37. С. 76-86. <https://doi.org/10.36710/ІОС-2024-37-08>
16. Мащенко Ю. В., Соколовська І. М., Ткач А. Ф. Продуктивність сої залежно від її частки в сівозміні та системи удобрення в умовах північного Степу. *Подільський вісник: сільське господарство, техніка, економіка*. Випуск 1 (38). 2023. С. 26–32. DOI: <https://doi.org/10.37406/2706-9052-2023-1.4>
17. Фіненко І. І., Білявська Л. Г., Снітко Л. О. Соя – стратегічна культура світового землеробства. *Полтавська державна аграрна Академія*. Полтава. 2017. 100 с. <https://www.pdau.edu.ua/sites/default/files/node/3165/soya.pdf>
18. Hamza M., University O. M., Basit A. W., Shehzadi I., Tufail U. Global Impact of Soybean Production: A Review. *Asian Journal of Biochemistry, Genetics and Molecular Biology*. 2024. Vol. 16, No. 2. P. 12-20. <https://doi.org/10.9734/ajbgmb/2024/v16i2357>

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