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Nitrogen-Fixing Capacity of Soybean Varieties Depending on Seed Inoculation and Foliar Fertilization with Biopreparations

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ABSTRACT

The article reveals the role of soybean varieties and the value of their crops, capable of fixing atmospheric nitrogen and being a favorable predecessor in modern crop rotations, the importance of optimizing organo-mineral nutrition, seed treatment with nitrogen-fixing and phosphate-mobilizing bacteria for improving the nitrogen-fixing capacity of soybean varieties. Development of the technology of growing soybeans with environmentally friendly elements requires scientific substantiation and adaptation to the soil and climatic conditions of a particular growing zone, as well as the research of their impact on the varietal characteristics of a crop. The research outcomes confirmed the maximum formation of the symbiotic apparatus indicators: the number and weight of soybean nodules and their intensive functioning with the formation of the highest indicators of the total and active symbiotic potential as well as the amount of biologically fixed nitrogen, it is necessary to jointly inoculate seeds with Rizoline and double application of chelated microfertilizers at microstage BBCH 12-13: Organic Balance + Azotophyte + Helprost Soybean + Liposam and at microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam. At the same time, the total number of soybean nodules was formed in the Samorodok variety − 50.3, of which 36.0 pcs./plant were active, in the Amadeus variety – 55.6 and 40.0 pcs./plant. The total and active weight of soybean nodules in the Samorodok variety made up 515 and 399 mg/plant, and in the Amadeus variety – 586 and 454 mg/plant. Indicators of total and active symbiotic potential were 31.2 and 21.6 thousand kg/day per ha in the Samorodok variety, as for the Amadeus variety – 36.5 and 25.5 thousand kg/day per ha and biologically fixed nitrogen in the Samorodok variety – 119.0 kg/ha, in the Amadeus variety – 140.1 kg.

Keywords: soybean, number of nodules, weight of nodules, nitrogen fixation, symbiotic potential, nitrogen.

INTRODUCTION

The global character of ecological and economic challenges, as well as the lack of protein for the global population, requires an increase in production of the most complete and inexpensive protein-containing products, one of which is soybean seeds (Godfray et al., 2010). Ukraine is the leader in soybean production among European countries, where a competitive soybean industry is being formed: the sown areas, yield level and production of soybean are growing. At the same time, being a highly profitable crop, soybean is one of the best predecessors in modern crop rotations, which helps to increase soil fertility (Berbenets, 2019). Moreover, soybean cultivation has a positive impact on the whole agriculture as an ideal predecessor for cereal crops, due to the presence of nitrogen-fixing bacteria. This is very important in economic terms when there are insufficient volumes of fertilizer application (Ogurtsov et al., 2016). Biologization of agriculture is currently becoming more and more popular in Ukraine country, but a careful attitude to the environment should be supported by scientific developments (Branitskyi et al., 2022; Myronova et al., 2023).

The use of biopreparations is not yet so common compared to chemicals, but this situation is changing rapidly over time. Due to the irrational use of chemicals in agriculture, the number of beneficial soil microorganisms is significantly reduced and pesticides accumulate, which have a toxic impact on the soil. Therefore, there is a problem of growing organic crop production. One of the safest means of protecting and nourishing plants in organic farming is the use of biological preparations and biofertilizers (Panwar, 2016; Panda, 2017). They are an alternative to mineral fertilizers, pesticides, which disrupt the natural circulation of substances, adversely affect biota and the natural environment. The widespread use of biological factors to intensify agriculture has not only an ecological, but also in most cases an economic priority. At the same time, the more complex soil-climatic and weather conditions are, the more important the role of biologization in crop growing technologies is. The use of biopreparations in the process of growing crops while organic farming increases the number of microorganisms of the main ecological and trophic groups, improves the nutrient regime of the soil, and enhances its enzymatic activity (Dumych, 2018). Bacteria, which make up the biopreparations, increase the availability of nutrients in the rhizosphere, influence positively root growth and promote the development of beneficial plant-microbial symbioses (Vessey, 2003), as a result, it increases plant yields. The use of biopreparations makes it possible not only to improve the growth and development of plants, but also enhance their resistance to diseases; that is of particular importance in organic farming (Fuentes-Ramirez and Caballero-Mellado, 2006).

The agricultural market of biopreparations is growing in Ukraine too. Today, more than 200 biopreparations have been registered in Ukraine. They have been included in the State Register of Pesticides and Agrochemicals Permitted for Use in Ukraine. The largest share among them consists of inoculants (biological preparations that use live microorganisms useful for plants to improve the health of the crop). There are several plants in Ukraine that will produce biological products, including the PRJSC "Biovetpharm", known in Ukraine and abroad as an enterprise specialized in the production of veterinary drugs and biological crop protection products; the Ladyzhyn Plant of Bio- and Enzyme Preparations "Enzim Biotech Agro", which manufactures plant protection products on the basis of microbial synthesis technologies – biofungicides of the "Phyto Doctor" brand for a wide range of crops, bioinsecticides, inoculants; the BTU-Center company – a Ukrainian manufacturer of microbial and enzyme preparations for agriculture, among the products there are lines for plant protection and nutrition, soil improvement, biological products, etc.; Engineering-Technological Institute "Biotekhnika" of the National Academy of Agrarian Sciences of Ukraine, which takes an active part in the scientific- manufacturing activities of Ukraine, particularly in the development of industrial technologies for the production of entomological, bacterial, fungal and viral plant protection products, as well as bacterial fertilizers (Pereverzieva et al., 2021).

Today the cultivation of so-called biological products is quite relevant. For this, microbiological products are increasingly used, they are currently enjoying great popularity among those who want to obtain environmentally friendly products. Modern biological preparations contain various microorganisms that can enhance the resistance of plants to diseases and pests, promote growth and development, as well as improve the qualitative composition of soil microbiota.

Now, in the organically-oriented agricultural production of Ukraine, special attention is paid to the preservation of soil biota and regulation of their vital activity, the organization of agrotechnical measures, and the maintenance of soil microorganisms at the proper level, particularly their number and composition. Biopreparations are being presently produced and implemented to enrich the soil with fungi and bacteria, as well as special bioorganic fertilizers enriched with microorganisms and biocatalysts. Since organic production does not involve the use of mineral fertilizers and chemical plant protection products, an alternative to them is the use of biological preparations of various effects. In the biologization of modern agricultural technologies for growing soybeans, a special attention is paid to soil microorganisms. One of the main ways to optimize the agroecosystem under the conditions of organic production of this crop is the use of biological preparations based on nitrogen-fixing and phosphate-mobilizing bacteria. Thus, the inoculation of soybean seeds usually contributes to a rise in the size of the symbiotic apparatus, increases its yield, productivity, crude protein and fat content. In the organic production of soybean seeds, microbiological preparations created on the basis of natural strains of microorganisms are effectively used. Therefore, during the cultivation of soybeans, microorganisms convert complex compounds into simple and nutritious plants. Owing to a full-fledged complex of microorganisms, the soybean plant receives the necessary root nutrition, which realizes the genetic potential of its yield (Horodyska et al., 2018).

It is known that high yields of crops directly depend on providing them with mineral nutrients, among which the main one is available nitrogen. Insufficient nitrogen supply is one of the main factors that inhibits the processes of plant growth and development. The low N:C ratio in plant organisms is explained by the fact that for the plants capable of active assimilation of carbon dioxide from the atmosphere, the possibilities of receiving nitrogen are very limited. As noted by a number of authors (Patyka et al., 1993; Kots et al., 2010), the paradox of this situation lies in the fact that, suffering from nitrogen deficiency, plants "bathe" in nitrogen available in the environment: the atmosphere consists of 78% molecular nitrogen, and soil organic matter (humus, lignin, chitin, peptides) contains a lot of fixed nitrogen. However, it is inaccessible to plants, since they lack enzyme systems for fixing molecular nitrogen and destroying soil organic matter. The natural way out of this situation is the cooperation of plants with microorganisms that have nitrogenase or enzymes to break down the nitrogen-containing components of soil.

The symbiosis of leguminous plants with nodule bacteria is one of the most effective systems of biological nitrogen fixation, which is of great ecological and practical significance. In the legume-rhizobial symbiosis, a combination of two global biochemical processes – nitrogen fixation and photosynthesis – is achieved, due to which the nitrogen-carbohydrate balance of the plant organism is normalized. Activation of agronomic-beneficial microbial processes in the root zone of plants is possible in two ways: by applying organic and mineral fertilizers to the soil, which optimize the activity of the native soil microflora, and by enriching the soil with highly effective strains of nitrogen-fixing, phosphate-mobilizing microorganisms as well as microorganisms producing growth-regulating and antibiotic substances (Kots et al., 2011; Yatsenko et al., 2023). The positive role of leguminous crops, including soybeans, in agriculture is famously associated with the vital activity of nodule bacteria, with which the above mentioned plants are in close symbiotic relationships. This unique ability allows leguminous crops to absorb 130–390 kg/ha of air nitrogen during the growing season, which provides cheap vegetable protein without the use of expensive and environmentally hazardous mineral nitrogen fertilizers (Patyka et al., 2017; Panchyshyn et al., 2023). Under optimal conditions, soybeans can biologically fix 180 kg/ha and more of nitrogen, leaving behind 25–40 kg/ha for subsequent crops in crop rotation. However, the average indicators of biological nitrogen fixation by the crop are still much lower (Patyka et al., 2017).

Scholars of the National Academy of Agrarian Sciences of Ukraine have determined the varietal differences of leguminous plants in terms of the intensity of biological fixation and on their basis, using biotechnology, genetics and breeding, more than 70 varieties of leguminous crops have been created, including 44 varieties of a new generation, included in the State Register of Plant Varieties Suitable for Dissemination in Ukraine, which are characterized by an increased intensity of biological fixation of nitrogen in main agricultural regions (Petrychenko et al., 2013; Biliavska et al., 2021; Mazur et al., 2023).

In this regard, as a mandatory element in the technologies of growing leguminous crops should be pre-sowing seed treatment with biopreparations on the basis of the selected strains of specific rhizobia, which not only increases plant productivity, but also promotes the introduction of highly effective strains of nodule bacteria into soil microbocenoses. To increase the productivity of symbiotic nitrogen fixation in agrocenoses as well as create favorable conditions for the effective functioning of legume-rhizobial symbiosis, it is necessary to select varieties of leguminous crops and strains of nodule bacteria taking into consideration specific soil-climatic and agrotechnical conditions (Mostovenko et al., 2022).

MATERIALS AND METHODS

Research methods

The weight monitoring and monolith methods for determining the size of the symbiotic apparatus of soybeans and to establish the value of biologically fixed nitrogen; statistical and mathematical methods for checking the reliability of the obtained research results.

The field studies were conducted in 2022-2023 on the experimental field of the Scientific-Research Farm "Agronomichne" of Vinnytsia National Agrarian University on gray forest medium-loamy soils. During the studies, the hydrothermal conditions were contrasting, the conditions of 2023 were more favorable in terms of moisture supply in critical periods and temperature conditions (Fig. 1, 2). Agricultural technology in the experiment is generally accepted for the Forest-Steppe zone, with the exception of the factors that were under research. The ratio of factors is 2×2×4. The area of accounting plots – 25 m^2. The frequency is four times. The varieties Amadeus and Samorodok were studied during the researches.

Amadeus. Originator: Semenses Prograin Inc. Early ripening. The growing season is 115 days. Resistance to lodging and shedding – 8 points. The protein content is 38–47%. The recommended growing zone is Forest-Steppe. This variety adapts to a wide range of soil and climatic growing conditions.

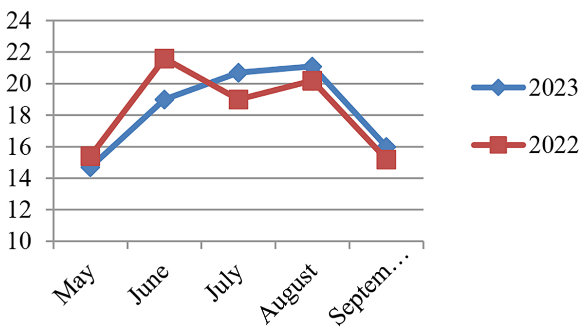

Figure 1. Temperature regime during the growing season (BBCH-10-99)

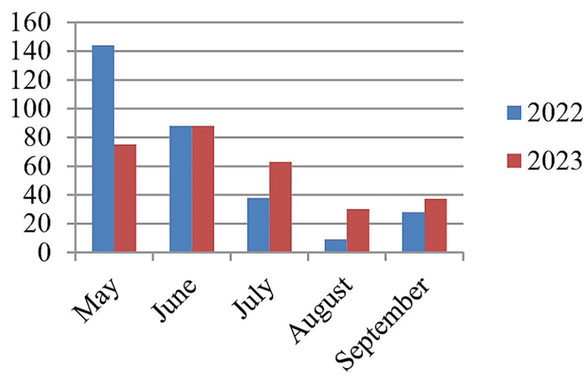

Figure 2. Amount of precipitation during the growing season (BBCH-10-99)

Samorodok. Originator: Podillia Institute of Fodder and Agriculture. Fast-ripening. Growing season makes up 97–117 days. The height of the plants is 66–78 cm. The attachment height of the lower bean is 11.0–15.0 cm. 1000 pcs. seeds weight 138.8–149.4 g. Protein content in seeds – 41.0–41.7%, oil – 21.1–22.6%. Resistance to lodging and shedding – 8 points. The recommended growing zone is Forest-steppe.

Pre-sowing tillage included plowing to a depth of 22–25 cm and cultivation to a depth of 5–6 cm. Pre-sowing seed treatment was carried out with modern bioinoculants in liquid form Rizoline + Rizosave (*Bradyrhizobium japonicum* and *Rhizobium leguminosarum*) provided by the BTU-Center company with a drug consumption rate of 2.0 l/t + 0.5 l/t of seeds, working solution of 5.0 l/t. The sowing of seeds was done to a depth of 3–4 cm with a row spacing of 45 cm. Fertilizing was carried out with multicomponent chelated complex microfertilizers Azotophyte-R (0.5 l/ha) and organic balance (0.5 l/ha) in combination with trace elements Helprost Soybean (1.0 l/ha) and Helprost Boron (0.5 l/ha) at the microstage BBCH 12–13 and at the microstage BBCH 51-69. The experiment scheme is shown in Table 1.

Harvesting was carried out by using the method of direct combining. Rizoline is a biological preparation for seed inoculation of leguminous crops. Composition: viable cells of nodule bacteria: Bradyrhizobium japonicum, symbiotic to soybeans, titer (2.0–6.0) × 10^9 CFU/cm^3 Rhizobium leguminosarum, symbiotic to peas, titer (2.0–6.0) × 10^9 CFU/cm^3 other strains of nodule bacteria symbiotic to certain legumes Macro- and microelements, biologically active waste products of bacteria (vitamins, heteroauxins, gibberellins, etc.). Rizosave is a protector for prolongation of fixation of inoculants and mycorrhizal preparations on seeds 30 days before sowing. Azotophyte-R is a bioactivator, a biological preparation, a plant growth stimulator, which has fungicidal properties. The biological preparation contains an active factor – living cells of the natural nitrogen-fixing bacterium Azotobacter chroococcum, micro and macro elements, biologically active waste products of bacteria: amino acids, vitamins, phytohormones, fungicidal substances. The biological product has growth-stimulating and fungicidal properties, which are based on the ability of the Azotobacter chroococcum bacterium to actively fix the molecular nitrogen of the atmosphere, converting it into a

Table 1. Scheme of the experiment

(Factor A) Sort	(Factor B) Inoculation	(Factor C) Foliar fertilization of crops
Samorodok Amadeus	Without inoculation (control) Rizoline-r	1. No fertilization (control); 2. Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam; 3. Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam; 4. Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; treatment of crops at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam.

form accessible to plants; it also improves mineral nutrition of plants, reduces the amount of mineral fertilizers, in particular nitrogen fertilizers; synthesizes growth-stimulating substances (nicotinic acid, pantothenic acid, pyridoxine, biotin, heteroauxin, etc.), improves plant photosynthesis, releases fungicidal substances that inhibit the growth of phytopathogenic microflora, produces metabolites capable of dissolving poorly soluble soil phosphates, accelerates as well as increases seed germination and engraftment of seedlings and seedlings, stimulates the development of the root system and accelerates plant growth, strengthens plant immunity, increases plant resistance to diseases, negative factors and pesticides, accelerates and prolongs flowering phases, reduces the number of treatments, due to compatibility with other plant protection and nutrition preparations, increases yields and improves the taste of fruits, heals the soil as well as improves its natural fertility (Prysiazhniuk, 2015).

Helprost is an organic-mineral fertilizer. This drug has been developed on the basis of the bacterial waste products of Bacullus subtilis and Enterococcus sp. include: amino acids, polysaccharides, B vitamins. The drug has been created for foliar feeding (spraying) of plants, has a stimulating effect, as well as accelerates the growth and development of plants. Helprost fertilizer contains l/g to: macelrments (P-70.8; K – 94.4); mesoelements (S – 9.44; Mg – 25.96); microelements (B – 14.16; Zn – 23.6; Fe – 0.59; Mn – 7.67; Cu – 21.24; Co – 0.059; Mo – 0.236); biologically active substances: vitamins of group B – 0.118; peptides – 11.8; polysaccharides – 0.59. The drug stimulates and enhances plant growth, increases the bioavailability of macro- and microelements, increases plant immunity, plant resistance to stress, as well as productivity and frost resistance. The percentage of assimilation by plants is 98–100%.

Organic Balance is a biological preparation of systemic action, consisting of beneficial microorganisms that are destructors, nitrogen fixers as well as stabilizers of phosphorus and potassium. Agronomically useful microorganisms, which make up the preparation, are stronger and more active than those in the soil, so they easily fight pests and diseases. The biopreparation stimulates the growth and development of crops, resistance to stress and balanced nutrition. Organic Balance helps to improve nitrogen, phosphorus and potassium nutrition, accelerates the decomposition of organic matter and the formation of humus in the soil, that is, it contributes to the development of beneficial soil microflora, its improvement and increase in soil fertility. It inhibits the effects of phytopathogens, harmful fungi and bacteria that cause plant diseases, increases yields, as well as makes plants stronger and more resistant against various ailments and diseases. The biopreparation increases the resistance of plants to stress factors: biotic, anthropogenic, climatic, edaphic, increases germination, ensures uniformity and friendliness of seedlings, delivers balanced nutrition of plants, improvement of development, and improves the quality of products. The preparation is intended for pre-sowing seed treatment, and spraying plants during the growing season. As part of the biological product Organic Balance, nitrogen-fixing bacteria, which provide plants with nitrogen, phosphorus- and potassium-mobilizing bacteria, convert poorly soluble compounds into the forms available to plants natural saprophytic fungi and components of the nutrient medium organic substances – stabilizers, biologically active substances, vitamins, enzymes for decomposition of residues. It constitutes a concentrate of viable microorganisms: bacteria-antagonists of pathogenic fungi and cells of bacteria *Bacillus subtilis*, *Azotobacter chroococcum*, *Paenibacillus polymyxa*, etc., titer $1 \times 10^8 – 1 \times 10^9$ CFU/cm^3.

Liposam is an adhesive for plants' protection and nutrition, it fixes biopreparations on seed material, provides their close contact with the treated surface, forms a protective elastic mesh that retains moisture, does not destroy the natural shell of the seed, ensures free respiration and photosynthesis, it provides high efficiency of soil herbicides under adverse weather conditions, stabilizes the effect of herbicides, fungicides and insecticides, protects plants during the growing season from sunburn, anddrought, enables better assimilation of macro- and microelements during foliar feeding, as well as works in a wide range of temperatures up to 50 °C. The preparation is intended for pre-sowing seed treatment, spraying plants during the growing season together with preparations of biological and chemical origin for the plants' protection and nutrition, soaking the seedlings' roots and other planting material.

Determination of the number and weight of nodules was realized by using the monolith method, imposing a frame measuring 300 × 167 mm (0.05 m^2). Therefore, knowing the area of the monolith and the average density of plants, the number and weight of nodules on one plant were determined (Posypanov, 1991).

Active symbiotic potential (ASP) was calculated using the Formula 1.

$$\mathrm{ASP} = \frac{\mathrm{M\,1+M\,2}}{2} \times \mathrm{T} \tag{1}$$

where: T – the time between two adjacent analysis periods, days; $\frac{\mathrm{M\,1+M\,2}}{2}$ – the average weight of nodules with leghaemoglobin for the period T, kg/ha.

The amount of fixed nitrogen was calculated according to the active symbiotic potential and the specific activity of symbiosis, using the methods (Posypanov, 1991; Volkogon, 2010). The results of crop accounting were subjected to variance analysis (Moiseichenko et al., 1996).

RESULTS AND DISCUSSION

The conducted studies revealed the peculiarities of forming the soybean plants' symbiotic apparatus under the influence of inoculation and foliar fertilization with biological preparations. According to the obtained results of the experimental research, the positive effect of these technological methods of cultivation on the formation of the number and weight of nodules on the soybean root system was found. It was also proven by other authors' research results. In particular, legumes in symbiosis with nodule bacteria are able to absorb nitrogen. Moreover, the process of symbiotic nitrogen fixation is environmentally friendly, it occurs due to the energy of photosynthesis, its intensity is regulated by the plant itself. Under such conditions, there is no nitrate pollution of products and the environment, biological nitrogen is much cheaper than the nitrogen of mineral fertilizers. This confirms the expediency of increasing the area under leguminous crops in the overall structure of crops. At present, in fact, it does not even reach 10%, while the scientifically justified share of legumes in crop rotations is 20–30%. With the achievement of optimal areas of legumes, it would be possible to solve the problem of food and feed protein as well as ensure the reproduction of soil fertility. At the same time, as the author notes, this is possible provided that a highly effective symbiosis of leguminous plants with nodule bacteria is guaranteed, without which they are not able to perform their nitrogen-fixing function. Without the use of biopreparations for the treatment of leguminous seeds (without nitraginization), production lacks at least 10–30% of the yield (Tolkachov, 2002)

It was discovered that pink nodules were formed at the highest intensity at the BBCH 68-69 microstage, after which both the number and weight were significantly reduced to the microstage 80–90 (Table 2). The decrease in the plants' late microstages due to the above determined indicators can be explained by the weakening of the translocation of assimilates from the leaves to the roots and the nodules' capacity to move photoassimilates (Babych and Petrychenko, 1994; Komok et al., 2010).

On average, during the period of research at the microstage of BBCH 51-59 in the control variant (without inoculation of seeds and foliar feeding) 15.5 nodules were formed on the roots of one Samorodok soybean plant variety, 17.5 nodules were formed on the roots of one Amadeus variety, among them active – 12.2 and 13.8 pcs./plant (Table 3). Scientific sources show that trace elements (molybdenum, cobalt, boron, copper, zinc, manganese, etc.) have a significant impact on the symbiotic fixation of nitrogen (Gutyansky, 2015).

According to the scientific sources the microelements (molybdenum, cobalt, boron, copper, zinc, manganese, etc.) have a significant impact on the symbiotic fixation of nitrogen (Hutianskyi,

Table 2. Dynamics of the total number of nodules (pcs/plant) on soybean roots depending on foliar fertilization and seed inoculation (average for 2022–2023)

Variety	Foliar fertilization	Microstage							
		BBCH 51-59		BBCH 61-62		BBCH 68-69		BBCH 80-90	
		Inoculation							
		un/i	i	un/i	i	un/i	i	un/i	i
Samorodok	No fertilization (control)	15.5	27.1	25.8	38.5	33.7	46.3	19.8	31.4
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	16.6	28.5	27.7	40.9	35.9	49.5	22.0	34.3
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	16.7	28.6	27.9	40.9	36.4	49.8	22.3	34.5
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	16.8	28.8	28.0	41.0	37.0	50.3	22.7	34.9
Amadeus	No fertilization (control)	17.5	31.9	28.8	42.7	38.9	51.6	23.2	34.9
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	18.7	33.6	30.7	45.2	41.6	54.9	25.3	38.1
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	18.8	33.8	30.9	46.0	41.8	55.2	25.4	38.2
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	18.9	34.0	31.5	46.6	41.9	55.6	25.7	38.6
$LSD_{0.05}$ of the main effect of factor A		0.12		0.27		0.18		0.28	
$LSD_{0.05}$ of the min effect of factor B		0.12		0.27		0.18		0.28	
$LSD_{0.05}$ of the min effect of factor C		0.18		0.38		0.25		0.39	
$LSD_{0.05}$ of interaction AB		0.18		0.38		0.25		0.39	
$LSD_{0.05}$ of interaction AC		0.25		0.54		0.36		0.56	
$LSD_{0.05}$ of interaction BC		0.25		0.54		0.36		0.56	
$LSD_{0.05}$ of interaction ABC		0.35		0.76		0.51		0.79	

2015). It is also confirmed by our the research results. With the twice-split application of chelated microfertilizers at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam, it provided an increase in the total number of nodules in the Samorodok variety by 1.1 pcs./plant, in the Amadeus variety – by 1.2 pcs./plant, of which there were an increase of active ones by 1.0 and 1.1 pcs./plant, respectively.

Similar results were achieved with the twice-split application of chelated microfertilizers at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Helprost Boron + Liposam provided an increase in the total number of nodules in the Samorodok variety by 1.2 pcs./plant, in Amadeus – by 1.3 pcs./plant, of which the active ones – by 1.1 and 1.3 pcs./plant, respectively. The highest increase in the

Table 3. Dynamics of the number of active nodules (pcs/plant) on soybean roots depending on foliar fertilization and seed inoculation (average for 2022–2023)

Variety	Foliar fertilization	Microstage							
		BBCH 51-59		BBCH 61-62		BBCH 68-69		BBCH 80-90	
		Inoculation							
		un/i	i	un/i	i	un/i	i	un/i	i
Samorodok	No fertilization (control)	12.2	20.5	19.3	28.0	24.5	33.1	14.6	22.8
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	13.2	22.1	20.8	30.2	26.4	35.7	16.5	25.3
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	13.3	22.3	21.1	30.6	26.5	35.9	16.8	25.6
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	13.5	22.5	21.3	30.9	26.6	36.0	17.0	25.9
Amadeus	No fertilization (control)	13.8	23.0	21.7	31.1	27.4	36.2	17.3	26.6
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	14.9	24.9	23.5	33.7	29.5	39.2	19.4	29.1
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	15.1	25.1	23.7	33.9	29.7	39.4	19.7	29.3
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	15.2	25.4	23.9	34.0	30.1	40.0	19.8	29.5
$LSD_{0.05}$ of the main effect of factor A		0.25		0.26		0.21		0.25	
$LSD_{0.05}$ of the min effect of factor B		0.25		0.26		0.21		0.25	
$LSD_{0.05}$ of the min effect of factor C		0.36		0.36		0.30		0.35	
$LSD_{0.05}$ of interaction AB		0.36		0.36		0.30		0.35	
$LSD_{0.05}$ of interaction AC		0.51		0.51		0.42		0.49	
$LSD_{0.05}$ of interaction BC		0.51		0.51		0.42		0.49	
$LSD_{0.05}$ of interaction ABC		0.72		0.72		0.59		0.70	

number of nodules was observed in the variant with the twice-split application of chelated microfertilizers at the microstage BBCH 12-13: Organic Balance + Azotophyte + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam, which ensured an increase in the total number of nodules in the Samorodok variety by 1.3 pcs./plant, in the Amadeus variety – by 1.4 pcs./plant, of which the active ones – by 1.3 and 1.4 pcs./plant, respectively.

Rhizobium bacteria provide a significant increase in the nitrogen-fixing capacity of soybean plants and serve as an important source of nitrogen supply. Treatment of soybean seeds with inoculants increased yield, protein content in seeds, number and weight of nodules in all researched varieties (Lavrynenko et al., 2012).

The obtained results have been confirmed by the conducted experimental research. Rizoline seed bacterization had a more positive influence on the number of nodules than foliar fertilization. Seed inoculation with a preparation on the basis of nodule bacteria strains (*Azotobacter chroococcum*) improved the nutritional regime in soybean crops and increased the total number of nodules and their active part in the Samorodok variety, by 11.6 and 8.3 pcs./plant and the Amadeus variety by 14.4 and 9.2 pcs./plant, respectively. The nodules of these plants had a characteristic pink color, which confirmed the presence of leghemoglobin and active biological fixation of molecular nitrogen. Thus, the combined effect of seed bacterization and foliar fertilization turned out to be the most effective agricultural measure for creating favorable conditions for the formation of a symbiotic apparatus. As a result, on the roots of plants with the twice-split application of chelated microfertilizers at the microstage at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam, the total number of nodules was formed in the Samorodok variety at the level of 28.5 pcs./plant, of which active – 22.1 pcs./plant, in the Amadeus variety – 33.6 and 24.9 pcs./plant. Higher rates were observed with the twice-split application of chelated microfertilizers at the microstage of BBCH 12-13: Organic Balance + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Helprost Boron + Liposam, where the total number of nodules was formed in the Samorodok variety at the level of 28.6 pcs./plant, of which active ones were 22.3 pcs./plant, in the Amadeus variety – 33.8 and 25.1 pcs./plant.

The highest rates were received in the variant with the twice-split application of chelated microfertilizers at the microstage BBCH 12-13: Organic Balance + Azotophyte + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam, where the total number of nodules was formed in the Samorodok variety at the level of 28.8 pcs./plant, of which active – 22.5 pcs./plant, in the Amadeus variety – 34.0 and 25.4 pcs./plant.

As it has already been mentioned, pink nodules were formed at the microstage BBCH 68-69 with the combined action of seed bacterization and foliar fertilization in the experimental variant with the twice-split application of chelated microfertilizers at the microstage BBCH 12-13: Organic Balance + Azotophyte + Help Growth Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helpprost Boron + Liposam, where the total number of nodules was formed in the variety Samorodok at the level of 50.3 pcs./plant, of which 36.0 pcs./plant are active, 55.6 and 40.0 pcs./plant are in the Amadeus variety. It is higher by 16.6 and 11.5 pcs.; 16.7 and 12.6 pcs. than the obtained results in the absolute control variant, respectively.

Moreover, another significant indicator of the activity of air nitrogen fixation by soybeans is the weight of nodules and the duration of their functioning (Table 4).

According to the research results, the value of both the total and active mass of root nodules changed like in the previously conducted analysis of the dynamics of the nodules' number. Depending on the variant of the experiment at microstages 51–59, the total weight of nodules varied from 31.4 to 38.7 mg/plant, of which the weight of active nodules ranged from 24.7 to 30.0 mg/plant (Table 5). In the control variant, the lowest indicators in terms of the nodules' total number and active weight were noted and amounted to 31.4 and 24.7 mg/plant in the Samorodok variety, as well as 35.3 and 27.8 mg/plant in the Amadeus variety, respectively. However, during the seed bacterization with Rizoline and the twice-split application of chelated microfertilizers at the microstage BBCH 12-13: Organic Balance + Azotophyte + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam, the largest total and active weight of nodules obtained in the experiment at microstage 51-59 in the variety Samorodok was 52.5 and 40.7 mg/plant, and in the Amadeus variety – 59.5 and 46.1 mg/plant, respectively. Subsequently, there was an increase in both the total and active weight of nodules, reaching its maximum at the microstage of BBCH 68-69 till the level of 319-586 and 252–454 mg/plant, respectively, in the variety Samorodok – 319–515 and 252–399, 327–586 and 258–454 mg/plant – in the Amadeus variety.

The most effective experimental variants for forming a high total and active mass of nodules were those that included seed bacterization with Rizoline and the twice-split application of chelated microfertilizers at the microstage BBCH 12-13: Organic Balance + Azotophyte + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam, the largest total and active mass of nodules was found in the experiment at microstage 68–69 in the Samorodok variety − 515 and 399 mg/plant, and in the Amadeus variety – 586 and 454 mg/plant. It is higher by 196; 147 and 259; 196 mg/plant than in the control variant, respectively.

At the BBCH microstage 80–90 soybean plants, there was a decrease in both total and active nodule mass to the level of 49–109 mg/plant, and 39–84.3 mg/plant, respectively.

Table 4. Dynamics of total nodule weight (mg/plant) on soybean roots depending on foliar fertilization and seed inoculation (average in 2022–2023)

Variety	Foliar fertilization	Microstage							
		BBCH 51-59		BBCH 61-62		BBCH 68-69		BBCH 80-90	
		Inoculation							
		un/i	i	un/i	i	un/i	i	un/i	i
Samorodok	No fertilization (control)	31.4	49.7	241	493	319	508	49.0	93.8
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	33.3	50.8	248	497	326	510	51	95.2
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	34.4	51.7	249	499	329	513	60.9	96.6
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	35.9	52.5	251	501	330	515	62.8	97.3
Amadeus	No fertilization (control)	35.3	56.1	250	503	327	579	52.0	102
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	36.4	57.3	256	504	337	581	55.2	104
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	37.9	59.2	260	508	340	586	56.2	107
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	38.7	59.5	262	509	351	586	57.8	109
$LSD_{0.05}$ of the main effect of factor A		0.30		2,79		2.12		0.79	
$LSD_{0.05}$ of the min effect of factor B		0.30		2.79		2.12		0.79	
$LSD_{0.05}$ of the min effect of factor C		0.43		3.94		3.0		1.11	
$LSD_{0.05}$ of interaction AB		0.43		3.94		3.0		1.11	
$LSD_{0.05}$ of interaction AC		0.60		5.57		4.25		1.57	
$LSD_{0.05}$ of interaction BC		0.60		5.57		4.25		1.57	
$LSD_{0.05}$ of interaction ABC		0.85		7.88		6.0		2.23	

One of the indicators that allow assessing the efficiency of legume-rhizobial symbiosis during the growing season is the total and active symbiotic potential, the value of which is determined by the duration of the symbiotic apparatus. As a rule, the values of the total symbiotic potential (TSP) are greater than the values of the active symbiotic potential (ASP), since the total symbiosis lasts from the appearance of the first nodules on the roots of plants until their complete disintegration, while the period of active symbiosis is limited by the time from the appearance to destruction of the red pigment in the nodules (Posypanov, 1991; Kots and Patyka, 2009). The active symbiotic potential is an accumulative indicator of the mass of nodules and the duration of their functioning, and determines the influence of individual factors on the legume-rhizobial symbiosis. Under optimal conditions of symbiosis, the active symbiotic potential of leguminous crops reaches 25 thousand pcs. (Tolkachov, 2002).

The obtained research results confirmed that seed inoculation and foliar fertilization had a positive influence on the formation of both general and active symbiotic potential (Table 6). Seed

Table 5. Dynamics of nodules' active mass (mg/plant) on soybean roots depending on foliar fertilization and seed inoculation (average in 2022–2023)

Variety	Foliar fertilization	Microstage							
		BBCH 51-59		BBCH 61-62		BBCH 68-69		BBCH 80-90	
		Inoculation							
		un/i	i	un/i	i	un/i	i	un/i	i
Samorodok	No fertilization (control)	24.7	38.5	190	382	252	394	39	72.7
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	25.8	39.4	192	386	253	396	39	73.8
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	26.7	40.1	193	387	255	397	47	74.9
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	27.8	40.7	195	388	256	399	48.7	75.4
Amadeus	No fertilization (control)	27.8	43.5	197	390	258	449	40.7	79.2
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	28.2	44.4	199	390	261	450	42.8	80.4
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	29.4	45.9	202	394	263	454	43.6	82.9
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	30.0	46.1	203	394	272	454	44.8	84.3
$LSD_{0.05}$ of the main effect of factor A		0.31		2.17		1.13		0.59	
$LSD_{0.05}$ of the min effect of factor B		0.31		2.17		1.13		0.59	
$LSD_{0.05}$ of the min effect of factor C		0.44		3.06		1.57		0.83	
$LSD_{0.05}$ of interaction AB		0.44		3.06		1.57		0.83	
$LSD_{0.05}$ of interaction AC		0.62		4.33		2.22		1.17	
$LSD_{0.05}$ of interaction BC		0.62		4.33		2.22		1.17	
$LSD_{0.05}$ of interaction ABC		0.87		6.12		3.14		1.65	

inoculation had the greatest influence on forming the value of the total and active symbiotic potential, in addition to revealing itself in better colonizing plant roots by symbiotic bacteria and forming both a greater nodule number and mass.

The duration of symbiosis, as well as the nodule mass, directly determine the indicators of the general symbiotic potential (GSP) and active symbiotic potential (ASP). Seed inoculation extended the duration of both general and active symbiosis in the Samorodok variety by 3 and 2 days, and in the Amadeus variety by 3 days, respectively. Among the experimental variants, the most effective for forming a long period of symbiosis were those which included seed bacterization with Rizoline and the twice-split application of chelated microfertilizers at the microstage of BBCH 12-13: Organic Balance + Azotophyte + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam, the highest values of GSP and ASP were observed in the experiment at the microstage BBCH 68-69 in the Samorodok variety − 85 and 76 days, and in the Amadeus variety – 91 and 81 days, which is higher compared to the absolute control by 5 and 7 days, respectively. In the same variant, the highest indicators of the general and active symbiotic potentials were noticed, which amounted to 31.2 and 21.6 thsd kg days / ha in the Samorodok variety, and for the

Table 6. Dynamics of forming the general symbiotic potential (GSP) and active symbiotic potential (ASP) depending on foliar fertilization and seed inoculation, thsd. kg·days/ha (average in 2022–2023)

Variety	Foliar fertilization	For the period of the microstage BBCH 51-90							
		Duration of symbiosis, days				Symbiotic potential, thsd. kg·days / ha			
		Total		Active		Total		Active	
		un/i	i	un/i	i	un/i	i	un/i	i
Samorodok	No fertilization (control)	80	83	71	73	16.5	29.9	11.5	20.4
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	82	84	73	74	17.4	30.6	12.0	20.9
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	82	85	73	75	17.7	31.0	12.2	21.3
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	82	85	73	76	17.9	31.2	12.3	21.6
Amadeus	No fertilization (control)	84	87	74	77	18	34.3	12.5	23.7
	Crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam	86	89	76	79	19	35.3	13.1	24.5
	Crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam	86	89	76	79	19.2	35.6	13.2	24.7
	Crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam	86	91	77	81	19.7	36.5	13.7	25.5
$LSD_{0.05}$ of the main effect of factor A		0.81		0.86		0.30		0.11	
$LSD_{0.05}$ of the min effect of factor B		0.81		0.86		0.30		0.11	
$LSD_{0.05}$ of the min effect of factor C		1.15		1.21		0.42		0.16	
$LSD_{0.05}$ of interaction AB		1.15		1.21		0.42		0.16	
$LSD_{0.05}$ of interaction AC		1.63		1.71		0.60		0.23	
$LSD_{0.05}$ of interaction BC		1.63		1.71		0.60		0.23	
$LSD_{0.05}$ of interaction ABC		2.30		2.42		0.85		0.32	

Amadeus variety – 36.5 and 25.5 thsd kg days/ha, that is higher by 14.7; 10.1 and 18.5; 13.0 thousand tons kg days/ha than in the absolute control, respectively. According to the research results, it was found that the magnitude and duration of soybean symbiosis depended on bacterization, foliar fertilization and variety, which significantly affected the amount of biologically fixed nitrogen by crops in the culmination (Fig. 3).

Among the experimental samples, as the most effective due to the level of accumulation of the amount of biologically fixed nitrogen the authors determined those which included seed bacterization with Rizoline and the twice-split application of chelated microfertilizers at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam, the highest amount of biologically fixed nitrogen was received in the Samorodok variety – 119.0 kg/ha, and in the Amadeus variety – 140.1 kg, that is 55.6 and 71.3 kg/ha higher than in the control sample, respectively. The plants of the Amadeus variety demonstrated the largest amount of nitrogen. A longer period of symbiosis and higher ASP values were typical for them, which in turn affected the amount of biologically fixed nitrogen.

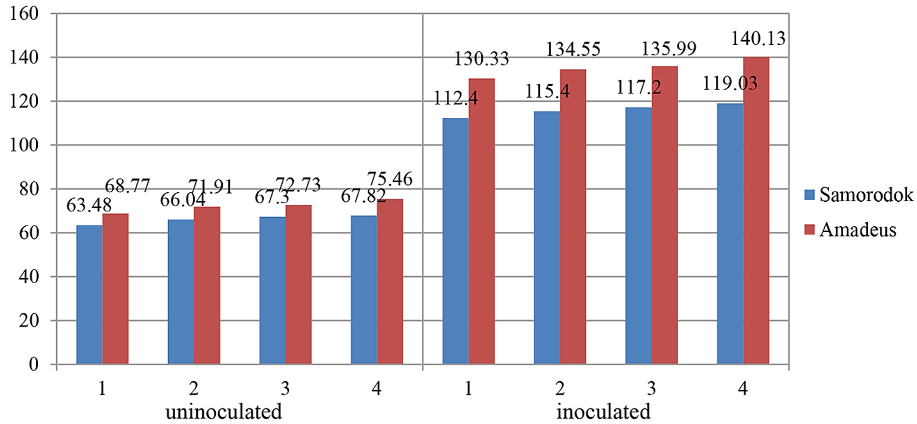

Fig. 3. Amount of biologically fixed nitrogen, kg/ha. 1. no fertilization (control); 2. crop treatment at the microstage BBCH 12-13: Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Azotophyte + Helprost Boron + Liposam; 3. crop treatment at the microstage BBCH 12-13: Organic Balance + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic balance + Helprost Boron + Liposam; 4. crop treatment at the microstage BBCH 12-13: Organic balance + Azotophyte + Helprost Soybean + Liposam; crop treatment at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam. LSD0.05 of the main effect of factor A 0.75, LSD0.05 of the min effect of factor B 0.75, LSD0.05 of the min effect of factor C 1.07, LSD0.05 of interaction AB 1.07, LSD0.05 of interaction AC 1.51, LSD0.05 of interaction BC 1.51, LSD0.05 of interaction ABC 2.13

CONCLUSIONS

Thus, it has been proven that under the conditions of the Right-Bank Forest-Steppe on gray forest medium-loamy soils, seed inoculation with bacterial inoculants on the basis of Bradyrhizobium japonicum combined with the treatment of plants during vegetation with chelated microfertilizers improves the formation and functioning of the symbiotic apparatus of soybeans. Under modern conditions the soybean cultivation technologies, combination of inoculation and chelated microfertilizers give opportunities to use the genetic potential of this variety in full measure.

The highest indicators of the symbiotic apparatus (number and weight of nodules) of soybean plants were formed at microstage 68-69 with the combined application of seed inoculation with Rizoline and the the twice-split application of chelated microfertilizers at the microstage BBCH 12-13: Organic Balance + Azotophyte + Helprost Soybean + Liposam and at the microstage BBCH 61-69: Organic Balance + Azotophyte + Helprost Boron + Liposam, where the total number of nodules was formed in the Samorodok variety at the level of 50.3 pcs./plant, among them the active ones were 36.0 pcs./plant, the Amadeus variety – 55.6 and 40.0 pcs./plant. This is higher than on the absolute control version by 16.6 and 11.5 pcs; 16.7 and 12.6 pcs, respectively. This variant also gave the largest total and active nodule weight in the Samorodok variety – 515 and 399 mg/plant, at the same time in the Amadeus variety – 586 and 454 mg/plant, respectively. It is higher by 196, 147 and 259 mg/plant than in the control sample, respectively. The highest indicators of general and active symbiotic potential were noted, which amounted to 31.2 and 21.6 thsd kg days / ha in the Samorodok variety, as for the Amadeus variety the made up 36.5 and 25.5 thsd kg days/ha, which is higher than in the absolute control – by 14.7; 10.1 and 18.5; 13.0 thsd kg days/ha, respectively. The highest amount of biologically fixed nitrogen was obtained in the Samorodok variety – 119.0 kg/ha, and in the Amadeus variety – 140.1 kg, that is 55.6 and 71.3 kg/ha higher than in the control sample.

The application of these preparations can serve as a measure to improve the economical and environmentally friendly technologies for growing soybeans, which helps to reduce the impact of stress factors on plants, the ability to fix up to 100–150 kg of atmospheric nitrogen, which is equivalent to the application of 15-20 tons of organic fertilizers. Soybean nitrogen, unlike the nitrogen of mineral fertilizers, does not pollute the environment and is easily absorbed by other plants. Soybean cultivation can drastically reduce the cost of mineral fertilizers, which are becoming more and more expensive.

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