ECOLOGY, BIOTECHNOLOGY, AGRICULTURE AND FORESTRY

IN THE 21ST CENTURY

PROBLEMS AND SOLUTIONS

EDITED BY

S. STANKEVYCH, O. MANDYCH

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The monograph is a collection of the results of scientists' achievements obtained directly in real conditions. The authors are recognized specialists in their fields, as well as young scientists and graduate students of Ukraine. The studies are conceptually grouped in sections: biotechnology, ecology, agriculture, forestry, sustainable development of the economy and the principles of effective agribusiness. The monograph will be of interest to specialists in biotechnology, ecology, breeding, plant protection, agrochemistry, soil science, forestry, agribusiness, etc., researchers, teachers, graduate students and students of specialized specialties of higher educational institutions, as well as everyone who is interested in sustainable development in the agricultural sphere and Green Deal Implementation strategies.

Keywords: sustainable development, modern technologies, agricultural production, biotechnology, ecology, plant protection, forestry, agribusiness.

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Soybean is an integral part of the cycle of substances in nature, thanks to photosynthesis and the ability to biologically fix atmospheric nitrogen, its cultivation makes it possible to improve the nitrogen balance in the soil, the phytosanitary condition of crops and significantly increase the productivity of a unit of crop rotation area. In addition, growing soybeans in crop rotation makes it possible to quickly increase agricultural culture, improve soil fertility, increase the amount of available nutrients for cultivated plants, and obtain ecologically clean products. Study of the soybean on the agro-ecological condition of the soil. The problem of intensification of agricultural production and environmental protection arouses interest in biological nitrogen in all countries of the world. Research is being conducted to study the features of nitrogen fixation, its importance in the nitrogen nutrition of plants and the nitrogen balance of the soil, since nitrogen-fixing microorganisms are an important reserve for improving the nitrogen balance in the soil and increasing the yield of agricultural crops. It was established that the best conditions for the maximum realization of the symbiotic potential of both the Horlytsia variety and the Vinnychanka variety were created in the experimental variants with the introduction of mineral fertilizers in a dose of $P_{60}K_{60}$, seed treatment (150 g/t) and foliar fertilization (0,5 kg/ha) with the Microfol Kombi micronutrient complex. It was determined that the highest indicator of active symbiotic potential of 20,971 thousand kg days/ha in the Horlytsia soybean variety and 22,981 thousand kg days/ha in the Vinnychanka soybean variety was recorded in the variants of the experiment with the introduction of mineral fertilizers in the dose of $P_{60}K_{60}$, with pre-sowing treatment of seeds (150 g/t) and foliar

feeding (0,5 kg/ha) with a complex of trace elements Mikrofol Combi. The highest amount of biologically fixed nitrogen, 144,4 and 164,4 kg/ha, respectively, was obtained in these areas of the experiment.
Key words: biologically fixed nitrogen, agroecological condition of the soil, nutrients, symbiotic potential.

Introduction

Nitrogen fixation is one of the most important processes that ensures nitrogen circulation in nature, which affects the biological productivity of plants. The column of air above one hectare of surface contains 80,000 tons of nitrogen. If wheat plants could absorb nitrogen directly from the air, it would be enough to produce a crop of 3 t/ha for more than half a million years. However, plants cannot absorb molecular nitrogen on their own, which has forced mankind to look for ways to provide plants with this important element through the industrial synthesis of nitrogen compounds available to plants, but, despite this, the natural process of nitrogen fixation by legumes in symbiosis with nodule bacteria remains important and a fairly cheap measure to increase soil fertility.

Soybeans as a legume crop are an important factor in increasing soil fertility. In the world, its main crops are placed on non-irrigated lands. In Ukraine, soybean crops are placed mainly on non-irrigated lands in regions with better moisture availability and thermal conditions, as well as on irrigated lands. Here, it will ensure high and stable yields with strict compliance with all requirements of cultivation technology, taking into account the biological characteristics of varieties in relation to local conditions.

Modern technology is based on the high culture of agriculture, high-yield varieties, the use of new technology, scientifically based standards, fertilizers, herbicides, optimal sowing dates, sowing methods and plant density; harvesting without losses, preserving the entire crop. It provides for the combination and sequential execution of operations in a single process of cultivation, reduction due to this and the amount of tillage, with accurate and high-quality execution of all works, application of new forms of labor organization. Modern varieties and technology make it possible to overcome the barrier of soybean productivity and obtain high productivity of crops and expand the area of its cultivation.

In the process of growing each agricultural crop, the primary task for the producer is to create favorable conditions for the realization of its potential. In connection with the expansion of the sown areas of such a leguminous crop as soybean, the question of finding out and forming nutrition conditions to ensure its high productivity arises. An important factor restraining the growth of soybean productivity is the insufficiently improved system of fertilization of this crop.

The problem of resource and energy conservation with the use of mineral fertilizers for this crop is of particular importance in modern conditions. This determines the further search for new ways to solve this problem with the rational and effective use of various preparations and mineral fertilizers. Soybean is a unique plant: due to the successful combination of two important processes - photosynthesis and biological nitrogen fixation - it meets its needs and improves the nitrogen balance of the soil and is a good precursor for other crops.

In modern agricultural production, the saturation of leguminous crop rotation can reach 20-25%. To ensure high rates of nitrogen fixation, the seeds of leguminous crops are treated with preparations containing a high titer (amount) of nodule bacteria before sowing. The procedure was called inoculation. Leguminous crops differ significantly in their ability to fix nitrogen from the air. The most productive: Alfalfa - up to 300 kg/ha, red clover - 180 kg/ha, lupine within 150 kg/ha, peas and soybeans - 50-70 kg/ha. Today, a group of free-living nitrogen fixers in soil from the genera Clostridium and Azotobacter is known. The biological ability of this crop to symbiotic type of nutrition thanks to nodular bacteria of the genus Rhizobium provides plants with fixed atmospheric nitrogen in the form of organic compounds in an unlimited amount and in the most necessary period of plant growth and development, which makes it possible to form stable and ecologically clean crops.

Therefore, in modern conditions, it is quite relevant to solve the issue of nitrogen fixation of leguminous crops using biological preparations based on promising nodule bacteria and the use of microelements to increase the productivity of soybean plants.

In the domestic agricultural market, soybean has for many years, along with grain crops, taken the leading positions in export and processing for food and fodder purposes, and also has a strategically important role in ensuring the country's food and economic security. The main prerequisites that led to the change in the position of this culture in the world over the past 20 years were shifts in the structure of nutrition of the population of developed countries, which are associated with the transition from the use of animal fats to vegetable and oil, as well as an increase in its number in Asian countries and a rapid development of the livestock industry in the EU.

All in all, this led to the growth of global demand for soybeans and the reorientation of many countries to its cultivation, including our country.

The question of the influence of nitrogen fixation of leguminous crops on the productivity of the following crops in crop rotation has been studied at a sufficient level by Didur I. M. (2020), Bakhmat M. (2020), Bondarenko V. (2022), Ovcharuk O. (2022), Chynchyk O. (2021), Tkachuk O. (2021) and others.

Analysis of recent research and publications

The activity of free-living nitrogen-fixing bacteria in the soil is limited by the lack of organic matter, and therefore their productivity is insignificant - about 5 kg/ha during the growing season. Bubble bacteria provide the leguminous plant with nitrogen fixed from the air, and the plant receives mineral salts and products of carbohydrate metabolism. The productivity of the process of assimilation of nitrogen from the air depends on many factors. The first and main condition is high virulence, which is a sign of a high-quality inoculant. Optimal soil moisture should be within 60-70% of the full moisture capacity. The minimum soil moisture at which nodule bacteria can develop is 16-18% of the full moisture capacity. At a lower level of soil moisture, nodule bacteria go into an inactive state, and their partial death is observed. Excessive humidity is also undesirable, as soil aeration is disturbed, which negatively affects the development of nodule bacteria. The process of nitrogen fixation takes place at a temperature of +10°C and above. The optimal temperature at which nitrogen fixation reaches maximum values is considered to be 20-25°C. A temperature above 30°C has a negative effect on the process of nitrogen fixation. The second important condition is the reaction of the soil, as an environmental factor affecting the activity and virulence of nodule bacteria [10-13, 22-24].

In acidic soils, manganese and aluminum compounds have a toxic effect on the development of the root system, reduce the availability of calcium, phosphorus, molybdenum, and carbon dioxide for plants, which negatively affects the processes of nitrogen assimilation. A soil reaction close to neutral is considered optimal. The acidic reaction of the soil affects both the plant itself - by impairing the development of the root system, and nodule bacteria, due to the reduction of the period of functioning of the bacteroid tissue, and therefore, the reduction of nitrogen fixation volumes. In addition, it should be noted that molybdenum, a key trace element for legumes, is better assimilated on soils with a neutral reaction. There is also a certain ecological adaptation of species and strains of nodule bacteria to soil acidity. Nodule bacteria of clover are more resistant to increased soil acidity than nodule bacteria of alfalfa, the crops of which are placed mainly on soils with a neutral and slightly alkaline reaction. The third feature is the conditions of mineral nutrition of leguminous plants. They have a significant effect on nitrogen fixation, since nodule bacteria receive mineral nutrients and carbohydrates from the host plant [1-5, 31-34].

Fig. 1. Nitrogen-fixing nodules formed on the root system of soybeans

Nitrogen and molybdenum are one of the most important nutrients that affect the process of symbiotic nitrogen fixation by legumes. Research has established that the higher the content of available forms of nitrogen, the more difficult it is for bacteria to penetrate the root, and therefore, fewer nodules are formed on the roots and their activity is low. The decrease in the share of atmospheric nitrogen absorbed by plants with an increased supply of mineral nitrogen is only relative. The absolute amount of nitrogen assimilated by bacteria from the air practically does not decrease, and in some cases even increases, compared to the variants of the experiment where nitrogen was not introduced. The supply of leguminous plants with phosphorus is important for nitrogen fixation, with a low content of which in the soil nodules may not form at all. Nitrogen assimilation deteriorates in plants with insufficient phosphorus nutrition. Legumes belong to crops with increased potassium removal, and therefore, fertilization with potassium fertilizers has a positive effect on the productivity of nitrogen fixation, which is obviously related to the physiological effect of potassium on carbohydrate metabolism in plants. Molybdenum and boron are particularly important trace elements for leguminous plants. A lack of molybdenum inhibits the formation of nodules, the synthesis of free amino acids and leghemoglobin is disrupted. Due to the lack of boron, vascular bundles are not formed in the nodules, as a result, the development of bacteroid tissue is disturbed. To overcome and prevent the possible manifestation of a deficiency of these important elements of mineral nutrition in production, microfertilizers are used in pre-sowing seed treatment and foliar application [6, 8, 9].

A high effect from the use of inoculation is observed on soils where there are no or low-productivity specific rhizobia. Thus, black earth soils are mainly dominated by inactive nodule bacteria with a low level of nitrogen fixation. The widespread use of biological nitrogen for leguminous plants is one of the alternative ways of obtaining an ecologically clean product for the needs of human nutrition and animal feeding. Pre-sowing inoculation of soybean seeds is an important agrotechnical measure of the resource- and energy-saving technology of growing this crop [13-16, 22-24].

A significant reserve for increasing soybean production is the use of new plant growth regulators and biopesticides. Soybean diseases are one of the main factors that destabilize the production of products in Ukraine. In global crop production, preparations of biological origin are increasingly used for its protection. Compared to pesticides of chemical origin, biological preparations have a high return, are harmless to mankind, animals and the environment. Among the highly effective and least expensive developments of domestic agricultural science in recent years, a significant place belongs to the introduction of domestic plant growth regulators [20-23].

One of the methods of stimulating the growth and development of plants, increasing the productivity, quality of soybean seeds, as well as the resistance of plants to pests and diseases, is the use of growth regulators. The widespread use of plant growth regulators, which have a versatile spectrum of action, contributes to a significant reduction in the use of plant protection agents against pests and diseases. In addition, having anti-stress properties, growth regulators increase the resistance of plants to low and high temperatures, excess water, drought and frost.

The use of growth regulators ensures:

- high field similarity indicators;

- development of a branched root system;
- acceleration of growth and development of the root system, which ensures effective assimilation of nutrients, including poorly soluble phosphorus compounds;
- reduction of crop failure;
- development of the leaf surface, increases the content of photosynthetic chlorophylls;
- resistance to adverse environmental factors, such as high temperatures, lack or excess of light and moisture;
- 15-20% increase in yield;
- improvement of product quality.

Manufacturers offer a wide range of chemicals, including plant growth regulators, inoculants, which could significantly increase crop yields. However, the lack of financial resources often prevents the introduction of scientific developments involving the use of these chemicals into agricultural production [35, 36, 37].

The success of the application of modern soybean cultivation technologies depends not only on the high-quality and timely implementation of the entire complex of technological measures, but to a large extent on the specific agrotechnical method, which must correspond to both the agro-climatic conditions of production and the varietal characteristics of soybeans.

An integral part of intensive cultivation technologies is the use of plant growth regulators. The need to treat soybean seeds with growth regulators, which contribute to a significant increase in crop productivity at low economic costs, has been confirmed. The development of new varieties of soybeans makes it necessary to conduct research on the effectiveness of using plant growth regulators both in their pure form and under other conditions.

Plant growth regulators contribute to increasing the biological and economic efficiency of crop production, reducing the content of nitrates, heavy metal ions, and radionuclides in the final product. Regulators are distinguished by a significant anti-stress effect, which has been proven by numerous experiments [39, 40].

It should be taken into account that plant growth regulators must be used in appropriate doses according to the terms and methods of application. Violation of these requirements may lead to a decrease in the expected effect.

As for soybeans, the correct selection of microbiological preparations, so-called inoculants, and their combination with plant growth regulators is of particular importance in modern technologies for its cultivation. Thanks to the latter, the development of nitrogen-fixing and phosphate-mobilizing bacteria is intensified.

The effectiveness of restregulatory drugs largely depends on the method of their application (seed treatment or spraying of crops). Plant growth regulators are used not only during seed treatment - they are used to spray crops in the appropriate phases of plant development, which are critical for growing conditions and nutrients. For soybeans, these are the phases of budding and flowering. It is advisable to combine spraying of crops with growth regulators with the application of pesticides in tank mixtures, as well as liquid complex fertilizers and trace elements. The most effective method is the combination of microbial preparations with plant growth regulators during seed treatment and spraying of soybean crops[30, 31, 32].

An effective system of soybean fertilization should be aimed at creating optimal conditions for nitrogen fixation processes and balanced provision of crops with phosphorus, potassium (in case of their lack, the development of nodule bacteria is sharply suppressed) and trace elements. To plan foliar top dressing of soybeans with macronutrients, it should be taken into account that the critical period in providing nitrogen is 2-3 weeks after the flowering of soybeans, and phosphorus is the first month of plant growth [33].

Of the trace elements in the formation of a high yield of soybeans, B, Mo and Co play a special role, which activate processes that ensure the symbiosis of nodule bacteria with the culture. Boron (B) is necessary for plants throughout the growing season. It provides transport of assimilants in the plant. Since boron is responsible for the differentiation of cells and the formation of cell walls, with its deficiency, young growing organs are especially affected, the growth points die off. Boron increases the number of flowers and fruits. Without it, the seed ripening process is disrupted. This trace element improves the supply of nitrogen to plants. Foliar fertilizing with boron is especially important on acidic ($pH < 5.5$) and alkaline ($pH > 7.5$) soils.

Soy is a very sensitive crop to the application of molybdenum-containing fertilizers. Molybdenum (Mo) promotes the growth of roots, accelerates the development and stimulates the activity of nodule bacteria, enhances the synthesis of chlorophyll. Mo is part of the nitrogenase enzyme, which contributes to the biological fixation of atmospheric nitrogen. The specific role of molybdenum in the process of nitrogen fixation determines the improvement of nitrogen nutrition of leguminous crops, increases the effectiveness of phosphorus and potassium fertilizers. At the same time, along with the increase in productivity, the protein content increases under the influence of molybdenum [7, 8, 12, 24].

Cobalt (Co), as a component of vitamin B12 (cobolamine), is also necessary for nitrogen fixation in leguminous plants. It increases the intensity of assimilation of nitrogen from the air, promotes the reproduction of nodule bacteria, activates the biosynthesis of chlorophyll and stimulates cellular reproduction of leaves.

It should be taken into account that soybean yields high yields when grown on soils rich in organic matter with a neutral reaction of the environment. On acidic soils, assimilation is disturbed and phosphorus, potassium, magnesium, calcium, and molybdenum deficiencies are observed. Alkaline soils contain sufficient amounts of potassium, calcium, magnesium, and nitrogen, but boron, manganese, copper, and phosphorus will be blocked. Boron and manganese often become difficult to access for legumes during liming. Legumes need for microfertilizers increases after the application of increased rates of mineral fertilizers. It is in such conditions that foliar fertilizing with microfertilizers is mandatory [9, 10, 11].

At the beginning of the growing season, soybean plants develop slowly, the root system is still poorly developed, and foliar feeding with mixtures of trace elements is of particular importance for the formation of the future crop. The technology of feeding soybeans with microfertilizer complexes is based on foliar treatment at critical stages of crop growth, when the greatest need for nutrients is observed.

The first important stage in the development of soybeans is the phase of 3-5 trifoliate leaves. The use of a complex fertilizer during this period with the addition of trace elements boron and molybdenum allows you to optimize the main physiological processes, stimulate the process of photosynthesis and the development of the root system, increase the plants' use of nutrients from the soil and fertilizers, and activate the activity of nodule bacteria. It is worth noting that the introduction of boron at this stage is an effective method of increasing the productivity of soybeans, since the beginnings of side shoots and inflorescences are laid [13-17, 25-29].

During the period of budding and flowering, the symbiotic activity of soybean sowing reaches its maximum. Therefore, to activate the activity of symbiotic bacteria and increase the efficiency of nitrogen fixation, molybdenum is applied foliarly. As a mandatory treatment, to stimulate pollination and the development of reproductive organs, it is recommended to fertilize with boron-containing fertilizers. At the late stages of reproductive development, in the phase of bean formation, in connection with the beginning of the flow of nutrients from the leaves to the seeds, soybean sharply reduces the activity of the root system. Foliar fertilization with microfertilizers during this period extends the life of the photosynthetic apparatus, contributes to the accumulation of biomass and, as a result, increases the yield [30, 31, 32].

In addition, at the end of the reproductive stage of development, to improve seed filling and stimulate the reutilization of nutrients for beans, it is worth applying a concentrated potash fertilizer with organic acids and trace elements.

During the growing season and especially during the flowering phase, plants are very sensitive to disease. In order to prevent disease and provide plants with available forms of phosphorus and potassium, it is advisable to use a fertilizer with a fungicidal effect. The phosphites of such drugs inhibit the growth of pathogenic organisms and contribute to the formation of the protective mechanism of plants in response to adverse environmental conditions. If there is a threat of heat, water or other stresses and to reduce the pesticide load, foliar fertilization with biologically active preparations with a high content of humic substances, amino acids and complexes based on highly available silicon compounds is recommended [27, 28].

Thus, understanding the physiological needs of the culture, the rational and justified application of foliar feeding with the necessary macro- and microelements and biologically active substances makes it possible to significantly increase the yield and environmental safety of soybean cultivation.

Conditions and methods of research.

Field studies on the influence of mineral fertilizers and methods of treatment with the Microfol Combi complex of trace elements on the productivity of soybean varieties of different maturity groups were conducted at the experimental field of the Vinnytsia National Agrarian University, which is located in the central part of the Vinnytsia region. The territory of the experimental field has a flat topography. The soil cover of the research area is represented by gray forest medium-loamy soils. According to their morphological features, physical and physico-chemical parameters, they are typical for the Vinnytsia region and in general for the Right-bank forest-steppe and are favorable for growing soybeans. Gray forest soils occupy an intermediate place between light and dark gray soils, the depth of the arable soil layer is 30 cm, medium-loam granulometric composition, lumpy structure. Its density is 1.32 - 1.4 g/cm^3.

Soybeans need 130-160% water from their mass for normal seed germination. The sprout is strongly suppressed when there is a lack of moisture. During the period of growth and development of soybean plants, the first relative maximum of moisture consumption occurs in the branching phase, and the second - more intensive - in the phase of seed formation and pouring. Thus, it can be concluded that the hydrothermal conditions of the growing region are one of the determining factors for obtaining high and stable soybean yields (Table 1) [10, 11].

Table 1

The necessary indicators of the temperature and water regime in the main periods of soybean growth and development

The period of growth and development of soybean	Air temperature, ^{0}C			Quantity of moisture, m^3/ha
	minimal	sufficient	optimal	
Sowing-emergence of seedlings	8–10	15–18	20–22	15–30
Emergence of seedlings-branching	10–12	17–20	22–25	15–30
Flowering	16–18	19–21	22–25	40–60
Bean formation	13–14	17–18	20–23	40–60
Maturation	7–8	13–16	18–20	30–40

According to the climatic conditions of the Right Bank Forest Steppe and according to the results of previous studies, soybean sowing in the region can be started from the first decade of May, and harvesting can be carried out in September-October.

Conducting research was carried out according to generally accepted methodical guidelines. The symbiotic productivity of soybean plants was determined according to the Posypanov method, taking into account such indicators as the total number and mass of nodules, the number and mass of active nodules, the total and active symbiotic potential, the specific activity of symbiosis [8, 9].

Research results

The problem of intensification of agricultural production and environmental protection arouses interest in biological nitrogen in all countries of the world. Research is being conducted to study the features of nitrogen fixation, its importance in the nitrogen nutrition of plants and the nitrogen balance of the soil, since nitrogen-fixing microorganisms are an important reserve for improving the nitrogen balance in the soil and increasing the yield of agricultural crops.

Effective use of the activity of nodule bacteria, which fix air nitrogen and mobilize hard-to-reach forms of soil phosphorus, makes it possible to increase soil fertility, and ultimately makes it possible to save a significant amount of mineral nitrogen and phosphorus fertilizers and obtain stable crops [1-7].

Together with carbon, oxygen and hydrogen, nitrogen forms a group of elements called organogens. Although almost 78% of the atmosphere consists of nitrogen, it is unavailable to most plants. Nitrogen does not support respiration and combustion, so D. Rutherford called it non-vital, despite the fact that it is part of nucleic acids, proteins and many other organic compounds.

Almost 8 tons of nitrogen are accumulated over each square meter of the Earth's surface. The amount of nitrogen in nature is not limited by this. It is believed that in the plowed soil layer at a depth of 30 cm per 1 ha, the amount of organic and mineral nitrogen in chernozem is 18 tons. However, the main sources of nitrogen nutrition for plants - nitrates and ammonium salts do not exceed 1%, therefore no other element limits nutrient resources in such a way substances in ecosystems, such as nitrogen [9].

Among nitrogen fixers, free-living organisms (Azotobacter, Clostridium) and their symbiotic associations with higher plants (Rhizobium) are distinguished. Although we are surrounded by an ocean of molecular nitrogen, the nitrogen molecule is so tightly bound that breaking three covalent bonds requires 940 kJ/mol of energy. Therefore, the technical synthesis of ammonia requires a temperature of about 500 °C and a pressure of 300-350 atmosphere, while nitrogen-fixing microorganisms function under normal conditions. This is explained by the fact that they have specific efficient enzyme systems that catalyze separate processes of nitrogen fixation. The amount of nitrogen from the air into the circulation in nature is determined by rather large numbers, every year about 190 million tons of nitrogen is fixed on the land surface, 30-130 million tons - in water systems [10-13].

That is why the study of biological and biochemical features of the process of fixing molecular nitrogen by microorganisms is of primary importance. Groups of soil microorganisms - nodule bacteria, which fix molecular nitrogen in symbiosis with leguminous plants - have the greatest practical importance in enriching soils with nitrogen, due to its assimilation from the air.

The powerful development of the symbiotic apparatus of leguminous crops depends not only on the effective interaction of the genotypes of the host plant and the symbiotrophic microorganism in certain growing conditions, but also on the fact that its intensity can be influenced by certain elements of the growing technology. Namely, the use of bacterial preparations, different doses of mineral fertilizers and methods of applying microfertilizers, plant growth stimulators.

To date, the most controversial issue in agricultural science is the feasibility of using nitrogen fertilizers for leguminous crops. Some scientists claim that in order to obtain high yields, it is necessary to apply large doses of mineral nitrogen to leguminous crops, despite its influence on the development of the symbiotic apparatus, and other researchers claim the feasibility of applying small «starting» doses of nitrogen fertilizers (20-30 kg/ha), which young plants will use at the first stages of development, when the symbiotic system has not yet formed [18-23].

The concept of the need to apply nitrogen fertilizers to leguminous crops does not agree with the theoretical foundations of biological nitrogen fixation and the results of a large number of field experiments. Thus, studies conducted with the use of mineral nitrogen on dark chestnut soils containing spontaneous nodule bacteria had a negative effect on the formation and functioning of nodules on soybean roots, delayed the formation of nodules, and reduced their nitrogenase activity, due to the fact that the supply of nutrients substances in the cotyledons and a significant amount of nitrate nitrogen in the soil ensure good plant development before the nodules function.

Phosphorus nutrition of leguminous plants is important for symbiotic nitrogen fixation. At a low phosphorus content in the soil, bacteria do not penetrate the roots of plants and do not form nodules. When growing soybeans on light chestnut soils, P_{120} was a strong stimulating factor for the formation of nodules. At the same time, there was an increase in root mass, an increase in the content of chlorophyll in the leaves, an increase in the yield of green mass and soybean grain [25-28].

In the conditions of the energy crisis and resource shortage, the importance of soybean as a high-protein crop is increasing, since it can form high yields even without the use of mineral fertilizers, in particular nitrogen fertilizers, due to the biological fixation of atmospheric molecular nitrogen. However, the high productivity of this culture depends on its symbiosis with nodule bacteria, which is determined by the activity and competitiveness of the strain in specific soil and climatic conditions, its complementarity to a certain variety, as well as the genetic features of the macrosymbiont.

Trace elements play an important role in symbiotic nitrogen fixation by leguminous plants: molybdenum, cobalt, boron, copper, zinc, manganese, vanadium. Among them, molybdenum and boron are most important in the formation of highly effective symbiotic systems. Molybdenum has a significant impact on symbiotic nitrogen fixation, as it directly participates in its individual stages, it is a component of nitrogenase and nitrate reductase, and its deficiency may cause competition between these elements. Cobalt increases the content of leghemoglobin in nodules and enhances the efficiency of their functioning, and as a result, the accumulation of biological nitrogen increases [22-24].

It is worth noting that a similar trend of influence of different doses of mineral fertilizers and various forms of application of a complex of trace elements on the formation of the symbiotic apparatus of soybean varieties was observed in our studies. On the basis of the three-year research, we found that the number of nodules during the growing season of soybean plants reaches its greatest value in the phase of the end of flowering, with its subsequent decrease, which can be explained by the rearrangement of plastic substances and carbohydrates, which ensure the functioning of nodule bacteria's reproductive organs.

Thus, the lowest number of nodules on the roots of soybean plants both in the mid-early Horlytsia variety (25,9 ± 7,6 pcs./plant) and the mid-ripe Vinnychanka variety (28,0 ± 8,1 pcs./plant), of which active, respectively, 21,2 ± 5,4 and 23,3 ± 6,1 pcs./plant with a total mass of 378,5 ± 95,2 and 412,8 ± 104,2 mg/plant, respectively, and a mass of active nodules, respectively, 316,3 ± 77,7 and 346,9 ± 87,6 mg/plant, was formed in the control variants of the experiment without the introduction of mineral fertilizers and the use of the Microfol Combi complex of trace elements.

The introduction of phosphorus-potassium mineral fertilizers had a positive effect on the formation of the number of nodules in plants of soybean varieties. Under these conditions, the total number of nodules in the Horlytsia variety increased to 36,8 ± 10,1 pcs./plant, of which 31,1 ± 7,9 pcs./plant were active, and their mass, respectively, was 547,8 ± 138,3 and 460,7 ± 116,3 mg/plant. In the Vinnychanka variety, these indicators were, respectively, 39,7 ± 11,1 and 34,1 ± 8,9 pcs./plant, with a mass of 574,3 ± 149,3 and 492,0 ± 127,9 mg/plant.

Additional use of mineral nitrogen in a dose of N_{30} to phosphorus-potassium fertilizer had a negative effect on the formation of symbiotic microflora of the root system, and the total number of nodules decreased by 14,1 – 16,0%, and the number of active nodules by 18,4 – 19,9% compared to with variants of the experiment where only phosphorus-potassium fertilizers were applied.

Table 2

The dynamics of the number of nodules in soybean plants depending on the variety, doses of mineral fertilizers and treatment with a complex of trace elements, on average for 2016-2018, pcs./plant

Variety	Fertilizer level	Processing with a complex of microelements	Growth and development phases							
			The first pair of genuine leaves		The beginning of flowering		The end of flowering		Full pouring of seeds	
			total amount	number of active	total amount	number of active	total amount	number of active	total amount	number of active
Horlytsya	no fertilizers	1	10,2±2,9	7,5±1,9	14,7±4,2	11,2±2,8	25,9±7,6	21,2±5,4	17,7±5,2	9,5±2,4
		2	11,3±3,0	8,6±2,0	16,2±4,6	12,0±3,1	28,1±8,0	22,3±5,8	18,2±5,2	10,0±2,6
		3	10,4±2,7	7,4±1,7	15,3±4,4	12,2±2,7	27,2±7,8	23,2±5,1	18,0±5,2	9,6±2,1
		4	11,3±3,0	8,8±2,1	16,8±4,9	12,9±3,3	28,7±8,4	23,5±6,0	18,5±5,4	10,3±2,6
	$P_{60}K_{60}$	1	20,5±5,6	15,1±4,0	26,6±7,3	21,4±5,5	36,8±10,1	31,1±7,9	23,8±6,5	12,8±3,3
		2	21,8±6,2	15,7±4,3	29,3±8,4	23,7±6,5	39,7±11,3	33,6±9,2	25,1±7,2	13,6±3,7
		3	20,2±6,2	14,9±4,5	28,9±8,9	22,8±6,6	39,0±12,0	32,3±8,8	24,6±7,5	13,5±3,8
		4	21,6±6,5	15,5±4,4	30,8±9,3	24,2±6,9	40,2±12,2	34,1±10,4	25,7±7,8	14,1±4,1
	$N_{30}P_{60}K_{60}$	1	13,5±3,5	9,3±2,4	20,1±5,3	15,2±3,9	30,9±7,9	24,9±6,4	19,9±5,1	11,3±3,0
		2	14,7±4,0	9,9±2,7	22,3±6,1	17,1±4,6	33,4±8,9	27,1±7,2	21,1±5,6	12,1±3,3
		3	13,7±4,1	9,4±2,8	22,0±6,5	16,6±4,8	32,7±9,5	26,2±7,6	20,4±5,9	11,8±3,5
		4	14,9±4,3	9,8±2,8	23,4±6,7	17,7±5,1	33,8±9,7	27,1±7,7	21,3±6,1	12,4±3,5
Vinnychanka	no fertilizers	1	11,4±3,4	8,9±2,3	16,2±4,7	13,0±3,4	28,0±8,1	23,3±6,1	19,4±5,8	10,7±2,8
		2	12,4±3,3	10,1±2,4	17,8±5,1	13,8±3,7	30,8±8,9	25,0±6,7	20,3±5,9	11,5±3,1
		3	11,7±3,0	8,9±2,0	17,0±5,0	13,9±3,2	30,1±8,8	25,4±5,7	19,7±5,8	11,1±2,5
		4	12,6±3,4	10,1±2,5	18,4±5,4	14,5±3,8	31,4±9,3	26,2±6,9	20,4±6,0	11,7±3,1
	$P_{60}K_{60}$	1	21,9±5,8	16,3±4,4	28,4±8,0	23,5±6,5	39,7±11,1	34,1±8,9	26,1±7,3	14,3±3,9
		2	23,4±6,8	17,0±4,5	31,4±9,1	25,8±7,2	42,9±12,5	36,7±10,3	27,9±8,1	15,4±4,3
		3	22,0±6,9	16,4±5,0	30,8±9,6	25,1±7,8	42,2±13,2	36,1±10,1	27,2±8,5	15,0±4,3
		4	23,0±7,1	16,9±5,0	32,8±10,1	26,6±8,1	43,7±13,5	36,9±11,5	28,3±8,7	15,9±4,9
	$N_{30}P_{60}K_{60}$	1	14,9±4,0	10,9±2,9	22,2±6,0	17,7±4,8	34,1±9,0	27,8±7,3	21,8±5,7	12,7±3,4
		2	16,0±4,5	11,6±3,2	24,7±6,9	19,5±5,5	37,0±10,1	30,2±8,2	22,9±6,2	13,6±3,8
		3	15,2±4,6	11,2±3,4	23,9±7,3	19,3±5,9	36,3±10,8	29,5±8,8	22,5±6,7	13,4±4,1
		4	16,5±4,7	11,7±3,4	25,9±7,5	20,6±6,0	37,7±11,0	30,4±8,8	23,5±6,8	14,1±4,1

1. No processing; 2. Treatment of seeds with Microfol Combi; 3. Foliar fertilization with Microfol Kombi; 4. Seed treatment + foliar fertilization with Microfol Combi

At the same time, the total number of nodules in the Horlytsia variety was 30,9 ± 7,9 pcs./plant, of which 24,9 ± 6,4 pcs./plant were active, with a weight of 467,0 ± 117,5 and 374,2 ± 94 respectively,1 mg/plant and in the Vinnychanka variety 34,1 ± 9,0 and 27,8 ± 7,3 pcs./plant with a weight of, respectively, 493,6 ± 128,2 and 405,1 ± 105,2 mg/ a plant. A similar effect of mineral nitrogen fertilizers on the formation of the symbiotic apparatus of leguminous crops was noted by other researchers.

On the basis of the conducted research, it was established that along with mineral fertilizers, the use of a complex of microelements has a certain influence on the formation of the symbiotic apparatus of soybean plants, which contributes to the growth of photosynthetic productivity of crops, and as a result, the provision of plants with plastic substances that directly participate in biological nitrogen fixation is improved.

It should be noted that on variants without fertilizers, the application of seed treatment with Microfol Combi (150 g/t) together with foliar fertilization with the same drug in a dose (0,5 kg/ha) ensured an increase in the number of active nodules by an average of 2,2-3,0 pcs./plant, and the mass of active nodules, respectively, by 23,3 – 32,9 mg/plant.

Our studies have shown that when treating seeds with a complex of microelements Microfol Combi (150 g/t) in combination with foliar feeding in the budding phase with the same preparation (0,5 kg/ha), the number of nodules not only increases compared to the control, but also increases significantly their mass due to the formation of larger nodules.

It is worth noting that the nature of the influence of the methods of application of a complex of microelements on the formation of the mass of active nodules is similar to the formation of their number. As noted, the most favorable conditions for the formation of the maximum number and mass of active nodules in soybeans were noted against the background of the application of mineral fertilizers in the dose of $P_{60}K_{60}$. Under these conditions, the combined use of Microfoul Combi for seed treatment (150 g/t) and foliar feeding (0,5 kg/ha) ensured an increase in the maximum number and mass of active nodules in the Vinnychanka variety, the number of active nodules by 2,8 and 3,0 pcs./plant, and their mass is 31,9 and 32,9 mg/plant, respectively, according to the variety. At that time, against the background of mineral fertilizers in the dose of $N_{30}P_{60}K_{60}$, these indicators were somewhat lower.

Thus, pre-sowing treatment of seeds with a complex of microelements Microfol Combi (150 g/t) is compatible with foliar feeding in the phase of budding with the same drug in a dose (0,5 kg/ha) against the background of applying mineral fertilizers in a dose of $P_{60}K_{60}$ contributes to the formation of nodules and their mass respectively, 36,9 ± 11,5 pcs./plant and 524,9 ± 150,6 mg/plant. In the Horlytsia variety, these indicators were slightly lower and were, respectively, 34,1 ± 10,4 pcs./plant and 492,6 ± 137,9 mg/plant.

Table 3

The dynamics of the raw mass of nodules in plants of soybean varieties depending on the doses of mineral fertilizers and treatment with a complex of trace elements, on average for 2016-2018, mg/plant

Variety	Fertilizer level	Processing with a complex of microelements	Growth and development phases							
			The first pair of genuine leaves		The beginning of flowering		The end of flowering		Full pouring of seeds	
			total amount	number of active	total amount	number of active	total amount	number of active	total amount	number of active
Horlytsya	no fertilizers	1	54,1±15,3	34,9±9,9	116,2±28,6	89,0±21,9	387,5±95,2	316,3±77,7	134,7±33,1	73,6±18,1
		2	57,8±15,6	36,4±9,8	129,8±29,9	102,4±25,6	409,9±99,2	336,4±82,7	139,6±33,8	77,8±19,1
		3	54,2±14,6	34,8±9,3	127,6±34,7	95,7±23,5	396,7±99,7	323,9±80,9	138,8±34,9	75,4±18,8
		4	57,4±16,0	36,6±10,2	134,7±32,2	104,2±27,8	413,5±107,3	339,8±90,6	143,3±37,2	80,5±21,5
	$P_{60}K_{60}$	1	108,6±31,4	79,7±23,1	220,2±55,6	178,0±44,9	547,8±138,3	460,7±116,3	181,6±45,8	104,8±26,5
		2	114,8±34,5	83,1±23,8	247,5±65,1	198,1±49,0	580,5±152,6	489,5±128,7	197,4±51,9	116,4±30,6
		3	106,3±33,4	79,4±25,0	245,3±68,7	194,3±54,0	574,7±150,3	479,1±133,1	191,5±50,1	112,7±31,3
		4	115,1±36,5	82,6±26,2	251,1±70,3	200,8±56,2	587,9±164,6	492,6±137,9	198,8±55,7	119,1±33,3
	$N_{30}P_{60}K_{60}$	1	70,3±20,2	47,2±13,6	156,8±39,5	119,7±30,1	467,0±117,5	374,2±94,1	159,2±40,1	96,5±24,3
		2	75,5±21,3	50,0±14,1	175,4±42,9	135,6±33,1	493,9±124,6	395,1±96,5	171,4±43,3	106,5±26,0
		3	68,1±20,9	47,9±14,7	172,3±46,4	131,1±35,3	483,5±130,4	389,4±105,0	167,6±45,2	102,2±27,6
		4	76,0±22,8	49,4±14,8	183,7±48,3	140,0±36,8	499,8±135,3	403,5±106,1	172,5±46,7	104,6±27,5
Vinnychanka	no	1	60,2±17,4	40,8±11,8	126,5±31,9	100,9±25,5	412,8±104,2	346,9±87,6	146,9 ±37,1	81,6±20,6
		2	63,7±17,5	42,6±11,7	140,4±33,2	108,0±27,6	436,1±108,2	355,0±89,6	151,9±37,7	85,5±21,6
		3	60,4±16,4	41,0±11,1	137,5±38,3	113,8±28,7	423,5±109,1	367,8±93,8	151,3±39,0	83,6±21,3
		4	63,8±18,0	42,5±12,0	145,3±35,3	116,4±31,7	439,4±116,3	370,2±100,8	155,1±41,0	88,7±24,1
	$P_{60}K_{60}$	1	115,3±34,1	85,9±25,4	231,6±60,2	187,9±48,9	574,3±149,3	492,0±127,9	193,9±50,4	114,1±29,7
		2	121,7±37,3	89,1±25,9	258,6±69,7	211,7±53,7	608,3±164,0	521,4±140,6	210,3±56,7	126,4±34,1
		3	115,9±37,3	85,8±27,6	257,8±74,0	204,6±58,5	601,8±161,8	510,9±146,0	204,3±54,9	122,7±35,1
		4	121,6±39,3	88,9±28,8	263,1±75,5	211,9±60,8	616,6±176,9	524,9±150,6	211,9±60,8	129,1±37,0
	$N_{30}P_{60}K_{60}$	1	76,8±22,7	53,4±15,8	168,1±43,7	133,4±34,7	493,6±128,2	405,1±105,2	171,8±44,6	104,1±27,0
		2	82,5±23,8	56,7±16,3	187,0±47,0	148,9±37,5	521,4±135,6	426,4±107,3	184,1±47,9	114,2±28,7
		3	77,9±24,4	54,3±17,0	184,1±51,1	145,2±40,3	510,6±141,6	420,1±116,5	180,4±50,0	109,7±30,4
		4	82,9±25,4	56,9±17,4	195,5±52,7	154,4±41,6	526,7±146,3	434,8±117,2	185,4±51,5	114,5±30,9

1. No processing; 2. Treatment of seeds with Microfol Combi; 3. Foliar fertilization with Microfol Kombi; 4. Seed treatment + foliar fertilization with Microfol Combi

Biological fixation of atmospheric nitrogen by symbiotic microorganisms takes place only in nodules that contain leghemoglobin, therefore, when determining the amount of nitrogen accumulation, only the

Table 4

The dynamics of the accumulation of raw mass of nodules in the ontogenesis of soybean varieties depending on the doses of mineral fertilizers and treatment with a complex of trace elements, on average for 2016–2018, kg/ha

Variety	Fertilizer level	Processing with a complex of microelements	Growth and development phases							
			The first pair of genuine leaves		The beginning of flowering		The end of flowering		Full pouring of seeds	
			total amount	number of active	total amount	number of active	total amount	number of active	total amount	number of active
Horlytsya	I	1	43,3	27,9	93,0	71,2	310,0	253,0	107,8	58,9
		2	46,2	29,1	103,8	76,6	327,9	269,1	111,7	62,2
		3	43,4	27,8	102,1	81,9	317,3	259,1	111,0	60,3
		4	45,9	29,3	107,8	83,4	330,8	271,8	114,6	64,4
	II	1	86,9	63,8	176,2	142,4	438,2	356,6	145,3	83,8
		2	91,8	66,5	198,0	157,4	464,4	390,0	157,9	93,1
		3	85,0	63,5	196,2	155,4	459,8	383,3	153,2	90,2
		4	92,1	66,6	200,9	163,0	470,3	396,2	159,0	95,8
	III	1	56,2	37,8	125,4	95,7	373,6	299,3	127,4	77,4
		2	60,4	40,0	140,3	108,5	395,1	316,1	137,1	83,7
		3	54,5	38,3	137,8	104,9	386,8	311,5	134,1	81,8
		4	60,8	39,5	146,9	112,0	399,8	325,5	138,0	84,9
Vinnychanka	I	1	48,2	32,6	101,2	80,7	330,2	277,5	117,5	65,3
		2	51,0	34,1	112,3	86,4	348,9	284,0	121,5	68,4
		3	48,3	32,8	110,0	91,0	338,8	294,2	121,0	66,9
		4	51,0	34,0	116,2	93,1	351,5	296,2	124,1	71,0
	II	1	92,2	68,7	185,3	150,3	459,4	393,6	155,1	91,3
		2	97,4	71,3	206,9	169,4	486,6	417,1	168,2	101,1
		3	92,7	68,6	206,2	163,7	481,4	408,7	163,4	98,2
		4	97,3	71,1	210,5	169,5	493,3	419,9	169,5	103,3
	III	1	61,4	42,7	134,5	106,7	394,9	324,1	137,4	83,3
		2	66,0	45,4	149,6	119,1	417,1	341,1	147,3	91,4
		3	62,3	43,4	147,3	116,2	408,5	336,1	144,3	87,8
		4	66,3	45,5	156,4	123,5	421,4	347,8	148,3	91,6
V, %			29,2	34,1	26,7	28,1	14,8	16,0	13,8	16,8
Sx%			6,0	7,0	5,4	5,7	3,0	3,3	2,8	3,4

Note: I. Without fertilizers; II. $R_{60}K_{60}$; III. $N_{30}P_{60}K_{60}$; 1. Without processing; 2. Seed treatment with Microfol Combi; 3. Foliar feeding with Microfol Combi; 4. Seed treatment + foliar feeding with Microfol Combi.

mass of active nodules should be taken into account, and the total mass of nodules has only a theoretical value, which characterizes the pace and dynamics of its growth.

Based on this, when calculating symbiotic productivity, an extremely important task is to determine exactly how and in what quantity the raw mass of nodules accumulates per unit area and the period of their active work, during which they are able to fix free atmospheric nitrogen. Based on the results of the calculations, it was established that the accumulation of the raw mass of nodules by sowing soybean varieties per unit area during the growing season is uneven and has a sinusoidal character.

Both the total mass of nodules and the mass of active nodules increase starting from the phase of the third trifoliate leaf to the phase of the end of flowering, after which it gradually decreases.

Thus, on average, during the years of research, the highest indicator of the total mass of raw nodules and the mass of active nodules was noted in the phase of the end of flowering. So in the Horlytsia variety on the control variant, the total mass of raw nodules was 310,0 kg/ha, and active 253,0 kg/ha, in the Vinnychanka variety, these indicators were, respectively, 330,2 and 277,5 kg/ha.

It was established that the investigated factors have different effects on the intensity of nodule mass formation in the ontogenesis of soybean varieties. Thus, in the experimental variants where the Horlytsia variety was grown, the application of mineral fertilizers in the dose of $P_{60}K_{60}$ contributed to an increase in the total mass of nodules on average by 128,2 kg/ha, and the mass of active nodules by 103,6 kg/ha, for the cultivation of the Vinnychanka variety, these indicators were respectively, 129,2 and 116,1 kg/ha. The application of mineral nitrogen in a dose of N_{30} along with phosphoric-potassium to a certain extent reduced the formation of nodule masses. Under these conditions, in the Horlytsia variety, the increase in the total mass of nodules was 63,6 kg/ha, and the active ones were 46,3 kg/ha. In the Vinnychanka variety, under the given growing conditions, the increase in total mass and mass of active nodules compared to the control was 64,7 and 46,6 kg/ha, respectively.

Along with this, the use of the Microfol Combi complex of trace elements had a positive effect on the accumulation of the raw mass of nodules. At the same time, the maximum effect was provided by the combined use of this preparation for pre-sowing seed treatment (150 g/t) in combination with foliar feeding (0,5 kg/ha). Under such growing conditions, the increase in the raw mass of active nodules was from 6,7% to 11,1%, depending on the background of mineral nutrition and variety.

Table 5

Dynamics of the general symbiotic potential of soybean varieties depending on the doses of mineral fertilizers and treatment with a complex of trace elements, on average for 2016–2018, thousand kg days/ha

Variety	Fertilizer level	Processing with a complex of microelements	Growth and development phases				For the entire duration of the symbiosis
			The first pair of genuine leaves	The beginning of flowering	The end of flowering	Full pouring of seeds	
Horlytsya	no fertilizers	1	0,909	2,417	9,300	3,879	16,506
		2	0,971	2,700	9,838	4,020	17,530
		3	0,911	2,654	9,520	3,997	17,082
		4	0,964	2,802	9,924	4,127	17,817
	$P_{60}K_{60}$	1	1,824	4,580	13,147	5,230	24,782
		2	1,929	5,148	13,932	5,685	26,694
		3	1,786	5,102	13,793	5,515	26,196
		4	1,934	5,223	14,110	5,725	26,992
	$N_{30}P_{60}K_{60}$	1	1,181	3,261	11,208	4,585	20,235
		2	1,268	3,648	11,853	4,936	21,706
		3	1,144	3,583	11,605	4,827	21,159
		4	1,277	3,820	11,994	4,968	22,059
Vinnychanka	no fertilizers	1	1,060	2,732	10,237	4,348	18,377
		2	1,121	3,033	10,815	4,496	19,465
		3	1,063	2,970	10,503	4,478	19,014
		4	1,123	3,138	10,897	4,591	19,749
	$P_{60}K_{60}$	1	2,029	5,003	14,243	5,739	27,014
		2	2,142	5,586	15,086	6,225	29,039
		3	2,040	5,568	14,925	6,047	28,580
		4	2,140	5,683	15,292	6,272	29,387
	$N_{30}P_{60}K_{60}$	1	1,352	3,631	12,241	5,085	22,309
		2	1,452	4,039	12,931	5,449	23,871
		3	1,371	3,977	12,663	5,340	23,350
		4	1,459	4,223	13,062	5,488	24,232
V, %			29,6	27,0	15,2	14,3	17,8
Sx%, %			6,0	5,5	3,1	2,9	3,6

Note: 1. No processing; 2. Seed treatment with Microfol Combi; 3. Foliar feeding with Microfol Combi; 4. Seed treatment + foliar feeding with Microfol Combi.

The total symbiotic potential for the entire vegetation period is calculated by the sum of indicators for individual vegetation periods. Active symbiotic potential is also calculated in the same way, in the calculations of which only the mass of active nodules, i.e. those that have a pink color, is taken into account. The active symbiotic potential is a unifying indicator of the mass of active nodules and the duration of their effective work, and also shows the participation of individual factors in the accumulation of biological nitrogen to one degree or another.

According to the results of our research and calculations, it was found that the highest indicator of both the total - 9,300 - 14,110 thousand kg-day/ha in the Horlytsia variety and 10,237 - 15,292 thousand kg-day/ha in the Vinnychanka variety, as well as the active symbiotic potential, respectively , 7,592 – 11,886 thousand kg-day/ha and 8,603 – 13,018 thousand kg-day/ha, were formed in the phase of the end of flowering (tables 5, 6).

Thus, on average over the years of research, for the entire period of symbiosis duration, the highest indicator of total 26,992 thousand kg-day/ha and active symbiotic potential of 20,971 thousand kg day/ha in the Horlytsia variety and, accordingly, 29,387 thousand kg day/ha and 22,981 thousand kg day/ha in the Vinnychanka variety was formed on the variants of the experiment, where mineral fertilizers were applied in a dose of $P_{60}K_{60}$ and pre-sowing treatment of seeds with a complex of trace elements Mikrofol Combi (150 g/t) was carried out in conjunction with foliar feeding in the budding phase with the same preparation (0,5 kg/ha), which, respectively, prevails over the control variants of the experiment without the introduction of mineral fertilizers and the use of a complex of trace elements by 10,486 and 8,821 thousand kg day/ha and 11,010 and 9,066 thousand kg day/ha.

The results we obtained showed that among the studied factors on the formation of the value of the active symbiotic potential, the use of phosphorus-potassium mineral fertilizers had a positive effect, which contributed to a more intensive colonization of the roots of soybean plants with symbiotic bacteria, and as a result, the formation of a larger number of nodules and an increase in their potential mass. as a result, the value of the active symbiotic potential increased. Therefore, the application of mineral fertilizers in the dose of $P_{60}K_{60}$ provided an increase in the active symbiotic potential over the entire period of symbiosis duration in the Horlytsia variety by 6,606 thousand kg day/ha and in the Vinnychanka variety by 7,234 thousand kg day/ha compared to the control without the application of mineral fertilizers . The use of nitrogen fertilizers in the dose of N_{30} had a

Table 6

Dynamics of the active symbiotic potential of soybean varieties depending on the doses of mineral fertilizers and treatment with a complex of trace elements, on average for 2016–2018, thousand kg days/ha

Variety	Fertilizer level	Processing with a complex	Growth and development phases				For the entire duration of the symbiosis
			The first pair of genuine leaves	The beginning of flowering	The end of flowering	Full pouring of seeds	
Horlytsya	no fertilizers	1	0,586	1,852	7,592	2,120	12,150
		2	0,612	1,991	8,073	2,241	12,917
		3	0,585	2,130	7,774	2,171	12,660
		4	0,615	2,168	8,155	2,319	13,257
	$P_{60}K_{60}$	1	1,339	3,702	10,697	3,018	18,756
		2	1,396	4,093	11,700	3,352	20,541
		3	1,334	4,042	11,499	3,246	20,121
		4	1,399	4,237	11,886	3,449	20,971
	$N_{30}P_{60}K_{60}$	1	0,793	2,489	8,980	2,786	15,048
		2	0,840	2,820	9,482	3,012	16,154
		3	0,805	2,726	9,345	2,943	15,819
		4	0,830	2,912	9,764	3,058	16,564
Vinnychanka	no fertilizers	1	0,718	2,179	8,603	2,415	13,915
		2	0,750	2,333	8,804	2,531	14,418
		3	0,722	2,458	9,121	2,475	14,776
		4	0,748	2,514	9,181	2,626	15,069
	$P_{60}K_{60}$	1	1,512	4,059	12,202	3,377	21,149
		2	1,568	4,573	12,931	3,741	22,813
		3	1,510	4,419	12,670	3,632	22,232
		4	1,565	4,577	13,018	3,821	22,981
	$N_{30}P_{60}K_{60}$	1	0,940	2,881	10,046	3,081	16,948
		2	0,998	3,216	10,575	3,380	18,169
		3	0,956	3,136	10,418	3,247	17,758
		4	1,001	3,335	10,783	3,389	18,508
V, %			34,5	28,4	16,5	17,2	19,6
Sx%, %			7,1	5,8	3,4	3,5	4,0

Note: 1. No processing; 2. Seed treatment with Microfol Combi; 3. Foliar feeding with Microfol Combi; 4. Seed treatment + foliar feeding with Microfol Combi.

negative effect on the formation of active symbiotic potential compared to the options where only phosphorus-potassium fertilizers were used, while the increase compared to the control was, respectively, 2,898 thousand kg day/ha and 3,033 thousand kg-day/ha.

As a result of the research, a positive effect on the formation of an active symbiotic apparatus of pre-sowing seed treatment (150 g/t) and foliar fertilization (0,5 kg/ha) with the Microfol Combi micronutrient complex was revealed. Thus, pre-sowing treatment of seeds with Microfol Combi (150 g/t) makes it possible to increase the level of active symbiotic potential by 0,503 – 1,785 thousand kg-day/ha, depending on the level of mineral nutrition and variety, while foliar feeding, respectively, by 0,510 – 1,365 thousand kg-day/ha. The combination of methods of applying a complex of trace elements was the most effective, while the increase in the level of active symbiotic potential was 1,107 – 2,215 thousand kg-day/ha.

Therefore, on the basis of the conducted research, it was established that in the conditions of the Right Bank Forest Steppe on gray forest soils, the best conditions for the formation of the maximum symbiotic potential of the studied soybean varieties are created under the conditions of a combination of pre-sowing treatment of seeds with a complex of trace elements Microfol Combi (150 g/t) and foliar feeding with the same preparation (0,5 kg/ha) in the phase of budding against the background of application of mineral fertilizers in the dose of $P_{60}K_{60}$.

Increasing the yield level of leguminous crops is directly related to the need for in-depth scientific determination of the optimal ratio of biological and mineral nitrogen in the plant nutrition system. There is an optimum in the ratio of the two sources of nitrogen nutrition, which is characteristic for each type of legume and which is affected by the type of soil and other growing conditions. Finding this optimum is the main task for the scientific substantiation of mineral nitrogen norms for leguminous crops [28].

To date, there are a number of methods for determining the level of biological fixation of atmospheric nitrogen, namely: the method of labeled atoms, the balance method, the method of comparing legumes with non-legumes, the method of comparison with non-inoculated crops, the method of calculating coefficients, the method of plant inoculation, the method of using isotope, acetylene method, calculation of fixed nitrogen by active symbiotic potential and specific activity of symbiosis; positive and negative soil nitrogen balance; prediction and control of providing plants with symbiotically fixed air nitrogen [18].

When determining the amount of biologically fixed nitrogen in our research, we were guided by the method of calculating the amount of active symbiotic potential and specific activity of symbiosis, respectively, by calculating the value of these indicators, we can also determine the amount of biologically fixed nitrogen for the corresponding period.

Based on the results of our study, it was found that the specific activity of the symbiosis of nodule bacteria in soybean crops varied depending on the variety and the year of the study. Thus, in 2016, the specific activity of symbiosis in the Horlytsia variety was 6,4 g·N/kg per day, in 2017 – 7,1 g·N/kg per day, and in 2018 – 7,0 g·N/kg per day day, in the Vinnychanka variety, these indicators were, respectively, 6,8, 7,4 and 7,1 g·N/kg. Such dynamics of the intensity of the specific activity of symbiosis can be caused by a change in the value of the active symbiotic potential by years of research and varieties. Thus, a higher indicator of active symbiotic potential was formed in the Vinnychanka variety, correspondingly, a higher activity of nitrogen fixation over the years of research.

Thus, according to the results of our research, it was found that the highest amount of biological nitrogen in the atmosphere of a soybean plant, Horlytsia variety 144,4 kg/ha and Vinnychanka variety 164,4 kg/ha, is recorded in the variants of the experiment with the introduction of mineral fertilizers in the dose of $P_{60}K_{60}$ and pre-sowing seed treatment with Microfol Kombi (150 g/t) in combination with foliar fertilization with the same drug at a dose (0,5 kg/ha), which is 60,7 and 65,0 kg/ha more than the control, respectively.

The introduction of mineral fertilizers in the dose of $P_{60}K_{60}$ helped to increase the level of biological nitrogen accumulation by an average of 45,2– 51,7 kg/ha, depending on the variety, while the additional application together with phosphorus-potassium fertilizers of nitrogen (N_{30}) negatively affected biological fixation nitrogen, while the level of its accumulation was 19,8 – 21,7 kg/ha more compared to the control (Table 7).

Pre-sowing seed treatment with Microfol Combi (150 g/t) contributed to an increase in the level of nitrogen fixation by 5,2–10,1 kg/ha in the Horlytsia variety and by 3,6–12,0 kg/ha in the Vinnychanka variety. Foliar top dressing with Microfol Combi (0,5 kg/ha) in the budding phase increased the accumulation of biological nitrogen, respectively, by 3,4–4,7 and 5,9–7,9 kg/ha. The greatest increase in the level of accumulation of biological nitrogen in the Horlytsia variety 8,1 – 12,1 kg/ha and in the Vinnychanka variety 8,4 – 13,3 kg/ha was ensured by the complex application of seed treatment and foliar fertilization.

Table 7

The amount of biologically fixed nitrogen depending on the doses of mineral fertilizers and processing with a complex of trace elements, on average for 2016-2018, kg/ha

Fertilizer level	Processing with a complex of	Horlytsya				Vinnychanka			
		the years							
		2016	2017	2018	average over the years	2016	2017	2018	average over the years
no	1	63,6	110,6	76,5	83,7	78,3	133,1	86,9	99,4
	2	67,6	117,5	81,5	88,9	80,9	137,7	90,5	103,0
	3	64,7	115,1	81,7	87,2	81,5	141,1	94,2	105,6
	4	66,9	122,4	84,6	91,3	81,8	146,1	95,4	107,8
$P_{60}K_{60}$	1	101,2	167,8	117,7	128,9	120,4	203,9	129,1	151,1
	2	106,4	189,9	127,8	141,4	126,8	220,7	141,8	163,1
	3	105,2	188,9	121,1	138,4	125,1	219,3	132,6	159,0
	4	107,8	195,5	129,8	144,4	126,2	226,6	140,3	164,4
$N_{30}P_{60}K_{60}$	1	80,8	138,0	91,6	103,5	97,7	163,3	102,3	121,1
	2	85,2	147,6	100,6	111,1	103,5	173,7	112,2	129,8
	3	82,8	147,4	96,3	108,8	100,0	173,7	107,2	127,0
	4	87,2	152,0	102,6	113,9	102,9	179,7	114,3	132,3

Note: 1. No processing; 2. Seed treatment with Microfol Combi; 3. Foliar feeding with Microfol Combi; 4. Seed treatment + foliar feeding with Microfol Combi.

It should be noted that along with the influence of the studied factors on biological nitrogen fixation, the amount of symbiotic nitrogen accumulation in the soil directly depended on the weather conditions of the years of research. Thus, the weather conditions of 2016 were the most difficult for the formation of the symbiotic apparatus. 2017 was the most favorable year for the maximum realization of the symbiotic potential, it should be noted that the largest amount of biologically fixed nitrogen was observed in the conditions of this year.

Based on the results of the correlation-regression analysis, the dependence of the level of accumulation of biological nitrogen by soybean varieties on the amount of precipitation during the growing season was reliably determined. This dependence is described by the following regression equations for the Horlytsia variety (1) and for the Vinnychanka variety (2):

Y= -109,3352+0,8004*x (1)

Y= -18,8643+0,492*x (2)

where: Y – amount of biologically fixed nitrogen, kg/ha; X – amount of precipitation during the growing season, mm.

At the same time, the correlation coefficient was r= 0,749 for the Horlytsia variety, r = 0,772 for the Vinnychanka variety, and the adjusted coefficient of determination was, respectively, r^2= 0,561 and r^2= 0,596.

Conclusions

The best conditions for the maximum realization of the symbiotic potential of both the Horlytsia variety and the Vinnychanka variety were created in the experimental variants with the introduction of mineral fertilizers in a dose of $P_{60}K_{60}$, seed treatment (150 g/t) and foliar fertilization (0,5 kg/ha) with the Microfol Kombi micronutrient complex. The highest indicator of active symbiotic potential of 20,971 thousand kg days/ha in the Horlytsia variety and 22,981 thousand kg days/ha in the Vinnychanka variety was recorded in the variants of the experiment with the introduction of mineral fertilizers in the dose of $P_{60}K_{60}$, with pre-sowing treatment of seeds (150 g/t) and foliar top dressing (0,5 kg/ha) with a complex of trace elements Mikrofol Combi. The highest amount of biologically fixed nitrogen, 144,4 and 164,4 kg/ha, respectively, was obtained on these experimental sites.

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