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**INFLUENCE OF MICROBIOLOGICAL PREPARATION AND  
MINERAL FERTILIZER ON THE FORMATION OF CHICKPEAS  
PRODUCTIVITY**

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*Increasing the gross yield of chickpea seeds as a source of highly nutritious vegetable protein is one of the important aspects of ensuring national food security and nutrition of the population. The experiment to determine the effect of biological product based on nitrogen-fixing microorganisms, different doses of NPK, boron-containing fertilizer and their combinations on the formation of chickpea productivity was conducted in field conditions of a two-factor experiment in the conditions of the state enterprise “Experimental farm “Stepne” of the Institute of Pig Breeding and Agricultural Research of the NAAS” during 2023–2024. The results of the study showed that improving the nutritional regime of chickpea plants by inoculating seeds with a microbiological preparation based on nitrogen-fixing microorganisms, applying different doses of mineral fertilizers, foliar application of chickpea in the budding phase with microfertilizers and their combination improved the conditions for the formation of the leaf surface of plants and contributed to the extension of the duration of the period of its stay in an active state. Accordingly, the amount of absolutely dry aboveground mass accumulated by plants and the mass of seeds formed in beans increased. The most effective in this regard was the complex use of the microbiological preparation Anderiz (3.9 l/t) for pre-sowing inoculation of seeds and foliar application of crops with microfertilizer SmartGrow Bor-150 (1.5 l/ha) against the background of  $N_{15}P_{60}K_{60}$  application, which, along with the highest values of the photosynthetic activity of plants in crops, ensured the yield of chickpea seeds at the level of 2.56 t/ha.*

**Keywords:** chickpea, seed inoculation, foliar feeding, mineral fertilizers, photosynthesis, yield.



## ВПЛИВ МІКРОБІОЛОГІЧНОГО ПРЕПАРАТУ ТА МІНЕРАЛЬНОГО УДОБРЕННЯ НА ФОРМУВАННЯ ПРОДУКТИВНОСТІ НУТУ

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*Збільшення валових зборів насіння нуту, як джерела високопоживного рослинного білка є одним із вагомих аспектів забезпечення державної продовольчої безпеки та харчування населення. Дослідження із вивчення впливу біопрепарату на основі азотфіксуючих мікроорганізмів, різних доз NPK, боровмісного добрива та їх комбінацій на формування продуктивності нуту було проведено у польових умовах двохфакторного дослідження в умовах державного підприємства “Дослідне господарство “Степне” Інституту свинарства і АПВ НААН” впродовж 2023–2024 рр. Результатами досліджень показали, що покращення поживного режиму рослин нуту за рахунок проведення інокуляції насіння мікробіологічним препаратом на основі азотфіксуючих мікроорганізмів, внесення різних доз мінеральних добрив, проведення позакореневого підживлення посівів нуту у фазі бутонізації мікродобивом та їх поєднання покращувало умови формування листкової поверхні рослин та сприяло подовженню тривалості періоду перебування її у активному стані. Відповідно кількість накопиченої рослинами абсолютно сухої надземної маси та маси сформованого у бобах насіння збільшувалися. Найбільш ефективним у цьому відношенні виявилось комплексне застосування мікробіологічного препарату Андерізі (3,9 л/т) для передпосівного інокулювання насіння та позакореневого підживлення посівів мікродобивом SmartGrow бор-150 (1,5 л/га) на фоні внесення  $N_{15}P_{60}K_{60}$ , що поряд із найвищими значеннями показників фотосинтетичної діяльності рослин у посівах забезпечило отримання урожайності насіння нуту на рівні 2,56 т/га.*

**Ключові слова:** нут, інокулювання насіння, позакореневе підживлення, мінеральні добрива, фотосинтез, урожайність.

**Introduction.** In solving the global problem of food security, the expansion of sown areas and the application of the latest agrotechnological aspects in the cultivation of leguminous crops as the main source of highly nutritious protein resources are of strategic importance. It is well known that protein is an important nutritional component necessary for ensuring vital functions of the body, such as body growth, tissue repair, strengthening the immune system, as well as regulating chemical and biochemical processes (Singh P., Krishnaswamy K., 2020; Çakor Ö. et al., 2019).

In the structure of protein resources used by the population for nutrition, animal proteins play a significant role (Pasiakos S.M. et al., 2015) However, as shown by the results of scientific research, the consumption of a significant amount of meat products causes the emergence and development of diseases of the cardiovascular and digestive systems, as well as the metabolic system. On the other hand, hidden hunger, caused by an insufficient amount of microelements in the daily diet, is the root cause of many health



problems, including growth retardation, underweight and the occurrence of cognitive disorders (Ibeanu V.N. et al., 2020). In this regard, an important element of the healthy nutrition system of the population of both developed countries and countries with a low standard of living can be highly nutritious products, the raw material of which is the seeds of leguminous crops (Yeremko L. et al., 2023).

A valuable representative of this group of crops is chickpeas, the main biological characteristics of which are drought resistance, heat resistance and, at the same time, resistance to the effects of low positive temperatures and short-term frosts (Karalija E. et al., 2022; Mir A.H. et al., 2021).

Due to the high content of proteins, fiber, mineral elements, as well as vitamins and biologically active compounds (Wang J. et al., 2021), the consumption of chickpea seeds normalizes the physiological processes of the human body and can be recognized as a potential candidate for the classification of "functional foods" to reduce the occurrence and development of various types of diseases (Begum N. et al., 2023; Jha U.C. et al., 2024).

Chickpea plants, by creating symbiotic relationships with nodule bacteria of the genus *Mesorhizobium*, such as *Mesorhizobium ciceri* and *Mesorhizobium mediterraneum* and converting or reducing molecular nitrogen from the air to ammonia, can provide about 70% of the need for this nutrient for metabolic reactions (Yeremko L. et al., 2024). At the same time, the interaction of plants with microorganisms provides them with biological control over the development of pathogens, increased resistance to the effects of adverse biotic and abiotic factors and better phosphorus availability (Monteoliva M. et al., 2022) due to the solubilization of phosphates (Sridevi M., Mallaiiah K.V., 2009).

In this regard, a promising environmentally safe agrotechnological technique may be the use of biological preparations based on nitrogen-fixing bacteria for pre-sowing seed inoculation (O'Callaghan M., 2016). The introduction into the rhizosphere zone (root system formation) of highly active specific strains of nodule bacteria, which are characterized by higher competitiveness compared to aboriginal strains in the processes of infection and nodule formation and, accordingly, can increase the efficiency of legume-rhizobial symbiosis, and increase plant productivity (Pastor-Bueis R. et al., 2019; Sánchez-Navarro V. et al., 2020). At the same time, scientists note that despite the fact that atmospheric nitrogen is an unlimited resource of nitrogen nutrition, its symbiotic fixation by nodule bacteria usually cannot fully satisfy the plant's needs for this element. Thus, nitrogen uptake during legume-rhizobial symbiosis usually does not reach the same level as the uptake of  $\text{NO}_3^-$  and  $\text{NH}_4^+$  by the root system, provided that they are sufficiently present in the soil. This phenomenon explains the inhibition of symbiotic nitrogen fixation by the application of high doses of mineral nitrogen, and plants satisfy their nitrogen needs by absorbing mineral nitrogen from the soil as non-symbiotic higher plants (Lepetit M., Brouquisse R., 2023). However, other researchers indicate the need to apply starting doses of nitrogen until the root system is sufficiently developed and the proper symbiotic apparatus is formed.

Phosphorus is the second most important element in plant nutrition. It plays a fundamental role in the regulation of various metabolic and physiological processes related to energy supply, cell division, DNA synthesis and phospholipid biosynthesis. This element is involved in the synthesis of sucrose, starch and cellulose and provides energy for the biosynthesis of phospholipids. Energy-rich phosphates, such as ATP, GTP, ADP, modulate the activity of enzymes through reverse phosphorylation (Isidra-Arellano M.S. et al., 2021).

Its sufficient presence in the soil ensures increased tolerance of plants to the effects



of increased average daily air temperature, drought, waterlogging, soil salinity and toxicity of heavy metals in it (Hawkesford M.J. et al., 2023).

Phosphorus deficiency, on the contrary, negatively affects the processes of root system development and plant productivity, which ultimately leads to a decrease in the number of fruits and their mass (Lambers H., 2022).

Potassium in the plants acts as an activator of more than 60 enzyme systems that catalyze numerous metabolic reactions. It maintains osmotic pressure and cell turgor, regulates their cation-anion balance and cytoplasmic pH, controls membrane polarization, cell expansion and stomatal movement, thus regulating the supply of CO<sub>2</sub> and moisture (Yeremko L. et al., 2024). This nutrient is involved in complex physiological processes of photosynthesis, synthesis of proteins, sugars and starch and their redistribution between plant organs.

Potassium is an important element that determines the adaptive capacity of plants to abiotic stresses and the level of crop quality indicators. In legumes, potassium, as the most common intracellular cation, plays an important role in the formation of a powerful root system and its absorption of moisture, the formation of root hairs, which, in turn, improves nodulation and N<sub>2</sub> fixation (Nakei M.D., 2022). At the same time, its presence ensures the maintenance of turgor pressure of bacterial cells, pH regulation, gene expression and activation of cellular enzymes (Domínguez-Ferreras A, 2009).

Microelements play a key role in increasing the yield of legume crops due to their influence on the physiological processes occurring in plants. They act as co-factors in the enzymatic system, and also participate in the key physiological processes of photosynthesis and respiration. These compounds contribute to the stabilization of cell walls of leguminous plants, membrane integrity, sugar transport and utilization of calcium and nitrogen (Flores R.A. et al., 2017). In addition, boron is an element that determines the reproductive ability of plants, due to its positive effect on the processes of pollination and fertilization and fruit formation. The role of this element is more pronounced during the reproductive stage of development. Scientists note that its deficiency during this period leads to pollen sterility and significantly reduces grain yield (Wang N., 2015).

At the same time, scientists note that boron deficiency indirectly affects photosynthesis by weakening vascular tissues responsible for ion transport (Goldbach H.E., Wimmer M.A., 2007). Thus, there is an assumption that disturbances in chloroplast membranes, the stomatal apparatus, the energy gradient across the membrane and thylakoid electron transport are the main reason for the decrease in photosynthesis under conditions of boron deficiency (El-Feky S.S. et al., 2012).

Thus, the review of scientific publications indicates the importance of chickpeas as a source of highly nutritious organic compounds in many areas of human life. Scientists note that the provision of plants with mineral nutrition elements is a significant factor in shaping the productivity of this crop. However, at present there is no consensus among researchers on the need to use mineral nitrogen in chickpea growing technology, and the level of mineral fertilizer is different for different growing regions. Thus, the scientific justification of the dose of mineral fertilizer for the Forest-Steppe zone of Ukraine is currently quite relevant. In this context, we conducted a study, the main goal of which was to determine the effect of different doses of mineral fertilizers in combination with the use of a biological preparation based on nitrogen-fixing microorganisms and boron microfertilizer on the formation of chickpea seed productivity and yield.

The purpose of the research is to determine the effect of different doses of mineral fertilizers in combination with the use of seed inoculation with a biological preparation based on nitrogen-fixing bacteria and foliar top dressing of crops with boron-containing fertilizer, on the formation of chickpea productivity.



**Materials and methods.** The study was conducted on the basis of the State Enterprise "Research Farm "Stepne" of the Institute of Pig Breeding and Agricultural Research of the NAAS".

The soil of the experimental site is a typical low-humus deep-boiling chernozem. By mechanical composition, the soil of the experimental site is a heavy loam with a content of coarse dust - 37–43%, silty particles - 25–38%. Colloidal particles are distributed in the profile to a small extent.

The value of the specific gravity of the arable soil layer (0–30 cm) is 2.63 g/cm<sup>3</sup>, total porosity – 55.1–59.8%, moisture content of stable wilting – 8.9–9.4%, field moisture capacity – 29.7–30.5%. According to agrochemical indicators, the soil can be considered suitable for the purposes of production of agricultural crops available on the farm. Thus, the humus content in the 0–20 cm horizon is 4.9–5.2%, in the 35–45 cm horizon – 3.72–4.07%, in the 1.5 m horizon – 0.6–0.7%. In the arable soil layer, the cation absorption capacity is at the level of 33.0–35.0 mg-eq. per 100 g.

The reaction of the soil solution is slightly acidic, with a pH of saline extract at 6.3. The hydrolytic acidity of the soil is 1.6–1.9 mg-eq. per 100 g of soil. The content of basic elements in the arable layer of soil is at the level of: easily hydrolyzed nitrogen – 5.44–8.10 mg, (according to Tyurin and Kononova), mobile phosphorus – 10–15 mg (according to Chirikov), exchangeable potassium – 16–20 mg per 100 g of soil (according to Maslova).

The initial development of chickpea plants in 2023 took place with moderate air warming and a sufficient level of moisture reserves in the soil. The average air temperature in April was 9.8 °C, while the average long-term value of this indicator was at 9.3 °C. In total, 30.9 mm of precipitation fell during the month. May was characterized by moderate air temperatures and a rather uneven distribution of precipitation. The bulk of precipitation fell in the second decade of the month, while the first and third decades were dry.

Active development of the above-ground part of chickpeas occurred in June, which was characterized by a higher average daily air temperature by 0.9 °C compared to the long-term value. The amount of precipitation for the month was 33.8 mm, which is 27.9 mm less than the long-term value. Chickpeas ripened under hot, dry conditions in July and insufficient moisture supply to plants, which negatively affected the formation of crop productivity (Table 1).

*Table 1*

**Air temperature and precipitation values for the growing season of 2023**

Indicators	Months					
	April	May	June	July	August	
Actual average daily air temperature, °C per month	9,8	15,0	20,3	24,3	20,0	
Average daily temperature, norm per month	9,3	15,7	19,4	21,2	20,1	
Absolute maximum t air, °C	actual	25,8	30,6	33,8	35,3	33,8
	norm	22,4	28,0	31,0	33,2	32,7
Precipitation, mm actual per month	30,9	27,3	34,6	25,2	22,9	
Precipitation, mm multi-year norm per month	31,2	45,5	65,2	61,1	42,7	



Weather conditions in 2024 were extremely unfavorable for the growth and development of plants and the formation of chickpea yields. In general, the growing season was characterized by a significant deficit of precipitation during the growing season of agricultural crops and chickpeas in particular. In turn, the air temperature during the growing season exceeded the average multi-year values to varying degrees. The combination of the complete absence of precipitation in the third decade of June and in July and high air temperatures led to a disruption of all physiological processes associated with the formation of the yield. (Table 2).

Table 2

**Air temperature and precipitation values for the growing season of 2024**

Indicators	Months				
	April	May	June	July	August
Actual average daily air temperature, °C per month	9,1	16,3	23,2	25,2	22,7
Average daily temperature, norm per month	9,3	15,7	19,4	21,2	20,1
Absolute maximum t air, °C					
actual	26,3	28,6	34,8	39,7	37,2
norm	22,4	28,0	31,0	33,2	32,7
Absolute minimum t air, °C					
actual	-4,2	3,4	8,1	13,0	12,0
norm	-3,7	2,1	6,8	9,9	8,5
Precipitation, mm actual per month	41,5	38,4	32,8	0,1	0,0
Precipitation, mm multi-year norm per month	31,2	45,5	65,2	61,1	42,7

The factors studied in the experiment were:

- seed inoculation with a biological preparation based on nodular nitrogen-fixing bacteria *Mesorhizobium ciceri* strain MC 285 (Anderiz 3.9 l/t) (factor A);
- mineral fertilizer control (without fertilizers), N<sub>15</sub>P<sub>30</sub>K<sub>30</sub>, N<sub>15</sub>P<sub>60</sub>K<sub>60</sub>, foliar application with SmartGrow boron-150, N<sub>15</sub>P<sub>30</sub>K<sub>30</sub>+SmartGrow boron-150, N<sub>15</sub>P<sub>60</sub>K<sub>60</sub>+SmartGrow boron-150. Fertilization with SmartGrow boron-150 microfertilizer at a dose of 1.5 l/ha was carried out in the budding phase (factor B).

The chickpea variety Budzhak was grown in the experiment. The placement of variants and repetitions was randomized. The repetition of the placement of variants was fourfold. The sowing and accounting area of the plot was 40 m<sup>2</sup>. The chickpea growing technology in the experiment was generally accepted for the Forest-Steppe zone, with the exception of the studied elements.

During the research, the leaf surface area and dry weight of plants were determined according to the methods proposed by Z. M. Hrytsaienko and co-authors (2003), the net productivity of photosynthesis and photosynthetic potential were calculated according to the formulas proposed by A. A. Nychporovych (1963). Before harvesting, sheaf samples were taken to determine the elements of individual plant productivity (number of beans, number of seeds in one bean, mass of seeds from one plant, mass of 1000 seeds) (Yeshchenko V. O. et al., 2005).

**Research results.** Plant productivity is determined as the result of the work of a holistic system. Thus, photosynthesis provides metabolic processes with carbon and



energy, on which the entire system relies, but this interaction is not linear, it is determined by the interrelation of several factors, such as development, structure of plant cover, size of leaf blades, ratio of source and sink, as well as intensity and productivity of photosynthesis. Leaf blades are the main organs of photosynthetic activity of plants, therefore their size is a key parameter of influence on various biological processes, for example, on plant growth and their reproduction. The development of the leaf surface is significantly influenced by environmental factors, among which the provision of plants with mineral nutrition elements plays a significant role.

The obtained research results indicate a positive effect of mineral fertilizer, the use of a microbiological preparation, microfertilizers, and their combination on the process of leaf surface formation of chickpea plants (Fig. 1).

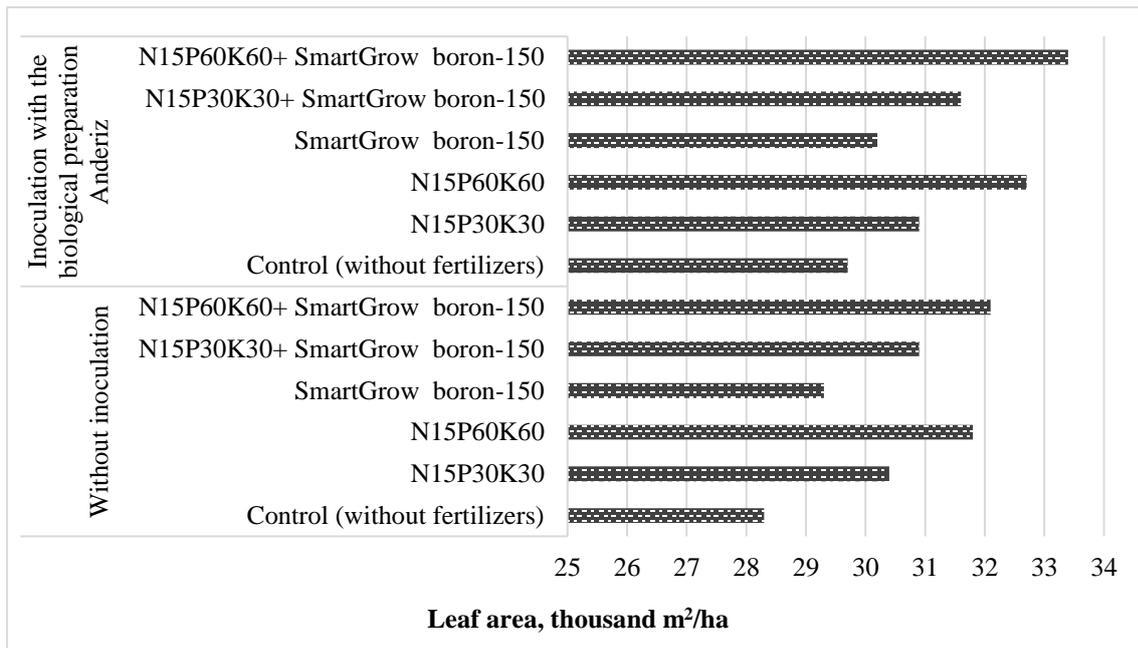


Fig. 1. Leaf surface area of chickpea crops in the bean formation phase depending on seed bacterization and fertilization, thousand m<sup>2</sup>/ha (2023-2024)

In variants with application N<sub>15</sub>P<sub>30</sub>K<sub>30</sub>, the leaf surface area of chickpea crops exceeded the control option in the bean formation phase by 2.1 thousand m<sup>2</sup>/ha. The application of N<sub>15</sub>P<sub>50</sub>K<sub>40</sub> provided better development of the leaf surface than N<sub>15</sub>P<sub>25</sub>K<sub>20</sub>.

Foliar fertilization of crops with boron contributed to an increase in the leaf surface of chickpea crops compared to the control by 1.0–3.8 thousand m<sup>2</sup>/ha depending on the fertilization background. It should be noted that the values of this indicator increased as the plants' supply of mineral nutrition elements improved. Pre-sowing seed inoculation turned out to be less effective. This is indicated by the smaller values of the leaf surface area compared to the application of boron in the budding phase.

The combination of seed inoculation and foliar application of plants with boron-containing fertilizer contributed to an increase in the leaf surface area of chickpea crops in the bean formation phase, depending on the NPK dose, by 1.9–5.1 thousand m<sup>2</sup>/ha relative to the control. The highest values of this indicator were noted in the variant of combining seed inoculation and foliar fertilization of crops with boron against the background of N<sub>15</sub>P<sub>60</sub>K<sub>60</sub> application.

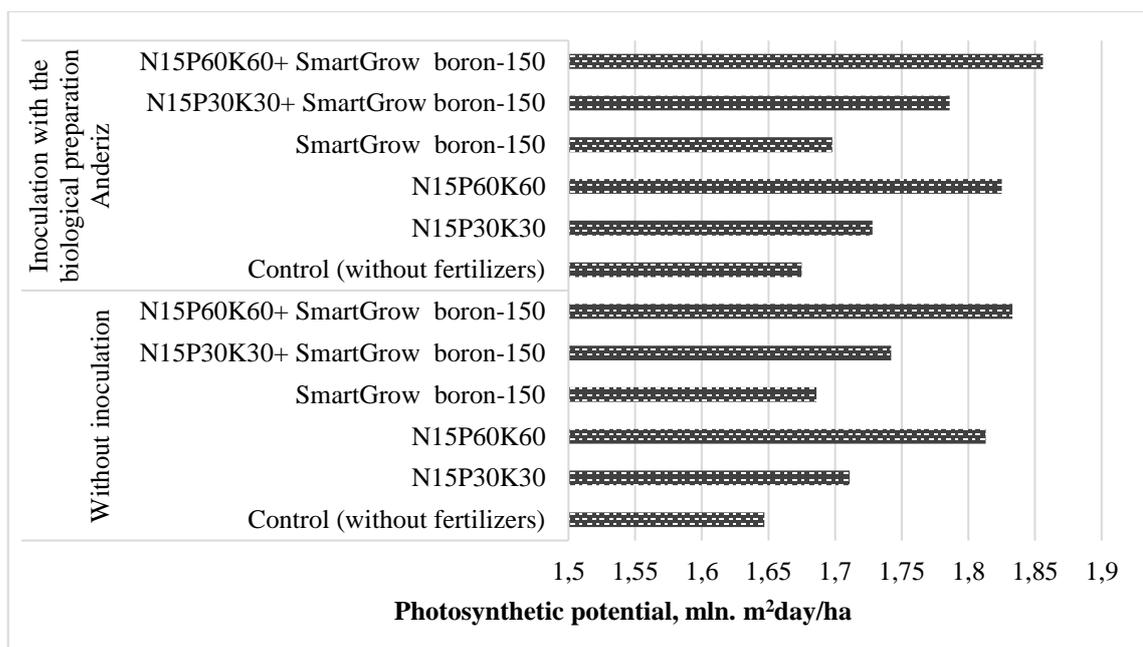
In the process of photosynthesis, leaf blades absorb the energy of sunlight during the vegetation period and convert it into biomass. Thus, the amount of organic matter



synthesized by the plant is determined not only by the size of the leaf surface, but also by the duration of the period of its active functioning. The duration of the leaf surface in the active state determines the indicator of the photosynthetic potential of the crop.

The results of the studies indicate a positive effect of mineral fertilizer, seed inoculation, foliar fertilization of crops with boron and their combination on the duration of active photosynthetic work of the leaf surface of chickpea crops. The factors studied in the experiment had different effects on the duration of leaf blade functioning. In the variants of NPK application, the value of the photosynthetic potential of chickpea crops increased compared to the control by 0.064-0.166 million  $m^2 \times day/ha$ , and an increase in the level of mineral fertilizer extended the duration of photosynthetic work of the leaf surface of chickpea crops (Fig. 2).

Seed inoculation contributed to an increase in the value of the photosynthetic potential of chickpea crops by 0.028 million  $m^2 \times day/ha$  relative to the control. In the variants of combining seed inoculation and mineral fertilizer application, the excess of this indicator over the control was 4.91–10.8%, increasing as the supply of plants with mineral nutrition elements improved. The combination of seed inoculation and foliar fertilization of plants with boron contributed to an increase in the value of the photosynthetic potential of chickpea crops to 1.698 million  $m^2 \times day/ha$ , and it was highest in the variant where mineral fertilizers were applied at a dose of  $N_{15}P_{60}K_{60}$ , sowing was carried out with seeds pre-treated with the microbiological preparation Anderiz and fertilizing the crops with the microfertilizer SmartGrow boron-150.



**Fig. 2. Photosynthetic potential of chickpea crops in the flowering-bean formation phase depending on seed bacterization and fertilization, million  $m^2 \times day/ha$  (2023-2024)**

Photosynthesis is the basis for biomass formation by plants. Thus, in the process of photosynthetic activity, plants synthesize about 95% of organic compounds, which ensures the passage of all vital processes.

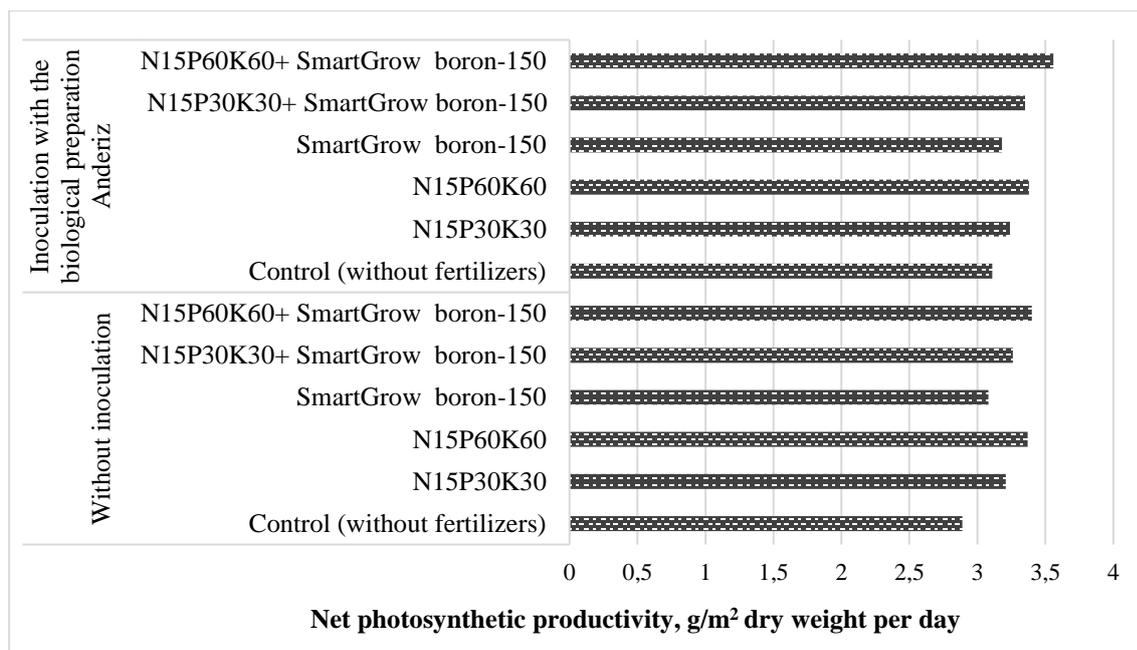
In specialized structures, chloroplasts, plants use the energy of sunlight to convert carbon dioxide and water into glucose and oxygen. This process not only stimulates plant growth, but also leads to the accumulation of organic matter in the form of biomass. The



energy obtained in the process of photosynthesis accumulates in plant cells and can be used for various purposes, which makes plants an invaluable resource for both natural ecosystems and human activities.

The dynamics of the accumulation of organic biomass by plants is evidenced by the net productivity of photosynthesis. Its value expresses the amount of dry matter created in the process of photosynthesis per unit of leaf surface over a certain period of time.

In the experiment, the value of this indicator, depending on the influence of the factors studied, varied from 2.89 to 3.56 g/m<sup>2</sup> per day (Fig. 3). It should be noted that the influence of mineral fertilizers as a whole in the experiment on the net productivity of photosynthesis was the most pronounced. Thus, in the variants of NPK application, the excess of the values of net productivity of photosynthesis relative to the control was 11.1% for N<sub>15</sub>P<sub>30</sub>K<sub>30</sub> and 16.6% for N<sub>15</sub>P<sub>60</sub>K<sub>60</sub>. Inoculation of seeds with the biological preparation Anderiz and fertilizing plants in the budding phase with the microfertilizer SmartGrow boron-150 ensured an increase in the value of this indicator by 6.50 and 7.60%, respectively, and in the variant of their combination, the net productivity of photosynthesis of chickpea crops increased compared to the control by 10.0%. The most effective in this regard was the complex application of a microbiological preparation, and N<sub>15</sub>P<sub>60</sub>K<sub>60</sub>. In this variant, the excess of the net productivity of photosynthesis over the control was 23.2%.



**Fig. 3. Net photosynthetic productivity of chickpeas in the flowering-bean formation phase depending on the use of the biological preparation and levels of mineral nutrition, g/m<sup>2</sup> per day (2023-2024)**

The intensity of accumulation of organic compounds determined the amount of dry aboveground biomass of plants. The results of the study showed a regular increase in it as the supply of plants with mineral nutrition elements improved (Table 3). Thus, the application of mineral fertilizers ensured an increase in the mass of plants in an absolutely dry state in the grain ripening phase by 0.81–1.66 g compared to the control. At the same time, it should be noted that the application of N<sub>15</sub>P<sub>60</sub>K<sub>60</sub> turned out to be more effective compared to N<sub>15</sub>P<sub>30</sub>K<sub>30</sub>.



Seed inoculation contributed to an increase in the absolutely dry biomass of plants by 0.18 g compared to the control. Foliar application of plants with micronutrient SmartGrow boron-150 turned out to be more effective in this regard. The combination of seed inoculation and foliar feeding contributed to an increase in the absolute dry weight of plants relative to the control by 5.6%. The value of this indicator was maximum in the variant Anderiz + N<sub>15</sub>P<sub>60</sub>K<sub>60</sub> + SmartGrow boron-150.

Table 3

**Formation of dry biomass of chickpea plants depending on seed inoculation and fertilizer levels, (2023-2024)**

Seed inoculation	Fertilizer	Plant weight in a completely dry state, g
Without inoculation	Control (without fertilizers)	5,32
	N <sub>15</sub> P <sub>30</sub> K <sub>30</sub>	6,13
	N <sub>15</sub> P <sub>60</sub> K <sub>60</sub>	6,98
	SmartGrow boron-150	5,44
	N <sub>15</sub> P <sub>30</sub> K <sub>30</sub> + SmartGrow boron-150	6,34
	N <sub>15</sub> P <sub>60</sub> K <sub>60</sub> + SmartGrow boron-150	7,42
Inoculation with the biological preparation Anderiz	Control (without fertilizers)	5,50
	N <sub>15</sub> P <sub>30</sub> K <sub>30</sub>	6,25
	N <sub>15</sub> P <sub>60</sub> K <sub>60</sub>	7,34
	SmartGrow boron-150	5,62
	N <sub>15</sub> P <sub>30</sub> K <sub>30</sub> + SmartGrow boron-150	6,72
	N <sub>15</sub> P <sub>60</sub> K <sub>60</sub> + SmartGrow boron-150	8,13

The results obtained indicate a positive influence of the studied factors and their complex interaction on the mass of 1000 chickpea seeds. The studies have established an increase in the value of this indicator by 10.9–18.8% in the variants of NPK application relative to the control. At the same time, the highest values of the mass of 1000 chickpea seeds were also noted when applying maximum doses of mineral fertilizers.

In the variants of seed inoculation and foliar application of plants with boron-containing fertilizer, the mass of 1000 seeds increased by 1.1 and 2.6%, respectively, compared to the control. The most effective was the complex use of the studied factors, in particular the application of N<sub>15</sub>P<sub>60</sub>K<sub>60</sub> and the combination of seed inoculation and foliar application of plants, which ensured an increase in this indicator relative to the control by 8.4%.

Intensive growth of the above-ground part and root system of plants, sufficient development of the photosynthetic surface of plants and increased photosynthetic activity, contributed, in turn, to an increase in the amount of synthesized metabolites and the accumulation of dry matter by plants, as well as an increase in the average number of beans and seeds formed on plants, the mass of 1000 seeds. The values of these elements of plant productivity determined the increase in the seed yield (Table 4).

The highest values of this indicator were recorded in the variant of combining seed inoculation, foliar application of plants with microfertilizer SmartGrow boron-150 N<sub>15</sub>P<sub>60</sub>K<sub>60</sub> mineral fertilization. The average seed yield over the years of the study in this variant of the experiment was the highest and amounted to 2.56 t/ha. The increase in chickpea seed yield from the application of different doses of mineral fertilizers was at the level of 0.14–0.36 t/ha, relative to the variant without fertilizers.



Table 4

**Chickpea seed yield depending on the use of biological product and mineral nutrition elements, t/ha**

Seed inoculation	Fertilizer	Seed yield, t/ha		Average by years, t/ha
		2023	2024	
Without inoculation	control (without fertilizers)	2,24	1,68	1,96
	N <sub>15</sub> P <sub>30</sub> K <sub>30</sub>	2,46	1,74	2,10
	N <sub>15</sub> P <sub>60</sub> K <sub>60</sub>	2,78	1,86	2,32
	SmartGrow boron-150	2,31	1,77	2,04
	N <sub>15</sub> P <sub>30</sub> K <sub>30</sub> + SmartGrow boron-150	2,57	1,89	2,23
	N <sub>15</sub> P <sub>60</sub> K <sub>60</sub> + SmartGrow boron-150	2,91	1,95	2,43
Inoculation with the biological preparation Anderiz	control (without fertilizers)	2,28	1,71	2,00
	N <sub>15</sub> P <sub>30</sub> K <sub>30</sub>	2,50	1,83	2,17
	N <sub>15</sub> P <sub>60</sub> K <sub>60</sub>	2,83	1,98	2,41
	SmartGrow boron-150	2,35	1,83	2,09
	N <sub>15</sub> P <sub>30</sub> K <sub>30</sub> + SmartGrow boron-150	2,63	1,96	2,30
	N <sub>15</sub> P <sub>60</sub> K <sub>60</sub> + SmartGrow boron-150	3,08	2,04	2,56
HIP <sub>0,95</sub>		factor A – 0.09; factor B – 0.12; interaction of factors AB – 0.15.		

Seed inoculation and foliar fertilization of crops contributed to an increase in seed yield compared to the control by 0.03 and 0.09 t/ha, respectively, and in the variant of their combination, the increase in yield was 0.15 t/ha.

**Discussion.** The magnitude of plant productivity is expressed by the totality of the effects of various environmental factors on a number of physiological and morphological processes occurring in plants during the growing season. Photosynthesis is a fundamental process during which the energy of solar radiation is used by plants to convert CO<sub>2</sub> into carbohydrates, which constitute about 90% of their biomass (Simkin et al., 2019; Muhie, 2022).

In turn, the productivity of photosynthetic activity of plants is largely determined by the size of the leaf surface, as the main assimilation organ of plants. Its size can serve as an indicator of the strategy of resource use by plants and have important consequences for the energy and water balance. The main factor in the formation of a developed leaf surface is the provision of plants with mineral nutrition elements. The results of our research indicate a positive effect of mineral fertilizer on the development of the leaf surface of plants. Its largest value was observed in the variant of the combination of factors studied. Along with this, the obtained data are consistent with the studies conducted by H. Ali, M.A. Khan and S.A. Randhawa (2004), where improving plant phosphorus nutrition by increasing the dose of P<sub>2</sub>O<sub>5</sub> from 90 to 120 kg/ha increased the value of the leaf area index to 3.78. At the same time, scientists note that nitrogen deficiency leads to a decrease in the leaf area index, the productivity of photosynthetic activity and, accordingly, plant biomass (Chemining wa G. N., Vessey J. K., 2006).

In other studies, an increase in the level of nitrogen absorption by plants with improved phosphorus nutrition is noted. R.S. Jat, I.P.S. Ahalawat (2004) reported that the application of P<sub>26,4</sub> significantly increased the total absorption of nitrogen and phosphorus



by plants. In the studies of R. Meena et al. (2004), the introduction of P<sub>60</sub> increased the amount of N, P, K absorbed by plants.

Other researchers agree with these statements, who found an increase in the intensity of chickpea growth processes due to the use of macronutrients, i.e. N, P and K (Goud V.V. et al., 2014; Shah T. et al., 2016), micronutrients (El-Habbasha S.F. et al., 2012), biofertilizers (Dutta D., Bandyopadhyay P., 2009). They note that the positive effect of microorganisms on plant growth and development may be associated not only with the improvement of their nitrogen nutrition due to legume-rhizobial interaction, but also due to the synthesis of phytohormones such as auxin, secondary metabolites in inoculated plants. They promote seed germination, root system development and at the same time increase the amount of moisture and nutrients absorbed by it, which in turn stimulates the growth of the leaf surface (Werner D., Newton W. E., 2005)

Scientific studies indicate an increase in the growth rate of the absolutely dry matter of plants, due to better development of the leaf surface, which in turn increases the accumulation of solar radiation by plants and the production of organic compounds by increasing the intensity and productivity of photosynthesis (McKenzie, B. A., Hill, G. D., 1995). This position was confirmed by the results of our studies, where an increase in the area of the leaf surface and an extension of the duration of its active functioning due to the complex use of seed inoculation, foliar application of plants with boron against the background of the application of various doses of mineral fertilizers contributed to the enhancement of the production of organic matter by plants, an increase in the mass of plants in a completely dry state and an increase in the level of seed yield up to 2.56 t/ha. Our results are consistent with the conclusions made by Reinprecht Y. With co-authors (2020) in the course of their studies. They note that the main source of nutrients entering the seed during its formation, filling and ripening is the process of photosynthesis and root nutrition, as well as the reuse of organic compounds from vegetative organs. Improving the conditions for the formation of plant productivity against the background of the application of mineral fertilizers may be associated not only with the positive effect of each nutrient on vital processes, but also with their synergistic effect. This is evidenced by the results of our studies, which are also consistent with the data obtained by other scientists (Meena R. et al., 2020., Kumar D. et al., 2014).

Scientists also note that a positive aspect of increasing plant productivity can be not only an increase in the number of doses of applied fertilizers, but also the ratio of mineral nutrition elements in them (Rashid A. et al., 2013). At the same time, the increase in leaf surface area, plant mass in a completely dry state and, accordingly, seed yield in the variant of foliar fertilizing of plants with boron and its combination with the application of mineral fertilizers, noted in our study, can be explained by the favorable effect of these nutrients on metabolism and biological activity, as well as their stimulating effect on the development of the leaf surface and an increase in the concentration of photosynthetic pigments, the activity of enzymes, which, in turn, have a stimulating effect on the vegetative growth of plants.

#### **Conclusions:**

1. The use of a microbiological preparation based on nitrogen-fixing bacteria for pre-sowing treatment of chickpea seeds, mineral fertilizers, foliar application with microfertilizer SmartGrow Bor-150 and their combination showed a positive effect on the formation of the leaf surface by chickpea plants. In this regard, the most effective was the combination of seed inoculation, foliar application of plants with boron and N<sub>15</sub>P<sub>60</sub>K<sub>60</sub> fertilization.

2. The size of the leaf surface, productivity and duration of its photosynthetic work, which increased as the supply of plants with mineral nutrition elements improved,



in turn determined the intensity of the accumulation of aboveground dry biomass by plants and the supply of organic compounds to seeds during their formation and filling. Accordingly, the dry weight of plants and the weight of 1000 seeds were the highest in the combination of seed inoculation foliar application of plants with boron and N<sub>15</sub>P<sub>60</sub>K<sub>60</sub> fertilization.

3. It was established that the introduction of NPK provided an increase in the yield of chickpea seeds relative to the control at the level of 0.14-0.36 t/ha. In the variants of using the microbiological preparation Anderiz based on nitrogen-fixing bacteria and the microfertilizer SmartGrow Bor-150, the seed productivity of chickpea crops increased compared to the control by 0.03 and 0.09 t/ha, respectively, and in the variant of their complex application, the yield increased by 0.15 t/ha. The most appropriate is the combination of seed inoculation, foliar application of plants with SmartGrow Bor-150 and N<sub>15</sub>P<sub>60</sub>K<sub>60</sub> fertilization, which makes it possible to increase the yield of chickpea seeds to 2.56 t/ha.

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