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**SCIENTIFIC PRINCIPLES
OF OPTIMIZING THE MINERAL
NUTRITION SYSTEM FOR CHICKPEA
(*CICER ARIETINUM* L.) CULTIVATION
IN THE SOUTHERN STEPPE
OF UKRAINE**

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This monograph provides a scientific rationale and establishes the specific features of grain yield formation in chickpea grown under rainfed conditions, depending on the applied nutrition system. A mineral nutrition system for chickpea has been developed for the conditions of the Southern Steppe of Ukraine, suitable for cultivation technologies incorporating elements of biologization or minimal mineral fertilizer input.

The practical value of the obtained results lies in the development and implementation of a nutrition system that ensures chickpea yields of 2.55 t/ha, a high protein content, and a profitability level of 120–130%. The incorporation of biologization elements into chickpea cultivation contributes to a 58.4% reduction in mineral fertilizer costs.

The publication is intended for students, postgraduate students, lecturers, researchers of agricultural institutions, and specialists of the agro-industrial sector.

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LIST OF ABBREVIATIONS

- HA** – humic acids
- HP** – humate-containing preparations
- HTC** – hydrothermal coefficient
- LCF** – liquid complex fertilizers
- LOMF** – liquid organo-mineral fertilizers
- PGR** – plant growth regulators
- FA** – fulvic acids
- PP** – photosynthetic potential

CHAPTER 1

AGROTECHNOLOGICAL JUSTIFICATION OF CHICKPEA NUTRITION SYSTEM

In global agriculture, chickpea (*Cicer arietinum*) occupies approximately 17 million hectares with an average yield of 1.38 t/ha. Among leguminous crops, it ranks third in terms of production volume, following pea and bean (15.42% of total production), and second in terms of cultivated area (15.3%) [236; 252]. Chickpea is cultivated in 57 countries across diverse ecological zones. South and Southeast Asia dominate global production, contributing 80% of the regional output [263]. For developing countries, particularly in South Asia and on the Indian subcontinent, chickpea is one of the most important pulses as a source of highly digestible dietary protein. India is the global leader in chickpea production, accounting for 28–62% of the total share, with sown areas exceeding 7 million hectares. Other major producers include Turkey, Pakistan, and Mexico [247; 252].

In Ukraine, the chickpea cultivation area has significantly expanded over the past 2–3 years: from 7.1 thousand hectares in 2016 to almost 15 thousand hectares in 2020. The overall production of niche crops is nearly 500 thousand tonnes, while chickpea output increased 7.5-fold during this period, with 80–85% concentrated in the steppe regions of Ukraine. Although chickpea's share in the total balance of legumes remains relatively small (6–12%), it demonstrates a steady upward trend [2; 44; 202].

The growing interest in this crop is driven by its unique nutritional qualities and by current and projected climate changes. Abrupt weather fluctuations are already observed. In the Southern Steppe of Ukraine, particularly in Odesa, Mykolaiv, and Kherson regions, winters are characterized by severe frosts interrupted by sudden prolonged thaws, while summers experience an increasing number of abnormally hot days. Droughts have become more intense and frequent. Although total annual precipitation has increased, its distribution has changed: rainfall events have become less frequent but more intense, with up to 80% of precipitation falling as downpours in certain months, while the remainder was ineffective. The distribution of rainfall across

the growing seasons of major crops has deteriorated. Compared to 1961–1990, the Hydrothermal Coefficient (HTC) significantly worsened in 2017. According to scientific forecasts, these phenomena will intensify, and by 2050, a significant part of the above-mentioned regions will face desertification. Consequently, agricultural producers will be forced to revise their crop composition, technologies, and breeding strategies.

In this context, chickpea is considered a promising crop due to its tolerance to air and soil drought. It is regarded as one of the most stress-resilient legumes, which is attributed to its well-developed root system, efficient water use per unit area, high bound-water content in leaf tissues, xeromorphic leaf structure, pubescence, and the presence of organic acids [158]. Its drought and heat tolerance are particularly relevant for stabilizing domestic agriculture under current climatic variability.

Furthermore, chickpea possesses valuable nutritional properties. Its seeds contain 20–30% protein, 4–7% fat, 50–60% carbohydrates, 2–5% mineral substances, as well as vitamins A, B1, B2, B3, C, B6, PP, and essential amino acids. The vitamin C content in chickpea seeds varies from 2.2 to 20 mg/100 g. Chickpea protein is easily digestible and, in terms of amino acid profile, is comparable to that of animal origin [45; 185; 255].

Chickpea flour is used in combination with cereals as a source of protein and phenolic compounds [265]. It may also serve as a supplier of antioxidant ingredients in food production [220]. According to some researchers, chickpea contains biologically valuable compounds with antioxidant effects that are preserved under various processing technologies [276]. Of particular importance are reports of growing industrial interest in chickpea flour and proteins due to their emulsifying, foaming, bioactive properties, and their ability to retain oil and water [226].

At present, chickpea also demonstrates high financial attractiveness. In 2018, the average procurement prices for commercial chickpea products ranged from 19,000 to 30,000 UAH per tonne, while seed prices started from 40,000 UAH per tonne. In Odesa region, food-grade grain prices varied from 10,000 to 25,500 UAH per tonne, whereas seed material prices ranged from 35,000 to 140,000 UAH

per tonne. The cost of seed was determined by the variety and seed caliber, which is also taken into account when determining the value of commercial grain [98; 210]. Thus, even at a minimum yield of 1.0 t/ha, producers could obtain a net profit of about 600 UAH/ha, while in the Northern Steppe net profits ranged from 4,852 to 6,576 UAH/ha, with profitability levels reaching 248.8% [38; 174].

Ukrainian chickpea is exported both to European countries—Poland, Germany, the United Kingdom, Sweden—and to Asian markets such as Turkey, Pakistan, Iraq, Saudi Arabia, Jordan, Lebanon, Sri Lanka, Singapore, Israel, as well as to CIS countries, primarily Moldova. In 2016, chickpea exports from Ukraine exceeded imports by a factor of 23.3, and in 2017 already by 40 times, with average prices ranging from 510 to 786 USD per tonne depending on the variety. By 2020, Ukraine exported 43 thousand tonnes of chickpea, the highest figure among all leguminous crops [5].

In southern Ukraine, chickpea cultivation technology remains insufficiently studied, with most producers applying general approaches to nutrition systems, crop protection, soil tillage, and crop management [25]. A scientifically substantiated plant protection technology has been developed, yet weed control remains a critical issue [20; 22; 114]. Varieties most adapted to the climatic conditions of the Black Sea Steppe have been identified [21; 24; 104]. Regarding fertilization systems, no unified view exists either on the expediency of fertilizer use in chickpea cultivation or on the optimal rates and timing of application. This highlights the need to develop an effective chickpea cultivation technology for rainfed conditions in the Southern Steppe of Ukraine, taking into account projected global climate changes as well as the results of personal and leading agronomists' research [122; 152; 200].

1.1. Application of Mineral Fertilizers in Chickpea Nutrition Systems

As a leguminous crop, chickpea satisfies a significant portion of its nitrogen requirement through symbiotic fixation. The amount of nitrogen accumulated can reach 80–150 kg/ha [56; 246; 251]. Atmospheric nitrogen is converted into a plant-available form by

Rhizobium bacteria, which are either naturally present in the soil or introduced through inoculation.

Chickpea is a promising crop for improving nitrogen balance in rotations with cereals. The amount of biologically fixed nitrogen ranged from 29 to 85 kg/ha, while nitrate nitrogen in the soil was effectively utilized by chickpea, resulting in savings of 6 to 31 kg/ha of active substance compared to wheat plots. The difference in soil nitrate content between wheat and chickpea plots ranged from 29 to 51 kg/ha in the second year of the study [244].

For normal growth and development, chickpea requires other macro- and micronutrients present in the soil or supplied through fertilizers. Plant response to applied nutrients depends on soil fertility, agro-climatic conditions, type of fertilizer or preparation, and various agrotechnical measures.

Regarding the effect of mineral fertilizers, particularly nitrogen, on the productivity of leguminous crops, researchers in many countries have adopted four main approaches: growing the crop without fertilizers, applying only starter fertilizer, supplying half of the required fertilizer with the remainder provided through nitrogen fixation, and fully satisfying the crop's mineral nutrition requirements with fertilizers. No consensus has been reached on the optimal nutrition system for legumes, resulting in a wide range of recommended fertilizer application rates.

Notably, under favorable growing conditions, chickpea's nitrogen demand can be fully met by nodulating bacteria, while starter nitrogen applications may delay or suppress their development and nitrogenase activity [13; 49–52; 67; 119].

At the same time, studies on soils with low phosphorus and sufficient potassium content, using nitrogen application rates from 0 to 120 kg/ha, have shown that these rates enhance individual plant productivity. Nitrogen, phosphorus, potassium, and iron content in the grain did not significantly affect Mg, Zn, Mn, or Cu concentrations, but plant response depended on both the nitrogen rate and the presence or absence of inoculation. In the absence of inoculation, the maximum increase in nitrogen content in chickpea grain was observed at N₃₀, which represented an 8% increase relative to the control. Increasing nitrogen application rates further reduced nitrogen content, even

compared to the unfertilized variant, by 1.0–8.8%. Inoculated plants showed a maximum increase in grain nitrogen content of 36.9% relative to the zero-application control at N₆₀. Application rates of N₃₀, N₉₀, and N₁₂₀ also provided increases of 25.5%, 31.9%, and 6.8%, respectively. The decrease in nitrogen synthesis at N₁₂₀ compared to N₆₀ was 22.0% [235]. Similar results were obtained with nitrogen rates from 25 to 75 kg/ha [221; 251].

Nitrogen application under controlled greenhouse conditions enhanced plant height, root and shoot biomass [234], whereas in field conditions, it increased total plant biomass [228].

Research by international scientists has shown that chickpea requires relatively low starter nitrogen application rates of 15–20 kg/ha [296]; mineral nitrogen positively affects pod formation and pod mass, in contrast to phosphorus fertilizers, which have little impact on these parameters [256].

Studies on chickpea response to starter nitrogen at rates of 0, 15, 30, and 45 kg/ha indicated that application at 45 kg/ha increased seed yield by 0.221 t/ha compared to the control [300].

Application of mineral nitrogen (urea) at rates of 50–75 kg/ha on a background of P₅₀ improved the growth, development, and yield of inoculated chickpea. Nitrogen was applied in three splits: pre-sowing, at the 6–8 leaf stage, and at flowering [266].

In trials involving five chickpea cultivars, pre-sowing application of N₄₀P₈₀ in the form of diammonium phosphate, phosphorus fertilizers (triple superphosphate), and top-dressing with urea before and during full flowering proved effective [247]. The intensity of the effect depended on annual weather conditions, but in both years, treatment prior to flowering produced a greater response. Maximum nodule formation on roots was observed in treatments where nitrogen top-dressing was applied before flowering, resulting in small nodules merging into larger conglomerates. A positive effect of all fertilizers and their interactions on plant condition and nitrogen fixation was observed, highlighting the importance of a small amount of available nitrogen in the soil during early development. Phosphorus fertilizers had a significant effect on nodule formation, whereas inoculation had a comparatively smaller impact.

The application of mineral nitrogen has a mixed influence on nitrogen fixation mechanisms [51; 197]. There is evidence of a negative

effect of mineral nitrogen on nodule formation in chickpea. For example, experiments on meadow chernozem and southern chernozem soils demonstrated that N_{30} and N_{60} nitrogen applications reduced the number of nitrogen-fixing nodules by 10–50%, their biomass by 2–6 times, nitrogenase activity by 2–18 times, and symbiotic nitrogen content in the seed yield by 9–67%.

Experimental data suggest that the most economically advantageous fertilizer rates, considering soil fertility, are $P_{30-60}K_{45-60}$. To increase the efficiency of phosphorus uptake from soil and fertilizers, it is recommended to use bio-preparations based on phosphorus-mobilizing microorganisms [15; 23; 186]. The effectiveness of such bio-preparations has been confirmed [253; 270].

It is generally accepted that effective nitrogen fixation requires a sufficient amount of available phosphorus in the soil [19]. It should be noted that global losses in legume crop yield due to insufficient phosphorus and nitrogen reach 653,000 t per year [222].

Under these conditions, application of P_{10-15} at sowing is advisable [36]. Similar results were obtained in the northern part of Montana, USA, where high chickpea grain yields were achieved with P_{30} application under favorable hydrothermal conditions [230]. Studies on phosphorus rates of 45 and 90 kg/ha concluded that they increase plant biomass, enhance pod formation, positively affect seed size, but only under adequate moisture availability [260].

In the dry steppe regions, to improve yield, symbiotic productivity, and soil fertility, it is recommended to inoculate seeds with bacterial preparations and molybdenum before sowing and apply fertilizers at $P_{30}K_{30}$ [204; 216].

The most appropriate rates of mineral fertilizers for chickpea crops have been determined as $P_{40-60}K_{40-60}$ [26; 129; 194], while application at $P_{60}K_{60}$ during primary soil preparation increased grain yield by 0.22 t/ha [215]. A slightly higher fertilizer rate, $P_{60}K_{90}$, has also been recommended [102].

It has been established that phosphorus application at P_{90} increased chickpea grain yield by 0.2 t/ha when combined with inoculation [61; 79; 179]. Application of P–K fertilizers at $P_{30-60}K_{45-60}$ in agricultural enterprises of the Odessa region produced the highest chickpea yields [137]. With $P_{30}K_{30}$, chickpea yield increased by

8.3%, while further increases of P–K fertilizer rates two to threefold contributed to yield growth of 13.2–16.5% (2.74–2.82 t/ha) [130]. Application of N₃₀ on a P₃₀K₃₀ background improved the quality parameters of chickpea grain.

To achieve high chickpea grain yields, classical calculation methods for determining plant nutrient requirements should be applied, taking into account nitrogen-fixing activity, soil type, cultivation technology, and the fact that at a yield of 2.0 t/ha, chickpea plants remove 106 kg N, 36 kg P, 150 kg K, and 23 kg Mg from the soil. Therefore, to obtain high yields, it is necessary to apply organic fertilizers at 30–50 t/ha to the preceding crop and the calculated rate of mineral fertilizers (N₄₈P₁₈K₂₀) for chickpea [36; 261; 273].

In areas with unstable moisture, the most effective fertilizer application for chickpea was P₆₀K₆₀ during primary soil preparation and N_{7.5}P₂₀ before sowing combined with seed inoculation with Nitrogen [62]. Studies conducted in the northern part of the Ukrainian Steppe on fertilizer rates showed no significant difference in yields, which were 1.86 t/ha without fertilizers, 1.89 t/ha at N₈P₃₂, and 2.02 t/ha at N₁₆P₆₄ [141].

For chickpea grown on chestnut soils with P–K fertilizers, the optimal nitrogen rate was N_{20–30} [78]. Similar results were obtained on unirrigated dark-chestnut soils of the Southern Steppe of Ukraine, where the most rational fertilizer rate was N₂₀P₆₀ [208].

Research in the Kherson region indicated the best results with N_{30–60}P_{30–60}K_{45–60} [76]; other sources reported N₃₀P₄₅K₃₀ [151], and generalized recommendations suggest N_{30–60}P₆₀K₆₀ [9]. On chernozem and dark-chestnut soils, chickpea responds well to P–K fertilizers, with optimal application rates of 40–60 kg/ha of active ingredient. Potassium fertilizers are required for chickpea grown on light soils, and on medium- and light-textured chernozems, the optimal nitrogen rate in dry years is 50–70 kg/ha [275].

In the Luhansk region, it is recommended to apply nitrogen at 20 kg/ha as a starter pre-sowing and row fertilizer together with phosphorus [116]. In southern Italy, the highest chickpea seed yields were achieved with pre-sowing application of mineral fertilizers at N₃₀P₄₀K₁₀₀; further increases in phosphorus rates did not improve yield [272].

The nutrient removal by chickpea depends on the nutrition conditions. Of the total nitrogen removed, the main portion is directed to seed formation (42–82%), while with increasing grain yield, the amount of nitrogen in the straw decreases. Nitrogen concentration in seeds ranged from 3.6 to 4.1%, whereas in straw it was 0.8–1.4%. This pattern of nitrogen removal by chickpea was directly proportional to the nitrate nitrogen content in the soil, which increased with higher rates of nitrogen fertilizer application (0, 50, 100, 150 kg/ha of active ingredient) applied to the preceding winter wheat crop [214; 258].

Economically, a single application of mineral fertilizers during plowing is effective. On poor soils, it is recommended to apply at least 400–500 kg/ha of superphosphate, 300–400 kg/ha of ammonium sulfate, and 150–200 kg/ha of potassium salt. On fertile soils, fertilizers may not be required. In regions with sufficient moisture, surface application of $N_{30}P_{60}K_{60}$ in spring is recommended, or localized application at 30–50% of the standard rate [8].

According to some studies, chickpea does not require fertilizer application, but sowing with 50 kg/ha of nitroammophoska or $N_{30}-40$ is acceptable [6]. Other researchers indicate that, to achieve maximum productivity under arid conditions, 100 kg/ha of nitroammophoska should be applied at sowing, and during branching, foliar fertilization with 80 L/ha of urea–ammonium nitrate solution (CAS-32, equivalent to 100 kg/ha) is necessary [92].

In fields in Jordan, for high chickpea grain yields under irrigation, 100 kg/ha of diammonium phosphate is recommended before sowing [267]. On southern chernozems, it is considered necessary to apply 200 kg/ha of ammonium phosphate during pre-sowing cultivation, and with urea at 60 kg/ha, chickpea grain yield increased by 33.5% [180].

In crop rotations, chickpea grain yields of 2.0 t/ha were achieved with $N_{20}P_{60}K_{40}$, and 2.5 t/ha with $N_{40}P_{80}K_{60}$ [80; 159]. The most rational fertilizer rate for achieving 2.5 t/ha grain yield under efficient water use and soil fertility preservation is $N_{60}P_{20}K_{20}$, which ensures active nodule bacterial activity and planned productivity, provided deep non-inversion tillage of at least 0.3 m is applied [216].

On dark-chestnut medium-loam soils of the Southern Steppe of Ukraine, the most appropriate approach for determining mineral

fertilizer rates for chickpea is the calculation method, based on actual and optimal soil nutrient content and removal by the planned yield. If this method is not feasible, then with low soil nitrate nitrogen content and medium levels of available phosphorus and potassium, mineral fertilizers should be applied at $N_{30}P_{30}K_{30}$ [36; 200].

In the Forest-Steppe region on ordinary chernozem, chickpea can be effectively grown with $N_{30}P_{45}K_{45}$ fertilization. Before sowing, seeds should be treated with Rizotorfin (200 g/ha) and Tensokokteil (at a rate of 100 g/t) [95]. On southern chernozems, application of $N_{30}P_{60}K_{60}$ along with seed inoculation increased yield by 0.3–0.8 t/ha [148], while in the western regions, fertilization with $N_{40}P_{40}$ was effective [181]. Higher fertilizer rates are recommended in Romania, where $N_{44}P_{44}$ is applied during pre-sowing cultivation [283].

Fertilization also determines the efficiency of other resources and agronomic practices. For instance, fertilizer application in conjunction with main soil tillage significantly affected plant water availability: chickpea water use efficiency increased from 4.7 to 6.8 kg/ha×mm with nitrogen fertilizer rates increasing from 0 to 112 kg/ha of active ingredient, but only under no-till. Seed inoculation increased water use efficiency by 30–33% under no-till and by 9% under conventional tillage. Inoculation achieved the same level of water use efficiency as 84 kg/ha of nitrogen application [240]. The efficiency of herbicide application, such as Frontier, under $N_{40}P_{60}$ fertilization was 72–76%, while on unfertilized plots it was 62–70% [128].

Fertilization systems should be regionally recommended. According to the Odesa Agricultural Institute, the highest chickpea yield of 3.37 t/ha was achieved with $N_{60}P_{60}K_{60}$. Further increase in phosphorus application to 120 kg/ha did not increase yield [78].

Under unstable moisture conditions on dark-chestnut soils, chickpea grown with Nitramin inoculation and $N_{60}P_{60}$ mineral fertilizers applied during main soil tillage and at sowing achieved a yield of 2.85 t/ha with 26.6% protein content in seeds [63].

For surface soil treatments to a depth of 6–12 cm with mulching, nitrogen fertilizers should be applied at 60–80 kg/ha [209]. On southern chernozems, under favorable hydrothermal conditions, application of $N_{60}P_{90}$ increased grain yield by 1.46 t/ha (40%), while

single nitrogen application at N₆₀ increased it by 1.12 t/ha (30%). Under arid conditions, fertilizer rates should be limited to N₃₀, ensuring a 0.89 t/ha (26%) yield increase compared to control [201].

For chickpea grown as a transplant crop to reduce cold damage, acclimation effects are not compensated by either calcium treatments (which reduce oxidative stress effects) or abscisic acid (which modulates solute metabolism). However, calcium plays a more significant role in the plant recovery process [243].

Some researchers consider foliar application of mineral nitrogen in chickpea crops to be advantageous, as plants utilize 90% of nitrogen via foliar feeding compared to only 10% when applied to soil. For example, foliar application of a 2% urea or potassium nitrate solution on top of pre-sowing N₂₅P₅₀ improved biological yield and seed protein content [250; 289; 298]. Combining pre-sowing N₂₅P₅₀ fertilization, nitrogen-potassium foliar feeding (KNO₃), and specialized water-soluble fertilizers such as Speedfol Pulses and Speedfol Legumes, which contain microelements and growth stimulants, increased nitrogen uptake by chickpea plants 1.9-fold, phosphorus 2.5-fold, potassium 1.7-fold, and microelements from 2.4 (Zn) to 4.6-fold (Mn) [249]. Similar effects of foliar feeding on the physiological processes of chickpea and other leguminous crops have been noted by other researchers [33; 34; 274; 285].

1.2. Elements of Biologization in Chickpea Cultivation Technologies

In the soils of Ukraine, indigenous root nodule bacteria are absent; only in isolated areas where chickpea has been previously cultivated can local populations of *Mesorhizobium ciceri* be found. To establish an effective legume–rhizobial nitrogen-fixing system and ensure plant nutrition with molecular nitrogen from the air, seed inoculation (nitraginization) is necessary—pre-sowing treatment of seeds with biofertilizers developed from selected strains of chickpea rhizobia [14; 40; 54; 87; 91; 199].

Elements of biologization in chickpea cultivation technologies include pre-sowing inoculation with biofertilizers that enhance

symbiotic activity or suppress phytopathogen development [90; 96; 167; 193; 238].

As non-synthetic seed treatments, biological agents are used, including arbuscular mycorrhizal fungi [203], cyanobacteria [48], and growth-promoting rhizobacteria [175; 217; 255; 299; 301]. These beneficial microorganisms suppress phytopathogens, positively influence the formation of the legume–rhizobia symbiosis, and improve chickpea productivity.

It has been shown that under moderate infection levels of the seed material, treatment with biofertilizers based on *Pseudomonas koreensis* IB-4 and *Paenibacillus ehimensis* IB 739 not only reduces seedling mortality and diseases by 8.0–12.0%, but also stimulates plant growth by 13.2–19.2% [118].

Ukrainian researchers have demonstrated that a single treatment of chickpea varieties Budzhak and Rozanna with *Bacillus thuringiensis* 0376 reduces damage by the chickpea miner (*Liriomyza cicerina* Rd.) by 43–46% and increases the average crop yield by 0.5 t/ha. The highest efficiency was observed when using the STAR-T preparation based on *B. thuringiensis* 0376 [156]. Biofertilizers based on *Bacillus* strains 01-1 and 12501 have also been successfully applied to enhance chickpea resistance against root rot [7].

In environmentally friendly chickpea cultivation technologies, growth-stimulating products based on plant amino acids are used for treatment of vegetative plants, increasing the physiological level of plant resistance to various stress factors [27].

In the chickpea seed treatment system, a complex of several preparations is used, including biofungicides, mycorrhiza-forming and phosphorus-mobilizing agents that increase the absorptive surface of the root system, a range of micro- and macroelements, inoculants, and adjuvant-spreaders that prolong the activity of accompanying treatments [100; 111; 112; 127; 197].

In technologies with partial biologization of chickpea and other legume cultivation, mineral fertilizers are combined with pre-sowing seed inoculation with biofertilizers [13; 52; 67; 95; 119; 230; 264; 268], or with treatment using the herbicide Panda, pre-sowing seed inoculation with Rizobofit, and the plant growth regulator Stimpo. This combination of cultivation practices increased chickpea grain yield by

0.64 t/ha and was accompanied by an increase in the thousand-seed weight [93; 97].

The effectiveness of chickpea seed bacterization with microbial preparations is enhanced by micronutrients. For example, seed inoculation combined with treatment with a colloidal molybdenum solution increased plant stress resistance and survival during the vegetation period by 6.5–10.5%, whereas inoculation without the colloidal molybdenum solution resulted in only 1.9–2.5% improvement [39].

Particular attention is given to the use of complex water-soluble fertilizers in chelated form, which easily penetrate the leaf surface during foliar application and improve plant nutrition with micronutrients [32; 57; 58; 91; 117; 157; 274; 278; 284]. Currently, scientists and practitioners have begun using organo-mineral preparations based on amino acids with micronutrients (amino chelates). Studies conducted in different countries and on various crops have shown that they have a significant impact on plant productivity compared to conventional fertilizers and synthetic chelates [89; 166; 263; 287; 292; 293; 304]. The main advantage of such fertilizers is their safety for plants and the environment. However, plant response to their application must be studied under specific conditions, as soil status, plant species, and weather can influence their effectiveness.

The market of fertilizers and growth stimulators is enriched with products derived from organic raw materials such as vermicompost, peat, brown coal, sapropel, etc. These products contain humic and fulvic acids. Humic acids promote amino acid synthesis in plants and increase root mass, while fulvic acids enhance the proportion of assimilated nutrients [45; 115; 136; 169; 219]. These reagents, when added to organo-mineral fertilizers, improve plant resistance to adverse environmental conditions [47; 101; 176; 184].

A comparison of mineral fertilizers ($N_{35}P_{55}K_{55}$) with foliar application of humic acid (2 kg/ha) revealed no significant differences in plant height, yield, or thousand-seed weight [250]. At the same time, application of Humate Na/K and RPP Albit (50 g/t), Sileplant (0.05 l/t), Zircon (40 ml/t) activated net photosynthetic productivity by 0.02–0.12 g/m² per day, and combined application of Albit and

Humate Na/K resulted in grain yield increases of 13% and 14% relative to the control, respectively [101].

A promising direction in the biologization of chickpea cultivation technologies is the use of organic fertilizers of various origins. For example, combining biohumus with 50 kg/ha of phosphorus fertilizers resulted in higher yield than the use of mineral fertilizers alone [229]. The effectiveness of green manures has also been demonstrated; they were incorporated into the soil (0–20 cm layer) one month before sowing at three application rates. The lowest rate was equivalent to mineral fertilizers N₃₀P₄₀K₁₀₀, and the other two were 1.5 and 2 times higher [272]. In this case, chickpea grain yield in the organic variant was 88% and 91% of the mineral fertilizer variant, and no significant increase in plant productivity was observed with higher rates of green compost application.

Conclusions from Section 1

It has been determined that the fertilization system remains a key element of agricultural intensification even under global climate change. The range of fertilizers has significantly expanded due to the introduction of new types based on extracts from various raw materials, chelated and complex fertilizers, and technologies that incorporate microorganisms, macro- and micronutrients.

It has been clarified that achieving consistently high chickpea grain yields largely depends on determining an optimal nutrition system that takes into account zonal soil and climatic conditions.

It has been established that research results from Ukrainian and foreign scientists are somewhat contradictory regarding the effectiveness of various fertilizers in legume crops. Specifically, for chickpea, scientific opinions can be categorized into four main approaches: cultivating the crop without fertilizers, applying only starter fertilizers, applying half of the required fertilizers, and no unanimous position has been reached. Contradictions and a lack of sufficient studies on the effects of fertilizers on nitrogen fixation and nodule development have been noted. This highlights the need for modern experimental research aimed at optimizing chickpea nutrition

within cultivation technologies for the arid Southern Steppe of Ukraine.

It can be concluded that the degree of biologization of chickpea cultivation technologies and the effectiveness of biofertilizers in combination with mineral fertilizers under Southern Steppe conditions have not been sufficiently studied. Research in this area on southern chernozem soils under rainfed conditions will provide recommendations for producing highly effective and environmentally safe fertilizers with stimulatory properties. Therefore, addressing this issue has both scientific and practical significance.

CHAPTER 2

SOIL AND CLIMATE CONDITIONS AND RESEARCH METHODOLOGY

2.1. Soil and Climate Characteristics

The research was conducted during 2016–2020 at the experimental field of the Odessa State Agricultural Research Station of the NAAS of Ukraine (until 2017 – the Institute of Agriculture of the Black Sea Region of the National Academy of Agrarian Sciences of Ukraine; after 2022 – Odessa State Agricultural Research Station of the Institute of Water Problems and Reclamation NAAS; currently – Odessa State Agricultural Research Station of the Institute of Climate-Oriented Agriculture NAAS of Ukraine), located in the Bilyaivka district of Odessa region. The territory of Odessa region is somewhat elongated from north to south and belongs to two zones of Ukraine: forest-steppe and steppe, so the climatic conditions of its individual districts vary significantly.

The experimental field is flat with a slightly developed microrelief and a 0–1° slope facing south. The soil of the experimental site is southern low-humus chernozem, heavy loam on loess-like deposits, with a humus layer thickness of 41–50 cm. Bulk density of the southern chernozem is 1.12–1.30 g/cm³, and porosity is 56.5% [163].

The arable layer (25 cm) has the following agrochemical characteristics: humus content – 2.9% (according to Tyurin), sum of absorbed bases – 31.0–32.2 mg eq./100 g soil, pH (water) – 7.7, hydrolyzable nitrogen – 1.13–1.34 mg/100 g soil (Tyurin-Kononova method), mobile phosphorus – 113–129 mg/kg of dry soil, and exchangeable potassium – 100–118 mg/kg of dry soil (Chirikov method). Thus, the soil of the experimental site is characterized by extremely low nitrogen content and elevated phosphorus and potassium levels. This indicates that during chickpea cultivation, nitrogen supply will be insufficient, while phosphorus and potassium content will be adequate to achieve high yields.

Overall, the climate of Odessa region is moderately continental, with insufficient precipitation, a short mild winter, and a long hot summer. The annual total solar radiation ranges from 104–105 kcal/cm² in the northern part to 116–120 kcal/cm² in the south, and the radiation balance varies from 47 to 53–54 kcal/cm². Approximately 75% of solar radiation occurs during the spring-summer period [3; 4].

The steppe zone occupies the southern part of Odessa region, stretching along the Black Sea from the Danube to the Tiligul River, and is divided into two subzones: Northern Steppe and Southern Steppe. In the extreme southeastern part of the region, a Dry Steppe subzone is also present, although the boundaries between subzones are indistinct. The Southern Steppe subzone occupies a broad coastal strip of the Black Sea lowland and is further subdivided into several agro-soil provinces [170]. The Bilyaivka district, where the experimental field of the Odessa State Agricultural Research Station is located, belongs to the Steppe natural-climatic zone; the agro-soil province is SS-1: Dry Black Sea Steppe, characterized by a relatively flat and weakly dissected landscape.

The temperature regime is influenced by latitude and proximity to the sea. A distinctive feature of the region is the insufficient amount of precipitation, its uneven distribution throughout the growing season, a significant number of dry days with relative humidity below 50%, and winds with speeds of 10–12 m/s [3].

In the southern steppe areas, the warmest months are July and August, with air temperatures reaching 36–39 °C. Winters are unstable, with frequent thaws and short-term frosts, lasting 56–72 days.

The thermal resources of the region are sufficient for obtaining high-quality chickpea grain. The average annual air temperature ranges from 9.9 to 11.9 °C, with the warmest month, July, averaging 21–23 °C, and the coldest month, January, averaging –3 to –5 °C [4].

The average long-term duration of the frost-free period is 195–205 days. Spring frosts typically end in the first decade of April, with the latest frosts occurring at the beginning of May. The growing season generally begins between March 15–22 and ends between November 20–25. The duration of the growing season is 230–240 days, with variations in individual years ranging from 200 to 300 days. The period of active growth for agricultural crops (with

average daily air temperatures of 10 °C and above) lasts 175–190 days, and in some years ranges from 145 to 215 days. According to personal calculations, the sum of positive temperatures above 10 °C during this period reached 2,900–3,600 °C in 1971–1999 and 3,600–4,000 °C in 2000–2022.

Meteorological summer, i.e., the period with average daily air temperatures of 15 °C and above, lasts 125–145 days. The sum of positive temperatures above 15 °C during this period ranges from 2,480 °C to 2,670 °C. The sum of active temperatures required for chickpea is 1,410–1,950 °C, and its growing season lasts 80–110 days, so the Odesa region has sufficient heat to ensure full maturation [186]. This zone also has high solar radiation resources. During the chickpea growing season, the area receives an average of 1,641–1,838 MJ/m² of photosynthetically active radiation (PAR) [3]. The PAR energy requirement for chickpea during the growing season ranges from 1,160 MJ/m² for early-maturing varieties to 1,250 MJ/m² for mid-maturing varieties. Therefore, the PAR energy in this zone is fully sufficient for the effective growth and development of chickpea.

The climate of the Black Sea Steppe is characterized by a natural deficit and extreme unevenness of precipitation. With an average annual precipitation of 453 mm, the range varies from 250 mm to 700 mm (Table 2.1) [162; 233]. A deficit of precipitation combined with high air temperatures leads to wind and soil droughts, which in combination significantly reduced chickpea yields in 2019, 2021, and 2022, and practically destroyed its crops in 2003, 2007, and 2020.

Climate changes are occurring worldwide, including in the Southern Steppe of Ukraine, particularly in the Odesa region [12; 17; 18; 30; 120]. Analysis of weather conditions in the research area from 1971–2020 showed that every year since the beginning of the 21st century, the average air temperature in the Odesa region was consistently above the climatic norm. Deviations ranged from 0.8 °C to 2.7 °C, with the highest recorded in January and July: the average temperature in January increased by 1.3 °C and in July by 2.2 °C over the 51-year period [17; 18].

Table 2.1

**Main climate characteristics of the Odesa region,
average for 1981–2010, source [129]**

Indicator	Month												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Air temperature, °C													
Maximum	15.1	18.6	24.1	29.4	33.3	35.6	39.3	38.0	32.4	30.5	26.0	16.3	39.3
Minimum	-26.2	-28	-16	-5.9	0.3	5.2	7.5	7.9	-0.8	-13.3	-14.6	-19.6	-28
Average	-0.5	-0.2	3.5	9.4	15.6	20.0	22.6	22.3	17.2	11.6	5.4	1.1	10.7
Precipitation, mm	34	37	32	27	36	49	47	39	41	35	41	35	453
Number of days													
Rainy	9	7	10	11	12	13	10	8	9	10	13	10	122
Snowy	11	10	6	0.4	0	0	0	0	0	0.2	4	9	41
Air humidity, %	83	81	78	74	71	70	66	65	72	77	72	84	75

During this observation period, the average annual precipitation was 456.8 mm with a probability of 70.6%. Over the past 20 years, significant changes in total precipitation relative to the climatic norm have not been observed, but redistribution of precipitation across months and seasons is evident. Additionally, the number of days with precipitation has decreased on average to 61.5 days, and over the last 10 years – to 53 days, compared with the 86.2 days recorded during 1970–1992.

The characteristics of precipitation by intensity have also changed: on average, during 2011–2021, the share of days with precipitation less than 1 mm decreased 3.2 times, the percentage of days with precipitation of 5.0–9.9 mm and 10.0–19.9 mm increased by 1.6 and 1.4 times, respectively, and the share of days with more than 20 mm of precipitation increased 1.6 times, while days with more than 50 mm of precipitation doubled compared to the long-term average for 1961–1990.

For a combined assessment of heat and moisture availability, the hydrothermal coefficient (HTC) is used. It is calculated as the ratio of the sum of precipitation to the sum of active temperatures divided by 10 over a defined period. The average HTC in southern Ukraine during the active growing season ranges from 0.6–0.7, indicating that evaporation exceeds precipitation [196].

2.2. Weather Conditions During the Study Years

The research was conducted during 2016–2020, which differed significantly in terms of weather conditions. In particular, the winter–spring period of 2016 developed in a wave-like manner: the stable transition of daily average air temperatures through 0 °C occurred on January 27, through 5 °C on February 22, and continued until March 13. Until March 26, fluctuations of daily average temperatures ranged from 2.0 to 10.5 °C; on March 27, the temperature consistently exceeded 5 °C, and on March 30 it exceeded 10 °C in the upward direction.

During the pre-sowing period until March 31, 41.0 mm of precipitation fell. The total precipitation during the growing season of chickpea was 233.3 mm, which was 1.7 times higher than the long-term average.

By the end of May, the accumulation of active temperatures above 0 °C reached 1,077.8 °C, effective temperatures above 5 °C – 1,014.3 °C; above 10 °C – 280.8 °C; and above 15 °C – 57.5 °C. By the end of June, these values had increased to 1,719.8; 1,661.3; 1,400.2, and 275.5 °C, respectively (Appendix A1).

Thus, the main weather parameters of the chickpea growing season (precipitation, daily average temperature, dynamics of effective and active temperature accumulation) mostly exceeded the long-term average, confirming the trend of climate change in the Odesa region toward an increased temperature gradient, higher total precipitation, and uneven distribution of rainfall throughout the chickpea vegetation period.

Meteorological conditions in March 2017 were characterized by higher temperatures, the absence of effective precipitation, and low relative humidity. The monthly average air temperature in March was 4.5 °C above the climatic norm, reaching 7.1 °C, while precipitation totaled 7.0 mm, which corresponds to 20.6% of the monthly norm. The transition of daily average temperatures through 5 °C occurred as early as February 27, and through 10 °C on April 29–30.

The monthly average air temperature in April was almost at the norm, amounting to 9.1 °C. During April, a significant amount of precipitation fell – 52.6 mm, which is 187.9% of the monthly norm. May was warmer than normal by 1.8 °C, with an average air

temperature of 16.9 °C, and precipitation amounted to 33.4 mm, which is 92.8% of the monthly norm. By the end of May, the accumulation of active temperatures above 10 °C reached 506.0 °C.

The summer period was characterized by precipitation of varying intensity and both soil and atmospheric drought. Monthly precipitation in June amounted to 35.0 mm, which corresponds to 64.8% of the monthly norm. The average monthly air temperature in June was 21.8 °C, 1.7 °C above the norm. In July, 75.0 mm of precipitation fell, accounting for 144.2% of the monthly norm; however, 84% of it fell as heavy downpours, which negatively affected the state of chickpea crops. The average monthly air temperature in July was 25.3 °C, 2.8 °C above the climatic norm.

Chickpea harvest was recorded on August 8. During the entire growing season, total precipitation reached 201 mm, and active temperatures accumulated up to 2,325 °C.

Spring 2018 was characterized by a late onset, followed by a sharp rise in temperature and the absence of productive precipitation from sowing to flowering. Although 50.5 mm of precipitation fell before chickpea sowing in March, which corresponds to 148.5% of the monthly norm, the daily average air temperature was only 1.1 °C, nearly three times lower than the long-term average.

In April, the rapid accumulation of active heat began. According to data from the meteorological station of the Odesa State Agricultural Experimental Station of NAAS, the average monthly air temperature was 3.3 °C above the climatic norm. Against the background of elevated temperatures, there was a significant shortage of productive rainfall.

Precipitation in May amounted to 9.9 mm, or 27.1% of the monthly norm, mostly minimal or below productive levels, while temperatures exceeded the monthly norm by 2.6 °C (Appendix A2).

In 2018, the sowing of early cereals and legumes, including chickpea, was delayed by 3–4 weeks compared to long-term averages and took place on April 21. Average productive moisture reserves before chickpea sowing in the 0–20 cm arable layer were 19 mm, which was insufficient.

Due to the lack of precipitation and high daytime temperatures, soil drought, which began in the upper soil layers from mid-April, spread and deepened significantly.

In March 2019, the average monthly temperature in southern Ukraine was 5.0 °C, 2.3 °C above the long-term norm. Overall, that year, the transition of daily average air temperature above +5 °C occurred on March 17, which was significantly earlier than in 2018 (March 31) and 2017 (March 5).

In April, rapid warming was observed in the third decade. Average temperatures increased from 6.7 °C in the first decade, 7.7 °C in the second, to 14.5 °C in the third decade. The monthly average temperature was 9.8 °C, corresponding to the long-term norm.

During May, high air temperatures exceeded the long-term norm by 4.8 °C. Temperature accumulation during the month progressed gradually by decade: 11.3 °C in the first, 16.3 °C in the second, and 20.5 °C in the third decade.

The actual average monthly temperature in June (+28 °C) exceeded the long-term norm by 8.4 °C, while the July temperature corresponded to the long-term average.

The spring of 2019 was extremely dry (Fig. 2.1). No precipitation fell in March; in the second decade of April, 23 mm fell, which is 10.3 mm below the long-term norm. In May, precipitation was extremely low – only 14.5 mm, 22.1 mm less than the long-term norm. These rains were short-lived and only moistened the surface soil layer. The practical absence of precipitation negatively affected the initial stages of chickpea development.

In June, 15.5 mm of precipitation fell, which accounted for only 28.2% of the long-term average, and only in July did the amount of precipitation approach the norm: 59 mm fell, corresponding to 107.3% of the long-term average. During the chickpea growing season, total precipitation amounted to 108 mm.

The temperature regime in 2020 was marked by anomalous phenomena: throughout the period from September 2019 to April 2020, the average monthly air temperature exceeded long-term averages by 2.1–4.6 °C, whereas in May, the average monthly temperature was 2.1 °C below the norm (Fig. 2.2). Spring weather was further complicated by frosts, when night-time surface soil temperatures in early March's second decade dropped to –9 to –11 °C. Generally, frosts in other years occurred much later, even in May, but temperatures never fell below –1.0 °C.

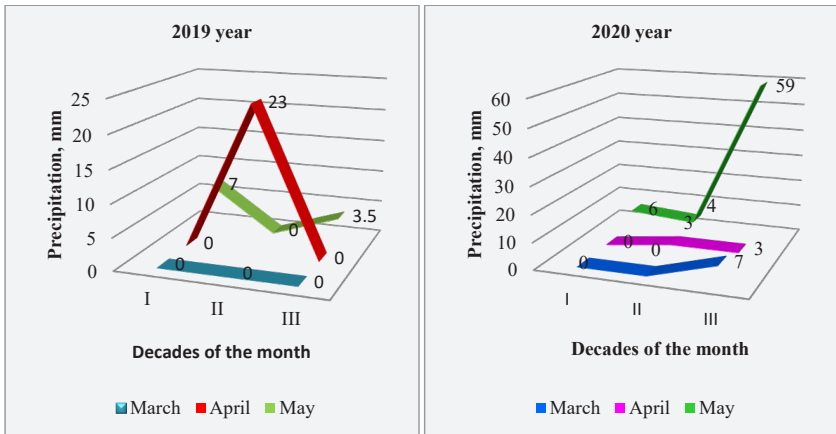


Fig. 2.1. Decadal precipitation during the spring period of 2019–2020

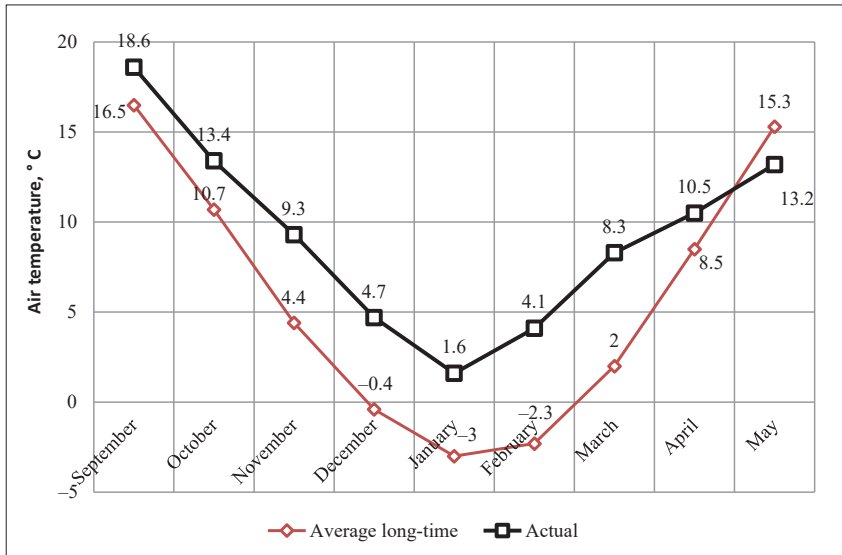


Fig. 2.2. Actual average monthly air temperature for the 2019–2020 agricultural year compared with long-term averages, °C

In March 2020, the temperature regime was warmer than in the previous four years (Fig. 2.3). In particular, the average monthly temperature in March was 8.3 °C, which is 5.6 °C above the long-term norm, whereas during 2016–2019 it ranged from 1.1 to 7.1 °C.

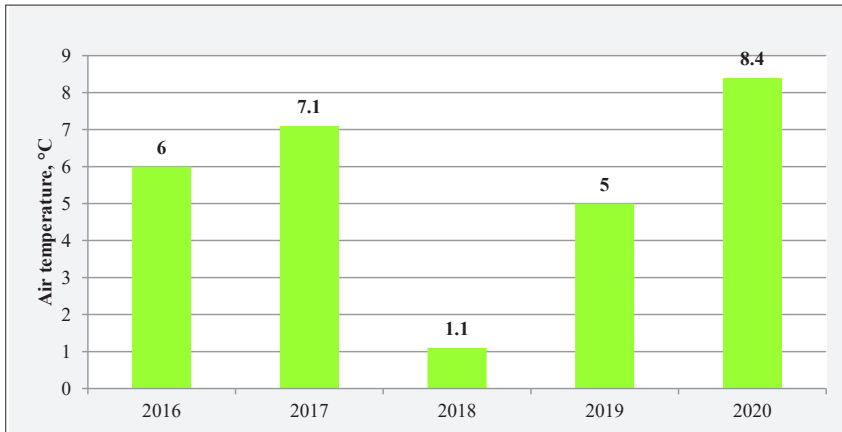


Fig. 2.3. Average monthly air temperature in March for the years of the study, °C

In the first decade of April, the daily average air temperature was 8.4 °C. In the second and third decades, it reached 11.5 °C, and the monthly average was 10.5 °C. During May, the air temperature was below the long-term norm by 2.1 °C, with fluctuations by decade: 13.4 °C in the first, 15.9 °C in the second, and decreasing to 13.1 °C in the third decade.

The accumulation of moisture in early spring depends on precipitation during the cold period of the year. Overall, from November 2019 to February 10, 2020, total precipitation amounted to 87 mm, which is 78% of the monthly norm. According to the winter assessment of productive moisture reserves conducted on February 8, soil moisture in the 0–20 cm arable layer was 25.9 mm. In the 1-meter soil layer, moisture reserves reached 98.3 mm, corresponding to satisfactory levels. Productive moisture reserves in the 1-meter soil layer at the beginning of field operations in spring 2020 were minimal in March and completely absent in April.

The spring period of 2020 was extremely dry (Fig. 2.1). During the first decades of March and April, no precipitation occurred. In total, only 7 mm and 6 mm of precipitation fell in March and April, respectively, i.e., they were almost absent. Thus, for the third consecutive year, the lack of rainfall negatively affected the growth and development of chickpea plants. The rainy period, as noted earlier, shifted to the early summer months: the first decade of June was dry, 28 mm of precipitation fell in the second decade, and in the third decade, a single rainfall event brought 60 mm, of which 48 mm fell during a heavy rain on June 30. The total precipitation in June was 88 mm.

After the May rainfall, the overall condition of the chickpea plants improved, but the development of ascochitosis and weed regrowth was observed.

For a detailed characterization of atmospheric moisture conditions during the chickpea growing season, the hydrothermal coefficient (HTC) by Selyaninov was calculated. Considering HTC values as an indicator of moisture availability (<0.4 – very severe drought; 0.4–0.5 – severe drought; 0.6–0.7 – moderate drought; 0.8–0.9 – mild drought; 1.0–1.5 – wet), it should be emphasized that the chickpea growing season mostly (4 out of 5 years of study) occurred under drought conditions of varying intensity: from mild in 2017 to moderate in 2020, and very severe during 2018–2019. Only the 2016 growing season experienced sufficient soil moisture (Fig. 2.4).

It should be noted that HTC values are also characterized by temporal and spatial variability (Figs. 2.5, 2.6). The driest period at the beginning of the growing season in April was observed during 2018–2020, where HTC values fell within the “very severe drought” category, ranging from 0.0 to 0.25.

At the same time, in our view, HTC alone is not always sufficient or objective for characterizing weather conditions. Rainfall frequency during the growing season, its distribution, and precipitation intensity are also of great importance (Table 2.2).

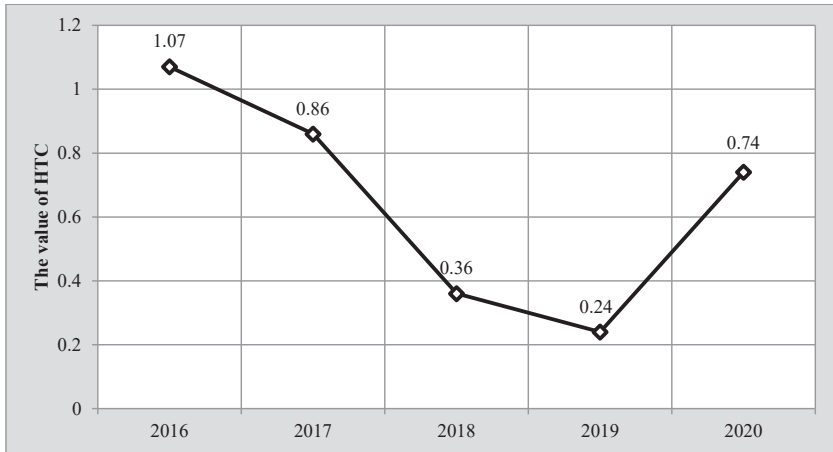


Fig. 2.4. Average HTC values during the chickpea growing season, 2016–2020

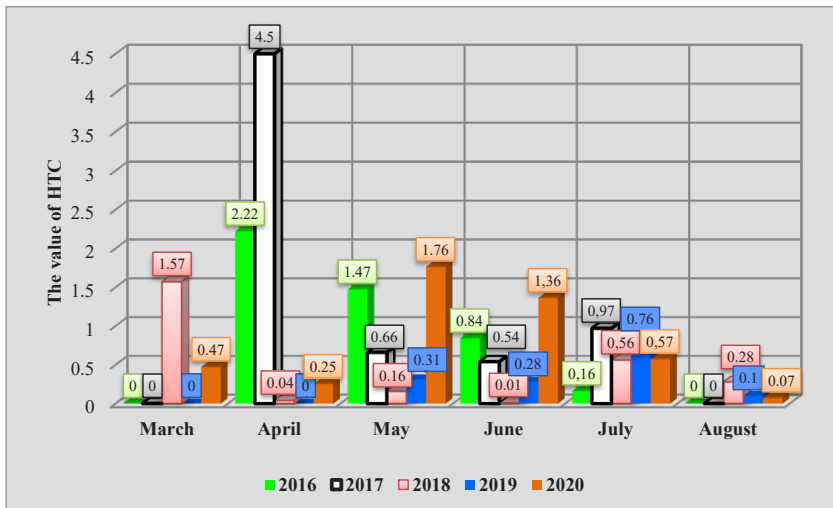


Fig. 2.5. Variability of moisture conditions during the chickpea growing season in the years of study

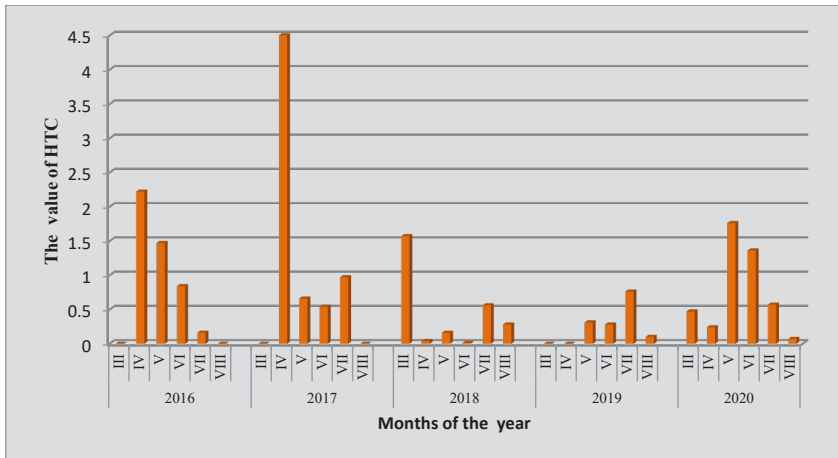


Fig. 2.6. Variability of moisture conditions during the chickpea growing season by months, 2016–2020

Table 2.2

Total precipitation and its gradation during the years of the study

Year	Total precipitation during chickpea growing season, mm						
	precipitation, mm	total days	Days with precipitation				
			% of total days				
			≤5 mm	5.0–9.9 mm	10–20 mm	>20 mm	>50 mm
2016	274.3	46	62.5	7.5	17.5	12.5	0
2017	201.0	26	53.8	19.2	19.2	7.8	0
2018	116.5	33	90.9	3.1	3.0	3.0	0
2019	126.0	13	30.8	46.2	7.7	0	15.3
2020	218.5	19	36.8	42.1	5.2	5.2	10.7

During 2019–2020, the minimum number of rainy days was recorded throughout the chickpea growing season, and on most days (77–79%), precipitation did not exceed 10 mm. Moreover, in 2019–2020, the number of days with heavy (hazardous) rainfall increased to 10–15%, with 60–80 mm of precipitation falling at a single event, accounting for 50–80% of the total precipitation.

Thus, these adverse weather conditions inevitably affected the growth processes of chickpea, the formation of its productivity and quality, the effectiveness of fertilization systems, and the plant response to mineral fertilizers, including their impact on nodule formation.

2.3. Research Program and Methodology

To achieve the set objectives, two two-factorial field experiments were conducted during 2016–2020. The experiments used chickpea seeds of the cultivar Pamyat, which belongs to the Eurasian subspecies (subsp. *eurasiaticum* G. Pop.), type kabuli, variety bogemico-allutaceum G. Pop. [186]. The vegetation period lasts 90–120 days, plant height is 50–55 cm, and the height of the lowest pods is 20–22 cm.

The originator of the Pamyat cultivar is the Selection and Genetic Institute – National Center for Seed Science and Variety Testing of NAAS, registered in the Plant Variety Registry of Ukraine since 2002, recommended for cultivation in the steppe zone. Authors: R. G. Vedyshcheva, O. V. Bushulyan, V. I. Sichkar.

Agronomic and biological characteristics: high-yielding; mid-season, with a vegetation period of 90–95 days; slightly affected by fusariosis and ascochitosis; high drought resistance; plant height 55–60 cm; lowest pod attachment 20–22 cm; erect growth habit, lodging-resistant; notable for regrowth resistance under high moisture.

Seed quality: protein content up to 28–30%, oil – 3–4%. Good nutritional qualities and important as a concentrate for livestock, especially pigs and poultry.

Approbation characteristics: belongs to the southern European ecological group (subsp. *eurasiaticum* G. Pop.), type Kabuli, variety bogemico-allutaceum G. Pop. Vegetative organs densely pubescent, bluish-green. No anthocyanin coloration. Flowers solitary, medium-sized, white. Pods rhomboid, medium-sized, yellow-straw at maturity. Seeds light brown, rounded. 1000-seed weight 280–300 g.

Experiment No. 1 – Formation of Chickpea Productivity Depending on the Level of Mineral Nutrition. In the field experiment, the effectiveness of various factors was evaluated across different treatments.

Factor A – Fertilizer treatments: 1 – Control (no fertilizers); 2 – $P_{30}K_{30}$; 3 – $P_{30}K_{30} + N_{30}$; 4 – $P_{30}K_{30} + N_{30} + N_{30}$; 5 – $P_{30}K_{30} + N_{60}$; 6 – $N_{30}P_{30}K_{30}$; 7 – $N_{60}P_{30}K_{30}$; 8 – N_{30} applied at sowing; 9 – N_{60} applied at sowing; 10 – N_{90} applied at sowing; 11 – N_{120} applied at sowing; 12 – $N_{30} + N_{30}$ applied during vegetation.

Fertilizers were applied manually at sowing in the form of ammonium nitrate, simple granular superphosphate, potassium salt, and nitroammophoska (15:15:15). For top-dressing during the growing season (at the onset of branching and the beginning of flowering), urea was used.

Factor B – Inoculation:

1 – Control (no inoculation);

2 – Inoculation with Rhizobofit, Rizogumin, and BTU inoculant for chickpea.

The experiment was conducted with four replications, and the plot layout followed a split-plot design. The main plot area was 80 m², and the sub-plot area was 20.6 m².

Seeds were treated 1–2 hours before sowing with biopreparations containing selected high-efficiency strains of nodule bacteria (Rhizobofit, Rizogumin, and BTU inoculant in a 1:10 ratio) at the recommended inoculum rate of 10⁶ bacteria per seed.

Experiment No. 2 – Evaluation of the Effectiveness of Liquid Organo-Mineral Formulations in Chickpea Cultivation Technologies with Elements of Biologization under the Arid Conditions of the Southern Steppe.

Factor A – Basal nutrition: 1 – Control (no fertilizers); 2 – N_{60} applied as follows: N_{30} – pre-sowing application + N_{30} – top-dressing at branching. Factor B – Application of liquid organo-mineral formulations according to the scheme (Table 2.3). All plots were treated with the solutions three times during chickpea vegetation: at the beginning of branching, during the budding phase, and at the beginning of pod filling.

The experiment was conducted with five replications, arranged in a randomized layout. Treatments in each tier were offset relative to the same treatments in other tiers. The total plot area was 50.0 m², and the net plot area was 26.4 m².

Table 2.3

**Variants of Chickpea Cultivation Technologies
with Elements of Biologization**

No	Treatment Variant	Application Rate by Growth Phase, L/ha		
		Branching	Budding	Pod filling
1	Control	–		
2	Amino	0,5	0,5	0,5
3	Amino Micro	0,5	0,5	0,5
4	Fulvo TE	0,5	0,5	0,5
5	SeedTreatment	1,5	1,5	1,5
6	AntiStress (SG Protector)	1,0	2,0	1,0
7	EXTRA	1,0	1,5	1,0
8	RootMost	2,0	2,0	2,0
9	Polymicrostim	2,0	2,0	2,0
10	Avatar Organica + Avatar Protection + Avatar Barrier	0,5	0,5	0,5

The experiments were established in accordance with standard field research methodologies for assessing the effectiveness of agrotechnical practices in crop cultivation, following widely recognized methodological guidelines and manuals [64; 66; 99; 142].

Chickpea seeds of the Pamyat variety were sown in the following crop rotation sequence: black fallow – winter wheat – chickpea – winter wheat. Standard agronomic practices for chickpea cultivation in the conditions of the Southern Steppe of Ukraine were applied [187]. After harvesting the previous crop (winter wheat), stubble was disked twice to depths of 6–8 and 10–12 cm. For additional weed control and soil leveling, a harrow cultivation to 12–14 cm was performed. In spring, after the soil reached physical maturity, fields were harrowed (BZZS-1.0), followed by pre-sowing cultivation with seed placement at 5–7 cm depth. Sowing was carried out in the third decade of March using a solid-row method with a row spacing of 15 cm. The seeding rate was 500–600 thousand seeds per hectare. After sowing, the field was rolled using ring-spur rollers.

To control pests during the “budding – beginning of flowering” phase, the insecticide Nurel D was applied at a rate of 1.0 L/ha.

The experiment was accompanied by phenological observations and soil and plant sample analyses. Samples were collected before sowing, during the branching and flowering phases, and at full plant maturity. All observations and measurements were conducted on two non-adjacent replications.

Soil moisture was determined according to DSTU ISO 11465:2001 using the thermostat-weighing method in the 0–100 cm soil layer at 10 cm intervals [31; 177; 164].

The calculation of productive soil moisture reserves, total water consumption, and chickpea water consumption coefficient was based on soil moisture and bulk density measurements. Using these data, taking into account moisture content and wilting, the total and productive soil moisture reserves were estimated.

The total soil water reserve per hectare was calculated using the following formula 2.1:

$$P = 100 \times H \times B \times A, \quad (2.1)$$

where PPP – total water reserve, m³/ha; HHH – depth of the soil layer, m; VVV – soil moisture content of the layer (% of dry mass); AAA – bulk density of the soil, t/m³.

Conversion of water reserves from m³/ha to mm/ha was performed using the ratio 10 m³/ha = 1 mm/ha.

Total water consumption ($\Sigma W \setminus \Sigma W$, mm/ha or m³/ha) was calculated as:

$$\Sigma W = W_0 - W_k + \Sigma O, \quad (2.2)$$

where W₀ – productive soil moisture reserve in the 0–100 cm layer before sowing; W_k – productive soil moisture reserve in the 0–100 cm layer at the end of the growing season; $\Sigma P \setminus \Sigma P$ – total precipitation during the growing season [46; 164].

The water consumption coefficient (K_w, m³/t), reflecting water use per ton of seed, was calculated based on total water consumption and chickpea yield for each experimental treatment:

$$K_w = \Sigma W : Y, \quad (2.3)$$

where Y – seed yield (t/ha) [164].

Phenological observations were conducted on permanent plots, where 50 representative plants per plot were marked and monitored for the onset of developmental phases. The beginning of a phase was

recorded when 10% of plants reached it, and full phase – when 75% of plants reached it [139].

Plant density was determined at full emergence and before harvest by counting plants along fixed sampling areas using the trial plot method [99]. Aboveground biomass accumulation was assessed by weighing 10 representative plants at each sampling [139].

Leaf area was determined using the accelerated method with APFill Ink Toner Coverage Meter 5.8 as follows [59]:

- Pre-dried leaves were placed on a transparent sheet on the scanner;
- Leaves were pressed under the scanner cover and scanned;
- The resulting black-and-white image was uploaded to the software to calculate the leaf area coverage by ink;
- The leaf coverage percentage was obtained, and the total leaf area was calculated as:

$$S = I \times A, \quad (2.4),$$

where SSS – leaf area, III – leaf coverage percentage, and AAA – A4 sheet area ($297 \times 210 \text{ mm}^2$).

Photosynthetic potential (PP) was calculated as:

$$PP = \frac{[(L1+L2) \cdot T1 + (L2+L3) \cdot T2 \dots]}{2}, \quad (2.5)$$

where $L1+L2$, L_1+L_2 – sum of leaf areas over the periods (thousand m^2/ha); $T1, T_1, T_2, T_1, T_2$ – duration of leaf activity (days) [183].

Chlorophyll content in fully developed leaves was determined from upper leaves of the main stem at branching, green pod, and maturity phases. Leaf extracts were prepared in 100% acetone, and chlorophyll a and b were measured spectrophotometrically at 662 nm and 644 nm, respectively [171; 302].

Yield structure was studied in bundle samples collected at full maturity from 0.25 m^2 plots in four replications. The following parameters were determined: bundle weight, number of plants, shoots, pods on main and lateral branches, seeds per pod, seed number and weight per plant, 1000-seed weight, total plant height, and lower pod attachment height.

Chickpea harvest was conducted using a Sampo-500 combine harvester, with grain samples taken for quality analysis. Grain weight was adjusted to standard moisture content and 100% purity.

Grain quality parameters were determined using standard methods [132; 134]: protein content by near-infrared spectroscopy (Spectran-119M) according to DSTU 4117:2007 [68]; 1000-seed weight according to DSTU ISO 520:2015 [70]; moisture content by thermogravimetric method (DSTU 29144:2009) [69].

Soil analyses included mobile phosphorus and exchangeable potassium by modified Chirikov method (DSTU 4115-2002) [73], nitrate content by colorimetry with disulfo-phenol acid (DSTU 4729:2007) [74], nitrification capacity according to Kravkov after seven days of composting at 28 °C and 60% of full water capacity, and soil moisture by thermostat-weighing method.

Statistical analysis was performed using ANOVA, correlation, regression, and graphical methods with Excel and Statistica software [65; 110; 206; 207; 211].

Economic efficiency of chickpea cultivation technologies was calculated considering all costs, production norms, direct and overhead expenses at prices and tariffs valid on 01.01.2021 [212]. Energy efficiency of treatments was determined according to the methodology of Ushkarenko et al. [138; 205].

2.4. Characteristics of Fertilizers and Preparations Used in the Experiment

Mineral fertilizers: Nitroammophoska (16:16:16), Ammonium nitrate – 34% active ingredient, Urea – 46% active ingredient, Simple superphosphate – 20% active ingredient, Potassium salt – 40% active ingredient.

Inoculants: BTU-R – a bioinoculant for chickpea, pea, soybean, and other leguminous crops. It contains viable cells of *Mesorhizobium ciceri*, symbiotic with chickpea, at a titer of 2.0×10^9 CFU/cm³; *Bradyrhizobium japonicum*, symbiotic with soybean; *Rhizobium leguminosarum*, symbiotic with pea; and other rhizobial strains specific to certain leguminous crops. It also includes macro- and micronutrients and

biologically active bacterial metabolites, such as vitamins, heteroauxins, and gibberellins. Recommended application rate: 2.0 L per ton of seed.

Chickpea Rhizobiofit – used in powdered form for greater stability under environmental conditions. A sticker agent was used for seed treatment. The product is registered in Ukraine (Series A N°01663). Active ingredient content: bacterial cell titer of $2\text{--}3 \times 10^9$ per gram of product. Application rate: 2 kg per ton of seed.

Rhizogumin (peat-based form) – a biofertilizer for chickpea seed bacterization. It consists of specially prepared peat enriched with *Mesorhizobium ciceri* cells and contains physiologically active biological substances such as auxins, cytokinins, amino acids, humic acids, chelated micronutrients, and macroelements in starter concentrations. For seed treatment, the product is suspended in chlorine-free tap water. For bacterization of 1 ton of seed, 2 kg of Rhizogumin is mixed with 10 L of water.

Liquid Organomineral Preparations (LOMP) [1; 77]:

Amino – a highly effective liquid fertilizer containing 200 g of amino acids per 1 L.

Amino Mikro – a combined liquid fertilizer based on amino acids (100 g/L) and microelements for foliar feeding. Composition: N – 33.0 g/L; P₂O₅ – 20 g/L; K₂O – 15 g/L; MgO – 29 g/L; microelements (g/L): B – 3.0; Cu – 3.25; Fe – 3.8; Zn – 3.2; Mn – 6.1; Mo – 0.02.

Fulvo TE – a preparation based on fulvic acids (200 g/L), containing N – 72.5 g/L, K₂O – 45 g/L; microelements (g/L): Co – 0.01; B – 0.22; Cu – 0.2; Fe – 1.13; Zn – 0.62; Mn – 1.45; Mo – 0.042.

SeedTreatment – an organomineral fertilizer based on fulvic acids (100 g/L), containing 2 g/L of fullerene.

Antistress (SG Protector) – a liquid, highly concentrated fertilizer with a high content of silicon and humic acids (150 g/L), containing 25 g/L of fulvic acids, 25 g/L of nitrogen, 85 g/L of K₂O, 60 g/L of silicon dioxide. It enhances the anti-stress effect and strengthens plant immunity. Applied at: branching stage – 1.0 L/ha, budding – 2.0 L/ha, grain filling – 1.0 L/ha.

Rootmost – a liquid organomineral fertilizer based on seaweed extract (200 g/L) and polysaccharides (70 g/L), containing per 1 L:

20 mg of amino acids, 3.0 mg of cytokinins, 1.0 g of nitrogen, 100 g of P₂O₅, 150 g of K₂O, and 15–20 mg of microelements.

Extra – an innovative organomineral fertilizer based on fullerene, applied at 1.0 L/ha. Applied at: branching stage – 1.0 L/ha, budding – 1.5 L/ha, grain filling – 1.0 L/ha.

Polymicrostim – a multicomponent macro- and microelement complex containing Mg, Zn, Fe, Mn, Cu, Co, Mo, and Al in chelated form with ethylenediaminetetraacetic acid (EDTA), as well as potassium, phosphorus, boron, and iodine in the form of acidic orthophosphate, borate, and iodide.

Avatar Organic – an environmentally friendly multicomponent microelement preparation compatible with most seed dressings, enhancing plant stress resistance. When used together with urea solutions and humic preparations, it demonstrates synergistic action, improving their efficiency, stimulating growth, and increasing soil microbial activity. Active substance concentrations (%): K – 0.00–0.10; S – 0.001–0.10; Si – 0.0001–0.01; Mg – 0.02–0.2; Mn – 0.001–0.05; B – 0.001–0.035; Co – 0.001–0.10; Fe – 0.001–0.10; Mo – 0.001–0.01; Cu – 0.001–0.10; Zn – 0.001–0.10; Ce – 0.0001–0.05; V – 0.000001–0.005; Ge – 0.000001–0.001; I – 0.00001–0.01; Se – 0.000001–0.001; Ag – 0.000001–0.001; Ti – 0.000001–0.002.

Avatar Protect – Legumes and Avatar Barrier (Protect) – the effectiveness of these preparations is due to the fungicidal, bactericidal, and insectoacaricidal action of sulfur, copper, iodine, aluminum, nickel, bismuth, and vanadium ions. These preparations are produced using nanotechnologies and exist in organic compounds with citric acid, which ensures their high bioavailability and rapid penetration into the cells of pathogens and pests.

Unlike other pesticides, the Avatar Protect series has no toxic effects on plants or animals, as confirmed by scientific studies and positive results in laboratory and field trials. The composition of Avatar Protect preparations is supplemented with essential plant micro- and ultra-microelements (Mg, Zn, Fe, Mn, Co, Mo, La, Ti, Se, Ge, Si, Cu, and B). These elements enhance the biological activity of many key enzymes responsible for photosynthesis, protein, carbohydrate, and lipid biosynthesis, as well as enzymes of plant defense and antioxidant systems.

According to the manufacturer, the preparation is a powerful stress protector, increasing plant resistance to drought, snowless frosts, and soil salinity. In stress-prone plants, the preparation activates adaptive processes.

Conclusions to Chapter 2

1. A characteristic feature of the Southern Steppe of Ukraine, where the research was conducted, is its aridity, which results from insufficient precipitation and its uneven distribution during the growing season, often aggravated by elevated temperature conditions. In certain years, prolonged rainless periods, dry winds, and low relative air humidity are observed, leading to a decline in the physiological activity of chickpea plants, reduced productivity, and lower economic efficiency. Therefore, it is necessary to develop and implement cultivation technologies for chickpea that focus on preserving soil moisture and ensuring its rational use. For this purpose, optimization of the chickpea nutrition system is particularly relevant, including the use of inoculants, mineral fertilizers, and organo-mineral preparations.

2. The research was carried out during 2016–2020 under arid conditions of the Southern Steppe of Ukraine. Based on meteorological indicators, the year 2016 can be classified as moisture-sufficient, whereas 2017–2020 were classified as arid years.

3. Field experiments were conducted in two two-factor trials at the experimental field of the Odesa State Agricultural Research Station of the Institute of Water Problems and Land Reclamation of NAAS, located in Bilyaivka district of Odesa region. The experiments were carried out in accordance with generally accepted methodologies for field research and methodological recommendations. The chickpea variety Pamyat, included in the State Register of Plant Varieties Suitable for Dissemination in Ukraine, was studied. A generally accepted technology of chickpea cultivation under rainfed conditions of Southern Ukraine was applied, except for the nutritional elements under investigation.

CHAPTER 3

DEPENDENCE OF WATER CONSUMPTION IN CHICKPEA PLANTS ON NUTRITIONAL SYSTEMS

The leaves of chickpea plants consist of 80–90% water, while the roots contain 70–80%. Without water, no physiological or biochemical processes in plants are possible. Insufficient water supply to plant cells slows down their biochemical and physiological activities, which in turn reduces yield and worsens product quality.

Thus, chickpea seed yield is the outcome of numerous growth and development processes, expressed through its components. The rate and completeness of these processes largely depend on the available water supply, which often varies considerably. Overall water availability for crops is determined by soil water reserves, precipitation levels, and their distribution during the vegetation period. In the conditions of the Southern Steppe, the contribution of soil moisture reserves to chickpea grain yield formation under natural moisture conditions averages 61.3%, while effective precipitation accounts for only 38.7% [124]. Under arid conditions, the decisive factors include: moisture content of the one-meter soil layer during the branching stage (33.0%); precipitation during the growing season (31.4%); soil moisture before sowing (16.0%); and tillage layer density (7.9%) [35].

Soil water deficit is the principal constraint on expanding chickpea production [223-225; 232; 239; 240; 248; 254; 257; 259; 271; 279–282; 290; 291]. It has been established that in chickpea, water use efficiency per unit of dry matter and seed yield amounted to 8.7 kg/ha and 3.2 kg/ha, respectively, while estimated soil evaporation was 105 mm [308]. On loamy soils under rainfed conditions, chickpea water use amounted to 175 mm, with a critical maximum potential soil moisture deficit of approximately 150 mm and 90 mm, depending on sowing dates [224].

Chickpea is considered a drought-tolerant crop, yet researchers have established a direct linear relationship between water use and biomass yield ($R^2 = 0.80-0.92$), and between water use and seed yield ($R^2 = 0.63-0.75$) [75; 99]. However, greater biomass accumulation

did not always translate into higher yields. This is linked to the biological peculiarity of chickpea: as an indeterminate crop, it continues vegetative growth during flowering and seed development, which may create competition for assimilates between ongoing vegetative growth and grain formation.

The literature provides different views on the drought-sensitive periods of chickpea. Some authors suggest that the crop is more sensitive to drought during flowering or prior to flowering, when water consumption was 46–49% higher compared to the period after flowering [223; 224; 248]. It has been established that the first 60–100 days of chickpea growth and development are the most critical. Water shortage during this period significantly reduced yield. Rainfall occurring after 100 days is largely unused by the crop, particularly if it has already experienced water stress between days 60 and 100 [209]. However, other studies suggest that the critical phases for chickpea water demand occur after flowering—namely pod formation and grain filling [279; 280; 281].

The negative impact of drought can be partially mitigated through agronomic practices, including scientifically justified crop rotation, irrigation, soil cultivation, and optimized sowing dates [103; 108; 122–124; 141; 143]. Fertilization also affects water use. For instance, compared to the control, the application of phosphorus fertilizers increased water use efficiency by 25% [241]. Mineral fertilizers influence the distribution of the components of total water consumption: under natural moisture conditions, the share of soil reserves in unfertilized plots was 59.8%, while application of N₄₅P₄₅ increased it to 61.4%, and N₉₀P₉₀ to 62.4%. Conversely, the contribution of effective precipitation exhibited an opposite trend relative to soil reserves [122; 124]. Foliar application of micronutrients during the chickpea branching stage reduces the water consumption coefficient by 4.3–11.4% [145].

In the Southern Steppe of Ukraine, crop yield levels are primarily determined by soil reserves of productive moisture accumulated during the autumn-winter period. Precipitation during the warm season (April–August) does not provide deep soil wetting and is largely lost to surface evaporation. Under high temperatures and low air humidity, August rainfall almost entirely evaporates, while September rainfall is lost by 60–70% [218].

As repeatedly noted, the study years differed significantly in weather conditions: of the five years, only 2016 was favorable in terms of water availability, while the remaining years were drought-prone. Consequently, when analyzing soil moisture dynamics, a clear dependence on weather conditions during the study period is observed: calculated correlation coefficients between soil productive moisture reserves and the hydrothermal coefficient across all chickpea growth phases indicate a direct functional relationship ($r = 0.92\text{--}0.97$).

The water availability in the one-meter soil layer of the experimental plots prior to chickpea sowing was highest in 2016, satisfactory in 2017–2018, and extremely low in the last two years, 2019–2020 (Figure 3.1).

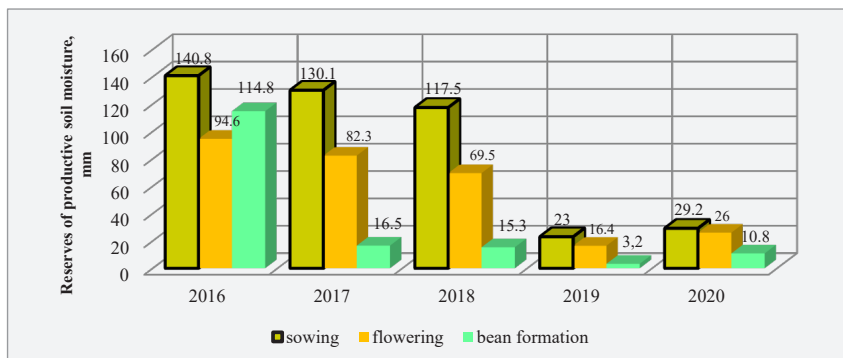


Fig. 3.1. Average reserves of productive soil moisture in the one-meter soil layer during the main chickpea growth phases across the study years, mm

Correspondingly, the average yield ranged from 1.33 t/ha to 3.14 t/ha, while in 2019 it reached an extremely low value of 0.67 t/ha.

The overall water consumption provides a more reliable characterization of the water availability conditions for crop stands. Calculations indicated that total water consumption in chickpea plots fertilized with mineral fertilizers ranged from 3,942 m³/ha to 2,225 m³/ha, with an average of 3,144 m³/ha. During 2019–2022, on plots treated with liquid organo-mineral preparations (ROMP), water consumption ranged from 2,480 to 1,455 m³/ha, with an average

of 1,964 m³/ha. The difference between the fertilization variants within each year varied from 0.3% to 2.8% and was statistically insignificant.

At the same time, the average water consumption by chickpea crops across the study years fluctuated considerably. Taking the control variant of 2016 as 100%, total water consumption was 83.7% in 2017, 58.4% in 2018, 38.4% in 2019, and 63.4% in 2020. The difference between the average values for 2016–2018 and 2019–2020 was 37.5% and was determined not by the nutrient systems applied, but by the weather conditions of the respective years.

The structure of water consumption during the study years also draws attention (Fig. 3.2).

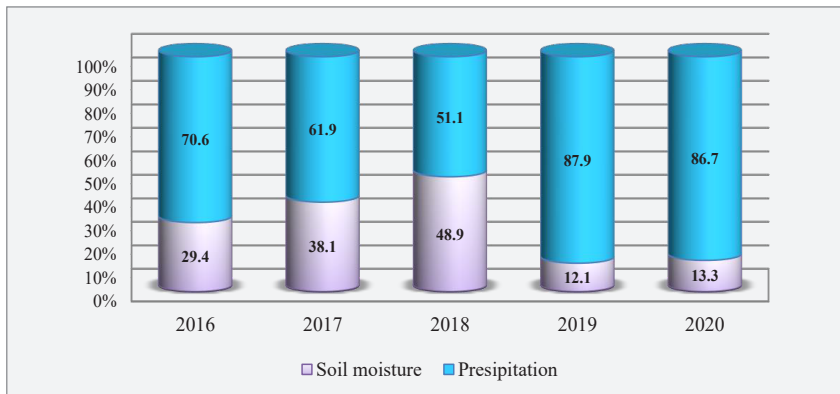


Fig. 3.2. Structure of total water consumption by chickpea across the study years, %

Specifically, the results from the first three years indicate that with increasing atmospheric drought, the contribution of soil moisture to chickpea yield formation increased—from 29.4% in 2016 to 48.9% in 2018. However, the results of the subsequent two years initially appear to contradict this conclusion. These years were generally characterized as “extremely dry,” and the proportion of water uptake from soil by chickpea plants decreased to 12.1–13.3%. Thus, the chickpea plants survived and produced a yield, albeit a small one, relying almost entirely on atmospheric precipitation. The reserves of productive moisture in the one-meter soil layer during the growing

season of these years were below 30 mm. In 2019 and 2020, chickpea plants experienced severe stress from combined soil-air drought during the pre-flowering period, as the first significant precipitation occurred only in the second decade of April and the third decade of May, respectively. Subsequent rainfall could not compensate but only supported the plants' survival. These findings align with conclusions from international studies [154; 241].

When mineral fertilizers were applied, chickpea plants required 1,294–1,471 m³ of water to produce 1 t of seed, depending on the application rate. Under natural conditions, this value was 1,483 m³/t (Table 3.1).

Table 3.1
Water consumption per unit of chickpea yield depending on the rate of mineral fertilizer application, average 2016–2018

Fertilizer variant	m ³ /t	%	
		of control	of P ₃₀ K ₃₀
Control, no fertilizers	1483	100	105.0
P ₃₀ K ₃₀	1412	95.2	100
P ₃₀ K ₃₀ +N ₃₀	1319	88.9	93.4
P ₃₀ K ₃₀ +N ₆₀	1453	98.0	102.9
N ₃₀ P ₃₀ K ₃₀	1433	96.6	101.5
N ₆₀ P ₆₀ K ₆₀	1471	99.2	104.2
N ₃₀	1336	90.1	94.6
N ₆₀	1408	94.5	99.7
N ₃₀ +N ₃₀	1294	87.3	91.6

Pre-sowing application of complete phosphorus-potassium fertilizers and nitrogen at a rate of 60 kg/ha had a minimal effect on water-use efficiency of chickpea crops: water consumption per unit of production ranged from 94.5% to 99.2% of the control. Application of N₃₀ alone or on the background of R₃₀K₃₀ reduced water consumption by 9.9% and 11.1%, respectively, compared to the unfertilized control, and by 5.4% and 6.6% relative to the R₃₀K₃₀ variant. A similar effect was observed for nitrogen fertilizers applied twice during the branching and early pod-filling stages at N₃₀: water use decreased by 12.7% and 8.4%, respectively (Appendices C1–C3).

During 2019–2020, water consumption per 1 t of seed was 2,611 m³ in the pure control variant. In the variant with two nitrogen applications (30 kg/ha pre-sowing and 30 kg/ha as foliar fertilization), water consumption decreased to 2,225 m³, or 14.8% less. Triple foliar application of ROMP solutions containing microelements reduced water consumption under natural conditions by 22.4%, and under nitrogen background by 21.0%. Comparing the efficiency of the preparations depending on the nutrient background, the difference was 13.2% in favor of the nitrogen background (Appendices C4–C5).

Among the preparations, the lowest water consumption per ton of seed was observed for Fulvo TE, based on fulvic acids and containing nitrogen, K₂O, and microelements (Co, B, Cu, Fe, Zn, Mn, Mo). The water consumption coefficient for this variant averaged over two years was 1,904.6 m³/t under natural conditions and 1,613.8 m³/t under N₃₀+N₃₀ background, corresponding to 72.9% and 72.5% of the control, respectively. Similar effects of microelements have been reported under other arid conditions [146].

Conclusions for Chapter 3

1. Weather conditions during the chickpea growing season significantly influence its water consumption and the structure of the crop water balance. With increasing atmospheric drought, but in the absence of significant soil drought, the contribution of soil moisture to chickpea yield formation can range from 29.4% to 48.9%. Under severe combined atmospheric and soil drought, when productive moisture reserves in the one-meter soil layer remain ≤30 mm throughout the growing season and no effective precipitation occurs from sowing to the onset of flowering, the share of soil moisture in total water consumption decreases to 12–13%. During this period, severe stress experienced by chickpea plants prevents full utilization of subsequent post-flowering precipitation, resulting in reduced crop productivity of 0.7–1.3 t/ha.

2. Application of mineral fertilizers positively affects the water-use efficiency of chickpea crops. The lowest water consumption coefficients were observed with N₃₀ applied on the background of R₃₀K₃₀ and

with two foliar nitrogen applications (N_{30}) during the branching and early pod-filling stages, amounting to 1,319 m³/t and 1,294 m³/t, respectively, compared to 1,483 m³/t on unfertilized plots.

3. Triple foliar application of liquid organo-mineral fertilizers containing a complex of macro- and microelements reduces water consumption per 1 t of seed by an average of 21.7%.

4. The lowest overall water consumption per 1 t of seed was recorded for the variant with Fulvo TE, based on fulvic acids. This preparation also contains nitrogen, K₂O, and microelements (Co, B, Cu, Fe, Zn, Mn, Mo). The water consumption coefficient in this variant is 27.3% lower than the control.

CHAPTER 4

GROWTH AND DEVELOPMENT OF CHICKPEA PLANTS DEPENDING ON NUTRITION SYSTEMS

4.1. Phenological Observations of Chickpea Plants

Determination of the stages of chickpea growth and development according to the Nolan system is based on counting the number of nodes on the main stem [277]. Their descriptions are developed on the basis of visual observations of vegetative (V) and reproductive (R) phases. The “V” stage was determined by counting the number of developed nodes on the main stem above the soil surface. The node at which the first branch appears on the main stem above the ground is considered node 1. In chickpea, subsequent primary branches usually arise from nodes slightly above the soil level, typically 1–8 primary branches on the main stem, depending on the growing conditions. A node is considered developed when 6–15 leaflets reach the stage of full expansion. The leaves of the last counted node must be unfolded.

The vegetative stage is considered to last from germination to the appearance of the first flower; however, a distinctive feature of chickpea is that its terminal bud remains vegetative and continues to grow. Vegetative growth thus continues even after the plant has entered the reproductive phase. The “R” stages occur when the plant begins to flower at any node and continue until full maturity. Such a classification of developmental phases is rather cumbersome and has not gained acceptance in Ukraine.

As a rule, during the chickpea growing season, the following main phases of growth and development are distinguished: emergence, budding, flowering, pod formation, ripening, and full seed maturity [186]. Determining the rates of growth and development of chickpea varieties during ontogenesis provides an opportunity to reveal the most important dependencies in the process of productivity formation in this crop [97; 112].

The vegetation period of chickpea ranges from 80 to 120 days and depends on the genetic characteristics of the variety as well as on the applied elements of cultivation technology [21; 60; 204].

Chickpea, as a drought-tolerant plant, is considered a promising crop under conditions of global climate change [19; 154; 218]. At the same time, according to numerous researchers, it responds sensitively to fluctuations in moisture availability and air temperature [232; 257; 295]. Meteorological studies indicate significant seasonal and monthly variations in precipitation totals and temperature regimes across different soil and climatic zones of Ukraine [41; 269]. Researchers also draw attention to changes in precipitation patterns and temperature trends [89; 147; 150]. These negative tendencies directly affect the phenology and duration of the interphase periods of growth and development in agricultural crops.

The above assumption is confirmed by studies showing a reduction in the period from sowing to full maturity of chickpea by an average of 2.73 to 4.89 days under a temperature increase of 0.82–1.15 °C [306]. It has been noted that temperature stress during the flowering and pod formation phases affects the duration of the interphase periods and leads to a sharp decline in chickpea yield—by 44% and 50%, respectively [239]. Similar results have been obtained under different soil and climatic conditions in Ukraine [36; 87; 122; 200; 290; 291]. Under conditions of adequate moisture and moderate air temperatures, the growth and development rates of chickpea plants slow down, while the intensity of the bioproductivity process increases [122; 125].

Thus, moisture conditions have a significant impact on the growth and development of chickpea plants, as they determine the availability of nutrients and water supply, thereby enhancing the intensity of growth processes. In conditions of moisture deficiency, there is a marked decrease in the grain yield of this important legume crop.

According to research results, the timing and duration of chickpea phenological growth and development phases depend considerably on moisture conditions during the years of study. The duration of the period from sowing to emergence is directly related to temperature: the higher the sum of active temperatures, the faster the emergence ($r = 0.87$). However, a lack of moisture combined with high temperatures delays emergence (determination coefficient = 0.85).

Based on the research conducted in 2016–2018, full emergence of chickpea was recorded as follows: in 2016 – after 12 days, in 2017 – after 15 days, in 2018 – after 17 days; in 2019 – after 16 days; and in 2020 – after 14 days.

In 2016, weather conditions favored faster emergence but extended the overall vegetation period of chickpea. Excessively moist spring and early summer conditions, when spring precipitation exceeded the long-term average by 2–3 times, and June precipitation was 13.8% above the norm, resulted in a significant prolongation of the vegetation period as a whole and the duration of individual growth and development phases in particular (Table 4.1).

Table 4.1

**Duration of Interphase Periods in Chickpea Ontogenesis,
Average for 2016–2020**

Year	Duration of Interphase Periods					Duration of the Vegetation Period
	Sowing – Emergence	Emergence – Budding	Budding – flowering	Flowering – pod formation	Pod formation – full maturity	
2016	12	19	16	20	52	119
2017	15	16	16	18	50	115
2018	17	13	18	18	42	108
2019	16	15	12	16	34	93
2020	14	16	13	16	43	102
M ± m	14,8 ± 0,9	15,8 ± 1,0	15,0 ± 1,1	17,6 ± 0,7	44,2 ± 3,3	107,4 ± 4,6

In particular, the phase of full maturity occurred after 119 days, while in the hottest years it was reached in 93–108 days. The average duration of interphase periods in the vegetation cycle of the Pamiat variety of chickpea was as follows: “sowing – emergence” – 14.8 days, “emergence – budding” – 15.8 days, “budding – flowering” – 15.0 days, “flowering – pod formation” – 17.6 days, “pod formation – full maturity” – 44.2 days, and the total vegetation period – 107.4 days. The average values were within the standard deviations of the sample mean with a 95% confidence probability. The results of our studies on the significant influence of meteorological factors are consistent with the findings of other researchers [148; 150].

It is important to emphasize that the author assessed the influence of soil and climatic parameters—such as precipitation, the hydrothermal coefficient (HTC), the sum of temperatures above 10 °C, and the amount of productive moisture in the one-meter soil layer—on the duration of the chickpea vegetation period and its individual interphase periods. The effect of nutrition systems was not considered in this analysis, primarily because the differences in the duration of interphase periods between their variants did not exceed 1–2 days during the early “emergence – budding” phase and later leveled out. Secondly, the efficiency and degree of influence of nutrition systems are also largely determined by weather conditions.

The study was based on established results for other crops showing that rhythmic fluctuations of abiotic factors create a certain physiological tension that affects the duration of the vegetation period, as well as the formation of chickpea yield structure and overall productivity [43; 131; 153; 183].

Therefore, identifying correlation relationships to determine statistical criteria for managing the variability of such traits as the duration of chickpea interphase periods is a relevant research objective from both scientific and practical perspectives.

Table 4.2 presents the influence of weather conditions on the duration of interphase periods in the Pamat chickpea variety grown under rainfed conditions in the Southern Steppe of Ukraine. The selection of weather data periods is based on their correspondence to the developmental phases of the chickpea plants. In other words, the sum of effective temperatures or the amount of precipitation preceding a specific phenological phase may have a significant impact on its duration. However, the indicators corresponding to subsequent growth and development phases cannot determine the duration of the phases that have already occurred.

The duration of the “sowing – emergence” period is influenced by the sum of effective temperatures $\geq +10$ °C in April and by precipitation in the pre-sowing period (March), with correlation coefficients of $r = -0.54$ and $r = 0.53$, respectively. Evidently, the sum of effective temperatures has a positive effect on the rate of chickpea emergence, reducing the period from sowing to seedling appearance.

Table 4.2

Correlation between the Duration of Chickpea Interphase Periods and Weather Parameters during the Growing Season

Interphase Period	Weather Parameter	Correlation Coefficient, r	
Sowing – Emergence	March precipitation	0.53	
	Σ temperatures > 10 °C in April	-0.54	
	Productive moisture reserves in the 0–100 cm soil layer during sowing	-0.14	
Emergence – Budding	April precipitation	April	0.58
		May	0.55
	Σ temperatures > 10 °C	April	-0.63
		May	-0.75
Budding – Flowering	Productive moisture reserves in the 0–100 cm soil layer		0.78
	Σ temperatures > 10 °C	April	0.80
		May	0.88
June	-0.71		
Flowering – Pod Formation	Productive moisture reserves in the 0–100 cm soil layer		0.84–0.95
	May precipitation		0.43
	Σ temperatures > 10 °C	May	0.88
June		-0.70	
Pod Formation – Full Maturity	Productive moisture reserves in the 0–100 cm soil layer		0.91–0.71
	Σ temperatures > 10 °C	June	-0.70
Entire Vegetation Period	Productive moisture reserves in the 0–100 cm soil layer	sowing	0.94
		flowering	0.98
		pod formation	0.69
	precipitation	April	0.71
		May	0.54
		July	-0.36
	Σ temperatures > 10 °C	April	0.43
		May	0.43
		June	-0.70

The duration of the interphase period “emergence – budding” moderately depends on April and May precipitation, with correlation coefficients of $r = 0.58$ and $r = 0.55$, respectively. It also exhibits a strong negative correlation with the sum of effective temperatures $\geq +10$ °C in April and May ($r = -0.63$ and $r = -0.75$, respectively).

The durations of the “budding – flowering” and “flowering – pod formation” periods are critical in relation to productive soil moisture reserves, with correlation coefficients of $r = 0.78$ and $r = 0.84-0.95$, respectively. The sums of effective temperatures $\geq +10$ °C in May and June are $r = 0.80-0.88$ and $r = -(0.71-0.70)$, respectively. Although chickpea plants received sufficient heat supply during earlier growth stages prior to the “budding – pod formation” period, the contribution of these factors to subsequent growth and development remains significant.

Important factors determining the duration of the “pod formation – full maturity” period are the productive soil moisture reserves in the 0–100 cm soil layer ($r = 0.91-0.71$). The sums of effective temperatures $\geq +10$ °C for June and July are $r = -0.70$ and $r = -0.50$, respectively. The direct positive relationship between productive soil moisture reserves and the 0–100 cm layer indicates that increased soil moisture prolongs the pod formation and grain ripening phases. Conversely, higher sums of active temperatures accelerate grain maturation, shortening the duration of this interphase period.

Overall, the duration of the entire chickpea vegetation period is highly sensitive to productive soil moisture reserves from sowing to pod formation ($r = 0.98-0.69$), as well as to April and May precipitation ($r = 0.71-0.54$). At the end of the vegetation period in July, precipitation shows an inverse relationship ($r = -0.36$). The vegetation period is also affected by the sums of effective temperatures $\geq +10$ °C in April and May ($r = 0.43$), while the sum of effective temperatures $\geq +10$ °C in June has a negative influence ($r = -0.70$).

4.2. Influence of Nutrition Systems on the Linear Dimensions of Chickpea Plants

Under optimal provision of all essential growth factors, the vertical growth of leguminous crops is an almost continuous process, unlike most other agricultural crops whose linear dimensions are mainly formed before the flowering stage. If precipitation occurs during chickpea ripening, and the plant has already developed grain, it resumes growth, forms new buds, and continues flowering. From a technological standpoint, this is undesirable, as it complicates harvesting and requires agrotechnical drying measures.

At the same time, there is a strong positive correlation between chickpea yield and morphological traits—particularly plant height—with a correlation coefficient of $r = 0.66$ [125; 141; 144].

According to the research results, pre-sowing inoculation and the type of inoculant had no noticeable effect on the progression of growth and development phases. Therefore, the linear dimensions of plants corresponding to the branching and full maturity stages are presented according to the variants of fertilization systems and years of research (Tables 4.3, 4.4).

Table 4.3

Height of chickpea plants depending on the fertilizer system at the branching stage

№	Fertilizer system	Plant height, cm				± to Control	
		2016	2017	2018	Average	cm	%
1	2	3	4	5	6	7	8
1	Control	18.5	13.4	12.9	14.9	0	0
2	P ₃₀ K ₃₀	20.6	15.3	13.8	16.6	1.7	11.4
3	P ₃₀ K ₃₀ +N ₃₀	21.6	15.4	14.1	17.0	2.1	14.1
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	23.4	15.3	14.2	17.6	2.7	18.1
5	P ₃₀ K ₃₀ +N ₆₀	24.4	14.8	13.6	17.6	2.7	18.1
6	N ₃₀ P ₃₀ K ₃₀	24.6	14.6	13.5	17.6	2.7	18.1
7	N ₆₀ P ₃₀ K ₃₀	25.3	14.3	13.8	17.8	2.9	19.5
8	N ₃₀ applied at sowing	21.3	15.4	14.1	16.9	2.0	13.4
9	N ₆₀ applied at sowing	24.2	15.8	14.7	18.2	3.3	22.1

Continuation of Table 4.3

1	2	3	4	5	6	7	8
10	N ₉₀ applied at sowing	25.4	14.9	14.4	18.2	3.3	22.1
11	N ₁₂₀ applied at sowing	24.8	15.1	14.6	18.2	3.3	22.1
12	N ₃₀ +N ₃₀ during vegetation	19.6	14.1	13.8	15.8	0.9	6.0
LSD _{0.5}		1.1	1.3	1.5	–		

It should be noted that inoculants also significantly increased the linear dimensions of chickpea plants at the branching stage compared to the control – by an average of 13.5% over the years of the study. No statistically significant difference was observed between the inoculant variants.

Table 4.4

Height of Chickpea Plants Depending on the Fertilizer System at the Full Maturity Stage

№	Fertilizer system	Plant height, cm				± to Control	
		2016	2017	2018	Average	cm	%
1	Control	53.1	40.3	30.8	41.6	0	0
2	P ₃₀ K ₃₀	61.7	40.9	31.0	44.5	2.9	7.1
3	P ₃₀ K ₃₀ +N ₃₀	61.7	42.3	33.3	45.8	4.2	10.0
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	66.9	43.8	35.2	48.6	7.0	16.9
5	P ₃₀ K ₃₀ +N ₆₀	67.8	41.2	35.1	48.0	6.4	15.5
6	N ₃₀ P ₃₀ K ₃₀	70.4	43.7	36.2	50.1	8.5	20.4
7	N ₆₀ P ₃₀ K ₃₀	70.3	42.0	35.8	49.4	7.8	18.7
8	N ₃₀ applied at sowing	60.9	41.5	36	46.1	4.5	10.9
9	N ₆₀ applied at sowing	55.2	42.5	37.2	45.0	3.4	8.1
10	N ₉₀ applied at sowing	52.8	43.1	37.6	44.5	2.9	7.0
11	N ₁₂₀ applied at sowing	51.4	40.8	37.0	43.1	1.5	3.5
12	N ₃₀ +N ₃₀ during vegetation	56.7	46.1	37.2	46.7	5.1	12.2
LSD _{0.5}		1,5	1.4	1.7	24.5	–	

On average, during 2016–2018, all fertilizer systems (except variant 12) significantly increased chickpea plant height at the branching stage, with growth ranging from 11.4% to 22.1%

The degree of influence varied by year: in 2016, all fertilizer treatments significantly increased plant height compared to both the control and the phosphorus–potassium variant; in 2017, nearly all variants, except those with full mineral fertilization before sowing, showed a significant increase compared to the control; in 2018, significant differences were observed only between the control and treatments with N₆₀–N₁₂₀ applied at sowing.

The average plant height at the branching stage was 22.8 cm in 2016, 14.9 cm in 2017, and 13.9 cm in 2018. At the end of the growing season, during full maturity, the average height reached 59.9 cm, 42.2 cm, and 35.1 cm, respectively.

Thus, fertilizer systems – with minor variations – affected the linear size of chickpea plants at full maturity similarly to the branching stage.

In the experiment evaluating the effectiveness of biological preparations (ROMP), no significant differences were found between variants at the branching stage (Table 4.5, Fig. 4.1). The height values ranged from 11.2 to 11.8 cm in variants without nitrogen application, and from 13.0 to 13.6 cm with N₃₀ applied at sowing.

Table 4.5

Effect of Liquid Organo-Mineral Preparations and Nitrogen Fertilizers on the Dynamics of Chickpea Plant Height

Variant	Treatment	Plant Height by Phases		
		Branching	Flowering	Grain Filling
1	2	3	4	5
Without nitrogen fertilization	Control	11.15	28.05	32.15
	Amino	11.20	30.05	32.98
	Amino Micro	11.15	30.55	33.83
	Fulvo TE	11.05	33.48	35.52
	SeedTreatment	11.13	32.21	34.83
	Anti-stress (SG Protector)	11.82	33.15	37.05
	EXTRA	11.25	30.75	34.67
	RootMost	11.23	32.38	37.55
	Polymicrostim	11.51	31.46	35.89

Continuation of Table 4.5

1	2	3	4	5
	Avatar Organic + Avatar Protection + Avatar Barrier	11.08	29.95	32.37
	LSD _{0.5}	1.25	1.85	2.23
With N ₃₀ +N ₃₀ background	Control	13.45	30.28	35.37
	Amino	13.25	25.48	27.43
	Amino Micro	13.34	27.55	31.97
	Fulvo TE	13.55	33.45	35.38
	Seed Treatment	13.05	33.58	35.45
	Anti-stress (SG Protector)	13.63	34.41	38.85
	EXTRA	12.98	33.72	37.37
	RootMost	13.15	34.25	36.22
	Polymicrostim	13.19	34.15	38.77
	Avatar Organic + Avatar Protection + Avatar Barrier	13.02	26.70	28.5
	LSD _{0.5}	2.45	2.43	3.05

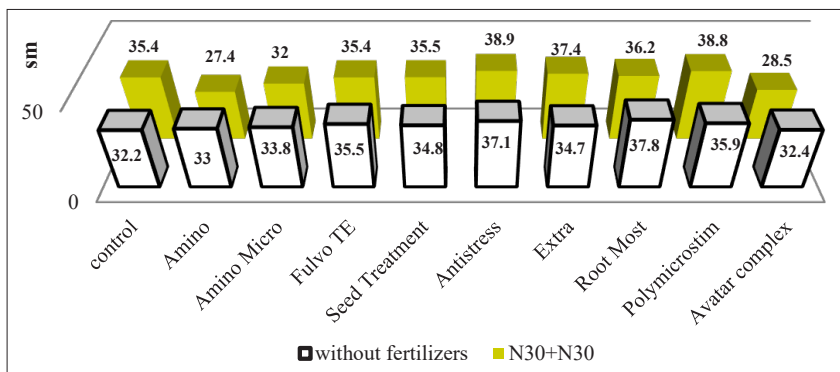


Fig. 4.1. Effect of Nutritional Background on Chickpea Plant Height at the Grain Filling Stage, cm

This can be explained by the fact that the experimental factors had not yet influenced growth processes, as chickpea plants were treated with the preparations for the first time at the branching stage. During flowering and grain filling, chickpea plants differed significantly in height depending on the combination of experimental factors.

It should be noted that after treatment at the branching stage, plants in the Amino and Amino Micro variants showed burn symptoms; therefore, in the next two phases, the working solution concentration of these preparations was halved, yet the plants under these treatments still lagged in development compared to others.

Application of pre-sowing mineral nitrogen at 30 kg/ha positively affected the linear dimensions of chickpea plants; in the control variant, plant height increased by 10.0% (Fig. 4.1). However, the combined effect of mineral nitrogen and liquid organo-mineral preparations (LOMP) was not so straightforward: the best plant growth was observed in the Seed Treatment, Anti-stress (SG Protector), EXTRA, and Polymicrostim treatments, where the increase ranged from 1.8 to 8.0% compared to the same treatments without fertilization.

A similar trend persisted until full grain maturity. Plants on plots with nitrogen application were taller than control plants: by 6.6% compared to the untreated control, and by 7.0–7.1% in the Amino Micro, Fulvo TE, and Polymicrostim variants (Fig. 4.2). The minimal increase, 1.9%, was recorded with the Avatar complex, while a slight decrease of -0.6% occurred with Amino.

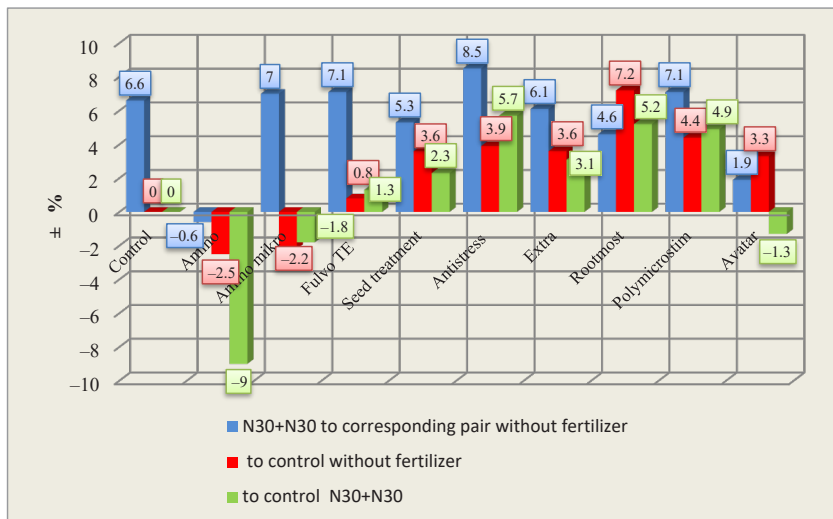


Fig. 4.2. Deviations in Chickpea Plant Height at Full Maturity

When comparing treatments within each nutritional block, in variants with biopreparations versus the respective control, there was an obvious reduction in plant height by 2.5–2.2% for Amino and Amino Micro. Combined application of mineral nitrogen with Amino resulted in a maximum decrease of 9.0%. Under nitrogen fertilization, the greatest positive effect on plant growth and development was observed with RootMost (+5.2%) and Anti-stress (+5.7%), while on unfertilized plots, the maximum was observed with RootMost (+7.2%).

4.3. Effect of Mineral Fertilizers and Inoculants on Chlorophyll Synthesis

The process of photosynthesis is fundamental to life on our planet, as it transforms solar energy into the chemical energy of synthesized compounds. Chloroplasts play the leading role in this process; they consist of pigments, proteins, vitamins, and chloroplast RNA, which ensures protein synthesis in plants. The activity of photosynthesis is assessed based on the concentration of the main photosynthetic pigments—chlorophylls. Most green plants contain two forms of chlorophyll: alpha (α) and beta (β).

It has been established that high temperatures accelerate leaf senescence, which leads to chlorophyll degradation and halts the translocation of assimilates to the grain [227; 259]. Chickpea plants, however, are more sensitive to soil water deficiency than to high air temperatures when water supply is adequate [286].

Water deficit, which damages the photosynthetic structures of plants, causes shifts in the balance between photosynthesis and photoinhibition processes [297]. The content of green pigments in leguminous crops (such as common bean and mung bean) under drought conditions decreases significantly due to reductions in both chlorophyll α and chlorophyll β [182]. These findings were confirmed in studies where the percentage decrease in pigment content under drought conditions ranged from 7.35 to 35.84% for chlorophylls and from 13.36 to 31.15% for carotenoids, depending on the chickpea genotype and plant developmental stage [282].

The extent of pigment degradation also depends on various other factors, including the type, rates, and timing of mineral fertilizer application, particularly nitrogen [288]. Researchers note that up to 75% of leaf nitrogen is contained in chloroplasts [242; 245]; thus, nitrogen deficiency often leads to a decrease in the chlorophyll index, resulting in reduced photosynthesis and lower yields of leguminous crops [304]. Studies on wild pea samples indicate a relationship between high seed protein content and elevated chlorophyll and carotenoid levels [16].

Significant differences in chlorophyll content have been observed depending on nitrogen levels during the early flowering stages of rapeseed. Phosphorus alone does not influence this trait, but at the late flowering stage, the interaction between nitrogen and phosphorus becomes significant [305]. An increase in chlorophyll α and β content was also observed in the leaves of red clover throughout all vegetative phases under moderate mineral fertilizer application rates – $N_{31}P_{32}K_{36}$ [192]. Mineral fertilization at rates of $N_{90}P_{60}K_{40}$, with zinc included in the phosphorus fertilizers, delayed the degradation of the pigment complex in winter wheat and contributed to higher chlorophyll and carotenoid concentrations compared to unfertilized controls [117].

Fertilization of spring wheat significantly increased the content of photosynthetic pigments in the leaves, with the optimal effect achieved through combined foliar feeding using urea at 30 kg/ha in combination with KristaLon. Increasing the urea rate to 40 kg/ha did not result in a noticeable increase in the photosynthetic pigment content in the leaves [178]. The results of these studies demonstrate a direct and strong correlation between the pigment content in leaves and the yield of agricultural crops.

At the same time, there is a limited body of research on chickpea cultivation in the Southern Steppe of Ukraine. According to studies conducted in the Forest-Steppe zone of Ukraine, the highest chlorophyll content in chickpea leaves was observed during the flowering phase in treatments with $N_{45}P_{45}K_{45}$ application [37]. In this case, split nitrogen application—30 kg/ha at primary soil tillage + 15 kg/ha at the beginning of branching—contributed to a 3.3% increase in green pigment content compared to a single application of N_{45} . The same trend was observed with $N_{30}P_{30}K_{30}$ application. Overall, mineral

fertilization increased the total chlorophyll α and chlorophyll b content compared to the control by 2.4% to 28.0%, while seed inoculation with Rizogumin before sowing and the combined effect of fertilization and inoculation increased chlorophyll content by 14.0% and 19.5–33.8%, respectively, relative to the untreated control.

Therefore, it is of interest to determine the effect of different mineral fertilizer rates, methods of application, and pre-sowing seed inoculation on chickpea chlorophyll content, as such studies are limited across the various soil-climatic conditions of Ukraine.

The dynamics of chlorophyll α content under different fertilizer treatments during the study years are illustrated for the non-inoculated seed block (Fig. 4.3).

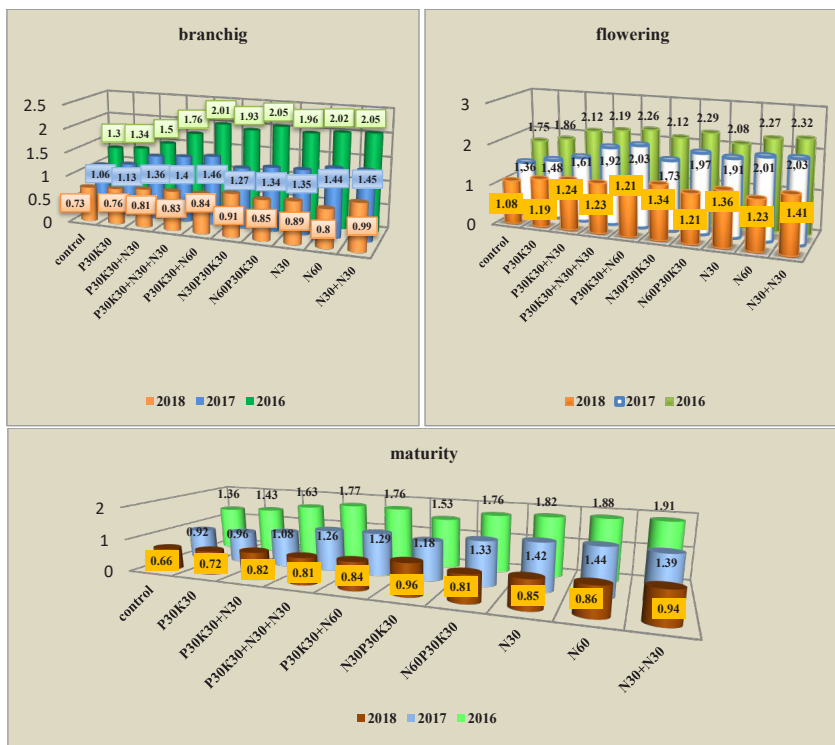


Fig. 4.3. Dynamics of chlorophyll α content in chickpea leaves during the study years, mg/g fresh weight

For example, in 2016, the highest pigment levels across all vegetative phases were observed in the treatment with two-stage $N_{30}+N_{30}$ fertilization and with pre-sowing $N_{60}P_{30}K_{30}$ application, which amounted to 2.05 mg/g during branching, 2.32 mg/g during flowering, and 1.91 mg/g at maturity (Appendix C).

Under the weather conditions of 2017, during the branching and flowering phases, the highest chlorophyll α levels were observed in treatments with a single N_{60} application on a phosphorus–potassium background and in the $N_{30}+N_{30}$ split application, reaching 1.46 and 1.45 mg/g as well as 1.92 and 2.03 mg/g, respectively. In the maturation phase, the maximum pigment level was achieved with a single N_{30} application (1.42 mg/g) and N_{60} (1.44 mg/g). In 2018, chlorophyll α synthesis was generally lower, but the $N_{30}+N_{30}$ treatment again showed the highest pigment levels, ranging from 0.94 to 1.41 mg/g.

The average results over three years of research are presented in Figs. 4.4 and 4.5, where fertilizer treatments are grouped by type: nitrogen, phosphorus–potassium, complete fertilization, and mineral nitrogen top-dressing on a P–K background.

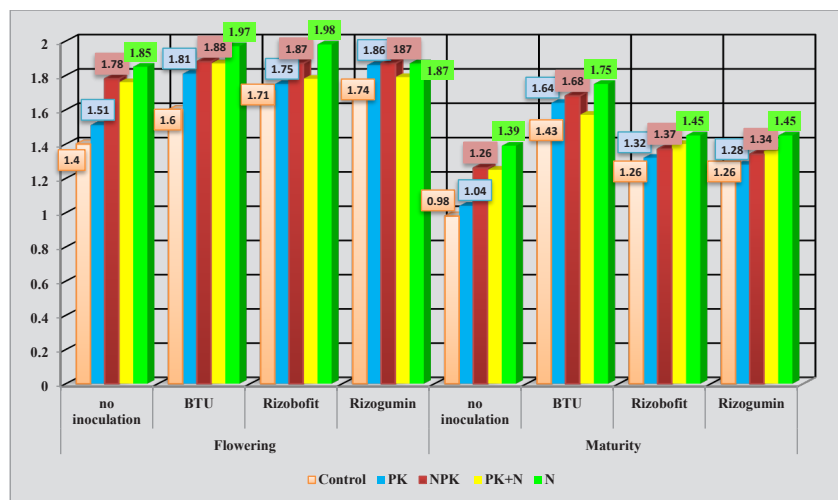


Fig. 4.4. Effect of mineral fertilizers and pre-sowing seed treatment on chlorophyll α content in chickpea leaves, mg/g fresh weight, average 2016–2018

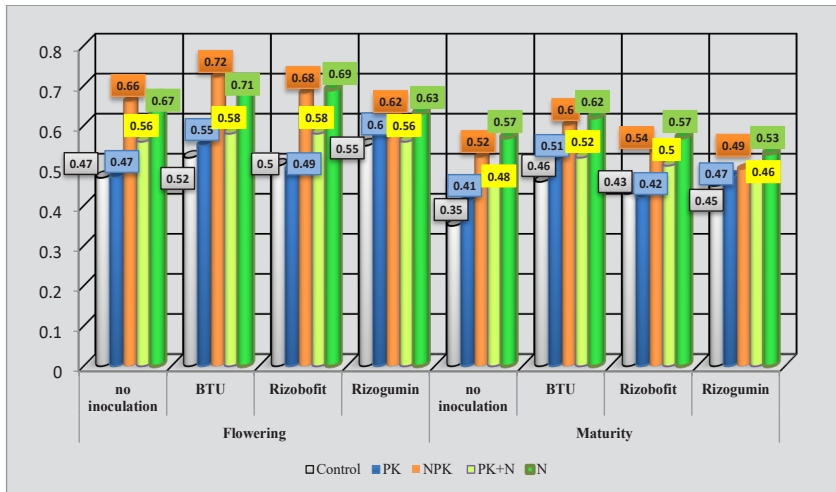


Fig. 4.5. Chlorophyll b concentration in chickpea leaves under fertilization and inoculation treatments, mg/g fresh weight, average 2016–2018

Both during flowering and at maturity, higher chlorophyll α concentrations were observed with nitrogen fertilization: during flowering, treatments with pre-sowing inoculation with BTU or Rizobofit yielded 1.97–1.98 mg/g, while BTU application during maturity resulted in 1.75 mg/g.

For chlorophyll b content during flowering, the highest levels were observed in treatments with complete mineral fertilization and nitrogen combined with BTU inoculant (0.72 mg/g and 0.71 mg/g) or Rizobofit (0.69 mg/g and 0.68 mg/g). During pod formation and chickpea maturation, the same fertilizers combined with BTU seed inoculation ensured maximum pigment retention, reaching 0.60–0.62 mg/g compared to 0.35 mg/g in the untreated control.

On average, for 2016–2018, combined fertilization and inoculation increased chlorophyll α content in chickpea leaves compared to the unfertilized, non-inoculated control by 29.3–41.4% during flowering and by 30.6–78.6% at maturity (Fig. 4.6). The best results were generally obtained with the combination of fertilization and pre-sowing BTU seed inoculation.

A similar effect was observed for chlorophyll b concentration (Fig. 4.7). Notably, before flowering, the use of Rizogumin on a P–K background was most effective for chlorophyll α and b, while during maturation and throughout the vegetative period, the combination of fertilization with BTU inoculant particularly full mineral fertilization plus nitrogen top-dressing showed the greatest advantage.

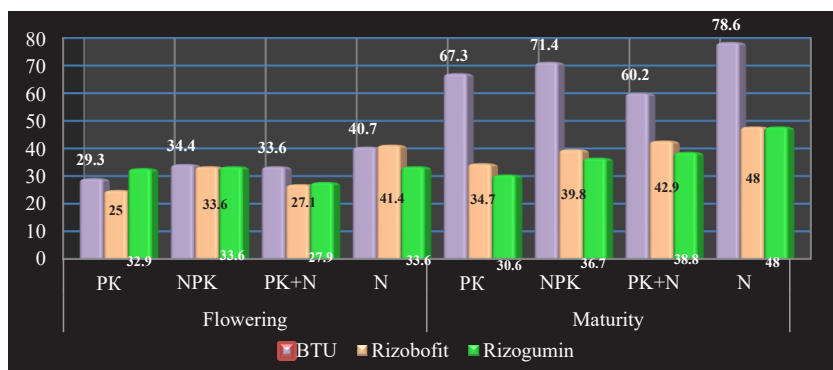


Fig. 4.6. Increase in chlorophyll α content in chickpea leaves under combined fertilization and inoculation, %, average 2016–2018

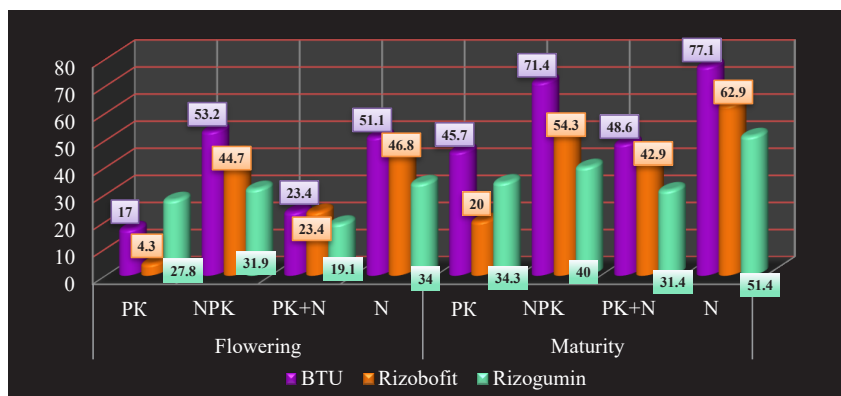
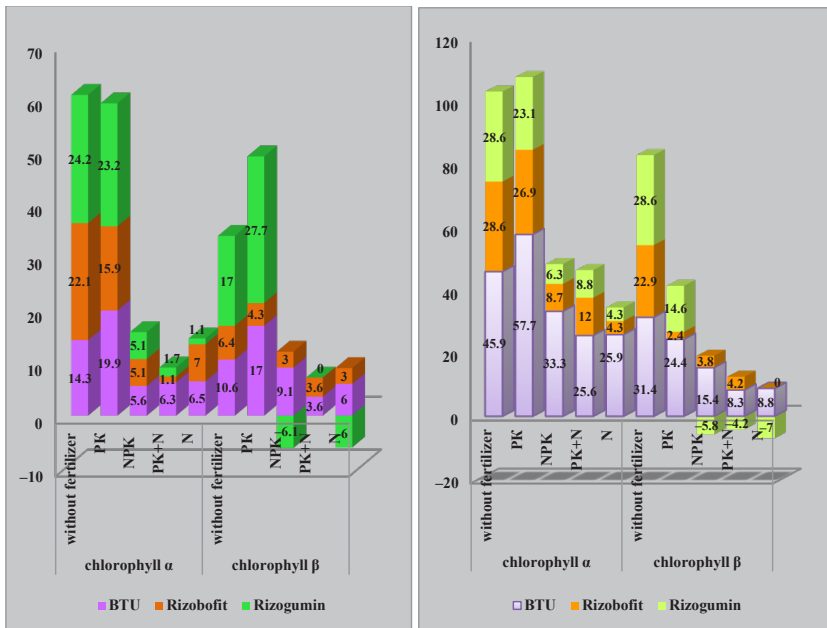


Fig. 4.7. Increase in chlorophyll b content in chickpea leaves under combined fertilization and inoculation, %, average 2016–2018

Analysis of inoculant effects confirmed previous conclusions: during 2016–2018, for chickpea grown without fertilization and with P–K application up to flowering, pre-sowing seed treatment with Rizogumin was more effective, contributing to chlorophyll increase as follows: without fertilization – 24.2% and 17.0%, with P–K – 23.2% and 27.7% (Fig. 4.8). However, from the beginning of the grain filling phase, BTU inoculant had a stronger influence on pigment accumulation, both with and without fertilization.

It is noteworthy that the effect of inoculants depended on the type of fertilization: the maximum impact was observed with all treatments without mineral fertilization and with P₃₀K₃₀ application. Adding nitrogen to phosphorus–potassium fertilizers, regardless of application method pre-sowing or split reduced the effectiveness of Rizogumin in pigment synthesis or retention, sometimes to zero or even negative values.



a) flowering

b) maturity

Fig. 4.8. Increase in chlorophyll a and b content in chickpea leaves due to inoculant application, %, average 2016–2018

Calculation of paired correlation coefficients revealed a strong positive relationship between nitrogen fertilizer rate and chlorophyll concentration in chickpea leaves: for α , the correlation coefficients over the study years were 0.90, 0.75, and 0.75; for b – 0.94, 0.88, and 0.86. Phosphorus–potassium fertilizers tended to have a negative effect on chlorophyll synthesis: the absolute values of the correlation coefficients ranged from 0.10 to 0.51 for the α fraction and from 0.31 to 0.41 for the b fraction.

Correlation–regression analysis indicated that the chlorophyll α : b ratio in chickpea chloroplasts within a single developmental phase depended on the combined effect of factors. The significance of regression coefficients ranged from 75.6% to 85.7% with values of 0.89–0.91; only for the interaction “mineral fertilizers + Rizogumin” did it reach 32.9% ($R = 0.60$). Temporal fluctuations of this ratio were primarily determined by chickpea developmental phases and influenced by the studied factors to a degree of 18.7–29.2% ($R = 0.43$ –0.54).

Despite variations in absolute α / b values, it is notable that this ratio decreases in each phase and in all inoculation variants when moving from phosphorus–potassium and complete mineral fertilization to nitrogen mono-fertilizer application (Table 4.6). This decrease occurs due to an increased proportion of chlorophyll b in total chlorophyll, from +3.0–3.5% during branching to +1.5–2.5% at maturity.

The proportion of chlorophyll b also varied depending on weather conditions. For example, in the optimal year of 2016, under different fertilization systems and inoculation variants, it ranged from 20.5 to 27.0% (α / $b = 3.89$ –2.73); during the soil drought in 2018, the range increased to 30.5–41.7% (α / $b = 2.03$ –1.54). Thus, under stress conditions, the absolute content of chlorophyll fractions and their ratio changed: during soil drought, the share of chlorophyll b in the total increased.

As noted above (Figures 4.4 and 4.5), the maximum chlorophyll content was observed during the flowering phase of chickpea. Therefore, we calculated the correlation coefficients between chickpea grain yield and chlorophyll concentration during this phase for the years of study. For the pair “yield – chlorophyll α ”, $r = 0.78$; 0.56; 0.64; for the pair “yield – chlorophyll b ”, $r = 0.28$; 0.10; 0.40. Hence, the influence of chlorophyll b content on chickpea yield was more

noticeable in the less favorable weather conditions of 2018, whereas the influence of chlorophyll α content was more pronounced in the more favorable 2016.

Table 4.6

Ratio of chlorophyll fractions in leaf blades of chickpea plants by developmental phase, fertilizer treatment, and pre-sowing seed inoculation, mg/g fresh weight, average 2016–2018

Variant	Vegetation phase											
	Branching				Flowering				Maturity			
	K	BTU	RB	RG	K	BTU	RB	RG	K	BTU	RB	RG
Without fertilizer	2.65	3.19	3.31	3.00	2.96	3.11	3.45	3.16	2.83	3.21	2.95	2.90
P ₃₀ K ₃₀	2.76	3.45	3.17	2.96	3.25	3.32	3.65	3.10	2.63	3.31	3.22	2.79
P ₃₀ K ₃₀ +N ₃₀	2.76	3.47	3.19	2.91	3.15	3.37	3.31	3.21	2.71	3.12	2.98	2.91
P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	2.74	3.31	3.03	2.85	3.23	3.28	3.10	3.22	2.75	3.11	2.72	2.88
P ₃₀ K ₃₀ +N ₆₀	2.72	3.02	2.88	2.92	3.04	3.07	2.83	3.29	2.61	3.09	2.72	3.01
N ₃₀ P ₃₀ K ₃₀	2.48	2.74	2.79	2.74	2.60	2.59	2.66	3.13	2.32	3.11	2.70	2.83
N ₆₀ P ₃₀ K ₃₀	2.46	2.89	3.03	2.77	2.76	2.72	2.83	3.10	2.54	2.67	2.57	2.77
N ₃₀	2.39	2.64	2.59	2.75	2.67	2.84	2.89	2.94	2.33	2.89	2.46	2.83
N ₆₀	2.38	2.60	2.82	2.87	2.81	2.87	2.75	3.23	2.52	2.98	2.62	2.70
N ₃₀ +N ₃₀	2.43	2.59	2.63	2.74	2.79	2.81	2.97	2.98	2.49	2.76	2.72	2.83

Note: K – control; BTU – BTU inoculant; RB – Rizobofit; RG – Rizogumin.

Our results are consistent with findings from studies on chickpea and spring triticale, which show that weather conditions, particularly stress from soil drought, affect pigment synthesis intensity, and the variability of chlorophyll content under fertilization in such conditions is higher [178; 282].

Thus, it has been established that under stress conditions, especially drought, chlorophyll content decreases, particularly the α fraction, as it is less stable compared to chlorophyll b, and the ratio between these pigment forms decreases (see Table 4.6), which aligns with results from other researchers [86]. The ratio of chlorophyll α to chlorophyll b is considered an indicator of chromatic adaptation and, depending on the fertilization variants, decreased in the descending order: P-K → NPK → N. The effect of chickpea seed inoculation was determined

more by the type and timing of mineral fertilizer application than by weather conditions.

4.4. Leaf Area and Photosynthetic Potential

Researchers have established that the photosynthetic productivity of plants depends on the assimilation surface, the intensity of photosynthesis, and the efficiency of solar energy utilization. It has been determined that the optimal leaf area lies in the range of 40–50 thousand m²/ha; exceeding this range in crop fields disrupts gas exchange and reduces light penetration, leading to a sharp decline in productivity [149]. The intensity of photosynthesis typically reaches its maximum during the budding and flowering phases, then decreases as leaves age. The maximum development of chickpea leaf area coincides with the pod formation [189], flowering [126], and grain filling phases [55; 294].

The formation of leaf area in any cultivated plant depends both on a set of agronomic practices and on soil-climatic conditions. The temperature optimum for photosynthesis is 20–25 °C, which corresponds to maximum productivity. However, under field conditions, productivity remains nearly unchanged in the 16–29 °C range, provided plants have sufficient water. Under water deficit, photosynthesis operates at only 5–20% of its full capacity, and further water loss reduces its intensity; a 50% water deficit can completely halt photosynthesis. Dehydration affects stomatal function, which controls the entry of CO₂ into leaf tissues. Numerous studies on legumes such as chickpea, beans, and lentils have shown that stomatal closure under water stress reduces CO₂ concentration in leaves [225; 278]. By closing stomata, plants minimize water loss, but the decreased CO₂ concentration significantly reduces photosynthesis [237].

Drought conditions limit leaf area expansion and photosynthetic activity. During a 16-day water deficit, chickpea plants show a progressive decrease in photosynthetic activity, with net photosynthesis declining by an average of 45.3% by the end of the period. The same trend is observed in plant growth and leaf area development [254].

Increased growth intensity and extended photosynthetic activity are usually accompanied by increased leaf area. However, the relationship between photosynthesis intensity and grain yield is complex: photosynthesis only accumulates primary assimilates in leaves, while the quantity and quality of the harvest depend on the efficiency of their utilization for plant organ growth. Growth processes largely depend on the optimization of the nutrient regime, which is critical for the productive performance of chickpea crops as photosynthesizing systems.

The use of mineral and organic fertilizers, seed inoculants, growth stimulants, and other treatments affects photosynthetic parameters. For instance, chickpea leaf area reached a maximum under the application of $N_{30}P_{45}K_{45} + N_{15}$, averaging 47.4 thousand m^2/ha , which is 29.9% higher than the unfertilized control [37].

The quantitative and qualitative effects of different types of fertilizers on photosynthetic processes are also limited by temperature and moisture conditions, as noted in various studies. For example, the optimal application of organic fertilizer, such as biohumus, positively influenced all parameters of chickpea only under non-stress conditions. Under moderate drought stress, higher rates of biohumus increased only the photosynthetic pigments and photosynthetic potential. However, under severe water stress, no positive effects were observed on any of the parameters [245].

When soil moisture was sufficient, at 75% of full water capacity, the leaf area of chickpea plants receiving phosphorus fertilizers increased by an average of 59% compared to unfertilized plants. However, this parameter significantly decreased under water-limiting conditions for all phosphorus nutrition regimes [231].

In the Right-Bank Forest-Steppe on gray forest soils, pre-sowing treatment of seeds with rhizobial bacteria combined with foliar fertilization had little effect on leaf area during the early development stages of chickpea. The highest leaf area, 40.2 thousand m^2/ha , was recorded during the grain-filling phase in the Pegas variety, which represented an increase of 7.6 thousand m^2/ha compared to the control. Overall, the positive effect of combining pre-sowing seed treatment with the bioinoculant Rizoline + Rizoseive and two foliar applications of the micronutrient fertilizer Urozhay Bobovi was noted. This created the most favorable conditions for achieving maximum

photosynthetic productivity of the Pegas and Triumph chickpea varieties. In this variant, the highest photosynthetic productivity during the “full emergence – full maturity” period reached 1.798 and 1.662 million m²/ha, respectively [143].

Studies on the influence of pre-sowing treatments and varietal characteristics on the formation of the assimilatory apparatus of chickpea indicate that the photosynthetic potential of chickpea crops increases not only due to seed inoculation but also varies depending on the plant development stage, reaching maximum values from pod formation to seed maturation [91].

Our research confirmed the variability in the effectiveness of the “fertilizer–inoculant” complex on the development of chickpea leaf area: the direction and magnitude of the effect varied with the type of fertilizer and over time, depending not only on the growth stages within a single year but also on the differing responses of the same phase across years (Table 4.7). The most unstable results were observed in 2017, when chickpea grew under mild drought, while in years with contrasting hydrothermal conditions–2016 (optimal) and 2018 (severe drought)–the combined effect of the factors was generally significant, although grain yield in 2016 was several times higher than in 2018.

Table 4.7

Frequency of significant effects of the “fertilizer–inoculant” complex on chickpea leaf area by growth stages and study years, % of total cases

Year	Stage								
	1	2	3	1	2	3	1	2	3
	BTU	RB	RG	BTU	RB	RG	BTU	RB	RG
2016	91,7	83,3	75,0	100	100	100	100	100	100
2017	83.3	25.0	8.3	91.7	58.3	58.3	91.7	58.3	58.3
2018	100	100	100	100	100	100	100	100	100

Note: 1 – branching; 2 – flowering; 3 – full maturity; RB – Rizobofit; RG – Rizogumin.

On average, over three years of research, at the early stage of chickpea development, the largest leaf area was obtained in the variants with P₃₀K₃₀ and P₃₀K₃₀+N₃₀ in combination with BTU inoculant seed treatment (Table 4.8).

Table 4.8

Leaf area of chickpea plants depending on mineral fertilizer variants during branching, thousand m²/ha, average 2016–2018

Fertilizer (Factor A)	Inoculants			
	no inoculation	BTU	Rizobofit	Rizogumin
Control	7.86	8.59	8.73	8.46
P ₃₀ K ₃₀	9.15	10.22	9.02	9.39
P ₃₀ K ₃₀ +N ₃₀	9.29	10.86	9.67	9.75
P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	9.14	9.94	9.69	9.69
P ₃₀ K ₃₀ +N ₆₀	9.37	10.20	9.45	9.97
N ₃₀ P ₃₀ K ₃₀	10.04	10.08	10.45	10.14
N ₆₀ P ₃₀ K ₃₀	9.16	9.78	10.07	10.12
N ₃₀ at sowing	9.03	9.73	9.56	9.76
N ₆₀ at sowing	9.92	9.45	8.50	8.41
N ₉₀ at sowing	8.47	9.34	9.32	9.08
N ₁₂₀ at sowing	8.58	8.98	8.20	8.54
N ₃₀ +N ₃₀ in vegetation	8.36	10.00	9.37	8.83
LSD _{0.5} for factors: A = 0.85; 0.43; 0.28. B = 1.04; 0.37; 0.25. AB = 0.53; 0.79; 0.12.				

The increase was 30.0% and 38.2% compared to the untreated control without pre-sowing seed treatment. The positive effect of all inoculants was noted with N₃₀P₃₀K₃₀, with increases of 28.3% for BTU, 33.0% for Rizobofit, and 29.0% for Rizogumin.

Maximum leaf area was observed in all variants during the flowering phase. Increases for fertilizer variants without inoculation ranged from 11.2% (N₁₂₀) to 21.2% (N₆₀); with BTU – from 19.0% (N₆₀P₃₀K₃₀) to 32.8% and 31.9% (P₃₀K₃₀+N₃₀ and N₃₀+N₃₀) (Table 4.9). Rizobofit was more effective in combination with two nitrogen top-dressings N₃₀+N₃₀ (+29.2%). The combination of Rizogumin and P₃₀K₃₀+N₃₀ provided an increase in leaf area of 24.6%.

At the end of vegetation, the P₃₀K₃₀+N₃₀ fertilization system combined with pre-sowing seed treatment with biological preparations increased leaf area as follows: BTU – +34.1%; Rizobofit – +23.2%; Rizogumin – +25.1%.

Two-time nitrogen top-dressing provided an increase in leaf area of: BTU – +31.4%; Rizobofit – +29.4%; Rizogumin – +21.2% (Table 4.10).

Table 4.9

Leaf area of chickpea plants depending on mineral fertilization variants during flowering, thousand m²/ha, average 2016–2018

Fertilizer (Factor A)	Inoculants			
	no inoculation	BTU	Rizobofit	Rizogumin
Control	20.79	23.40	23.47	22.87
P ₃₀ K ₃₀	23.46	25.19	23.77	24.69
P ₃₀ K ₃₀ +N ₃₀	23.80	27.61	25.45	25.90
P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	23.5	25.64	24.20	24.87
P ₃₀ K ₃₀ +N ₆₀	23.55	26.12	24.12	24.14
N ₃₀ P ₃₀ K ₃₀	24.51	25.51	24.64	24.57
N ₆₀ P ₃₀ K ₃₀	23.93	24.74	24.89	25.66
N ₃₀ at sowing	23.89	25.93	24.80	24.61
N ₆₀ at sowing	25.18	25.74	24.85	25.28
N ₉₀ at sowing	24.67	25.18	25.79	24.73
N ₁₂₀ at sowing	23.11	24.79	23.87	23.96
N ₃₀ +N ₃₀ in vegetation	24.31	27.42	26.85	25.21

LSD_{0.5} for factors: A = 1.27; 1.00; 1.19. B = 1.31; 0.85; 1.09.
AB = 0.94; 1.33; 0.51.

Table 4.10

Leaf area of chickpea plants depending on mineral fertilization variants at full maturity, thousand m²/ha, average 2016–2018

Fertilizer (Factor A)	Inoculants			
	no inoculation	BTU	Rizobofit	Rizogumin
Control	10.48	11.80	11.80	11.57
P ₃₀ K ₃₀	11.77	12.69	12.03	12.52
P ₃₀ K ₃₀ +N ₃₀	11.99	14.05	12.92	13.11
P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	11.83	13.01	12.18	12.48
P ₃₀ K ₃₀ +N ₆₀	11.97	13.28	12.29	12.26
N ₃₀ P ₃₀ K ₃₀	12.50	12.81	12.42	12.43
N ₆₀ P ₃₀ K ₃₀	12.20	12.55	12.63	13.01
N ₃₀ at sowing	12.09	13.24	12.65	12.51
N ₆₀ at sowing	12.77	13.06	12.53	12.75
N ₉₀ at sowing	12.54	12.66	12.90	12.48
N ₁₂₀ at sowing	11.70	12.54	12.07	12.08
N ₃₀ +N ₃₀ in vegetation	12.33	13.77	13.56	12.70

LSD_{0.5} for factors: A = 1.24; 0.42; 0.57. B = 0.80; 0.36; 0.52.
AB = 0.55; 0.56; 0.24.

In the above tables, a visual trend of decreasing leaf area with increasing rates of mineral nitrogen in its pure form is observed. Therefore, it was considered appropriate to determine the regression equation parameters, treating nitrogen application rates as a factor influencing leaf area when combined with different inoculants (Table 4.11). This can effectively be regarded as the influence of nitrogen rates on the efficiency of pre-sowing seed treatment. The parameters of the equations were determined using the least squares method, and the reliability of the approximation was evaluated using the coefficient of determination [206].

Table 4.11

Trend equations

Inoculant	Growth stage		
	Branching	Flowering	Full maturity
BTU	$-0.02x^2-0.13x+9.865$	$-0.05x^2-0.148x+26.151$	$0.015x^2-0.325x+13.575$
R ²	0.969	0.982	0.962
Rizobofit	$0.2025x^2-1.315x+10.708$	$-0.493x^2+2.28x+22.83$	$-0.185x^2+0.791x+11.955$
R ²	0.540	0.619	0.589
Rizogumin	$0.735x^2-4.30x+13.39$	$-0.36x^2+1.55x+23.47$	$-0.16x^2+0.644x+12.045$
R ²	0.754	0.943	0.969

The behavior model is sufficiently accurately described by a second-degree equation (Appendix C). Trend lines are closest to actual data for BTU in all growth stages and for Rizogumin during flowering and full maturity, as the coefficient of determination ranges between 0.962–0.982 and 0.943–0.969, respectively. It is generally accepted that when $R^2 \geq 0.85$, smoothing is considered reliable [211]. In the case of Rizobofit, the relationship is not as tight, but still reasonably high, ranging from 0.54 to 0.62.

One of the main indicators of photosynthetic activity in agricultural crops is photosynthetic potential. In 2016, chickpea crops formed the largest leaf area, which also affected photosynthetic potential. From branching to full maturity, photosynthetic potential varied depending on fertilizer variants from 2.40 (P₃₀K₃₀) to 2.66 million m²/day/ha (N₃₀). Specifically, in 2017 – from 1.73 (P₃₀K₃₀) to 1.93 (N₃₀+N₃₀ in vegetation), and in 2018 – from 1.07 (N₃₀) to 1.29 (N₉₀) (Fig. 4.9).

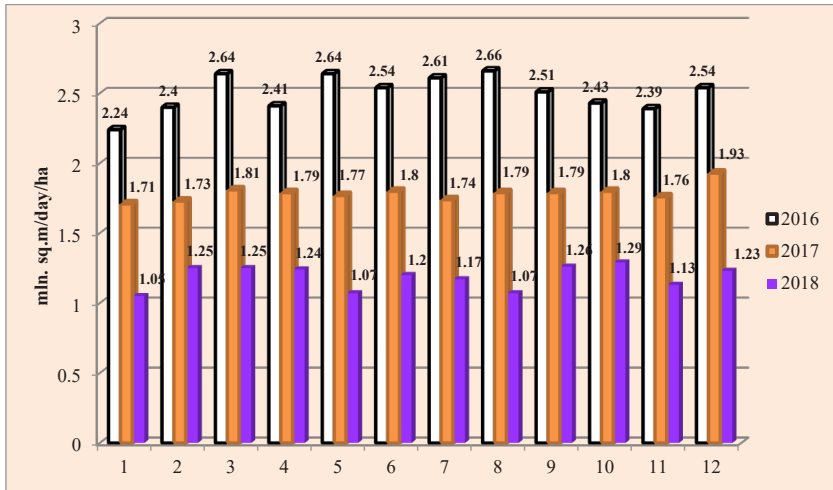


Fig. 4.9. Photosynthetic potential of chickpea crops depending on fertilizer application variants and study years

Note: 1 – control (no fertilizer); 2 – P₃₀K₃₀; 3 – P₃₀K₃₀ + N₃₀; 4 – P₃₀K₃₀ + N₃₀+N₃₀; 5 – P₃₀K₃₀ + N₆₀; 6 – N₃₀P₃₀K₃₀; 7 – N₆₀P₃₀K₃₀; 8 – N₃₀; 9 – N₆₀; 10 – N₉₀; 11 – N₁₂₀; 12 – N₃₀+N₃₀ in vegetation.

The effect of inoculants across years was similar, with BTU inoculant standing out in quantitative terms (Fig. 4.10).

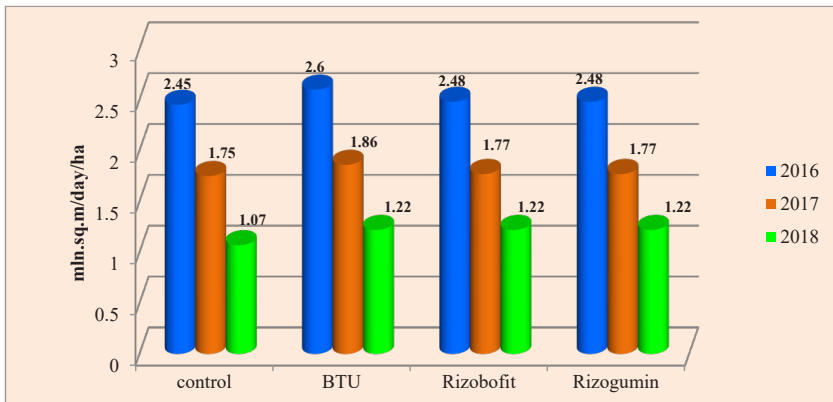


Fig. 4.10. Photosynthetic potential of chickpea crops depending on pre-sowing seed treatment variants and study years

The use of ROP solutions in chickpea crops also modified the leaf area depending on the fertilization background and the weather conditions of the year. In 2019, at the branching stage, the effect was significant only for the mineral fertilization background and ROP on the background of mineral nitrogen fertilization. In contrast, in 2020, ROP solutions were significantly effective on control plots (Table 4.12).

Table 4.12

Leaf area of chickpea plants depending on fertilization background and ROP foliar applications during branching, thousand m²/ha

Variant	Treatment	2019			2020		
		AB	A	B	AB	A	B
Without nitrogen fertilization	Control	2.53	2.72	2.96	3.35	3.92	3.68
	Amino	2.83		3.44	3.90		4.01
	Amino Micro	2.61		3.36	4.04		4.02
	Fulvo TE	2.68		3.65	4.00		4.12
	SeedTreatment	2.68		3.71	4.19		4.23
	Antistress (SG Protector)	2.72	-	3.81	4.07	-	4.18
	EXTRA	2.81		3.47	3.90		3.92
	RootMost	2.85		3.51	3.85		3.95
	Polimicrostim	2.63		3.54	3.94		4.01
	Avatar complex	2.86		3.36	3.91		3.85
On N ₃₀ +N ₃₀ background	Control	3.38	4.24		4.00	4.08	
	Amino	4.05			4.11		
	Amino Micro	4.12			3.91		
	Fulvo TE	4.62			4.23		
	SeedTreatment	4.74			4.26		
	Antistress (SG Protector)	4.90	-	-	4.30	-	-
	EXTRA	4.12			3.94		
	RootMost	4.16			4.04		
	Polimicrostim	4.45			4.08		
	Avatar complex	3.86			3.80		
LSD _{0.5}		0.38	0.39	1.07	0.23	0.23	0.76

During flowering, the increase in leaf area under factor A over the years amounted to 1.08 and 1.60 thousand m²/ha, respectively, with

LSD_{0.05} = 0.80 and 0.71 (Table 4.13). On unfertilized plots, all ROP products, except the Amino group and Avatar complex, positively affected the formation of leaf area. Triple foliar application of Fulvo TE, SeedTreatment, Antistress, RootMost, and Polimicrostim on the background of nitrogen fertilization increased leaf area from 0.65 to 1.47 thousand m²/ha in 2019 and from 1.04 to 2.21 thousand m²/ha in 2020 compared to the control without ROP, with LSD_{0.05} = 0.58 and 0.28, respectively. The greatest increase was observed with RootMost in both 2019 and 2020.

Table 4.13

**Leaf area of chickpea plants depending on fertilization
background and ROP foliar applications during flowering,
thousand m²/ha**

Variant	Treatment	2019			2020		
		AB	A	B	AB	A	B
Without nitrogen fertilization	Control	11.86	13.37	12.74	11.32	11.71	11,67
	Amino	12.13		13.00	11.33		11,71
	Amino Micro	12.78		13.42	11.43		11,81
	Fulvo TE	13.45		13.86	11.87		12,47
	SeedTreatment	13.13		14.10	11.97		13,03
	Antistress (SG Protector)	14.00	-	14.43	11.99	-	13,08
	EXTRA	14.12		14.43	11.87		12,92
	RootMost	14.27		14.69	11.98		13,10
	Polimicrostim	14.14		14.57	12.04		13,11
	Avatar complex	13.78		13.81	11.33		12,24
On N ₃₀₊ N ₃₀ background	Control	13.63	14.45		12.02	13.31	
	Amino	13.87			12.09		
	Amino Micro	14.06			12.19		
	Fulvo TE	14.28			13.06		
	SeedTreatment	15.07			14.08		
	Antistress (SG Protector)	14.87	-	-	14.17	-	-
	EXTRA	14.73			13.96		
	RootMost	15.10			14.23		
	Polimicrostim	15.01			14.18		
	Avatar complex	13.83			13.16		
LSD _{0,5}		0.58	0.80	0.90	0.28	0.71	1.15

By the full maturity stage, the total leaf area decreased compared to the flowering stage, consistent with previous study years. This is likely related both to plant aging and leaf loss, as well as the use of accumulated assimilates for seed formation and maturation.

In 2019, unlike 2020, nitrogen fertilizers did not maintain a significant effect on leaf area at full maturity (Table 4.14).

Table 4.14

Leaf area of chickpea plants depending on fertilization background and ROP foliar applications at full maturity, thousand m²/ha

№	Variant	2019			2020		
		AB	A	B	AB	A	B
Without nitrogen fertilization	Control	7.28	9.34	7.71	7.02	7.58	7.41
	Amino	8.73		9.02	7.37		7.62
	Amino Micro	8.66		8.62	7.43		7.68
	Fulvo TE	9.24		9.95	7.72		8.10
	SeedTreatment	9.61		10.11	7.78		8.47
	Antistress (SG Protector)	10.21		10.35	7.79		8.50
	EXTRA	10.23		10.40	7.72		7.40
	RootMost	9.68		9.88	7.78		8.52
	Polimicrostim	10.66		10.77	7.82		8.52
	Avatar complex	9.07		9.18	7.36		7.96
On N ₃₀ +N ₃₀ background	Control	8.14	9.86	-	7.81	8.65	-
	Amino	9.31			7.86		
	Amino Micro	8.58			7.93		
	Fulvo TE	10.67			8.50		
	SeedTreatment	10.61			9.15		
	Antistress (SG Protector)	10.49			9.21		
	EXTRA	10.58			9.07		
	RootMost	10.08			9.25		
	Polimicrostim	10.89			9.22		
	Avatar complex	9.28			8.55		
LSD _{0.5}		0.78	1.07	0.71	0.18	0.48	0.74

However, the combined effect of nitrogen fertilization and ROP foliar applications significantly influenced leaf area up to full maturity

in both study years: in 2019, the difference from the control ranged from 0.91 thousand m^2/ha (Amino Micro) to 3.0691 thousand m^2/ha (Polimicrostim) with $LSD_{0.5} = 0.71$. In 2020, a significant increase of 1.06–1.11 thousand m^2/ha was observed for plots treated with SeedTreatment, Antistress, EXTRA, RootMost, and Polimicrostim, with $LSD_{0.5} = 0.74$.

The photosynthetic potential of chickpea crops from branching to full maturity for each fertilization background was almost identical across years. The variant using mineral nitrogen N_{30} – pre-sowing and N_{30} – at branching exceeded the control by 10.3% in 2019 and 12.5% in 2020 (Fig. 4.11).

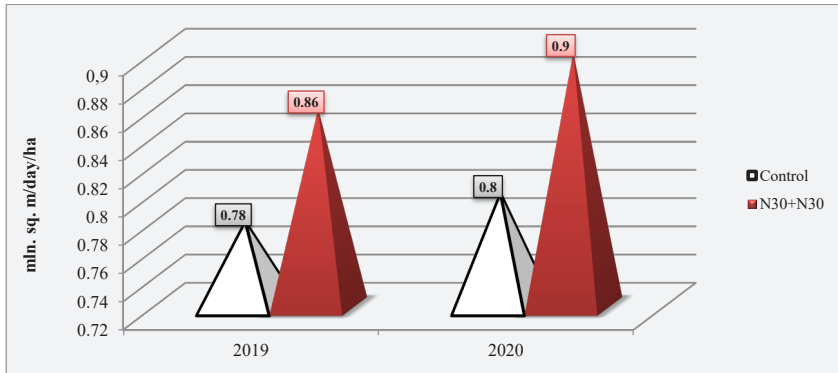


Fig. 4.11. Photosynthetic potential of chickpea crops under different fertilizer backgrounds

Under the variants of triple foliar feeding with ROMP solutions, an increase in the photosynthetic potential was observed in all treatments. However, the highest values were recorded in the variants using SeedTreatment, Antistress, EXTRA, RootMost, and Polymicrostim, which exceeded the control by 14.7–18.7% (Fig. 4.12).

Thus, under the conditions of the Southern Steppe of Ukraine, the formation of the assimilating surface and the photosynthetic potential of the chickpea variety Pamiat largely depended on the studied factors. It was established that the combination of the $P^{30}K^{30} + N_{30}$ fertilization system with pre-sowing seed inoculation using BTU

inoculant increased the leaf area by 34.1%, while combining nitrogen fertilization with three foliar feedings using the organic–mineral preparations SeedTreatment, Antistress, EXTRA, RootMost, and Polymicrostim provided the highest photosynthetic potential.

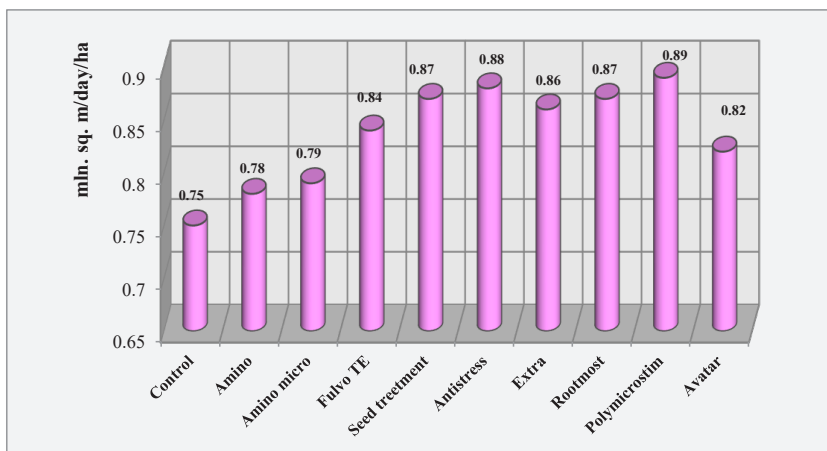


Fig. 4.12. Photosynthetic potential of chickpea crops under ROMP feeding variants, average for 2019–2020

4.5. Effect of Fertilizer Systems and Pre-sowing Seed Treatment on Chickpea Nodule Growth and Development

The number and weight of nodules, depending on the fertilization systems and pre-sowing seed treatment, were determined at the branching, flowering, and grain-filling stages.

The study showed that nodules began to form on chickpea roots starting from the branching stage. Without seed inoculation, an average of one nodule per two plants was formed, while with inoculant application – 1.4 to 2.0 nodules per plant (Table 4.15).

At the early stages of plant development, the effect of inoculants on nodule formation processes was 17%, while at the flowering stage, the number of nodules depended on inoculation by 37%. The average

number of nodules per plant at the flowering stage ranged from 4.1 to 4.3 pcs, which was 1.6–1.7 times higher than in the control. At the grain-filling (milk ripeness) stage, the number of nodules was 0.7–1.0 pcs compared to 0.3 pcs in the control.

In treatments with the same amount of mineral fertilizers but different inoculants, the nodule mass per plant also differed, particularly at the flowering stage (Table 4.16).

Table 4.15

Table 4.15. Dynamics of the number of nodules per plant at different chickpea growth stages under various fertilization systems (pcs)

Growth stage	Nodule number per plant												
	1	2	3	4	5	6	7	8	9	10	11	12	Aver.
Control (no inoculation)													
Branching	0.41	0.23	0.19	0.57	0.31	0.39	0	0.27	1.07	1.07	1.47	4.33	0.60
Flowering	3.4	3.0	2.5	2.0	1.85	2.2	2.4	3.1	3.4	2.8	2.1	2.2	2.60
Grain filling	0.38	0	0	0	0	0	0	0	0	0.67	0.80	1.29	0.26
BTU-inoculant													
Branching	1.12	0.64	0.43	0.92	1.25	0.70	2.13	1.18	2.67	2.58	5.79	5.29	2.06*
Flowering	3.6	4.0	5.1	4.8	3.75	4.15	3.25	3.75	4.0	4.15	5.8	3.2	4.13*
Grain filling	0.11	0	0.25	1.2	0	0	0.17	0.67	0.20	1.25	1.4	2.5	0.65
Rhizobofit													
Branching	0.75	1.08	0.92	0.93	1.07	0.58	1.46	0.50	1.20	1.86	1.64	4.31	1.36
Flowering	2.8	3.35	4.90	3.70	4.0	3.85	2.45	4.15	3.25	5.40	4.15	6.8	4.11*
Grain filling	0.40	0.17	0	1.0	0	1.4	0	1.5	1.25	1.00	2.50	3.20	1.04*
Rhizogumin													
Branching	1.50	0.93	0.28	1.13	0.27	0.67	1.42	2.20	1.21	0.92	2.43	4.33	1.44
Flowering	4.0	5.2	4.85	3.95	3.65	3.90	2.95	7.0	5.6	3.20	3.75	4.05	4.34*
Grain filling	0.60	1.50	0.20	0	0	0	0	0	0.17	2.25	1.82	2.38	0.74*
Statistical analysis results													
Branching	LSD _{0.5} – 0.80; factor effect – 17%; experimental precision – 20.5%.												
Flowering	LSD _{0.5} – 0.78; factor effect – 37%; experimental precision – 7.2%.												
Grain filling	LSD _{0.5} – 0.41; factor effect – 11%; experimental precision – 21.3%.												

Table 4.16. Dynamics of nodule mass per plant at different chickpea growth stages under various fertilization systems (mg/plant)

Growth stage	The mass of nodules												
	1	2	3	4	5	6	7	8	9	10	11	12	Aver.
Control (no inoculation)													
Branching	5.3	1.2	5.3	13.2	2.5	10.8	0	6.0	60.0	14.0	19.3	47.7	15.4
Flowering	1480	1350	1250	1360	1200	1750	1265	2200	1650	1345	1020	1200	1422.5
Grain filling	17.5	0	0	0	0	0	0	0	0	130.0	58.0	7.1	17.7
BTU-inoculant													
Branching	69.4	13.7	25.8	58.1	12.0	36.7	10.9	11.9	48.3	48.3	113.0	116.0	47.0*
Flowering	2450	2620	3250	3160	2950	3420	2780	3100	2930	2130	1250	2950	2749.2*
Grain filling	11.1	0	35.0	56.0	0	0	55.0	111.1	100.0	115.0	89.0	30.0	50.2
Rhizobifit													
Branching	10.6	18.3	27.5	8.6	35.7	14.2	34.6	12.1	17.3	57.9	123.0	87.7	37.3*
Flowering	1860	3100	2940	4230	2560	3650	2240	3800	3580	3120	1520	3180	2981.7*
Grain filling	4.0	98.3	0	627.5	0	270.0	0	252.5	247.5	247.5	22.0	92.0	155.1
Rhizogumin													
Branching	20.0	11.8	6.7	10.6	3.2	9.2	50.0	65.3	25.0	20.8	45.7	97.5	30.5
Flowering	2750	4640	4250	2650	2800	2840	2950	3500	3210	2750	2940	3550	3235.8*
Grain filling	380.0	947.5	172.0	0	0	0	150	196.5	120.0	6.7	58.0	107.5	178.2*
Statistical analysis results:													
Branching	LSD _{0.5} – 19; 9; factor effect – 13%; experimental precision – 21.5%.												
Flowering	LSD _{0.5} – 419; 6; factor effect – 59%; experimental precision – 5.7%.												
Grain filling	LSD _{0.5} – 142.2; factor effect – 16%; experimental precision – 49.9%.												

Compared to the control, the best results were observed in the variant with seed treatment using Rhizobofit and foliar fertilization with N₃₀ at the branching and early flowering stages, where 6.8 nodules per plant with a total mass of 3.2 g were formed. The maximum nodule mass per plant was recorded with Rhizogumin treatment on the background of P₃₀K₃₀ application and additional foliar N₃₀ feeding at the branching stage. Overall, 59% of the nodule mass was determined by seed inoculation with biological preparations.

The total nodule mass per plant at the flowering stage increased in the following order:

Control (1.4 g) → BTU-inoculant (2.8 g) → Rhizobofit (3.0 g) → Rhizogumin (3.2 g).

A similar trend was observed for the average mass per nodule: 0.55 g → 0.67 g → 0.73 g → 0.75 g.

Despite the high variability in data on the number and mass of nodules per plant – from 30.6–35.6 at flowering to 93.0–98.6 at branching, and up to 127.1–173.5 at grain filling, as reflected by the relatively low experimental accuracy for these stages (20.5–49.9%) – the positive effect of pre-sowing inoculation of chickpea seeds with biological preparations (BTU-inoculant, Rhizobofit, Rhizogumin) was statistically significant or approached the significance level regardless of the growth stage.

The results also showed that increasing the rate of pre-sowing nitrogen application from 30 to 120 kg/ha inhibited nodule formation.

In the non-inoculated variant, the number of nodules per plant decreased by 32.3%, with BTU-inoculant – by 15.8%, Rhizobofit – by 22.2%, and Rhizogumin – by 54.3%, while their mass decreased by 53.6%, 59.7%, 60.0%, and 21.4%, respectively.

An increase in nitrogen rates in the complete mineral fertilizer from N₃₀ to N₆₀ reduced the number of nodules by 19.7% and their mass by 26.7% on average.

Moreover, applying N₃₀P₃₀K₃₀ compared to P₃₀K₃₀ inhibited nodule formation slightly (4.5%, not statistically significant), whereas applying N₆₀P₃₀K₃₀ caused a more pronounced decrease (26.7%).

Thus, the research confirmed the negative effect of higher nitrogen application rates on nodule formation on chickpea roots – a trend also reported by other researchers across various soil types [13; 52; 67; 119; 270].

Conclusions to Chapter 4

1. Correlation analysis revealed that the duration of individual interphase periods and the total vegetation period of chickpea were most strongly influenced by the sum of effective temperatures $\geq +10^\circ\text{C}$ in April, May, and June, with correlation coefficients ranging from 0.70 to 0.88 (in absolute values). For productive soil moisture reserves in the 0–10 cm soil layer, the correlation coefficient was $r = 0.69\text{--}0.98$, and for precipitation sums – $r = 0.43\text{--}0.70$. These indicators were important for nearly all growth and development stages of chickpea plants, with differences manifested mainly in the strength and direction of the correlations.

2. It was established that mineral fertilizers significantly affect the linear dimensions of chickpea plants. On average, when applying fertilizer systems during 2016–2018, a statistically significant increase in plant height at the branching stage ranged from 11.4% to 22.1%. In a dry year, nitrogen fertilizers had a greater effect, whereas in years with sufficient moisture, all fertilizer types were effective.

When liquid organo-mineral preparations were used, the best plant growth was observed with SeedTreatment, Antistress (SG Protector), Extra, and Polymicrostim. Against the background of mineral nitrogen application ($\text{N}_{30} + \text{N}_{30}$), plant height increased by 1.8–8.0% compared to the same treatments without fertilizers.

3. Changes in the chlorophyll pool in chickpea leaves during growth stages were observed both in response to fertilizer application and pre-sowing seed treatments. The maximum chlorophyll content was recorded during flowering and early grain filling, amounting to 2.51–2.69 mg/g of fresh matter in variants combining inoculants with $\text{N}_{30-60}\text{P}_{30}\text{K}_{30}$ and N_{30-60} fertilization, compared to 1.83–1.87 mg/g in the control (without fertilizers or inoculation). The difference between nitrogen fertilizer rates was not statistically significant.

The effectiveness of inoculants in increasing chlorophyll content depended on the fertilizer background: the highest relative efficiency was observed in unfertilized variants and with $\text{P}_{30}\text{K}_{30}$ application. At the flowering stage, inoculants could be ranked as Rhizogumin > Rhizobofit > BTU, and at the ripening stage – BTU > Rhizogumin > Rhizobofit.

Under soil drought conditions, chlorophyll content decreased, particularly the chlorophyll α fraction and the α/b ratio, which ranged from 2.03–1.54 versus 3.89–2.73 under optimal conditions. The α/b ratio tended to decrease both across growth stages and inoculation variants when transitioning from phosphorus–potassium to nitrogen fertilization, due to an increase in the proportion of chlorophyll b in total green pigments (by 1.5–3.5%).

A direct correlation was established between chlorophyll concentration in chickpea leaves at the flowering stage and grain yield: the correlation coefficient for yield–chlorophyll α was 0.64–0.78, and for chlorophyll b – 0.28–0.40. Across study years, a stronger relationship between chlorophyll b and yield was observed under less favorable weather conditions (2018) – 16.0% influence, compared to 1.0–7.8% in other years, whereas the relationship for chlorophyll α was stronger in favorable conditions (2016) – 60.8% versus 32.5–41.0%.

4. The combination of the $P_{30}K_{30}+N_{30}$ fertilization system with pre-sowing seed inoculation using the BTU inoculant increased the leaf area by 34.1%, while combining nitrogen fertilization with three foliar applications of organo-mineral preparations (SeedTreatment, Antistress, EXTRA, RootMost, or Polymicrostim) provided the highest photosynthetic potential.

5. The maximum number and mass of nodules on chickpea roots were formed during the flowering stage. Depending on pre-sowing treatment variants, the average number of nodules per plant ranged from 4.1 to 4.3, exceeding the control by 1.6–1.7 times. The interaction of fertilization and inoculation factors revealed that the application of Rhizogumin on a $P_{30}K_{30}$ background resulted in the highest total nodule mass – 4.64 g per plant.

Increasing the pre-sowing nitrogen rate from 30 to 120 kg/ha inhibited nodule formation: by 32.3% without inoculation, 15.8% with BTU-inoculant, 22.2% with Rhizobofit, and 54.3% with Rhizogumin. Nodule mass decreased correspondingly by 53.6%, 59.7%, 60.0%, and 21.4%. Increasing the nitrogen rate in the complete mineral fertilizer from N_{30} to N_{60} reduced nodule number by 19.7% and mass by 26.7%. Pre-sowing application of $N_{30}P_{30}K_{30}$, compared to $P_{30}K_{30}$, slightly inhibited nodule formation (by 4.5%, statistically insignificant), while $N_{60}P_{30}K_{30}$ caused a significant reduction (26.7%).

CHAPTER 5

OPTIMIZATION OF THE EFFECT OF NUTRITION SYSTEMS ON THE YIELD AND GRAIN QUALITY OF CHICKPEA

5.1. Grain Yield and Its Structure

The level of formed yield serves as a quantitative indicator of the effect of a particular factor. Based on the obtained experimental data, it can be concluded that all elements of the cultivation technology had a significant impact on chickpea grain yield.

According to the results of studies conducted during 2016–2018, the combined effect of mineral fertilizers and inoculants was not always clearly traceable (see Appendices D1–D2). In particular, in 2016 – the most favorable year in terms of weather conditions – almost all combinations of factors significantly increased chickpea yield, except for the treatment with Rhizogumin under N_{120} application, where the yield remained at the level of the uninoculated control with N_{120} (Table 5.1).

In 2017, the efficiency of BTU inoculant in this treatment was comparable to the respective control, whereas the application of Rhizobophyte and Rhizogumin led to a significant decrease in yield – by 12.7% and 12.2%, respectively. A pronounced decline in the effectiveness of the combined factor was observed in 2017 when a full mineral fertilizer ($N_{60}P_{30}K_{30}$) with an increased nitrogen dose was applied directly at sowing: with BTU inoculant – by 21.6%, with Rhizobophyte – by 30.1%, and with Rhizogumin – by 36.4%.

On average over the study years, high effectiveness of inoculants was recorded in the treatment where mineral nitrogen was applied twice during the growing season: in 2016, Rhizobophyte contributed to a yield increase of 24.5%; in 2017, BTU inoculant by 17.5%; and in 2018, Rhizogumin also by 17.5%.

On average across all years, under the background of $N_{30}+N_{30}$ application, chickpea yield increased as follows: with BTU inoculant – by 13.9%, with Rhizobophyte – by 11.8%, and with Rhizogumin – by 4.0%.

Table 5.1

Chickpea grain yield under different fertilization systems, t/ha

№	Fertilizer (Factor A)	Inoculant (Factor B)	Fertilizer + Inoculant (A+B)				Average by Fertilizer Type			
			2016	2017	2018	Aver	2016	2017	2018	Average
1	2	3	4	5	6	7	8	9	10	11
1	Control	Control	2.10	1.90	1.18	17.3	2.68	2.47	1.30	2.15
		BTU	2.77	2.70	1.42	2.30				
		Rhizobophyte	2.82	2.68	1.31	2.27				
		Rhizogumin	2.80	2.60	1.29	2.23				
2	P ₃₀ K ₃₀	Control	2.14	2.02	1.26	1.81	3.06	2.43	1.41*	2.30
		BTU	3.89	2.60	1.66	2.72				
		Rhizobophyte	2.80	2.50	1.33	2.21				
		Rhizogumin	3.44	2.60	1.37	2.47				
3	P ₃₀ K ₃₀ + +N ₃₀	Control	2.68	2.44	1.28	2.13	3.74	2.56	1.35	2.55
		BTU	5.56	2.70	1.44	3.23*				
		Rhizobophyte	3.57	2.60	1.38	2.52				
		Rhizogumin	3.14	2.50	1.31	2.32				
4	P ₃₀ K ₃₀ + +N ₃₀ +N ₃₀	Control	2.83	2.48	1.28	2.20	2.98	2.56	1.36	2.30
		BTU	3.51	2.82	1.39	2.57				
		Rhizobophyte	2.84	2.51	1.41	2.25				
		Rhizogumin	2.75	2.43	1.34	2.17				
5.	P ₃₀ K ₃₀ + +N ₆₀	Control	3.05	2.43	1.25	2.24	3.23	2.33	1.28	2.28
		BTU	3.73	2.50	1.30	2.51				
		Rhizobophyte	3.05	2.30	1.26	2.20				
		Rhizogumin	3.07	2.26	1.29	2.21				
6	N ₃₀ P ₃₀ K ₃₀	Control	3.17	2.12	1.40	2.23	2.99	2.19*	1.57*	2.25
		BTU	2.87	2.20	1.55	2.21				
		Rhizobophyte	2.90	2.22	1.69	2.27				
		Rhizogumin	3.01	2.22	1.65	2.29				
7	N ₆₀ P ₃₀ K ₃₀	Control	3.23	2.36	1.28	2.29	3.11	1.84*	1.48*	2.14
		BTU	3.07	1.85	1.56	2.16				
		Rhizobophyte	3.10	1.65	1.61	2.12				
		Rhizogumin	3.07	1.50	1.47	2.01				
8	N ₃₀	Control	2.92	2.30	1.30	2.17	3.57	2.30	1.51*	2.46
		BTU	4.19	2.40	1.55	2.71				
		Rhizobophyte	4.06	2.30	1.71	2.69				
		Rhizogumin	3.11	2.20	1.48	2.26				

Continuation of Table 5.1

1	2	3	4	5	6	7	8	9	10	11
9	N ₆₀	Control	3.16	2.40	1.23	2.26	3.23	2.53	1.32	2.36
		BTU	3.87	2.72	1.34	2.64				
		Rhizobophyte	2.92	2.51	1.37	2.27				
		Rhizogumin	2.94	2.49	1.32	2.25				
10	N ₉₀	Control	3.59	2.45	1.22	2.42	3.05	2.54	1.34	2.31
		BTU	2.87	2.60	1.38	2.28				
		Rhizobophyte	2.68	2.46	1.40	2.18				
		Rhizogumin	3.04	2.65	1.34	2.01				
11	N ₁₂₀	Control	2.68	2.13	1.21	2.01	2.78	1.99*	1.32	2.03
		BTU	3.04	2.10*	1.40	2.18				
		Rhizobophyte	2.73	1.86	1.35	1.98				
		Rhizogumin	2.69	1.87	1.32	1.96				
12	N _{30+N₃₀}	Control	3.06	2.40	1.43	2.30	3.27	2.65	1.58*	2.50
		BTU	3.38	2.82	1.65	2.62				
		Rhizobophyte	3.81	2.80	1.56	2.72				
		Rhizogumin	2.81	2.70	1.68	2.40				
LSD _{0.5}	A	–				1.64	1.0	2.0	1.1	–
	B	0.12	0.11	0.06	1.40	–				
	AB	0.17	0.32	0.21	1.13	–				

According to the results of fertilization systems, three treatments were distinguished: P₃₀K₃₀+N₃₀, N₃₀+N₃₀, and N₃₀, where the average yield over three years amounted to 2.55 t/ha, 2.50 t/ha, and 2.46 t/ha, respectively. These values exceeded the unfertilized control by 14.4–18.6%.

The trends observed for fertilization systems were analogous to those identified for the combined factor. In 2016, all fertilization systems ensured a significant yield increase (with N₁₂₀ being at the threshold of significance). In 2017, a considerable reduction in chickpea yield was observed when applying N₁₂₀ and the full mineral fertilizer at sowing – by 19.4%, 11.3%, and 25.5%, respectively, compared to the unfertilized variant.

Chickpea grain yield under Factor B – seed pre-sowing treatment – is presented in Table 5.2.

Based on their effect on yield, the inoculants can be arranged in the following order:

BTU > Rhizobophyte > Rhizogumin – a sequence consistently observed throughout all years of the study, despite variations in absolute yield performance indicators for chickpea.

Table 5.2

Influence of Inoculants on Chickpea Grain Yield, t/ha

Inoculant	2016	2017	2018	Average	± to Control	
					t/ha	%
Control	2.88	2.29	1.28	2.15	0	0
BTU	3.56	2.50	1.47	2.51	0,36	16,7
Rhizobophyte	3.11	2.37	1.45	2.31	0,16	7,4
Rhizogumin	2.99	2.34	1.40	2.24	0,09	4,2
LSD _{0,5}	0.12	0.11	0.06			

It was determined that the increase in yield resulting from pre-sowing seed bacterization with the BTU inoculant exceeded that obtained from using Rhizobophyte and Rhizogumin (Figure 5.1). The maximum increase – 23.6% – was recorded for the BTU inoculant treatment in 2016, which was the most favorable year in terms of weather conditions.

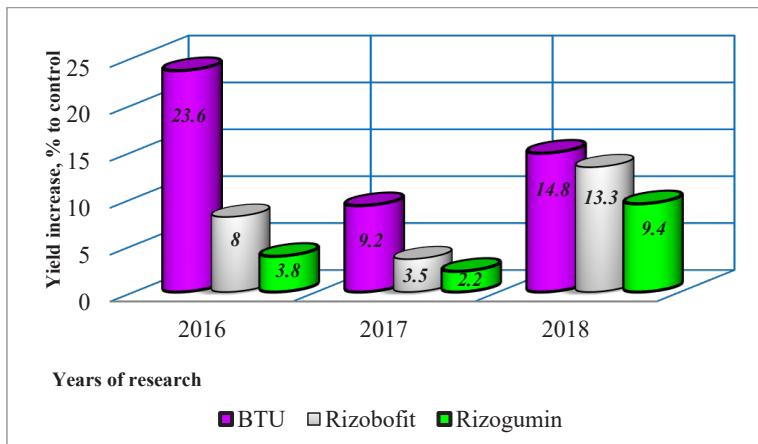


Figure 5.1. Increase in chickpea grain yield under different variants of Factor B

As for the two other inoculants, their effect was more pronounced under the conditions of 2018: yield increases were 13.3% and 9.4%, compared to 8.0–3.5% and 3.8–2.2% in previous years, respectively.

Thus, among the inoculants, BTU inoculant demonstrated the greatest positive effect on chickpea yield. Among the fertilization systems, the most effective were the treatments involving a minimal nitrogen rate and the combined action of inoculants, specifically the bacterization of seeds with BTU inoculant or Rhizobophyte combined with the application of N₃₀+N₃₀ at the beginning of branching and flowering stages.

When evaluating the effectiveness of organo-mineral products in chickpea crops, it should be emphasized that extremely unfavorable weather conditions during the 2019 growing season had a significant impact on grain yield levels (Table 5.3). The average yield in the control treatment was 0.61 t/ha, while the application of N₃₀ before sowing and one top dressing at the branching stage contributed to a considerable yield increase of 0.12 t/ha.

Table 5.3

**Influence of organo-mineral products on chickpea yield, t/ha
(2019–2020)**

Factor A – Nutritional background	Factor B – Bioproducts	2019			2020		A	B
		AB	A	B	AB			
1	2	3	4	5	6	7	8	
Control without fertilizers	1. Control	0.51	0.61	0.57	1.04	1.27	1.10	
	2. Amino	0.52		0.59	1.14		1.18	
	3. Amino mikro	0.63		0.67	1.26		1.31	
	4. Fulvo TE	0.72		0.78	1.37		1.51	
	5. Seed treatment	0.58		0.61	1.25		1.24	
	6. Antistress	0.62		0.71	1.44		1.47	
	7. Extra	0.70		0.74	1.30		1.38	
	8. Rootmost	0.63		0.70	1.38		1.40	
	9. Polymicrostim	0.63		0.69	1.37		1.51	
	10. Avatar	0.57		0.66	1.18		1.22	

Continuation of Table 5.3

1	2	3	4	5	6	7	8
N ₃₀ +N ₃₀	1. Control	0.65	0.73	-	1.16	1.39	-
	2. Amino	0.66			1.22		
	3. Amino mikro	0.71			1.36		
	4. Fulvo TE	0.83			1.65		
	5. Seed treatment	0.64			1.23		
	6. Antistress	0.80			1.51		
	7. Extra	0.78			1.45		
	8. Rootmost	0.72			1.43		
	9. Polymicrostim	0.75			1.66		
	10. Avatar	0.73			1.27		
LSD _{0.5}		0.06	0.019	0.041	0.043	0.014	0.031
Share of influence, %		0	35	44	0	15	75
Experimental error, %		3.1			1.1		

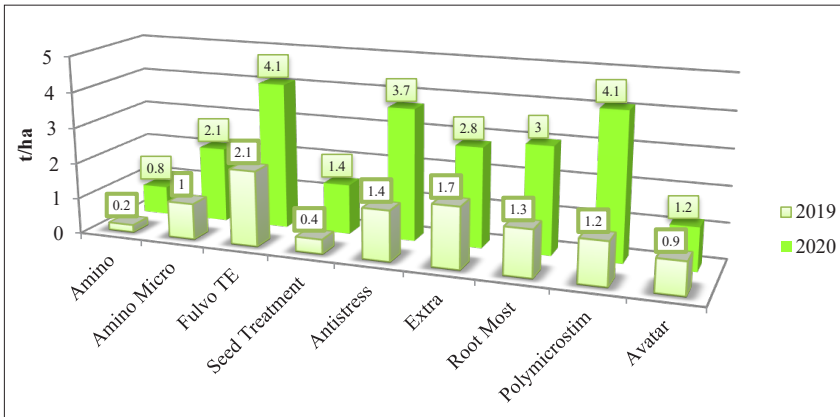


Fig. 5.2. Increase in chickpea grain yield under different organo-mineral treatment variants

Under unfertilized conditions, almost all products (except Amino and Avatar) had a positive effect on chickpea yield. On the background of nitrogen fertilization, the Amino and Seed Treatment products did not significantly increase yield, although their values were still higher compared to the absolute control (Appendices E1–E2).

The highest yield increase in 2019 was provided by Fulvo TE, both under unfertilized and fertilized conditions: compared with the absolute control – by 0.21 t/ha, and compared with the fertilized control – by 0.18 t/ha.

In 2020, the highest increase in chickpea grain yield was obtained with the application of Fulvo TE and Polymicrostim, amounting to 0.41 t/ha. The average yield increase for chickpea grain under Factor B across the years of the study, excluding the nutrient background, is presented in Fig. 5.2.

Since the grain yield in the control treatment with mineral nitrogen application was significantly higher than that of the pure control – by 0.12–0.14 t/ha—it is natural that the yield increases within this block were lower compared to those observed under the zero-fertilizer background. In 2020, these increases ranged from 0.06 t/ha with the application of Amino to 0.50 t/ha with Polymicrostim (Appendices E3–E4).

The volumetric normalized stacked histogram illustrates the percentage contribution of each studied factor to the total yield increase, averaged over the two years of the experiment (Fig. 5.3). As seen from the diagram, the yield improvement resulting from the use of most preparations—except Amino and Avatar—exceeded that achieved with mineral nitrogen fertilization, while the effects of Polymicrostim and mineral nitrogen were practically equivalent.

When comparing the effects of preparations based on amino, fulvic, and humic acids, it is notable that among amino acid-based products, Amino mikro ensured the highest increase—ranging from 9.2% to 19.1%, depending on weather conditions and nutrient background. Preparations based on humic and fulvic acids, on average over the two study years, contributed to yield increases as follows: Fulvo TE by 35.9%, Antistress by 28.0%, and amino-chelated preparations by 17.3%. Our findings regarding amino-chelated fertilizers are consistent with those of other researchers, who reported a 16.2% yield increase following double foliar feeding with an amino-chelate solution of similar composition [166], as well as positive effects of liquid organo-mineral formulations based on humic and fulvic acids [176].

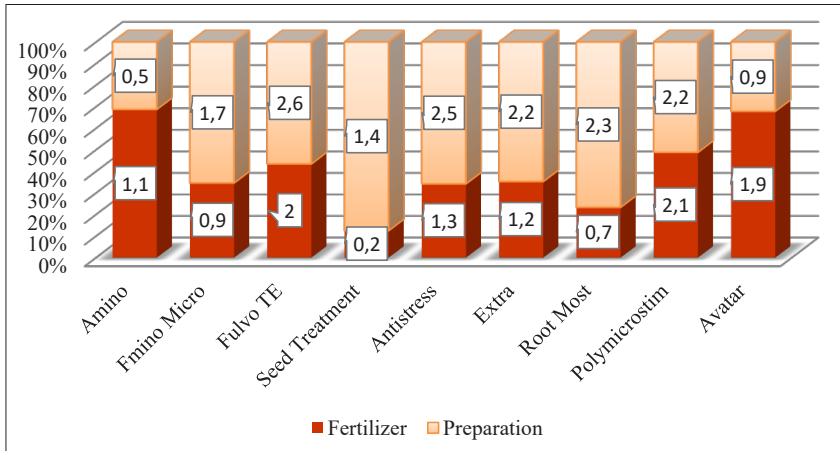


Fig. 5.3. Contribution of organo-mineral preparations to the total chickpea yield increase, average for 2019–2020

It is important to emphasize that we support the conclusion that mineral fertilizers supplying nitrogen, phosphorus, and potassium cannot be completely replaced by chelates and humates; however, their application rates may be reduced through the enhanced nutrient uptake they promote [110]. Indeed, our calculations show that the nitrogen utilization coefficient from mineral fertilizers varied from 20.5% to 37.8–50.4% in treatments with organo-mineral preparations, compared to 19.1% in their absence.

Our research conducted during 2016–2020 clearly indicates a variable chickpea response to moisture availability, a pattern also observed by other researchers [232; 257; 296]. Chickpea seed yield decreases by 50% under temperature stress during pod formation and by 44% under stress during flowering [239]. Similar findings have been reported both in Ukraine and abroad [36; 87; 122; 169; 271].

Given the above, a detailed analysis of the average climatic conditions during the study years was conducted. The obtained data were compared with long-term averages and clearly demonstrated an increase in mean monthly air temperatures throughout the agricultural year (Fig. 5.4). The greatest rise was observed in June (+2.9 °C) and August (+3.5 °C), while winter months were also warmer by 1.8–2.6 °C.

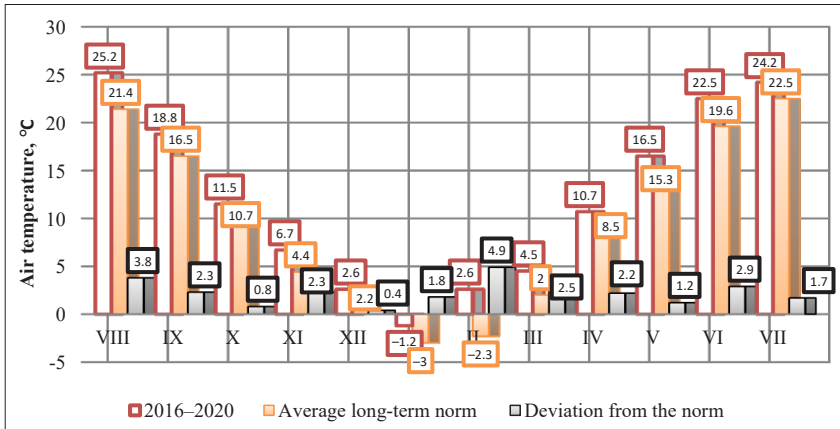


Fig. 5.4. Average air temperature during 2016–2020

The negative impact of elevated air temperatures was further aggravated by an insufficient amount or uneven distribution of precipitation. Thus, the average precipitation during 2016–2020 was lower in almost all chickpea vegetation months compared to the climatological standard norm for 1977–2006 and 2007–2020 (Fig. 5.5).

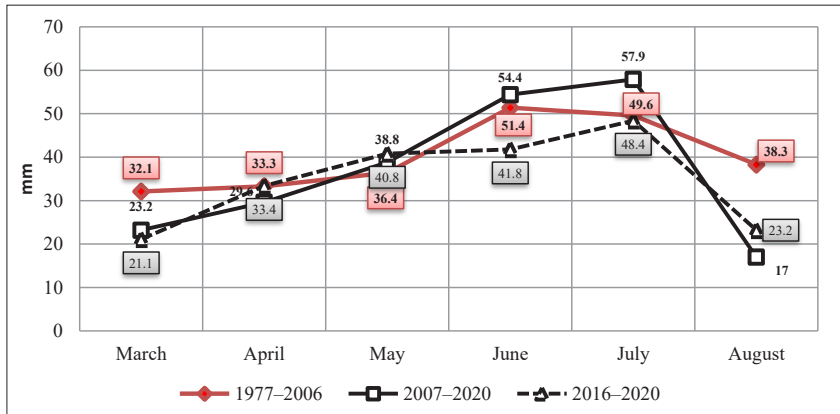


Fig. 5.5. Average monthly precipitation during the chickpea growing season

The early growth stages of spring crops largely depend on winter precipitation, as it determines the reserves of available soil moisture at sowing. The maximum precipitation during the pre-sowing period (106.6 mm) was recorded in 2018, while the minimum (41 mm) occurred in 2017, accounting for 47.8% and 14.3% of the total annual precipitation, respectively. In 2019, no precipitation was recorded in February (Fig. 5.6).

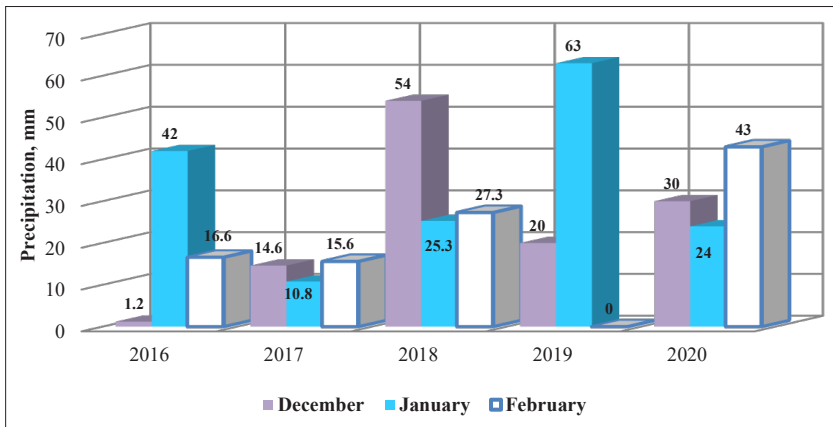


Fig. 5.6. Winter precipitation during the study years

As already noted, 2019 and 2020 were unfavorable not only in terms of the total amount of precipitation but also because of its uneven distribution. In 2019, during the period from emergence to pod formation, most of the precipitation was non-productive or low-productive, whereas from grain filling to full maturity, nearly 80% of the rainfall occurred in the form of heavy downpours. The year 2020 was characterized by intense rainfall in May and June and an almost complete absence of precipitation at the early stages of chickpea development. Such conditions negatively affected plant formation, and the average yield in the experiment did not exceed 0.67 t/ha in 2019 and 1.33 t/ha in 2020.

Under the most favorable distribution of rainfall observed in 2016 and 2017, the chickpea yield on unfertilized plots reached 2.1 t/ha and 1.9 t/ha, respectively. The ratio of precipitation across

seasons–winter : spring : summer–was 1.0 : 3.3 : 1.4 with a total of 350 mm in 2016, and 1.0 : 2.4 : 2.7 with a total of 250 mm in 2017, reflecting a relatively uniform temporal distribution.

The findings of other researchers also confirm significant seasonal and monthly variations in precipitation amounts and patterns, as well as in temperature trends, all of which strongly influence the productivity of agricultural crops, including chickpea [41; 83; 150; 165; 191; 269].

The variability of weather conditions during the study years and their impact on yield, yield structure, and grain quality are reflected in the corresponding coefficients of variation (Table 5.4).

Table 5.4

Results of statistical analysis, 2016–2020

Indicator	Yield, t/ha	*Height, cm		Number per plant			
		1	2	beans	grains	gram	Branches
Mean	1.35	38.7	26.2	15.2	17.8	3.68	3.84
Maximum	2.10	49.6	32.9	18.1	22.6	4.75	5.3
Minimum	0.51	30.8	21.6	9.9	8.2	1.89	1.8
Standard error	0.29	3.28	2.13	1.43	2.54	0.53	0.70
Standard deviation	0.65	7.34	4.76	3.2	5.67	1.18	1.58
Kurtosis	-0.16	-0.08	-1.37	2.54	3.14	-0.15	-2.57
Skewness	-0.03	0.79	0.63	-1.49	-1.72	-1.0	-0.64
Coefficient of variation	48.4	19.0	18.1	21.0	31.8	32.1	41.1

Notes: 1* – total plant height; 2* – height to the first pod attachment.

According to the generally accepted agronomic criteria for assessing variability, the variability of yield and such traits as branching are considered high; indicators of individual productivity and plant density are of medium variability (20–40%), while variation in plant height is low (10–20%) [65]. The density distribution of data relative to the mean is mostly characterized by negative (left-skewed) asymmetry.

To identify the most influential meteorological factors affecting chickpea yield formation and its structural components, statistical dependencies were calculated for these parameters in relation to precipitation, as well as the ratio between precipitation and air

temperature (hydrothermal coefficient – HTC) during different growth periods. In addition, the degree of linear relationship between yield and its individual elements was determined.

A strong correlation was found between chickpea productivity and such yield-forming elements as plant height, branching, the number of seeds per plant, and seed weight. The pairwise correlation coefficients ranged from 0.81 to 0.85, indicating a significant correlation, as the calculated reliability criterion for the correlation coefficient exceeded the theoretical one. The multiple correlation coefficient was 0.89.

It should be noted that the height of the lowest pod attachment had little effect on chickpea yield ($r = 0.44$). This parameter was determined by 84.6% of the overall plant height and, apparently, influences grain losses during harvesting.

Crop yield formation depends on the individual productivity of plants, the development of which is also influenced by meteorological factors. Drought in April not only delays germination but also reduces field emergence, i.e., the number of plants per unit area ($r = 0.60$), which naturally affects yield. The multiple correlation coefficient between the April HTC, plant density, and yield was 0.80.

Weather conditions in May determine the number of pods formed, since this period coincides with chickpea flowering and pollination. The pairwise correlation between HTC and the number of pods formed was 0.68. Visual observations showed that heavy rains, particularly downpours occurring in 2019 and 2020, caused pollen clumping and hindered chickpea pollination. At the same time, extreme drought during this period ($HTC = 0.4-0.07$) also limited pod formation and reduced yield (pairwise correlation between May HTC and yield = 0.88), which agrees with other studies [88; 232; 257]. Overall, most researchers have noted that the stages of pod and seed development in all legumes are the most sensitive to drought [290; 291].

5.2. Chickpea Grain Quality

The size and caliber of chickpea seeds meaning their dimensions and weight are among the key characteristics determining the commercial value of chickpea grain on the global market. Therefore, producing chickpeas with the largest possible seed size and weight, alongside achieving high yields, remains one of the main objectives in the cultivation of this important legume crop.

In our studies, the 1000-seed weight of chickpea was primarily determined by the crop's genetic characteristics, as well as by specific elements of the cultivation technology (Table 5.5; Appendix F).

Table 5.5

Effect of mineral fertilizers and inoculants on the 1000-seed weight of chickpea, g

№	Fertilization System	1000-Seed Weight (g)				± to Control	
		2016	2017	2018	Average	g	%
1	2	3	4	5	6	7	8
Without Inoculation							
1	Control	222.0	210.3	177.6	203.3	0	0
2	P ₃₀ K ₃₀	241.0	222.6	198.5	220.7	17.4	8.6
3	P ₃₀ K ₃₀ +N ₃₀	255.4	241.0	180.4	225.6	22.3	11.0
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	251.6	240.7	182.8	225.1	21.8	10.7
5	P ₃₀ K ₃₀ +N ₆₀	256.0	247.2	201.8	235.0	31.7	15.6
6	N ₃₀ P ₃₀ K ₃₀	256.8	230.0	192.3	226.4	23.1	11.4
7	N ₆₀ P ₃₀ K ₃₀	266.7	259.8	164.0	230.2	26.9	13.2
8	N ₃₀ at Sowing	255.4	244.1	187.3	228.9	25.6	12.6
9	N ₆₀ at Sowing	252.8	241.9	193.6	229.4	26.1	12.8
10	N ₉₀ at Sowing	251.6	239.4	186.7	225.9	22.6	11.1
11	N ₁₂₀ at Sowing	252.2	248.1	185.4	228.6	25.3	12.6
12	N ₃₀ +N ₃₀ in Vegetation	258.2	257.6	188.1	234.6	31.3	15.4
LSD _{0.5} = 8.4; Experimental Precision = 2,9%; Factor Influence = 72%.							
BTU-Inoculant							
1	Control	245.3	232.3	198.1	225.2	0	0
2	P ₃₀ K ₃₀	266.7	259.5	194.9	240.4	15.2	6.7
3	P ₃₀ K ₃₀ +N ₃₀	248.8	253.6	196.0	232.8	7.6	3.4
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	262.7	241.0	190.3	231.3	6.1	2.7
5	P ₃₀ K ₃₀ +N ₆₀	252.6	260.2	186.2	233.0	7.8	3.5

Continuation of Table 5.5

1	2	3	4	5	6	7	8
6	N ₃₀ P ₃₀ K ₃₀	245.2	268.0	194.1	235.8	10.3	4.7
7	N ₆₀ P ₃₀ K ₃₀	242.6	255.7	186.2	228.2	3.0	1.3
8	N ₃₀ at Sowing	264.8	245.2	202.2	237.4	12.2	5.4
9	N ₆₀ at Sowing	265.1	252.0	199.5	238.9	13.7	6.1
10	N ₉₀ at Sowing	277.1	256.4	166.2	233.2	8.0	3.6
11	N ₁₂₀ at Sowing	259.2	257.3	190.5	235.7	10.5	4.7
12	N ₃₀ +N ₃₀ in Vegetation	277.3	298.3	191.4	255.7	30.5	13.5
LSD _{0.5} = 7,1; Experimental Precision = 1,5%; Factor Influence= 20%.							
Rhizobophyte							
1	Control	238.6	236.3	193.6	222.8	0	0
2	P ₃₀ K ₃₀	241.0	251.2	200.5	230.9	8.1	3.6
3	P ₃₀ K ₃₀ +N ₃₀	251.6	258.0	180.6	230.1	7.2	3.2
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	256.0	251.4	183.9	230.4	7.6	3.4
5	P ₃₀ K ₃₀ +N ₆₀	281.9	264.7	183.3	243.3	20.5	9.2
6	N ₃₀ P ₃₀ K ₃₀	255.4	253.6	190.6	233.2	10.4	4.7
7	N ₆₀ P ₃₀ K ₃₀	289.1	247.8	205.2	247.4	24.5	11.0
8	N ₃₀ at Sowing	256.8	259.1	181.4	232.4	9.6	4.3
9	N ₆₀ at Sowing	267.1	259.7	187.4	238.1	15.2	6.8
10	N ₉₀ at Sowing	255.4	251.5	193.4	233.4	10.6	4.8
11	N ₁₂₀ at Sowing	238.6	253.0	190.4	227.3	4.5	2.0
12	N ₃₀ +N ₃₀ in Vegetation	281.9	280.2	186.7	249.6	26.8	12.0
LSD _{0.5} = 7.6; Experimental Precision = 2.2%; Factor Influence = 31%.							
Rhizogumin							
1	Control	245.3	248.4	194.1	229.3	0	0
2	P ₃₀ K ₃₀	266.7	257.1	201.8	241.9	12.6	5.5
3	P ₃₀ K ₃₀ +N ₃₀	262.7	264.3	180.5	235.8	6.5	2.8
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	252.6	240.9	190.0	227.8	-1.5	-0.6
5	P ₃₀ K ₃₀ +N ₆₀	245.2	248.2	199.3	230.9	1.6	0.7
6	N ₃₀ P ₃₀ K ₃₀	268.6	258.1	185.2	237.3	8.0	3.5
7	N ₆₀ P ₃₀ K ₃₀	269.6	240.0	186.0	231.9	2.6	1.1
8	N ₃₀ at Sowing	264.8	257.1	203.3	241.7	12.5	5.5
9	N ₆₀ at Sowing	244.8	254.2	181.1	226.7	-2.5	-1.1
10	N ₉₀ at Sowing	247.5	257.8	181.6	229.0	-0.3	-0.1
11	N ₁₂₀ at Sowing	249.8	257.4	187.1	231.4	2.2	0.9
12	N ₃₀ +N ₃₀ in Vegetation	277.2	276.6	196.8	250.2	20.9	9.1
LSD _{0.5} = 7.2; Experimental Precision = 1.6%; Factor Influence = 0,23%.							

It was found that the 1000-seed weight of chickpea depended significantly on elements of the cultivation technology, particularly the application of mineral fertilizers, which proved to be a powerful factor influencing seed size [105]. This trend is clearly visible when comparing control plots (without fertilizer application) to those receiving mineral fertilization. Chickpea cultivation on natural soil fertility produced the smallest 1000-seed weight—on average 203.3 g without inoculation—while under fertilized conditions, it ranged from 220.7 g to 234.6 g.

In the absence of pre-sowing inoculation, the use of mineral fertilizers substantially improved the seed caliber, increasing the 1000-seed weight by 8.4% to 15.4%. Among the inoculants, the most pronounced effects on seed weight were observed for Rhizobophyte, BTU-inoculant, and Rhizogumin, with increases ranging from 3.2% to 12.0%. When BTU-inoculant was used, the 1000-seed weight also increased but to a relatively smaller extent (2.7–13.5%).

The least influence was observed for Rhizogumin, where increases ranged from 0.7% to 9.1%, and in some treatments involving $N_{90}-N_{120}$ or $P_{30}K_{30}+N_{30}+N_{30}$, a slight reduction in seed caliber was recorded. Fractional application of mineral nitrogen—both without inoculants and in combination with bacterial inoculation—ensured an increase in the 1000-seed weight from 15.0% (without inoculation) to 9.1–13.5% (with inoculation).

In terms of their effect on seed mass, the inoculants can be ranked in the following descending order: BTU-inoculant (13.5%) → Rhizobophyte (12.0%) → Rhizogumin (9.1%).

The seed caliber under various treatments with liquid organo-mineral products is presented in Table 5.6. It was found that the 1000-seed weight varied significantly between years. In 2019, under nitrogen fertilization, this parameter reached 276.61 g, while in the control it was 270.45 g ($LSD_{0,5} = 2.9$); in 2020, the values were 222.2 g and 226.8 g, respectively ($LSD_{0,5} = 3.2$).

In the weather conditions of 2019, the most significant effects among the biopreparations were observed for Antistress, Rootmost, Polymicrostim, and the Avatar complex, increasing seed weight by 8.9 g, 7.2 g, 7.5 g, and 9.9 g, respectively ($LSD_{0,5} = 6.5$). Combined application of mineral nitrogen with Extra, Rootmost, and Polymicrostim significantly increased chickpea seed caliber compared

to the control. In 2020, Amino, Seed treatment, and Rootmost were the most effective, increasing 1000-seed weight by 11.6 g, 12.9 g, and 10.1 g, respectively ($LSD_{0.5} = 7.0$).

Table 5.6

1000-Seed Weight of Chickpea Following Winter Wheat, g

Factor A – Fertilization Background	Factor B – Liquid Organo-Mineral Preparations (ROMP)	2019			2020		
		AB	A	B	AB	A	B
Control without fertilizer	Control	260.6	270.5	269.3	220.3	222.2	219.7
	Amino	270.1*		266.8	229.2		231.3*
	Amino mikro	270.3*		270.6	224.4		224.9
	Fulvo TE	268.2		271.9	214.0		217.9
	Seed treatment	268.7		272.9	225.0		232.6*
	Antistress	276.9*		278.2*	221.2		223.7
	Extra	264.7		271.9	222.0		224.4
	Rootmost	273.5*		276.5*	223.2		229.8*
	Polymicrostim	270.2*		276.8*	228.3		224.9
	Avatar	279.7*		279.2*	214.2		215.6
$N_{30} + N_{30}$	Control	278.1	276.6	–	219.2	226.8	–
	Amino	263.5			233.4*		
	Amino mikro	270.9			225.3		
	Fulvo TE	275.8			221.8		
	Seed treatment	277.2			240.1*		
	Antistress	277.9			226.3		
	Extra	279.1			226.8		
	Rootmost	279.5			236.4*		
	Polymicrostim	279.4			221.5		
	Avatar	277.1			217.1		
$LSD_{0.5}$		8.4	2.9	6.5	10.0	3.2	7.0
Contribution of factor, %		0	10.0	17.0	0	13	42
Experimental error, %		1.1			1.7		

*Note: * – significant difference.

Mineral fertilizers significantly affected the protein content of chickpea seeds in all years of the study, with the contribution of this factor ranging from 84% to 92% depending on the pre-sowing treatment (Table 5.7).

Table 5.7

Effect of Mineral Fertilizers and Inoculants on Crude Protein Concentration in Chickpea Seeds, % of Dry Matter

№	Fertilization System	Crude Protein, %				± to Control	
		2016	2017	2018	Average	abs. %	rel. %
1	2	3	4	5	6	7	8
Without Inoculation							
1	Control	21.6	23.2	21.4	22.1	0	0
2	P ₃₀ K ₃₀	27.3	24.1	24.6	25.3	3.2	14.5
3	P ₃₀ K ₃₀ +N ₃₀	30.5	23.8	23.2	25.8	3.7	16.7
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	27.6	24.0	23.6	25.1	3.0	13.6
5	P ₃₀ K ₃₀ +N ₆₀	25.5	24.6	24.2	24.8	2.7	12.2
6	N ₃₀ P ₃₀ K ₃₀	28.9	23.9	24.8	25.9	3.8	17.2
7	N ₆₀ P ₃₀ K ₃₀	29.3	24.6	25.1	26.3	4.2	19.3
8	N ₃₀ at Sowing	26.3	24.5	23.9	24.9	2.8	12.8
9	N ₆₀ at Sowing	28.5	24.3	25.7	26.2	4.1	18.6
10	N ₉₀ at Sowing	23.2	24.8	25.6	24.5	2.4	11.2
11	N ₁₂₀ at Sowing	23.2	24.4	26.2	24.6	2.5	11.5
12	N ₃₀ +N ₃₀ in Vegetation	23.0	24.9	23.2	23.7	1.6	7.4
LSD _{0.5} = 2.4; Experimental Precision = 3.9%; Factor Influence = 92%.							
BTU-inoculant							
1	Control	22.1	25.3	22.6	23.3	0	0
2	P ₃₀ K ₃₀	26.0	25.5	25.4	25.6	2.3	9.3
3	P ₃₀ K ₃₀ +N ₃₀	28.7	25.9	25.6	26.7	3.4	14.6
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	25.4	25.8	25.6	25.6	2.3	9.7
5	P ₃₀ K ₃₀ +N ₆₀	26.7	25.1	25.2	25.7	2.4	10.0
6	N ₃₀ P ₃₀ K ₃₀	28.3	25.7	23.7	25.9	2.6	11.0
7	N ₆₀ P ₃₀ K ₃₀	28.2	25.1	25.5	26.2	2.9	12.6
8	N ₃₀ at Sowing	26.3	26.3	24.7	25.8	2.4	10.4
9	N ₆₀ at Sowing	28.7	26.4	25.1	26.7	3.4	14.6
10	N ₉₀ at Sowing	24.1	27.1	25.2	25.5	2.2	9.1
11	N ₁₂₀ at Sowing	23.9	27.1	26.1	25.7	2.4	10.1
12	N ₃₀ +N ₃₀ in Vegetation	24.8	26.6	25.0	25.5	2.2	9.1
LSD _{0.5} = 1.9; Experimental Precision = 2.5%; Factor Influence = 90%.							
Rhizobiphyte							
1	Control	22.6	24.8	21.1	22.8	0	0
2	P ₃₀ K ₃₀	28.3	25.8	22.5	25.5	2.7	11.8

Continuation of Table 5.7

1	2	3	4	5	6	7	8
3	P ₃₀ K ₃₀ +N ₃₀	27.5	25.5	25.6	26.2	2.4	14.7
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	29.9	25.4	24.8	26.7	3.9	16.9
5	P ₃₀ K ₃₀ +N ₆₀	28.1	25.7	24.6	26.1	3.3	14.5
6	N ₃₀ P ₃₀ K ₃₀	28.2	24.5	25.2	26.0	3.1	13.7
7	N ₆₀ P ₃₀ K ₃₀	28.7	25.3	24.9	26.3	3.5	15.2
8	N ₃₀ at Sowing	24.1	25.2	24.6	24.6	1.8	7.9
9	N ₆₀ at Sowing	26.5	26.1	25.1	25.9	3.1	13.4
10	N ₉₀ at Sowing	28.3	26.1	25.4	26.6	3.8	16.5
11	N ₁₂₀ at Sowing	24.2	25.7	24.9	24.9	2.1	9.2
12	N ₃₀ +N ₃₀ in Vegetation	24.2	25.8	25.1	25.0	2.2	9.6
LSD _{0.5} = 1.8; Experimental Precision = 2.2%; Factor Influence = 84%.							
Rhizogumin							
1	Control	23.3	24.7	22.9	23.6	0	0
2	P ₃₀ K ₃₀	29.7	25.3	30.4	25.8	4.8	20.5
3	P ₃₀ K ₃₀ +N ₃₀	28.8	25.4	30.0	28.1	4.4	18.8
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	30.2	25.3	29.7	28.4	4.8	20.2
5	P ₃₀ K ₃₀ +N ₆₀	27.1	25.5	27.4	26.7	3.1	12.8
6	N ₃₀ P ₃₀ K ₃₀	28.0	24.3	28.1	26.8	3.2	13.4
7	N ₆₀ P ₃₀ K ₃₀	28.1	25.3	28.4	27.3	3.6	15.4
8	N ₃₀ at Sowing	27.3	25.3	27.2	26.6	3.0	12.6
9	N ₆₀ at Sowing	27.3	26.1	28.0	27.1	3.5	14.8
10	N ₉₀ at Sowing	28.2	26.2	28.0	27.5	3.8	16.2
11	N ₁₂₀ at Sowing	24.3	25.5	24.9	24.9	1.3	5.4
12	N ₃₀ +N ₃₀ in Vegetation	26.3	25.7	25.7	25.9	2.6	9.6
LSD _{0.5} = 1.2; Experimental Precision = 2.6%; Factor Influence = 85%.							

The significant influence of fertilizers on the crude protein concentration in chickpea seeds was confirmed in subsequent years when evaluating the effectiveness of liquid organo-mineral preparations, as the contribution of mineral nitrogen over the years ranged from 20% to 69%, compared with Factor B – 10% and 5% (Table 5.8). In the 2019 growing season, the application of mineral nitrogen did not significantly affect the crude protein concentration in chickpea seeds, with an increase of only 0.18% (LSD_{0.5} = 0.23); however, liquid organo-mineral preparations had a significant effect at each fertilization level.

Table 5.8

**Crude Protein Content in Chickpea Seeds,
% of Absolutely Dry Matter**

Factor A	Factor B	2019			2020		
		AB	A	B	AB	A	B
Control without fertilizer	Control	22.96	25.18	24.03	25.70	24.99	25.72
	Amino	26.04		25.06	25.02		25.45
	Amino mikro	25.61		25.08	24.73		25.93
	Fulvo TE	25.89		25.69	24.69		26.09
	Seed treatment	25.56		25.58	24.69		25.87
	Antistress	25.58		25.44	25.17		26.03
	Extra	24.88		25.19	24.84		25.52
	Rootmost	25.15		25.21	25.21		25.76
	Polymicrostim	25.21		25.23	25.21		25.68
	Avatar	24.88		25.06	24.87		25.60
N ₃₀ +N ₃₀	Control	25.10	25.36	-	26.01	26.55	-
	Amino	24.08			25.88		
	Amino mikro	24.56			27.13		
	Fulvo TE	25.49			27.49		
	Seed treatment	25.60			27.06		
	Antistress	25.30			26.89		
	Extra	25.49			26.21		
	Rootmost	25.28			26.31		
	Polymicrostim	25.24			26.15		
	Avatar	25.23			26.34		
LSD _{0.5}	0.73	0.23	0.51	0.62	0.20	0.44	
Contribution of factor, %	0	20	10	0	69	5	
Experimental error, %	1,2			0.8			

In 2020, a slightly different trend was observed: a statistically significant effect of fertilizers on seed protein content was recorded on average across fertilization backgrounds. Without mineral nitrogen application, liquid organo-mineral preparations did not positively affect this indicator; however, their use on plots supplemented with mineral nitrogen increased chickpea seed protein content, except for Amino. In cases of Amino mikro, Fulvo TE, Seed treatment, and Antistress, this increase was statistically significant, ranging from 0.88% to 1.37% (LSD_{0.5} = 0.62) (Appendices I1–I2).

On average, over the two years of the study, the increases in these parameters relative to the control variant did not exceed the 5% experimental error range (Fig. 5.7).

It should be noted that in our experiments, the protein content in chickpea seeds varied depending on the weather conditions during the years of study, which were characterized by the hydrothermal coefficient (HTC), with a correlation coefficient of 0.77. However, this relationship differed somewhat between the pure control and experimental variants. Chickpea seeds grown on the natural fertility of the southern chernozem soil showed the lowest protein content (22.4%) in 2016, a year with optimal moisture conditions. In the more arid years of 2017–2020, protein concentration ranged from 24.50% to 25.76%. The correlation coefficient between protein content in the control variants and the HTC during the chickpea growing season was $|r| = 0.64$ ($R^2 = 0.409$).

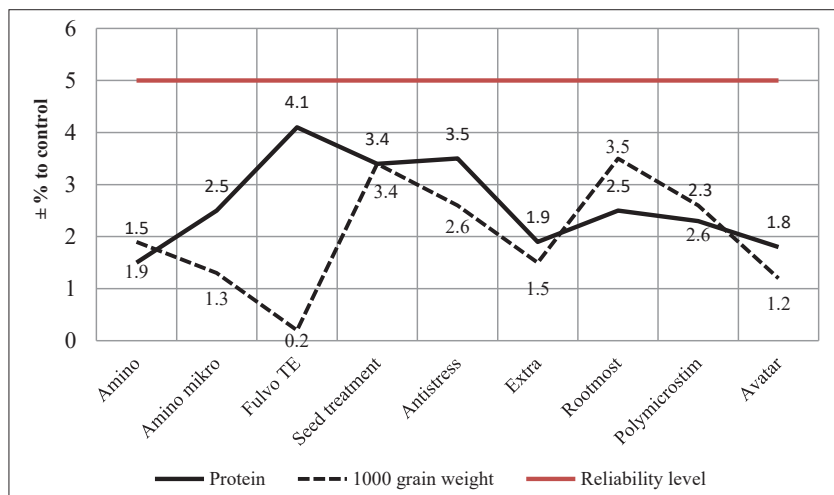


Fig. 5.7. Average increase in protein content and seed size of chickpea relative to control, depending on the application of liquid organo-mineral preparations and years of study

The formation of protein content in chickpea seeds in variants treated with mineral fertilizers or liquid organo-mineral preparations

was less determined by weather conditions during vegetation compared to the control variants ($r = 0.48$; $R^2 = 0.230$). Protein concentration in chickpea seeds from experimental plots during 2017–2020 averaged 25.35% to 26.96%, while in 2016 it reached 27.02%, which is 0.06–1.67% higher than in the drier years. A similar trend was observed for fat content in chickpea seeds (Appendix J).

At first glance, this appears to contradict data from other researchers [11; 36; 106; 123; 185]. However, a detailed analysis of the relationship between HTC values for specific periods of chickpea growth and seed protein content revealed the most significant correlation ($r = -0.882$; $R^2 = 0.778$) in the “protein content – July HTC” link. In 2016, the HTC in June was the lowest (0.16), while in other study years it ranged from 0.56 to 0.94. It should be noted that the highest HTC value in July was in 2016, at 0.97, corresponding to the lowest protein concentration compared to other years, which was 25.35%.

Conclusions to Section 5

1. Among the examples of mineral nutrition for chickpea, the variant with the application of $P_{30}K_{30}$ during pre-sowing cultivation combined with N_{30} at the branching stage and seed inoculation with the BTU-r preparation was distinguished, where the yield increase reached 1.50 t/ha, or 16.7 kg per unit of active fertilizer substance, compared to the unfertilized variant.

2. On average, across the seed inoculation variants, compared to the $P_{30}K_{30}$ treatment, a single foliar application of mineral nitrogen at 30 kg/ha during the branching stage provided a yield increase of 0.25 t/ha.

3. In fields with medium or higher content of available phosphorus and potassium, an effective two-stage nitrogen application consists of N_{30} at the branching stage plus N_{30} at the beginning of budding. These treatments are best combined with pre-sowing seed inoculation using BTU-inoculant and Rhizobophyte, resulting in a yield increase of 0.99–0.89 t/ha.

4. Under the arid conditions of the Southern Steppe of Ukraine, liquid organo-mineral preparations based solely on amino acids did not

exhibit a stimulatory effect on chickpea yield. Amino-chelated liquid organo-mineral fertilizer, where amino acids act as ligands, ensured an average yield increase of 17.3%; Fulvo TE based on fulvic acids – 35.9%; and Antistress, based on humic and fulvic acids – 28.0%.

5. A correlation dependence of chickpea yield and the formation of individual structural elements on growing season weather conditions was established:

- The pairwise correlation coefficient between the hydrothermal coefficient (HTC) in May and the number of pods formed was 0.68, and with the yield – 0.88;

- Pod formation is limited both by extreme drought ($HTC \leq 0.4$) and by heavy rainfall;

- A significant correlation was found between the productivity of chickpea crops and elements such as plant height, branching, number of seeds per plant, and seed weight, with correlation coefficients ranging from 0.81 to 0.85.

6. Weather conditions during the study years influenced the protein content of chickpea seeds. The pairwise correlation coefficient between protein content and the HTC during vegetation was 0.64 in the control variants and 0.48 in the experimental treatments. The formation of protein was most strongly affected by the hydrothermal conditions in July, where $r = -0.882$.

CHAPTER 6

ECONOMIC AND ENERGY EFFICIENCY OF CHICKPEA NUTRITION SYSTEMS

6.1. Cost-effectiveness of nutrition systems

Amid the global economic crisis, the use of all types of fertilizers, chemical ameliorants, and plant protection products has sharply declined, resulting in an irreversible loss of accumulated soil fertility reserves and, consequently, a reduction in crop productivity [159].

Research has demonstrated that even under the current global price disparities, high cost-effectiveness of applied nutrients can be achieved through scientifically justified selection of fertilizer type, rate, and application method, based on soil-plant diagnostics and the biological requirements of crops [29; 82]. This approach can lead to yield increases of 50–60% in agricultural crops [159].

Indicators of fertilizer use efficiency are among the main parameters characterizing the performance of agricultural enterprises. Their values determine the volume of product sales, production costs, profit, profitability, financial stability, solvency, and other economic indicators of the enterprise. Therefore, the analysis of cultivation technology should begin with the assessment of fertilizer use efficiency.

Fertilizer efficiency is defined as the amount of agricultural output obtained from their application. It is expressed as the increase in crop yield in kilograms per 1 kg of active ingredient in mineral fertilizers, or per 1 t of organic fertilizers.

According to FAO data, in recent years the correlation coefficient between harvested yield and the amount of mineral fertilizers applied in 40 countries has ranged from 0.83 to 0.85. The contribution of applied fertilizers to yield formation continues to increase. Depending on the level of agricultural intensification, the share of fertilizer nutrients in the yield of Western European countries ranges from 60% to 75%, in France – 50–70%, and in the USA – 50%. At the same time, due to various circumstances, fertilizer use efficiency is often quite low [236].

The return on 1 kg of NPK in terms of grain in farms ranges from 4 to 6 kg, whereas in field trials of research institutions it reaches

12–14 kg of grain. According to FAO standards, an optimal return is considered 10–12 kg of grain per 1 kg of NPK applied. Although nutrients not utilized in the current year's harvest may be taken up by plants in subsequent years, from an economic perspective, this delayed effect represents a freezing of resources, reducing their return and investment efficiency. Therefore, appropriate measures are required to maximize nutrient utilization in the year of application [172].

According to field research, the cost-effectiveness of 1 kg of active ingredient of mineral fertilizers, in terms of yield increase of main crops, is as follows: winter wheat – 3.5–6.5 kg, winter rye – 3.5–6.2 kg, spring wheat – 3.4–6.0 kg, barley – 3.2–8.0 kg, oats – 2.5–7.0 kg, maize – 2.2–7.0 kg, rice – 5.7–12.0 kg, potatoes – 20–50 kg, sugar beet – 18–70 kg, flax straw – 4.0–8.5 kg, sunflower – 2.0–4.0 kg, vegetables – 10–50 kg, hay from grasses – 7–25 kg, fruits and berries – 10–35 kg [129; 172].

Practical results indicate that the highest return on yield per unit of fertilizer occurs with the application of relatively low rates of fertilizers. However, since the yield increase per unit area at low application rates is also small, the costs of fertilizer application may not be fully compensated by the resulting yield gain. With an increase in fertilizer rates up to a certain level, both yield and profit rise, but the cost-effectiveness of each unit of fertilizer gradually decreases. Practical experience confirms that it is more profitable to apply smaller rates of fertilizers over a larger area and obtain higher overall yields than to use high rates over a smaller area [85].

Under modern conditions, it is important not only to determine the effectiveness of fertilizers in the current year but also to evaluate them based on market conditions for crop products and the profitability of their application in the near future [113; 159; 189; 257]. Currently, the contribution of mineral fertilizers to the total productivity of arable land is 40–45%. The primary goal of improving the efficiency of chemical inputs is to increase the return on mineral fertilizers to 8.0 kg of grain per 1 kg of NPK [82; 85].

The cost-effectiveness of applied mineral fertilizers varies significantly depending on the technological measures used in crop cultivation. When nutrient supply fully satisfies the plant's requirements under optimal conditions for growth and development,

producers can achieve maximum effect. In arid conditions, where yield is limited by water availability, the biological efficiency of fertilizers is minimal.

Our studies indicate that the cost-effectiveness of 1 kg of active ingredient of mineral fertilizers in terms of chickpea grain yield, averaged over the years of research, in the optimal variant with $N_{30}+N_{30}$ application, was 5.80 kg, fluctuating between 9.8 and 3.0 kg per kg of active ingredient, which is below optimal levels.

Application of N_{30} on the $P^{30}K^{30}$ background, compared with the unfertilized control, ensured an average return of 8.3 kg per kg of nitrogen active ingredient over the years of research, ranging from 22.7 to 2.0 kg per kg of active ingredient. Compared with the pure control, this fertilization system provided an average fertilizer return of 4.4 kg, and in the optimally moist year – 11.7 kg per kg of active ingredient.

When using liquid organo-mineral preparations, the highest yield increase, both on the unfertilized and nitrogen-fertilized backgrounds in 2019, was achieved with the preparation containing fulvic acids and macro- and microelements (Fulvo TE): compared with the unfertilized control, the increase was 0.21 t/ha, and relative to the fertilized control – 0.18 t/ha. In 2020, Fulvo TE (+0.33–0.49 t/ha) and Antistress (+0.40–0.35 t/ha) showed the greatest effect. Among amino acid-based preparations, Amino mikro provided the highest yield increase, ranging from 9.2% to 19.1%, depending on weather conditions and nutrient background. On average, over two years, the application of liquid organo-mineral preparations based on humic and fulvic acids increased chickpea yield as follows: Fulvo TE – 35.9%, Antistress – 28.0%, amino-chelated fertilizer – 17.3%.

The contribution of nitrogen fertilizers to chickpea productivity varied in absolute terms over the years, but the application of liquid organo-mineral preparations had a greater effect than mineral nitrogen: 44% and 75% versus 35% and 44%, respectively, during the research years.

6.2. Economic and Energy Efficiency

Table 6.1 presents the economic efficiency of chickpea cultivation under different levels of mineral nutrition.

Production costs for growing chickpeas under various mineral nutrition systems range from 10.3 to 15.4 thousand UAH/ha, while the net conditional profit reaches 11.4–20.4 thousand UAH/ha, depending on the yield obtained. The profitability of chickpea production varies from 73.8% to 174.7%, while in the control variant it is 189.9%.

Table 6.1

Economic efficiency of chickpea cultivation under different mineral nutrition systems, average for 2016–2018

Fertilizer variants			Yield, t/ha	Gross product cost, th. UAH/ha	Total expenses, th. UAH/ha	Cost price, th. UAH/t	Net conditional profit, th. UAH/ha	Profitability, %
before sowing	beginning of branching	beginning of flowering						
Control – no fertilizers			2.15	26.9	9.3	4.31	17.6	189.9
P ₃₀ K ₃₀	–	–	2.30	28.8	12.9	5.59	15.9	123.6
P ₃₀ K ₃₀	N ₃₀	–	2.55	31.9	13.9	5.46	17.9	129.1
P ₃₀ K ₃₀	N ₃₀	N ₃₀	2.30	28.8	14.9	6.51	13.8	92.1
P ₃₀ K ₃₀	N ₆₀	–	2.28	28.5	14.9	6.56	13.5	90.5
(NPK) ₃₀	–	–	2.25	28.1	12.1	5.39	15.9	131.9
N ₆₀ P ₃₀ K ₃₀	–	–	2.14	26.8	15.4	7.19	11.4	73.8
N ₃₀	–	–	2.46	30.8	10.3	4.19	20.4	197.9
N ₆₀	–	–	2.36	29.5	11.4	4.82	18.1	159.3
N ₉₀	–	–	2.31	28.9	12.4	5.38	16.5	132.4
N ₁₂₀	–	–	2.03	25.4	13.5	6.64	11.9	88.2
–	N ₃₀	N ₃₀	2.50	31.3	11.4	4.55	19.9	174.7

The highest production costs, 15.4 thousand UAH/ha, were recorded in the variant with the highest fertilizer rate, N₆₀P₃₀K₃₀, where the average yield was 2.14 t/ha, the profitability level was 73.8%, and the cost of grain was 7.2 thousand UAH/t.

With the application of phosphate–potassium fertilizers and nitrogen top-dressing, the net conditional profit ranged from 13.6 to 15.9 thousand UAH/ha, with a profitability level of 90.5–123.6%. In the variant with $N_{30}P_{30}K_{30}$, at a yield of 2.25 t/ha, the net conditional profit was 15.4 thousand UAH/ha, with a profitability of 131.9%.

The most economically efficient option for chickpea cultivation in the conditions of the Southern Steppe of Ukraine is the variant in which nitrogen fertilizers are applied at a rate of N_{30} during sowing. In this variant, total production costs amount to 10.3 thousand UAH/ha, the net conditional profit is 20.4 thousand UAH/ha, and the profitability level is 197.9%.

A detailed analysis of the cost structure shows that with an increase in fertilizer rates, the share of fertilizer expenses rises when cultivating chickpea under dryland conditions.

The economic efficiency of liquid organo-mineral preparations over the two-year study period is presented in Table 6.2. The calculation took into account the costs determined by the specifics of the technology: purchase and application of the preparations and nitrogen fertilizers, as well as the value of the obtained grain yield increase, since all other costs were the same across the fertilizer variants.

Table 6.2

Economic efficiency of biopreparations in chickpea crops, UAH of net conditional profit per 1 UAH of additional expenses

Biopreparation	Fertilization background	
	without fertilizers	$N_{30}+N_{30}$
Amino	0.25	-0.75
Аміно Мікро	3.25	0.10
Fulvo TE	5.60	1.50
SeedTreatment	4.20	0.70
Antistress (SG Protector)	5.40	0.90
EXTRA	4.50	0.25
RootMost	4.60	0.30
Polymicrostim	4.65	1.25
Avatar Organic + Avatar Protection + Avatar Barrier	1.25	-0.25

It was established that under the weather conditions of 2019–2020, at the levels of yield increase obtained in variants with the use of liquid organo-mineral preparations on the background of mineral nitrogen (0.05–0.25 t/ha), their combined application was, in most cases, economically unprofitable. Only treatment with Fulvo TE and Polymicrostim allowed achieving 1.25–1.50 UAH of net conditional profit per 1 UAH of expenses. Fertilizer costs accounted for 58.4% of the total expenses.

On unfertilized plots, a yield increase of 0.20–0.25 t/ha provided from 4.5 to 5.6 UAH of profit per 1 UAH of expenses.

The coefficient of energy efficiency when using biopreparations averaged 6.22, while with the use of mineral fertilizers and biopreparations on the background of mineral nutrition, it varied from 4.28 to 3.25.

The increase in the energy efficiency coefficient by 45.3–89.6% when using biopreparations is due to lower costs compared to mineral fertilizers and the higher energy intensity of synthetic fertilizers.

Conclusions to Section 6

1. Over the period 2016–2020, based on a comprehensive assessment of indicators, the most favorable variant was identified as: application of $P_{30}K_{30}$ before pre-sowing cultivation + N_{30} at the branching stage. In fields with medium and high levels of available phosphorus and potassium, it is advisable to apply nitrogen twice: N_{30} at the branching stage + N_{30} at the beginning of budding. These schemes are complemented by pre-sowing inoculation of chickpea seeds with BTU-inoculant and Rhizobophyte.

2. On average, over the years of research, the payback of 1 kg of active ingredient of mineral fertilizers in terms of chickpea grain yield in the optimal variant with $N_{30}+N_{30}$ application was 5.80 kg. Application of N_{30} on the background of $P_{30}K_{30}$, compared to the basal variant, provided a payback of 1 kg of nitrogen active ingredient of 8.3 kg. Compared with the untreated control, this fertilization system ensured an average fertilizer payback of 4.4 kg, reaching 11.7 kg/kg of active ingredient in the optimal moisture year.

3. Cultivation of chickpea with varying levels of mineral nutrition and pre-sowing seed treatment with inoculants in the conditions of the Southern Steppe of Ukraine is economically efficient and profitable, despite the high cost of mineral fertilizers. With total technological costs for crop cultivation, the net conditional profit ranges from 11.4 to 20.4 thousand UAH/ha, and the grain cost ranges from 4.2 to 7.2 thousand UAH/t, depending on the fertilizer rate and composition. The profitability level ranges from 88.2% to 197.9%.

4. Analysis of data on the use of liquid organo-mineral preparations demonstrates a significant advantage in the economic and energy efficiency of chickpea cultivation variants. A clear trend is observed, exceeding the control variants when crops are treated three times at the branching, budding, and beginning of grain filling stages with the following preparations:

- On unfertilized background – Fulvo TE, Antistress, Polymicrostim, Extra, and RootMost provided a yield increase of 0.23–0.27 t/ha, with an economic effect of 4.6–5.6 UAH of net conditional profit per 1 UAH of additional expenses, and an energy efficiency coefficient of 6.22.

- On the background of mineral nitrogen application at N_{30} at sowing + N_{30} as the first top-dressing at branching, maximum payback was observed with Fulvo TE and Polymicrostim, with a yield increase of 0.30–0.34 t/ha, slightly less for Antistress (0.25 t/ha). Economic effect was 1.50, 1.25, and 0.90 UAH of net conditional profit per 1 UAH of expenses, and the energy efficiency coefficient ranged from 4.28 to 3.25.

CONCLUSIONS

The monograph presents a theoretical synthesis and a novel solution to the scientific problem of optimizing nutrient systems in chickpea cultivation technologies under the arid conditions of the Southern Steppe of Ukraine. The results of experimental studies conducted during 2016–2020 provide a basis for increasing the production of high-quality legume crops while reducing the economic and energy costs of their cultivation.

1. On average, over the years of research, the total water consumption of chickpea crops in the 0–100 cm soil layer was 3,144 m³/ha in variants with mineral fertilizers, and 1,964 m³/ha in variants with liquid organo-mineral fertilizers. The difference between the mean values for 2016–2018 and 2019–2020 amounted to 37.5% and was determined not by the nutrient systems but by the weather conditions of the respective years, as the differences between fertilization variants within each year ranged from 0.3% to 2.8% and were statistically insignificant. The contribution of soil moisture reserves and precipitation to chickpea water consumption on the chernozem soils of southern Odesa region depended on weather conditions: in the absence of or under mild soil drought, and with moderate atmospheric drought, the contribution of soil moisture to yield formation ranged from 29.4% to 48.9%; with productive moisture reserves in the 0–100 cm soil layer ≤30 mm and no effective precipitation from sowing to the beginning of flowering under severe combined atmospheric-soil drought, this share decreased to 12–13%. Severe stress experienced by chickpea plants during this period limits their ability to fully utilize post-flowering precipitation, resulting in low yields of the Pamyat' cultivar, ranging from 0.7 to 1.3 t/ha.

2. It was established that the lowest water consumption per 1 t of seed was recorded in the variant with N₃₀ applied on the background of R₃₀K₃₀ and in the variant with two foliar applications of N₃₀ during the branching and early pod-filling stages: 1,319 m³/t and 1,294 m³/t, respectively, compared to 1,483 m³/t in the unfertilized control. Triple foliar application of liquid organo-mineral fertilizers containing a complex of macro- and microelements reduced water consumption

per 1 t of seed by an average of 21.7%, and by 27.3% when using Fulvo TE.

Mathematical analysis of the research results established correlations between the duration of interphase periods and weather conditions: the sum of effective temperatures ($\geq +10$ °C) in April, May, and June ($r = 0.70-0.88$), the sum of precipitation ($r = 0.43-0.70$), and the productive moisture reserves in the 1 m layer of southern chernozem soils ($r = 0.69-0.98$). These weather indicators influence chickpea growth throughout the entire vegetation period, with the main differences observed in the strength and direction of these correlations.

3. It was found that mineral fertilizers significantly affect the linear dimensions of chickpea plants. On average, using fertilization systems, plant height during the branching phase increased significantly by 11.4% to 22.1%. In drought years, nitrogen fertilizers had the greatest effect, whereas in years with favorable moisture conditions, all types of fertilizers contributed to growth.

Using liquid organo-mineral fertilizers, the best plant growth was observed in variants treated with Seed Treatment, Antistress (SG Protector), Extra, and Polimicrostim. On the background of mineral nitrogen fertilization ($N_{30}+N_{30}$), growth increased by 1.8–8.0% compared to these same variants without fertilization.

4. Maximum chlorophyll content in chickpea leaves was observed from flowering to the beginning of pod-filling, reaching 251–269 mg/100 g fresh weight under the combined action of inoculants and fertilizers ($N_{30-60}P_{30}K_{30}$ and N_{30-60}) compared to the unfertilized, uninoculated control (183–187 mg/100 g). Differences between nitrogen fertilizer rates were not statistically significant. The ratio between chlorophyll fractions decreased due to an increased share of chlorophyll b in total green pigments, both across plant developmental stages and fertilization/inoculation variants, when moving from complete mineral fertilizers to nitrogen-only fertilization.

5. A direct correlation was established between chlorophyll concentration in chickpea leaves at the flowering stage and yield: for the pair yield–chlorophyll a, the correlation coefficient ranged from 0.64 to 0.78, while for chlorophyll b, it ranged from 0.28 to 0.40. A relatively stronger relationship between chlorophyll b content and

chickpea yield was observed in a less favorable year, accounting for 16.0% of the influence, compared to 1.0–7.8% in more favorable years, whereas chlorophyll α had a greater impact in favorable years (60.8% versus 32.5–41.0%).

6. The application of the mineral fertilization system $P_{30}K_{30}+N_{30}$ combined with pre-sowing seed treatment with a BTU-inoculant increased the photosynthetic leaf area of chickpea by 34.1%. The combination of nitrogen background fertilization ($N_{30}+N_{30}$) with triple foliar application of one of the liquid organo-mineral fertilizers SeedTreatment, Antistress, EXTRA, RootMost, or Polimicrostimensured the highest photosynthetic potential.

7. It was found that the maximum number of nodules on chickpea roots, both in quantity and mass, was formed during the flowering stage. Pre-sowing treatment variants resulted in an average of 1.6–1.7 times more nodules per plant compared to the control. Regarding the interaction of fertilization and inoculation factors on nitrogen-fixing capacity, the highest nodule mass (4.64 g per plant) was achieved with Rizogumin on the background of phosphorus-potassium fertilization ($R_{30}K_{30}$).

8. Increasing the pre-sowing nitrogen rate from 30 to 120 kg/ha suppressed nodule formation: by 32.3% in the control, 15.8% with BTU-inoculant, 22.2% with Rizobofit, and 54.3% with Rizogumin, while nodule mass decreased by 53.6%, 59.7%, 60.0%, and 21.4%, respectively. Similarly, increasing nitrogen from 30 to 60 kg/ha within a complete mineral fertilizer reduced nodule number by an average of 19.7% and their mass by 26.7%.

9. A significant correlation was established between chickpea yield and structural plant elements, including plant height, branching, number of seeds per plant, and seed weight. Correlation coefficients ranged from 0.81 to 0.85, while weather conditions influenced specific yield components ($r = 0.68$ for May hydrothermal coefficient vs. number of pods) and protein content in chickpea seeds ($r = -0.88$ for July hydrothermal coefficient vs. protein).

10. The optimal mineral fertilization system–pre-sowing application of $R_{30}K_{30}+N_{30}$ at the branching stage combined with BTU-inoculated seed treatmentensured a chickpea yield of 2.55 t/ha,

a profitability level of 129.1%, and an average fertilizer payback of 4.4 kg per 1 kg of dry matter.

When growing chickpea without mineral fertilizers, effective yield increases were achieved through triple foliar applications at branching, budding, and early pod-filling stages using liquid organo-mineral fertilizers: amino-chelate-based (Amino Mikro) increased yield by 17.3% on average; fulvic acid-based (Fulvo TE) and EDTA-based (Polimicrostim) by 35.9%; and humic and fulvic acid-based (Antistress) by 28.0%. The economic efficiency of these treatments ranged from 3.3 to 5.6 UAH of net profit per 1 UAH of additional costs, with an energy efficiency coefficient of 6.22.

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APPENDIX

Appendix A₁

**Weather Conditions During the Chickpea Growing Season
(2016–2020), According to Data from the Odesa State
Agricultural Research Station Meteorological Post**

Month	Ten-Day Period	Average Daily Air Temperature, °C					Precipitation, mm				
		2016	2017	2018	2019	2020	2016	2017	2018	2019	2020
1	2	3	4	5	6	7	8	9	10	11	12
March	I	7.7	5.7	-5.0	4.0	9.7	24.0	1.0	8.0	0	0
	II	4.9	6.0	3.4	4.7	7.7	3.4	1.0	29.1	0	0
	III	7.2	9.6	2.4	6.0	7.5	13.6	5.0	13.4	0	7
	Total	6.6	7.1	1.5	4.9	8.3	41.0	7.0	50.5	0	7
	Long-term average	2.0					20				
	Deviation from average	+4.6	+5.1	-0.5	+2.9	+6.3	+21.0	-13.0	+30.5	-20.0	-13.0
April	I	11.6	9.4	13.4	5.8	8.4	1.5	6.8	1.3	0	0
	II	14.2	8.6	14.1	7.6	11.6	28.3	21.8	0.8	23	3
	III	11.2	9.2	15.6	9.8	11.5	52.2	24.0	1.2	0	3
	Total	12.3	9.1	14.4	7.7	10.5	82.2	52.6	3.3	23	6
	Long-term average	8.5					27				
	Deviation from average	+3.8	+0.6	+5.9	-0.8	+2.0	+55.2	+25.6	-23.7	-4.0	-21.0
May	I	15.0	16.8	20.0	12.9	13.9	5.2	4.8	6.9	7	6
	II	15.1	14.7	16.7	16.2	15.9	32.0	23.3	3.0	4	4
	III	20.2	19.1	19.3	21.0	13.1	40.0	5.3	0	3.5	59
	Total	16.9	16.9	18.6	16.2	13.2	77.2	33.4	9.9	14.5	69
	Long-term average	15.3					35				
	Deviation from average	+1.6	+1.6	+3.3	+0.9	-2.1	+42.2	-1.6	-25.1	-20.5	+34

Continuation of *Appendix A₁*

1	2	3	4	5	6	7	8	9	10	11	12
June	I	16.8	20.5	19.7	23.0	17.7	58.2	0	0	22.5	0
	II	22.4	20.3	21.6	28.5	22.2	4.4	23.0	0	0	28
	III	27.5	21.5	21.1	26.9	23.2	0	12.0	0.8	0	60
	Total	22.2	21.8	20.8	26.1	21.0	62.6	35.0	0.8	22.5	88
	Long-term average	19.6					55				
	Deviation from average	+2.6	+2.2	+1.2	+6.5	+1.4	+7.6	-20.0	-54.2	-32.5	+33
July	I	23.5	22.8	21.4	23.6	25.4	11.5	12.0	0	7	2.5
	II	23.8	23.1	22.2	20.5	22.6	0	43.0	0	0	35.0
	III	24.4	25.3	25.9	27.5	25.3	0	20.0	45	60	6.0
	Total	23.9	23.8	23.2	23.9	24.4	11.5	75.0	45	67	43.5
	Long-term average	22.5					44				
	Deviation from average	+1.4	+1.3	+0.7	+1.4	+1.9	-32.5	+31.0	+1.0	+23	-0.5

Appendix A₂

Distribution of Precipitation by Intensity and Chickpea Growth Periods During the Research Years

Year	Period*	% of total precipitation	% distribution by rainfall class				
		Total	< 5 mm	5–9,9 mm	10–19,9 mm	≥20 mm <50 mm	> 50 M
2016	1	17.3	25.1	74.9	0	0	0
	2	57.8	21.0	9.0	40.0	30.0	0
	3	24.9	20.0	16.0	0	64.0	0
2017	1	14.3	75.6	24.4	0	0	0
	2	32.5	21.0	17.0	37.0	25.0	0
	3	53.2	11.0	10.0	19.0	60.0	0
2018	1	47.8	39.8	12.2	48.0	0	0
	2	28.6	60.0	17.0	23.0	0	0
	3	23.6	7.0	13.0	0	80.0	0
2019	1	31.9	18.1	18.1	63.8	0	0
	2	14.4	31.0	69.0	0	0	0
	3	53.7	0	10.0	11.0	0	79.0
2020	1	30.7	14.4	18.6	35.0	32.0	0
	2	26.0	12.0	31.0	0	57.0	0
	3	43.3	8.0	18.0	13.0	61.0	0

* 1 – before sowing (winter period); 2 – seedling to pod formation (spring period);
3 – grain filling to full maturity (summer period).

Appendix B₁**Soil Moisture Reserves (0–100 cm layer) Under Chickpea Crops
Depending on Fertilization Variants, 2016**

Fertilization Variant	Growth Stages				
	sowing	sprouting	flowering	pod formation	full ripeness
Control	140.1	130.2	94.7	128.1	31.2
P ₃₀ K ₃₀	142.5	128.4	94.5	127.3	29.3
P ₃₀ K ₃₀ +N ₃₀	139.8	125.6	89.5	121.1	25.4
P ₃₀ K ₃₀ +N ₆₀	144.6	136.4	90.1	117.8	32.7
N ₃₀ P ₃₀ K ₃₀	141.8	131.0	86.2	115.2	21.8
N ₆₀ P ₃₀ K ₃₀	140.5	127.8	84.8	97	20.6
N ₃₀ at Sowing	139.6	130.4	90.7	114.3	27.3
N ₆₀ at Sowing	142.1	129.4	91.1	111.8	26.7
N ₃₀ +N ₃₀ during vegetation	140.8	131.2	94.6	124.3	28.4

Appendix B₂**Reserves of productive moisture in the one-meter soil layer
under chickpea crops depending on mineral fertilizer
application options, 2017**

Fertilization Variant	Growth Stages				
	sowing	sprouting	flowering	pod formation	full ripeness
Control	125.2	115.4	82.3	16.5	5.3
P ₃₀ K ₃₀	120.9	116.2	81.1	4.2	3.9
P ₃₀ K ₃₀ +N ₃₀	126.3	115.1	68.2	3.4	2.3
P ₃₀ K ₃₀ +N ₆₀	124.8	112.0	69.1	2.9	1.7
N ₃₀ P ₃₀ K ₃₀	130.0	114.2	65.7	0.8	0.9
N ₆₀ P ₃₀ K ₃₀	128.1	110.5	60.1	1.5	0
N ₃₀ at Sowing	126.7	114.8	72.4	11.5	4.0
N ₆₀ at Sowing	127.8	113.2	70.8	12.4	4.0
N ₃₀ +N ₃₀ during vegetation	130.1	111.4	75.3	14.3	3.6

Appendix B₃**Reserves of productive moisture in the one-meter soil layer under chickpea crops depending on mineral fertilizer application options, 2018**

Fertilization Variant	Growth Stages				
	sowing	sprouting	flowering	pod formation	full ripeness
Control	110.2	90.2	64.5	12.9	3.1
P ₃₀ K ₃₀	117.6	110.4	60.3	10.2	0
P ₃₀ K ₃₀ +N ₃₀	106.	100.8	58.4	13.8	0
P ₃₀ K ₃₀ +N ₆₀	112.4	96.7	60.1	15.0	2.2
N ₃₀ P ₃₀ K ₃₀	115.8	104.7	60.4	15.4	1.0
N ₆₀ P ₃₀ K ₃₀	110.4	90.1	57.2	14.0	0
N ₃₀ at Sowing	115.4	94.2	68.8	12.8	2.4
N ₆₀ at Sowing	112.2	89.4	57.9	15.0	1.7
N ₃₀ +N ₃₀ during vegetation	117.5	92.4	69.5	15.3	2.8

Appendix B₄**Reserves of productive moisture in the one-meter soil layer under chickpea crops depending on ROMP application options, 2019**

A	Factor B	Growth Stages				
		sowing	sprouting	flowering	pod formation	full ripeness
Without fertilizer	Control	22.3	20.5	21.2	2.8	1.0
	Amino Micro	21.8	19.8	18.8	1.2	0.8
	Fulvo TE	20.7	18.4	20.7	2.7	1.2
	Antistress (SG Protector)	21.0	19.2	24.3	5.0	0.9
	Polymicrostim	20.4	18.6	15.6	4.4	1.0
N ₃₀ +N ₃₀	Control	26.0	21.0	17.4	3.8	0
	Amino Micro	22.1	20.1	19.0	2.6	0
	Fulvo TE	20.3	22.6	18.1	3.0	0.4
	Antistress (SG Protector)	23.7	21.2	15.8	4.3	0.5
	Polymicrostim	23.0	22.4	16.4	3.2	1.0

Appendix B₅**Reserves of productive moisture in the one-meter soil layer
under chickpea crops depending on ROMP application options,
2020**

A	Factor B	Growth Stages				
		sowing	sprouting	flowering	pod formation	full ripeness
Without fertilizer	Control	28.5	29.1	31.8	12.4	4.2
	Amino Micro	28.4	19.8	23.2	11.5	3.3
	Fulvo TE	30.1	28.1	29.3	8.9	3.6
	Antistress (SG Protector)	28.8	22.4	24.1	9.1	2.4
	Polymicrostim	24.6	20.5	22.8	4.5	2.3
N ₃₀ +N ₃₀	Control	29.2	26.4	41.2	8.3	2.8
	Amino Micro	27.3	22.8	25.3	5.9	0.5
	Fulvo TE	26.5	23.1	30.2	6.2	2.5
	Antistress (SG Protector)	30.1	28.4	29.8	11.2	0.6
	Polymicrostim	27.3	25.2	26.0	10.8	2.6

Appendix C₁

Chlorophyll content in chickpea leaves depending on mineral fertilizer application options

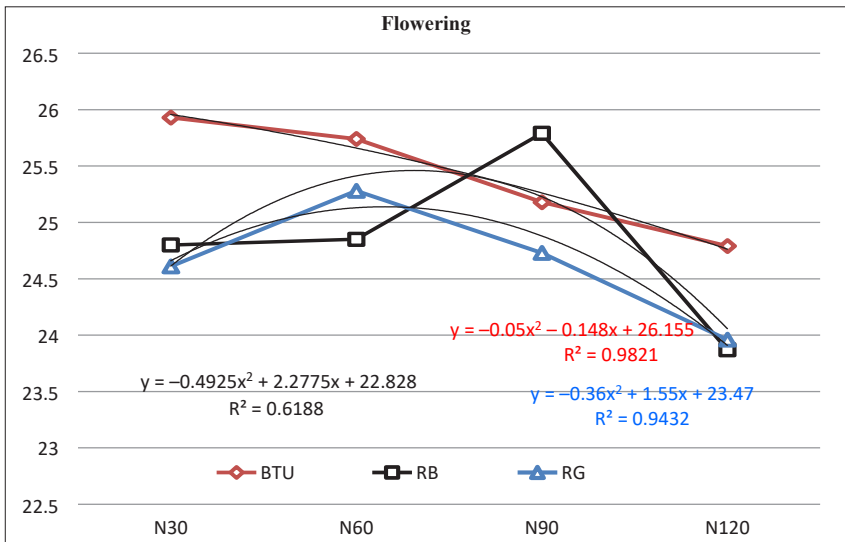
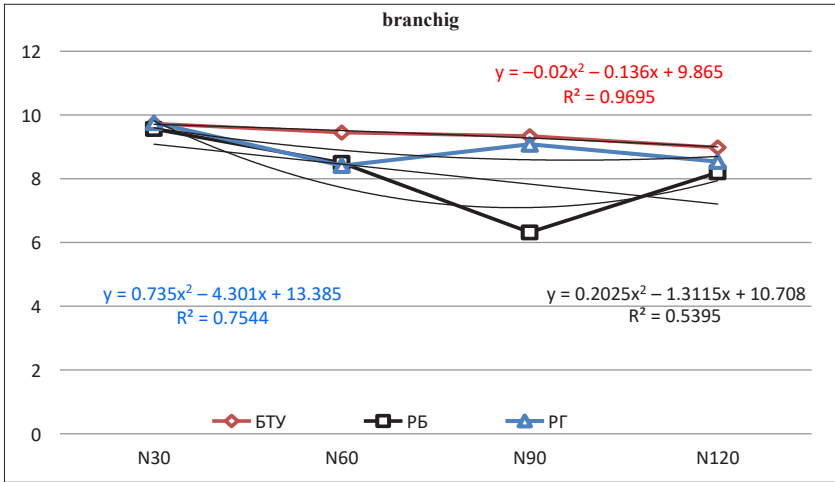
Variant	Growth Stages															
	branching						flowering						ripening			
	K	BTU	RB	RG	K	BTU	RB	RG	K	BTU	RB	RG	K	BTU	RB	RG
1	2	3	4	5	6	7	8	9	10	11	12	13				
Chlorophyllα																
without fertilizers	1.03	1.41	1.43	1.39	1.40	1.60	1.71	1.74	0.98	1.43	1.26	1.26				
P ₃₀ K ₃₀	1.08	1.59	1.41	1.50	1.51	1.82	1.75	1.86	1.04	1.64	1.32	1.28				
P ₃₀ K ₃₀ +N ₃₀	1.22	1.69	1.53	1.44	1.66	1.87	1.81	1.80	1.18	1.59	1.41	1.33				
P ₃₀ K ₃₀ +N ₃₀ +N ₆₀	1.33	1.64	1.46	1.42	1.78	1.84	1.76	1.74	1.28	1.57	1.34	1.34				
P ₃₀ K ₃₀ +N ₆₀	1.44	1.62	1.40	1.45	1.83	1.90	1.76	1.82	1.30	1.56	1.36	1.41				
N ₃₀ P ₃₀ K ₃₀	1.37	1.55	1.54	1.49	1.73	1.81	1.82	1.88	1.22	1.70	1.40	1.36				
N ₆₀ P ₃₀ K ₃₀	1.41	1.65	1.58	1.49	1.82	1.95	1.92	1.87	1.30	1.66	1.39	1.33				
N ₃₀	1.40	1.67	1.60	1.51	1.78	1.97	1.99	1.84	1.36	1.71	1.45	1.42				
N ₆₀	1.42	1.68	1.44	1.48	1.84	1.97	1.85	1.83	1.39	1.73	1.43	1.45				
N ₃₀ +N ₆₀	1.50	1.69	1.65	1.51	1.92	1.97	2.10	1.93	1.41	1.80	1.48	1.47				
Chlorophyllβ																
without fertilizers	0.38	0.45	0.44	0.46	0.47	0.52	0.50	0.55	0.35	0.46	0.43	0.45				
P ₃₀ K ₃₀	0.39	0.47	0.45	0.51	0.47	0.55	0.49	0.60	0.41	0.51	0.42	0.47				
P ₃₀ K ₃₀ +N ₃₀	0.44	0.48	0.48	0.50	0.53	0.55	0.55	0.56	0.45	0.52	0.48	0.47				
P ₃₀ K ₃₀ +N ₃₀ +N ₆₀	0.48	0.50	0.49	0.50	0.55	0.57	0.57	0.55	0.48	0.51	0.50	0.48				
P ₃₀ K ₃₀ +N ₆₀	0.52	0.55	0.49	0.50	0.60	0.63	0.63	0.56	0.51	0.53	0.51	0.49				

Continuation of Appendix G₁

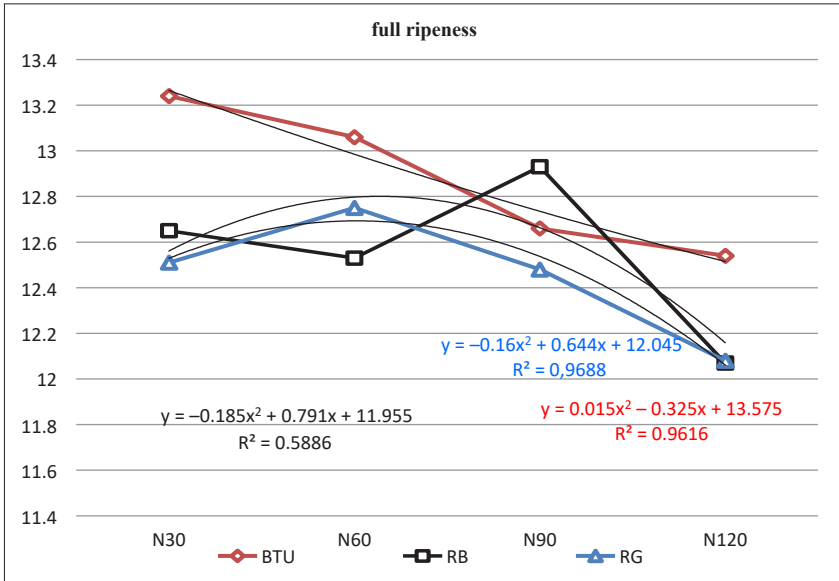
1	2	3	4	5	6	7	8	9	10	11	12	13
N ₃₀ P ₃₀ K ₃₀	0.54	0.58	0.57	0.56	0.67	0.71	0.69	0.63	0.53	0.57	0.53	0.49
N ₆₀ P ₃₀ K ₃₀	0.56	0.60	0.55	0.54	0.66	0.73	0.68	0.62	0.52	0.63	0.55	0.49
N ₃₀	0.57	0.63	0.62	0.55	0.66	0.70	0.69	0.64	0.58	0.61	0.61	0.52
N ₆₀	0.58	0.66	0.61	0.52	0.65	0.70	0.67	0.57	0.55	0.58	0.55	0.55
N ₃₀ +N ₃₀	0.61	0.66	0.64	0.57	0.69	0.71	0.71	0.67	0.57	0.66	0.56	0.53
α/b												
without fertilizers	2.65	3.19	3.31	3.00	2.96	3.11	3.45	3.16	2.83	3.21	2.95	2.90
P ₃₀ K ₃₀	2.76	3.45	3.17	2.96	3.25	3.32	3.65	3.10	2.63	3.31	3.22	2.79
P ₃₀ K ₃₀ +N ₃₀	2.76	3.47	3.19	2.91	3.15	3.37	3.31	3.21	2.71	3.12	2.98	2.91
P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	2.74	3.31	3.03	2.85	3.23	3.28	3.10	3.22	2.75	3.11	2.72	2.88
P ₃₀ K ₃₀ +N ₆₀	2.72	3.02	2.88	2.92	3.04	3.07	2.83	3.29	2.61	3.09	2.72	3.01
N ₃₀ P ₃₀ K ₃₀	2.48	2.74	2.79	2.74	2.60	2.59	2.66	3.13	2.32	3.11	2.70	2.83
N ₆₀ P ₃₀ K ₃₀	2.46	2.89	3.03	2.77	2.76	2.72	2.83	3.10	2.54	2.67	2.57	2.77
N ₃₀	2.39	2.64	2.59	2.75	2.67	2.84	2.89	2.94	2.33	2.89	2.46	2.83
N ₆₀	2.38	2.60	2.82	2.87	2.81	2.87	2.75	3.23	2.52	2.98	2.62	2.70
N ₃₀ +N ₃₀	2.43	2.59	2.63	2.74	2.79	2.81	2.97	2.98	2.49	2.76	2.72	2.83

Appendix C₂

Graphical representation of the dependence of leaf area on increasing rates of mineral nitrogen application and pre-sowing treatment options during the growth stages of chickpea plants



Continuation of *Appendix C₂*



Appendix D₁

Chickpea yield structure under combined fertilization and nodule bacteria inoculation, 2016

№	Variant		Plant height, cm		Height of first pod attachment, cm		Pods per stem, pcs		Seeds per plant, pcs		Seed weight, g/plant		Total branching, branches/plans	
			1	2	1	2	1	2	1	2	1	2	1	2
	Fertilizer	Inoculant	1	2	1	2	1	2	1	2	1	2	1	2
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Control	Control	49.6	53.1	32.9	36.9	19.5	24.6	22.0	29.2	4.38	5.04	5.7	7.5
		BTU	52.4		35.6		27.7		34.8		5.40		9.0	
		Rhizobophyte	54.7		38.7		24.7		29.0		4.92		7.8	
		Rhizogumin	55.9		40.3		26.4		31.1		5.46		7.4	
2	P ₃₀ K ₃₀	Control	57.8	61.7	42.9	46.2	19.65	22.80	31.2	29.0	4.23	5.74	6.2	6.8
		BTU	60.1		43.2		29.40		35.5		7.23		7.9	
		Rhizobophyte	67.2		51.8		22.50		27.5		5.55		6.8	
		Rhizogumin	61.8		46.7		19.65		21.9		5.94		6.3	
3	P ₃₀ K ₃₀ +N ₃₀	Control	60.2	61.7	45.1	46.1	24.1	28.4	28.0	29.5	4.68	5.86	6.5	8.6
		BTU	59.5		41.5		33.7		37.8		7.71		10.3	
		Rhizobophyte	64.2		51.4		29.3		24.2		5.55		8.9	
		Rhizogumin	62.8		46.5		26.3		28.0		5.49		8.8	
4	P ₃₀ K ₃₀ +N ₃₀ +N ₃₀	Control	67.6	66.9	51.9	52.0	22.5	20.7	24.0	23.6	4.80	4.70	6.3	6.4
		BTU	66.4		50.9		22.4		25.8		5.22		6.0	
		Rhizobophyte	63.9		49.8		16.0		20.2		4.32		7.3	
		Rhizogumin	69.8		55.5		21.7		24.2		4.44		6.0	
5	P ₃₀ K ₃₀ +N ₆₀	Control	64.8	67.8	46.5	51.7	24.6	21.9	27.9	23.8	5.82	5.45	8.1	6.8
		BTU	69.5		52.6		18.6		21.6		5.85		6.3	
		Rhizobophyte	66.1		53.4		20.6		20.2		5.19		6.3	
		Rhizogumin	70.9		54.3		23.6		25.6		4.95		6.3	
6	N ₃₀ P ₃₀ K ₃₀	Control	72.5	70.4	60.4	59.3	17.5	18.5	19.0	20.7	5.10	4.98	6.7	7.4
		BTU	65.1		53.7		18.9		21.6		4.65		7.5	
		Rhizobophyte	73.5		64.3		20.6		22.8		5.10		8.6	
		Rhizogumin	70.6		58.9		17.0		19.2		5.07		6.6	
7	N ₆₀ P ₃₀ K ₃₀	Control	75.4	70.3	61.5	57.2	14.8	18.4	16.3	21.0	5.01	5.00	5.3	8.6
		BTU	66.6		52.1		19.2		23.3		5.03		8.2	
		Rhizobophyte	70.3		57.4		20.0		22.4		5.01		11.2	
		Rhizogumin	68.8		57.8		19.7		22.1		4.95		9.5	
8	N ₃₀	Control	57.9	60.9	44.2	46.4	21.5	24.0	24.0	27.8	4.83	5.91	6.9	9.2
		BTU	65.4		49.9		27.0		31.0		6.66		8.5	
		Rhizobophyte	52.6		36.8		27.3		33.9		6.89		11.5	
		Rhizogumin	67.6		54.9		20.2		22.2		5.25		9.9	

Continuation of *Appendix D₁*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
9	N ₆₀	Control	67.5	55.2	52.7	42.3	20.6	23.4	22.9	25.8	5.22	5.62	7.0	7.8
		BTU	60.0		48.5		25.6		27.1		6.52		9.6	
		Rhizobophyte	47.6		34.4		24.2		28.1		5.44		7.7	
		Rhizogumin	45.6		33.5		23.2		25.1		5.28		6.8	
10	N ₉₀	Control	50.5	52.8	35.2	38.7	28.0	23.2	30.0	25.9	6.08	5.38	7.0	6.9
		BTU	51.3		37.4		23.0		26.3		6.14		6.9	
		Rhizobophyte	54.2		40.4		19.6		22.1		4.48		6.8	
		Rhizogumin	55.2		41.9		22.1		25.2		4.83		6.7	
11	N ₁₂₀	Control	54.1	51.4	39.4	36.9	19.4	18.6	21.4	21.4	4.08	4.17	6.4	6.9
		BTU	54.6		39.6		20.2		21.9		4.53		6.6	
		Rhizobophyte	46.8		34.2		16.7		20.9		3.90		8.0	
		Rhizogumin	49.9		34.2		18.2		21.5		4.17		6.7	
12	N _{30+N₃₀}	Control	48.7	46.7	32.7	32.3	21.8	22.4	26.6	26.8	4.98	5.28	6.2	6.2
		BTU	44.2		31.2		21.5		24.5		5.28		6.6	
		Rhizobophyte	48.0		34.1		24.6		30.7		5.79		6.3	
		Rhizogumin	46.0		31.3		21.7		25.2		5.07		5.7	

Appendix D₂

Chickpea yield structure under combined fertilization and nodule bacteria inoculation, 2017

№	Variant		Plant height, cm		Height of first pod attachment, cm		Pods per stem, pcs		Seeds per plant, pcs		Seed weight, g/plant		Total branching, branches/plants	
	Fertilizer	Inoculant	1	2	1	2	1	2	1	2	1	2	1	2
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Control	Control	42.2	43.0	29.2	29.4	10.2	12.2	11.6	12.2	2.58	2.99	5.03	6.07
		BTU	43.3		29.7		12.9		12.0		3.41		7.24	
		Rhizobiohyte	45.2		30.3		12.8		13.7		3.31		5.87	
		Rhizogumin	41.3		28.4		12.9		11.5		2.60		6.13	
2	P ₃₀ K ₃₀	Control	43.0	40.9	32.7	30.4	10.9	12.5	9.9	12.5	2.78	3.07	8.73	6.74
		BTU	39.5		29.3		14.3		12.3		2.85		5.73	
		Rhizobiohyte	40.9		30.4		12.1		13.4		2.83		5.27	
		Rhizogumin	40.3		29.0		12.6		13.9		3.82		7.23	
3	P ₃₀ K ₃₀ + +N ₃₀	Control	41.4	42.3	30.9	32.1	17.3	18.4	16.7	18.9	4.36	4.82	5.73	6.70
		BTU	40.1		30.1		22.6		18.8		4.56		6.07	
		Rhizobiohyte	43.5		33.3		17.5		22.5		5.89		7.87	
		Rhizogumin	44.2		34.2		16.3		17.7		4.49		7.13	
4	P ₃₀ K ₃₀ + +N ₃₀ +N ₃₀	Control	42.5	43.8	33.5	31.9	11.2	14.8	11.8	14.0	2.52	3.78	7.30	7.25
		BTU	43.2		30.1		16.3		16.3		4.56		8.10	
		Rhizobiohyte	43.6		31.7		17.7		14.5		4.75		6.17	
		Rhizogumin	45.9		34.3		13.4		13.3		3.27		7.43	
5	P ₃₀ K ₃₀ + +N ₆₀	Control	41.5	41.2	29.7	29.2	14.1	15.1	12.5	14.6	3.71	4.02	7.47	6.83
		BTU	42.6		30.7		15.6		15.7		4.5		7.10	
		Rhizobiohyte	39.9		27.9		15.1		14.3		4.02		6.67	
		Rhizogumin	40.6		28.6		15.5		15.8		3.86		6.1	
6	N ₃₀ P ₃₀ K ₃₀	Control	42.5	43.7	29.0	29.7	17.7	21.2	18.5	20.6	4.63	5.71	6.67	7.86
		BTU	44.6		30.0		23.0		21.8		6.7		9.93	
		Rhizobiohyte	45.1		30.8		21.2		21.6		5.63		7.87	
		Rhizogumin	42.5		28.8		23.0		20.5		5.87		6.97	
7	N ₆₀ P ₃₀ K ₃₀	Control	43.0	42.0	29.9	28.7	14.5	17.5	18.5	17.8	4.88	4.46	5.03	6.53
		BTU	40.7		28.4		17.2		15.6		3.63		6.07	
		Rhizobiohyte	43.3		29.5		18.7		17.8		4.2		7.07	
		Rhizogumin	41.2		26.9		19.7		19.2		5.16		7.97	
8	N ₃₀	Control	43.4	41.5	30.4	29.3	13.7	16.1	13.6	15.6	3.47	4.3	6.30	6.75
		BTU	42.3		30.2		15.0		14.4		4.04		5.47	
		Rhizobiohyte	41.7		28.5		21.6		20.7		5.81		9.60	
		Rhizogumin	38.8		28.1		14.1		13.8		3.89		5.63	

Continuation of *Appendix D₂*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
9	N ₆₀	Control	41.2	42.5	30.0	31.0	13.2	14.6	12.3	13.9	3.69	3.93	6.43	6.81
		BTU	42.9		30.6		15.3		14.2		3.95		7.60	
		Rhizobophyte	43.2		31.7		15.6		15.3		4.39		7.00	
		Rhizogumin	42.8		31.6		14.2		13.9		3.70		6.21	
10	N ₉₀	Control	42.2	43.1	31.5	31.9	10.8	15.8	11.8	16.4	3.41	4.57	7.07	6.98
		BTU	41.5		30.0		18.3		19.3		4.86		7.47	
		Rhizobophyte	45.7		34.3		14.8		14.7		4.12		7.17	
		Rhizogumin	42.9		31.6		19.2		19.7		5.91		6.23	
11	N ₁₂₀	Control	44.7	40.8	32.3	29.9	15.3	16.4	15.2	16.2	3.75	4.47	7.50	6.58
		BTU	38.3		29.0		16.3		15.0		4.90		5.80	
		Rhizobophyte	38.3		28.7		15.0		15.0		3.85		6.90	
		Rhizogumin	42.0		29.5		19.1		19.3		5.40		6.13	
12	N _{30+N₃₀}	Control	43.1	43.1	29.5	29.0	16.7	20.9	18.0	20.6	4.47	5.67	6.73	6.61
		BTU	43.5		29.0		25.5		25.5		6.6		7.53	
		Rhizobophyte	43.6		28.8		21.8		20.3		6.30		5.83	
		Rhizogumin	42.0		28.5		19.7		18.8		5.28		6.33	

Appendix E₁

Effect of ROMP on chickpea yield, t/ha, 2019

Factor A – Fertilization background	Factor B – Biopreparations	Replications					Average		
		i	ii	iii	IV	V	AB	A	B
Control without fertilizer	1. Control	5.15	4.89	5.11	5.42	4.98	5.11	6.09	5.70
	2. Amino	5.09	5.35	5.06	5.16	5.20	5.17		5.90
	3. Amino mikro	6.28	6.25	6.24	6.36	6.47	6.32		6.72
	4. Fulvo TE	7.33	7.15	6.80	7.03	7.54	7.17		7.76
	5. Seed treatment	5.67	6.11	5.48	5.58	6.10	5.79		6.07
	6. Antistress	6.01	6.28	5.91	6.42	6.33	6.18		7.10
	7. Extra	6.62	7.14	7.11	6.96	6.92	6.95		7.36
	8. Rootmost	6.30	6.53	6.26	6.53	5.87	6.30		7.04
	9. Polymicrostim	6.19	6.42	6.35	6.21	6.15	6.27		6.88
	10. Avatar	5.79	5.40	5.92	5.64	5.56	5.66		6.62
N ₃₀ +N ₃₀	1. Control	6.39	6.66	6.53	6.65	6.41	6.53	7.28	
	2. Amino	6.64	6.48	6.44	6.54	7.00	6.62		
	3. Amino mikro	7.48	7.51	6.98	6.76	6.89	7.12		
	4. Fulvo TE	8.51	7.91	8.17	8.42	8.71	8.34		
	5. Seed treatment	6.16	6.19	6.43	6.49	6.45	6.35		
	6. Antistress	8.19	7.89	7.82	8.00	8.17	8.01		
	7. Extra	8.28	7.81	7.58	7.59	7.57	7.77		
	8. Rootmost	7.34	6.80	7.20	7.20	7.50	7.21		
	9. Polymicrostim	6.91	7.47	7.32	8.81	7.68	7.54		
	10. Avatar	6.94	7.43	7.11	7.43	7.63	7.31		
LSD _{0.5}							0.58	0.19	0.41
Contribution of factor, %							0	0.35	0.44
Experimental error, % = 3.1									

Appendix E₂

Effect of ROMP on chickpea yield, t/ha, 2020

Factor A – Fertilization background	Factor B – Biopreparations	2020					
		i	ii	iii	AB	A	B
Control without fertilizer	1. Control	10.29	10.46	10.48	10.41	12.7	11.0
	2. Amino	11.23	11.59	11.46	11.43		11.8
	3. Amino mikro	12.61	12.71	12.58	12.63		13.1
	4. Fulvo TE	13.73	13.79	13.41	13.65		15.1
	5. Seed treatment	12.74	12.66	12.17	12.53		12.4
	6. Antistress	14.29	14.34	14.52	14.38		14.7
	7. Extra	13.03	12.90	13.08	13.0		13.8
	8. Rootmost	13.59	13.73	13.96	13.76		14.0
	9. Polymicrostim	13.85	13.49	13.82	13.72		15.1
	10. Avatar	11.74	11.71	11.83	11.76		12.2
N ₃₀ +N ₃₀	1. Control	11.5	11.3	11.85	11.56	13.9	
	2. Amino	12.2	12.3	11.99	12.15		
	3. Amino mikro	13.1	13.6	14.09	13.61		
	4. Fulvo TE	16.7	16.2	16.64	16.5		
	5. Seed treatment	12.0	12.4	12.55	12.32		
	6. Antistress	15.1	14.8	15.27	15.06		
	7. Extra	14.3	14.6	14.73	14.54		
	8. Rootmost	14.3	14.6	14.73	14.31		
	9. Polymicrostim	16.5	17.0	16.24	16.59		
	10. Avatar	12.5	13.0	12.75	12.74		
LSD _{0.5}				0.43	0.14	0.31	
Contribution of factor, %				0	0.15	0.75	
Experimental error, % = 1.1							

Appendix E₃

Chickpea Yield Structure, 2019

Factor A	Factor B – Biopreparations	height, cm		Per plant				
		Plant	lower pod attach- ment	Branches		pods	seeds	Seed weight
				main	second- ary			
				number of pieces				
AverageFactor AB								
1	2	3	4	5	6	7	8	9
Control without fertilizer	1. Control	34.63	25.06	2.80	1.84	9.85	8.20	1,89
	2. Amino	33.51	21.72	3.10	1.90	9.40	8.30	1,87
	3. Amino mikro	32.28	21.89	2.85	2.23	10.05	9.15	2,18
	4. Fulvo TE	36.99	26.35	3.15	2.92	10.75	11.15	2,27
	5. Seed treatment	36.67	25.11	3.25	2.49	12.00	9.50	1,91
	6. Antistress	36.84	24.35	2.90	2.74	13.90	11.50	2,65
	7. Extra	36.74	24.47	3.10	3.07	12.25	12.40	2,80
	8. Rootmost	38.12	26.36	3.05	2.43	10.70	9.35	2,20
	9. Polymicrostim	38.46	26.39	3.30	3.12	13.60	12.65	1,87
	10. Avatar	34.67	23.12	2.85	2.40	11.45	10.85	2,19
N ₃₀ +N ₃₀	1. Control	36.12	26.15	3.00	2.23	10.25	9.10	1,91
	2. Amino	30.14	22.15	3.10	2.23	10.45	9.25	1,94
	3. Amino mikro	34.50	23.40	3.20	2.43	11.00	9.85	1,89
	4. Fulvo TE	37.28	26.94	3.20	3.17	15.10	13.25	2,55
	5. Seed treatment	36.85	26.72	3.15	2.87	12.15	11.20	2,30
	6. Antistress	39.19	25.85	2.80	3.21	16.35	11.75	2,39
	7. Extra	37.94	24.76	2.70	3.18	13.15	11.80	2,71
	8. Rootmost	39.02	26.95	3.40	2.60	13.25	12.00	2,38
	9. Polymicrostim	39.67	27.49	3.30	3.68	14.20	12.95	2,96
	10. Avatar	33.49	23.36	2.90	2.57	11.55	12.00	2,40
LSD _{0.5}		1,87	1,33	0,38	0,40	3,30	2,00	0,33
AverageFactor A								
1	Control	35.88	24.48	3.04	2.76	11.40	10.31	2,18
2	N ₃₀ +N ₃₀	36.42	25.38	3.08	3.10	12.75	11.32	2,34
LSD _{0.5}		0,59	0,42	0,12	0,13	1,05	0,63	0,10
Contribution of factor,%		1,0	2,0	0	1,0	2,0	2,0	4,0

Continuation of *Appendix E₃*

1	2	3	4	5	6	7	8	9
AverageFactor B								
1	Control	35.37	25.60	2.90	2.05	10.10	8.65	1,90
2	Amino	31.83	21.95	3.10	2.07	9.93	8.78	1,91
3	Amino mikro	33.40	22.64	3.03	2.33	10.50	9.50	2,04
4	Fulvo TE	37.13	26.65	3.18	3.44	12.90	12.20	2,41
5	Seed treatment	36.80	25.91	3.209	2.67	12.10	10.40	2,11
6	Antistress	38.01	25.10	2.85	2.98	15.10	11.60	2,52
7	Extra	37.34	24.61	2.90	3.12	12.70	12.10	2,75
8	Rootmost	38.55	26.65	3.23	2.52	12.00	10.70	2,29
9	Polymicrostim	39.10	26.94	3.30	3.40	13.90	12.80	2,41
10	Avatar	34.10	23.24	2.88	2.48	11.50	11.40	2,30
LSD _{0.5}		1,32	0.94	0.27	0.28	2.32	1.40	0.23
Contribution of factor,%		37,0	37.0	7.0	10.0	9.0	17.0	41.0
Experimental error,%		1,8	1.9	4.4	5.1	9.6	6.5	5.2

Appendix E₄

Chickpea Yield Structure, 2020

Factor A	Factor B – Bioprepara- tions	height, cm		Per plant				
		Plant	lower pod attach- ment	Branches		pods	seeds	Seed weight
				main	sec- ondary			g
				number of pieces				
AverageFactor AB								
1	2	3	4	5	6	7	8	9
Control without fertilizer	Control	38.04	21.66	1.4	4.8	18.1	20.3	3.46
	Amino	37.32	20.83	2.4	6.3	21.1	25.4	4.31
	Amino mikro	38.64	22.32	1.8	6.0	20.1	22.6	4.67
	Fulvo TE	36.25	21.70	2.2	4.5	18.9	23.2	4.28
	Seed treatment	38.56	23.00	2.4	6.6	19.9	24.2	4.22
	Antistress	38.59	23.00	2.3	8.7	23.5	25.0	4.74
	Extra	38.52	22.83	2.5	7.4	20.9	23.7	4.61
	Rootmost	39.70	22.70	2.6	8.7	22.7	28.5	4.90
	Polymicrostim	37.41	21.87	2.3	6.8	14.9	18.8	3.86
	Avatar	40.39	21.68	2.5	9.3	22.1	26.3	4.91
N ₃₀ +N ₃₀	Control	41.37	23.47	2.3	8.1	21.6	24.6	4.10
	Amino	40.24	23.99	2.9	10.8	27.4	30.7	5.33
	Amino mikro	41.41	24.34	2.7	9.2	24.0	25.6	6.12
	Fulvo TE	41.08	24.42	2.7	7.4	22.9	27.4	5.36
	Seed treatment	42.30	24.89	2.6	10.9	23.8	28.1	5.28
	Antistress	42.59	24.75	2.4	11.2	28.2	29.3	5.98
	Extra	41.93	25.67	2.5	9.2	27.3	28.3	5.45
	Rootmost	42.36	24.86	2.6	11.0	27.4	29.9	5.94
	Polymicrostim	41.44	24.39	2.4	8.8	22.4	31.3	4.38
	Avatar	42.86	24.89	2.7	10.9	27.2	25.0	5.77
LSD _{0.5}		1,37	1.0	0.4	1.2	1.3	2.6	0.55
AverageFactor A								
1.	Control	38.34	22.16	2.2	6.9	20.3	23.8	4.40
2.	N ₃₀ +N ₃₀	41.76	24.58	2.6	9.8	25.2	28.0	5.37
LSD _{0.5}		0,43	0.32	0.11	0.4	0.40	0.8	0.14
Contribution of factor,%		68	70	20	45	51	37	39

Continuation of *Appendix E₄*

1	2	3	4	5	6	7	8	9
1.	Control	39.70	22.57	1.9	6.5	19.9	22.4	3.78
2.	Amino	38.77	22.42	2.7	8.6	24.3	28.1	4.82
3.	Amino mikro	40.02	23.32	2.3	7.6	22.1	24.1	5.4
4.	Fulvo TE	38.67	23.08	2.5	6.0	20.9	25.3	4.82
5.	Seed treatment	40.45	23.95	2.5	8.8	21.9	26.1	4.75
6.	Antistress	40.60	23.88	2.3	9.9	25.9	27.2	5.36
7.	Extra	40.22	24.25	2.5	8.3	24.1	26.0	5.03
8.	Rootmost	41.07	23.83	2.6	9.9	25.1	29.2	5.42
9.	Polymicrostim	39.42	23.13	2.4	7.8	18.7	25.1	4.12
10.	Avatar	41.62	23.3	2.6	10.1	24.6	25.7	5.34
LSD _{0.5}		0.97	0.71	0.3	0.9	0.9	1.9	0.39
Contribution of factor, %		19	16	36	41	42	47	46
Experimental error, %		1.2	1.6	4.1	4.2	2.0	3.6	3.9

Appendix F

**Effect of Fertilizer System and Pre-Sowing Seed Inoculation
on Chickpea Grain Quality Indicators, 2016**

№	Variant		1000-Seed Weight, g		Protein Content, %	
			Average by variants:			
	Fertilizer	Inoculant	Inoculation	Fertilizer	Inoculation	Fertilizer
1	2	3	4	5	6	7
1	Control	Control	177.56	190.84	21.60	22.42
		BTU	198.09		22.12	
		Rhizobophyte	193.61		22.65	
		Rhizogumin	194.08		23.33	
2	P ₃₀ K ₃₀	Control	198.45	198.91	27.32	27.84
		BTU	194.85		26.00	
		Rhizobophyte	200.53		28.32	
		Rhizogumin	201.80		29.73	
3	P ₃₀ K ₃₀ + +N ₃₀	Control	180.41	184.40	30.50	28.88
		BTU	196.04		28.72	
		Rhizobophyte	180.64		27.47	
		Rhizogumin	180.52		28.82	
4	P ₃₀ K ₃₀ + +N ₃₀ +N ₃₀	Control	182.84	186.75	27.65	28.29
		BTU	190.29		25.43	
		Rhizobophyte	183.86		29.87	
		Rhizogumin	190.01		30.23	
5	P ₃₀ K ₃₀ + +N ₆₀	Control	201.77	192.65	25.46	26.85
		BTU	186.22		26.74	
		Rhizobophyte	183.34		28.13	
		Rhizogumin	199.30		27.07	
6	N ₃₀ P ₃₀ K ₃₀	Control	192.30	190.55	28.88	28.33
		BTU	194.06		28.28	
		Rhizobophyte	190.64		28.18	
		Rhizogumin	185.23		27.98	
7	N ₆₀ P ₃₀ K ₃₀	Control	164.00	185.36	29.33	28.57
		BTU	186.22		28.17	
		Rhizobophyte	205.24		28.70	
		Rhizogumin	185.98		28.10	

Continuation of *Appendix F*

1	2	3	4	5	6	7
8	N ₃₀	Control	187.30	193.79	26.34	26.00
		BTU	202.24		26.27	
		Rhizobophyte	182.36		24.05	
		Rhizogumin	203.28		27.32	
9	N ₆₀	Control	193.59	190.41	28.54	27.76
		BTU	199.52		28.71	
		Rhizobophyte	187.42		26.53	
		Rhizogumin	181.13		27.28	
10	N ₉₀	Control	186.73	181.96	23.17	25.95
		BTU	166.16		24.14	
		Rhizobophyte	193.40		28.27	
		Rhizogumin	181.56		28.21	
11	N ₁₂₀	Control	185.35	188.34	23.19	23.89
		BTU	190.49		23.86	
		Rhizobophyte	190.39		24.23	
		Rhizogumin	187.13		24.27	
12	N ₃₀ +N ₃₀	Control	188.14	190.76	23.00	24.56
		BTU	191.43		24.80	
		Rhizobophyte	186.68		24.17	
		Rhizogumin	196.80		26.28	

Appendix G₁

Thousand-seed weight, g, 2019

Factor A	Factor B – Bioprepara- tions	Replications					Average		
		I	II	III	IV	V	AB	A	B
Control without fertilizer	1. Control	259.50	260.47	263.85	263.68	255.65	260.63	270.45	269.34
	2. Amino	265.87	279.16	275.24	273.62	256.70	270.12		266.82
	3. Amino mikro	265.92	274.96	271.40	266.80	272.15	270.25		270.59
	4. Fulvo TE	276.64	259.50	277.50	256.40	270.80	268.17		271.91
	5. Seed treatment	268.80	270.15	264.12	271.02	269.34	268.69		272.92
	6. Antistress	287.04	270.88	263.00	274.50	288.96	276.88		278.22
	7. Extra	270.80	273.10	255.54	268.22	255.72	264.68		271.90
	8. Rootmost	274.92	280.12	273.72	270.60	268.28	273.53		276.53
	9. Polymicrostim	281.48	263.36	271.16	264.08	271.12	270.24		276.83
	10. Avatar	277.16	280.30	280.00	283.32	277.48	279.65		279.22
N ₃₀ +N ₃₀	1. Control	276.52	289.60	285.25	260.25	278.65	278.05	276.61	
	2. Amino	261.65	267.30	265.20	260.64	262.80	263.52		
	3. Amino mikro	270.50	268.40	269.70	266.75	279.30	270.93		
	4. Fulvo TE	278.05	270.55	275.15	271.45	283.68	275.78		
	5. Seed treatment	277.50	277.85	274.80	272.10	283.55	277.16		
	6. Antistress	288.50	273.35	264.25	275.75	287.60	277.89		
	7. Extra	274.65	291.10	277.15	279.95	272.80	279.13		
	8. Rootmost	271.55	286.65	269.80	285.00	284.70	279.54		
	9. Polymicrostim	284.95	288.85	281.15	279.95	282.20	279.42		
	10. Avatar	289.05	262.60	270.75	284.90	278.15	277.09		
LSD _{0.5}							8.39	2.90	6.49
Contribution of factor, %							0	10.0	17.0
Experimental error, % = 1.1									

Appendix G₂

Thousand-seed weight, g, 2020

Factor A – Fertilization background	Factor B – Bioprepara- tions	2020					
		I	II	III	AB	A	B
Control without fertilizer	Control	227.8	218.1	215.0	220.3	222.2	219.7
	Amino	222.3	236.4	228.8	229.2		231.3*
	Amino mikro	224.1	219.3	229.9	224.4		224.9
	Fulvo TE	211.4	212.7	218.0	214.0		217.9
	Seed treatment	215.1	227.4	232.6	225.0		232.6*
	Antistress	213.9	233.6	216.0	221.2		223.7
	Extra	231.0	217.3	217.8	222.0		224.4
	Rootmost	216.0	225.3	226.4	223.2		229.8*
	Polymicrostim	231.4	223.8	229.8	228.3		224.9
	Avatar	212.6	214.4	215.5	214.2		215.6
N ₃₀ +N ₃₀	Control	225.1	218.2	214.2	219.2	226.8	
	Amino	227.0	240.1	233.1	233.4*		
	Amino mikro	226.2	227.1	222.5	225.3		
	Fulvo TE	220.4	219.8	225.2	221.8		
	Seed treatment	244.4	247.2	228.8	240.1*		
	Antistress	219.1	229.3	230.5	226.3		
	Extra	228.3	226.8	225.2	226.8		
	Rootmost	232.2	236.8	240.3	236.4*		
	Polymicrostim	218.3	224.1	222.2	221.5		
	Avatar	220.8	212.6	217.9	217.1		
LSD _{0.5}				10.0	3.2	7.0	
Contribution of factor, %				0	13	42	
Experimental error, % = 17.0							

Appendix I₁

**Crude protein content in chickpea grain,
% on absolutely dry matter, 2019**

Factor A	Factor B	Replications					Average		
		I	II	III	IV	V	AB	A	B
Control without fertilizer	1. Control	22.512	23.638	22.198	23.819	22.624	22.958	25.176	24.030
	2. Amino	26.542	25.605	25.096	26.236	26.734	26.043		25.064
	3. Amino mikro	25.299	25.560	24.911	26.178	26.092	25.608		25.083
	4. Fulvo TE	26.712	25.077	25.695	25.695	26.283	25.892		25.691
	5. Seed treatment	25.616	25.780	25.707	24.892	25.816	25.562		25.580
	6. Antistress	26.209	25.366	25.460	24.330	26.520	25.577		25.440
	7. Extra	25.218	24.316	25.349	25.374	24.149	24.881		25.188
	8. Rootmost	25.839	25.384	24.819	24.672	25.020	25.147		25.211
	9. Polymicrostim	25.460	25.007	25.135	25.179	25.266	25.213		25.225
	10. Avatar	24.605	25.755	23.945	25.180	24.914	24.880		25.057
N ₃₀ +N ₃₀	1. Control	23.132	26.148	25.734	25.648	24.845	25.102	25.360	
	2. Amino	23.575	23.401	23.849	24.889	24.707	24.084		
	3. Amino mikro	24.884	23.169	24.841	24.238	25.664	24.559		
	4. Fulvo TE	25.983	25.684	25.047	25.765	24.970	25.490		
	5. Seed treatment	25.657	26.202	25.992	24.203	25.934	25.598		
	6. Antistress	25.362	25.069	24.103	26.038	25.924	25.303		
	7. Extra	25.886	25.456	25.613	25.027	25.487	25.494		
	8. Rootmost	25.412	24.620	25.135	26.074	25.138	25.276		
	9. Polymicrostim	25.246	25.364	25.205	25.260	25.109	25.237		
	10. Avatar	25.946	23.913	25.575	25.045	25.684	25.233		
LSD _{0.5}							0.73	0.23	0.51
Contribution of factor, %							0	20	10
Experimental error, % = 1.2									

Appendix I₂**Crude protein content in chickpea grain,
% on absolutely dry matter, 2020**

Factor A – Background	Factor B – Bio- preparations	2020					
		I	II	III	AB	A	B
Control without fertilizer	Control	25.70	25.59	25.019	25.70	24.99	25.72
	Amino	24.86	24.50	25.692	25.02		25.45
	Amino mikro	24.25	25.05	24.895	24.73		25.93
	Fulvo TE	24.79	24.72	24.566	24.69		26.09
	Seed treatment	24.16	24.57	25.321	24.69		25.87
	Antistress	24.59	24.63	26.276	25.17		26.03
	Extra	24.83	24.57	25.11	24.84		25.52
	Rootmost	25.21	24.93	25.47	25.21		25.76
	Polymicrostim	25.47	24.93	25.21	25.21		25.68
	Avatar	24.91	24.85	24.86	24.87		25.60
N ₃₀ +N ₃₀	Control	25.39	26.51	26.12	26.01	26.55	
	Amino	25.90	25.64	26.11	25.88		
	Amino mikro	26.90	27.13	27.35	27.13		
	Fulvo TE	27.23	27.39	27.85	27.49		
	Seed treatment	21.24	27.05	26.89	27.06		
	Antistress	26.90	26.76	27.02	26.89		
	Extra	26.55	25.76	26.32	26.21		
	Rootmost	25.84	26.23	26.87	26.31		
	Polymicrostim	26.43	26.12	25.89	26.15		
	Avatar	26.21	26.34	26.46	26.34		
LSD _{0.5}				0.62	0.20	0.44	
Contribution of factor, %				0	69	5	
Experimental error, % = 0.8							

Appendix J

Fat content in chickpea grain, %, 2019

Factor A	Factor B – Bio-preparations	Replications					Average		
		I	II	III	IV	V	AB	A	B
Control without fertilizer	1. Control	7.92	7.36	7.81	7.31	7.42	7.60	7.56	7.49
	2. Amino	7.46	7.88	8.23	8.00	7.83	7.88		7.63
	3. Amino mikro	7.74	7.89	7.64	7.86	7.80	7.79		7.35
	4. Fulvo TE	8.37	7.81	8.03	8.11	7.83	8.03		7.50
	5. Seed treatment	7.78	7.79	8.14	7.83	7.84	7.88		7.51
	6. Antistress	8.92	8.28	8.28	7.66	8.30	8.29		7.82
	7. Extra	8.10	7.93	7.00	6.35	6.90	7.26		7.23
	8. Rootmost	7.32	7.04	7.26	6.71	6.94	7.05		7.29
	9. Polymicrostim	7.61	7.04	7.21	7.06	7.14	7.21		7.17
	10. Avatar	7.74	7.24	6.55	6.71	6.73	6.99		7.11
N ₃₀ +N ₃₀	1. Control	6.49	7.98	7.31	7.54	7.60	7.38	7.23	
	2. Amino	7.35	7.29	7.62	7.13	7.46	7.37		
	3. Amino mikro	7.18	6.10	7.04	6.52	7.71	6.91		
	4. Fulvo TE	7.06	7.07	6.90	7.22	7.61	6.97		
	5. Seed treatment	7.18	7.34	7.60	5.92	7.60	7.13		
	6. Antistress	7.59	7.02	6.13	8.18	7.76	7.34		
	7. Extra	7.26	6.99	7.06	7.46	7.20	7.19		
	8. Rootmost	7.03	8.35	7.41	7.64	7.24	7.53		
	9. Polymicrostim	6.78	7.74	7.10	7.14	6.90	7.13		
	10. Avatar	7.40	6.78	7.47	7.08	7.41	7.23		
LSD _{0.5}							0.80	0.25	0.56
Contribution of factor, %							0	5.0	16.0
Experimental error, % = 3.8									

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