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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 Nitrogyn [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].