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THE IMPACT OF OPTIMISED FERTILISATION ON THE YIELD AND QUALITY OF APPLE FRUIT

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Проаналізовано літературні джерела вітчизняних і зарубіжних науковців щодо впливу удобрення, як одного з ключових агротехнологічних заходів, на продуктивність інтенсивних яблуневих насаджень. Розглянуто вплив оптимізованого удобрення на продуктивність яблуні, зокрема ріст, врожайність, якість плодів та фізіолого-біохімічні процеси в рослинах. Проаналізовано ефективність органічного, мінерального та комбінованого живлення, а також позакореневих підживлень у забезпеченні оптимального балансу макро- і мікроелементів. На основі проведеного аналізу встановлено, що на даний час досліджень щодо норм добрив основного удобрення та строків застосування позакореневого підживлення макро- та мікроелементами у насадженнях різних сортопідщепних комбінувань проведено досить мало. Тому, питання раціонального оптимізованого удобрення та підживлення інтенсивних насаджень яблуні різних сортопідщепних комбінувань залежно від конструкції насаджень є актуальним і потребує досконалого вивчення.

Ключові слова: *яблуня, оптимізоване удобрення, позакореневе підживлення, ріст дерев, продуктивність, якість плодів, сортопідщепні комбінування.*

State of the problem. Fertilization is one of the effective factors for increasing the yield of fruit plantations and improving fruit quality, thanks to the powerful technological capabilities based on a wide range of traditional fertilizers and improved biotechnological products [1]. However, excessive fertilization enhances the growth of trees, worsens the quality and shelf life of fruits, and contaminates the environment. To grow high-quality, ecologically clean products in intensive fruit plantations, it is necessary to apply fertilizers, the rates of which are calculated based on soil and leaf diagnostics, and to use biological plant protection products [2–3].

The global experience of intensive land resource use convincingly shows that 30–40 % of the increase in agricultural production in Western Europe and the USA is ensured by the use of mineral fertilizers [4]. The extensive root system allows plants to absorb almost all nutrients from the soil, making fertilisation the main way of feeding them. The availability of nutrients depends on many factors. The main ones are soil type, organic matter content, pH and climatic conditions. These factors, by inducing microbiological and chemical processes in the soil, affect their absorption [5].

Research methodology. The methodological framework of the research was based on contemporary scientific works by both domestic and foreign scholars. The research methods included a systems approach, comparative analysis, and generalization.

Results of the research. The purpose of fertilization in intensive apple orchards is to create optimal nutrition conditions for fruit trees by providing them with the necessary elements for growth and development. An important task is to determine the optimal doses of macro- and microelements, taking into account the age phases of tree development, the characteristics of rootstock-scion combinations, and soil nutrient content. Rational optimized fertilization not only contributes to increased yield and fruit quality but also strengthens the trees' resistance, their ability to withstand abiotic and biotic factors, as well as helps maintain soil fertility in the long term [6].

A special significance in such technologies is nitrogen nutrition. On one hand, this is related to the high intensity of vegetative growth and yield formation, and on the other hand, trees on vegetative rootstocks have a shallow root system that explores a smaller soil volume compared to trees on seed rootstocks [7–10]. At the same time, with a high level of nitrate nitrogen in the soil under fruit trees, the uptake of phosphorus, iron, and other elements may be blocked, which in turn leads to physiological diseases and reduced yield. Most importantly, it harms the ecosystem by leaching nitrate nitrogen into deeper soil layers [11, 12].

Studies [7] found that fruit trees respond to different conditions of nitrogen nutrition by changing the synthesis of substances. Depending on the physiological factors (age of the trees, nutrition regime, growth intensity), the activation of vegetative and generative processes occurs differently, including changes in growth rate, enhanced bud formation, and fruit set. The combination of these factors constitutes the influence of fertilizers on increasing fruit yield.

In cases of nitrogen deficiency in fruit plants, growth is primarily weakened, biomass accumulation decreases, and the ratio between the above-ground part of the plant and the root system changes. This is a result of reduced photosynthesis, caused by a reduction in the leaf's assimilatory surface area and chlorophyll content [8, 13].

The use of nitrogen fertilizers in apple orchards affects not only the growth and development of plants but also the quality of the fruit, which can either improve or, conversely, deteriorate, as well as the structure of the yield. It has been established that providing trees with nitrogen enhances vegetative growth, delays the end of the growing season, and also influences the yield structure, size, and chemical composition of the fruits [14].

According to Chen Q. [8], the application of nitrogen fertilizers in intensive pear and apple orchards contributed to an increase in the total sugar content in the fruits due to monosaccharides, had no significant effect on the acidity level, while slightly increasing the amount of dry soluble substances and ascorbic acid.

Studies on different nitrogen fertilizer application methods in dwarf apple orchards in Brazil show that nitrogen application is not essential for ensuring excellent fruit quality on soils with high organic matter content. This is likely due to the fact that an adequate amount of nitrogen for tree growth and fruiting is obtained through the mineralization of organic matter [15]. A similar result was found in a study conducted in Poland [16] at the Warsaw University of Life Sciences. The experiment on different rates and methods of autumn nitrogen fertilization in apple trees with various rootstock types showed that nitrogen fertilization had no significant effect on yield and fruit quality, but the type of rootstock had a substantial impact on these indicators. It is recommended to apply nitrogen in the spring, when the demand for this element is highest, and the release of nitrogen through the mineralization of organic matter is insufficient.

The importance of phosphorus supply to apple trees is due to the normal functioning of reproductive processes such as flowering and fruiting. However, phosphorus deficiency can affect the growth of apple trees even when other elements are provided in sufficient amounts. Phosphorus plays a crucial role in fundamental processes such as photosynthesis and respiration. Excessive phosphorus fertilization of fruit trees can lead to blockage of nutrient uptake, such as nitrogen and zinc [17, 18].

Potassium, like nitrogen, is one of the most important nutrients for the growth of fruit crops. The application of potassium fertilizers at different stages of orchard growth and development can help increase yield, improve fruit quality, and maintain a relatively constant potassium level in the leaves. It should be noted that with increased fruit crop yields, the potassium content in the soil decreases below the optimal level due to higher absorption by the fruits [19, 20]. Studies conducted in China [21] have shown that the potassium content in the soil decreases below the optimal level due to increased potassium consumption by the fruits with higher yields. Therefore, more comprehensive research is needed on the application of potassium fertilizers in fruit orchards.

According to R. V. Yakovenko [22], in a study on optimized soil fertilization with repeated cultivation of pear trees of the Conference and Osnovianska varieties, increased yield was achieved with fertilization that included an additional application of $N_{30}K_{30}$ above the calculated norms (background), which was 37 % and 36 % higher, respectively, compared to unfertilized trees, and 7 % and 6 % higher compared to trees fertilized annually with $N_{90}P_{60}K_{90}$, where the nitrogen, phosphorus, and potassium ratio was less balanced, despite the higher total amount of fertilizer.

A number of studies [23] indicate that the increase in yield is not always proportional to the increase in fertilizer dosage, and in some cases, it can lead to a decrease. There are two main reasons for the unstable effectiveness of fertilizers in horticulture: first, in most climatic zones, the recommended fertilizer application rate ranges from N_{60} to N_{120}, regardless of age-related characteristics, orchard structure, planting scheme, and yield level; second, the timing of fertilizer application does not always correspond to the periods of the plants' highest nitrogen demand.

In studies [24] conducted at the Uman National University of Horticulture in a pear orchard, a significant impact of fertilization was observed on the changes in crown projection area and the average shoot length. When applying $N_{90}P_{60}K_{90}$, an increase in the length of one-year-old shoots was observed by 10–27 %, depending on the variety. The optimized background with additional fertilization of $N_{30}K_{30}$ resulted in a 19–38 % increase in the crown projection area compared to the absolute control (without fertilization).

Nitrogen fertilization as part of a complete mineral fertilizer significantly increased the dry matter content in the fruits of the Idared apple variety by 0.9–1.8 % [25]. In a study combining soil fertilization with foliar feeding in the Idared orchard, an increase in dry matter content was observed, ranging from 1.4 % to 2.3 %. When applying double and triple doses of nitrogen, an increase in dry matter content was recorded in the range of 1.1–2.5 % and 1.6–2.0 %, respectively [26].

Along with soil fertilization to provide the trees with necessary nutrients, especially during heavy fruit load and stress periods of growth, foliar feeding is applied, which effectively meets the plants' nutritional needs. Foliar feeding has a positive effect on flowering strength, increases the number of flower buds, stimulates fruit set, reduces the drop of flowers and fruits, and promotes their attachment to the fruiting spurs. It also enhances the plants' resistance to adverse factors [27–30].

An important task is to provide trees with micronutrients, even in conditions where the soil contains sufficient amounts of them, because the supply of these elements from the soil to the aboveground part of the tree during critical periods is complicated [31]. When foliar feeding is applied, micronutrients are delivered to the plant’s aboveground mass, and they are absorbed more quickly than through the roots. Absorption occurs through the epidermis and stomata of the leaf. The lower side of the leaf absorbs more nutrients. In drought-resistant plants, substances are absorbed more slowly due to the higher density of the epidermis [32].

One of the important micronutrients for fruit trees is boron. The demand for it increases sharply during flowering. At this time, it plays a role in pollen germination and fruit formation. During this period, the demand for boron is so high that it can accumulate in the plant roots, but it does not accumulate sufficiently in the aboveground parts, despite its adequate content in the soil [33]. Calcium, together with boron, plays a very important role in the formation of a future high-quality harvest. It plays a key role in stabilizing the pectin of the cell wall and regulating its permeability. The number of known processes involving this ion is vast and encompasses almost all aspects of plant development. Calcium is also important for fruit quality, and its deficiency often leads to physiological disorders [34]. Therefore, it is important to maintain a balance of nutrients for plants throughout the entire growing season. The positive role of boron and calcium in foliar fertilization of apple trees has been confirmed by many researchers [35], who observed a significant increase in the number of fruits after treatment with these micronutrients.

Over the years, interest in environmentally safe technologies for growing agricultural crops has been increasing [36]. Modern growth regulators and antistressants are classified as non-toxic substances according to sanitary and hygienic classification. They positively affect plant growth and development and are quickly transformed by soil organisms and plant cells [37].

The use of growth regulators in fruit plantations ensures increased yields and improves the quality characteristics of the fruits. It has also been noted that growth regulators enhance winter hardiness and the plants' resistance to extreme weather conditions [38]. This is because under stress conditions, plants lose their ability to absorb nutrients, as all energy expenditures are directed towards overcoming the stress [37, 39]. During the growing season, fruit trees are sensitive to temperature fluctuations, especially during flowering, fruit setting, and growth, as well as the formation of flower buds. During the flowering period, frost damage to reproductive organs is particularly dangerous, which is why the use of growth regulators and antistressants is essential [40].

Conclusions. Soil fertilization and foliar feeding play a key role in increasing the overall productivity of apple orchards. Rationally optimized nutrition promotes the active development of the root system, improves nutrient uptake, and contributes to the formation of high-quality fruits. Modern research focuses on determining the optimal rates, timing, and methods of fertilization in different soil and climatic conditions, which allows for the adaptation of nutrition systems according to the needs of the plantations. An important aspect remains the evaluation of the effectiveness of combining soil fertilization and foliar feeding, particularly their impact on growth, yield, and fruit quality in apple trees.

An important issue remains the study of the relationship between the fertilization system and rootstock-scion combinations in specific agro-climatic conditions. Considering these factors allows for increased fertilizer application efficiency, minimized losses, improved soil condition, and ensures a stable high-quality yield.

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Annotation

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The impact of optimised fertilisation on the yield and quality of apple fruit

The literature sources of domestic and foreign scientists regarding the impact of fertilization, as one of the key agronomic practices, on the productivity of intensive apple orchards have been analyzed. The article examines the impact of optimized fertilization on apple tree productivity, specifically growth, yield, fruit quality, and the physiological-biochemical processes in plants. The effectiveness of organic, mineral, and combined fertilization, as well as foliar feeding, in ensuring the optimal balance of macro- and microelements, has been analyzed. An important task is to determine the optimal doses of macro- and microelements, taking into account the age phases of tree development, the characteristics of rootstock-scion combinations, and soil nutrient content. Rational optimized fertilization not only contributes to increased yield and fruit quality but also strengthens the trees' resistance, their ability to withstand abiotic and biotic factors, as well as helps maintain soil fertility in the long term. It has been established that providing trees with nitrogen enhances vegetative growth, delays the end of the growing season, and also influences the yield structure, size, and chemical composition of the fruits. Based on the conducted analysis, it was found that there is currently a lack of research on the fertilizer rates for basic fertilization and the timing of foliar feeding with macro- and microelements in plantings of different rootstock-scion combination. Therefore, the issue of rational optimized fertilization and feeding of intensive apple orchards with different rootstock-scion combination, depending on the orchard design, is highly relevant and requires thorough study.

Soil fertilization and foliar feeding play a key role in increasing the overall productivity of apple orchards. Rationally optimized nutrition promotes the active development of the root system, improves nutrient uptake, and contributes to the formation of high-quality fruits. Modern research focuses on determining the optimal rates, timing, and methods of fertilization in different soil and climatic conditions, which allows for the adaptation of nutrition systems according to the needs of the plantations. An important aspect remains the evaluation of the effectiveness of combining soil fertilization and foliar feeding, particularly their impact on growth, yield, and fruit quality in apple trees.

Key words:*apple tree, optimized fertilization, foliar feeding, tree growth, productivity, fruit quality, rootstock-scion combination.*