ANNOTATION
of the dissertation work
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on the topic " Scientific substantiation of the system of application of fertilizers in intensive apple orchards in the conditions of south Kazakhstan " submitted for the degree of Doctor of Philosophy (PhD) in the educational program (specialty) 8D08102 – "Soil Science and agrochemistry"

Relevance of the research topic. The apple tree (Malus domestica Borkh.) is a strategically important fruit crop for Kazakhstan, occupying leading positions in the structure of industrial plantations. Despite the significant potential of the southern and southeastern regions of the country, characterized by favorable soil and climatic conditions, domestic production meets the internal market by less than 50%, maintaining the republic's high dependence on imports. In the context of global climate change and the growing deficit of water resources in Central Asia, traditional extensive methods of horticulture are becoming economically and environmentally unsustainable. The modern stage of industry development is associated with an active transition to intensive cultivation of orchards with high planting density (2500–3000 trees/ha) on low-growing rootstocks (M9). However, the specificity of the soil cover in southern Kazakhstan, predominantly represented by gray-brown carbonate soils with low humus content (1.5–2.1%) and alkaline reaction (pH 7.4–8.2), creates serious agrochemical barriers. Under these conditions, traditional technologies of surface application of mineral fertilizers show low efficiency: up to 30–50% of nitrogen is lost due to leaching and volatilization, phosphorus undergoes rapid retrogradation into inaccessible forms, and potassium is leached from the root-inhabited layer of light loams. This leads to a chronic deficiency of nutrient elements during critical phases of tree development, reduced productivity and fruit quality, and also creates risks of salinization and groundwater pollution. There is an urgent need to develop a scientifically substantiated system for managing mineral nutrition, adapted to the specific soil and climatic conditions of the region. Fertigation — the technology of delivering dissolved nutrients directly to the zone of active root activity through drip irrigation systems — is considered the most promising solution to this problem. Despite its widespread use in global practice, comprehensive scientific studies justifying optimal regimes, doses, and timing of fertigation, taking into account the phenological phases of development of the apple variety "Jeromini," are lacking in the conditions of southern Kazakhstan. Issues of the influence of fertigation on the migration and transformation of nutrient elements in the profile of carbonate soils, as well as its role in forming qualitative indicators of fruits and their storage life, have not been studied. Thus, the development of a resource-saving and environmentally safe fertilizer system that ensures the realization of the genetic potential of intensive orchards, increases production profitability, and enhances the competitiveness of domestic products is a relevant scientific and practical task of great importance for the sustainable development of the agro-industrial complex of the Republic of Kazakhstan.

Research Aim. To scientifically substantiate and determine effective methods of fertilizer application under drip irrigation in intensive apple orchards, taking into account the peculiarities of vegetative tree development, thereby ensuring sustainable growth in fruit productivity in the conditions of southern Kazakhstan.

Research Objectives:

1. Provide an agrochemical characterization of gray-brown soils in intensive orchards of southern Kazakhstan.
2. Study the depth of migration under fertigation and the dynamics of soil nutrient supply under apple trees by development phases.
3. Identify the peculiarities of vegetative tree development and photosynthetic activity under various fertilizer application methods.
4. Determine the influence of nutrition systems on yield and qualitative fruit indicators (marketability, sugar content, storage life).
5. Calculate the economic efficiency of applying various fertilizer application methods and develop recommendations for production.

Research methods. The studies were conducted from 2020–2023 in the Turkestan region on the basis of LLP "Kentau." The research object was apple plantations of the "Jeromini" variety on the M9 rootstock. The experimental scheme included three variants: 1) Control (without fertilizers), 2) Soil application of NPK, 3) Fertigation. Field, vegetative, and laboratory-analytical methods were used. Soil agrochemical indicators (pH, humus, NPK) were determined using generally accepted methods (Tyurin, Machigin, Kjeldahl). Biometric records, determination of leaf area (LAI), and photosynthetic potential were carried out using modern equipment (Plant Canopy Analyzer). Statistical data processing was performed using analysis of variance (ANOVA) and regression modeling. Soil samples were taken in layers up to a depth of 100 cm (0-20, 20-40, 40-60, 60-80, 80-100 cm). Biometric indicators were recorded monthly (stem diameter, shoot growth length, leaf surface area). Physiological studies included determination of net photosynthetic productivity (NPP) by the weight method. Yield accounting was conducted using a continuous per-tree method with fruit sorting and laboratory analysis of chemical composition (sugars, acids, vitamin C). All data were processed according to Dospekhov's methods.

Main provisions put forward for defense. Proven scientific hypotheses and other conclusions that constitute new knowledge:

1. The influence of fertigation on the optimization of agrochemical properties of gray-brown soils and the distribution of nutrient elements in the root-inhabited layer.
2. Patterns of growth, development, and photosynthetic activity of apple trees on the dwarf rootstock M9 depending on the method of mineral fertilizer application.
3. Productivity and qualitative indicators of apple fruits under various mineral nutrition systems.
4. Economic efficiency and resource-saving potential of fertigation technology in intensive horticulture of southern Kazakhstan.

Description of the main research results. It has been established that fertigation contributes to the optimization of the agrochemical properties of gray-brown soil. The application of physiologically acidic fertilizers through a drip irrigation system allowed for a reduction in the pH of the soil solution in the rhizosphere from 8.0 to optimal values of 7.2–7.4, which increased the availability of phosphorus and microelements. The humus content in the fertigation variant increased to 2.44% by 2023. A local decrease in soil alkalinity in the dripper zone by 0.6–0.8 pH units was recorded. Nitrogen and potassium levels were maintained at an optimal level throughout the critical vegetation period (June-August). According to Appendix B data, the dynamics of electrical conductivity (EC) of the soil solution in the fertigation variant showed stable values within 0.8–1.2 mS/cm, indicating the absence of salinization and improvement in soil structure. Additionally, the four-year dynamics of macroelement content (Appendix C) revealed an increase in easily hydrolyzable nitrogen by 15–20% in the upper layer (0–20 cm) compared to the control, confirming the long-term positive impact of fertigation on the fertility of gray-brown carbonate soils.

The advantage of fertigation in ensuring the migration of nutrient elements to the zone of active root activity (0–40 cm) without the risk of leaching into deep horizons has been proven. The nitrate nitrogen content during the active growth period was maintained at 28.2 mg/kg, and exchangeable potassium — up to 355 mg/kg, which is significantly higher than the indicators for soil application. The analysis of the soil granulometric composition (Appendix A) showed that light loams with low humus content (1.5–2.1%) predominate in the 0–100 cm profile, which enhances the effect of fertigation due to precise delivery of nutrients. The removal of NPK with fruits from one tree (Appendix E) in the fertigation variant reached 0.45 kg N, 0.18 kg P, and 0.52 kg K per tree in 2023, which is 25–30% higher than in the soil variant, demonstrating increased efficiency of element assimilation.

A positive influence of fertigation on biometric indicators has been identified. The net photosynthetic productivity (NPP) reached 8.86 g/m²·day, which is 19.2% higher than with soil application and 77.2% higher than the control. The above-ground tree biomass amounted to 53.7 t/ha. The leaf surface area in the fertigation variant was 22% higher than with traditional application. Biometric data by year (Appendix D) indicate stable growth in stem perimeter (up to 120–130 mm in 2023) and fruit quantity (up to 180–200 pcs/tree), with an average fruit weight of 170 g. This confirms the stimulation of vegetative development on the dwarf rootstock M9, especially during the flowering and fruit filling phases.

It has been established that fertigation ensures maximum plantation productivity. The average yield was 30.6 t/ha, which is 24.5% higher than the soil application variant (24.7 t/ha). At the same time, the yield of first-class marketable products reached 60%, and the overall marketability of the harvest was 93.9%. The share of marketable apples (large fraction, intense coloring) was 93.9%. The average fruit weight increased to 170 g (compared to 142 g in the traditional variant). Gross yield by year (Appendix Zh) showed a peak in 2023 — 32.43 t/ha for fertigation, with NPK removal up to 120–150 kg/ha. The harvest structure (Appendix I) revealed

the predominance of Class I (up to 70% in 2023), which is associated with uniform nutrition during phenological phases.

Fruit quality indicators under fertigation significantly surpass traditional methods: sugar content reached 24.1%, dry matter — 14.7%, fruit storage life increased to 16.3%. Quality assessment (Appendix K) confirmed distribution by classes with predominance of large fruits (diameter >70 mm), and laboratory analyses showed elevated vitamin C content (up to 15 mg/100 g). This quality improvement is related to the optimization of mineral nutrition, as indicated in the provisions for defense, where the role of fertigation in forming marketable characteristics is emphasized.

Economic analysis showed high efficiency of the proposed technology. Production profitability under fertigation was 423.2%, net income reached 7863 thousand tenge/ha. The cost of 1 kg of products decreased to 62.4 tenge, which is 1.8 times lower than with traditional soil application (112.9 tenge/kg). The payback of 1 kg of active substance fertilizers was 90.4 kg of apples. Operational expenses for fertigation amounted to 1.9 million tenge/ha, which is 700 thousand tenge less than with soil application. The fertilizer utilization coefficient increased almost twofold. Mathematical data processing confirmed the reliability of the results ($P < 0.05$). Dispersion analysis (ANOVA, Appendix Sh) for 2023 yield showed high significance of differences ($F=1948.46$ at $P<0.01$), with $LSD05=0.745$ t/ha, confirming the superiority of fertigation. Implementation on 210 ha at LLP “Kentau” (Appendix N) led to a reduction in anthropogenic load and acceleration of orchard payback by 1.5–2 years.

Justification of the novelty and importance of the obtained results. For the first time, in the conditions of gray-brown soils of southern Kazakhstan, a comprehensive study of the influence of fertigation on nutrient migration and transformation of soil properties in intensive apple orchards has been conducted. Regression models of productivity dependence on fertilizer doses have been developed ($R^2=0.978$). Optimal doses and timing of fertigation have been scientifically substantiated, taking into account the phenological phases of development of the "Jeromini" variety and ensuring an increase in the fertilizer utilization coefficient. The results are of great importance for preventing soil degradation, ensuring phosphorus assimilation in an alkaline environment, and accelerating the payback of intensive orchards by 1.5–2 years. The developed recommendations have been implemented in LLP "Kentau" on an area of 210 ha, which allows increasing yield by 24–30%, increasing the yield of marketable products, and reducing production costs. The results can be used by horticultural farms in the south and southeast of Kazakhstan to increase production profitability.

Compliance with scientific development directions or state programs. The research was conducted within the framework of the initiative project: 0119RKI0098 “Study of the Effectiveness of Liquid Fertilizers in Intensive Orchards under Drip Irrigation in the Conditions of LLP ‘Ken Tau’ in the Turkestan Region” and corresponds to the priority directions of science development in the field of soil science and agrochemistry. It contributes to the implementation of tasks to reduce

import dependence on fruit products, resource conservation, and adaptation to climate change in Central Asia.

Description of the doctoral student's contribution to the preparation of each publication. The author took direct participation in all stages of the work: from setting up field experiments, conducting phenological observations, sampling soil and plant samples to laboratory agrochemical analyses, statistical data processing, economic evaluation, and interpretation of results. Conclusions and practical recommendations were formulated. Based on the dissertation materials, 10 scientific works have been published, including 2 articles in international journals included in the Scopus and Web of Science databases (personal contribution: development of methodology, data analysis, writing the main text); 6 articles in publications recommended by the Committee for Control in the Sphere of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan (personal contribution: field studies, statistical processing, formulation of conclusions); and 2 abstracts in materials of international conferences (personal contribution: preparation of reports and presentations). The results were tested at conferences in Yakutsk (2023), Almaty (2024), and at a round table at the Kazakh Research Institute of Agriculture and Plant Growing (2025), where the doctoral student presented reports.

Volume and structure of the dissertation. The dissertation work is presented on 190 pages of computer text, consists of an introduction, literature review, research methodology, results and their discussion, conclusion, list of used sources with 331 titles, and 23 appendices. The work is illustrated with 29 tables and 26 figures.