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Effect of Drip Irrigation and Mineral–Micronutrient Fertigation on Yield and Agrobiological Indicators in Cucumber Cultivation

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Abstract

This study evaluated the agrobiological efficiency of mineral and micronutrient fertigation in cucumber cultivation under drip irrigation conditions. The experiments investigated the effects of applying NPK fertilizers at different application rates and growth stages, as well as their combination with micronutrient fertilizers, on the growth, development, and yield of cucumber. The results demonstrated that the distribution of mineral fertilizers according to phenological growth stages and their combined application with micronutrients improved nutrient uptake by the plants. The highest agrobiological and economic efficiency was achieved in the treatment where the scientifically recommended NPK rate was applied in combination with micronutrient fertilizers. It was also established that even with a partial reduction in the rate of mineral fertilizers, high yield and production efficiency could be maintained through the use of micronutrients. The findings provide a scientific basis for improving resource-efficient, environmentally sustainable, and highly effective fertigation systems for cucumber cultivation.

Keywords: Cucumber, drip irrigation, mineral fertilizers, NPK, micronutrient fertilizers, fertigation, yield, plant nutrients, economic efficiency, resource-saving technology.

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1. Introduction

Global population growth, climate change, and the increasing scarcity of water resources necessitate the adoption of resource-efficient technologies in agricultural production. Ensuring food security requires the sustainable development of the vegetable sector and the production of high-quality agricultural products. In this context, cucumber (Cucumis sativus L.) occupies an important position among vegetable crops due to its high nutritional value, rich content of vitamins and minerals, and its widespread use in the human diet. The continuous expansion of cucumber cultivation and the growing market demand further emphasize the need to improve cultivation technologies for this crop [1,4].

In regions experiencing increasing water scarcity, drip irrigation has become an important agricultural practice

that enables efficient water use while increasing crop productivity. This technology also allows the integration of mineral nutrient application with irrigation through fertigation. As a result, nutrient losses are reduced, and nutrient use efficiency by plants is significantly improved [2,3].

As a high-yielding crop, cucumber has a substantial demand for nitrogen, phosphorus, and potassium. The balanced application of these nutrients according to the crop's phenological growth stages has a direct impact on plant growth, development, yield, and fruit quality. In addition, micronutrients perform essential physiological functions in photosynthesis, enzyme activity, and the development of reproductive organs. Scientific studies have reported that the combined application of micronutrients.

Introduction (continued)

With mineral fertilizers enhances nutrient use efficiency [4,5].

Recent studies have shown that the split application of mineral fertilizers through fertigation not only increases crop yield but also improves water and fertilizer use efficiency. Furthermore, optimizing the nutrient solution composition and maintaining an appropriate micronutrient balance are among the key factors determining product quality and economic profitability [5,6].

Therefore, evaluating the agrobiological efficiency of mineral and micronutrient fertigation under drip irrigation conditions, as well as determining the optimal fertilizer rates and application timing, is an important scientific objective. The aim of this study was to determine the effects of mineral and micronutrient fertigation on cucumber growth, development, yield, and economic efficiency.

2. Methods

The object of the study was cucumber (Cucumis sativus L.) cultivated under a drip irrigation system, together with its mineral nutrition management. The research aimed to determine the effects of mineral and micronutrient fertigation on cucumber growth, development, yield, and product quality.

Field experiments were designed considering the changing nutrient requirements of the crop throughout the growing season. The experimental design included ten treatment variants to evaluate the effects of applying nitrogen, phosphorus, and potassium fertilizers at different application rates and growth stages, as well as the additional effects of micronutrient fertilizers.

The control treatment received no mineral fertilizers. The second treatment consisted of the conventional NPK fertilization system commonly used in commercial farming and served as the reference treatment. In the remaining treatments, mineral fertilizers were applied in different proportions based on scientific recommendations, while selected treatments also received supplementary liquid micronutrient fertilizers. The experimental treatments are presented in Figure 1. The treatments were grouped according to the mineral nutrition system, the level of micronutrient application, and the timing of fertigation (Figure 1).

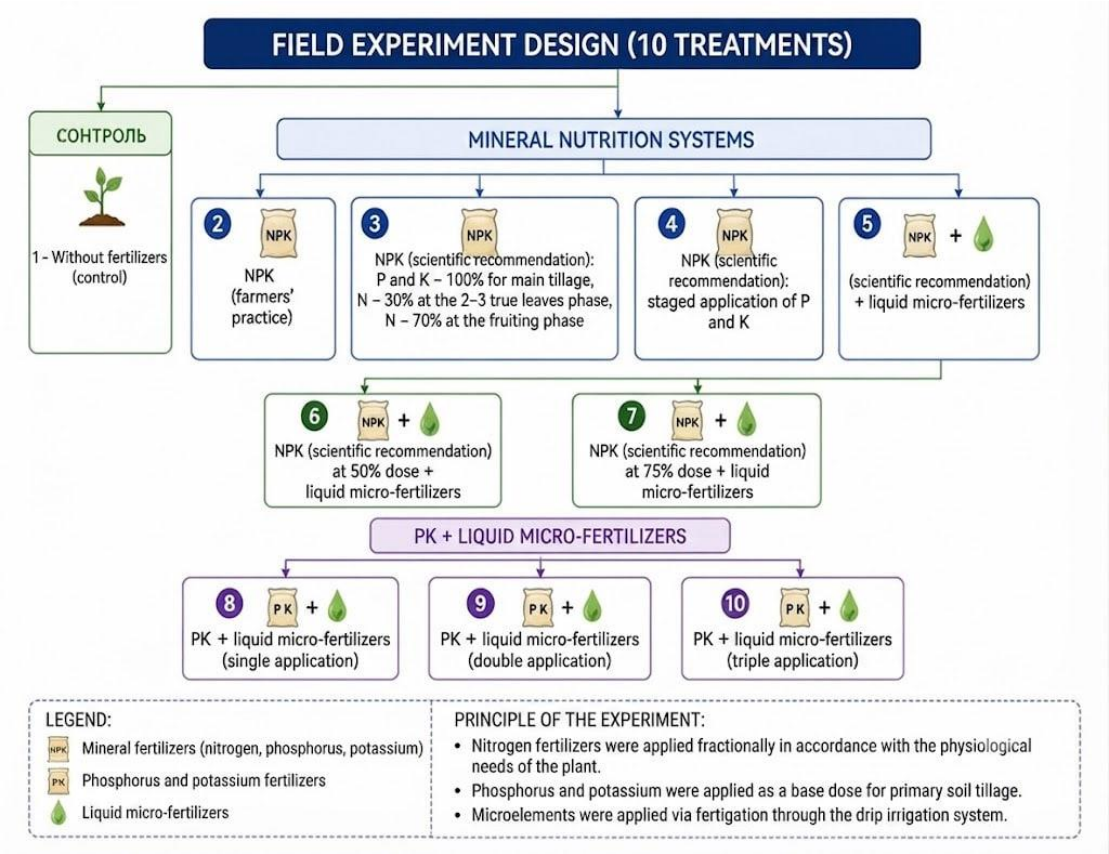

Figure 1. Experimental Design of Mineral and Micronutrient Fertigation Treatments for Cucumber Cultivation under Drip Irrigation Conditions

This approach made it possible to evaluate the interaction between macro- and micronutrients, as well as the agrobiological efficiency of resource-saving fertigation technologies.

When developing the experimental design, the high mobility of nitrogen and the possibility of its leaching were taken into account, as well as the relatively stable retention of phosphorus and potassium in the soil. According to...

For this reason, the main portion of phosphorus and potassium fertilizers was applied before sowing, while nitrogen fertilizers were applied in several doses according to the physiological requirements of the plants.

In the treatments involving micronutrients, the interaction between macro- and micronutrients, as well as their effects on yield and product quality, were evaluated. In addition, the experiment provided an opportunity to determine resource-saving and economically efficient fertigation systems by reducing the rates of mineral fertilizers by 50–75%.

The inclusion of treatments without nitrogen application made it possible to assess the independent effects of phosphorus and potassium, as well as to analyze indicators related to product quality and nitrate accumulation. This, in turn, served as an important scientific basis for improving environmentally safe and highly efficient plant nutrition technologies.

3. Results and Discussion

The results of the conducted experiments showed that different fertigation systems used in cucumber cultivation differed significantly in their effects on yield (Figure 2). In the control treatment, where no fertilizers were applied, the average yield was 14.9 t/ha, and this value was used as the main reference criterion for comparison.

In the treatment with the traditional NPK fertilization system commonly used in farming practices, the yield reached 21.9 t/ha. This result was 7.0 t/ha, or 47.0%, higher compared with the control. This confirmed the positive effect of mineral nutrient supply on cucumber growth and productivity.

In the 3rd and 4th treatments, where scientifically based mineral nutrition systems were applied, the yields reached 26.4 and 29.7 t/ha, respectively. These values were 77.2–99.3% higher than the control treatment, indicating that the distribution of nitrogen according to phenological growth stages, along with the application of phosphorus and potassium at optimal rates, enhances the generative development of the plant.

The highest result was obtained with the combined application of the scientifically recommended NPK rate together with micronutrient fertilizers. In this treatment, the yield reached 34.9 t/ha, which was 20.0 t/ha, or 134.2%, higher than the control treatment. This demonstrates that the synergistic interaction between macro- and micronutrients increases nutrient uptake efficiency by plants. The application of micronutrients contributed to increased photosynthetic activity, enhanced enzyme activity, and improved formation of productive plant organs.

Even in treatments with partially reduced mineral fertilizer rates, relatively high yields were maintained. In particular, in the treatment where micronutrients were applied with 50% of the scientifically recommended NPK rate, the yield was 27.1 t/ha, while at 75% of the recommended rate, it reached 26.2 t/ha. These results indicate that even under reduced mineral fertilizer input, high agrobiological efficiency can be achieved through the application of micronutrients.

In treatments based on phosphorus, potassium, and micronutrients, the yield ranged from 17.1 to 24.1 t/ha. Although these treatments provided a certain yield increase compared with the control, the absence of nitrogen became the main limiting factor affecting productivity. This once again confirms that nitrogen plays a decisive role in cucumber cultivation technology.

The obtained results demonstrated that the application of mineral fertilizers at scientifically justified rates and in accordance with phenological growth stages, as well as their combination with micronutrients, significantly increases cucumber yield. In addition, it was established that.

The results showed that, with the involvement of micronutrients, it is possible to partially reduce the rate of mineral fertilizers, which is of great importance for the development of resource-saving fertigation technologies.

The results of the economic analysis also demonstrated a close relationship with the agrobiological indicators. As yield increased, the conditional costs per unit of production decreased, while the profitability level increased. The highest economic efficiency was observed in the treatment where the scientifically recommended NPK rate was applied in combination with micronutrient fertilizers. In this treatment, the high level of yield formation not only compensated for the additional costs of fertilizers but also resulted in a significant increase in net profit and profitability indicators.

Therefore, this treatment was recognized as the most optimal fertigation system from both agrotechnological and economic perspectives.

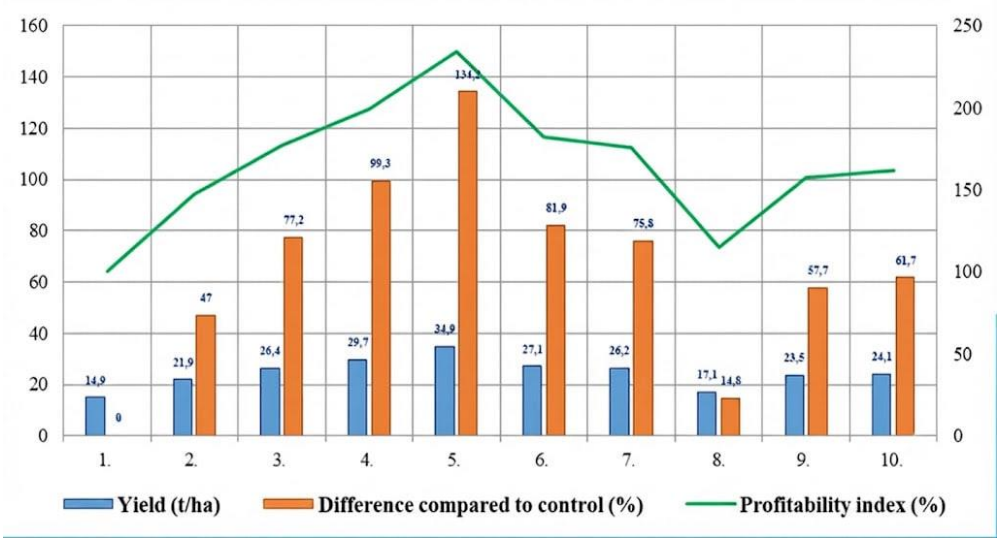

Fig. 2. Effect of Different Fertigation Treatments on the Economic Efficiency of Cucumber Cultivation (Profitability Index, %)

Mineral fertilizer rates reduced to 50% and 75% of the scientifically recommended level, when applied together with micronutrient fertilizers, also ensured the maintenance of high economic efficiency in the respective treatments. As a result of reducing mineral fertilizer consumption, production costs decreased in these treatments, while the relatively high preservation of yield levels contributed to a reduction in production costs per unit and an increase in profitability. This indicates that micronutrient fertigation improves the efficiency of mineral fertilizer utilization and expands the potential for implementing resource-saving technologies.

In treatments based solely on phosphorus and potassium, as well as on micronutrients, the fertigation system demonstrated relatively low economic efficiency. The lack of nitrogen limited the productive potential of the plants, resulting in reduced yield and economic performance.

The results of the study showed that the highest economic efficiency in cucumber cultivation can be achieved through the application of mineral fertilizers at scientifically justified rates and according to phenological growth stages, as well as through their integrated use with micronutrient fertilizers.

4. Conclusion

The results of the study established that mineral and micronutrient fertigation systems have a significant effect on the growth, development, yield, and economic efficiency of cucumber cultivation under drip irrigation conditions. Among the studied nutrient management systems, the highest agrobiologically efficiency was achieved through the combined application of the scientifically recommended NPK rate with micronutrient fertilizers. In this treatment, the yield reached 34.9 t/ha, which was 134.2% higher compared with the control treatment.

The combined application of mineral and micronutrient fertilizers increased the efficiency of nutrient uptake by plants, stimulated photosynthetic processes, and enhanced the formation of productive organs. This, in turn, contributed to increased yield and economic efficiency due to the synergistic interaction between macro- and micronutrients.

In addition, reducing the mineral fertilizer rate by 50–75% in combination with micronutrient fertilizers also ensured high agrotechnological efficiency. Along with reducing mineral fertilizer consumption, this approach contributed to lowering production costs while maintaining economic profitability. This factor is of great importance for the implementation of resource-saving fertigation technologies in agricultural production.

In treatments based only on phosphorus and potassium, as well as on micronutrients, yield and economic efficiency were relatively low, confirming the crucial role of nitrogen in the formation of cucumber productivity.

Based on the obtained results, it was established that the rational distribution of mineral fertilizers according to phenological growth stages in combination with micronutrient fertigation under drip irrigation conditions during cucumber cultivation is an effective agrotechnological method that ensures...

high yield, economic efficiency, and rational resource utilization.

Practical Recommendations

Based on the results of the study, it is recommended that cucumber cultivation under drip irrigation conditions should involve the phased application of nitrogen, phosphorus, and potassium fertilizers according to the phenological growth stages of the plant, as well as their combined use with micronutrient fertilizers through fertigation. The combination of scientifically justified mineral fertilizer rates with micronutrients increases nutrient use efficiency, enhances yield, and improves economic performance.

In addition, the application of micronutrient fertigation with a 50–75% reduction in mineral fertilizer rates is recommended as a resource-saving technology. This approach not only reduces mineral fertilizer consumption but also provides an opportunity to maintain high productivity.

The results of the study are of significant importance for developing optimal fertigation regimes for cucumber cultivation in irrigated soils prone to degradation in the Republic of Karakalpakstan, as well as for improving agrotechnological practices aimed at preserving soil fertility and ensuring rational resource utilization.

This research was conducted within the framework of the applied project №AL-9124093877 entitled “Development of Modern Agrotechnologies for the Cultivation of Agricultural Crops on Degraded Soils”, and the obtained results will further contribute to the development of vegetable production vegetable

production sector in the region, strengthening food security, and improving the efficiency of agricultural production.

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