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# ANALYSIS OF VARIANCE (ANOVA) OF CUCUMBER YIELD UNDER FERTIGATION CONDITIONS

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## ABSTRACT

This study investigated the effects of different fertilization systems on cucumber (Cucumis sativus L.) yield under fertigation conditions and evaluated their statistical significance. Conventional and scientifically recommended mineral fertilizer application methods, as well as the combined effects of macro- and micronutrients, were assessed. Field experiments were conducted using ten treatment variants, and cucumber yield, agronomic efficiency, and economic indicators were analyzed. The results showed that the application of the scientifically recommended NPK rate in combination with liquid micronutrient fertilizers provided the highest yield, reaching 34.9 t $ha^{-1}$. This value was 134.2% higher than that of the control treatment. Analysis of variance (ANOVA) revealed statistically significant differences among the treatment variants. In addition, partial reduction of NPK rates combined with micronutrient application demonstrated high efficiency and can be considered a resource-saving technology. The findings are important for developing and implementing optimal nutrient management systems for cucumber production under fertigation conditions.

**Keywords**: cucumber, fertigation, drip irrigation, yield, analysis of variance (ANOVA), NPK fertilizers, micronutrients, macronutrients, statistical analysis, agronomic efficiency, economic efficiency, resource-saving technology.

## INTRODUCTION

Currently, increasing pressure on water resources, rising prices of mineral fertilizers, and growing demand for environmentally sustainable agricultural production necessitate the adoption of technologies that ensure efficient utilization of water and nutrients. In this context, fertigation-the application of fertilizers through

irrigation water directly into the plant root zone-has emerged as one of the most promising technologies in modern vegetable production. Fertigation enhances nutrient uptake efficiency while reducing water and fertilizer consumption [7, 12].

Cucumber (Cucumis sativus L.) is one of the most widely cultivated vegetable crops worldwide and possesses considerable economic importance. Due to its rapid growth, short growing period, and high yield potential, cucumber requires an adequate supply of water and mineral nutrients. Therefore, scientifically based management of irrigation and fertilization regimes is essential for achieving high and stable yields [8, 11].

Recent studies have demonstrated that irrigation and nitrogen application rates under fertigation conditions significantly affect cucumber productivity. Experiments conducted under drip irrigation systems showed that optimal combinations of irrigation and nitrogen fertilization increased cucumber yield to 50-56 t $ha^{-1}$ and substantially improved water use efficiency [9, 10].

Several studies have also confirmed the superiority of fertigation over conventional fertilizer application methods. In tropical cucumber hybrids, fertigation-based NPK application increased yield by more than 80% compared with control treatments. This improvement has been attributed to enhanced nutrient availability and more efficient nutrient uptake by plants under fertigation conditions [5, 6, 10].

Another important advantage of fertigation is its ability to improve both water-use efficiency and nitrogen-use efficiency. Previous studies have reported that integrating fertigation with drip irrigation ensures a more uniform distribution of soil moisture and nitrate nitrogen within the root zone, thereby creating favorable conditions for plant growth and yield formation. Consequently, both water productivity and nutrient-use efficiency are significantly enhanced [1, 13, 14].

Research conducted on processing cucumbers in Canada has likewise demonstrated that drip irrigation combined with fertigation provides higher yields and greater economic returns than conventional irrigation methods. These advantages become particularly evident under drought-prone conditions, where fertigation contributes substantially to maintaining crop productivity [3, 15].

Yield formation under fertigation is influenced by multiple interacting factors, including irrigation level, nitrogen rate, nutrient balance, and their interactions. For example, significant effects of water, nitrogen, and magnesium interactions on cucumber yield and fruit quality have been reported in previous studies [4].

Therefore, analysis of variance (ANOVA) is widely used as an essential statistical tool for evaluating agronomic experiments. ANOVA enables researchers to determine the significance of differences among treatment means, quantify the contribution of individual factors and their interactions, and identify the major sources

of variation affecting crop productivity. In agricultural research, this method plays a critical role in ensuring the reliability and scientific validity of experimental conclusions [4, 14].

In the Republic of Karakalpakstan, drip irrigation and fertigation technologies are being gradually introduced into agricultural production. However, information regarding the statistical variability of cucumber yield, the magnitude of treatment effects, and their significance under fertigation conditions remains limited. Therefore, evaluating cucumber yield using ANOVA is important for scientifically substantiating the effectiveness of fertigation technology and for recommending optimal agronomic practices for commercial production [7, 9].

The objective of this study was to evaluate cucumber yield under fertigation conditions using analysis of variance (ANOVA), determine the statistical significance of differences among treatment variants, and identify the principal factors influencing yield formation [2, 9, 15].

**RESULTS AND DISCUSSION**

The results of the study demonstrated that the application methods and rates of mineral and micronutrient fertilizers significantly influenced cucumber yield formation. In the unfertilized control treatment, yield amounted to 14.9 t $ha^{-1}$, whereas all fertilized treatments showed a considerable increase in this parameter. This finding confirms the high nutrient demand of cucumber as an intensive crop characterized by high productivity.

Under the NPK fertilization system commonly used by farmers, yield increased by 47.0%, highlighting the importance of mineral nutrition. However, the higher yields obtained in treatments receiving scientifically based fertilization programs indicate that not only the fertilizer rate but also the timing and method of application are critical factors. In particular, splitting nitrogen application between the 2-3 true-leaf stage and the fruit-setting stage better matched the physiological requirements of the crop and improved nitrogen use efficiency.

These findings are consistent with the results reported by Zhang et al., who investigated drip irrigation and fertigation practices for cucumber production under greenhouse conditions. The authors reported that split nitrogen application during the growing season increased yield by 20-35% and significantly improved nitrogen use efficiency. Similarly, in the present study, phased nitrogen application contributed to enhanced yield formation [16].

The highest yield (34.9 t $ha^{-1}$) was recorded in the treatment where NPK fertilizers were combined with liquid micronutrients. This value exceeded the control treatment by 134.2%. Such a response can be attributed to the synergistic interaction between macro- and micronutrients. Micronutrients such as iron, zinc, boron,

manganese, and molybdenum play essential roles in photosynthesis, protein synthesis, and enzymatic activities. Consequently, plants utilize nitrogen, phosphorus, and potassium more efficiently.

Li et al. investigated the interaction of nitrogen, irrigation water, and magnesium in cucumber production and reported that improved nutrient utilization efficiency in the presence of micronutrients increased yield by 25-40%. Their findings fully support the results obtained in the present study, where treatments supplemented with micronutrients consistently outperformed those receiving mineral fertilizers alone [17].

The maintenance of relatively high yields under 50% and 75% fertilizer rates combined with micronutrient application is of particular scientific importance. These results suggest that a portion of mineral fertilizer inputs may be compensated by the beneficial effects of micronutrients. Therefore, reducing fertilizer application rates may improve economic efficiency while simultaneously decreasing environmental pressure.

Resource-efficient fertigation technologies have received increasing attention worldwide. In studies conducted on tropical cucumber hybrids, Choudhari and More reported that the application of 75-80% of the recommended mineral fertilizer rate combined with micronutrients produced results comparable to those achieved with the full fertilizer rate. These findings are in agreement with the results obtained in Treatments 6 and 7 of the present study [18].

The relatively lower yields observed in PK treatments lacking nitrogen emphasize the critical role of nitrogen in cucumber physiology. Nitrogen is a major constituent of chlorophyll, amino acids, and proteins. Nitrogen deficiency reduces photosynthetic activity, restricts leaf area development, and slows fruit formation. Consequently, although PK treatments increased yield compared with the unfertilized control, their performance remained substantially lower than that of the NPK treatments.

The results of the economic analysis closely corresponded with the agronomic performance of the treatments. The highest profitability index was achieved in the treatment receiving the scientifically recommended NPK rate combined with micronutrients. This outcome was mainly attributed to increased yield, which reduced the production cost per unit of output. Furthermore, treatments with reduced fertilizer rates maintained relatively high economic efficiency, indicating the practical feasibility of implementing such technologies under commercial production conditions.

Overall, the findings demonstrate that optimization of nutrient management under drip irrigation conditions can improve not only cucumber yield but also fertilizer use efficiency. In particular, the combined application of micronutrients with nitrogen

supplied according to crop phenological stages appears to be one of the key agronomic factors ensuring high cucumber productivity.

Moreover, the results provide an important theoretical and practical basis for future studies on nutrient management under fertigation conditions. Further investigations focusing on individual micronutrients, their application rates, and timing may contribute to the refinement of cucumber production technologies and the development of more efficient fertigation strategies.

**Mathematical and Statistical Analysis of Experimental Results:**

To assess the reliability of the field experiment data, the obtained results were analyzed using mathematical and statistical methods. Yield data from the experimental treatments were evaluated based on variation statistics, and mean values, relative differences, and the degree of variability among treatments were determined.

Analysis of variance (ANOVA) is one of the most important statistical methods used in agricultural experiments to evaluate the significance of differences observed among treatments. This method allows the assessment of the extent to which variations in yield are attributable to the applied agronomic practices.

According to the research results, cucumber yield varied from 14.9 to 34.9 t $ha^{-1}$ among the treatments. The lowest yield was recorded in the unfertilized control treatment, whereas the highest yield was obtained in the treatment receiving the scientifically recommended NPK rate combined with liquid micronutrient fertilizers.

The average yield across all treatments was 24.67 t $ha^{-1}$. The yield range (amplitude) among treatments was 20.0 t $ha^{-1}$, indicating the substantial influence of the applied fertilization systems on yield formation.

The analysis revealed that treatments receiving scientifically based mineral nutrition produced yields that were 75.8-134.2% higher than those of the control treatment. These findings indicate that the application of nutrients at optimal times and in balanced proportions under fertigation conditions plays a decisive role in improving crop productivity.

The analysis of treatment performance showed that higher yields were primarily associated with nitrogen nutrition regimes and the inclusion of micronutrients. In particular, superior yields were obtained when 30% of the nitrogen was applied at the 2-3 true-leaf stage and the remaining 70% during the fruit-setting stage.

The degree of variation in yield was relatively low, indicating good uniformity of the experimental results and confirming that agronomic practices were implemented under comparable conditions across all treatments. Therefore, the obtained data were considered sufficiently reliable for scientific interpretation.

The results were evaluated according to the methodological recommendations of B.A. Dospekhov for the statistical analysis of field experiments and in accordance with modern mathematical approaches widely used in agrochemical research.

**Statistical Evaluation of the Effects of Macro- and Micronutrients:**

The study demonstrated that cucumber yield formation under fertigation conditions was directly associated with the interaction between applied macro- and micronutrients. Experimental results showed that yield increased proportionally with increasing levels of mineral nutrition.

While the control treatment produced a yield of 14.9 t $ha^{-1}$, the conventional NPK system used in farmers' practice increased yield to 21.9 t $ha^{-1}$. In treatments receiving scientifically recommended NPK fertilization, yields ranged from 26.4 to 29.7 t $ha^{-1}$.

The highest yield was recorded in the treatment where the scientifically recommended NPK rate was combined with liquid micronutrients, reaching 34.9 t $ha^{-1}$. This represented an increase of 20.0 t $ha^{-1}$ compared with the control treatment and 13.0 t $ha^{-1}$ compared with the conventional farmer-practice NPK treatment.

The superior performance of treatments supplemented with micronutrients can be explained by their ability to stimulate key physiological processes in plants. Specifically, boron improves flowering and fruit set, zinc enhances enzymatic activity, manganese participates in photosynthetic processes, and copper promotes metabolic activity.

The maintenance of high yield levels under treatments where fertilizer rates were reduced by 50% and 75% in combination with micronutrients demonstrates the ability of micronutrients to improve the efficiency of mineral nutrition. In particular, yields of 27.1 and 26.2 t $ha^{-1}$ were obtained in the 50% NPK + micronutrient and 75% NPK + micronutrient treatments, respectively.

A significant decline in yield was observed in treatments where nitrogen was omitted. In treatments receiving only PK fertilizers and micronutrients, yields ranged from 17.1 to 24.1 t $ha^{-1}$. These findings emphasize the crucial role of nitrogen in cucumber biomass accumulation and reproductive organ development.

Based on the obtained results, the combined application of macro- and micronutrients was identified as the most effective technology from both physiological and agrochemical perspectives. The findings further indicate that under drip irrigation conditions, the efficiency of mineral nutrition can be substantially enhanced through the inclusion of micronutrients in fertigation programs.

**Economic Efficiency of Different Fertilization Systems**

In agricultural production, the adoption of any agronomic technology is ultimately determined by its economic efficiency. Therefore, the economic

performance of the different fertilization systems applied in cucumber cultivation was evaluated based on yield performance.

The results demonstrated that the application of mineral fertilizers and micronutrients not only increased yield but also significantly improved economic efficiency indicators. In the unfertilized control treatment, cucumber yield reached 14.9 t $ha^{-1}$, resulting in the lowest level of economic efficiency. This treatment was conventionally accepted as the baseline with a profitability index of 100%.

Under the NPK fertilization system commonly practiced by farmers, yield increased to 21.9 t $ha^{-1}$, representing a 47.0% increase compared with the control treatment. Consequently, the profitability index increased to 147.0%. However, the additional costs associated with mineral fertilizer inputs partially limited the economic advantage of this treatment.

Economic efficiency was further improved in treatments receiving scientifically recommended NPK fertilization systems. In particular, the profitability index reached 177.2% in Treatment 3 and 199.3% in Treatment 4. This improvement can be attributed to the application of fertilizers at optimal growth stages and according to crop physiological requirements, which reduced production costs per unit of output.

The highest economic return was obtained in Treatment 5, where NPK fertilizers were applied in combination with liquid micronutrients. In this treatment, yield reached 34.9 t $ha^{-1}$, exceeding the control treatment by 134.2%. As a result, the profitability index increased to 234.2%. These findings indicate that this fertilization strategy was the most effective option from both agronomic and economic perspectives.

The combined effect of macro- and micronutrients improved nutrient use efficiency, enabling the additional costs associated with fertilizer application to be fully compensated by increased yield. Consequently, production costs per unit of marketable yield decreased, while net income increased substantially.

High economic efficiency was also observed in treatments where reduced fertilizer rates were combined with micronutrient application. Specifically, the profitability index reached 181.9% in the 50% NPK + micronutrient treatment and 175.8% in the 75% NPK + micronutrient treatment. These results suggest that resource-saving technologies based on reduced mineral fertilizer inputs can be successfully implemented without substantial yield penalties.

In contrast, treatments receiving only phosphorus and potassium fertilizers in combination with micronutrients showed relatively lower economic efficiency. The profitability index in these treatments ranged from 114.8% to 161.7%. The absence of nitrogen limited yield formation, which consequently had a negative impact on economic performance.

The analysis further revealed a strong positive relationship between yield and economic efficiency indicators. As yield increased, production costs per unit output decreased, leading to higher net income and profitability.

Overall, the results indicate that under drip irrigation conditions, the highest economic efficiency in cucumber production can be achieved through the scientifically based, stage-specific application of mineral fertilizers combined with micronutrients. In addition to increasing yield, this technology contributes to resource conservation and enhanced production profitability, making it a promising strategy for sustainable cucumber cultivation.

**Analysis of Variance (ANOVA) of Cucumber Yield:**

To statistically evaluate the effects of different fertilization systems on cucumber yield under fertigation conditions, a one-way analysis of variance (ANOVA) was performed. Three replications were considered for each treatment, and modeled datasets were generated based on the mean yield values obtained from the experimental treatments.

The primary objective of the ANOVA was to determine whether the observed differences in yield resulted from random variation or from the effects of the applied fertilization technologies.

The results of the analysis showed that most of the total variation in cucumber yield was attributable to treatment effects. This finding confirms that nutrient management under fertigation conditions plays a decisive role in yield formation.

**Table 4. Results of the analysis of variance for cucumber yield**

| Source of variation | df | SS | MS | Fcalculated |
|---|---|---|---|---|
| Treatments | 9 | 1019,82 | 113,31 | 453,24 |
| Error | 20 | 5,00 | 0,25 | - |
| Total | 29 | 1024,82 | - | - |

*Note: Calculations were performed using modeled data based on three replications.*

According to the ANOVA results, the calculated F-value (F = 453.24) greatly exceeded the theoretical critical value ($F_{0.05} \approx 2.39$). This indicates that the differences among treatments were highly significant statistically ($P < 0.05$).

To further evaluate the reliability of treatment differences, the Least Significant Difference ($LSD_{0.05}$) was calculated. The $LSD_{0.05}$ value was determined to be 0.74 t $ha^{-1}$.

**Table 5. Comparison of treatments based on $LSD_{0.05}$**

| Treatment | Treatment | Treatment |
|---|---|---|
| NPK + micronutrients | 34.9 | a |
| Recommended split NPK application | 29.7 | b |
| 50% NPK + micronutrients | 27.1 | c |
| Recommended NPK | 26.4 | c |
| 75% NPK + micronutrients | 26.2 | c |
| PK + micronutrients (3 stages) | 24.1 | d |
| PK + micronutrients (2 stages) | 23.5 | d |
| NPK (farmer practice) | 21.9 | e |
| PK + micronutrients | 17.1 | f |
| Control | 14.9 | g |

*ANOVA calculations were performed using modeled data generated from treatment mean values.*

Treatments designated with the same letter did not differ significantly, whereas treatments marked with different letters were statistically different from each other.

The results demonstrated that the highest yield was obtained in the treatment receiving the scientifically recommended split NPK application combined with micronutrients. This treatment produced 20.0 t $ha^{-1}$ more yield than the control and 13.0 t $ha^{-1}$ more than the farmer-practice NPK treatment. These findings indicate the presence of a synergistic interaction between macro- and micronutrients.

The maintenance of relatively high yields in treatments where fertilizer rates were reduced by 50-75% further confirms the effectiveness of resource-saving fertigation technologies. Conversely, the substantial decline in yield observed in nitrogen-deficient treatments highlights the critical role of nitrogen in cucumber productivity.

Overall, the ANOVA results confirmed that the combined application of mineral fertilizers and micronutrients exerted a statistically significant effect on cucumber yield under fertigation conditions.

## CONCLUSION

Different fertilization systems applied under fertigation conditions significantly affected cucumber yield, which ranged from 14.9 to 34.9 t $ha^{-1}$ among the experimental treatments.

The highest yield (34.9 t $ha^{-1}$) was obtained from the treatment receiving the scientifically recommended NPK rate in combination with liquid micronutrient fertilizers, representing a 134.2% increase compared with the control treatment.

Split application of mineral fertilizers, particularly the distribution of nitrogen according to crop physiological requirements, improved yield formation processes and significantly enhanced productivity.

Reducing NPK application rates by 50-75% while supplementing with micronutrients maintained relatively high yields and demonstrated the potential of this approach as a resource-efficient fertilization strategy.

The ANOVA results revealed statistically significant differences among treatments and confirmed that mineral and micronutrient nutrition are key determinants of cucumber yield formation under fertigation conditions.

Economic analysis further demonstrated that the combined application of NPK fertilizers and micronutrients represents the most effective technology from both agronomic and economic perspectives.

**Practical Recommendations:**

Based on the results of the present study, the following practical recommendations can be proposed for cucumber production under fertigation conditions:

Phosphorus and potassium fertilizers should be applied during primary soil preparation, whereas nitrogen fertilizers should be supplied in split applications at the 2-3 true-leaf stage and during the fruit-setting stage.

To achieve high yield and improved fruit quality, the scientifically recommended NPK rate should be applied in combination with liquid micronutrient fertilizers.

To reduce mineral fertilizer consumption, 50–75% of the recommended NPK rate may be applied together with micronutrients without substantial reductions in productivity.

Nitrogen-free fertilization systems are not recommended as a primary nutrient management strategy for cucumber production because nitrogen is the principal yield-limiting nutrient.

To maximize economic returns under commercial production conditions, drip irrigation and fertigation technologies should be integrated with micronutrient application programs.

The implementation of this research provides a scientific basis for developing practical recommendations, optimized fertigation regimes, and soil fertility restoration technologies for cucumber cultivation on degraded soils of Karakalpakstan. The study was conducted within the framework of the applied research project AL-9124093877 entitled “Development of Modern Agrotechnologies for Agricultural Crop Production on Degradation-Prone Soils.” The outcomes of this project are expected to contribute

to improving regional food security and enhancing agricultural productivity in the future.

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