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MINERAL NUTRITION OPTIMIZATION FOR APPLE TREES BY FERTIGATION TO ENHANCE PRODUCTIVITY AND FRUIT QUALITY IN INTENSIVE ORCHARDS OF SOUTHERN KAZAKHSTAN

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Abstract. In response to Kazakhstan's priority of enhancing food security and reducing fruit imports, this study investigates the efficacy of different fertilization methods on the yield, fruit quality, and economic performance of intensive apple orchards. Given the increasing area of apple cultivation in Kazakhstan, optimizing fertilization practices is crucial for maximizing production and ensuring sustainability.: The study aims to evaluate the impact of three fertilization methods-existing technology without NPK, NPK incorporation into the soil, and fertigation-on the yield and quality of Geromini apple trees grown on dwarf M9 rootstocks. The research also assesses the economic efficiency of each method. Conducted from 2019 to 2022 in Turkestan, Kazakhstan, the study employed a randomized block design with four replications for each fertilization Treatment. Key parameters measured included fruit yield, quality (sugar content, dry matter, firmness), macroelement uptake (nitrogen, phosphorus, potassium), and economic metrics. Fertigation emerged as the most effective method, resulting in the highest average gross yield (30.6 t/ha), marketable yield (28.7 t/ha), and fruit quality metrics, including sugar content (24.1%) and average fruit weight. Fertigation also demonstrated superior macroelement uptake, with the highest levels of nitrogen, phosphorus, and potassium. Economically, fertigation proved to be the most cost-effective method, providing a favorable return on investment compared to soil incorporation and traditional fertilization methods. The study concludes that fertigation significantly enhances both the yield and quality of apples while optimizing economic returns. This method's efficiency in nutrient delivery and uptake positions it as the most advantageous practice for intensive apple orchards. Further research is recommended to refine fertigation techniques and explore sustainable practices for long-term orchard productivity.

Key words: apple orchards, yield optimization, fruit quality, fertigation, macronutrient uptake, intensive cultivation.

INTRODUCTION

Food security and the ability to provide the population with fruit is of national wide priority. According to the Bureau of national statistics in Kazakhstan consumption of apple is 268 thousand tons per year, and about 90 thousand tons of them is imported. In the country, its per capita consumption is 13.4 kg per year [1], exceeding the world average in the world is 12.2 kg. [2].

Over the last 14 years in the South and Southeast of Kazakhstan, there has been an increase in areas allocated to fruit crops; however, there has been a little study of the mineral nutrition of perennial plantations and soil fertility under them so far [3-6].

The average duration of apple tree fruiting in extensive orchards is 25 years, for the intensive orchards up to 15 years. In extensive orchards tree feeding area is much more than in intensive orchards, which averaged 2500-2800 trees per hectare. As literature sources documented, the yield of an intensive apple orchard increases in the first 3-5 years and reaches a maximum in the 5th-15th year of the orchard's life, gradually decreasing with aging [7]. In horticulture in Kazakhstan, the problems of optimizing mineral nutrition of apple orchards, including intensive ones, require solutions in terms of improving plant nutrition, allowing increasing the yield and quality of products. This article presents the results of a comparative study of two modes of mineral nutrition of apple trees in intensive orchards.

MATERIALS AND METHODS

Over the 2019-2022 an field investigations in intensive orchards were conducted at "Kentau" LLP, Shakpak-baba village, Tulkubas district, Turkestan region, at the coordinates of 42°29'57.8"N and 70° 29'47.2"E on 940-1028 meters above the see level (figure 1).

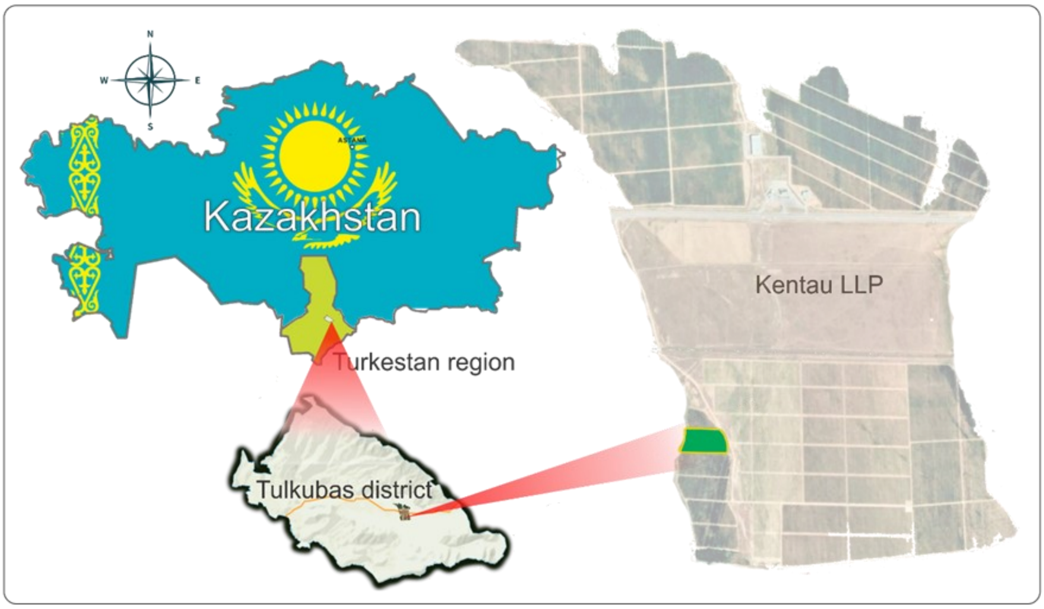

Figure 1 – Experimental plots site location

The prevailing climate in the area is continental, characterized by hot and dry summers. The sum of active temperatures is 3900-5100°C, with an annual heat accumu lation index ranging 120-135 kcal/cm^2. Precipitation is limited, varying 190-420 mm annually, with approximately 240-300 days experiencing air temperatures above 10°C [8].

The soil type under the research plots represents a vertical zonation of mountainous regions, displaying a dark grey color comprised of the upper A horizon, A+B horizons with a few humus content and thickness, and features a marked transition to gravelly and pebbly deposits displaying a clumpy-granular structure. Theinitial soil fertility characteristics under the apple orchard are presented in table 1.

Table 1 - The initial soil fertility characteristics under the apple orchard plots

Organic matter (humus), %	1.54-2.11
pH, water	7.4-7.8
Ammonium nitrogen, mg/kg	5.5-6.5
Nitrate nitrogen, mg/kg	7.4-10.7
Available phosphorus, mg/kg	15.6-25.2
Exchangeable potassium, mg/kg	162-275

The intensive apple orchard was cultivated on a trellis culture with a height of 2.2m and a tree-planting scheme of 1 x 3.5m. The seedlings used were featured frost-resistant variety 'Jerominee' of French origin, from Mondial Fruit Selection SARL, with fruits of unusual flesh color, grafted onto dwarf scion M9 in 2014. Jerominee (Malus domestica) belongs to the Red Delicious group, derived in the process of mutation of Early Red One (Erovan) variety known for more than 30 years. The crown is rounded, medium dense. The average weight of an apple is 170-190 grams, the content of sugars - 15.5%, titratable acids - 0.51%, ascorbic acid - 6.0 mg/100g, P-active substances - 130 mg/100g [9].

The experiment plot includes three treatments with varying nutrition regime replicated four times (figure 2, table 2).

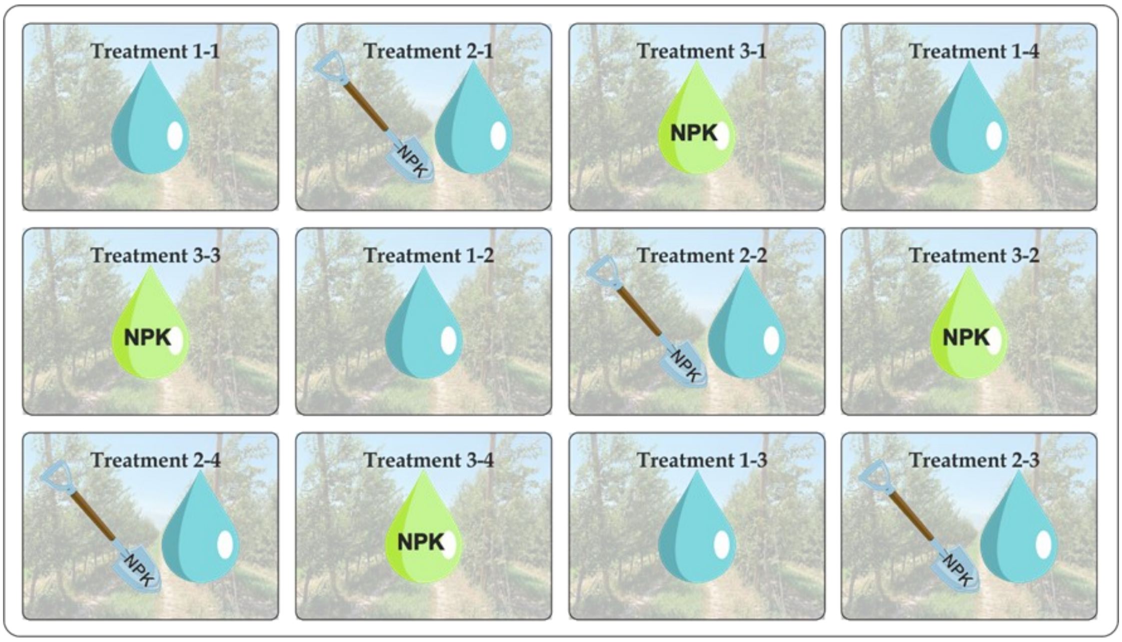

Figure 2 – Experimental design: Treatment-1 - Control (without NPK); Treatment-2 - NPK incorporating with soil; Treatment-2 - NPK through fertigation

Table 2 – Experiment scheme 2019-2022

Method of fertilizer application	Fertilizer doses, kg a.i./ha
Treatment 1 - Control - without NPK	N0P0K0
Treatment 2 - NPK incorporating with soil	N82P54K97
Treatment 3 - NPK through fertigation	N52P36K91

The aim of the study was to obtain targeted apple yield without harming the environment. Based on the standard кemoval of nutrients by 1 ton of apples (with the corresponding by-products), NPK doses were calculated for both soil application (Treatment 2) and for application through fertigation (Treatment 3) (table 3).

Table 3 - Calculation of fertilizer doses for the targeted apple yield

Indicators	Measure-ment unit	2019-2022		
		N	P	K
Tratment 2				
Removal of nutrients by 1 ton of apples (with the corresponding by-products)	kg	3,3	1,1	4,8
Observed apple fruit yield without fertilizers	t/ha	15,0		
Targeted increase in apple yield per hectare	t/ha	10,0		
Removal of nutrients by yield increase	kg	32,7	10,7	48,3
Generalized coefficient of nutrient uptake from fertilizers	%	40,0	20,0	50,0
Needed fertilizers to apply taking into account the coefficient of use, kg of a.i.	kg/ha	82	54	97
Tratment 3				
Removal of nutrients by 1 ton of apples (with the corresponding by-products)	kg	3,3	1,1	4,8
Observed apple fruit yield without fertilizers	t/ha	15,0		
Targeted increase in apple yield per hectare	t/ha	15,0		
Removal of nutrients by yield increase	kg	49,1	16,1	72,5
Generalized coefficient of nutrient uptake from fertilizers	%	95,0	45,0	80,0
Needed fertilizers to apply taking into account the coefficient of use, kg of a.i.	kg/ha	52	36	91

At determining fertilizer doses, we used the data on the removal of mineral nutrition elements given in the reference manual [10]. At the application of fertilizers by different methods the coefficients of nutrient uptake varied and were as follows: for soil incorporation: nitrogen - 40%, phosphorus -20% and potassium - 50%, for fertigation: nitrogen - 95%, phosphorus - 45% and potassium - 80% [11].

Based on the observed apple fruit yield without fertilizers in 2018 made 15 t/ha, in 2019-2022 the fertilizer doses were calculated to increase the yield by 10 and 15 t/ha, for Treatment 2 and Treatment 3, respectively.

In Treatment 2 phosphorus and potassium fertilizers were applied in autumn, the entire dose of nitrogen fertilizers was incorporated into the soil in early spring to a depth of 12-16 cm [12].

In Treatment 3 nitrogen, phosphorus and potassium fertilizers were applied in accordance with the accepted nutrition regimes for fertigation at the "Kentau"LLP [13-19].

Research methodology. The studies were conducted according to the methodological guidelines for setting and conducting experiments with fertilizers in fruit and berry plantations [20]. Biometric observations and records related to the growth and productivity of plantations were conducted according to the methodological guidelines for agrotechnical experiments with fruit and berry crops [21].

Measurements and record keeping. The number of fruits after mass drop of ovaries and fruits was counted visually on all counted plants in all replications. The perimeter of the tree trunk was measured with measuring tape at a height of 20-25 cm from the soil surface in the fall, after the end of vegetation.

Sampling and analysis. Fruit samples were taken at harvest time and removal from storage for evaluation of keeping quality. Soil samples for agrochemical characteristics were taken in the second decade of August 2018; laboratory analyses for humus content, pH, nitrate and ammonium nitrogen, available phosphorus, mobile potassium were determined by accepted methods in laboratory practices [13-19].

Fruit yield and its keeping quality measurements. At harvest time and during storage fruit measurements, keeping quality, dry matter and total sugar content were determined [22, 23].

RESULTS AND DISCUSSIONS

According to the four year research, the following results were obtained (table 4).

Table 4 - Biometric and yield characteristics of apple trees depending on the method of fertilizer application

Fertilizer options	Number of fruits, per tree	Average weight of fruit, g	Gross yield, t/ha	Marketable yield, t/ha	Marketability, %
2019					
Treatment 1	59,0	90,6	15,2	4,8	31,8
Treatment 2	59,8	142,9	24,4	19,6	80,2
Treatment 3	63,6	161,3	29,3	27,1	92,7
LSD05	1,9	4,5	0,9	0,8	
2020					
Treatment 1	58,3	87,9	14,7	4,7	32,1
Treatment 2	61,0	142,5	24,9	19,8	79,5
Treatment 3	63,0	167,6	30,2	28,3	93,7
LSD05	2,7	5,3	1,4	1,2	
2021					
Treatment 1	58,9	83,9	14,1	2,8	19,8
Treatment 2	60,9	140,5	24,5	19,2	78,7
Treatment 3	62,0	172,1	30,5	28,7	94,1
LSD05	1,7	2,9	0,6	0,5	
2022					
Treatment 1	57,6	82,8	13,6	2,4	17,5
Treatment 2	62,2	142,1	25,2	19,6	77,7
Treatment 3	63,4	179,0	32,4	30,9	95,3
LSD05	2,0	2,4	1,3	0,8	
Average for 2019-2022					
Treatment 1	58,5	86,3	14,4	3,7	25,3
Treatment 2	61,0	142,0	24,7	19,6	79,0
Treatment 3	63,0	170,0	30,6	28,7	93,9
LSD05	1,7-2,7	2,4-5,3	0,6-1,4	0,5-1,2	

According to table 4, the highest number of fruits was recorded with the use of mineral nutrition through fertigation, averaging 63.0 fruits per tree over the entire study period. This figure is 4.5 fruits higher compared to the control, where only drip irrigation and foliar micronutrient fertilization were applied (58.5 fruits per tree). The increase in fruit number with fertigation is likely due to more uniform and effective nutrient distribution in the root zone, ensuring continuous access to macro- and micronutrients during the growing season [24].

A significant increase in the average fruit mass was observed with mineral nutrition through fertigation—170.0 g compared to 86.3 g under drip irrigation with foliar micronutrient fertilization. The fruit mass nearly doubled, which can be attributed to the higher availability of nutrients and optimized water management during fertigation. Fertilizer application via fertigation ensures an optimal nutrient level during critical phases of fruit formation, leading to larger fruit sizes [25].

Gross yield with fertigation reached 30.6 t/ha, which is 16.2 t/ha higher compared to the control (14.4 t/ha). A similar trend is seen in marketable yield- 28.7 t/ha versus 3.7 t/ha in the control. This is likely due to increased productivity from better plant nutrition with macroelements, as well as a reduction in losses from low-quality fruit drop. The variant involving fertilizer incorporation into the soil also showed a significant yield increase, though less pronounced compared to fertigation [26].

The highest percentage of marketable yield was recorded with fertigation (93.9%), whereas under drip irrigation with foliar micronutrient fertilization, this figure was only 25.3%. Clearly, fertigation not only increases total yield but also significantly improves fruit quality. This could be explained by the fact that fertigation supplies nutrients to the plants at optimal phases of fruit formation and ripening, positively affecting their appearance and transportability.

The Least Significant Difference (LSD05) indicates that the differences in yield and fruit quality between fertilization methods are statistically significant. For example, the difference in gross yield between fertigation and drip irrigation exceeds the LSD05 threshold (0.6-1.4 t/ha), confirming the reliability of the results and suggesting that fertigation has a substantial positive impact on yield.

Based on the data, it can be hypothesized that mineral nutrition through fertigation is the most optimal strategy for intensifying apple orchards under the conditions of this experiment. This is explained not only by the higher gross and marketable yields but also by the increased average fruit mass, which may result from more efficient macroelement absorption during key growth and development stages. Future research may focus on elucidating the mechanisms behind the improved biometric and yield characteristics with fertigation, as well as on developing optimal mineral nutrition rates for each stage of the growing season.

Table 5 - Fruit quality of apple fruits depending on the method of fertilizer application, 2019-2022

Fertilizer option	Dry matter, %	* Sugar content of fruits, %	* keeping quality, %
Treatment 1	13,8	17,4	14,5
Treatment 2	14,9	23,2	16,5
Treatment 3	14,7	24,1	16,3
LSD05	0,3-0,7	1,1	0,4

* - Data for 2022

According to table 5, the study on apple fruit quality based on various fertilization methods was conducted using parameters such as dry matter content, sugar content, and fruit firmness. A more detailed description of the methodology for determining nutrients in soil and plant material is given in a previously published article [27]. The data obtained provide insights into the impact of each method on these parameters [22, 23].

The content of dry matter in the fruits varied depending on the fertilization method. The highest values were observed with the second method, which involves the incorporation of mineral nutrients into the soil (14.9%). This figure exceeds the control (13.8%) by 1.1%, suggesting a deeper penetration and uptake of nutrients by the plants with this method. The third method (fertilization through fertigation) showed results close to the second method (14.7%), indicating comparable effectiveness. It is hypothesized that the increased dry matter content with fertilization is associated with improved conditions for the accumulation of carbohydrates and other metabolites in the fruit, making them denser and more nutritious.

The highest sugar content was recorded with the third method (fertigation), reaching 24.1%. This result is 6.7% higher than the control (17.4%). The second method also showed a significant increase in sugar level — 23.2%. The high sugar content can be attributed to fertigation's ability to provide a uniform and continuous supply of macro- and micronutrients, especially potassium, which plays a crucial role in carbohydrate synthesis and accumulation. The LSD05 for sugar content is 1.1%, confirming a statistically significant difference between fertilization methods. This suggests that both fertigation and soil incorporation of mineral fertilizers significantly enhance the taste quality of the fruit due to increased sugar content.

The firmness of the fruits, which reflects their ability to maintain quality during storage, was highest with the second method — 16.5%. The third method (fertigation) showed similar results (16.3%), slightly lower than the second method. Drip irrigation with foliar micronutrient fertilization resulted in the lowest firmness — 14.5%. This may be related to the fact that optimal nutrition through the root system, particularly with elements such as calcium and magnesium, positively impacts the strength of fruit cell walls, increasing their resistance to mechanical damage and biochemical changes during storage. The LSD05 for firmness is 0.4%, indicating significant differences between the fertilization methods.

Based on the data, it can be concluded that the use of mineral fertilizers, whether incorporated into the soil or applied through fertigation, positively affects apple fruit quality. Specifically, these methods contribute to increased sugar and dry matter content in the fruits, as well as improved firmness. Fertigation demonstrated the highest sugar content, suggesting a need for further research to optimize this method for enhancing plant nutrition and productivity.

The analysis of macroelement uptake yielded the figures 3-5:

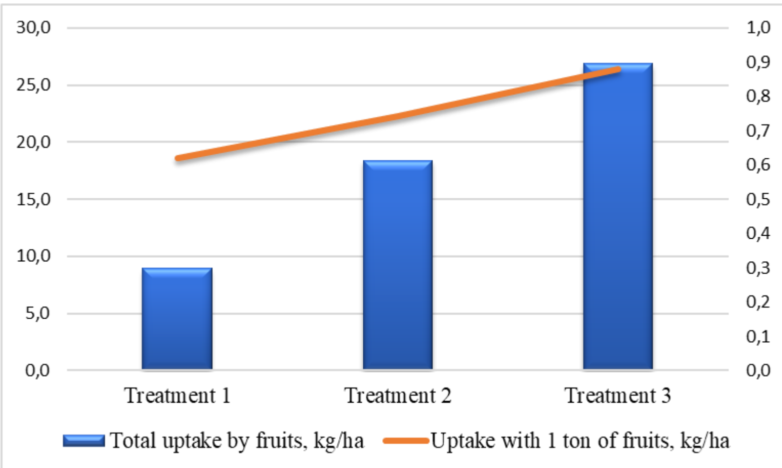

Figure 3 – Nitrogen uptake with fruit from one hectare and content in one ton of crop

Total nitrogen uptake in the fruits per hectare varied significantly depending on the applied fertilization method. Treatment 1, representing the existing technology without NPK, showed a nitrogen uptake of 8.9 kg/ha. Treatment 2, which involved NPK incorporation into the soil, exhibited an increased nitrogen uptake of 18.4 kg/ha. The highest nitrogen uptake was recorded for Treatment 3, where NPK was applied via fertigation, amounting to 26.9 kg/ha. These results indicate that the fertigation method provides the most effective nitrogen uptake, while soil incorporation also significantly improves nitrogen uptake compared to the existing technology.

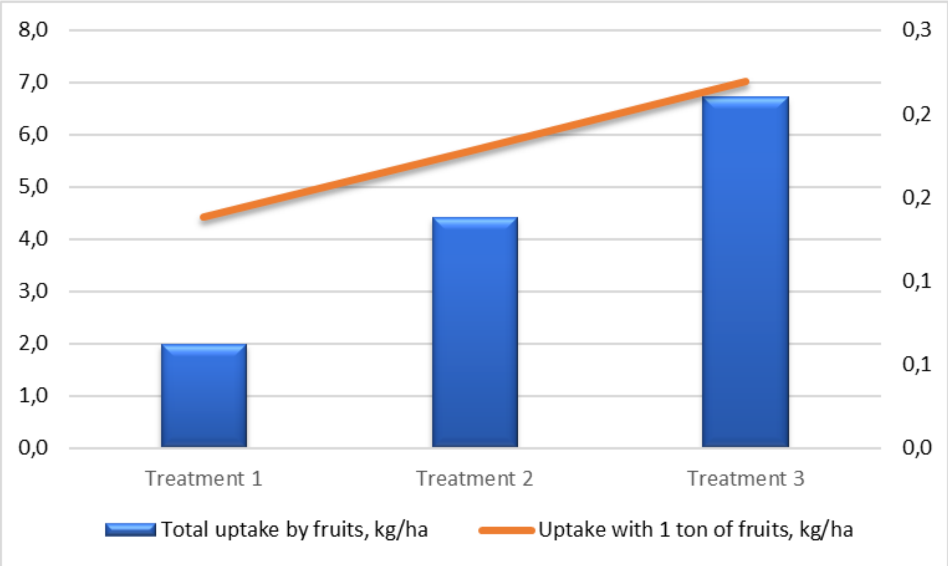

Figure 4 – Phosphorus uptake with fruit from one hectare and content in one ton of crop

Phosphorus uptake analysis revealed that Treatment 1, without NPK, had a total phosphorus uptake of 2.0 kg/ha. In Treatment 2, with NPK incorporated into the soil, the uptake increased to 4.4 kg/ha. The highest phosphorus uptake was observed in Treatment 3, with NPK applied via fertigation, reaching 6.7 kg/ha. These findings highlight that the fertigation method facilitates the most efficient phosphorus uptake, surpassing the effectiveness of the other two methods.

For potassium, the results showed that Treatment 1, with traditional fertilization, had a potassium uptake of 23.6 kg/ha. Treatment 2, involving NPK incorporation into the soil, resulted in an increased potassium uptake of 50.9 kg/ha. The highest potassium uptake was recorded for Treatment 3, with NPK applied via fertigation, amounting to 53.9 kg/ha. These data indicate that fertigation is the most effective method for potassium uptake, although soil incorporation also significantly increases uptake compared to the existing technology [28-30].

The study results demonstrate that fertilization methods have a substantial impact on macroelement uptake in apple tree fruits. Fertigation showed the highest efficiency for nitrogen, phosphorus, and potassium uptake compared to traditional fertilization methods. These findings underscore the advantages of employing fertigation in intensive apple orchards to optimize macroelement uptake and enhance orchard productivity.

The evaluation focuses on total costs, gross income, net income, cost price per kilogram, profitability, and economic efficiency. The results are summarized in table 6.

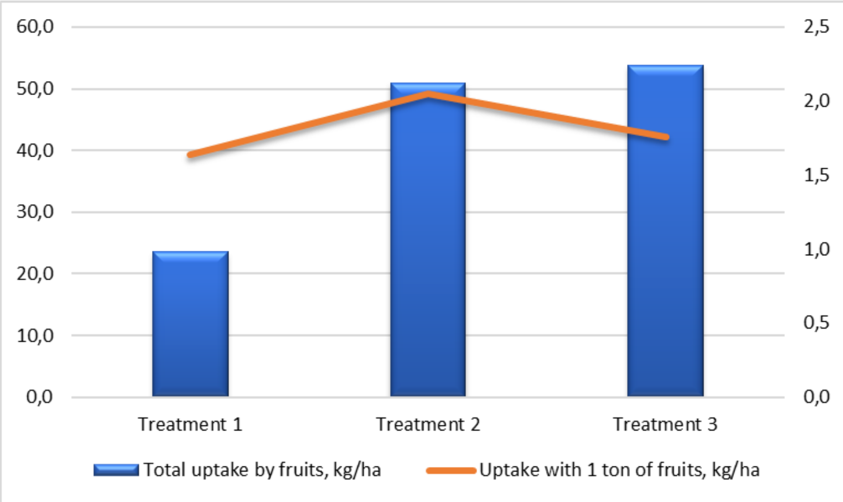

Figure 5 – Potassium uptake with fruit from one hectare and content in one ton of crop

Table 6 - Economic efficiency of fertilizer application methods on apple trees

Fertilizer options	2019	2020	2021	2022	Mean for 2019-2022
Total costs, thousand tenge/ha					
Treatment 1	407,64	401,96	395,96	390,41	398,99
Treatment 2	2637,29	2582,95	2583,60	2592,22	2599,01
Treatment 3	1754,37	1871,73	1992,51	2014,04	1908,16
Gross income from marketable crop, thousand tenge/ha					
Treatment 1	2345,47	2539,04	2081,05	1896,07	2215,41
Treatment 2	5767,34	7624,89	7064,30	6941,06	6849,39
Treatment 3	7534,62	9432,37	9929,62	10195,86	9273,12
Net income, thousand tenge/ha					
Treatment 1	1937,83	2137,09	2081,05	1505,66	1915,41
Treatment 2	3130,05	5041,94	7064,30	4348,84	4896,28
Treatment 3	5780,25	7560,64	9929,62	8181,82	7863,08
Cost price, tenge/kg					
Treatment 1	26,77	27,43	28,07	28,70	27,74
Treatment 2	108,07	105,84	105,62	132,06	112,90
Treatment 3	59,96	62,04	65,38	62,10	62,37
Profitability, %					
Treatment 1	475,38	118,68	195,20	385,66	293,73
Treatment 2	118,68	329,48	403,94	167,76	254,97
Treatment 3	329,48	531,67	425,57	406,24	423,24
Economic efficiency vs to control, thousand tenge/ha					
Treatment 1		-	-	-	-
Treatment 2	1192,21	2904,85	2795,61	2843,18	2433,96
Treatment 3	3842,42	5423,55	6252,02	6676,16	5548,54
Economic efficiency of fertigation vs to soil incorporation, thousand tenge/ha					
Treatment 2	-	-	-	-	-
Treatment 3	2650,21	2518,70	3456,41	3832,98	3114,57
Payback of fertilizers by apple fruit yield, kg/kg					
Treatment 1	-	-	-	-	-
Treatment 2	39,4	43,8	44,4	50,0	44,4
Treatment 3	78,4	86,7	91,5	105,2	90,4

As shown in table 6 total costs per hectare exhibit notable variations among the treatments. Treatment 1 incurs the lowest average cost of 398.99 thousand tenge per hectare. This reflects its cost-efficient approach due to the absence of NPK fertilizers. Treatment 2 demonstrates significantly higher average costs of 2599.01 thousand tenge per hectare, indicative of the substantial expenses associated with NPK incorporation into the soil. Treatment 3 shows an intermediate cost profile, averaging 1908.16 thousand tenge per hectare. The increasing trend in costs over the years suggests rising expenses related to fertigation technology.

Gross income from commercial harvests is highest for Treatment 3, with an average of 9273.12 thousand tenge per hectare. This reflects the enhanced revenue generation capabilities attributed to the efficacy of fertigation. Treatment 2 also yields substantial gross income, averaging 6849.39 thousand tenge per hectare, due to the benefits of NPK incorporation. Treatment 1 generates the lowest average gross income of 2215.41 thousand tenge per hectare, consistent with its lower cost and reduced yield efficiency.

Net income further highlights the financial performance of each Treatment. Treatment 3 leads with the highest average net income of 7863.08 thousand tenge per hectare, underscoring its superior profitability despite higher costs. Treatment 2 achieves an average net income of 4896.28 thousand tenge per hectare, reflecting significant financial returns, though lower than Treatment 3. Treatment 1 has the lowest average net income at 1915.41 thousand tenge per hectare, demonstrating lower profitability due to its minimal cost structure.

The cost price per kilogram of fruit is lowest for Treatment 1, averaging 27.74 tenge/kg, indicating cost-effective production. Treatment 3 has a moderate average cost price of 62.37 tenge/kg, balancing higher costs with improved production efficiency. Treatment 2 exhibits the highest cost price of 112.90 tenge/kg, reflecting the significant expenditures on NPK incorporation and its impact on cost efficiency.

Profitability percentages reveal the financial efficacy of each treatment. Treatment 3 exhibits the highest average profitability of 423.24%, highlighting its superior economic performance relative to the other treatments. Treatment 2 shows an average profitability of 254.97%, demonstrating considerable financial returns, albeit lower than Treatment 3. Treatment 1 has the lowest average profitability of 293.73%, reflecting its lower net income despite cost-effective production.

Treatment 3 demonstrates the highest economic efficiency relative to the control, with an average value of 5548.54 thousand tenge per hectare. This indicates the most substantial economic benefit derived from fertigation. Treatment 2 also shows significant economic efficiency with an average of 2433.96 thousand tenge per hectare. Treatment 1 lacks data for comparison against the control and thus is excluded from this metric.

Treatment 3 displays an average economic efficiency of 3114.57 thousand tenge per hectare relative to fertigation, highlighting a strong return on investment for this method. The efficiency of using fertilizers with incorporation into the soil, compared to fertigation, is well demonstrated by the results of the payback of the applied fertilizers; the latter turned out to be 2 times more efficient in terms of the payback of a unit of applied fertilizers by apple tree fruit products [31].

The economic evaluation of the fertilization treatments reveals that Treatment 3, utilizing fertigation, offers the highest net income and profitability over the four-year period, despite its higher costs compared to Treatment 1. While Treatment 2 shows a higher net income than Treatment 1, its significantly higher cost price per kilogram impacts its cost efficiency. Treatment 1, with its lower costs and cost price, results in the lowest net income. Overall, Treatment 3 provides the most favorable economic outcome, effectively balancing higher initial costs with superior returns, thus offering significant advantages in intensive apple orchard management.

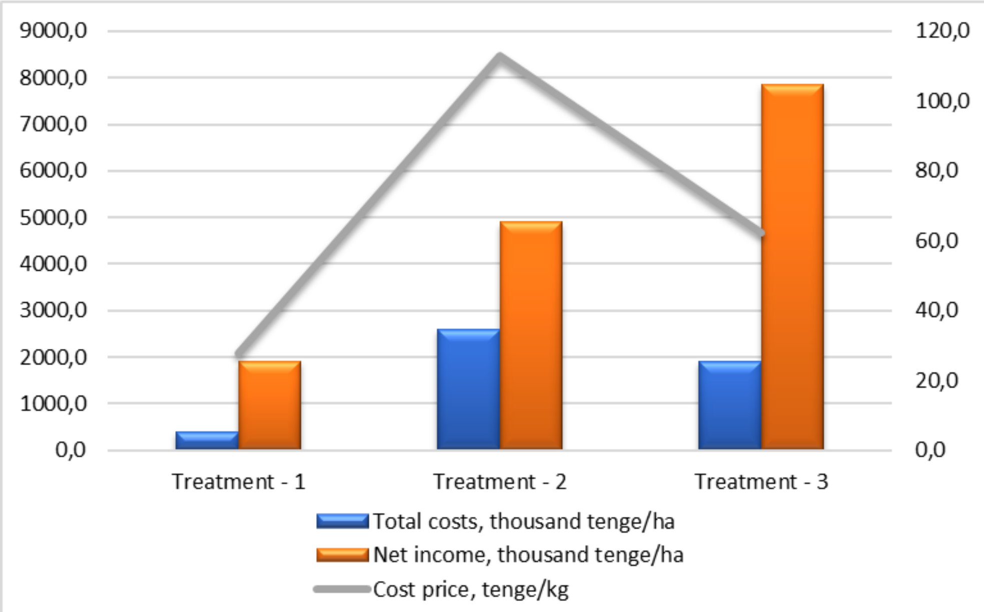

Figure 6 – Economic efficiency of fertilizer application methods on apple trees (average for 2019-2022)

The analysis included total costs, net income, and the cost price per kilogram of fruit for each treatment. The results are summarized in figure 6.

The analysis reveals significant variations in total costs among the Treatments. Treatment 1, which utilizes the existing technology without NPK, incurs the lowest cost of 399.0 thousand tenge per hectare. In contrast, Treatment 2, involving NPK incorporation into the soil, results in a substantial increase in total costs to 2599.0 thousand tenge per hectare. Treatment 3, which employs fertigation, incurs a cost of 1908.2 thousand tenge per hectare, positioning it between Treatments 1 and 2 in terms of expenditure. The higher costs associated with Treatments 2 and 3 reflect the additional input and application costs compared to Treatment 1.

Net income varies markedly between the treatments. Treatment 1 yields a net income of 1915.4 thousand tenge per hectare, indicating a positive financial return given its relatively low cost structure. Treatment 2 generates a higher net income of 4896.3 thousand tenge per hectare, attributed to increased yields and higher market value of the produce, despite the elevated costs. Treatment 3 achieves the highest net income of 7863.1 thousand tenge per hectare. This suggests that, while the costs are higher compared to Treatment 1, the returns from fertigation are significantly superior, leading to the highest profitability.

The cost price per kilogram of fruit provides additional insight into production efficiency. Treatment 1 exhibits the lowest cost price of 27.7 tenge per kilogram, reflecting its cost-effective production process. Conversely, Treatment 2 has a considerably higher cost price of 112.9 tenge per kilogram, due to the increased total costs associated with soil incorporation of NPK. This higher cost price indicates lower production efficiency relative to net income. Treatment 3 presents an intermediate cost price of 62.4 tenge per kilogram, balancing higher costs with improved production efficiency compared to Treatment 2.

The economic analysis demonstrates that Treatment 3, utilizing fertigation, provides the highest net income despite its higher total costs relative to Treatment 1. While Treatment 2 yields a higher net income than Treatment 1, its significantly higher cost price per kilogram diminishes its cost efficiency. Treatment 1, although the least expensive in terms of both total costs and cost price, results in lower net income. Overall, Treatment 3 offers the most favorable economic outcome, effectively balancing higher initial costs with superior returns.

CONCLUSIONS

This study evaluated the impact of different fertilization methods on the yield, fruit quality, and economic performance of intensive apple orchards. The experimental data revealed significant differences in both agricultural and economic metrics across the three fertilization treatments: existing technology without NPK, NPK incorporation into the soil, and fertigation.

Yield and Fruit Quality. Fertigation consistently outperformed other methods in terms of fruit yield and quality. The highest average yield, both gross and marketable, was achieved with fertigation, reaching 30.6 t/ha and 28.7 t/ha respectively. This method also resulted in the highest number of fruits per tree and the largest average fruit weight. These findings highlight fertigation's superior capability in delivering nutrients directly to the root zone, optimizing nutrient uptake, and ultimately enhancing fruit production.

In terms of fruit quality, fertigation yielded the highest sugar content (24.1%) and comparable dry matter content (14.7%) to the soil incorporation method. These results suggest that fertigation provides a more consistent supply of nutrients, particularly potassium, which is crucial for carbohydrate accumulation and fruit sweetness. However, soil incorporation also showed substantial benefits in dry matter content and fruit firmness.

Macroelements Uptake. The analysis of macroelement uptake demonstrated that fertigation was the most effective method for nitrogen, phosphorus, and potassium uptake. Specifically, nitrogen uptake was 26.9 kg/ha, phosphorus was 6.7 kg/ha, and potassium was 53.9 kg/ha under fertigation. This enhanced uptake underlines fertigation's efficiency in delivering essential nutrients directly to the plants, leading to improved growth and productivity.

Economic Performance. Economically, fertigation proved to be the most cost-effective method, despite its higher initial investment compared to soil incorporation. The lower cost price per kilogram and higher net income under fertigation underscore its economic viability. The significant increase in gross income and profitability, coupled with lower production costs, suggests that fertigation provides a favorable return on investment compared to traditional methods.

Overall Implications. The results of this study suggest that fertigation is the most advantageous fertilization method for intensive apple orchards, offering superior yield, fruit quality, and economic efficiency. The method's effectiveness in nutrient delivery and uptake, coupled with its positive impact on fruit characteristics and overall orchard profitability, makes it a valuable practice for optimizing apple production.

Future research should focus on refining fertigation techniques, exploring optimal nutrient combinations, and assessing long-term sustainability to further enhance the productivity and economic viability of intensive apple orchards.

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ТҮЙІН

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ОҢТҮСТІК ҚАЗАҚСТАННЫҢ ИНТЕНСИВТІ БАҚТАРЫНДА ЖЕМІСТЕРДІҢ ӨНІМДІЛІГІ МЕН САПАСЫН АРТТЫРУ ҮШІН АЛМА АҒАШЫНЫҢ МИНЕРАЛДЫҚ ҚОРЕКТЕНУІН ФЕРТИГАЦИЯ АРҚЫЛЫ ОҢТАЙЛАНДЫРУ

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Қазақстанның азық-түлік қауіпсіздігін арттыру және жеміс импортын азайту бойынша басымдықтарына жауап ретінде, бұл зерттеу қарқынды алма бақтарындағы әртүрлі тыңайтқыш қолдану әдістерінің өнімділікке, жеміс сапасына және экономикалық тиімділікке әсерін зерттейді. Қазақстанда алма өсіру алаңдарының ұлғаюына байланысты тыңайтқыштарды тиімді пайдалану өндірісті барынша арттырып, тұрақтылықты қамтамасыз ету үшін маңызды. Зерттеудің мақсаты - M9-карлик телітамырына егілген Геромини алма ағаштарының өнімділігі мен сапасына үш тыңайтқыш қолдану әдісінің - NPK тыңайтқыштарынсыз қолданыстағы технологияның, NPK тыңайтқыштарын топыраққа енгізудің және фертигацияның әсерін бағалау. Сондай-ақ әр әдістің экономикалық тиімділігі бағаланды. Зерттеу 2019-2022 жылдар аралығында Қазақстанның Түркістан облысында жүргізілді, онда тыңайтқыш қолданудың әртүрлі әдістері үшін төрт қайталанымнан тұратын рандомизацияланған блоктық дизайн пайдаланылды. Негізгі өлшенген параметрлерге жеміс өнімділігі, сапа көрсеткіштері (қант мөлшері, құрғақ зат, қаттылық), макроэлементтердің сіңуі (азот, фосфор, калий) және экономикалық көрсеткіштер кірді. Фертигация ең тиімді әдіс ретінде анықталды, орташа жалпы өнімділік (30,6 т/га), нарықтық өнімділік (28,7 т/га) және жеміс сапасы көрсеткіштері, соның ішінде қант мөлшері (24,1%) және орташа жеміс салмағы бойынша ең жоғары көрсеткіштерге қол жеткізілді. Фертигация азот, фосфор және калийдің ең жоғары деңгейлерімен макроэлементтердің сіңуін де жақсартты. Экономикалық тұрғыдан алғанда, фертигация шығындардың тиімділігі жағынан ең тиімді әдіс болып шықты, топыраққа енгізу және дәстүрлі тыңайтқыш әдістеріне қарағанда қолайлы инвестициялық қайтарымды қамтамасыз етті. Зерттеу фертигацияның өнімділік пен жеміс сапасын айтарлықтай жақсартатынын, сонымен қатар экономикалық тиімділікті оңтайландыратынын көрсетеді. Қоректік заттарды жеткізу мен сіңіру тиімділігі бұл әдісті қарқынды алма бақтары үшін ең тиімді әдіс ретінде көрсетеді. Фертигация әдістерін жетілдіру және ұзақ мерзімді бақ өнімділігі үшін тұрақты тәжірибелерді зерттеу бойынша қосымша зерттеулер ұсынылады.

Түйінді сөздер: қарқынды алма бақтары, өнімділікті оңтайландыру, жеміс сапасы, фертигация, макроэлементтерді сіңіру, қарқынды өсіру.

РЕЗЮМЕ

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ОПТИМИЗАЦИЯ МИНЕРАЛЬНОГО ПИТАНИЯ ЯБЛОНИ ПУТЕМ ФЕРТИГАЦИИ ДЛЯ ПОВЫШЕНИЯ ПРОДУКТИВНОСТИ И КАЧЕСТВА ПЛОДОВ В ИНТЕНСИВНЫХ САДАХ ЮЖНОГО КАЗАХСТАНА

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Согласно приоритета Казахстана по повышению продовольственной безопасности и сокращению импорта фруктов, данное исследование рассматривает эффективность различных методов удобрения на урожайность, качество плодов и экономическую эффективность в интенсивных яблоневых садах. С учётом увеличения площадей под яблоневые сады в Казахстане, оптимизация методов удобрения становится ключевым фактором для максимизации производства и обеспечения устойчивости. Целью исследования является оценка влияния трёх методов удобрения - существующей технологии без NPK, внесения NPK в почву и фертигации - на урожайность и качество яблонь сорта Геромини, привитых на карликовый подвой M9. Исследование также оценивает экономическую эффективность каждого метода. Исследование проводилось в

Туркестане, Казахстан, с 2019 по 2022 год с использованием рандомизированного блочного дизайна с четырьмя повторениями для каждого метода удобрения. Основные параметры включали урожайность плодов, качество (содержание сахара, сухое вещество, твёрдость), поглощение макроэлементов (азот, фосфор, калий) и экономические показатели. Фертигация оказалась наиболее эффективным методом, обеспечив наибольшую среднюю валовую урожайность (30,6 т/га), товарную урожайность (28,7 т/га) и показатели качества плодов, включая содержание сахара (24,1%) и средний вес плодов. Фертигация также показала лучшие результаты по поглощению макроэлементов, с наивысшими уровнями азота, фосфора и калия. В экономическом плане фертигация оказалась самым рентабельным методом, обеспечив наилучшую отдачу от инвестиций по сравнению с внесением удобрений в почву и традиционными методами. Исследование показывает, что фертигация значительно улучшает как урожайность, так и качество плодов, одновременно оптимизируя экономическую эффективность. Эффективность доставки и усвоения питательных веществ делает этот метод самым выгодным для интенсивных яблоневых садов. Рекомендуется продолжить исследования для совершенствования фертигационных технологий и изучения устойчивых практик для долгосрочной продуктивности садов.

Ключевые слова: интенсивные яблоневые сады, оптимизация урожайности, качество плодов, фертигация, поглощение макроэлементов, интенсивное земледелие.

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