RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
58 (3) 1454-1463, 2026
http://doi.org/10.54910/sabrao2026.58.3.48
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

GRAPE (*VITIS VINIFERA* L.) RESPONSE TO FERTILIZER COMBINATIONS THROUGH AGROBIOLOGICAL AND ECONOMIC EFFICIENCY IN THE GARABAGH, AZERBAIJAN

E.V. MUSAYEVA[1], M.A. HUSEYNOV[2*], and V.S. SALIMOV[1]

[1]Scientific Research Institute of Viticulture and Wine-making, Baku, Azerbaijan
[2]Azerbaijan State University of Economics, UNEC, Baku, Azerbaijan
*Corresponding author's email: movlud.huseynov@unec.edu.az
Email addresses of co-authors: elnuremusazade1988@gmail.com, vuqar.salimov@agro.gov.az

SUMMARY

The effect of various combinations and dosages of nutrients on agrobiological and quality traits of technical grape (*Vitis vinifera* L.) cultivars grown in the Garabagh region was the main focus determined by this research, being a viable viticulture of Azerbaijan. The local grape cultivar Khindogni and the introduced grape cultivars, Cabernet Sauvignon and Pinot Noir, were the selected objects of the study. Experiments comprising different fertilizer applications proceeded in four variants. In the experimental four variants, obtaining positive results was successful on various traits of the studied grape cultivars. For three grape cultivars, the following combinations and pattern of fertilizers proved to be most optimal for quality, yield, and economic efficiency. For the cultivar Khindogni, these were $N_{120}P_{120}K_{120}$ (under the roots) + 2.5 kg/ha NPK 20:20:20 (on the leaves) and 8.5 kg/bush; for the cultivar Cabernet Sauvignon, data were $N_{120}P_{120}K_{120}$ (under the roots) + 2.5 kg/ha NPK 20:20:20 (on the leaves) and 7.7 kg/bush; and for the cultivar Pinot Noir, these were $N_{150}P_{150}K_{150}$ (under the roots) + 3.0 kg/ha NPK 20:20:20 (on the leaves) and 7.6 kg/bush.

Keywords: Grape (*V. vinifera* L.), cultivars, fertilizer combinations, productivity, quality, nutrition

Key findings: The successful determination of optimal fertilization methods for quality, yield, and economic efficiency of the technical grape (*V. vinifera* L.) cultivars Khindogni, Cabernet Sauvignon, and Pinot Noir resulted in the Garabagh Region of Azerbaijan.

Communicating Editor: Dr. Anita Restu Puji Raharjeng

Manuscript received: December 16, 2025; Accepted: January 19, 2026.

Citation: Musayeva EV, Huseynov MA, Salimov VS (2026). Grape (*Vitis vinifera* L.) response to fertilizer combinations through agrobiological and economic efficiency in the Garabagh, Azerbaijan. *SABRAO J. Breed. Genet. 58 (3) 1454-1463. http://doi.org/10.54910/sabrao2026.58.3.48*.

INTRODUCTION

Azerbaijan's climatic zone emerged to be most favorable for grape (*Vitis vinifera* L.) growing, being considered one of the first centers of grape cultivation and the origin of viticulture and winemaking. Azerbaijan has the rich potential of grape genes (De-Lorenzis *et al.,* 2015). One of the current tasks of the agriculture sector of Azerbaijan is to obtain a sustainable and high-quality harvest of the crops. Hence, it is necessary to carry out a set of agrochemical, agrotechnical, and land reclamation measures in a timely manner to achieve this goal. It is a fact that to obtain a higher yield with better quality of crops, it is vital to apply various types of mineral and organic fertilizers to the soil (Zarmaev and Borisenko, 2018; Makarova, 2019; Salimov *et al.,* 2022). Wide use of fertilizers served to maintain soil fertility and meet the nutrient needs of crop plants. However, the excessive use of chemicals leads to soil degradation, groundwater pollution, and the destruction of biological diversity. Therefore, organic farming has become a recommendation for reducing environmental damage and ensuring sustainable production (Sabir *et al.,* 2020; Salimov *et al.,* 2025).

Based on past research, fertilizers' share in the formation of grape yield and quality is around 30%–40%, which is considerably higher than other factors, such as favorable weather conditions, irrigation, protection from diseases and pests, and technological operations (Makarova, 2019; Salimov *et al.,* 2022). With effective and balanced soil fertilization, the physical, chemical, and biological structure of the soil improves, with the nutrient extracts by grape plants returned to the soil for future use (Kasap, 2012; Salimov and Huseynov, 2025). Crops absorb quite a large amount of macro- and microelements from the soil, which significantly reduces its fertility; therefore, applying effective fertilizers to the soil should depend on the crop's needs. Previous studies enunciated that the introduction of nitrogen (170–180 kg ha^{-1}), phosphorus (170–180 kg ha^{-1}), and potassium (60–90 kg ha^{-1}) in the vineyard increased the yield by up to 40% (Kandelaki and Kenchiashvili, 2011; Russo and Krasilnikov, 2014; Krasilnikov *et al.,* 2015).

In deep layers of the soil, the application of nitrogen fertilizers can improve its structure and microbiological activities. However, prolonged soil fertilization can also lead to considerable variations in the composition and function of microbial communities (Dai *et al.,* 2018; Huseynov and Aghayev, 2024). Therefore, more research is essential to better understand the effect of fertilizers on soil structure and microbiological activities (Ma *et al.,* 2021; Gumbatov *et al.,* 2024). Fertilizer application should take place based on the type of soil and the nutrient requirements and supply. For ordinary black and brown soils with very low nutrient content, the fertilizer rate per hectare should be N_{120}, P_{180}, and K_{240}; for soils with low nutrient content (N_{100}, P_{150}, K_{180}); for soils with medium nutrient content (N_{80}, P_{120}, K_{120}); and for soils with high nutrient content (N_{60}, P_{90}, K_{90}) (Kandelaki and Kenchiashvili, 2011; Mammadov *et al.,* 2025). In the vineyards of the Absheron Region, Azerbaijan, the fertilizers' amount was $N_{120}P_{120}K_{120}$ (for soils with heavy and medium mechanical composition) and $N_{150}P_{120}K_{120}$ (for soils with light composition), which significantly increased the yield and quality of the grape harvest (Shukurov, 2016; Salimov *et al.,* 2018).

For ensured duration of soil fertility, the use of fertilizers must continue in a balanced manner according to needs (Gaiotti *et al.,* 2014). Optimization of nitrogen use by plants increases yield and reduces the harmful effects on the environment (Midolo *et al.,* 2018; Chen *et al.,* 2020). Therefore, balanced fertilizer application is particularly important for ensuring agricultural stability and sustainability (Zhang *et al.,* 2023; Asadullayev *et al.,* 2024). Proper management of nitrogen dosages is critical from both an economic and environmental perspective (Jat *et al.,* 2012; Shukurova *et al.,* 2026). Soil fertilization is an essential agrotechnical measure in viticulture. The rational use of fertilizers plays an influential role in obtaining consistently high and high-quality yields. One of the main conditions for achieving success by using fertilizers is their adequate and balanced dosing. Too-high and too-low doses of fertilizers can negatively affect crop plants' development. Therefore, for calculating the fertilizer rate, it is imperative to determine the level of nutrients in the soil and the plant requirements.

Balanced fertilizer application ensures optimal plant development and helps preserve a clean environment. Past studies conducted to improve the yield and quality of technical grape cultivars resulted in a wide range (Tudor *et al.,* 2013; Shukurov *et al*., 2025). This research work aimed to investigate the effects of various methods of fertilization (under roots and on leaves) on technical grape cultivars of Khindogni, Cabernet Sauvignon, and Pinot Noir. The study also sought to analyze soil samples from the experimental site in the village of Tugh, District Khojavend, Garabagh Region, Azerbaijan.

MATERIALS AND METHODS

The research ensued from 2022 to 2025 at the experimental site of the village of Tugh, District Khojavend, Garabagh Region, Azerbaijan. The fertilization experiments comprising four variants were control (no fertilizers), variant I ($N_{80}P_{80}K_{80}$ under the roots + 1.5 kg/ha NPK 20:20:20 on the leaves); variant II ($N_{100}P_{100}K_{100}$ under the roots + 2.0 kg/ha NPK 20:20:20 on the leaves); variant III ($N_{120}P_{120}K_{120}$ under the roots + 2.5 kg/ha NPK 20:20:20 on the leaves), and variant IV ($N_{150}P_{150}K_{150}$ under the roots + 3.0 kg/ha NPK 20:20:20 on the leaves).

Nitroammofoska (16:16:16) fertilizer treatment was for root fertilization, with NanoNTECH (20:20:20) used for leaf fertilization. Nitroammofoska fertilizer application to the soil occurred in early winter at the rate of 500 kg (variant I), 625 kg (variant II), 750 kg (variant III), and 937.5 kg (variant IV) based on the calculation of physical weight. Applying NanoNTECH fertilizer transpired four times during the growing season: before flowering (mid-May), after flowering (mid-June), during the formation and development of berries (early July), and before berry ripening (mid-August). Agrobiological measurements of studied grape cultivar bushes and harvests entailed recording using the methodology of Zarmaev and Borisenko (2018) and the methods proposed by the International Organization of Vine and Wine (OIV, 2023; 2024).

The data accuracy of the quantitative traits underwent verification by the parametric U-criteria method (Wilcoxon-Mann-Whitney test). A comparative analysis of the results obtained continued using the mathematical and statistical methods. The correlation coefficient between the fertilizing variants and the yield and quality traits, also determined, employed the Pearson's method (Glanz, 1998; Huseynov *et al.,* 2026). For determining economic efficiency, profitability served as the basis, with US dollars (USD) as the monetary unit. The official exchange rate of the manat against the US dollar during the research period was 1.7020 AZN.

RESULTS AND DISCUSSION

The effect of various fertilizer applications on the technical grape cultivars Khindogni, Cabernet Sauvignon, and Pinot Noir succeeded in their exploration by studying the composition of macro- and microelements during the four years (2022–2025) in various phenological phases. The results appear in Tables 1 and 2 and Figures 1 and 2. The grape cultivar Khindogni emerged with the total number of green shoots that developed from the eyes on grapevines with different fertilization rates, as compared to the control variant (40) and variant III (38). Moreover, the best result obtained appeared in variants I and IV (46). In the cultivar Cabernet Sauvignon, the said trait value was 40 in the control treatment, with the highest trait value recorded in variant IV (46). The cultivar Pinot Noir variety reached a record of 36 green shoots in the control variant, as compared to variants I and III (38) and variant IV (42). Insufficient amounts of macro- and microelements in the soil that are necessary for crops limit the plants' intake of nutrients from the soil, which negatively affects crop growth and development and yield and quality traits (Karaman, 2012; Atesh and Turan, 2015).

Table 1. Agrobiological indicators of the studied grape cultivars.

Cultivars	Variants	Number of green shoots	Number of fruitful shoots (%)	Coefficient of fruitfulness of green shoots	Coefficient of fruitfulness of fruitful shoots	Number of bunches	Average weight of bunches (g)	Yield (kg/bush)	$\Delta \bar{X}$, %	Reliability of the difference relative to the control, p	Yield per hectare (c)	Average number of berries in a bunch, pcs	100-berries weight (g)	Sugar content in berry juice, (g/100 cm^3)	Shoot length (cm)	Degree of maturation of shoots (%)
Khindogni	Control	40	55.0	0.7	1.27	28	180	5.0	-	-	111.0	108	166	21.8	216	98.2
	$N_{80}P_{80}K_{80}$ (under the roots) + 1.5 kg/ha NPK 20:20:20 (on the leaves)	46	56.5	0.8	1.23	32	240	7.7	+54	>0.05	171.0	133	180	21.6	236	98.0
	$N_{100}P_{100}K_{100}$ (under the roots) + 2.0 kg/ha NPK 20:20:20 (on the leaves)	44	54.5	0.57	1.04	25	310	7.8	+56	>0.05	173.3	169	183	19.6	262	97.4
	$N_{120}P_{120}K_{120}$ (under the roots) +2.5 kg/ha NPK 20:20:20 (on the leaves)	38	60.5	0.68	1.13	26	327	8.5	+70	<0.05	188.8	166	196	20.2	268	97.2
	$N_{150}P_{150}K_{150}$ (under the roots) + 3.0 kg/ha NPK 20:20:20 (on the leaves)	46	52.2	0.54	1.04	25	304	7.6	+52	>0.05	168.8	162	188	19.8	266	96.6
Cabernet Sauvignon	Control	40	62.5	0.65	1.04	26	166	4.3	-	-	95.5	169	152	19.6	176	97.4
	$N_{80}P_{80}K_{80}$ (under the roots) +1.5 kg/ha NPK 20:20:20 (on the leaves)	42	66.7	0.71	1.07	30	198	5.9	+37.2	>0.05	131.0	121	164	19.8	208	98.0
	$N_{100}P_{100}K_{100}$ (under the roots) + 2.0 kg/ha NPK 20:20:20 (on the leaves)	38	76.3	0.82	1.07	31	188	5.8	+34.8	>0.05	128.8	112	168	18.6	220	96.7
	$N_{120}P_{120}K_{120}$ (under the roots) +2.5 kg/ha NPK 20:20:20 (on the leaves)	38	68.4	0.79	1.15	30	256	7.7	+79.0	<0.001	171.0	138	186	19.4	232	96.8
	$N_{150}P_{150}K_{150}$ (under the roots) + 3.0 kg/ha NPK 20:20:20 (on the leaves)	46	47.8	0.57	1.18	26	272	7.0	+62.8	<0.05	156.0	154	177	18.7	245	91.3
Pinot Noir	Control	36	66.7	0.81	1.21	29	158	4.6	-	-	102.2	96	165	20.4	194	98.6
	$N_{80}P_{80}K_{80}$ (under the roots) +1.5 kg/ha NPK 20:20:20 (on the leaves)	38	55.3	0.74	1.33	28	186	5.2	+30.4	>0.05	115.5	104	178	20.0	223	98.4
	$N_{100}P_{100}K_{100}$ (under the roots) + 2.0 kg/ha NPK 20:20:20 (on the leaves)	40	57.5	0.85	1.48	34	189	6.4	+39.1	>0.05	142.2	104	181	18.6	246	96.4
	$N_{120}P_{120}K_{120}$ (under the roots) +2.5 kg/ha NPK 20:20:20 (on the leaves)	38	63.2	0.82	1.29	31	240	7.4	+60.8	<0.05	164.4	125	192	19.4	257	95.4
	$N_{150}P_{150}K_{150}$ (under the roots) + 3.0 kg/ha NPK 20:20:20 (on the leaves)	42	50	0.79	1.57	33	232	7.6	+65.2	<0.05	168.8	122	190	19.2	263	90.3
Correlation between the increase in the amount of fertilizers and indicators. r		0.394	-0.297	-0.154	0.145	0.087	0.707	0.815	-	-	0.816	0.307	0.788	-0.540	0.833	-0.631

Note:* $p < 0.05$ - reliable; **$p < 0.001$ - reliable; ***$p > 0.05$ -unreliable; P - reliability of the difference relative to the control (according to the U-criteria); $\Delta \bar{X}$, % - average increment relative to the control, %.

Table 2. Economic efficiency indicators of the studied grape cultivars.

Cultivars	Variants	Total expenses (USD per ha)	Biological yield (c/ha)	Cost of one kg of harvest (USD)	Total income per ha (USD)	Net profit (USD)		Profitability (%)	
						from one centner	from one hectare	total	increment
Khindogni	Control	1647.0	111.0	14.8	3265	14.6	1619.0	98.4	-
	$N_{80}P_{80}K_{80}$ (under the roots) + 1.5 kg/ha NPK 20:20:20 (on the leaves)	1892.0	171.0	11.0	5029	18.4	3138.0	1660	676
	$N_{100}P_{100}K_{100}$ (under the roots) + 2.0 kg/ha NPK 20:20:20 (on the leaves)	1954.0	173.3	11.2	5097	18.2	3150.0	161.7	63.3
	$N_{120}P_{120}K_{120}$ (under the roots) + 2.5 kg/ha NPK 20:20:20 (on the leaves)	2016.0	188.8	10.6	5553	18.7	3543.0	176.2	77.8
	$N_{150}P_{150}K_{150}$ (under the roots) + 3.0 kg/ha NPK 20:20:20 (on the leaves)	2127.0	168.8	12.6	4965	16.8	2615.0	133.6	35.2
Cabernet Sauvignon	Control	1647.0	95.5	17.2	2809	12.2	1163.0	70.6	-
	$N_{80}P_{80}K_{80}$ (under the roots) + 1.5 kg/ha NPK 20:20:20 (on the leaves)	1892.0	131.0	14.4	3853	15.0	1965.0	104.1	33.5
	$N_{100}P_{100}K_{100}$ (under the roots) + 2.0 kg/ha NPK 20:20:20 (on the leaves)	1954.0	128.8	15.2	3765	14.2	1810.0	93.7	23.1
	$N_{120}P_{120}K_{120}$ (under the roots) + 2.5 kg/ha NPK 20:20:20 (on the leaves)	2016.0	171.0	12.0	5029	17.6	3018.0	150	79.4
	$N_{150}P_{150}K_{150}$ (under the roots) + 3.0 kg/ha NPK 20:20:20 (on the leaves)	2127.0	156.0	13.6	4588	15.8	2468.0	116.4	45.8
Pinot Noir	Control	1647.0	102.2	16.1	3006	13.4	1365.0	83.1	
	$N_{80}P_{80}K_{80}$ (under the roots) + 1.5 kg/ha NPK 20:20:20 (on the leaves)	1892.0	115.5	16.4	3397	13.1	1508.0	79.8	22.6
	$N_{100}P_{100}K_{100}$ (under the roots) + 2.0 kg/ha NPK 20:20:20 (on the leaves)	1954.0	142.2	13.7	4182	15.7	2234.0	114.5	31.4
	$N_{120}P_{120}K_{120}$ (under the roots) + 2.5 kg/ha NPK 20:20:20 (on the leaves)	2016.0	164.4	12.2	4835	17.2	2824.0	140.3	57.2
	$N_{150}P_{150}K_{150}$ (under the roots) + 3.0 kg/ha NPK 20:20:20 (on the leaves)	2127.0	168,8	12.6	4965	16.8	2840.0	133,6	50,5

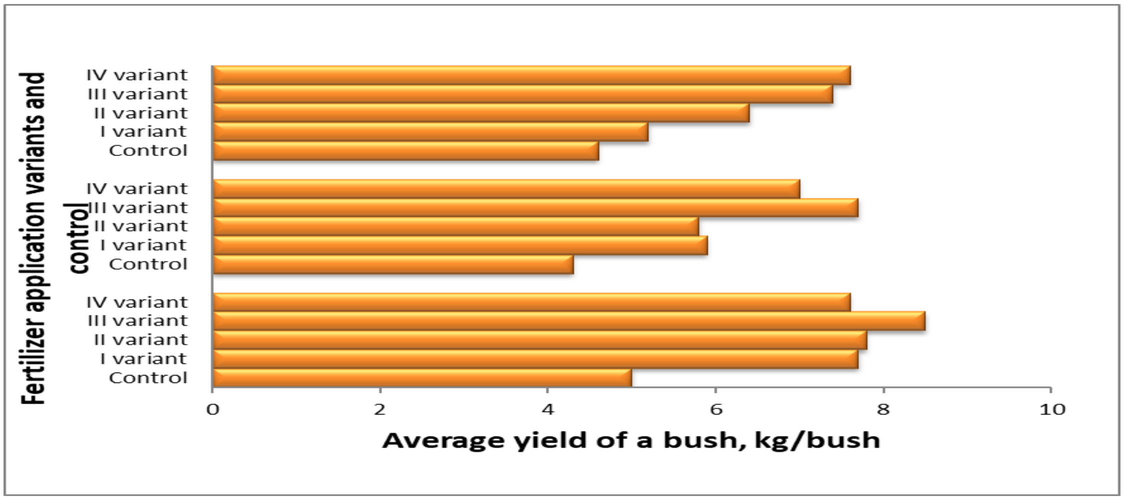

Figure 1. Effect of fertilizer combinations on the bush yield in grapes.

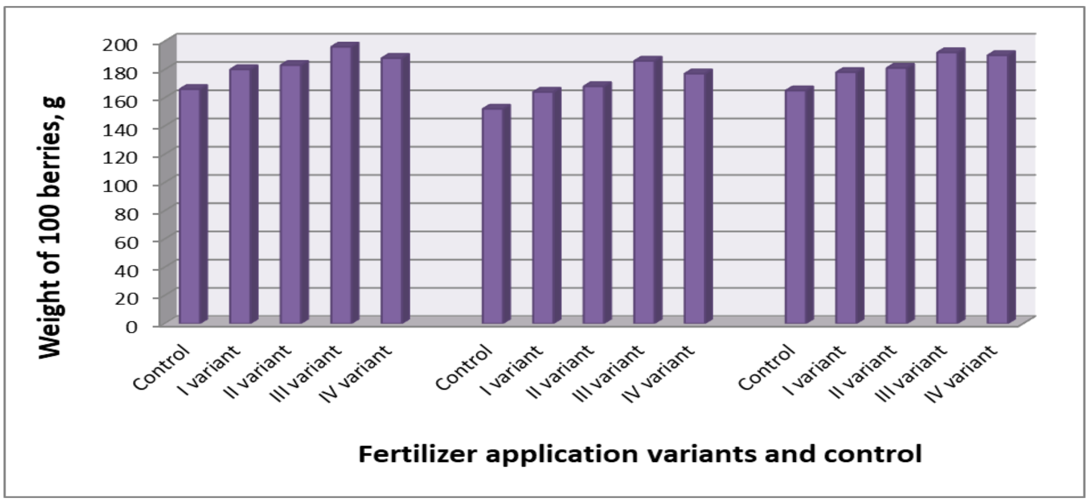

Figure 2. Effect of fertilizer combinations on the 100-berries weight in grapes.

Based on varietal peculiarities, the studied grape cultivars showed distinguishingly different ratios of fertile and non-fertile shoots. Thus, the number of fruitful shoots in the cultivar Khindogni was 22–26; in the cultivar Cabernet Sauvignon, it was 22–29; and in the cultivar Pinot Noir, it was 21–24. For the cultivar Khindogni, the best results occurred in variant I (26); the cultivar Cabernet Sauvignon variety was in variant II (29); and for the cultivar Pinot Noir, in variant III (24) (Table 1). The most common cation in grape plant tissues, in grape berries, and in its processed products (in juice and wine) was the potassium (K+). The effect of potassium on both grapevine development and the quality of grapes and wine has long been known; however, additional in-depth research is vital to determine the entire mechanism of the process (Rogiers *et al.,* 2017).

The fertile shoots percentage determination in the grape cultivars employed mathematical methods. The results revealed the cultivar Khindogni showed 55% fertile shoots in the control variant and 52.2%–60.5% in the fertilized variants. The cultivar Cabernet Sauvignon had 62.5% in the control and 47.8%–76.3% in the experimental variants, and the cultivar Pinot Noir had 66.7% in the control and 50.0%–63.2% in the fertilized variants. The fertility coefficient of green shoots also sustained studies in the cultivars Khindogni (0.54–0.8), Cabernet Sauvignon (0.57–0.82), and Pinot Noir (0.74–0.85). The highest coefficient of fruitfulness for the cultivar Khindogni was evident in variant I (0.8); for the cultivar Cabernet Sauvignon, it was in variant II (0.82); and for the cultivar Pinot Noir, it was in variant II (0.85). Knowledge of nitrogen requirements of plants proved highly important because of its critical role in plant growth and yield. Nitrogen is usually essential for plants in large doses, but it is often present in soils in limited quantities (Delgado and Follett, 2011; Huseynov *et al.,* 2025). Er *et al.*'s (2011) findings revealed the combined application of boron at the rate of 40 g per bush (on the leaves) and $N_{150}P_{50}K_{50}$ (under the roots) considerably increased grape yields by up to 70%. Barish (1983) argues that the macronutrients, such as nitrogen (N), phosphorus (P), and potassium (K), are mostly requirements of the grapevine, which have different effects on grape plants.

The numerous berries in a bunch is one of the indicators positively affecting grape yield. The results revealed that in the variants with various combinations of fertilizers, the average number of berries in a bunch was significantly higher than in the control variant. Thus, for the cultivar Khindogni, the number of berries in the control variant was 108 pieces, while in experimental variants, the number of berries varied from 133 (variant I) to 169 pieces (variant II), with the best result obtained in variant II. For the cultivar Cabernet Sauvignon, the average number of berries in a bunch in the control variant was 169, while in the experimental variants, the number of berries was lower in variant II (112) and variant IV (154). For the cultivar Pinot Noir, the number of berries in a bunch in the control variant was 96, whereas in the experimental variants the said trait values were 104 (variants I and II) and 125 (variant III). Topuz and Akın (2015) recorded the largest harvest (2.07 kg/bush) in the variant with pruning shoots for 18 eyes and using leaf fertilizers.

In grapes, the sugar content is the second most important variable in terms of prospects. In grape juice, the sugar content depends on the grapevine cultivars, environmental conditions of the existing location, and cultivation technology. According to the study results, in the cultivar Khindogni, the sugar content of berry juice in the fertilized variants ranged from 19.6 g/100 cm^3 (variant II) to 21.6 g/100 cm^3 (variant I), as compared to the control variant (21.8 g/100 cm^3) (Table 1). The cultivar Cabernet Sauvignon in the fertilized variants had a sugar content of 18.6 g/100 cm^3 (variant II), 19.8 g/100 cm^3 (variant I), and 19.6 g/100 cm^3 in the control variant. The grape cultivars, Pinot Noir and Khindogni, showed higher sugar contents in the control variant. In the experimental variants, the sugar content of the berry juice varied between 18.6 g/100 cm^3 (variant II) and 20.0 g/100 cm^3 (variant I), as compared to the control variant (20.4 g/100 cm^3). Oner (2009) reported the highest content of water-soluble dry matter resulted in the grape cultivar Cabernet Sauvignon (23.35%) with combinations of $K_0Mg_0Mikro_1$ elements on the leaves and in cultivar Merlot (24.55%) by applying combinations of $K_0Mg_2Micro_2$ elements.

The degree of ripening of shoots determines the readiness of grape bushes for winter and the condition of wintering eyes. According to observations, the degree of ripening of the shoots in the grape cultivars Khindogni, Cabernet Sauvignon, and Pinot Noir ranged from 90.3% to 98.6%. For the cultivar Khindogni, the ripening rate of shoots in variants with the fertilizers ranged from 96.6% (variant IV) to 98.0% (variant I), as compared to the control variant (98.2%), which revealed the best results. For the cultivar Cabernet Sauvignon, the ripening rate of shoots in variant IV was 91.3%, in variant I (98.0%), and in the control variant (97.4%). However, the highest rate (98.0%) was notable in variant I. For the cultivar Pinot Noir, the ripening rate of shoots in the fertilized variants ranged from 90.3% (variant IV) to 98.4% (variant I) versus the control variant (98.6%). The degree of ripening of shoots depends on the peculiarities of the grape variety and the number and length of shoots. The higher the degree of ripening of the shoots, the greater the output of the planting material (Makarova, 2019; Salimov *et al.,* 2022).

According to economic efficiency, the cultivar Khindogni, with various fertilizer combinations, showed a total cost per hectare range of USD 1647–2127. The cost per hectare of land in the control variant was USD 1647, followed by increased costs of variant I (USD 1892), variant II (USD 1954), variant III (USD 2016), and variant IV (USD 2127). The highest expenditure per hectare of land was remarkable in variant IV (USD 2127). The cost price of one centner of the cultivar Cabernet Sauvignon crop in the experimental variants ranged from USD 12.0 to 17.0. The lowest cost price index (USD 12.0) appeared in variant III, while the highest was in the control variant (USD 17.0). In variant I, the cost price of one centner crop was USD 14.0; in variant II, it was USD 15.0; and in variant IV, it was USD 14.0. The total income per hectare ranged from USD 2809 to 5029. The lowest income (USD 2809) resulted in the control variant, while the highest was in variant III (USD 5029). In other fertilizer variants, the total income per hectare was USD 3765 (variant II), USD 5029 (variant III), and USD 4588 (variant IV). The economic efficiency of the cultivar Pinot Noir with various fertilizer combinations showed a total cost per hectare ranging from USD 1647 to 2127. The per hectare cost of land in the control variant was USD 1647, followed by increased costs in variant I (USD 1892), variant II (USD 1954), variant III (USD 2016), and variant IV (USD 2127). However, the highest cost per ha was noteworthy in variant IV (USD 2127) (Oner, 2009; Jat *et al.,* 2012).

CONCLUSIONS

The applied fertilizer combinations had a positive effect on yields and on the development and agrobiological parameters of grapes. Given that the formation and development of inflorescences in buds went well under the influence of fertilizers, these formed numerous fertile shoots with large bunches. Based on the above facts, the researchers recommend the implementation of combined fertilizer application (under the roots and on leaves), based on the physico-chemical properties of the soil and the grape plant's need for fertilizers.

ACKNOWLEDGMENTS

The authors thank the staff of the Laboratory of Environmental Engineering of the Azerbaijan State University of Economics (UNEC) and the Laboratory of Agrochemistry of the Research Institute of Viticulture and Winemaking of the Ministry of Agriculture for supporting this research work.

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