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ECO-BIOLOGICAL STUDIES OF ANTHROPOGENIC IMPACTS ON SOIL USED FOR VITICULTURE

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SUMMARY

The presented research aimed to investigate the variations in agrocenoses parameters (soil and commercial yield) under biologized soil conditions of viticulture in the Shamakhi and Ganja regions, Azerbaijan. In the grapevine cultivars with varied salt tolerance, studies on the development of shoots and roots during their cultivation in salt solutions succeeded. Intensive monoculture production disrupts the small biological cycle of nutrients, reducing the productivity of agrocenoses. The said problem can reach an effective solution by the introduction of an eco-biological soil management system through green manuring, inter-row grassing, and the effective use of biofertilizers (live microbial inoculants) and agrobiological stimulators such as microorganisms. In Azerbaijan, for the first time, a comparison occurred between soil cultivation systems using a sod-humus substrate and a control option (bare fallow).

Keywords: Viticulture, eco-monitoring, environmental risks, erosion, landscapes, antropogenic factors

Key findings: The implementation of an eco-biological soil management system (using green manure, inter-row grazing, and biostimulants) can combat the negative anthropogenic effects of intensive monoculture farming and increase viticulture productivity.

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INTRODUCTION

Soil-ecological monitoring plays a vital role, as any variation in soil composition and properties considerably affects the performance of their ecological functions and ultimately disrupts the stability of ecosystems and the biosphere as a whole (Akbarova *et al.*, 2024). From an environmental perspective, vineyards stand out compared with other sectors of agricultural production due to their increased use of agricultural machinery and agrochemicals (Ali *et al.*, 2026; Bunyatova *et al.*, 2025). The agricultural activities mostly reflect an association with environmental risks and the depletion of natural resources; however, in plantation and orchard agroecosystems, including vineyards, their manifestation is at its greatest. Soil salinity remarkably reduces the yield of cultivated plants, including grapes, although grapevines show considerable salt tolerance (Gahramanova *et al.*, 2026; Ikhtiyar, 2024).

Soil salt contents at maximum concentrations proved to be particularly toxic to grapes, causing plant tissues and organ damage (Ismayil *et al.*, 2025a). Past studies revealed different cultivated grape cultivars attained classification with their tolerance to salinity as sulfate- and chloride-resistant (Cl^- and SO_4^{2-}) (Ibrahimova, 2025). The biomass of cutting structures results in the interaction of plant genetic and developmental factors. Therefore, the assessment based on the developmental state of shoots and roots in cuttings of grape cultivars grown under saline conditions plays a viable role (Ikhtiyar, 2024). The vineyard soil management is the primary factor in the modernization of the viticulture and winemaking industry (Ismayilova *et al.*, 2025a).

Soil degradation under intensive grape production disrupts the microbial cycle of nutrients and, consequently, reduces the productivity of agrocenoses. Among the most remarkable landscapes, human activities widely and considerably developed viticulture, with most of these activities included in the UNESCO World Heritage List. Viticulture is an important economic, cultural, and ecological system in many temperate biomes (between 30° and 50° latitude), providing numerous economic, ecological, and cultural benefits and ecosystem services to society (Ismayilova *et al.*, 2025b; Mammadova *et al.*, 2026). Agrocenoses entailed characterization with the same factors that weaken their stability (monoculture, low biodiversity, and deterioration of agrochemical and ecotoxicological indicators of the soil). However, for no other crop does the combination of climate, soil, and local landscape conditions have such a decisive impact on the productivity and quality of the product as for grapevines (Makki *et al.*, 2025; Mammadov *et al.*, 2025).

Sustainably developing the viticulture resulted in recommending a biological soil management system. This comprised the green manure with spring-summer tillage, continuous grassing of vineyards with periodic mowing, the development of vegetative mulch, and integrated use of biofertilizers and agrobiological stimulants (plant biostimulant), viz., effective microorganisms (Mammadova *et al.*, 2025a). The biologized soil management system can attain identification by abiotic environmental factors (rainfall and topography). In arid conditions (precipitation less than 440 mm), moisture availability for grapes during berry growth in plots with a biological system drops below optimal levels. However, in areas with sufficient moisture, on slopes up to 23°, a steam-green manure system is preferable, involving interspersed sodding for 1–2 years (Mammadova *et al.*, 2025b). On slopes steeper than 23°, continuous sodding with perennial grasses became the proposal. The primary requirements for perennial grasses sown between rows were low susceptibility to weather conditions, long-term dominance of the grass cover, and the formation of a dense canopy. Other essentials are the inhibition of weed growth and proliferation, shallow rooting (succulents, herbs, leafy greens, strawberries, and shrubs), and the establishment of a favorable environment for grape growth and development and fruiting (Mirzezadeh *et al.*, 2025).

The aim of this study was to determine changes in agrocenoses parameters (soil and marketable yield) under biologized soil conditions for viticulture in the Shamakhi and Ganja regions of Azerbaijan (Nazim *et al.*, 2025). This study, conducted for the first time in two different regions, utilizes an innovative approach.

MATERIALS AND METHODS

Grapevine cuttings (used cuttings were at least 3–5 cuttings per treatment) with 2–3 buds prepared from lignified shoots and continuously cultivated in treatments (1–5): control-water, NaCl (10^{-3} M), NaCl (10^{-2} M), Na_2SO_4 (10^{-3} M), and Na_2SO_4 (10^{-2} M). Salt tolerance of the grape cultivars Matrasa and Bayanshira cuttings underwent assessment using NaCl and Na_2SO_4 solutions, while other cultivars (Tavkveri, Rkasiteli, Shiraz, and Shirvanshah) succeeded in their evaluation using sodium chloride solutions (Nasirova *et al.*, 2026). The cuttings' response to salt exposure obtained scrutiny using a combination of traits: survival, timing, and vigor of root and shoot development, as well as their fresh and dry biomass. The experiments continued in different seasons, from 2024 to 2025, using Matrasa cultivars at the Shamakhi and Ganja regions' experimental stations, Azerbaijan.

The study took place over a two-year period (2024–2025) on grapes (40.61472° N, 48.56417° E; 40.809116° N, 46.351712° E). The study area location was in the transition zone from foothill to steppe, characterized by relatively high average annual temperatures (11.0±0.5 °C) and moderate annual precipitation (530±12 mm). However, 2025 surfaced as the most favorable year for grapevines concerning moisture conditions (637 mm per year). The vineyards sat on a gently leveled slope (slope up to 5-8°). The soil of the ampelocenoses in horticulture, classified as alluvial meadow carbonate soils (subtype of alluvial meadow carbonate soils proper), and according to agrochemical parameters, was low in humus, moderately stony, with low absorption capacity and a slightly alkaline soil solution pH (Macnunlu *et al.*, 2025).

The soil content represented in the vineyard's row spacing was bare fallow (K), strip (option 1), and continuous (option 2) sowing of a legume-cereal mixture with a legume component of 43%. The subplot area was 42 m^2 with three replications. The legume-cereal mixture with red clover (*Trifolium pratense* L., 11 kg/ha), Timothy grass (*Phleum phleoides* [L.] H. Karst., 7 kg/ha), and meadow fescue (*Festuca pratensis* Huds., 11 kg/ha) succeeded in their sowing between the rows on March 20, 2024. The grass stand mowing reached a height of 5 cm. The chopped mown residue served for mulching. In the fall of 2025, the plowing of crop and root residues into the soil progressed (Oqtay *et al.*, 2024).

The assessment of agrophysical and agrochemical parameters of the soil in 2025 included determining soil density and the content of low-value, agronomically valuable, and water-stable aggregates using the structure coefficient and water-stableness criterion (Mirzezadeh *et al.*, 2025). The study also determined total nitrogen content, easily hydrolyzable nitrogen content, and biological activity. The nitrogen (N), phosphorus (P), and potassium (K) balance in the cenoses soil underwent assessment based on the removal of the corresponding elements by the biological grape harvest (6.4 kg N, 3.1 kg P, and 7.4 kg K per ton) and their input through the sod-humus soil management system. In August 2024–2025, the soil temperature measurement began at the surface and at a depth of 20–45 cm. Grape production parameters' scrutiny relied on the length and weight of the bunch, evaluating grape juice based on the mass concentration of sugars and titratable acids (Mammadova *et al.*, 2025a).

Measurement of the basal respiration rate in the 0–5 cm surface horizon continued, with a consistent increase from the upper to the lower part of the slope. The concerned studies confirmed a close correlation between the content of organic matter and copper, which accumulates in the surface horizons of vineyards due to the intensive use of copper-containing pesticides to control fungal diseases (Shukurov *et al.*, 2025). Consequently, copper migrated downslope as part of complexes with

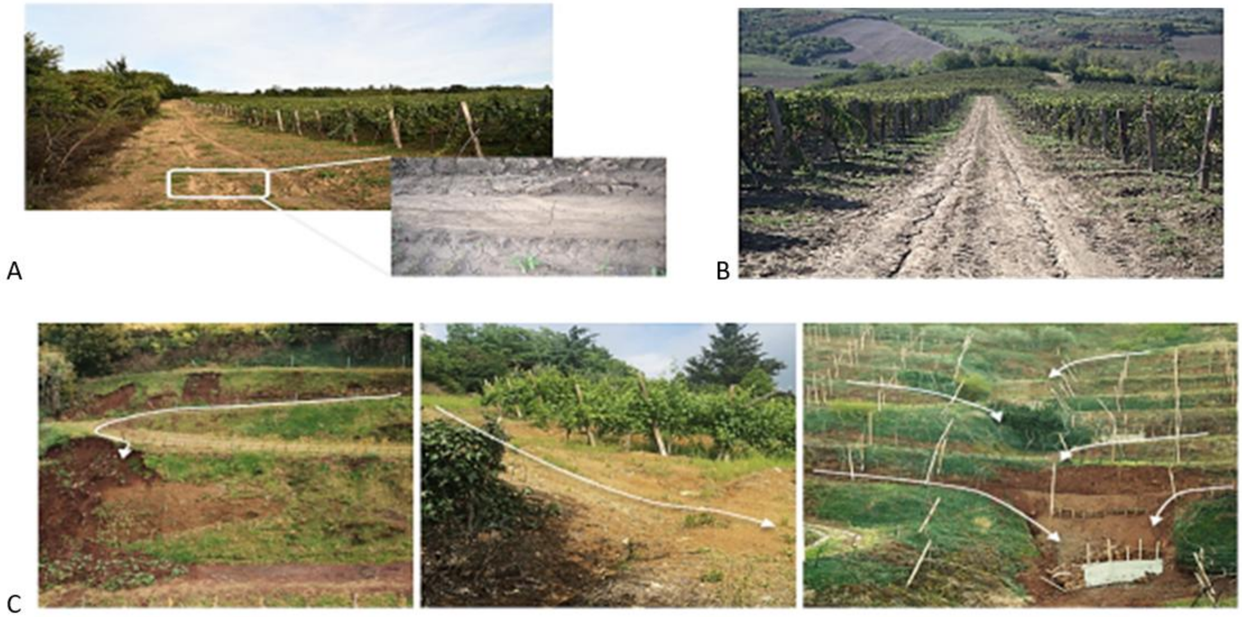

Figure 1. Madrasa village vineyards - Soil deposits at the bottom of a slope beneath (A), Fine-grained erosion of soil within the vineyard's technological track (B), and Erosion processes (C).

organic matter, resulting in the element's accumulation in the middle or lower parts of the slope, depending on the parameters of its meso- and microrelief (Figures 1A-C). In particular, the composition and intensity of geochemical flows of technogenic substances through agroecosystems can significantly change, developing accumulation and dispersion zones. The nature of accumulation and redistribution of organic matter along the profile and its qualitative composition can also change. Surface runoff can increase in erosion-prone areas, primarily in the row spacing and main roads of vineyards located in mountainous landscapes.

RESULTS AND DISCUSSION

The grassed-fallow variants compared with bare fallow recorded a considerable improvement in the hydrophysical properties of the soil. Its confirmation revealed more than a threefold increase in the soil structure coefficient at the depth of 20–45 cm, a 1.5-fold increase in the sum of agronomically valuable aggregates, a 28.1% increase in water-stable aggregates (WSAs), and a 26.8% increase in the water-stable criterion (option 1) (Table 1). According to past research, a sod-humus soil management system contributes to optimizing the microclimate of grape plants, and it prevents them from overheating (Nasirova *et al.*, 2026). Thus, in the control group, the average soil temperature exceeded the experimental variants at the soil surface, 20 cm depth, and 45 cm depth by 8.3 °C, 3.5 °C, and 1.5 °C, respectively (Makki *et al.*, 2025).

In improving the agrochemical parameters of the soil, the establishment of a significant role of the sod-humus system was successful. By comparing with the control, more considerable variations were evident in variant 1: a decrease in soil density (by 0.09 g/cm^3), an increase in humus content (by 0.14%), total nitrogen (by 0.11%), and easily hydrolyzable nitrogen (by 87 mg/kg). The biological activity, as an important soil parameter, gave significant increases in the strip grassing variant (by 21.6%) (Table 2). Over the two years of the experiment, perennial grasses formed a phytomass of 2.8 kg/m² (air-dry weight). By the end of the two years of the experiment, roots accounted for

Table 1. Characteristics of the structural and aggregate composition of the soil.

Option	Sampling depth (cm)	Soil aggregate content (%)			Structural coefficient	Water resistance criterion (%)
		I	II	III		
K	0-20	12.28	82.72	45.73	6.74	51.18
	20-45	56.24	41.91	51.86	0.74	53.42
1	0-20	12.47	78.83	54.21	6.32	55.85
	20-45	24.82	62.11	78.96	2.50	79.26
2	0-20	13.86	76.14	49.97	5.49	51.61
	20-45	24.25	58.02	61.88	2.39	62.18

Note: I - low-value (<0.25 and >10 mm), II - agronomically valuable (0.25–10 mm), and III – water resistance (0.25–10 mm).

Table 2. Agrochemical properties of ampelocenoses soil.

Option	Depth (cm)	Density (g/cm^3)	Content			Bioactivity (%)
			Humus (%)	Total N (%)	Easily hydrolyzable N (mg/kg)	
K	0-20	1.17	2.60	0.14	124	44.5
	20-45	1.26	2.48	0.10	82	48.0
	Average	1.21	2.54	0.12	103	46.3
1	0-20	1.04	2.80	0.26	218	65.2
	20-45	1.18	2.56	0.20	163	70.7
	Average	1.12	2.68	0.23	190	67.9
2	0-20	1.15	2.72	0.22	210	50.4
	20-45	1.20	2.50	0.18	152	59.6
	Average	1.11	2.61	0.20	181	55.0

75.4% of the grass phytomass. The bulk mass of the shallow root system (at the depth of 20 cm) plays a significant role in preventing erosion. According to phytochemical analysis (nutrients, pH, and OM), the after-harvest and root residues of red clover were richer in nitrogen and potassium than those of grasses (Figure 1) (Verdiyeva *et al.*, 2025).

In the effective biologized soil management system, one of the crucial indicators was an increase in grape yield and quality. On average, over the study period, with strip grassing, grape shoot length increased by 2.25 cm, bunch weight by 2.87 g, and yield by 3.76%. In addition to considerable variations in plant morphometric parameters (density, texture, shape, and stream length), the mass concentration of sugars in berry juice also increased (by 0.58 g/cm^3), while the concentration of titratable acids decreased (by 0.25 g/dm^3). In the two-year use of the sod-humus system, the agrocenoses revealed a deficit-free influx of nitrogen (+137.79 kg/ha), phosphorus (+7.47 kg/ha), and potassium (+83.55 kg/ha) into the soil-forming process, indicating restoration of the minor biological cycle of nutrients (Figure 2) (Shukurov *et al.*, 2025).

The results revealed improved water availability to grape plants, which positively correlates with commercial yield and its quality. With continuous grassing, a similar effect was noticeable only in 2025, under conditions of soil moisture uncharacteristic for this zone due to precipitation (Mammadova *et al.*, 2025a). In dry years, due to a sharp decrease in moisture supply to the grape plants during the berry growth period, the commercial yield was slightly lower than the control without changing the technological parameters of the juice. The results further exhibited the advantage of the sod-humus soil management system and the feasibility of its implementation on farms in the foothill and transitional steppe zones of the Shamakhi and Ganja regions, Azerbaijan (Mammadova *et al.*, 2025b).

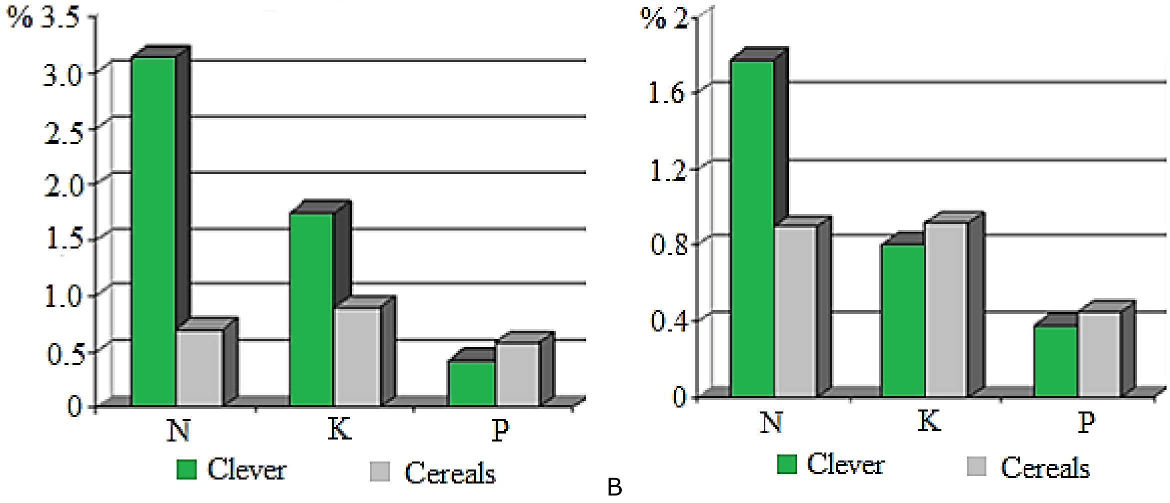

Figure 2. Chemical composition of phytomass components of the legume-cereal mixture: *A* - The aboveground, *B* – The underground. Source: by authors in 2025.

By choosing a method for inter-row grassing (strip or continuous), the total annual precipitation should ensure its accounting. With the biological soil management system, the study has also established that the moisture supply to grape plants corresponds (based on characteristics) to the optimal level during grape growth stages, with an annual precipitation of at least 650 mm. Under arid conditions (precipitation less than 450 mm), the moisture supply of grape plants during the berry growth period with a biological system drops (drought tolerance mechanisms such as stomatal closure to reduce transpiration and hydraulic signaling from roots) below the optimal level. Therefore, in the more arid regions of the republic (the transition zone from foothill to steppe) with a typical annual precipitation of 520–540 mm, strip grassing was advisable, while in the foothill region (with an annual precipitation of 600 mm or more), continuous grassing seemed preferable. The presented results confirmed the implementation of various biological soil management methods in vineyards (Makki *et al.*, 2025; Nasirova *et al.*, 2026).

Several studies reported the undeniable potential of this method of grape cultivation and its numerous environmental advantages over bare fallow (restoration of biological cycles and soil fertility, prevention of erosion and activation of microbiological processes, and biotransformation of toxic pesticides) (Mammadov *et al.*, 2025). The results showed the classical definition of soil indicators in the agrocenoses needs supplementation of eco-geochemical studies, particularly on the accumulation and migration levels of copper compounds and mobile sulfur, considering the landscape features of the area. Moreover, looking into biological activity is vital, which serves as an early indicator of negative changes occurring in the vineyard agroecosystem. In the latter case, eco-physiological indices (water potential, gas exchange, chlorophyll fluorescence, irrigation, climate change, leaf water status, and chlorophyll content), demonstrating the current status of the soil microbiome, serve as an informative and useful tool for the systemic analysis of problematic environmental situations (Nasirova *et al.*, 2026).

Cutting viability parameters

The cutting viability parameters varied by the grape cultivars and cultivation methods. By exposing cuttings of the cultivars Bayanshira and Matrasa to Na_2SO_4 solutions, they produced fewer roots and shoots with low biomass. However, in NaCl solutions, the wet and dry biomass of shoots and roots of the

Table 3. Ratio of wet (A) and dry (B) biomass of roots (1) and shoots (2).

Cultivars and options	Biomass parameters			
	A		B	
	1	2	1	2
Bayanshira	1665±336.3	2750±587.1	95.1±53.80	449.2±10.64
	1180±876.7	2333±272.1	156.6±40.14	384.7±13.3
	2686±290.2	2873±45.5	224.1±94.1	636.2±24.85
	894±355.1	1700±623.1	131.3±55.92	347.9±11.7
	450±127.1	1666±139.3	68.2±19.34	332.1±94.5
Matrasa	303±176.7	1250±35.5	26.5±13.75	212.1±18.34
	356±244.8	1383.473.6	48.6±24.73	258.4±87.04
	310±156.5	1436.78.0	40.3±18.8	265.7±46.4
	332±207.6	1506±318.2	51.3±26.74	257.4±81.6
	56±4.11	1250±277.7	8.4±0.60	267.4±67.9
Tavkveri	415±73.7	2851.2±111.57	37.95±6.25	380.7±73.17
	644±108.5	2813.3±1075.3	40.18±9.3	363.1±81.17
	542±162.7	2235.08±630.0	49.7±12.01	347.3±89.7
Rkasiteli	331±94.8	2028.3±535.1	22.5±20.03	289.4±99.7
	325±104.6	1630±683.1	20.68±74.14	245.7±103.3
	120±118.7	775.7±228.7	21.15±23.2	147.6±82
Shiraz	294±92.3	2566.6±965.2	44.97±23.3	321.3±75.14
	270±63.3	2076±2073.7	22.7±3.7	281.9±57.67
	495±129.15	2302±805.8	51.59±17.42	348.2±127.8
Shirvanshah	606±118.9	2762.3±2560.4	227.2±10.64	522.7±94.6
	348±84.7	1991.5±507.4	77.18±238.8	287.4±52/02

cultivar Bayanshira cuttings were higher than in Na_2SO_4 solutions. Both cultivars' cuttings showed a decrease in the wet-to-dry biomass ratio in Na_2SO_4 solutions. The wet biomass of roots and shoots of the cultivar Bayanshira in Na_2SO_4 solutions was 3.9 times lower than the control and five times lower than in the NaCl 10^{-2} solution. Therefore, the Premier cultivar emerged as more chloride-tolerant and less sulfate-tolerant (Table 3). Cuttings of almost all grape cultivars exhibited more depression in solutions of 10^{-2} than 10^{-3} M. The exceptions were the cultivars Shiraz and Bayanshira, whose cuttings have better dry biomass values at 10^{-2} NaCl, especially for roots. The wet biomass of shoots of the cultivar Tavkveri differed little from the control (Nazim *et al.*, 2025).

In NaCl solutions of 10^{-2} and 10^{-3}, the difference was approximately 100 mg. In contrast, the dry biomass of roots of cultivars Rkasiteli and Shirvanshah in the control was three times higher than that of the experimental variants. The salt tolerance index based on shoot dry weight in the cultivar Bayanshira cuttings was higher in salt solutions than in the control, with the same pattern observed for the cultivar Matrasa. However, a different picture was apparent for the wet biomass (Nasirova *et al.*, 2022).

Biomass growth ratios also attained comparison per day as a percentage. Grape cultivar Matrasa exhibited a greater shoot weight in all treatments than the control. However, the root weight did not increase in the salinity treatments. The opposite was true for cultivars Tavkveri and Shiraz: root weight gain was higher in salinity treatments, while shoot weight gain was lower than in the control. Given these discrepancies in root and shoot biomass values across the various treatments for cuttings of different cultivars, the data presentation in Table 1 was in points (1–4) for clarity. It reflected the greater or lesser viability of roots and shoots separately for each experiment (Table 4). The results more clearly revealed the differences in growth traits across various treatments (Mirzezadeh *et al.*, 2025).

Table 4. Biomass indices and the ratio of grape cultivars' resistance to salinity.

Cultivars and options	Biomass parameters				Mass/day			
	Polarity coefficient		Shoot salt tolerance index		1		2	
	A	B	A	B	mg	%	mg	%
Bayanshira	1.65	4.72	75.63	60.0	43.84	100	51.88	100
	1.97	2.45	70.0	80.0	30.25	69	45.74	88
	1.26	2.83	66.6	61.0	68.87	157	56.33	108
	1.90	2.64	73.3	66.6	24.13	55	32.07	61
	3.70	4.87	60.6	73.3	11.53	26	30.85	59
Matrasa	2.42	8.0	73.3	66.6	17.82	100	26.04	100
	2.57	5.31	80.0	66.6	10.17	57	28.81	110
	2.15	6.59	60.0	73.3	11.48	64	31.21	119
	4.52	5.01	74.07	74.04	10.09	56	30.73	118
	2.20	31.79	66.60	53.33	1.93	10	27.17	104
Tavkveri	8.71	10.03	60.0	66.6	15.8	100	83.89	100
	7.68	9.03	74.06	58.3	24.7	155	78.14	93
	4.65	6.98	66.60	61.9	21.5	135	67.2	80
Rkasiteli	6.12	12.86	66.5	66.4	12.7	100	78.01	100
	5.0	11.88	58.3	58.3	16.2	127	74.09	94
	6.46	6.97	57.14	61.9	6	47	24.23	31
Shiraz	8.71	7.14	59.25	70.37	11.7	100	75.48	100
	7.68	12.41	60.0	56.6	12.85	109	66.9	88
	4.65	6.74	63.3	63.33	19.8	169	60.5	80
Shirvanshah	4.5	2.30	70.0	66.6	21.6	700	78.8	100
	5.71	3.72	60.0	70.0	15.14	70	60.3	76
	5.18	2.35	59.0	60.0	15.2	70	56.34	71

Even in this comparison, the various treatments and grape cultivars showed a wide range of root and shoot scores; however, a general trend of grape root inhibition was noteworthy at higher concentrations (Verdiyeva *et al.*, 2025). The treatments' salt responses, although specific, were qualitatively comparable in scores. Cultivars Bayanshira and Tavkveri cuttings considerably predominate for shoot wet biomass accumulation in NaCl salts. Root biomass displayed a significant reduction in cultivar Matrasa cuttings with the Na$_2$SO$_4$ (10^{-2} M) treatment. The lowest values were typical for cuttings of the cultivar Rkasiteli, which proved to be susceptible to higher salinity levels (Ikhtiyar and Bahram, 2023).

The experimental data presented in assessing the salt tolerance of cultivars serve only as supplementary material to their field productivity trials. Therefore, the presentation of experimental results was in percentages, considering the biomass of roots and shoots separately (Tables 3–4). The biomass of each of these in the control was taken as 100%, although its initial values for roots and shoots differed. This allows us to conditionally identify the variants with the greatest inhibition of roots and shoots. Since root biomass inhibition in the cuttings was more significant than that of shoots, for clarity, the experimental results' presentation was in a ring diagram. The outer layer characterizes the condition of the shoots, and the inner layer characterizes the condition of the roots (Nazim *et al.*, 2025; Verdiyeva *et al.*, 2025).

Taking the sum of the biomasses of all experimental variants separately was at 100%. Individual variants sustained recalculation to this value according to the segments in the ring (Figure 2). The fresh and dry biomass of roots and shoots can be applicable to assess the salt tolerance of grape cultivars. For example, the cuttings of cultivar Rkasiteli exhibited tolerance only in low salt concentrations and showed an inhibition at 10^{-2}. Cultivar Matrasa tended to be as chloride-tolerant based on experimental results. However, Na$_2$SO$_4$ (10^{-2}) solutions have a depressive effect on its roots, which, in turn, does not affect the shoot biomass. The assessment of cultivars' resistance to stress in field trials relied on the combination of indicators of different structures. Therefore, this principle should also succeed in its implementation in laboratory conditions, considering which indicator and organ occurred to be dominant in the grape cuttings. These include the timing of root initiation and the strength of root biomass development, the degree of damage to leaves and growing points, and inhibition of shoot growth. This approach was helpful in this study to assess the salinity tolerance of grape cultivar cuttings. The results further advanced our understanding of the feasibility of modeling the salt tolerance of grape cultivars by assessing the condition of their cuttings during cultivation in saline conditions. The application of this approach to assessing the drought and frost tolerance of cultivars is worth testing, facilitating rapid agroecological comparisons of cultivars under laboratory conditions (Nazim *et al.*, 2024; Ismayilova *et al.*, 2025a).

CONCLUSIONS

In vine agrocenoses, the biological system of soil maintenance via inter-row and continuous grassing of spaces between rows with a legume-cereal mixture (red clover—40.0%; meadow fescue—26.7%; steppe timothy—33.3%) is beneficial. This includes mowing the grass and developing a mulch layer (sod-humus system). Hence, the system contributes to the restoration of soil fertility, improvement of its water-physical parameters, prevention of water erosion, development of a favorable microclimate, and enhancement in the commercial yield of grapes and grape juice quality.

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