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Optimizing Artificial Shading for Microclimate, Yield, Leaf Nutrient and Economic Benefits in Sinceri (*V. vinifera* L.) Grape Cultivation

Tuba Uzun Bayraktar[1,a,*], Önder Volkan Bayraktar[2,b], Mehmet Solak[3,c]

[1]*Siirt University, Faculty of Agriculture, Department of Horticulture, Siirt, Türkiye*
[2]*Siirt University, Faculty of Agriculture, Department of Agricultural Economics, Siirt, Türkiye*
[3]*Siirt University, Faculty of Agriculture, Department of Biosystem Engineering, Siirt, Türkiye*
[*]*Corresponding author*

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ABSTRACT

This study was conducted on the Sinceri grape cultivar grown for both table and raisin (drying) purposes, in the 2021 growing season in Siirt/Türkiye. The primary objective was to create a microclimate within the vine canopy by installing net covers with different shading rates (35%, 55%, and 75%) during the veraison period, thereby delaying the harvest and obtaining high-quality, high-yield grapes. Regarding phenological development, the period between full bloom and harvest was the shortest under the 55% shading treatment, which also recorded the lowest mean temperature (28.54 °C) and the lowest Effective Heat Summation (EHS) value (1965.70 dd). The highest mean temperature (26.28 °C) was observed under the 75% shading treatment, while the highest EHS value (2401.05 dd) was recorded under the 35% shading treatment. In terms of yield compared to the control, the 35% shading treatment provided a 21.75% increase, the 55% treatment yielded a 57.44% increase, and the 75% treatment led to a 37.45% increase. Furthermore, it was determined that all shading treatments increased the macro- and micronutrient contents in grapevine leaves. Economic analyses for the Sinceri grape cultivar revealed that the shading treatments had a statistically significant effect on yield. In conclusion, the net cover with a 55% shading rate proved to be the most effective treatment.

[a] tubauzun@siirt.edu.tr https://orcid.org/0000-0003-2625-0684
[b] onder.bayraktar@siirt.edu.tr https://orcid.org/0000-0001-5560-386X
[c] mehmetsolak@siirt.edu.tr https://orcid.org/0000-0002-0800-0334

Introduction

Shaped by thousands of years of meticulous cultivation and cultural integration, grapevine stands as one of the most economically profitable fruit species globally (Vivier & Pretorius, 2002). As a highly propagative species with exceptional regeneration capability, the grapevine has successfully disseminated and adapted across diverse regions of the world (Vivier & Pretorius, 2000). Throughout history, Anatolia has been regarded as the cradle of viticulture, offering an ideal environment for grape cultivation, where wild grapevines still thrive naturally (Vouillamoz et al., 2006). Türkiye, as a genetic center of viticulture is recognized for hosting approximately 1 500 cultivars (Hizarci et al., 2012). It is evident that grape cultivation holds not only a historic and genetic significance but also substantial economic value. As a leading grape producer, the Republic of Türkiye ranked as the 6th largest globally, producing nearly 3 670 000 tons of fresh grapes in 2021, of which 264 505 tons were exported as fresh grapes and 257 165 tons in processed forms (Country Statistics OIV, 2024). The economic significance of grape cultivation is further reinforced by its role in supporting both local and international markets as diverse consumer products like wine, table grape, raisins, juice and various industrial uses (Alston & Sambucci, 2019). To achieve sustainable and high-quality grape production, it is crucial to consider various factors influencing grape yield and quality. These factors include genetic diversity (Bigard et al., 2020), climatic conditions (Ponti et al., 2018), soil characteristics (Arnó et al., 2012; Li et al., 2024), and vineyard management practices (Tesic et al., 2007). Among these, cultural practices are particularly significant, as they directly affect vine growth, fruit development, and overall yield (Reynolds, 2022).

Cultural practices in viticulture encompass a wide range of interventions, such as pruning (Main & Morris, 2008), irrigation (Balint & Reynolds, 2017), canopy management (Smart et al., 1990), fertilization (James et al., 2023; Peuke, 2009), and pest control (Cabras & Angioni, 2000; Steenwerth & Guerra, 2012; Yilmaz et al., 2015). Also, the use of shading material has been reported to have a strong effect on reducing the severity of Botrytis cinerea (Cangi et al., 2011b; Kesgin, 2011). In addition to these, innovative techniques, such as the use of shading materials have emerged as effective tools for mitigating the effects of environmental stressors like excessive sunlight and heat (Lu et al., 2021). Türkiye's climate is predominantly Mediterranean, featuring hot, dry summers and mild wet winters. The country's varied topography and diverse land-use patterns significantly influence large-scale atmospheric dynamics due to the complexity of surface conditions. The mountain ranges that stretch parallel to the Mediterranean and Black Sea coasts create pronounced climatic differences between the northern and southern slopes of these mountains (Önol & Unal, 2014). Climate change is a major concern affecting agricultural production in mediterranean climate, furthermore grapevine production is highly prone to water deficits, mediately high temperatures (Santillán et al., 2020). Plant physiological activities are profoundly influenced by the amount of solar radiation reaching the leaves, as it directly impacts key processes such as stomatal regulation and leaf temperature. The intensity of solar radiation affects stomatal aperture, influencing gas exchange, transpiration, and photosynthesis rates. Additionally, excessive radiation can elevate leaf temperatures, potentially leading to heat stress, reduced enzymatic activity, and disruption of cellular functions. Balancing solar radiation exposure is thus crucial for optimizing plant health and productivity (Urban et al., 2017). To mitigate the adverse effects of heat and light-induced stress on grapevines, artificial shading is a promising and effective solution in viticulture. Shading, primarily impacts the vine microclimate, influencing temperature, humidity, and photosynthetically active radiation (PAR). These changes subsequently affect key grape characteristics, including phenology, anthocyanin levels, pH, acidity, and total soluble solids content (TSSC) (Kesgin et al., 2020). The effects of shading appear to vary depending on the cultivar and environmental conditions. The primary parameter is the shading percentage and net characteristics of the shading material (Miccichè et al., 2023).

This study aimed to evaluate the effects of different shading ratios on the canopy of the Sinceri grape cultivar by comparing shading treatments at 25%, 50%, and 75% with a control group. The comparisons focused on parameters such as Effective Heat Summation (EHS) values during phenological development stages, average canopy temperature, leaf nutrient element contents, and grape yield.

Material and Method

Material

Geographical location of the experimental vineyard

The experiment was conducted in a 5 decare producer vineyard established with the Sinceri grape cultivar in Bağtepe Village, Siirt province. The geographical coordinates of the vineyard are 37° 57' 33.5" N latitude and 41° 58' 36.2" E longitude, at an altitude of 1117 meters above sea level (Figure 1). The vineyard was established with a pergola-type wire training system. The vines used in the experiment were systematically identified and marked using a standardized labeling method to ensure precision and consistency throughout the study.

Plant material

Sinceri is a white grape cultivar widely cultivated in the Southeastern Anatolia Region. It is a local cultivar that has been grown for centuries in Siirt and its surrounding areas. The vines are typically pruned short or mixed, and the cultivar is considered mid-to-late in terms of maturation. Sinceri grapes are valued for their distinct aroma and are utilized both as table grapes and for drying, as well as in the production of fruit leather (pestil) (Ünal et al., 2019).

Shading material

In the experimental vineyard, polyethylene nets with three different shading densities (35%, 55% and 75%) were covered on the vines on June 19, 2021.

Method

Annual cultural maintenance operations such as pruning, soil cultivation, fertilization, and plant protection were carried out regularly. Winter pruning was performed on March 1, 2021, with the vines evenly pruned to 20±2 buds per vine.

Climate data of the experimental vineyard

The climate data for the experimental vineyard, including temperature, humidity were collected throughout the growing season, from budburst to leaf fall. Measurements were taken using a HOBO U12-013 Onset device installed at the level of the vine training wires, recording data at 60-minute intervals. The recorded data were processed into monthly averages to analyze their relationship with climatic parameters and treatments (Figure 2). The collected climate data were also used to calculate the Effective Heat Summation (EHS) to support further analysis of the growing conditions in the experimental vineyard.

Figure 1. Geographical location of experiment vineyard

Figure 2. HOBO U12-013 installed in the vineyard

Soil analysis

Soil samples were collected from a depth of 30–60 cm. The physical properties and macro and micro nutrient contents of the soil were evaluated according to the criteria set by Aksu (2008). The soil analysis was conducted through laboratory service procured from the Siirt University Science and Technology Application and Research Center. The soil analysis included the measurement of various physical and chemical parameters. Micro nutrient concentrations, including copper (Cu), manganese (Mn), iron (Fe), zinc (Zn), and boron (B), were determined. Macro nutrient levels, such as potassium (K_2O), phosphorus (P_2O_5), calcium (Ca), and magnesium (Mg), were analyzed. Additionally, the soil texture was assessed by determining the proportions of clay, silt, and sand, and the texture class was identified. Other measured parameters included pH, electrical conductivity (EC), organic matter content, and lime ($CaCO_3$) percentage.

Phenological observations of the applications in the experimental vineyard

Phenological observations of the applications in the experimental vineyard were conducted based on the classification of grapevine phenological stages proposed by (Eichorn & Lorenz, 1977).

Data collected from the vines

Harvesting was performed when the grapes reached 22% Total Soluble Solids Contents (TSSC) or when biotic and abiotic factors necessitated harvest. The number of clusters was determined by counting all clusters separately for each application and each repetition. The average weight of cluster was carried out on 10 randomly selected clusters from 5 vines in each replication. Grape yield was determined by weighing the total amount of harvested grapes and calculating yields per vine.

Leaf analysis

On September 1, 2021, 80 leaf samples taken randomly (only in the leaf blade) from each application and each repetition of after harvest leaves were analyzed for macro and micro nutrient content by the Siirt University Science and Technology Application and Research Center.

Economic analysis

In order to reveal the economic impact of different shade material applications and to find out which shade material application provides a higher net income, the partial budget analysis method was used. Partial budget analysis is a widely used method to determine whether different applications have an effect on gross income. Because only the inputs resulting from application differences are included in the yield calculations. Since other inputs are fixed or the same in all applications, it is possible to explain the relationship between yield and production cost directly with application differences. Thus, the formula for reaching the gross income per vine can be explained as follows;

$$\text{Gross Production Value} = \text{Price} \times \text{Yield}$$

The product prices in the formula represent the 2021 retail sales price (TL/kg), and the yield represents the yield obtained per vine (kg/vine).

$$\text{TVC} = (\text{SMP} \times \text{AU}) + \text{TL}$$

TVC : Total variable costs
SMP : Shading material price
AU : Amount used
TL : temporary Labor

The total variable costs in the formula represent the 2021 purchase cost of the shading material used for each application (TL/m^2) and the amount used per vine (m^2/vine). Labor represents the labor cost of applying shading material per vine for each application (TL/vine).

$$\text{GP} = \text{GPV} - \text{TVC}$$

GP : Gross Profit
GPV : Gross production value
TVC : Total variable costs

As a result, in order to obtain the gross profit in the partial budget analysis, the difference between the gross production value obtained from each application and the total variable costs was taken to reveal the level of profitability between the applications.

Statistical Analysis

The experiment was conducted using a randomized plot design with three replications (5 vines in each replication). After the data were analyzed with variance analysis, the difference between the means was examined with the Tukey multiple comparison test at the 5% level. The JMP package program was used in the analysis (Morris et al., 2001). Statistical differences are shown in lower case letters on the right side of the data.

In addition to basic descriptive statistics, the suitability of variables related to technical and economic data for normal distribution was tested. For variables that showed a normal distribution, the T-test was applied. For those that did not meet the normality assumption, non-parametric tests such as the Mann-Whitney U test were used.

The T-test compared the means of two groups to determine whether the observed difference was random or statistically significant. This test provided significant convenience for researchers, particularly when working with small sample sizes. On the other hand, the Mann-Whitney U test was employed when the data did not meet the assumptions of parametric tests and served as an alternative for testing the significance of differences between two means (Miran, 2002).

Results and Discussion

Phenological Observations of the Experimental Vineyard

The phenological observations of the vineyard where the experiment was conducted were determined by taking into account the classification of the phenological stages of the grapevine made by Eichorn & Lorenz (1977) (Table 1).

On April 6, 2021, budburst (Stage 2) was observed, marking the initiation of bud development. Subsequently, the flowering stages were closely monitored, beginning of flowering (Stage 21) was recorded on May 14, 2021, when 25% of the caps had fallen. Full flowering (Stage 23) was recorded on May 17, 2021, when 50% of the caps had fallen.

Table 1. Phenological observations of the Sinceri grape cultivar

Phenological Observations	Date*
Budburst	06.04.2021
Beginning of Flowering	14.05.2021
Full Flowering	17.05.2021
End of Flowering	20.05.2021
Berry Set	26.05.2021
Veraison	28.07.2021
Harvest	30.08.2021
Leaf Fall	30.11.2021

*Phenological observations were determined on the same dates in all treatments. Especially since the shading materials were laid on the vines during the veraison state, the observations were the same until this state. Harvest was done on the same day to compare the effects of the treatments on the must parameters. All treatments did not have any effect on the leaf fall date.

Table 2. Determination of soil structure of the experimental vineyard

Structure	Value
Clay (C) (%)	44.5
Silt (S) (%)	42.5
Sand (S) (%)	13.0
Texture Grade	SiC
Ph	7.46
Salt (µS)	0.16
Organic Matter (%)	1.59
Lime (%)	41.15

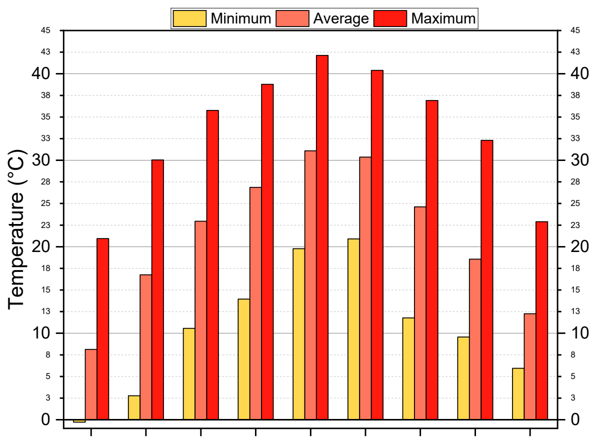

Figure 3. Monthly temperature data of the experimental area

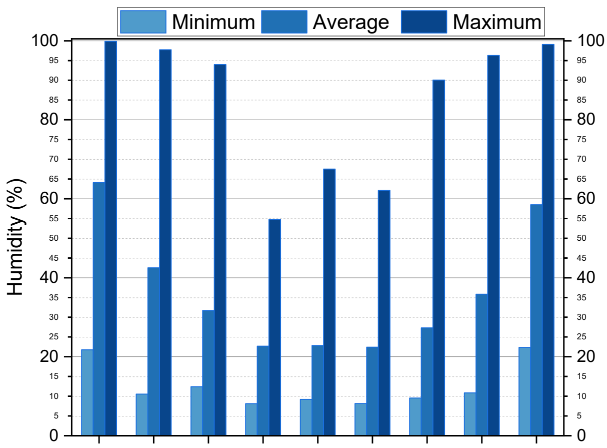

Figure 4. Monthly humidity data of experimental area

The end of flowering (Stage 25) on May 20, 2021, when 80% of the caps had fallen. Berry set (Stage 27) was observed on May 26, 2021, as berries reached a diameter of approximately 3–4 mm. The veraison stage (Stage 35), defined as the onset of berry softening, was documented on July 28, 2021. The harvest phase (Stage 38) was carried out on August 30, 2021, when the grapes reached maturity as determined by the maturity index. Finally, the leaf fall stage (Stage 47) was observed on November 30, 2021, with approximately when 70% of the leaves having fallen (Table 1).

Climate Data of The Experimental Vineyard

The climate data for the experimental vineyard were collected during the 2021 vegetation year. Monthly average temperature, minimum temperature, maximum temperature, average humidity, minimum humidity, and maximum humidity values were calculated for the period from budburst to leaf fall and are presented in Figure 3 and Figure 4.

As specified in Table 1, budburst for the Sinceri grape cultivar occurred on April 6, 2021, while leaf fall took place on November 30, 2021. Based on this period, monthly average temperature and humidity values were calculated.

The highest monthly average temperature was recorded in July at 31.08°C, while the lowest monthly average temperature was observed in March at 8.13°C. The minimum temperature occurred in March at -0.28°C, whereas the maximum temperature was recorded in July at 42.12°C (Figure 3).

The highest monthly average humidity was observed in March at 64.09%, while the lowest monthly average humidity was recorded in August at 22.42%. The minimum humidity was 8.13% in June, and the maximum humidity was 99.88% in March (Figure 4).

Lu et al. (2021) reported that the use of shading materials creates a microclimate area in the canopy of the grapevine to reduce the effects of environmental stress factors such as excessive sunlight and heat. Miccichè et al.

(2023) reported in their study that artificial shading, applied at full fruit set, interfered with the microclimate of the vines, causing partial effects on the grape ripening processes and delays leaf fall.

Soil Analysis of the Vineyard Land

The physical properties of the soils and their macro and micro nutrient element contents were evaluated according to Aksu (2008). The experimental vineyard soil is classified as silty clay (SiC) in texture, non-saline, highly calcareous, low in organic matter, and slightly alkaline (Table 2). When examining macro and micro nutrient concentrations, the levels of Cu and K were found to be adequate, while Mn and Fe concentrations were high. In contrast, Mg, Zn, and B were very low, and P and Ca were at low levels (Table 3).

Although viticulture can be practiced on a wide range of soil types, the ideal vineyard soils are loamy (L) or sandy-loamy (SL), slightly gravelly, well aerated, humus rich, and moderately calcareous. For vineyards, the most suitable soil pH is reported to be between 6 and 8 (Yetgin & Korkmaz, 1991; Çelik et al., 1998; Çelik, 2011).

Table 3. Determination of macro and micro nutrient elements of the experimental vineyard

Element	*Value*
Cu (ppm)	10.10
Mn (ppm)	91.74
Fe (ppm)	18.63
Zn (ppm)	0.18
B (ppm)	0.12
K_2O (kg/da)	34.36
P_2O_5 (kg/da)	5.33
Ca (kg/da)	599.39
Mg (kg/da)	28.44

Table 4. Effects of shading treatments on yield parameters

Treatment	Number of clusters (clusters/vine)	Average cluster weight (g)	Grape yield (g/vine)
Control (%0)	15.59±0.05c	181.75±5.27b	2832.83±74.22c
%35 Shading	17.72±0.15b	194.67±4.06b	3449.10±55.37bc
%55 Shading	19.90±0.80a	223.83±3.63a	4459.95±213.28a
%75 Shading	16.41±0.05bc	237.25±2.43a	3893.75±50.48ab

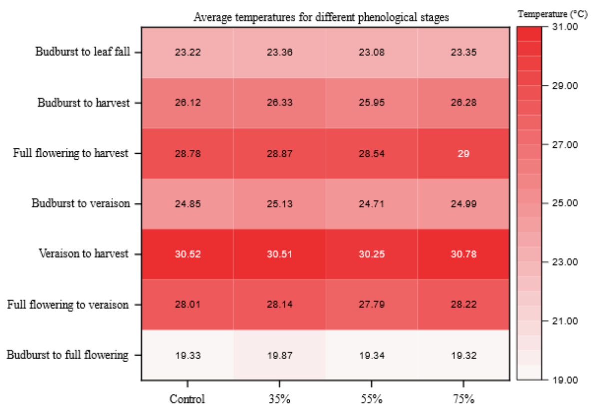

Figure 5. Heat map of average temperatures during different phenological stages

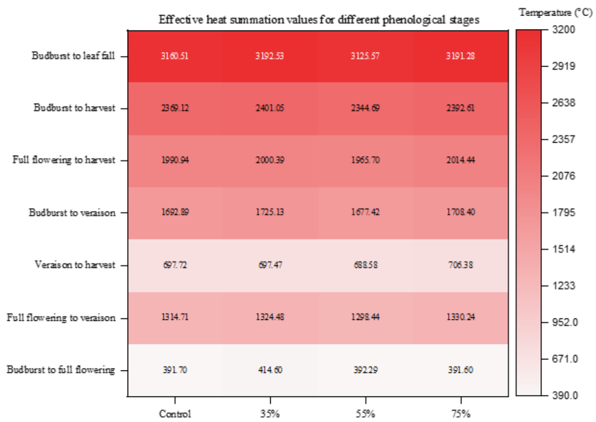

Figure 6. Heat map of Effective Heat Summation values for different phenological stages

Average Temperatures and Effective Heat Summation (EHS) according to Phenological Stages

Based on the data obtained from the HOBO devices installed in the experimental vineyard on March 1, 2021, Average temperatures and Effective Heat Summation (EHS) were calculated for the budburst-full flowering, full flowering-veraison, veraison-harvest, budburst-veraison, full flowering-harvest, budburst-harvest and budburst-leaf fall periods in each treatment (control and varying densities of shading materials). Average temperatures (Figure 5) and Effective Heat Summation (EHS) values (Figure 6) were calculated by considering the seven different phenological stages given above.

Effective Heat Summation (EHS) is one of the most critical parameters for determining the suitability of a region for viticulture and identifying which grape varieties can be cultivated in a specific ecology. This value is expressed as day-degrees (dd).

Except for the period between budburst and full flowering (since the shading materials were laid on the vines on June 19, 2021), the lowest result in terms of both average temperature and EST values in all other periods was determined in the 55% shading material treatment.

The lower limit of the Effective Heat Summation suitable for viticulture in an ecology is considered to be 900 dd (Eggeberger et al., 1975).

Their ecologies according to EHS values;
Cold=900-1400 dd
Cool=1401-1700 dd
Temperate=1701-1950 dd
Warm-temperate=1951-2250 dd
Hot= 2251 dd and above (Winkler et al., 1974).

According to the classification determined by Winker et al. (1974); it was determined that the ecology in which the study was conducted was in the hot climate class.

Effects of Shading Applications on Yield Parameters

Observations and calculations were conducted in the experimental vineyard, with the harvest taking place on August 30, 2021. The number of clusters (pcs), average cluster weight (g), and grape yield per vine (g) were calculated according to the specified methodology for each treatment, using five vines per replication. The effects of the shading treatments on yield parameters are summarized in Table 4.

The yield parameters in Table 4 shows the 55% shading treatment resulted in the highest values for both the number of clusters and grape yield per vine. According to Tukey's multiple comparison test, all differences were statistically significant at the 5% level.

In a previous study conducted on the Sinceri grape cultivar, Demirhan and Aslan (2022) reported a grape yield of 6.60 kg/vine and an average cluster weight of 323.05 g. Similarly, Koç (2018), in his research on local grape varieties in Muş province, determined the cluster weight of the Sinceri grape as 138.77 g and the grape yield as 5.16 kg/vine. Conversely, Miccichè et al. (2023) observed that shading significantly reduced berry size, resulting in lower cluster weight and vine yield. However, the findings of our study indicated that shading positively influenced yield parameters, particularly under the 55% shading treatment.

The Effects of Shading Material Treatments on The Nutrient Element Levels in Grapevine Leaves

As presented in Table 5, among the macro and micro elements analyzed, the highest levels of boron (B), magnesium (Mg), phosphorus (P), and nitrogen (N) were observed in the control treatment (0% shade), indicating that full exposure to sunlight supports higher concentrations of these elements. In contrast, the 35% shading treatment showed the highest levels of copper (Cu) and iron (Fe), suggesting that moderate shading may optimize the uptake or retention of these elements. For calcium (Ca), manganese (Mn), and zinc (Zn), the highest levels were detected under the 55% shading treatment, which may reflect a balance between light exposure and shading that favors the availability or mobility of these nutrients. Potassium (K), however, reached its maximum level under the 75% shading treatment, indicating that greater shading might enhance potassium accumulation in leaves, potentially due to reduced transpirational losses or specific physiological adaptations. These results highlight the differential impact of shading levels on the accumulation of macro and micro elements, suggesting that shading intensity can significantly influence nutrient dynamics in grapevine leaves.

Economic Analysis

As part of this study, a partial budget analysis was conducted using data obtained from the experimental results established in the producer vineyard. The most critical aspect of partial budgeting is the calculation of variable costs. Since all variable costs except those associated with shading materials were consistent across treatments, shading material costs were identified as the primary variable cost. In the control group, where no shading material was used, total variable costs were 0 TL/vine. In contrast, variable costs were calculated as 3.20 TL/vine for both the 35% and 55% shading material treatments, and 4.27 TL/vine for the 75% shading material treatment. The analysis was completed by determining the total gross profit following the partial budgeting process (Table 6).

Upon examining the data on gross production value, variable costs, and gross profit, it was found that the differences in gross profit across all three treatments were statistically significant at the 5% significance level according to the statistical analysis results. Based on the results, shading material was determined to have a statistically significant impact on yield, with the 55% shading treatment identified as the most economical option.

In a similar study, Cangi et al. (2011a) determined that “the second model with the highest total production costs (2144 TL/da) is the most profitable production model (due to the high amount of marketable grapes, the grapes being harvested at the latest and being sold at the highest prices)” in their study on the Sultani Cekirdeksiz grape variety.

Table 5. Macro and micro element levels in grapevine leaves

Treatment	B	Ca	Cu	Fe	K	Mg	Mn	P	Zn	N
	(ppm)	(%)	(ppm)	(ppm)	(%)	(%)	(ppm)	(%)	(ppm)	(%)
Control (%)	33.57	0.89	14.58	147.97	0.48	0.52	151.30	0.13	29.98	2.92
%35 Shading	14.16	0.81	14.99	149.57	0.58	0.37	104.59	0.12	33.21	2.12
%55 Shading	21.10	1.76	14.79	145.63	0.62	0.47	164.70	0.12	42.82	2.09
%75 Shading	21.19	1.36	14.87	137.77	0.74	0.51	127.20	0.11	31.98	2.05

Table 6. Economic analysis according to treatments

Treatment	Gross production value (TL/vine)	Total variable cost (TL/vine)	Gross Profit (TL/vine)
Control (%)	10.48	0.00	10.48
%35 Shading	12.76	3.20	9.56
%55 Shading	16.50	3.20	13.30
%75 Shading	14.41	4.27	10.14

The economic importance of grape production is steadily increasing in both local and international markets (Alston & Sambucci, 2019). Achieving sustainable and high-quality grape production requires attention to numerous factors influencing yield and quality (Reynolds, 2022). Consequently, implementing cultural practices that enhance grape yield, such as the use of shading materials, is essential for sustainable viticulture.

Conclusion

Based on Effective Heat Summation (EHS) values across different phenological stages under various treatments, the 55% shade material application consistently recorded the lowest results for both average temperature and EHS values in all periods except the interval between budburst and full flowering. Regarding yield parameters, the 55% shade material application yielded the highest values for both the number of clusters and grape yield per vine.

In terms of macro- and micronutrient levels in the leaves, the shading treatments positively influenced the accumulation of most elements, except for boron (B), magnesium (Mg), phosphorus (P), and nitrogen (N), where no significant increases were observed.

In conclusion, economic analyses for the Sinceri grape cultivar indicated that shading material applications have a statistically significant impact on yield. Based on the data obtained, the most effective shading treatment was determined to be the use of nets with a 55% shading rate.

Declarations

Data Availability

The data to support the results and conclusions of this study is presented within the article. Detailed data is available upon request.

Conflicts of interest

No potential conflict of interest was reported by the authors.

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