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ORIGINAL RESEARCH ARTICLES

Impact of organic and non-organic mulching on grape yield, quality and ecophysiological traits under irrigated and nonirrigated conditions

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ABSTRACT

In view of climate change and the possibility that drought stress in vineyards will increase, applying effective soil and water conservation measures is essential, especially where irrigation water is scarce. This study, conducted between 2021 and 2023 in Adana, Çukurova, Turkey, aimed to evaluate the efficacy of different organic (*Phacelia tanacetifolia* Benth., *Trifolium alexandrinum* L., *Lathyrus sativus* L. and *Vicia sativa* L. + *Triticale* sp.) and non-organic (basaltic pumice and zeolite) mulches on Black Magic grapevines under irrigation (50 % water) and nonirrigation (rainfed) conditions. The results show that limited irrigation increased grape yield, and cluster and berry parameter values. Weed-free, *V. sativa+Triticale* sp. and *T. alexandrinum* applications generally showed higher yield, and cluster and berry parameter values compared to other cover crops. Nonirrigated conditions resulted in higher total soluble solids and maturity index, but lower pH compared to limited irrigation. Leaf water potential (LWP) increased towards maturity, particularly under nonirrigated conditions, with significant differences in LWP between mulching treatments in the third year. Soil moisture was generally higher and temperature slightly lower under limited irrigation, with mulch application showing no significant effect on soil moisture and temperature. The discriminant analysis highlighted the influence of mulching materials on yield and its components, particularly under limited irrigation. Overall, organic and non-organic mulches proved to be effective in maintaining soil moisture and temperature, providing an environmentally friendly alternative to herbicides in vineyards under limited irrigation.

KEYWORDS: grapevine, leaf water potential, limited irrigation, mulching, soil moisture, soil temperature, sustainability

INTRODUCTION

Due to suitable ecological conditions, viticulture is a prominent agricultural sector in Turkey, with varying vineyard areas. The worldwide cultivated vine area is 7.2 million hectares, with a production of 77.3 million tons of grapes (OIV, 2024). Among the world's vine-growing countries, Turkey ranks fifth in terms of area under vine (413377 hectares), and sixth in grape production (4.2 million tons) (OIV, 2024).

As in viticulture worldwide, grape yield and quality in Turkey are influenced by ecological factors and cultural practices from soil preparation to harvest. These practices include summer and winter pruning, irrigation, fertilisation, soil management, and disease, pest and weed control. Turkey is in a semi-arid climate zone where seasonal rainfall is low in autumn and spring and almost non-existent in summer. The insufficiency of rainfall and the irregular distribution of annual rainfall over the seasons make irrigation necessary, especially for table grape vineyards. Consequently, irrigation is generally practiced in vineyards where water resources are available and rainfall is sufficient in Turkey and Europe (Çelik, 2011; Costa *et al.,* 2016).

Because pollution and water depletion contribute to climate change, efficient water use is crucial. Numerous studies focus on optimising irrigation in vineyards including deficit irrigation experiments to balance quality and production (Tangolar *et al.,* 2015; Keller *et al.,* 2016; Munitz *et al.,* 2017; Tangolar *et al.,* 2018; Caruso *et al.,* 2023). When considering the conservation of available water in the soil, weed control is critical (Lopes *et al.,* 2011; Cataldo *et al.,* 2020). Weeds compete with grapevines for water and nutrients, hindering the growth and development of the vines and thereby reducing yield (Ferrara *et al.,* 2015; Burg *et al.,* 2022). It has been estimated that weed-induced yield loss in vineyards is at least 10 % and that weeds are one of the main obstacles for traditional farmers to convert to organic farming (Peruzzi *et al.,* 2004). In our rapidly desertification world, competition between vines and weeds causes product losses, and weeds also host diseases and pests in vineyards, increasing yield losses. This situation calls for the development of alternative control methods to minimise any damage to the environment and other living organisms in the ecosystem caused by weed control chemicals. This is particularly important as young vines are sensitive to herbicides (Al-Khatib *et al.,* 2017). In the Çukurova region, applying herbicides and plowing are a means of weed control, but increasing these applications decreases soil moisture and nutrients, raising costs and harvesting difficulties. Basaltic pumice and zeolite, used for their water retention properties, show potential for use in agricultural activities in water-scarce areas (Demir & Polat, 2003). Turkey has rich deposits of basaltic pumice and zeolite, and both materials are easily accessible and more economical than the other mulch materials. The use of minerals such as basaltic pumice and zeolite in some soilless culture studies has led to trials on the usability of these materials in weed control, which is one of the plant protection problems (Tangolar *et al.,* 2019; Temel *et al.,* 2019).

Cover crops and mulch have been reported to improve soil ecology, protect soil, increase yield and contribute to environmental conservation (Ateş & Uygur, 2013; Şener & Uygur, 2015; Čížková *et al.,* 2021; Mairata *et al.,* 2023). Cover crops in organic and sustainable viticulture protect the soil from wind and rain erosion, regulate vine growth, increase soil cation exchange capacity, and improve yields. They also improve the water retention capacity of the soil and increase biodiversity in the root zone of the vines (Zhang *et al.,* 2014; Bavougian & Read, 2018; Costantini *et al.,* 2018; Mairata *et al.,* 2023). Additionally, cover crops provide habitat for generalist predators and parasitoids, facilitate cultivation and harvesting, and improve air and water quality in the environment.

In addition to soil degradation, the effects of global climate change, increased pest populations and inadequate pest control methods have a negative impact on crops (Bernardo *et al.,* 2018; Raza *et al.,* 2019). Cover crops also play a role in mitigating these problems by suppressing weeds, improving soil structure, increasing organic matter content and nitrogen fixation, enhancing microbiological functions and biodiversity, and reducing soil erosion and water loss in cultivated areas (Monteiro & Lopes, 2007; Steenwerth & Belina, 2008; Cabrera-Pérez *et al.,* 2022; Guerra *et al.,* 2022a). Given water scarcity and climate change, environmentally friendly practices will need to be implemented to comply with the Green Deal. This study investigates the effects of different organic (cover crops) and non-organic mulching materials on yield, quality, leaf water potential, soil moisture and temperature in vineyards under two different water regimes.

MATERIALS AND METHODS

1. Materials

The study was conducted over three years (2021, 2022 and 2023) at the Research and Application Vineyard, Horticulture Department, Çukurova University (coordinates 37.0299 N, 35.3786 E; altitude 70 m asl) in Adana, Turkey. The soil in the experimental area is sandy-clay loam, calcareous, salt-free, alkaline and is poor-moderate in organic matter at two soil depths. As shown in Figure 1, during the experimental years, the period from July to November was dry, and the climate was hot and dry in the summer and warm and rainy in the winter (Mediterranean climate). According to the Turkish State Meteorological Service (MGM, 2023), the 2020-2021 autumn-winter seasons deviated from the long-term averages, being warm and dry (Figure 1). In these years, it took a long time for the cover crops to germinate, emerge and establish populations. After short rains, the cover crops completed growth. The first rains fell in November of the second year (2021-2022). With rainfall and temperature following seasonal norms, the cover crops completed germination in about a month. That year, the coldest and wettest winter in 48 years was recorded. During the third winter (2022-2023)

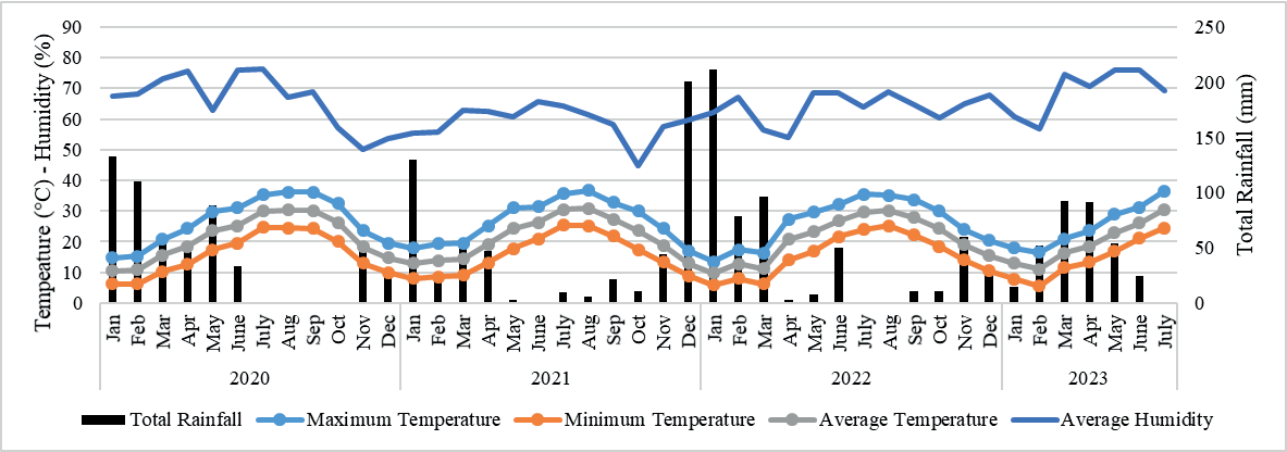


FIGURE 1. Some climate values from the experimental years (MGM, 2023).

substantial spring rains began in March and saturated the soil. In summary, the first year was dry and warm, the second year cold and rainy, and the third year had shifts in seasonal climate characteristics (Figure 1).

On 9 February 2021 and 7 April 2022, 30 kg/ha of 20-20 N-P was applied to the experimental area, and on 17 March 2023, 7-10 kg/ ha of urea fertilizer was applied. Between the rows, a cultivator or a rotavator were used for soil preparation, and standard pest control methods and pesticides recommended for vineyards were used for pest management.

2. Methods

2.1. The organic (cover crops) and non-organic mulching types with sowing times

The main plant material used in the study was the six-year-old (in 2021) Black Magic table grape variety grafted on 1103 Paulsen rootstock. The vines in the trial area were planted with a 2 m x 3.5 m within-row and inter-row spacing respectively. The vines were trained in a bilateral cordon system and spur-pruned every year. The organic mulching materials (cover crops) tested in the study were *Lathyrus sativus* (LSAT), *Trifolium alexandrinum* (TALE), *Phacelia tanacetifolia* (PTAN), and *Vicia sativa* + *Triticale* sp. (VSAT+TRIT). The tested non-organic mulching materials were basaltic pumice and zeolite (Demir & Polat, 2003; Gül, 2012). The results from the plots that received these organic and non-organic treatments were compared to those from the following control plots: one with weeds (Weedy), one which was weed-free (Weed-free) and the other to which herbicide was applied (Herbicide).

The application rates and timing of the treatments are given in Table 1. In the control plots, the soil was not covered with any mulch, and the weeds were left untouched (except in the weed-free plots) for one growing season. These plots were left undisturbed, allowing the natural weed flora to develop. In the weed-free control plots, the soil surface was also left uncovered, and the weeds were removed by hand when they reached a height of 10-15 cm. Glyphosate (herbicide) was selected as the active ingredient for the herbicide application. A registered glyphosate-based herbicide used for weed control in vineyards and preferred by farmers was applied once during the active winter weed season at the recommended rate dose of 3000 mL/ha. Basaltic pumice with a particle size of 0-5 mm and of a brownish colour and zeolite with a particle size of 2-4 mm were directly applied to the soil surface under the vine canopy once in November.

For the organic mulching, LSAT, TALE, PTAN and VSAT+TRIT were sown in late November or early December in all three years, as shown in Table 1. In April, when the cover crops were approximately 50 % flowering, they were harvested and spread over the ground as organic mulch. In addition, when the cover crops were harvested, fresh mulch samples were taken from a square metre area, then weighed and dried in an oven at 105 °C for 24 hours. The dry biomass was then weighed; the results are shown in Figure 2.

TABLE 1. Sowing time and amounts of cover crops for organic mulch, non-organic mulch and herbicide applications.

Amount of application / Month	Organic mulches*				Non-organic mulches		Herbicide (Glyphosate)
	VSAT+TRIT	LSAT	PTAN	TALE	Pumice	Zeolite	
	November	November	November	November	November	November	April
Amount/6 m²**	90 g +75 g	120 g	10 g	20 g	450 kg	450 kg	The recommended dose on the product label is 3000 mL/ha

*For cover crops, values represent the amount of seed used to establish the plot. **Plot width 6 m2 (1 m width x 6 m length- 3 vines). VSAT+TRIT; V.*sativa* + *Triticale* sp., LSAT; *L.sativus*, PTAN; *P.tanacetifolia*, and TALE; *T.alexandrinum*.

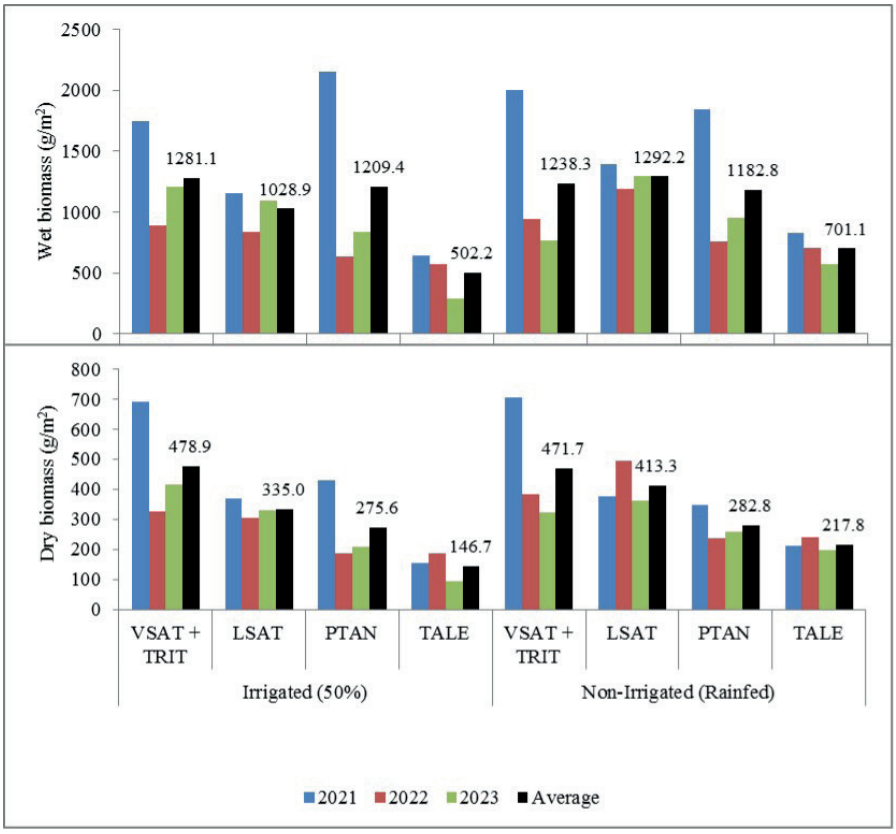


FIGURE 2. The wet and dry biomass of organic mulching materials left on the soil surface after mowing the cover crop.

VSAT+TRIT; V.*sativa* + *Triticale* sp., LSAT; *L.sativus*, PTAN; *P.tanacetifolia*, and TALE; *T.alexandrinum*.

2.2. Experimental design of the irrigation system

Irrigation in the experimental area was started when the midday leaf water potential (LWP) increased by -1.0 MPa (-10 bar). Irrigation was implemented at (approximately) weekly intervals as from early April, based on 50 % of cumulative Class A pan evapotranspiration (Epan) in the limited irrigation treatment. No irrigation was applied to the different types of mulch in nonirrigated (rainfed) conditions. The amount of water applied to irrigated plots was calculated using the following equation (Çetin *et al.,* 2002; Tangolar *et al.,* 2015; Tangolar *et al.,* 2018):

$$I = A.\ Epan.\ Kpc.\ P$$

Where "I" is the amount of irrigation water (L/vine), "A" is per vine area (2 m x 3.5 m = 7 m^2), "Epan" is the cumulative evaporation (L) on which the length of the irrigation intervals were based, measured by a class A pan located near the study area, "Kpc" is the coefficient pan (used at 50%) and "P" is the wetting area (used at 50 %) calculated at the beginning of the study using the method described by Kanber *et al*. (1992) and Ünlü *et al*. (2014).

The drip irrigation system comprised one lateral per row of vines placed 50 cm above the soil surface and close to the trunk. Drip lines with one emitter every 50 cm were operated at a flow rate of 3 L/h and a pressure of 1.5 bars. Irrigation rates and dates are shown in Table 2.

2.3. Studied traits

2.3.1. Yield and quality

Six cluster samples were taken from each plot during the grape ripening period when the total soluble solids (TSS) reached approximately 12-13 %. These cluster samples were used to determine cluster weight (g), 100-berry weight (g) and 100-berry volume (mL). TSS (%) concentration was determined using a digital refractometer, and titratable acidity (g/100 mL of grape juice) (TA) was determined by titration using 0.1 N NaOH and expressed as tartaric acid. pH was read using a pH meter. For the maturity index, TSS is proportional to TA. Grape yield (g/vine) was obtained by multiplying the number of clusters by the average cluster weight.

2.3.2. Ecophysiological indices

Leaf water potential (LWP): Two fully developed leaves exposed to direct sunlight were selected for LWP in each plot. To measure midday LWP (between 11:30 and 14:00), the target leaves were entirely covered by a small plastic bag, and then the petiole of the bagged leaf was cut from the shoot with a sharp blade. A portable pressure chamber device (Model 600, PMS Instrument Co. Albany, Oregon, USA) was used to obtain LWP values (in -bar).

Soil water content and temperature: Soil water content and temperature in the root zone (0-20, 20-40 and 40-60 cm depth) were measured using a capacitance probe (Aquacheck, model AQMOB-X) in June and July of both the 2021 and 2022 growing seasons. Soil water content and Temperature values were obtained with a single reading from each probe on each measurement date.

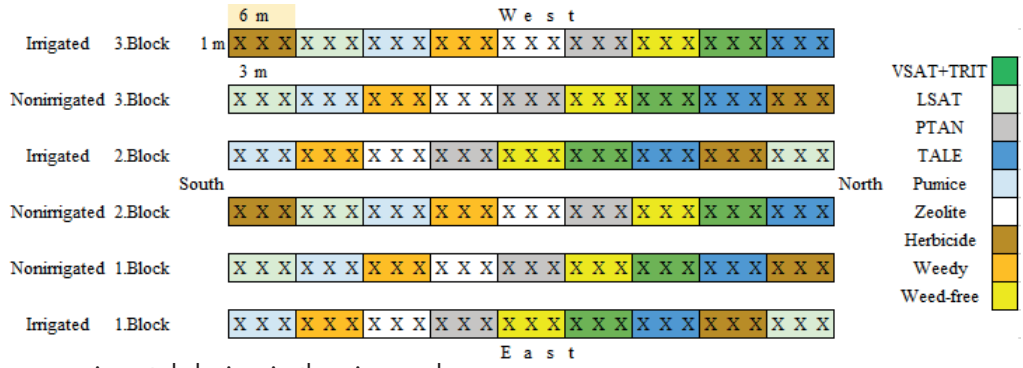


FIGURE 3. The experimental design in the vineyard.

TABLE 2. Number of irrigations, evaporation and limited amounts of water applied for each vine, and some phenological dates in the experimental area by year.

Irrigation number	2021			2022			2023		
	Date	Evaporation (mm)	Applied water (L)	Date	Evaporation (mm)	Applied water (L)	Date	Evaporation (mm)	Applied water (L)
1	26 May	57	100	27 May	60	105	11 May	40	70
2	4 June	70	123	3 June	55	96	22 May	71	124
3	11 June	58	102	10 June	39	68	8 June	55	96
4	16 June	43	75	24 June	40	70	21 June	57	100
5	24 June	74	130	-	-	-	-	-	-
Total			529			340			390
Phenological dates									
Bud burst	15 March			16 March			19 March		
Full bloom	5 May			8 May			12 May		
Harvest	6 July			8 July			12 July		

TABLE 3. Effect of year, irrigation and mulching material on yield, cluster weight, berry weight and volume.

Variation sources	Yield (g/vine)	Cluster weight (g)	100 berry weight (g)	100 berry volume (mL)
Year (A)				
2021	8392.0 c	285.9 b	525.6 a	496.3 a
2022	10165.0 b	314.6 a	522.8 a	500.7 a
2023	11319.0 a	286.1 b	481.4 b	455.8 b
LSD 5%	519.0	12.3	15.0	14.5
P-value	<0.0001	<0.0001	<0.0001	<0.0001
Irrigation (B)				
Irrigated (50% water)	11160.0 a	313.3 a	528.4 a	501.0 a
Nonirrigated (Rainfed)	8758.0 b	277.7 b	491.5 b	468.0 b
LSD 5%	423.0	10.1	12.3	11.9
P-value	<0.0001	<0.0001	<0.0001	<0.0001
Mulching material (C)				
VSAT + TRIT	10765.0 ab	300.0 bc	531.2 ab	506.0 a
LSAT	8080.0 e	270.0 de	500.6 cd	474.0 bc
PTAN	10347.0 bc	301.9 bc	514.0 abc	487.0 ab
TALE	10974.0 ab	323.4 a	527.2 ab	503.0 a
Pumice	8802.0 de	264.7 e	459.7 e	436.0 d
Zeolite	9249.0 d	290.8 cd	485.6 de	461.0 c
Herbicide	10296.0 bc	301.0 bc	527.9 ab	500.0 a
Weedy	9583.0 cd	291.4 c	508.2 bcd	485.0 abc
Weed-free	11534.0 a	316.5 ab	535.3 a	507.0 a
LSD 5%	898.0	21.4	26.1	25.0
P-value	<0.0001	<0.0001	<0.0001	<0.0001
Interaction				
P-value (AxB)	<0.0001	<0.0001	0.1551	0.0907
P-value (AxC)	0.0143	0.3260	0.8395	0.9062
P-value (BxC)	<0.0001	<0.0001	0.1179	0.0728
P-value (AxBxC)	0.8110	0.1802	0.4679	0.5008

* There is a statistically significant difference between the means indicated by different letters in the same column ($P \leq 0.05$).
VSAT+TRIT; *V.sativa* + *Triticale* sp., LSAT; *L.sativus*, PTAN; *P.tanacetifolia*, and TALE; *T.alexandrinum*.

2.4. Experimental design and statistical analyses

The experiment was carried out using three replications according to the split-plot experimental design (Figure 3). The irrigation levels of the main plots were irrigation (50 % limited water) and no irrigation (rain-fed). The sub-plots were composed of organic, non-organic mulches and controls. Each plot consisted of an area of 6m^2 (1m x 6m) and three vines. The variance analysis of data was carried out using the JMP statistical package, and the Least Significant Difference (LSD) test was used to determine the effects of the different groups at the 5 % significance level. Statistical analyses comprised a principal component analysis of some yield and quality characteristics for mulch applications.

RESULTS

1. Grape yield, cluster weight, berry weight and volume

The effect of year, irrigation and mulch applications on yield, cluster weight, 100-berry weight and berry volume were significant (Table 3). In terms of differences between years, the highest yield was observed in 2023 (11319.0 g/vine), cluster weight in 2022 (314.6 g), berry weight in 2021 and 2022 (525.6 g and 522.8 g respectively) and berry volume in 2021 and 2022 (496.3 mL and 500.7 mL respectively). Higher yields (11160.0 g/vine), cluster weight (313.3 g), berry weight (528.4 g) and volume (501.0 mL) were observed in irrigated plots compared to those without irrigation. Regarding the mulching materials, the highest yield (11534.0 g/vine) and berry weight (535.3 g) were obtained from the Weed-free, the cluster weight (323.4 g) from TALE and berry volume from Weed-free (507.0 mL), VSAT+TRIT (506.0 mL), TALE (503.0 mL) and Herbicide (500.0 mL). Interaction effects of Year x Irrigation and Irrigation x Mulching treatments can be observed, particularly for yield and cluster weight, as shown in Table 3.

2. Must

The effect of year, irrigation, and mulching treatments on must characteristics was significant. With limited irrigation, significant differences were only observed for TSS and pH (Table 4). The highest TSS values in 2021 and 2023 (16.46 % and 16.56 % respectively), the highest acidity values were recorded in 2022 and 2023 (0.381 and 0.381 g/100 mL respectively), while the highest pH (3.51 and 3.49 respectively) and maturity index values (45.48) were observed in 2021. Regarding irrigation applications, the highest TSS and pH values (16.57 % and 3.43) were obtained from nonirrigation and irrigation respectively. As regards the evaluation of organic and non-organic mulching applications, the highest

Table 4. Effect of year, irrigation and mulching on must characteristics.

Variation sources	Total soluble solids (TSS)(%)	Titratable acidity (g/100 mL grape juice)	pH	Maturity index (TSS/Acidity)
		Year (A)		
2021	16.46 a*	0.363 b	3.51 a	45.48 a
2022	16.12 b	0.381 a	3.27 b	42.57 b
2023	16.56 a	0.381 a	3.49 a	43.87 b
LSD 5%	0.29	0.010	0.02	1.35
P-value	0.0083	0.0007	<0.0001	0.0002
		Irrigation (B)		
Irrigated (50% water)	16.18 b	0.373	3.43 a	43.65
Nonirrigated (Rainfed)	16.57 a	0.377	3.41 b	44.29
LSD 5%	0.23	N.S.	0.01	N.S.
P-value	0.0013	0.3773	0.0106	0.2448
		Mulching material (C)		
VSAT + TRIT	16.43 ab	0.386 b	3.45 a	42.71 b
LSAT	16.58 ab	0.379 bc	3.44 a	44.13 ab
PTAN	16.19 bc	0.358 d	3.44 a	45.31 a
TALE	15.74 c	0.408 a	3.36 c	38.86 c
Pumice	16.78 a	0.365 cd	3.43 ab	46.19 a
Zeolite	16.63 ab	0.370 bcd	3.42 ab	45.12 a
Herbicide	15.93 c	0.380 bc	3.39 bc	42.27 b
Weedy	16.52 ab	0.364 cd	3.41 ab	45.51 a
Weed-free	16.59 ab	0.367 cd	3.45 a	45.63 a
LSD 5%	0.50	0.018	0.042	2.33
P-value	0.0005	<0.0001	0.0002	<0.0001
		Interaction		
P-value (AxB)	0.0003	0.0072	0.0484	0.0015
P-value (AxC)	0.3793	0.0817	0.0199	0.0908
P-value (BxC)	0.0039	0.1447	0.0380	0.0028
P-value (AxBxC)	0.1197	0.8656	0.3487	0.8657

* There is a statistically significant difference between the means indicated by different letters in the same column ($P \leq 0.05$). N.S.: Not significant.

VSAT+TRIT; *V.sativa* + *Triticale* sp., LSAT; *L.sativus*, PTAN; *P.tanacetifolia*, and TALE; *T.alexandrinum*.

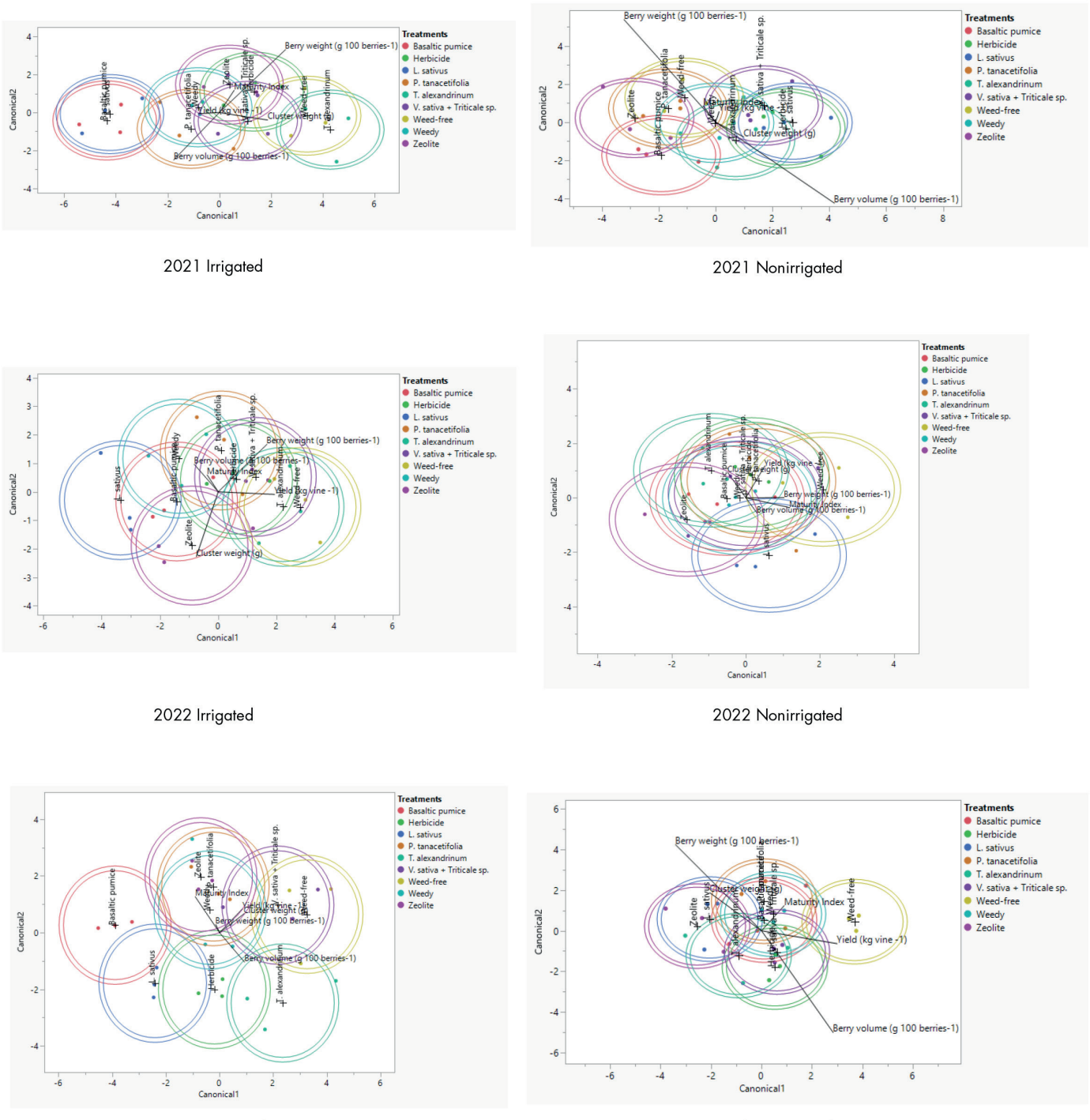


FIGURE 4. Discriminant analysis plot of mulching treatments for 2021, 2022 and 2023 under irrigation and nonirrigation conditions in the grapevines.

VSAT+TRIT; V.*sativa* + *Triticale* sp., LSAT; *L.sativus*, PTAN; *P.tanacetifolia*, and TALE; *T.alexandrinum*.

values were observed in Basaltic pumice for TSS (16.78 %), in TALE for acidity (0.408 g/100 mL) and in PTAN, Weed-free, VSAT+TRIT and LSAT for pH, for which they were statistically in the same group. Similarly, Basaltic pumice, Weedy, Zeolite, PTAN, and Weed-free values were in the same statistical group for the maturity index. Some treatment effects on must parameters varied depending on the year, irrigation and mulching, as shown by the interaction values in Table 4.

3. Component analysis showing the relationship between weed management practices and yield and yield components

Discriminant analysis was performed for the years 2021, 2022 and 2023 separately under 50 % water irrigated and nonirrigated conditions to determine the relationships between mulching and yield, cluster weight, berry weight, berry volume and maturity index parameters (Figure 4). Canonical discriminant analysis revealed differences

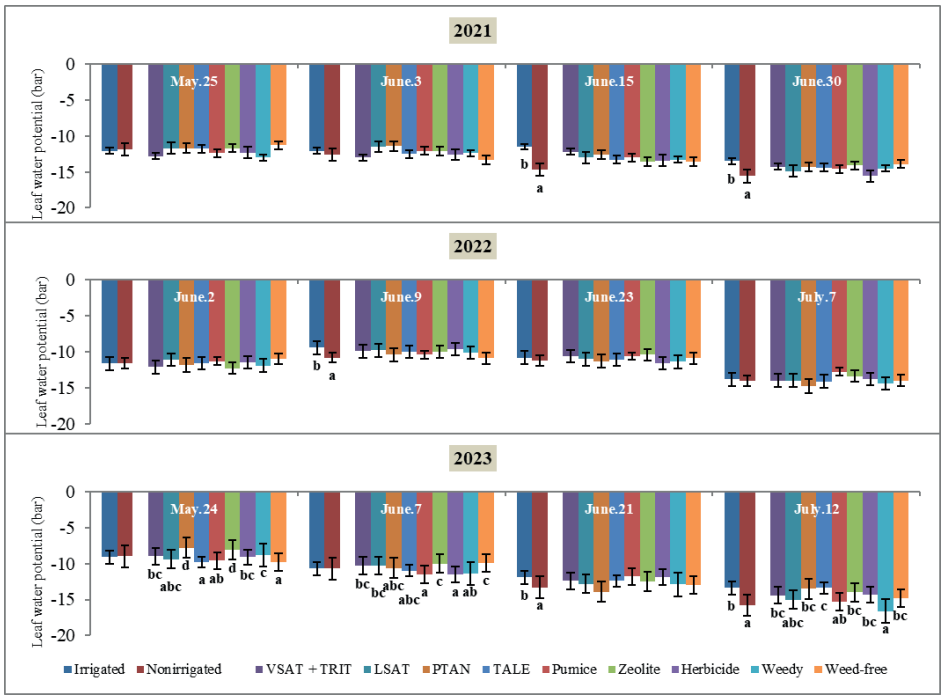


FIGURE 5. Effect of irrigation and mulching on Leaf water potential. Significant differences between the means are indicated by different letters ($P \leq 0.05$).

VSAT+TRIT; *V.sativa* + *Triticale* sp., LSAT; *L.sativus*, PTAN; *P.tanacetifolia*, and TALE; *T.alexandrinum*.

between treatments in yield, cluster and berry weight, berry volume and maturity index parameters for both irrigated and nonirrigated conditions in all three years. With irrigation (2021), 96 % of the correlations between the parameters were explained by the first canonical axis, while 69 % were explained by the second canonical axis. In the nonirrigated conditions (2021), 92 % of the correlations between the parameters were explained by the first canonical axis, while 73 % were explained by the second canonical axis. In the second year (2022) under irrigation, 91 % of the correlations between the parameters were explained by the first canonical axis, while 76 % were explained by the second canonical axis. In the same year (2022), under nonirrigated conditions, 77 % of the correlations between the parameters were explained by the first canonical axis, while 74 % were explained by the second canonical axis. In the final year of the experiment (2023), under irrigation, 94 % of the correlations between the parameters were explained by the first canonical axis, while 89 % were explained by the second canonical axis. Similarly, in the last year, under nonirrigated conditions, 90 % of the correlations between the parameters were explained by the first canonical axis. In comparison, 78 % were explained by the second canonical axis (Figure 4). When yield and yield characteristics were examined by year in the discriminant analyses, each treatment applied to the vineyard ring showed a differentiation between the values obtained under irrigation, indicating an effect of irrigation on the applied area. By contrast, in the nonirrigated area, these criteria were found to overlap and be close to each other, indicating minimal differences between treatments (Figure 4).

The discriminant analysis showed differences between mulching treatments and yield, cluster weight, berry weight, berry volume, and maturity index in 2021, 2022 and 2023 in irrigated and nonirrigated vineyards. When mulching used for weed control was compared with yield parameters, the practices clustered around similar canonical axes, but yield parameters tended towards different practices. For example, berry weight and berry volume in 2021 showed opposite directions in irrigated and nonirrigated vineyard areas. In the irrigated area, high berry weight values were associated with Herbicide and VSAT + TRIT mulching, while high berry volume was linked to PTAN mulching. In the nonirrigated plots, high berry weight values were found in the weed-free and PTAN mulching treatments, while high berry volume values were in the TALE mulching treatment. The effect of mulching treatments on yield parameters was highlighted by discriminant analysis, showing which treatment was more important in each area under both regimes (Figure 4).

4. Ecophysiological measurements

4.1. Leaf water potential (LWP)

No differences were observed between the LWP values measured on plots with and without irrigation on 25 May and 3 June 2021 (Figure 5). On 15 June and 30 June, LWP values (-14.7 and -15.6 bars respectively) were higher in the nonirrigated vines. The effects of organic and non-organic mulching on LWP were insignificant on the four measurement dates. Values ranged from -11.3 to -13.0 bars on 25 May (before first irrigation), -11.4 to -13.0 bars on 3 June, -12.2 to -13.6 bars on 15 June, and -13.9 to -15.6 bars on 30 June. No significant interaction was observed on any of the four measurement dates. In 2022 (Figure 5), significant differences were observed only in the second measurement date for the LWP values measured on four different dates. No effects of irrigation were observed during the other periods.

The interaction Mulching x Irrigation was not found to be significantly related LWP. The last two measurements on 21 June and 12 July of the third year (Figure 5) showed that irrigation reduced the LWP values. These measurements showed that the LWP values of the nonirrigated vines (-13.3 and -15.8 bars respectively) were higher than those of the irrigated vines (-11.9 and -13.4 bars respectively). Irrigation was shown to have made no difference in the first two measurements (24 May and 7 June). The effect of organic and non-organic mulching treatments on LWP values was different, except for the 21 June measurement. The highest LWP was measured on 24 May with TALE and Weed-free (-9.8 bar), on 7 June with Basaltic pumice and Herbicide (-11.5 bar), and on 12 July with PTAN (-16.6 bar). The interaction was significant for the 24 May and 12 July measurements but not significant for the 7 June and 21 June measurements (Figure 5).

4.2. Soil water content and temperature

The effects of irrigation and mulching applications on soil moisture and temperature values measured with Aquacheck at different soil depths are shown in Figures 6 and 7.

In the first year of the study (2021), irrigation application had an insignificant effect on soil moisture at different depths as shown by the May measurements, while the difference in soil temperature values was significant (Figure 6). It was found that the soil temperature was higher in the nonirrigated treatments at all three depths (0-20 cm, 20-40 cm and 40-60 cm) with values of 32.53 °C, 27.58 °C and 27.29 °C respectively. The interaction between organic and non-organic mulch applications on soil moisture and temperature at a depth of 40-60 cm, as well as the characteristics of soil moisture and temperature at different depths, showed no significance in Irrigation x Mulching interaction effects (Figure 6).

In the June measurements, the effect of irrigation on soil moisture was significant at three different depths, while its effect on soil temperature values was insignificant at the depths of 0-20 cm and 20-40 cm. However, its effect was significant at the 40-60 cm depth. For the deficit irrigation, the soil moisture content was higher at all three depths (23.93 %, 40.33 %, and 42.21 %, respectively) than that of the non-irrigated treatments. The effect on soil temperature was significant at a depth of 40-60 cm, with an irrigation value (30.59 °C) higher than that of the non-irrigated application (30.42 °C). The different mulching treatments did not significantly affect soil moisture and temperature at the three different depths. The interaction between irrigation and mulching material was also insignificant for soil moisture and temperature characteristics at different depths (Figure 6). In July of the same year, measurements showed that irrigation did not affect soil temperature but increased soil moisture at the depths of 0-20 cm and 40-60 cm (23.36 % and 40.88 % respectively). The July measurements showed the effect of different mulching applications on soil moisture content and temperature to be insignificant. The interaction between irrigation and mulching material was insignificant regarding soil moisture and temperature values at different depths (Figure 6).

In the second year of the study (2022), the effect of irrigation on soil moisture at different depths was significant for the measurements made on 2 June, while its effect on soil temperature was not significant (Figure 7). In this year, soil moisture was higher in the irrigated treatments at all three depths (22.79 %, 31.09 % and 43.31 % respectively). The effect of non-organic and organic mulching application on soil moisture at a depth of 40-60 cm was significant, with the highest soil moisture obtained from Weed-free (44.86 %), TALE (44.17 %), VSAT+TRIT (43.32 %), Weedy (43.00 %) and PTAN (41.68 %). The effect of different mulching

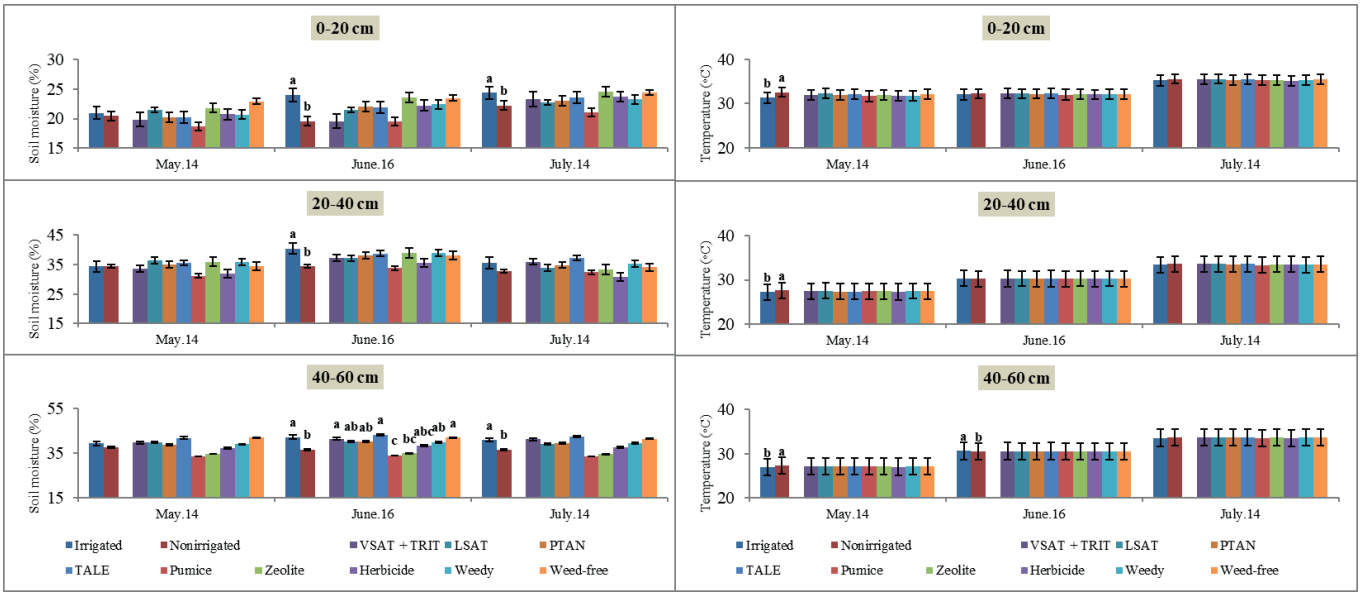


FIGURE 6. The effect of irrigation and mulch applications on soil moisture and temperature (oC) at different depths (cm) measured by Aquacheck (2021). Significant differences between the means are indicated by different letters ($P \leq 0.05$).

VSAT+TRIT; V.*sativa* + *Triticale* sp., LSAT; *L.sativus*, PTAN; *P.tanacetifolia*, and TALE; *T.alexandrinum*.

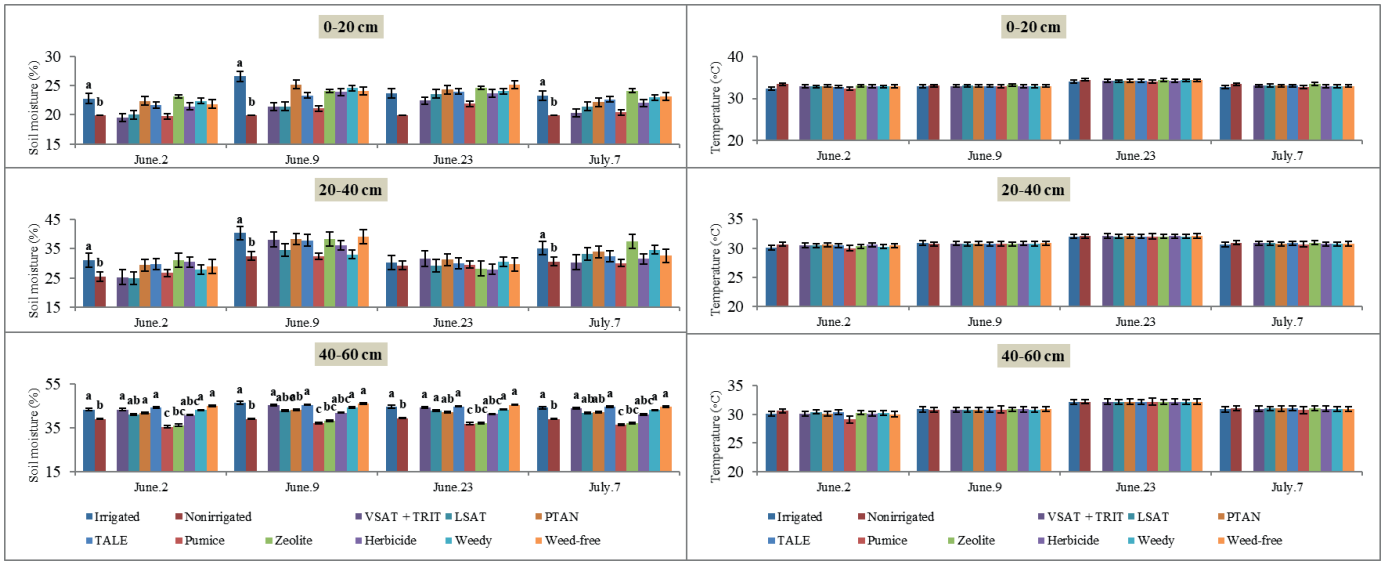


FIGURE 7. The effect of irrigation and mulching applications on soil moisture and temperature (oC) at different depths (cm) measured by Aquacheck (2022). Significant differences between the means are indicated by different letters ($P \leq 0.05$).

VSAT+TRIT; V.*sativa* + *Triticale* sp., LSAT; *L.sativus*, PTAN; *P.tanacetifolia*, and TALE; *T.alexandrinum*.

applications on soil temperature at three different depths was insignificant, as was the interaction between soil moisture and temperature at different depths (Figure 7). In the measurements made on 9 June this year, the effect of irrigation on soil moisture at three different depths was significant, while its effect on soil temperature was not significant. Soil moisture content was higher in the irrigated treatment (26.57 %, 40.35 %, and 46.30 %, respectively) than in the non-irrigated treatment. The effect of organic and inorganic mulching application was only significant for soil moisture content at 40-60 cm depth. The highest soil moisture content was obtained from the same treatments showing the same effect, including Weed-free (46.01 %), TALE (45.45 %), VSAT+TRIT (45.26 %) and Weedy (44.20 %). The effect of different mulching treatments on soil temperature and the interaction between irrigation and mulching material on soil moisture and temperature parameters at different depths were not significant (Figure 7).

DISCUSSION

In Turkey, most vineyards are dry farmed, which an important advantage for the country in the field of agriculture; nevertheless, commercial table grape producers with access to water resources irrigate once after berry set, once before veraison and once after harvest if necessary. The present study sets out to rely the message that limiting water use during these periods to when necessary should be encouraged. The aim here is to draw attention to the benefits that can be gained when limited water is used together with the covering material in the vineyards. Over the three-year study period, irrigation and mulching effectively impacted yield sustainability. Previous research reports have shown that using organic mulch increases grape yield (Cabrera-Pérez *et al.,* 2022). Similarly, in the present study, yield was found to increase with irrigation, and, in combination with bare soil, organic mulches such as VSAT+TRIT and TALE were also effective in increasing yield. Conversely, Ferrara *et al.* (2015) and Muscas *et al.* (2017) reported no significant effects of mulching on grape yield over shorter study durations. This discrepancy may be attributed to differences in environmental conditions, such as soil type, climatic variability and vineyard management practices. For instance, our study was conducted in a semi-arid Mediterranean climate and thus high summer temperatures and prolonged dry periods may have amplified the benefits of mulching by reducing water evaporation and preserving soil moisture; by contrast, regions with milder climates or shorter dry periods may not experience the same degree of water stress, diminishing the relative impact of mulching. These findings highlight the need to consider regional climatic factors when extrapolating mulching effects in viticulture. In recent years, rising temperatures due to heat waves have led to increased evaporation and transpiration from plants and soil, resulting in a gradual disruption of the soil moisture balance (van Leeuwen *et al.,* 2019; Chacon-Vozmediano *et al.,* 2020). As a result, grapevine growth in Mediterranean countries is often exposed to drought stress, leading to yield reductions (Santos *et al.,* 2020). The lack of negative impact on yield in our study may be due to the early maturity of the cultivar used, which results in relatively short exposure to extreme temperatures during grape ripening (Figure 1). In some years, spring in the Mediterranean region may be rainy enough to provide sufficient soil moisture until veraison and deep-rooted plants such as vines can meet this need with rainwater. On the other hand, in years of drought, additional irrigation may be required up to the ripening stage. In conclusion, this study highlights the feasibility of sustainable viticulture in semi-arid Mediterranean ecosystems through limited irrigation and mulching. These practices preserve soil moisture, reduce water competition, and mitigate drought stress, maintaining yield and quality under water-scarce conditions (Çolak &

Yazar, 2017; Burg *et al.,* 2022). Mulching stabilises soil temperatures, enhances water retention, and suppresses weeds, improving vineyard resilience to climate variability (Bavougian & Read, 2018; Cataldo *et al.,* 2020). Limited irrigation strategies optimise water use efficiency and sustain vine performance under deficit conditions (Chacon-Vozmediano *et al.,* 2020; Caruso *et al.,* 2023). These findings align with global efforts to adapt viticulture to climate change challenges. Regions like Southern Europe and California, which are facing similar drought and temperature issues, could benefit from these strategies to enhance vineyard resilience (Costa *et al.,* 2016; Santos *et al.,* 2020). These approaches offer a practical framework for climate-resilient viticulture, with an emphasis on region-specific adaptations and further long-term studies.

In Mediterranean vineyards, the use of row cover crops is limited, but this study demonstrates the potential for such practices to enhance sustainability. Globally, the implications of these findings extend to viticulture regions facing similar challenges of rising temperatures and water scarcity. With climate change increasingly impacting grape production, strategies such as permanent mulching could play a pivotal role in mitigating water stress while maintaining yield and quality. Living mulches have been reported to compete with vines for nutrients and water, reducing yield, plant development, and berry size (Guerra *et al.,* 2022b). Guerra *et al*. (2022b) reported an increase in grape yield in bare soil plots. Our results partially support this, as yield, cluster weight, 100-berry weight and volume obtained from the bare soil application were better than the other treatments under limited irrigation. Nevertheless, in interaction analyses, it was observed that the effects of organic mulch were similar to those of bare soil in VSAT+TRIT, TALE, and PTAN, depending on the year and whether irrigation was applied. These assessments indicate that applying only non-organic mulch to the vine rows as an alternative approach could help to overcome concerns about organic mulch competing with vines for water and nutrients. However, the lower values obtained from non-organic mulch applications indicate the need for further research to test this approach. The limited research on basaltic pumice and zeolite as mulching materials highlights the need for further investigation into their potential in viticulture. Basaltic pumice, with its high porosity and thermal insulation, improves soil moisture retention and reduces surface evaporation, making it valuable in water-scarce regions (Eroğlu & Şahiner, 2020). Similarly, zeolite, a natural aluminosilicate, is known for its high cation exchange capacity and water-holding properties, enhancing soil fertility and moisture while reducing nutrient leaching (Demir & Polat, 2003). These materials show promise for addressing water scarcity in vineyards. Their relatively low environmental impact compared to chemical herbicides supports sustainable viticulture (Abad *et al.,* 2020; Buesa *et al.,* 2021). However, the long-term effects on soil properties, vine growth and grape quality remain under-explored. Future studies should assess their applicability under diverse climatic and soil conditions to better understand their role in sustainable vineyard management. Yang *et al*. (2022) reported that water scarcity during flowering in European vineyards is critical for yield potential due to climate change. They emphasise that deficit water use in the vineyards of Europe is now a critical issue, and that new irrigation options need to be developed for vineyard management.

Significant differences were detected in all must characteristics examined according to the years. High values in TSS and pH were obtained in 2021 and 2023, while high acidity values decreased the maturity index in 2022 and 2023. Despite the results regarding the effect of irrigation on reducing TSS levels and increasing pH (van Leeuwen *et al.,* 2018), did not found significant differences in terms of acidity and maturity index among irrigation treatments. This phenomenon has also been observed in the results obtained with the grape varieties used in other studies (Tangolar *et al.,* 2015). Muscas *et al*. (2017) reported that competitive ground cover plants improved must quality, with results varying according to the type of cover plant used. Our study used TALE as an organic mulch, resulting in the lowest TSS, pH and maturity index values. Despite some differences from the different applications in the study, a general evaluation of the data suggests that there are no significant differences in the maturity level and timing based on must parameter values.

Our results show that VSAT+TRIT and PTAN were the most successful cover crops for organic mulch applied to the rows, while basaltic pumice was the most effective non-organic mulch. Basaltic pumice appears to have a positive effect on soil moisture (Eroğlu & Şahiner, 2020). Because irrigation in vineyards is known to increase weed abundance during the summer months in the Mediterranean region (Juárez-Escario *et al.,* 2018), this finding is important.

To the best of our knowledge, there are few studies on applying live and inert mulches to vineyard rows in the Mediterranean region (Abad *et al.,* 2020). Our study shows that permanent vineyard floor mulches can be successfully applied in semi-arid Mediterranean climates, suppressing weeds without compromising grape yield and quality. Permanent non-organic mulch is believed to largely prevent water competition with the vines, as it does not compete with them. Consequently, using permanent mulches on vineyard rows appears to be economically feasible, as they are associated with low maintenance costs over the years, without the need for mechanical or chemical weed control, thereby reducing economic and environmental costs (Guerra *et al.,* 2022a).

Midday LWP was higher in the non-irrigated vines on 15 June and 30 June 2021, 9 June 2022, and 21 June and 12 July 2023. None of the mulches were found to affect LWP on any of the measurement dates in the first and second years of the study. In the third year of the study, LWP values showed differences depending on the mulching material on three measurement dates. There was no significant difference in the effect of the different cover crops before the last measurement. In the last measurement just after harvest in the third year of the study, the lowest (-16.6 bar) and highest (-13.4 bar) LWP values were obtained from TALE and Weedy applications, respectively. Similar effects were observed in Zeolite, Weed-free and Herbicide plots. These values support previous

findings indicating that cover crops reduce soil moisture (Giese *et al.,* 2015). Researchers in Oregon and California working on related topics have also reported minimal effects of cover crops on LWP (Sweet & Schreiner, 2010).

Permanent mulch applications prevent excessive heating of the surface soil layer, especially during the summer months (Mundy & Agnew, 2002), whereas herbicide and mowing applications tend to increase soil temperature. Permanent mulches have a cooling effect on the soil surface by reducing evaporation and shading from solar radiation (Ham *et al.,* 1993; Bavougian & Read, 2018). This situation has minimal effect on the midday LWP results. The values, between -13.0 and -16.0 bars, are indicative of plant stress. As can be seen from our results, especially in the measurements taken close to maturity (30 June 2021), the highest value was obtained from the non-irrigated and herbicide-treated plot. In the second year (2022) measurements, no significant difference was observed between irrigation and mulch applications. Bavougian and Read (2018) found no difference in midday LWP between treatments in their study, concluding that it may not be necessary to maintain a bare soil strip under vines in established vineyards in regions where soil fertility and moisture are not limiting. Water deficit before harvest can negatively affect leaf growth, berry weight and yield per vine (Gambetta *et al.,* 2020). Under the present experimental conditions, there was no significant water stress due to rainfall that occurred between November and April in the first year, and between November and June in the second and third years. Vukicevich *et al*. (2019) evaluated the effects of cover crops on a row with four living mulch plants. They observed strong grapevine growth responses, such as reduced leaf N status in weeds. After two seasons, they reduced LWP in legumes and *Lotus corniculatus* L., depending on the living mulch species. They suggest that these effects are related to changes in soil C ratio and plant-induced changes in soil moisture. Cataldo *et al*. (2020) reported that, depending on the season and inter-row management, the water potential of the vine shoot under temporary cover crops tended to be more negative due to weed-vine competition than those of tillage and mulching with plant residues every two rows under conditions of low water availability. Competition in the growing environment under the temporary cover crop application led to differences in fruit set, which affected yield and resulted in significant differences in sugar and anthocyanin content.

Values from both years indicate that mulching applications lowered soil temperatures due to some prevention of evaporation. While not all results are consistent, these data support previous studies reporting lower soil temperatures in mulched areas than in bare soil (van Huyssteen *et al.,* 1984; Abdulaziz, 2015; Burg *et al.,* 2022). These results are likely due to the temperature difference, especially the decrease in total precipitation between February and July, which covers the period from emergence to maturity and varies from year to year (MGM, 2023). Mulches can alter the radiation and energy balance at the soil surface creating cooling, heating or moisture-retaining effects on the soil, depending on the type of material used and whether, as in the present study, it is left on the surface after mowing (dry mulching), or it is spread on the soil surface using external materials such as straw, sawdust and compost (Čížková *et al.,* 2021; Burg *et al.,* 2022). Mulches, which reduce evaporation and shade the soil surface from incoming sunlight, have a cooling effect on the soil (Ham *et al.,* 1993; Burg *et al.,* 2022). Soil moisture is an important variable affecting grapevine phenology, fruit yield and quality. Grapevines grown under mulch tend to have deeper roots due to reduced soil moisture near the surface, where mulched plant roots are more competitive (Smart *et al.,* 2006). Our results have shown that the remaining mulch after mowing can be used temporarily to reduce water use, thus providing more moisture to the vines during critical growth periods, such as flowering and fruit set (Centinari *et al.,* 2013).

CONCLUSION

Even though grapes require relatively little water for growth and ripening compared to most horticultural crops, they are likely to be affected by future climate changes characterised by rising temperatures and decreasing rainfall. Therefore, it is imperative to apply soil and water conservation measures - taking into account the climatic conditions of places where irrigation water availability is limited - to avoid that do not compromise yield and quality. Mulching has been identified as being one of the most valuable of such measures. This three-year study to determine the effect of mulching and limited water applications in vineyards showed that mulching and limited water applications resulted in an increase in yield and a higher quality of grape juice composition. Mulching contributed to vine performance. There were no significant differences in quality between vines irrigated with limited water (50 % water) and those irrigated with rainwater (control). Thus, these results show how water use in the Mediterranean region - where water resources are limited–can be optimised. Mulching and limited irrigation have been identified as a beneficial strategy contributing to the sustainability of viticulture. However, there were similar results for vine rows to which organic and non-organic mulch had been applied: the results of the three-year evaluation shows that the most successful mulching material was a combination of VSAT+TRIT and PTAN for organic mulching and Basaltic pumice for non-organic. The organic mulches VSAT+TRIT and PTAN–used as alternatives to herbicides–suppress weeds to a reasonable extent and can provide a food source for natural enemies, especially honey bees. However, applying these mulches requires plants to be resown every year, involving labour and increasing the workload of producers. By contrast, basaltic pumice offers greater practicality and longevity. Over the three growing seasons of the experiment, environmental factors like wind and rain did not disperse or deteriorate the basaltic pumice. It is believed that basaltic pumice can offset its initial application cost due to its long-term presence in the soil with which it mixes and is thus recommended to producers.

Based on these results, it can be concluded that further studies on organic and non-organic mulching need to be conducted over a longer period of time and in different ecological conditions to obtain more definitive results, especially under conditions of water stress, expected in regions where total rainfall during the growing season is low. The present results nevertheless indicate that mulching and limited water applications could be beneficial in that they improve yield and quality in vineyards.

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