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Physiological and growth responses of grapevine rootstocks (*Vitis* spp.) to organic and synthetic mulch application in arid ecology under the effect of climate change

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ABSTRACT

Agricultural applications in food production have great significance in alleviating the adverse influences of environmental stressors on grapevines. In this context, mulch applications are known as environment-friendly sustainable implementations for efficiently benefiting from limited water sources. Moreover, mulches have many other beneficial effects such as quality assurance, yield improvement, ripening modulation, soil amelioration, erosion prevention and weed control. Therefore the present investigations were performed in an arid ecological condition to reveal the effects of easily available organic mulch (straw) and synthetic mulch (plastic ground covering) on physiology and growth features of worldwide popular grapevine rootstocks (41 B, 99 R 44-53 M and Rupestris du Lot). Saplings of each rootstock variety were transplanted to experimental vineyard at the end of the winter season with the spacing of 1.5 x 3.0 m within and between the rows. Mulch applications were carried out at the transplanting date. Mulch applications provided significant water retention with the higher effect of organic mulch in the soil. Stomatal conductance, leaf temperature and chlorophyll content were generally increased due to mulching. They also significantly improved the leaf and shoot growth of the rootstocks in many cases. Finally, both two mulch applications could be recommended as modern techniques in viticulture to prevent the agricultural water loss and support the plant growth. However, the organic mulch could be employed for organic and/or sustainable grape production or areas where the straw is easily available as residues of animal production.

Keywords: grapevine, sustainable viticulture, mulch application, straw

INTRODUCTION

Extremes in climatic conditions due to global climate change became a challenging problem threatening the sustainability of agricultural productivity (Jia et al., 2021). A considerable part of vineyards around the world are often situated on land that has continental climate conditions (Xue et al., 2019), where arid or semiarid conditions restrict the plant productivity (Chaika et al., 2021). In these areas, water shortage, alkalinity and winter frost injury are common problems decreasing the grape yield and quality. In order to cope with these stress factors, grape growers are trying to choose the tolerant cultivars that could adapt to environmental constrains (Čop and Njavro, 2022), while they are also looking for precision agriculture techniques to minimize the damage emerging from multiple stress factors (Karaca and Sabir, 2018). Excessive use of chemical fertilizers and water sources to cope with environmental stress factors has been causing the loss of water reservoirs, depleting the agricultural soil and disturbing the ecosystem balance at an alarming rate. Agriculturalists have been forced to ensure the food needs of substantially increasing world population with sustainable strategies establishing a good balance between the exploitation and use of natural sources on the face of worsening environmental stress factors and climate extremities (Fraga et al., 2018). Agricultural sustainability necessitates both satisfactory crop yields that can be sustained and agricultural implementations that have acceptable impacts on ecosystem (Erisman et al., 2016). The European Community's concern on environmental conservation issues and increased awareness on the part of agricultural entrepreneurs drive scientific studies to sustainable agricultural techniques for the ecosystem (Di Natale, 2019). In this context, environment-friendly innovative approaches should be practiced to maintain the agricultural productivity over time. Soil amendments, water conservation, weed control, pest management, nutrient availability regulation and canopy trellising are major aspects to ensure a long term optimum balance between vegetative and reproductive developments of grapevines. Soil management methods have essential influences on soil biological activity (Nandhini et al., 2021), photosynthetic activity and stomatal gas exchange of the vines (Tomaz et al., 2021) and the nutrient acquisition of the grapevines are influenced by temperature, compaction, and water content of cultivated soil.

Mulching is a soil management practice established or left on the surface of top soil for water and soil management purposes (Jordan et al., 2011) to conserve water and cultivated soil and to keep favorable environments for grapevine growth (Jordan et al., 2010). The beneficial impacts of mulching (organic or synthetic) can be explained as; (a) soil conservation against the impact of extreme climatic conditions and improper cultivation practices, (b) rationale use of water sources, (c) improved infiltration capacity, (d) decrease in water loss via evaporation, (e) effective weed control, (f) enhanced soil organic content and structure, (g) better micro ecology for plant root growth, and (h) convenient micro ecology for beneficial organisms. For example, Chan et al. (2010) found that composted organic mulch application significantly modified soil temperature at the 10 cm depth by reducing daily maximum and increasing daily minimum temperatures, resulting in a reduction in the daily temperature range. Besides soil water content between 0–15 cm was higher under mulch when compared to the control. The benefits of using mulch in vineyards have already been reported in many parts of the world and include weed suppression, improved soil structure and crop yield increases (Pinamonti et al., 1998; Hostetler et al., 2007). Considering the mentioned benefits of the use of mulch, a research to investigate the effect of organic and synthetic mulches on four different grapevine rootstocks was carried out in a vineyard under continental climate and arid condition.

MATERIALS AND METHODS

Experimental vineyard and study layout

A field study was conducted on four grapevine rootstocks, 44-53 M [Vitis riparia x 144 M (*V. cordifolia* x *V. rupestris*)], Rupestris du Lot (V. rupestris), 99 R (*V. berlandieri* x *V. rupestris*) and 41 B (*V. vinifera* x *V. berlandieri*) in the Research and Implementation Vineyard of Selcuk University located at 38°01.785 N, 32°30.546 E and 1158 m above sea level (Central Anatolia, Turkey). According to the climatic data collected from 1929 to 2020 by Turkish State Meteorological Service (TSMS, 2021), climatic condition in the research vineyard is arid/semi-arid with cold winters, hot and dry summers. Annual mean temperature is 11.7 °C with the highest and lowest mean values of 18.0 and 5.4 °C, respectively. The highest temperature was 40.6 °C, while the lowest one was -28.2 °C. The coldest and the hottest months are January and July, respectively. Average precipitation is 329.2 mm, with a relative humidity below 50%, probably because the prevailing north wind and common south wind are dry. The study vineyard has a soil characterized with calcareous (pH: 7.5±0.2) clay loamy texture. The rooted three-year old cuttings with 15±3 cm single summer shoots were transplanted into the experimental vineyard at the beginning of the vegetation period (30.04.2018). In the experimental area, the grapevine rows were east–west oriented, and the transplantation spacing between grapevines and between rows were 1.3 and 2.7 m, respectively. The young plants were drip irrigated during the summer using single irrigation line per grapevine row, single emitter of about 4 L h^{-1} per vine each. The experimental vineyard consisted of three rows (one row per application) and each row, with a total of 24 plants, contained six plants per rootstock genotype. All the rows were watered two or three times per week during the study. The single summer shoot of each plant was tied with thread to wires 2.0 m above the ground to let plants grow on a perpendicular position to ensure equally benefiting from the sunlight. The experimental rows were composed of (I) control (without mulching), (II) organic mulching (Organic groundcovers were hand broadcast and raked in. The plant row was covered with wheat straw at 1 m wide and 10 cm high), and (III) synthetic mulching (covering the row surface with black polyethylene, 100 µ thick and UV supplemented, as commonly used in strawberry cultivation). The experimental area was covered by black net to protect the plants against hail and harsh climatic conditions (Figure 1).

Figure 1. Transplantation of rooted cuttings of the rootstocks on synthetic mulch row

Measurements and analyses

The water content around the root zone in the 20±5 cm soil profile was taken into account to compare the effects of mulch applications on water retention. Soil water content was measured gravimetrically at midseason when the evaporation was at the highest level. About 100 g soil samples were collected from various points of each rows and transported to the laboratory in plastic bags. Measurements on leaf stomatal conductance (gs) were carried out periodically during the summer season on the leaves at 6^{th} node each main shoot from all vines between 09:00 and 12:00 h (Sabir and Yazar, 2015). Fully expanded but not damaged sun exposed leaves at the grapevine canopy were selected for physiological investigations (Johnson et al., 2009). The gs of the leaf was measured near blade the central vein in the same area of the leaves with a portable leaf porometer (SC-1 Leaf Porometer) (Zufferey et al., 2011) and was described as mmol H_2O m^{-2} s^{-1}. Measurements regarding to fresh weight, dry weight and area of 12 expanded leaves per treatment were performed when the shoot growth was near to cease. Using one set of 12 leaves, leaf area was estimated using WinFolia computer image analysis system. Fresh weights of the leaf samples were determined with a balance with a 0.001 g precision using another set of 12 fresh leaves. After fresh weight records, the relevant leaf samples were subjected to imbibition for obtaining the turgid weight. The turgid weights of the leaves were recorded after 24 h imbibition. Afterwards, the dry weights of the leaves were investigated by heating the leaf samples in 105 °C at 24 h. When the sample reach a constant weight, the water loss was calculated to find % soil water content (Gardner, 1986). The leaf relative water content (RWC) was obtained by formula; RCW= (fresh weight – dry weight)/(turgid weight – dry weight) × 100 (Pieczynski et al., 2013). Measurements were performed with an analytical scale having a precision of 0.0001 g. Chlorophyll amount of the newly expanded mature leaves (third and fourth leaves at the shoot tip) were determined with a portable chlorophyll meter (SPAD-502, Minolta, Japan). Shoot length (measured with a sensitivity of 1 mm), and shoot diameter (obtained by caliper at an approximate point of 1 cm above the second node) were recorded at the end of vegetation period around the shoot growth cessation (Sabir, 2013) (Figure 2).

Statistical analysis

The numerical data were evaluated with statistical analysis using a randomized factorial design. Each experimental treatment was conducted with three replicates containing two healthy rootstock vines. The comparison of mean values was performed using the least significant difference (LSD) test. Statistical tests were carried out at $P<0.05$ using SPSS 13.0 for Windows (SPSS Inc., Chicago, IL, USA).

Figure 2. A photo showing the grapevine rootstocks at around the end of the vegetation period (From left to right: Control, synthetic mulch, organic mulch)

RESULTS AND DISCUSSION

As depicted in Figure 3, the water content of the experimental soil displayed significant variations in response to the mulch applications. The greatest water content was obtained from organic mulch application (12.3%), which was followed by synthetic mulch (8.7%), while the lowest value was obtained from control (7.5%).

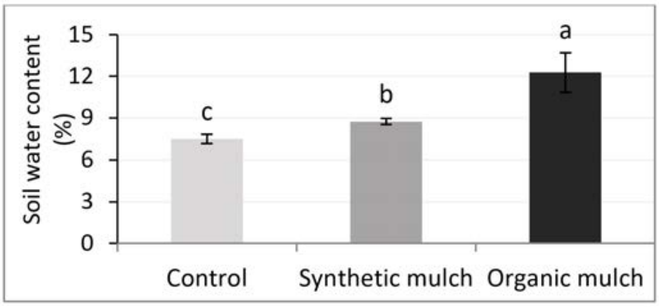

Figure 3. Changes in soil water content (%) as influenced by different mulch applications. Each column represents the mean of triplicate observations with three soil samples for replicate (n = 9). Error bar represents the standard deviation of that mean (at $P<0.05$ level by LSD).

In a study conducted in Germany, significant increase in soil water content of vineyard plots mulched with sawdust was reported (Huber et al., 2003). Mundy and Agnew (2002) also determined greater water content in the soil of experimental vineyard under a variety of organic mulch applications. As known, surface-applied plant residue mulches store water and decreases the evaporation from the soil surface (Blume, 2007), and thus they improve soil water retention (Bavougian and Read, 2018). Čížková et al. (2021) reported the beneficial effect of organic mulch materials on the retention of soil water content in vineyard. The storage of the limited soil water is among the major challenges for precision water management for sustainable agriculture in arid and semi-arid regions.

The water pathway from the plant root to leaf evaporation points has significant roles for managing the leaf water balance, providing stomata to maintain open, and resulting in convenient carbon capture. Mulch applications generally had significant effects on the stomatal conductance (gs) across the grapevine rootstocks during the vegetation season (Figure 4). In the first measurement date, the gs did not respond significantly for all the genotypes. But, in the second measurement about midseason, the gs displayed significant variations with the highest values obtained from organic mulch for 44-53 M, Rupestris du Lot and 41 B. For all of the rootstocks, the lowest gs values were obtained from control vines, probably due to decrease in available water around the root zone. Stomatal regulation is a complex physiology involving feedback managements which interact with a varieties of environmental stimuli such as light, temperature (Sabir and Yazar, 2015) and

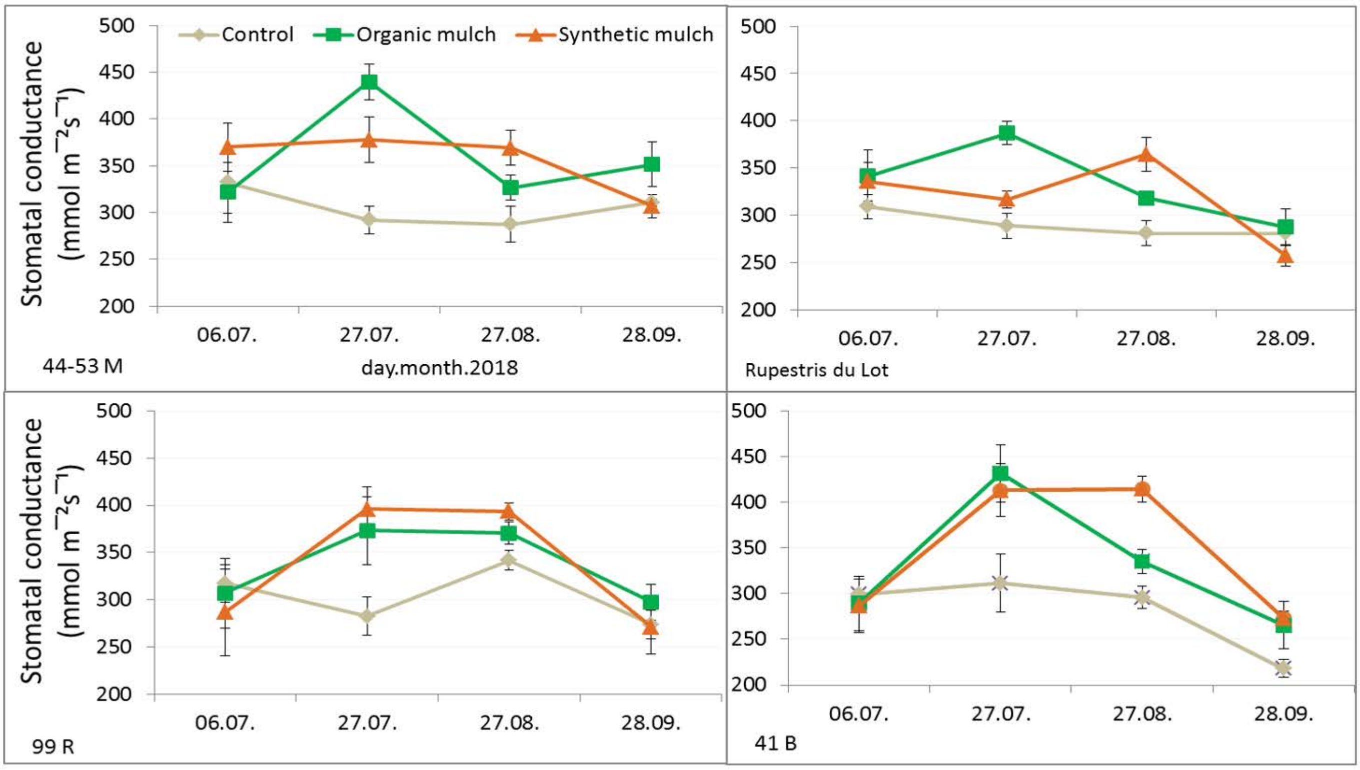

Figure 4. Seasonal course of average stomatal conductance (mmol $m^{-2}s^{-1}$) of the rootstocks as influenced by mulch applications. The data were collected over four different dates at clear sunny days. Each column represents the mean of six observations per application. Error bar represents the standard deviation of that mean (at P<0.05 level by LSD).

water status of the leaves in tree species (Johnson et al., 2009). Mulch applications resulted in significant increase in the gs at the third measurement date when the plant growth was at higher levels in the season. Afterwards, the gs underwent a remarkable decrease due to seasonal changes in climatic condition. Ferrara et al. (2012) studied the effects of the mulch application in the vine rows using two synthetic materials (geotextile as polypropylene and black polyethylene) and an organic matter (exhausted olive pomace) in an organically managed vineyard located in Puglia region of Italy. They concluded that exhausted olive pomace positively influenced the grapevine stomatal conductance.

Earlier investigations indicated that the use of mulches in vineyards or fruit orchards has been found to induce plant growth (Lanini et al., 1988), and mulch-dependent growth promotion could be attributed to the enhanced soil water availability with well-balanced diurnal temperature of the soil around the active roots as stated by (Chan et al., 2010). Studies on different grapevine genotypes also revealed that mulched compost can decrease water loss by evaporation and drainage into deeper soil horizons Pinamonti (1998), and increased photosynthesis per grapevine (Nguyen et al., 2013).

Seasonal changes in leaf chlorophyll concentration in response to mulch applications have been illustrated in Figure 5. Up to the midseason, mulch applications did not remarkably affect the chlorophyll content of the leaves. However, at the third measurement date (27.08.2021), synthetic mulch application resulted in the sharp increases in chlorophyll content across the rootstocks. In this period, organic mulch application also led to significant improvement in Rupestris du Lot and 41 B rootstocks. López et al., (2014) reported that mulching provided an increase in N and K contents of the soil, and the existence of such nutrients has been correlated with the greater production of photosynthetic pigments in plants. The findings of present study along with the mentioned report indicate the positive effect of mulching on improvement of leaf chlorophyll content.

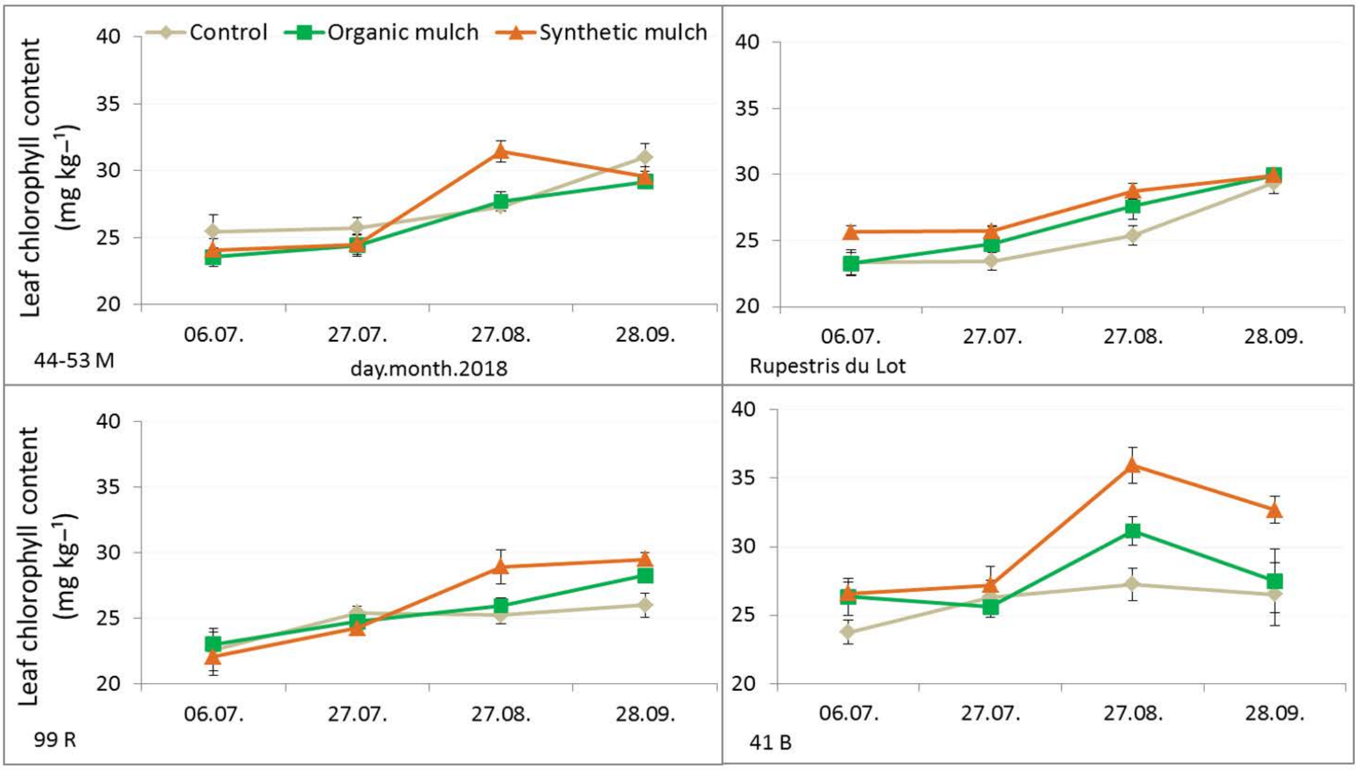

Figure 5. Seasonal course of average leaf chlorophyll content (mg kg^{-1}) of the rootstocks. The data were collected over four different dates at clear sunny days. Each column represents the mean of eleven observations per application. Error bar represents the standard deviation of that mean (at *P*<0.05 level by LSD).

Leaf growth displayed significant changes in response to mulch applications (Table 1). Organic mulch significantly increased the leaf fresh and dry weights in 44-53 M and 41 B rootstocks. On the other hand, the use of synthetic mulch resulted in the greatest leaf fresh and dry weight values in Rupestris du Lot and 99 R. Mulching also had remarkable effects on leaf RWC. The highest leaf RWC values were obtained from organic mulch application across the rootstocks. Leaf RWC is an important determinant of water status in plants; it describes the physiological balance between the leaf transpiration rate and water supply to the leaf tissue (Lugojan and Ciulca, 2011).

Mulch applications had significant effects on leaf areas of the rootstocks (Figure 6). Both organic and synthetic mulch significantly increased the leaf area in Rupestris du Lot and 41 B rootstocks. In 44-53 M, the greatest leaf area was obtained from synthetic mulch while organic mulch was the most effective one for 99 R. Many studies on grapevines have proven that an increase in leaf area will result in subsequent improvement in plant growth and reproductive development (Edson et al., 1995) as higher leaf area would provide much more benefit from sunlight for photosynthesis (Kliewer and Dokoozlian, 2005). Leaf area has been proven as one of the plant growth features determining the adaptation potential of grapevines to environmental stress (Lebon et al., 2006).

Mulch applications significantly increased the shoot length among the rootstocks, except for organic mulch in 44-53 M (Figure 7). The greatest shoot length values were obtained from synthetic mulch across the rootstocks with significant effects. On the other hand the lowest values were determined in control plants. In contrast to the present results, Nguyen et al. (2013) found that application of 5 cm thick organic compost mulch did not significantly affected shoot growth of 'Merlot' grapevines when applied to the grapevine row. On the other hand, in a study carried out during five years, organic mulches composed of municipal waste and sewage sludge plus bark had a beneficial influence on pruning residue weight

(Pinamonti, 1998). Van Huyssteen and Weber (1980) also indicated that full surface straw mulch had a positive impact on pruning mass and shoot growth in comparison to the clean cultivation, shallow and deep trench furrow systems. Differences between the studies might be due to the distinctness of the ecological conditions of the mentioned investigations. Use of mulches in orchards has been reported to support plant development (Lanini et al., 1988), and growth promotion due to mulch application is attributed to the enhanced soil environmental conditions and balanced diurnal temperature as well as increased soil water availability and nutrient release for grapevine roots (Chan et al., 2010).

Table 1. Changes in fresh weight (g), dry weight (g) and relative water content (RWC, %) of the leaf as influenced by different mulch applications

Rootstocks	Applications	Fresh weight (g)	Dry weight (g)	RWC (%)
44-53 M	Control	2.59±0.27b	0.85±0.03b	61.2±1.52b
	Organic mulch	2.71±0.14a	0.90±0.03a	65.3±1.78a
	Synthetic mulch	2.55±0.08b	0.83±0.02b	63.6±1.06ab
Rupestris du Lot	Control	2.85±0.05b	0.88±0.02b	61.8±1.28b
	Organic mulch	2.87±0.05b	0.87±0.09b	71.9±2.62a
	Synthetic mulch	3.03±0.04a	0.93±0.02a	63.5±0.87b
99 R	Control	1.66±0.07b	0.42±0.01c	61.0±2.32b
	Organic mulch	1.74±0.05b	0.63±0.03a	65.7±1.90a
	Synthetic mulch	1.94±0.05a	0.54±0.02b	59.8±2.50b
41 B	Control	2.88±0.11c	0.77±0.06b	59.9±2.62b
	Organic mulch	4.57±0.07a	1.16±0.18a	73.2±1.12a
	Synthetic mulch	4.24±0.04b	1.24±0.08a	57.8±2.54b
$LSD_{P<0.05}$ for 44-53 M		*0.19*	*0.04*	*2.95*
$LSD_{P<0.05}$ for Rupestris du Lot		*0.08*	*0.04*	*3.48*
$LSD_{P<0.05}$ for 99 R		*0.11*	*0.05*	*4.14*
$LSD_{P<0.05}$ for 41 B		*0.15*	*0.22*	*4.39*

All values are means ± standard error (*n* = 12). Means not connected by same letter are significantly different (*P*<0.05) level by LSD

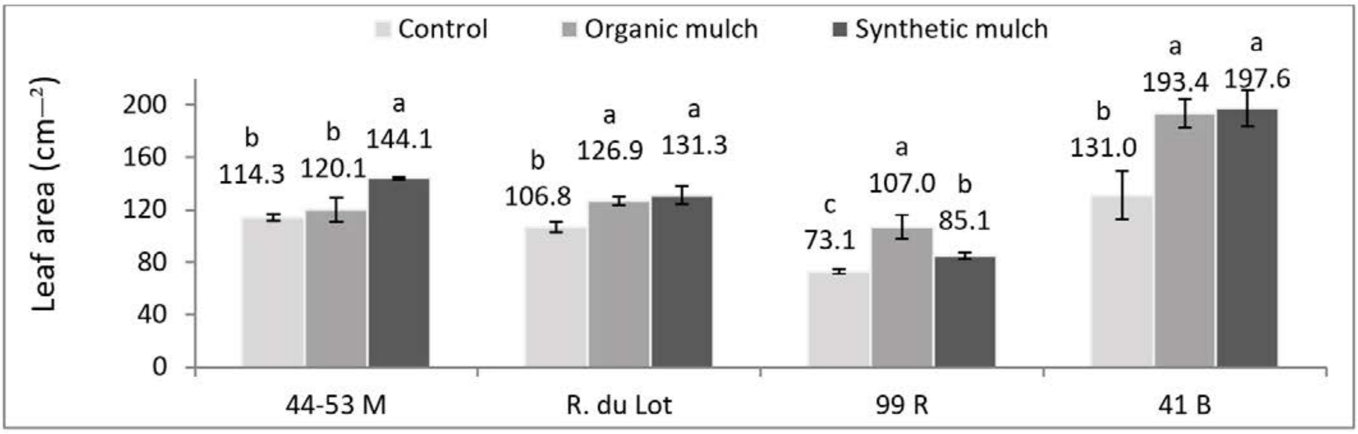

Figure 6. Changes in leaf area (cm^2) of the rootstocks as influenced by different mulch applications. Each column represents the mean of six plants per application. Error bar stands for the standard deviation of that mean (at *P*<0.05 level by LSD).

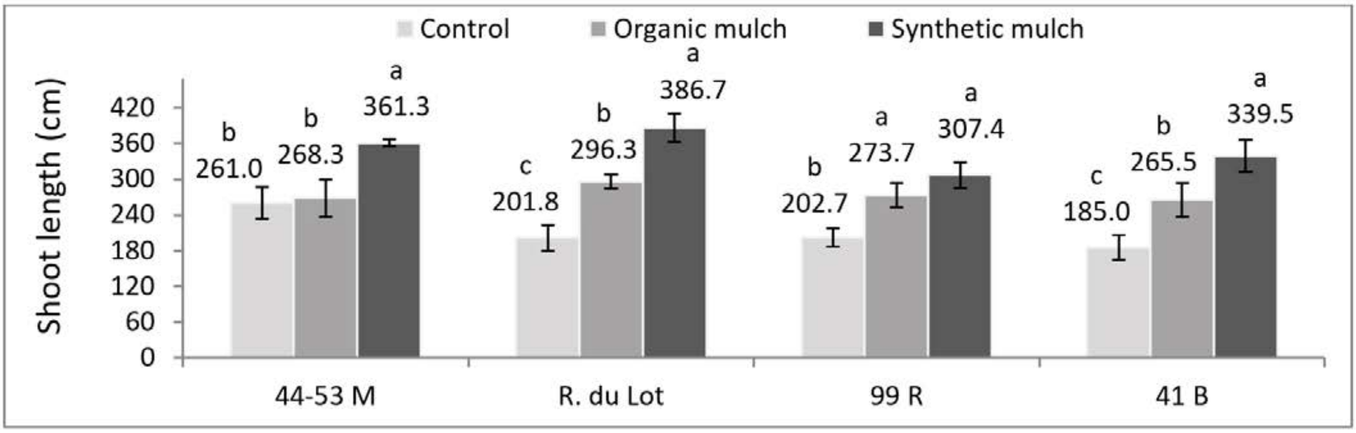

Figure 7. Changes in shoot lengths (%) of the rootstocks as influenced by different mulch applications. Each column represents the mean of six plants per application. Error bar stands for the standard deviation of that mean (at $P<0.05$ level by LSD).

Furthermore, mulch applications effectively reduced the evaporation by draining the water into deeper horizons of the vineyard soil (Pinamonti et al., 1998) and increased the photosynthesis of grapevines (Nguyen et al., 2013).

Similar to the findings on shoot length, the highest values on shoot diameter were obtained from synthetic mulch application, significantly improving the shoot diameter in comparison to control. Organic mulch also had significantly positive effect on shoot diameter except for 44-53 M rootstock. Promotion in shoot diameter after organic mulch application was also reported by Kara and Fakhar (2020) who studied the effects of different mulch applications on seedling growth of 110 R and Fercal rootstocks. Shoot diameter is considered as one of the growth features determining the tolerance potential to drought and cold stresses (Sabir and Sahin, 2018).

Therefore, mulch applications could be recommended to mitigate adverse effects of such environmental constraints on grapevines.

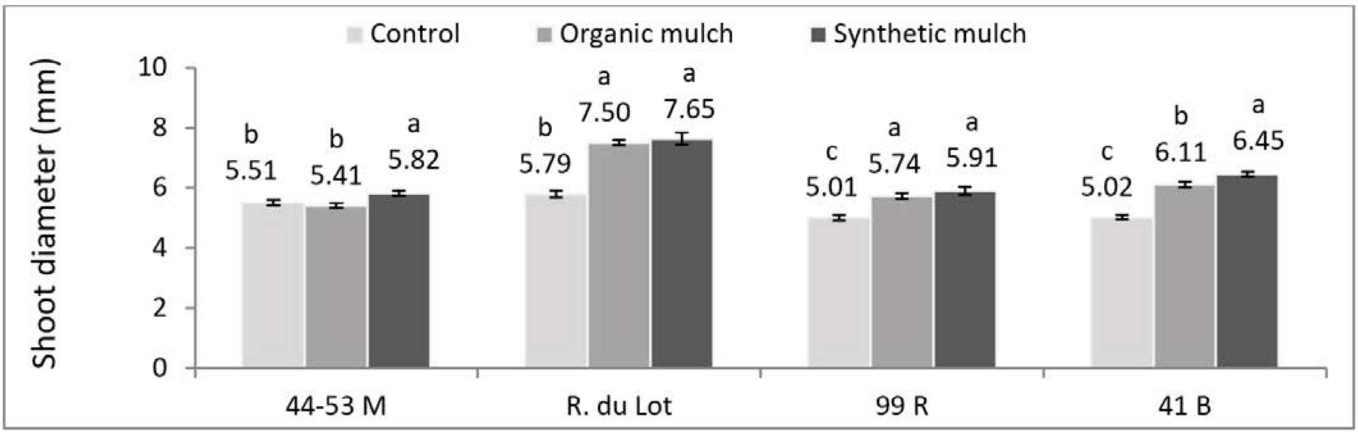

Figure 8. Changes in shoot diameters (mm) of the rootstocks as influenced by different mulch applications. Each column represents the mean of six plants per application. Error bar stands for the standard deviation of that mean (at $P<0.05$ level by LSD).

CONCLUSION

Soil water measurements in middle of summer season revealed that synthetic and organic mulch applications remarkably conserved the water content around the grapevine roots. This implied the significance of mulching for agriculture in arid and semi arid regions to sustainable conserve the limited water sources on the face of climate change events. The use of mulches also positively affected the physiology and growth features of grapevine rootstocks. Both mulch treatments can be recommended for viticulture in arid and semiarid areas, while the use of organic mulch could be advised as environment-friendly practice for organic grape growing or areas where the wheat straw are abundantly available as outputs of animal production.

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