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ORIGINAL PAPER

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EFFECTS OF VINE WATER STATUS ON VINE PERFORMANCE AND GRAPE COMPOSITION OF (*Vitis vinifera* L.) cv. 'Sultani Çekirdeksiz'

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ABSTRACT

Drought caused by climate change increased the relevance of irrigation management in viticulture. In order to regulate irrigation strategies for *Vitis vinifera* L., their influences on vine performance, yield and quality attributes need to be understood. This study evaluates the effects of different irrigation schedulings on vine performance and grape composition in a vineyard of cv. 'Sultani Çekirdeksiz' (*Sultana clone, H5*) during three consecutive years (2015–2017). Three irrigation treatments were assayed: (i) full irrigation (FI), soil water content was completed to field capacity within one week intervals; (ii) DI_{65}, applying 65% water of FI and (iii) DI_{35}, applying 35% water of FI. Water stress caused by the deficit irrigation treatments limited vine performance in terms of vegetative development and yield. The highest phenolic content, antioxidant capacity and total flavonoid accumulation were obtained under DI_{35}, although this treatment had lowest yield. In conclusion, DI_{65} (moderate stress) might result in a more balanced yield and grape quality attributes in comparison with FI and DI_{35}.

Key words: climate change, available water, deficit irrigation, grape quality, grapevine growth

INTRODUCTION

Climate is one of the most important factors affecting agricultural production. Some parameters such as crop yield and quality attributes depend on climate and consequently, are affected by climate change [Fraga et al. 2018]. In this context, climate change may have direct or indirect effects on viticulture in terms of grapevine morphological, phenological and physiological development, berry composition, yield, quality, maturation, irrigation, fertilization, storage, marketing etc. All these effects may show similarities or differences on grape varieties [Jones et al. 2012]. Water scarcity caused by climate change is one of the most important factors affecting grape production worldwide [Costa et al. 2016]. This situation becomes more problematic in the Mediterranean region due to the water stress that vineyards must face and the low expected yields [Permanhani et al. 2016]. Indeed, severe water stress directly and negatively affects grapevine vegetative growth, yield and berry quality attributes [Buesa et al. 2017, Cooley et al. 2017].

Irrigation time and quantity directly affect quality and yield in table and wine grape production [Shellie 2014, Intrigliolo et al. 2015, Permanhani et al. 2016]. Accurately determining irrigation needs for each grapevine variety will increase our ability to cope with water deficit problems that may occur in the future. Many studies reported that changes in water potential according to the phenological periods of grapevine in-

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fluence berry composition and other quality attributes by modifying vegetative development, yield, canopy microclimate and grapevine metabolism [Schultz 2016]. For instance, Bahar et al. [2011] carried out deficit irrigation treatments before the berry set to determine the effects of early water stress and found that berry size was negatively affected. Moreover, the effects of deficit irrigation on berry quality depend on climatic conditions, soil structure and physical properties, variety and irrigation time [Romero et al. 2013]. Furthermore, yield losses, deterioration in some quality characteristics, decrease in vegetative development and undesirable conditions in ripening may occur depending on the water stress level [Romero et al. 2014, Mirás-Avalos and Intrigliolo 2017]. On the other hand, excessive irrigation or water use does not have any positive effect on the vine yield. According to Proffitt and Campbell-Clause [2011], the relationship between irrigation water and yield is not linear but yield increases up to a certain point with the amount of water applied and, after reaching the maximum efficiency, additional water application has no effect on yield.

Moreover, in order to use available water resources effectively in the Mediterranean zone, it is necessary to develop new water saving techniques that increase water use efficiency. For this reason, it is necessary to develop appropriate irrigation strategies by estimating the amount of water needed by vines, and to use modern techniques that increase water use efficiency and save water in vineyards [Cancela et al. 2016, Fraga et al. 2018, Santos et al. 2020].

Therefore, sub-surface drip irrigation systems, which reduces water losses and increase water use efficiency, was used in our research. The present experiment was then aimed at exploring the effects of water deficit treatments on vine performance and berry composition of field grown 'Sultani Çekirdeksiz' (*Sultana clone*, *H5*) grapevines in western Turkey.

MATERIALS AND METHODS

Location, soil description and plant materials. This research was carried out in the experimental vineyard of Manisa Viticulture Research Institute (Manisa Province, Aegean Region, Turkey) during 3 years (2015–2017). The trial area is located at 38°37'N and 27°24'E, 43.7 m above the sea level. Long-term mean monthly (1980–2014) and 2015, 2016, 2017 growing seasons climatic data at the experimental area are presented in Table 1. The Aegean region has a Mediterranean climate; summers are hot and dry while winters are warm and rainy. According to the long-term data, the average annual rainfall is 685 mm but nearly 76% is concentrated from November to March. Temperature, relative humidity, wind speed and rainfall were monitored with a weather station during the 3 years of the study. Additionally, phenological growth stages (EL stages) were observed according to Lorenz et al. [1995]. Soil at the experimental site is loamy textured. Some physical properties of the soil are given in Table 2. Soil water content at field capacity is 233 mm and available water in the upper 90 cm of the soil profile (effective root depth) is 145 mm. Moreover, pH and average electrical conductivity (EC) values of irrigation water respectively varied between 7.55–7.74 and 0.446–0.432 dS m^{-1} in 2015–2017.

The experiment was conducted on 6 years old 'Sultani Çekirdeksiz' (syn. *Thompson Seedless*) table grape variety, grafted on 1103 Paulsen rootstock. Vines were planted on a 2.5 m to 3.0 m spacing and rows were oriented in the North-South direction. All vines were cane-pruned with each cane being approximately 10–12 nodes in length. Y-shaped (6 wires) training system was used. The same agrotechnical practices were applied to all treatment plots during 3 seasons (Tab. 3). The same concentrations of fertilizers were applied to all treatments. For this reason, soil samples were collected from the experimental site during the dormant period. Then fertilizer doses were determined according to the soil analyses.

Irrigation treatments and experimental design. Three different treatments were considered in the current study; namely full irrigation (FI) and two deficit irrigation treatments (DI_{35} and DI_{65}). For the "FI treatment", soil water deficit in the 90 cm of the soil profile (effective root depth) was replenished to field capacity. On the other hand "DI_{35} and DI_{65}" treatments received 35% and 65% of the water applied to FI. All treatments started when the available water decreased 50% in the effective root depth (90 cm) and continued with an interval of one week. A sub-surface drip irrigation system with drip laterals placed 40 cm below the soil surface was used. A single drip lateral was placed at 50 cm from each vine row for all

Table 1. Long-term (1980–2014) and 2015, 2016, 2017 growing seasons monthly weather conditions at the experimental site (Manisa Province, Aegean Region, Turkey)

Year	Parameters	Months					
		March	April	May	June	July	August
1980–2014	mean temperature (°C)	10.5	15	20.4	25.5	28.2	28
	rainfall (mm)	78.1	58.9	34.6	18.1	8.9	8.5
	relative humidity (%)	65.9	61.4	55.8	47.7	44.1	45.5
	wind speed (m s^{-1})	1.4	1.4	1.5	1.6	1.7	1.6
	number of rainy days	10	9	7	3	1	1
2015	mean temperature (°C)	10.8	13.7	21.6	23.7	28.8	28.6
	rainfall (mm)	74.6	32.4	53.8	55	0	74.4
	relative humidity (%)	72.4	57.2	51.7	58.4	42.8	49.8
	wind speed (m s^{-1})	1.3	1.6	1.5	1.5	1.5	1.4
	number of rainy days	11	11	4	6	0	5
2016	mean temperature (°C)	12	18.2	19.7	26.9	29	28.8
	rainfall (mm)	136.2	11.2	79.9	27	0	0
	relative humidity (%)	66.9	54.2	58	47.6	42.8	49.1
	wind speed (m s^{-1})	1.5	1.4	1.5	1.6	1.6	1.4
	number of rainy days	11	4	10	5	0	0
2017	mean temperature (°C)	12.1	15.5	20.8	25.7	28.9	28.5
	rainfall (mm)	75.2	16.5	48.1	10.3	0.2	2.0
	relative humidity (%)	68.9	53.9	54.1	52.3	43.2	47.2
	wind speed (m s^{-1})	1.2	1.3	1.3	1.3	1.5	1.5
	number of rainy days	11	5	9	7	1	1

Table 2. Soil physical and hydraulic properties at different depths in the experimental field

Soil depth (cm)	Saturation (%)	Texture class	FC (%)	WP (%)	BD (g cm^{-3})
0–30	39.18	loamy	15.33	6.92	1.53
30–60	40.21	loamy	19.34	6.73	1.51
60–90	40.21	loamy	17.08	5.97	1.47

FC: field capacity; WP: permanent wilting point; BD: bulk density

Table 3. Agrotechnical practices conducted during the experiment in 2015, 2016, 2017 growing seasons

Applications	2015	2016	2017
Winter pruning	16.02.2015	10.02.2016	13.02.2017
Cultivar	'Sultani Çekirdeksiz' (*Sultana clone, H5*) table grape variety (syn. *Thompson Seedless*)		
Plant density	1666 vine ha^{-1}		
Fertilization	P and K fertilization was applied deeply before bud break. N fertilization was applied during bud break and fruit set. All doses were determined according to the soil sample analysis		
Leaf removal	fruit set (only old leaves) and veraison (one quarter of leaves)		
Irrigation system	sub-surface drip irrigation system		
First irrigation	02.07.2015	16.06.2016	15.06.2017
Last irrigation	13.08.2015	04.08.2016	10.08.2017

treatments and laterals (Netafim Comp., Manisa, Turkey) with inline emitters with flow rate 3.0 L h^{-1} spaced at 40 cm intervals.

A randomized block design was used. There were 3 replications in each treatment and 6 vines in each replication (54 vines in total). Additionally, 128 vines were used as buffers.

Measurements. Soil water content (SWC) was determined by gravimetry analysis for the effective root depth (90 cm) once per week before the irrigations and the amount of irrigation water was calculated according to the following equation:

$$I = (FC - SWC) \times A \times P \tag{1}$$

In this equation, I is the amount of irrigation water (L); FC is the soil water content at field capacity (mm); SWC is the pre-irrigation soil water content (mm); P is the wetting percentage (35%) and A is the surface area of the plot (m^2).

Crop water use or evapotranspiration (ET) was calculated with the water balance equation.

$$ET = I + P \pm \Delta SW - Dp - Roff \tag{2}$$

In this equation, ET is the evapotranspiration (mm); I is the amount of irrigation water applied (mm); P is precipitation (mm); ΔSW is the change in the soil water content (mm); Dp is deep percolation (mm) and $Roff$ is amount of runoff (mm). Dp and $Roff$ were assumed to be negligible. Water use efficiency (WUE) was calculated as grapevine yield divided by seasonal ET [Çolak and Yazar 2017]. Midday leaf water potential (Ψ_{md}) measurements were conducted as described by Williams et al. [2012]. Ψ_{md} was measured using a Scholander Pressure Chamber (Skye Instrument Co., UK) between 12:30 and 13:30 h, UTC+3 time zone. Three mature, healthy and fully expanded leaves were selected from 3 vines from each replicate. The leaves were selected from the middle of the canopy at the sunny side and measurements were conducted once a week before the irrigation treatments.

At harvest, yield per vine and yield per decare were determined according to the hand harvested clusters in each replicate (6 vines). Additionally, physiological maturity of grapes were considered for the determination of the harvest date.

Vegetative performance of grapevines was also evaluated. For this purpose, Pruning wood weight (kg $vine^{-1}$) was determined by weighing the main and lateral canes of the vines during the pruning period according to Romero et al. [2014]. Vigor (g) was calculated by dividing PWW per vine by number of canes [Carbonneau 1998]. Puissance (strength of vine) were calculated according to the following equation [Carbonneau 1998]:

$$\begin{aligned} \text{Puissance} = {} & [(\text{PWW}(\text{kg vine}^{-1}) \times 0.5) + \\ & + [\text{Yeild}(\text{kg vine}^{-1}) \times 0.2] \end{aligned} \tag{3}$$

Ravaz Index (RI) was calculated by dividing yield per vine by PWW [Jones et al. 2009]. Trunk diameter (mm) was measured 20 cm above the graft union on 3 grapevines in each replication. Measurements were done at the beginning and the end of the vegetative period and the difference was calculated as a trunk diameter variation.

Grape samples were collected at harvest from each replicate (6 vines). Total soluble solids (TSS; %), pH, titratable acidity (TA; g L^{-1}), maturity index (MI), berry width (mm) and berry length (mm) were determined using the official methods of the International Organisation of Vine and Wine [OIV 1990]. Total phenolic content (mg kg^{-1}) of the grapes was determined by the Folin-Ciocalteu method and total flavonoid (mg kg^{-1}) was estimated using the aluminum chloride colorimetric assay. Antioxidant capacity (EC_{50}) was determined according to the DPPH method. Berry flesh firmness (kg force) and berry removal force (kg force) were measured with a dynamometer (Geratech SH-200 Model Digital Force Gauge).

Statistical analysis. JMP Pro 13.2.1 statistical software was used according to the randomized block design for determining differences among treatments and years. First, a normal distribution test (Shapiro-Wilk W Test) was performed for each variable in order to check the hypothesis of normality. In this study, "LogLn Transformation" was applied only for the maturity index in 2015, since this was the only variable that did not follow a normal distribution. Mean separation was performed using the LSD test.

RESULTS AND DISCUSSION

Climatic conditions and phenological development stages. According to the phenological ob-

Table 4. Phenological (EL) stages of 'Sultani Çekirdeksiz' grapevines during the experiment in 2015, 2016, 2017

EL-05		EL-23		EL-27		EL-35		EL-38	
bud burst	DOY	full flowering	DOY	fruit set	DOY	veraison	DOY	harvest	DOY
27.03.2015	86	25.05.2015	145	30.05.2015	150	20.07.2015	201	20.08.2015	232
21.03.2016	81	9.05.2016	130	15.05.2016	136	17.07.2016	199	10.08.2016	223
22.03.2017	81	19.05.2017	139	24.05.2017	144	16.07.2017	197	14.08.2017	226

DOY: day of the year

servations (Tab. 4), bud burst (EL-05) occurred on 27.03.2015 (86th day of the year, DOY), 21.03.2016 (81st DOY) and 22.03.2017 (81st DOY), respectively. The date of veraison (EL-35) occurrence was 20.07 (201st DOY) in 2015, 17.07 (199th DOY) in 2016 and 16.07 (197th DOY) in 2017. Phenological stages except harvest occurred at the same time on all treatments. Harvest (EL-38) was performed at 18–20% TSS on 20.08 (232nd DOY) in 2015, 10.08 (223rd DOY) in 2016 and 14.08 (226th DOY) in 2017 for the FI treatment. The number of days between fruit set (EL-27) and harvest (EL-38) in this treatment were 82, 87 and 82 days in the 2015, 2016 and 2017 growing seasons, respectively. Additionally, in 2015, harvest date occurred 4 days earlier under the DI_{35} treatment in comparison to FI. However, DI_{65} and FI were harvested on the same date. Moreover, in 2016 and 2017, the DI_{35} treatment provided 6–8 days earliness compared to FI, while DI_{65} treatment provided 3–4 days earliness compared to FI.

The number of days with maximum temperature above 35°C was 44, 48 and 46 days, respectively for the 2015, 2016 and 2017 growing seasons (Tab. 4). In addition, precipitation was 129.4 mm in 2015, 27 mm in 2016 and 12.5 mm in 2017 during summer (June–July–August). The long-term (1980–2014) average precipitation over the summer period in the area is 35.5 mm (Tab. 1). Although the amount of precipitation in the summer period was higher in 2015, stress symptoms were observed in vines because no rainfall was registered in July 2015.

Soil – grapevine water relations. Field capacity and wilting point down to 90 cm depth of the soil in the experimental site were 233 mm and 88 mm respectively. Accordingly, the amount of available water was 145 mm. Soil water content varied depending on the irrigation water amounts given to each treatment during the 3 experimental seasons (Fig. 1). Soil water content (SWC) remained above 50% of the available water level during the 2015 season (Fig. 1a) under the 3 (FI, DI_{65} and DI_{35}) treatments. In contrast, it decreased below 50% of the available water level under the DI_{35} treatment in 2016 (Fig. 1b) and 2017 (Fig. 1c) seasons. The highest SWC throughout the 3 experimental seasons was observed under FI, followed by DI_{65} and DI_{35}, respectively. Additionally, in the 2016 and 2017 seasons, which received less precipitation than the 2015 season, SWC tended to decrease towards the permanent wilting point at the end of the season under the DI_{35} treatment (Fig. 1). This reveals that the weekly SWC monitoring performed was appropriate. In a similar study conducted in the Royal table grape variety, SWC remained above 50% of the available water level under FI while decreased with the increment of the water stress level down to the wilting point under the non-irrigation treatment [Çolak and Yazar 2017]. The soil moisture content, which varies throughout the season, affects the water status in the root zone. This situation also affects stomatal conductivity and leaf water potential in the short term. In addition, the vine performance and yield attributes also vary with the evaporative demand in the long term period [Munitz et al. 2016, Buesa et al. 2017, Zufferey et al. 2018].

According to Table 5, seasonal irrigation water amounts varied with the experimental year. In the case of the FI treatment, irrigation ranged between 198–326 mm, depending on the rainfall received each year. On the other hand, when the ET values were examined, the lowest value was observed in DI_{35} (222 mm in 2016), while the highest value was observed in FI (463 mm in 2015). Ünal [2008], reported that the

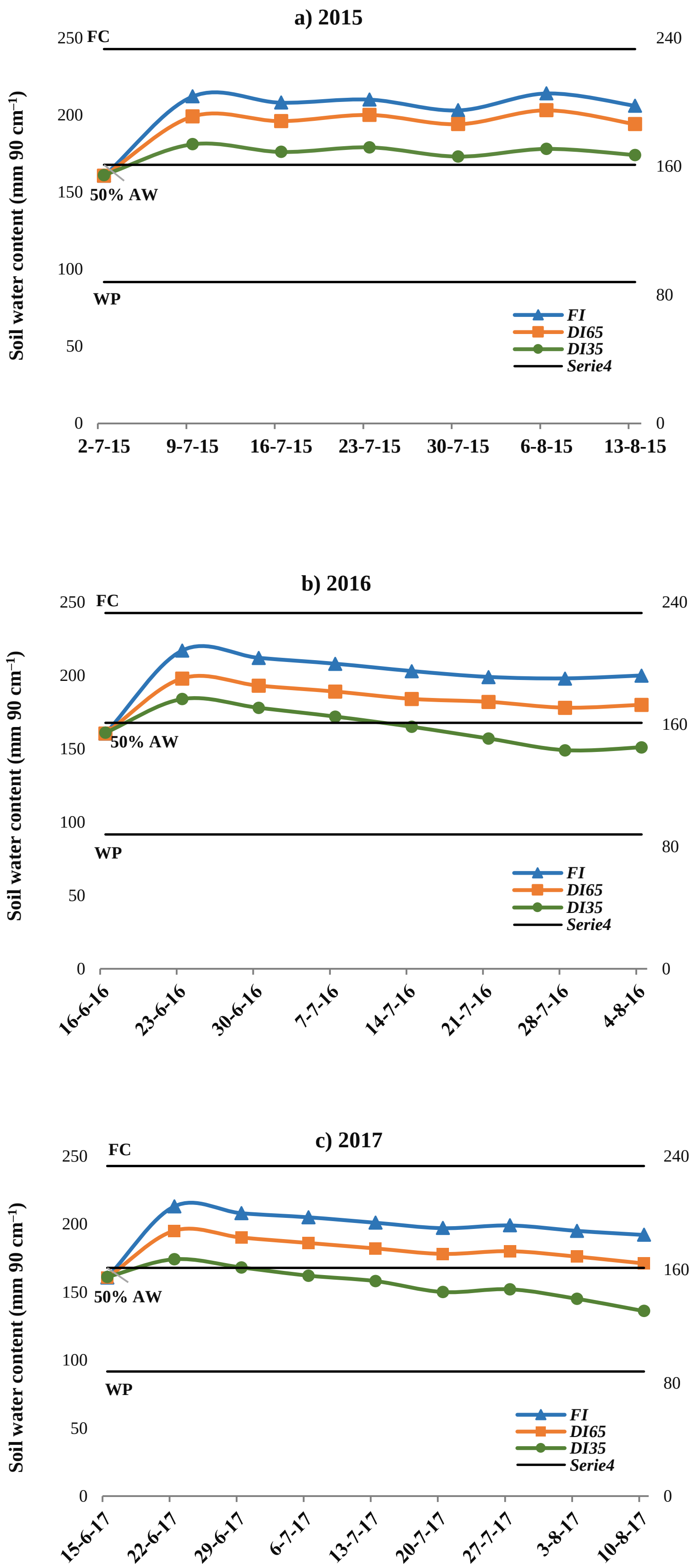

Fig. 1. Dynamics of soil water content under each irrigation treatment during the 2015 (a), 2016 (b) and 2017 (c) growing seasons. AW: available water; FI: full irrigation; DI_{65}: deficit irrigation (65% of FI); DI_{35}: deficit irrigation (35% of FI); FC: field capacity; WP: permanent wilting point

Table 5. Irrigation amount, ET and WUE under each treatment during the 3 years of the experiment

Year	Irrigation (mm)			ET (mm)			WUE (kg m^{-3})		
	FI	DI_{65}	DI_{35}	FI	DI_{65}	DI_{35}	FI	DI_{65}	DI_{35}
2015	198	129	69	463	393	334	4.73	5.23	6.09
2016	266	173	93	395	301	222	5.41	6.47	6.75
2017	326	212	114	444	330	232	4.71	5.95	6.52
Average	264	171	92	434	342	262	4.95	5.89	6.45

ET: evapotranspiration; WUE: water use efficiency; FI: full irrigation, DI_{65}: 65% × FI, DI_{35}: 35% × FI

seasonal ET of 'Sultani Çekirdeksiz' cv. varied between 112–232 mm in Manisa province. This low ET value in was related to climatic effects and therefore the amount of irrigation water supplied. During the current experiment, the highest ET calculated for the FI treatment according to phenological stages was obtained from fruit set (EL-27) to veraison (EL-35) with 151 mm, followed by 103 mm for veraison (EL-35) to harvest (EL-38) period. The average daily ET between EL-27 and EL-35 was 3 mm, while it reached 5 mm between EL-35 and EL-38. The main reason for the high daily ET between EL-35 and EL-38 could be due to a greater leaf surface between these two periods. In addition, the highest WUE value was observed for the DI_{35} treatment in 2016 with 6.75 kg m^{-3} while the lowest was observed for the FI treatment in 2017 with 4.71 kg m^{-3}. On average, ET from the DI_{65} and DI_{35} treatments was 21.2% and 39.6% lower than that from FI, respectively. ET values and WUE decreased with increasing irrigation amounts, similarly to previous studies [Çolak and Yazar 2017, Soltekin et al. 2020].

Fluctuations in Ψ_{md} values were observed over the growing season, especially in 2015 due to a higher precipitation in the vegetation period. In 2015 (Fig. 2a), the most severe water stress level was observed under the deficit irrigation treatments (DI_{65} and DI_{35}) with –1.5 MPa. In 2016 and 2017, the maximum water stress levels were observed in DI_{35} with –1.70 MPa and –1.75 MPa, respectively (Fig. 2b and Fig. 2c). Bahar et al. [2011] measured highest Ψ_{md} value in Merlot variety as –1.4MPa in a study carried out in France. Furthermore, more negative Ψ_{md} values were obtained under reduced irrigation treatments for Cabernet Sauvignon (–1.47MPa) and Malbec variety (–1.31MPa) in Idaho, USA [Shellie and Bowen 2014]. In the current study, at the end of the season, Ψ_{md} were more negative in all treatments than at the beginning of the season, which can be explained by the evaporative demand of the environment, which is higher by the end of the season [Cancela et al. 2016]. There are many studies showing that Ψ_{md} values during the post-veraison period are more negative than those measured at pre-veraison, which might have implications for both yield and grape composition [Romero et al. 2013, Conesa et al. 2014, Mirás-Avalos and Intrigliolo 2017].

Vine performance and yield. There were no statistically significant differences among irrigation treatments on the pruning wood weight (PWW) in any of the experimental years (Tab. 6), in agreement with Shellie [2014] but contrasting with a number of previous reports [Romero et al. 2013]. In turn, irrigation treatments significantly affected vigor values when averaged over the studied years ($p \leq 0.01$), being 2.47% and 12.16% higher under FI than under DI_{65} and DI_{35}, respectively (Tab. 6). Vigor values are considered very weak if <10 g; weak if 10–20 g; medium strength if 20–40 g; strong if 40–60 g; and very strong if >60 g [Carbonneau 1998]. The vigor values determined in the *Sultani Çekirdeksiz* variety were in the "very strong" group for all treatments. Although the vegetative development of wine and table grape varieties is different, the vigor values in the Cabernet-Sauvignon variety are over 60 g [Lopes et al. 2008], being similar to those of the *Sultani Çekirdeksiz* variety in the current study.

Puissance increased with the amount of irrigation water applied. FI had the highest puissance in the 3 studied years, and these values were 3.79 in 2015, 3.68 in 2016 and 3.55 in 2017 (Tab. 6). Therefore,

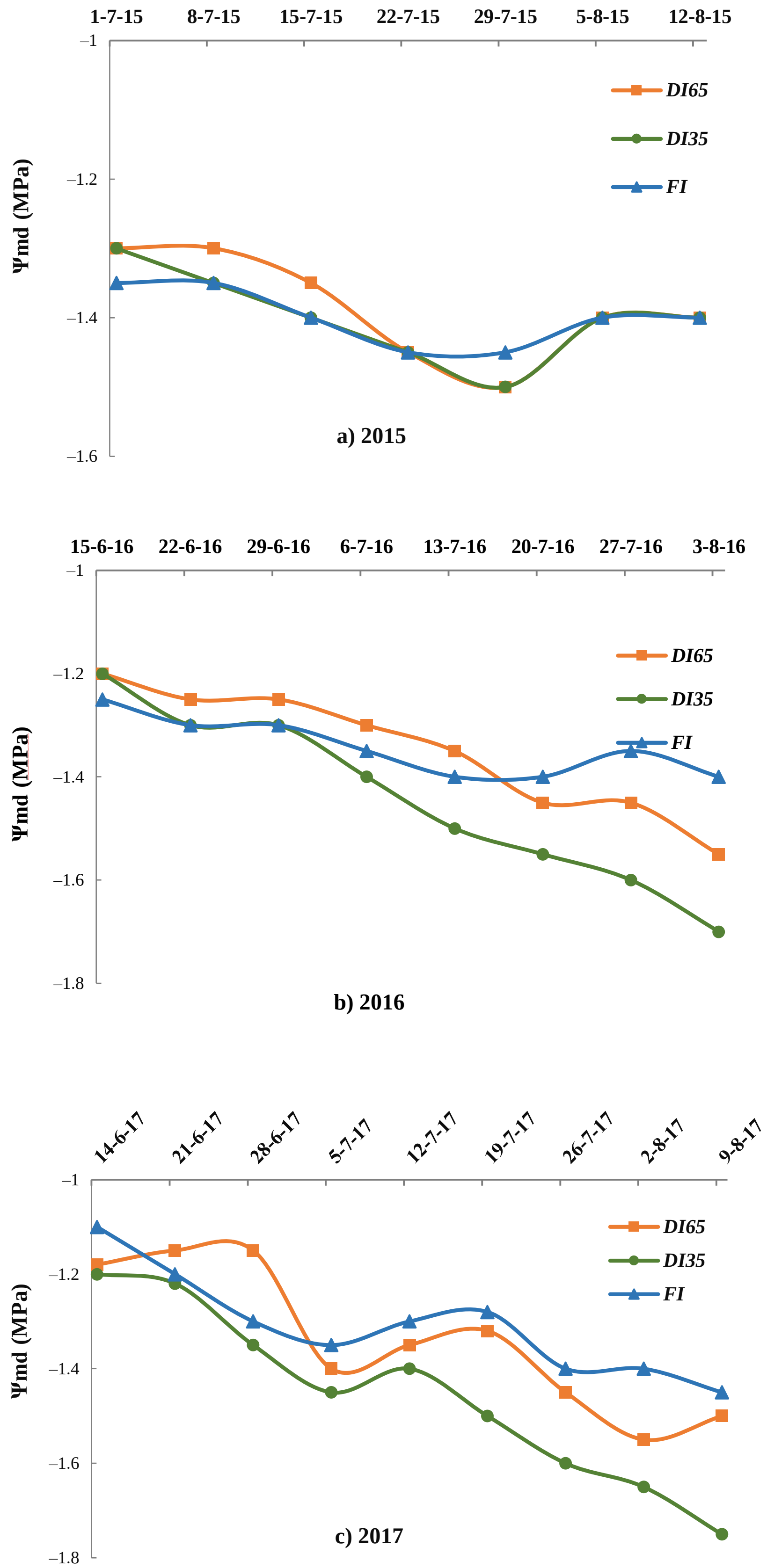

Fig. 2. Evolution of leaf water potential (Ψ_{md}) of 'Sultani Çekirdeksiz' grapevines under 3 irrigation treatments during 2015 (a), 2016 (b) and 2017 (c) growing seasons. FI: full irrigation; DI_{65}: deficit irrigation (65% of FI); DI_{35}: deficit irrigation (35% of FI)

Table 6. Vegetative growth parameters of 'Sultani Çekirdeksiz' grapevines under 3 irrigation treatments during 2015 (a), 2016 (b) and 2017 (c) growing seasons

Years	Treatments	PWW (kg vine^{-1})	Vigor (g)	Puissance	RI	Trunk diameter variation (mm)
2015	FI	2.34	85	3.79	5.60	0.66
	DI_{65}	2.31	84	3.62	5.36	0.58
	DI_{35}	2.14	79	3.50	5.70	0.49
	significance	ns	ns	ns	ns	ns
	CV (%)	5.36	8.73	3.85	7.13	7.53
	LSD	–	–	0.280	–	0.087
2016	FI	2.24	85	3.68 a	5.93	0.88 a
	DI_{65}	2.15	83	3.41 a	5.49	0.74 a
	DI_{35}	1.79	69	2.69 b	5.00	0.40 b
	significance	ns	ns	**	ns	**
	CV (%)	14.92	11.27	5.64	20.69	13.73
	LSD	–	–	0.368	–	0.186
2017	FI	2.10	79	3.55 a	5.99	1.11
	DI_{65}	2.00	77	3.35 ab	5.90	1.06
	DI_{35}	1.90	73	2.76 b	4.81	0.93
	significance	ns	ns	**	ns	ns
	CV (%)	5.71	11.62	11.91	22.00	20.42
	LSD	–	–	0.767	–	–
2015–2017	FI	2.23	83 a	3.67 a	5.84	0.89
	DI_{65}	2.15	81ab	3.46 ab	5.58	0.79
	DI_{35}	1.94	74 b	2.98 b	5.17	0.61
	significance	ns	**	**	ns	ns
	CV (%)	7.28	5.23	8.32	6.12	33.13
	LSD	–	8.290	0.560	–	–

Treatments included; FI (control): full irrigation. DI_{65} (moderate deficit irrigation): 65% × FI and DI_{35} (severe deficit irrigation): 35% × FI. Parameters; PWW: pruning wood weight; RI: Ravaz index
Means are separated by LSD test; values with different letter are significantly different. No letters indicate no differences
ANOVA: **: significant effect at $p \leq 0.01$; ns: non-significant

irrigation and vegetative performance of the vines were correlated positively. Korkutal et al. [2018] reported puissance between 1.21–1.65 in cv. 'Syrah', while Bahar et al. [2018] found puissance between 0.82–1.03 in cv. 'Cabernet-Sauvignon'. The puissance values of the *Sultani Çekirdeksiz* variety obtained in our study were higher than those reported for wine grape varieties. However, factors such as soil structure, plant nutrition and climate might affect the puissance of the vines. In addition, effects of irrigation treatments on RI were found non-significant. Nevertheless, RI increased with the amount of irrigation water applied. Although RI varies depending on the grapevine cultivar, it is generally accepted that RI between 5–10 are appropriate [Jones et al. 2009]. In the current study, RI values averaged for the three years were between 5–10 indicating that *Sultani Çekirdeksiz* grapevines were balanced in our experiment. Regarding trunk diameter variation, there were significant differences among irrigation treatments ($p \leq 0.01$) in 2015 and 2016, with the higher values obtained under FI and DI_{65} (Tab. 6). In previous studies, the effects of irrigation treatments on trunk development in vines were statistically non-significant [Ünal 2008, Faci et al. 2014]. In this

Table 7. Berry composition parameters of 'Sultani Çekirdeksiz' grapevines subjected to three irrigation treatments during the 2015, 2016 and 2017 growing seasons

Years	Treatments	TSS (%)	pH	TA ($g L^{-1}$)	MI	TPC ($mg kg^{-1}$)	TF ($mg kg^{-1}$)	AC (EC_{50})
2015	FI	19.10 b	3.64 b	4.60 a	41 b	294.55 c	52.57 c	43.81 a
	DI_{65}	19.63 b	3.69 a	4.34 c	45 a	548.38 b	101.62 b	29.20 b
	DI_{35}	21.07 a	3.57 c	4.48 b	47 a	655.29 a	131.74 a	28.86 b
	significance	*	**	**	**	**	**	**
	CV (%)	2.86	0.16	0.78	2.31	2.36	7.18	4.38
	LSD	1.140	0.012	0.070	1.066	23.511	13.669	2.971
2016	FI	19.40 b	3.57	4.99	39 b	707.91 c	140.71 c	40.47
	DI_{65}	20.57 b	3.57	4.88	42 ab	794.86 b	174.04 b	39.31
	DI_{35}	22.03 a	3.55	4.94	45 a	978.91 a	202.01 a	35.39
	significance	**	ns	ns	**	**	**	ns
	CV (%)	3.06	2.29	3.31	5.68	1.75	3.08	11.03
	LSD	1.262	–	–	4.757	28.905	10.611	–
2017	FI	19.50	3.48 b	5.31 a	37 b	500.92 b	95.49 b	42.71 a
	DI_{65}	20.03	3.66 a	4.54 c	44 a	513.69 b	98.48 b	39.98 a
	DI_{35}	19.20	3.42 b	5.17 b	37 b	595.10 a	140.39 a	31.35 b
	significance	ns	**	**	**	**	**	**
	CV (%)	2.29	0.98	0.71	2.76	2.66	5.99	5.90
	LSD	–	0.069	0.071	2.168	28.529	13.348	4.480
2015–2017	FI	19.33	3.56	4.97	39	501.13	96.26	42.33 a
	DI_{65}	20.08	3.64	4.59	44	618.98	124.71	36.16ab
	DI_{35}	20.77	3.51	4.86	43	743.10	158.05	31.87 b
	significance	ns	ns	ns	ns	ns	ns	**
	CV (%)	4.40	2.11	6.83	8.07	30.67	33.07	11.12
	LSD	–	–	–	–	–	–	8.175

Treatments; FI (control): full irrigation. DI_{65} (moderate deficit irrigation): 65% × FI and DI_{35} (severe deficit irrigation): 35% × FI. Parameters; AC: antioxidant capacity; MI: maturity index; TA: titratable acidity; TF: total flavonoid; TPC: total phenolic content; TSS: total soluble solids. Means are separated by LSD test; values with different letter are significantly different. No letters indicate no differences
ANOVA: *: significant effect at $p \leq 0.05$; **: significant effect at $p \leq 0.01$; ns: non-significant

context, when the parameters related to the vine performance were examined jointly, it was determined that the best development generally was achieved under FI. Our results were in agreement with those reported by Korkutal et al. [2019].

On average, yield from the DI_{65} and DI_{35} treatments were respectively 6.9% and 21.4% lower than that from FI. This reduction was also observed by Korkutal et al. [2019], reporting a 27.8% reduction in yield under deficit irrigation. Romero et al. [2013] observed that yield was significantly reduced in RDI (regulated deficit irrigation) vines compared to SDI (sustained deficit irrigation) vines. In addition, they determined that 38–57% reduction under RDI compared to SDI treatment. Shellie [2014] reported 23% and 44% reductions in yield in their STD_{70} and STD_{35} treatments relative to STD, respectively. In our research, the yield loss observed under DI_{65} relative to FI was lower than that reported in these previous studies.

Grape composition. Irrigation treatments had a statistically significant effect on TSS in 2015 ($p \leq 0.05$) and 2016 ($p \leq 0.01$). The highest TSS values were obtained under DI_{35} with 21.07% in 2015 and 22.03% in 2016. On average, TSS from the DI_{35} treatment was 7.45% higher than that from FI and 3.44% higher than that from DI_{65}. The TSS values observed in the current study were similar to those reported by Ünal [2008]. The effects of treatments on MI were statistically significant at the 1% level for the 3 years (Tab. 7). Soltekin et al. [2020] stated that TSS increased with water stress especially at the beginning of veraison. Moreover, it was reported that vegetative de-

Table 8. Berry size parameters of 'Sultani Çekirdeksiz' grapevines subjected to three irrigation treatments during the 2015, 2016 and 2017 growing seasons

Years	Treatments	Berry width (mm)	Berry length (mm)	Berry flesh firmness (kg-force)	Berry removal force (kg-force)
2015	FI	15.24 a	18.18	0.61 b	0.52
	DI_{65}	14.75 ab	17.83	0.63 b	0.52
	DI_{35}	13.98 b	17.81	0.79 a	0.52
	significance	*	ns	**	ns
	CV (%)	3.07	3.47	3.38	4.53
	LSD	0.899	–	0.046	–
2016	FI	14.16 a	16.00 a	0.75	0.65
	DI_{65}	13.22 b	15.60 ab	0.83	0.64
	DI_{35}	13.17 b	15.04 b	0.89	0.65
	significance	**	*	ns	ns
	CV (%)	1.82	2.12	8.98	4.06
	LSD	0.491	0.660	–	–
2017	FI	13.87	16.76	0.58	0.37
	DI_{65}	13.74	16.47	0.59	0.55
	DI_{35}	13.46	15.93	0.55	0.56
	significance	ns	ns	ns	ns
	CV (%)	5.61	4.01	7.37	42.62
	LSD	–	–	–	–
2015–2017	FI	14.43	16.98	0.65	0.51
	DI_{65}	13.90	16.63	0.68	0.57
	DI_{35}	13.54	16.26	0.74	0.58
	significance	ns	ns	ns	ns
	CV (%)	4.71	7.36	19.64	17.45
	LSD	–	–	–	–

Treatments; FI (control): full irrigation. DI_{65} (moderate deficit irrigation): 65% × FI and DI_{35} (severe deficit irrigation): 35% × FI
Means are separated by LSD test; values with different letter are significantly different. No letters indicate no differences
ANOVA: *: significant effect at $p \leq 0.05$; **: significant effect at $p \leq 0.01$; ns: non-significant

velopment increased with irrigation water. Therefore, sugar accumulation in shaded clusters is reduced. The water stress gradually occurring in the vines reduced the acidity but caused the pH and TSS to increase, as expected [Mirás-Avalos and Intrigliolo, 2017]. In contrast, rapid and severe water stress can result in lower soluble solids concentrations [Buesa et al. 2017].

The total phenolic content (TPC), total flavonoid (TF) and antioxidant capacity (AC) of grapes under the different among treatments are shown in Table 7. The averages of TPC and TF were significantly different at $p < 0.01$ in the 3 years. According to our study, as water deficit increased, the TPC and TF also increased, with the highest values under DI_{35}. These results were similar to those reported by Romero et al. [2013] and Soltekin et al. [2019]. However, a meta-analysis revealed that TPC in the grapes did not show a significant correlation with vine water status [Mirás-Avalos and Intrigliolo 2017]. This contrasting finding suggests that grapevine variety has a major effect on the TPC content in the grapes when compared to vine water status. In the current study, the highest TPC ranged from 595.10 to 978.91 mg kg^{-1} (2015–2017). For table grapes, values between 115 and 3446 mg kg^{-1} have been reported with the red varieties showing higher TPC than white varieties [Baydar et al. 2007]. The highest TF values were 131.74, 202.01 and 140.39 mg kg^{-1} in 2015, 2016 and 2017, respectively (Tab. 7). These data corroborate previous publications showing that flavonoid content and related berry quality traits increased in grapes from deficit irrigation treatments [Savoi et al. 2016, Soltekin et al. 2020].

Many studies reported a relationship between the phenolic content and antioxidant activity [Baydar et al. 2007, Król et al. 2014, Tzortzakis et al. 2020]. Antioxidant capacity values were determined as EC_{50} and the effects of deficit irrigation treatments were examined. EC_{50} values represent the antioxidant substance concentration that inhibits 50% of DPPH radicals, and low EC_{50} value indicates that the amount of antioxidant substances is high. The effects of treatments on EC_{50} were statistically significant ($p \leq 0.01$) in 2015 and 2017. The lowest values were obtained under DI_{35} with 28.86 mg kg^{-1} in 2015 and 31.35 mg kg^{-1} in 2017 (Tab. 7). Therefore the highest antioxidant levels were obtained under DI_{35} (severe stress). Nascimento and Fett-Neto [2010] stated that antioxidants are intensively synthesized under drought stress as a secondary metabolic product. Thus, these compounds protect cells against lipid peroxidation and protein denaturation [Król et al. 2014].

While the effects of treatments on berry width were statistically significant in 2015 ($p \leq 0.05$) and 2016 ($p \leq 0.01$), berry length was only affected in 2016 ($p \leq 0.05$). The highest berry width and berry length were observed under FI in all the experimental years. On average, berry width was 3.82% and 6.58% higher under FI than under DI_{65} and DI_{35}, respectively. On the other hand, FI had 2.11% and 4.43% higher berry length than DI_{65} and DI_{35}, respectively (Tab. 8). Water stress occurring during the period between flowering and veraison decreases berry size and, if there is no water stress after ripening, this situation is recovered [Proffitt and Campbell-Clause 2011]. Berry development was negatively affected by water stress. Therefore FI enhanced berry development and vine yield. The influence of deficit irrigation on berry size observed in this study supports previous findings [Shellie 2014, Faci et al. 2014, Cooley et al. 2017]. The treatments had no statistical effect on berry removal force in any of the experimental years (Tab. 8). On the other hand, the effect of treatments on berry flesh firmness was statistically significant at the 1% level only in 2015. The highest value was observed under DI_{35}, with 0.79 kg-force.

CONCLUSIONS

Water stress caused by deficit irrigation restricted vegetative development of vines cv. 'Sultani Çekirdeksiz'/P1103. Moreover, berry development was affected negatively by water deficit and berries remained smaller. According to our results, as the level of water stress increases, maturation accelerates and the accumulation of dry matter increases. Additionally, 3 to 8 days earliness in harvest date were observed under deficit irrigation treatments. Therefore, deficit irrigation has an advantage in terms of providing fresh grapes earlier to the market under the conditions of the current study. Furthermore, bioactive compounds such as total phenolics, total flavonoids and total antioxidant capacity increased under deficit irrigation.

In contrast, water deficit caused yield losses, although to a lesser extent under DI_{65} than under DI_{35}. Therefore, yield loss with DI_{65} (moderate stress) can be compensated by the improvement in berry quality parameters. DI_{65} can be the preferred irrigation strategy to provide an optimization between yield and quality. Considering negative effects of climate change, DI_{65} is recommended in order to increase water use efficiency in vineyards and ensure sustainable viticulture under the conditions of the current study.

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CONFLICT OF INTEREST

Oguzhan Soltekin and Ahmet Altındişli declare that they have no competing interests.

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