Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2015) 39: 887-897
© TÜBİTAK
doi:10.3906/tar-1502-39

Effects of different bud loads and irrigations applied at different leaf water potential levels on Kalecik Karası grape variety

Serpil TANGOLAR[1,*], Semih TANGOLAR[1], Sevilay TOPÇU[2]
[1]Department of Horticulture, Faculty of Agriculture, Çukurova University, Adana, Turkey
[2]Department of Agricultural Structures and Irrigation, Faculty of Agriculture, Çukurova University, Adana, Turkey

Received: 08.02.2015 • **Accepted/Published Online:** 07.06.2015 • **Printed:** 30.11.2015

Abstract: The effects of two irrigation practices (RDI-I and RDI-II) and two bud load treatments on the yield and quality of the Kalecik Karası red wine grape variety were studied. The midday leaf water potential thresholds were used for irrigation timing, and those values were set as –10 bars until flowering, –13 bars between the berry set–veraison and the veraison–ripening periods, and –12 bars after harvest for both irrigation treatments. Water volumes applied in the irrigations of the RDI-I plots were 50% and 75% of the cumulative evaporation from a class A pan between the berry set–veraison and veraison–ripening growth stages, respectively, while those portions for the RDI-II treatment were vice versa. The effects of control (K) and two-fold increased bud loads (2K) based on mean pruning weight on the grape yield and quality were also investigated. Irrigation and higher bud load treatments considerably increased grape yield in both years of the study. The highest and lowest grape yields were obtained in the RDI-II and the nonirrigated treatments, respectively. The increase in grape yield of irrigated vines in relation to nonirrigated ones was 53.3% in the first year and 54.3% in the second year. With doubling the bud load, the achieved increases in grape yield were 37.8% and 45.1% compared to the traditional bud loads in the first and the second year, respectively. The bud load effect was more apparent for the irrigated vines compared to the rain-fed cultivation. Cluster weight was also higher for the irrigated vines. These increases can most probably be related to improved canopy development under irrigation application. The leaf stomatal conductance was higher as a consequence of the higher soil water contents in both irrigated treatments. The improved gas exchange due to the stomatal openings led to a higher leaf area index as well as an increase in grape yield of the irrigated plants. Our findings reveal that the grape yield of the Kalecik Karası grape variety can be increased with irrigation and higher bud load applications. It is also worth noting that a limited irrigation application may help to maintain a better berry quality compared to the traditional rain-fed grape cultivation.

Key words: Bud load, irrigation, leaf water potential, viticulture, wine grape

1. Introduction

In Turkey, the Mediterranean Region ranks second in vineyard area and grape production after the Aegean Region (TÜİK, 2011). The late-ripening table, wine, and juice grape varieties are increasingly grown in the Mediterranean uplands with cold climate conditions such as in Pozantı (South Turkey), where the present study was conducted. Rain-fed farming is the traditional practice in this region, and irrigation is not applied even in summers without rainfall. The grapevines are well adapted to a semiarid climate, due to having large and deep root systems and physiological drought-avoidance mechanisms, such as an efficient stomatal control of transpiration and xylem embolism (Lovisolo et al., 2002). However, the high evaporative demand during summer in the Mediterranean is known to limit grapevine yield as well as berry and wine quality (Escalona et al., 1999; Chaves et al., 2007; Costa et al., 2007). Earlier studies indicated that significant increases in yield and quality for table and wine grape varieties can be achieved by irrigation, particularly in dry summers (Matthews and Anderson, 1989; Santos et al., 2003, 2005). Nevertheless, irrigation may promote excessive vegetative growth with a negative impact on berry pigment (color) and sugar content, and therefore decrease wine quality (Bravdo et al., 1985; Dokoozlian and Kliewer, 1996). Therefore, careful water management generally applied by using deficit irrigation strategies is recognized as a tool for achieving some control of grapevine growth and development as well as maintaining berry quality. Deficit irrigation strategies imply that water is supplied at levels below full crop evapotranspiration (ETc) throughout the growing season or in specific phenological stages. Regulated deficit irrigation (RDI) is known as such a management technique. Under RDI, plant water status

* Correspondence: stangolar@cu.edu.tr

is maintained within predefined limits during certain stages of the seasonal development, normally when fruit growth is least sensitive to water reductions (Kang and Zhang, 2004). The rationale underlying the RDI practice is that optimization of the number of berries, berry size, and quality will be achieved by keeping grapevine vigor in balance with potential production. If water deficit is applied early in the season, the effects will be achieved mostly through a reduction of berry cell division (McCarthy et al., 2002); if water deficits are imposed at later stages, the major effect will be an inhibition of berry growth (Williams and Matthews, 1990). Our study aimed to demonstrate the possibility of quality and quantity improvement with the application of irrigation based on plant evapotranspiration.

In addition to the economic use of water in wine grapes, improved fruit and wine quality by the reduction in vegetative growth from the RDI technique has been determined by many researchers (e.g., El-Ansary et al., 2005; Keller et al., 2008; Hellman and Basinger, 2009; Romero et al., 2010; Basile et al., 2011; Terry and Kurtural, 2011).

Along with irrigation, one of the important primary parameters that directly affect yield and quality in grapes is crop load, which represents the number of buds present during the pruning of grapevines (Winkler et al., 1974; Keller et al., 2008; Bowen et al., 2011; Terry and Kurtural, 2011; Geller and Kurtural, 2013). Generally, leaving more buds than required for increasing the yield can result in an insufficient photosynthetic area for satisfying the need of increased fruit load of a plant. Such a physiological imbalance between shoot growth and grape yield causes higher water demand, and in the case of insufficient water supply, the number of productive buds for the next growing season will be adversely affected (Winkler et al., 1974; Çelik, 2007). Adequate canopy management applying sufficient bud load is therefore crucial for ensuring the balance between vegetative and generative partitioning for sustaining the high yield and quality of a grapevine (Geller and Kurtural, 2013; Kurtural et al., 2013; Wessner and Kurtural, 2013).

This study was performed in order to increase grape yield while maintaining grape quality using RDI and bud load treatments on the Kalecik Karası red wine grape variety irrigated by drip irrigation. In addition, based on variations in the phenological stages of the region, optimization of timing and amount of irrigation was also undertaken.

2. Materials and methods

The study was carried out in a vineyard established at the Agricultural Research Center in Pozantı (altitude of 1080 m) located in the Mediterranean uplands of Southern Turkey during 2013 and 2014. The experimental soils had a slightly alkaline low lime with clay-loam and loam texture both at the surface and at 30–60 cm depth. Although available phosphorus was quite low, the available potassium was sufficient. Field capacity and the permanent wilting point values at two soil depths (0–30 cm and 30–60 cm) ranged from 26.6% to 25% and from 19.5% to 18.6%, respectively. The bulk densities were 1.38 and 1.36 cm^3 cm^{-3}. Some climatic data were obtained from the Pozantı Meteorological Station for September 2012 to August 2014 (Table 1). The average daily temperatures were 14.1 °C and

Table 1. Climatic data related to experimental area obtained from the Pozantı meteorological station of Adana.

Climatic characteristics	2012				2013								Average
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
Average temperature (°C)	22.1	15.2	9.8	4.7	3.1	5.9	8.3	12.3	17.7	19.6	24.9	25.4	14.1
Total rainfall (mm)	0.4	107.0	93.4	231.8	31.4	47.2	65.6	67.6	23.0	11.8	0.4	0.0	679.6*
Relative humidity (%)	40.1	62.8	68.3	66.8	67.7	69.8	56.2	59.3	54.2	47.5	38.9	35.2	55.6
Wind speed (m/s)	2.6	1.7	1.8	1.9	2.1	2.1	2.8	2.2	2.1	2.7	3.0	3.0	2.3

Climatic characteristics	2013				2014								Average
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
Average temperature (°C)	20.4	13.4	10.7	2.1	4.8	6.2	8.9	13.0	15.8	20.1	24.9	26.1	13.9
Total rainfall (mm)	1.8	30.4	10.4	19.4	94.8	10.6	124.8	42.6	87.2	76.8	0.6	1.4	500.8*
Relative humidity (%)	43.7	41.6	61.2	54.9	69.0	55.1	62.4	60.4	65.4	55.4	54.7	49.1	56.1
Wind speed (m/s)	1.1	1.2	0.7	0.9	1.4	1.9	2.4	1.9	1.9	2.3	2.3	2.3	1.7

* = Total value

13.9 °C and relative humidity was 55.6% and 56.1% with wind speeds of 2.3 and 1.7 m/s and annual precipitation of 679.6 and 500.8 mm in 2013 and 2014, respectively. The variety used in the experiment was a 16-year-old Kalecik Karası red wine grape variety of *Vitis vinifera* L. The grapes were grown on their own roots, which is still a common practice in many vineyards of the region. The plants in the vineyard were grown under nonirrigated conditions until the initiation of the study. The vine rows were oriented east to west, and the planting distance was 3 m between rows and 2 m between vines. The training system was trellising to a bilateral cordon with two shoot-tying wires.

Six treatments, composed of three different irrigation applications including rain-fed farming as the control, RDI-I, and RDI-II plus two bud load treatments including traditional (K) and increased bud load (2K) were applied in the experiment. The higher bud load was applied by pruning from the 3–4 buds of some spurs pruned from 1 or 2 buds previously or by increasing the number of spurs pruned from the 2 buds. The control treatment was not irrigated regardless of the sufficiency of the winter rainfalls since the growers had no irrigation facility and widely practiced rain-fed cultivation. The two RDI treatments, however, received irrigation based on midday leaf water potential (LWP), which is one of the widely used plant-based measures of water status and irrigation scheduling. In both RDI treatments, the irrigation time was scheduled according to midday LWP while the irrigation volume applied was calculated using cumulative evaporation (Epan) values obtained from a class A evaporation pan. The midday LWP values used for irrigation timing were the same for both RDI treatments; however, these values were different for each plant growth stage: –10 bars for before the flowering period, –13 bars between berry set and veraison and between veraison and ripening, and –12 bars for the postripening stage. The irrigation amounts applied to the RDI-I plots were 50% and 75% of the cumulative evaporation from the class A pan during the berry set–veraison and veraison–harvest growth stages, respectively, while these percentages were 75% and 50% of the evaporation from the pan for the same growth stages for RDI-II, respectively. For all three irrigation treatments (rain-fed, RDI-I, and RDI-II), two bud loads were investigated: K, which is traditional practice (20 for the first 500 g of pruning weight, and 10 more buds for every additional 500 g subsequently) (Winkler et al., 1974; Çelik, 2007) and 2K, with increased bud loads to double that of the control (Table 2). Average pruning weights were measured to determine bud loads after the dormant pruning done in March 2013 and March 2014. The irrigation water amount was calculated using the following equation based on cumulative class A pan evaporation within the irrigation intervals:

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

where I = irrigation water volume (L), A = plot area (m^2), Epan = evaporation from the class A pan (L), Kpc = the crop and class A pan coefficients (0.6), and P = the percentage of wetted area taken as the percentage of the average canopy shadow area measured at noon (50%). The drip irrigation was applied with drip lines placed close to a vine row. The drip laterals had 20 cm of emitter space and the inline emitters were operated with a 2 L/h flow rate at 1.5 bar pressure.

Soil water content in the root-zone (0–60 cm depth) was measured weekly using a capacitance probe (Aquacheck, Model AQMOB-X), which consists of several sensors installed on a probe. The probe enables recording the average of 2-s-long readings for a selected time period. The leaf water potential and stomatal conductance measurements were made on four fully expanded mature leaves exposed to direct solar radiation using a portable pressure chamber device (Model 600 pressure chamber, PMS instrument) and a leaf porometer (Decagon, SC-1), respectively, between 1130 and 1400 hours. The leaf area index (LAI) was estimated by taking an average of four measurements from different sites of the canopy, and those observations were made in two vines in each plot using a plant canopy analyzer (Accupar LP-80). In general, all of the physiological measurements were made at weekly intervals.

Ten cluster samples were taken from 10 different shoots from each plot during the ripening period of the grapes, when the amount of total soluble solids (TSS) reached approximately 22%–23%. Using these cluster samples, cluster weight (g), berry weight (g), TSS (%), titratable acidity (g/100 mL grape juice), and pH were determined. Grape yield (g/vine) was obtained by multiplying the number of clusters with the average cluster weight. Skin (g), pulp (g), seed (g), and grape juice (mL) ratios of the variety were calculated per 100 g of berry.

The experimental design was a split plot design with three replicates each consisting of 5 vines. Measurements and observations were made on the inner two vines. Irrigation treatments were the main plots and bud load treatments were the subplots. Variance analysis was performed using a SAS-based JMP statistical program. The least significant difference (LSD) test was used to separate significant means.

3. Results

According to the results obtained in 2013, which should be considered the transition year, the equally distributed buds based on average pruning weight in all treatments increased in the second year due to the difference in weight of the irrigated vines (Table 2). On the irrigated vines, 5 more buds in the K bud load treatment and 10 more buds in the 2K bud load treatment for each plant were applied compared to nonirrigated vines.

The LWP values for the different treatments are given in Figure 1. Critical values of LWP were not reached until 26 July in 2013 and 1 August in 2014, when the first irrigations were applied. The amounts of water supplied for the different irrigation treatments are also given in Table 3. The vines were irrigated two and four times until the ripening period in 2013 and 2014, respectively.

3.1. Effects on ecophysiological parameters

The observed soil moisture changes at a 60 cm profile depth in the two parallel experimental plots are shown in Figure 2. The soil water contents for the nonirrigated treatment were lowest at the effective root depth, particularly at the 0–30 cm soil layer. The soil water contents increased following irrigation for both the RDI-I and the RDI-II treatments, and this increase varied depending on the application time and was proportional to the amount of irrigation water in these two treatments. A limited increase occurred in the soil water content with the provided water amount from deficit irrigation as shown in Figure 2.

The stomatal conductance of the plants varied depending on the amount of irrigation water applied and the volumetric soil water content at the effective root depth in the test plots (Figure 3). Although leaf stomatal conductance in the nonirrigated plots showed resemblance to those measured from the irrigated treatments (RDI-I K, RDI-I 2K, RDI-II K, and RDI-II 2K) in the beginning of the experiment, increases in stomatal conductance were observed in plants under both RDI practices later.

The maximum LAI values measured in the 2014 vegetation period were lower for the rain-fed treatment than for the irrigated vines (Figure 4). This shows that an increase could take place in the vegetative growth depending on the amount of deficit irrigation. However, the effects of bud load treatments were not significant between the RDI-I and RDI-II practices.

3.2. Effects on grape yield and berry quality characteristics

Irrigation and higher bud load treatments considerably increased grape yield in both years (Table 4). The highest and the lowest grape yield values were detected in the RDI-II and nonirrigated treatments, respectively. The grape yield of the RDI-II treatment vines was 8812 g/vine (14,628 kg/ha) in the first year of the research, while in the second year it was 9764 g/vine (16,208 kg/ha). For the nonirrigated vines, the yield values in 2013 and 2014

Table 2. Average pruning weight (g/vine) and number of buds (n) left according to treatments.

Year	Irrigation	Bud load level	Pruning weight	K bud load [1]	2K bud load
2013	All treatments		500	20	40
2014	No irrigation	K	627	22	44
		2K	737	24	48
		Mean	682 b [2]	23	46
	RDI-I	K	957	29	58
		2K	920	28	56
		Mean	938 a	28	56
	RDI-II	K	1043	30	60
		2K	1093	32	64
		Mean	1068 a	31	62
	Mean	K	876	27	54
		2K	917	28	56
	LSD 5%	Irrigation	163		
		Bud load	NS [3]		
		Interaction	NS		

[1]K (control): 20 buds left for the first 500 g pruning weight and 10 more buds left for every additional 500 g.
[2]Means followed by different letters in the same column are significantly different according to LSD at $P < 0.05$.
[3]NS = nonsignificant.

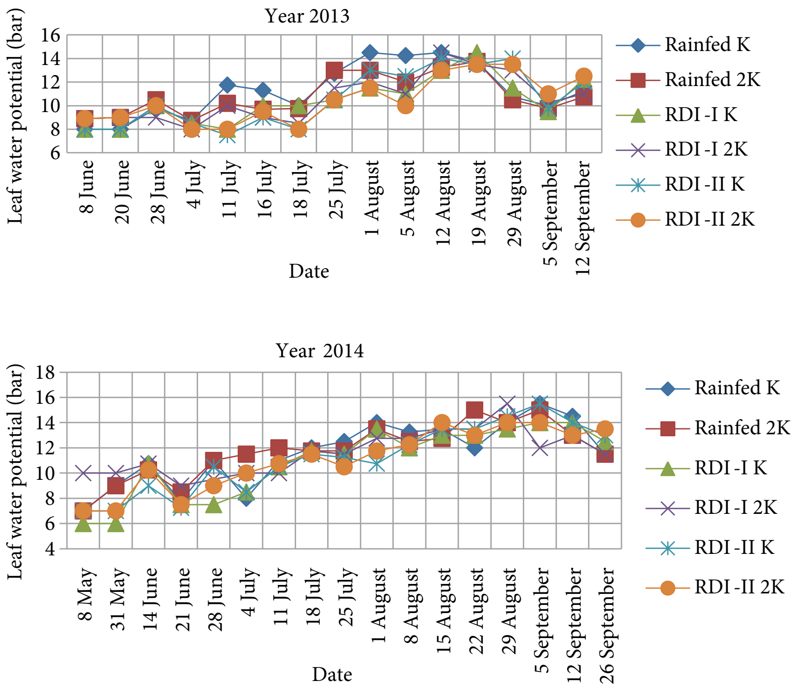

Figure 1. Changes in leaf water potential (bar) under different irrigation and bud load treatments.

Table 3. Irrigation dates and water amount applied (mm) for different treatments of Kalecik Karası.

Phenological stage	Irrigation date	2013		2014	
		RDI-I	RDI-II	RDI-I	RDI-II
Bud burst		22 April		20 April	
Full blooming		1 June		9 June	
Berry set		11 June		18 June	
	26 July	57.2	85.7		
	1 August			43.4	65.1
	8 August			39.2	58.7
Veraison		2 August		9 August	
Total (verasion–berry set)		57.2	85.7	82.6	123.8
	12 August	233.6	155.7		
	16 August			42.5	28.4
	22 August			72.2	48.2
Ripening		17 August		28 August	
Total (ripening–veraison)		233.6	155.7	114.7	76.6
	24 August	225.9	225.9		
	29 August	72.0	72.0	118.8	118.8
	9 September			72.0	72.0
	12 September	218.7	218.7		
	13 September			14.4	14.4
Total (after ripening)		516.6	516.6	205.2	205.2
General total		807.4	758.0	402.5	405.6

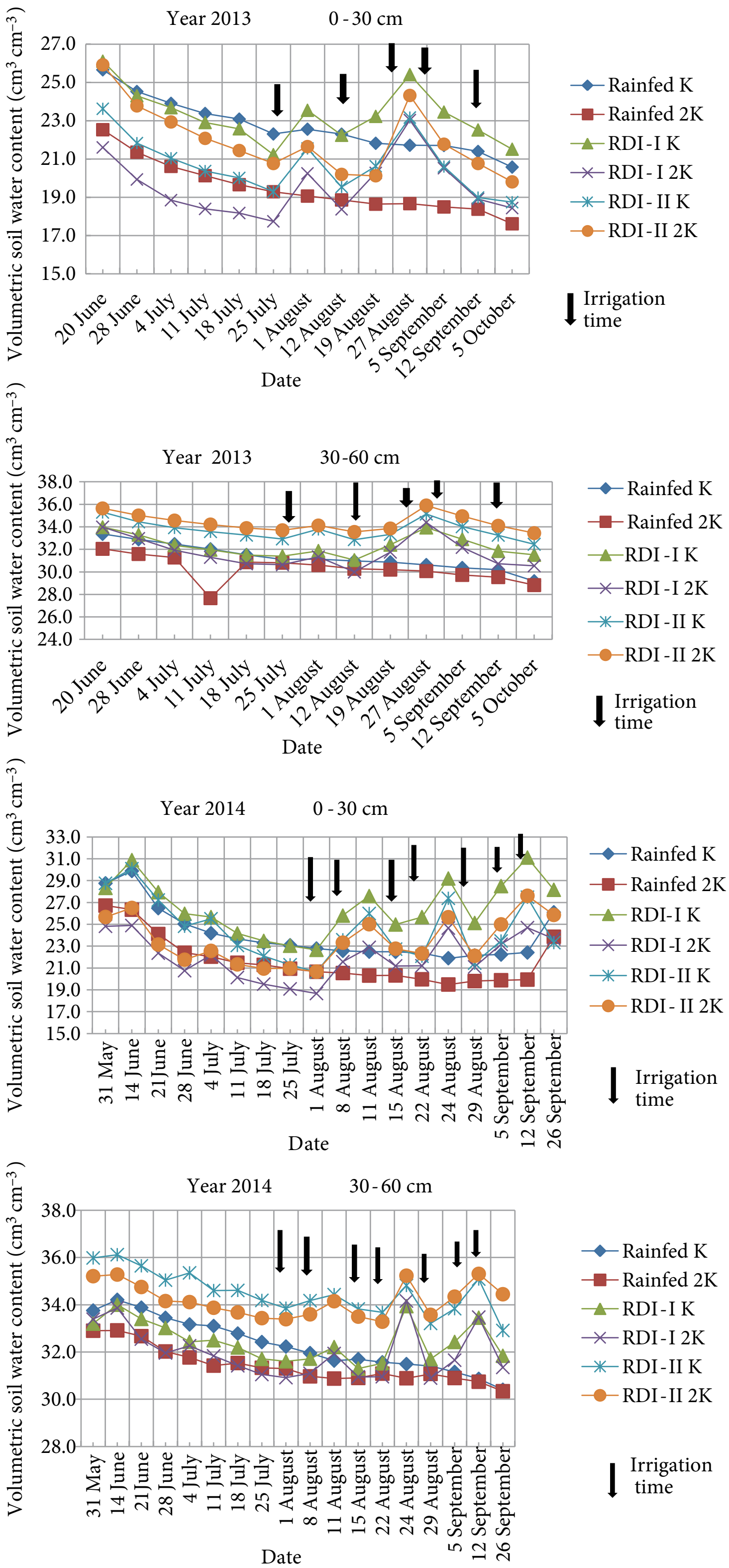

Figure 2. Seasonal changes of soil water content at two soil depths for the Kalecik Karası grapevine variety. Arrows in the graphs indicate the irrigation dates.

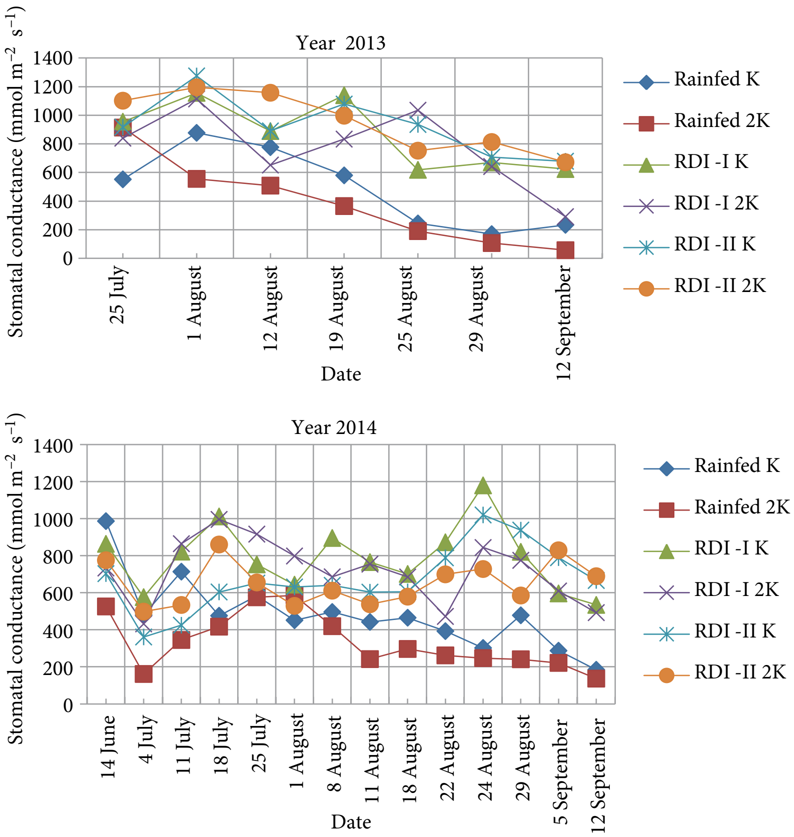

Figure 3. Seasonal changes of stomatal conductance of Kalecik Karası.

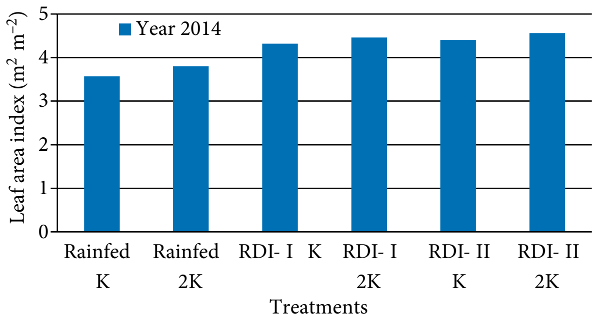

Figure 4. Maximum LAI measured under different irrigation treatments in 2014.

were 5750 g/vine (9545 kg/ha) and 6328 g/vine (10,504 kg/ha), respectively. These values indicate 53.3% and 54.3% increases in production with deficit irrigation in the first and second years of the experiment, respectively. A higher yield was obtained from the 2K than the K bud load treatment. The yields in 2013 under these treatments were 8252 g/vine (13,698 kg/ha) and 5990 g/vine (9943 kg/ha) for the 2K and K treatments, respectively, and were likewise 9988 g/vine (16,580 kg/ha) and 6885 g/vine (11,429 kg/ha) in 2014. With more bud load treatment, the increase in grape yield was 37.8% and 45.1% in the first and second years of the experiment, respectively. The treatment interaction was not significant in 2013. In 2014, while no statistical difference was determined for nonirrigated grapes, a significant increase was recorded for the 2K bud loaded irrigated vines.

The number of clusters did not vary significantly among the irrigated treatments; however, differences were found

Table 4. The effects of two regulated deficit irrigation (RDI) practices and two bud load levels on the yield, cluster, and berry components of Kalecik Karası.

Source of variance	Yield (g/vine)[1]		Number of clusters (n)		Cluster weight (g)		Berry weight (g/100 berry)		Skin rate (%)		Pulp rate (%)		Seed rate (%)		Juice rate (mL/100 g berry)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Irrigation																
No irrigation	5750 b	6328 b	24	45	232.4 b	145.4 b	236.1	211.3	8.67	6.88	88.57	90.2	2.88	3.09	68.97	71.39
RDI-I	6801 ab	9218 a	26	52	268.4 ab	178.6 a	249.0	222.7	8.58	6.75	88.56	90.5	2.86	2.85	70.00	74.17
RDI-II	8812 a	9764 a	30	55	296.6 a	175.1 a	248.8	208.7	8.15	6.67	88.97	90.2	2.88	3.18	70.25	72.23
LSD 5%	1843	2057	NS	NS	31.41	12.5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Bud load level																
K	5990 b	6885 b	23 b	40 b	260.2	169.4	248.1	210.6	8.46	6.87	88.77	90.2	2.85	3.06	69.28	74.45
2K	8252 a	9988 a	30 a	61 a	271.4	163.3	241.3	217.8	8.47	6.65	88.63	90.4	2.90	3.01	70.20	70.74
LSD 5%	1697	1680	4.8	7.3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction																
No irr. × K	4408	5403 b	19	33	225.9	162.6 c	237.5	190.8	8.41	6.89	89.00	90.3	2.83	3.10	69.33	71.67
No irr. × 2K	7092	7252 b	29	57	238.8	128.1 d	234.9	199.2	8.93	6.86	88.13	90.1	2.94	3.07	68.61	71.11
RDI-I × K	6134	7545 b	23	42	266.6	180.5 ab	254.8	201.7	9.09	6.90	88.07	90.3	2.83	2.84	69.61	76.11
RDI-I × 2K	7469	10890 a	28	62	270.2	176.6 abc	243.3	209.2	8.06	6.59	89.05	90.6	2.87	2.85	70.39	72.22
RDI-II × K	7429	7706 b	26	46	288.2	165.0 bc	252.0	208.3	7.88	6.83	89.24	89.9	2.88	3.25	68.89	75.56
RDI-II × 2K	10195	11823 a	33	63	305.1	185.1 a	245.6	193.3	8.41	6.51	88.70	90.4	2.89	3.10	71.61	68.89
LSD 5%	NS[2]	2909	NS	NS	NS	17.6	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]Means followed by different letters in the same column are significantly different according to LSD at $P < 0.05$.
[2] NS = nonsignificant.

among bud loads. As shown in Table 4, irrigation has a positive effect on cluster weight, but no significant effect was found on the seed, skin, berry pulp amount, berry weight, and grape juice yield of Kalecik Karası for either the irrigated or the 2K bud load vines. The effects of bud load on the TSS of berries in 2013, irrigation treatments on acidity in 2014, and both bud load and irrigation treatments on pH in 2013 year were significant (Table 5). In general, TSS was slightly higher and acidity was lower in nonirrigated vines. In 2013 and 2014, the average values were 23.6% and 21.8% for TSS, 0.905% and 0.878% for acidity, and 3.29 and 3.34 for pH, respectively. Thus, the TSS/acidity ratio was higher (26.92) in berries obtained under normal bud load treatments and nonirrigated conditions (28.13) in 2013. In the second year, there were no significant differences between the treatments. The average TSS/acidity ratio was 24.99 in 2014.

4. Discussion

Rainfall values, found to be sufficient for the growth of the vines (Winkler et al., 1974; Çelik et al., 1998; Çelik, 2007), were recorded as 679.6 mm and 500.8 mm for 2013 and 2014, respectively. Some studies have shown that irrigation and bud load effects are more evident in arid and semiarid conditions (Fereres and Soriano, 2007; Hellman and Basinger, 2009). In such regions, a sufficient amount and quality of grapes could be obtained with irrigation when needed. This was supported by our findings. According to McCarthy et al. (2002), the effect of RDI varies depending on the phenological stage of the grapevine and the level of water stress. A water shortage in the earlier periods between berry set and veraison decreases grapevine vigor and controls berry size compared to full water (Keller, 2005; Terry and Kurtural, 2011).

Table 5. The effects of two regulated deficit irrigation (RDI) practices and two bud load levels on the juice characteristics of Kalecik Karası.

Source of variance	TSS (%)[1]		Acidity (g/100 mL juice)		pH		TSS/Acidity ratio	
	2013	2014	2013	2014	2013	2014	2013	2014
Irrigation								
No irrigation	24.64	21.61	0.880	0.845 b	3.29 b	3.32	28.13 a	25.66
RDI-I	23.56	21.77	0.910	0.852 b	3.30 b	3.37	25.99 b	25.74
RDI-II	22.63	22.07	0.923	0.937 a	3.35 a	3.32	24.67 b	23.57
LSD 5%	NS[2]	NS	NS	0.046	0.03	NS	1.48	NS
Bud load level								
K	24.43 a	22.01	0.911	0.876	3.31 a	3.34	26.92 a	25.23
2K	22.78 b	21.62	0.898	0.880	3.26 b	3.33	25.62 b	24.75
LSD 5%	1.33	NS	NS	NS	0.03	NS	1.30	NS
Interaction								
No irr. × K	25.23	21.60	0.894	0.855	3.31	3.31	28.35	25.23
No irr. × 2K	24.05	21.62	0.866	0.835	3.28	3.32	27.92	26.09
RDI-I × K	24.57	22.13	0.903	0.840	3.33	3.40	27.32	26.49
RDI-I × 2K	22.55	21.40	0.918	0.863	3.27	3.34	24.66	24.99
RDI-II × K	23.50	22.30	0.938	0.932	3.27	3.31	25.09	23.96
RDI-II × 2K	21.75	21.83	0.909	0.942	3.23	3.33	24.24	23.18
LSD 5%	NS	NS	NS	NS	NS	NS	NS	NS

[1]Means followed by different letters in the same column are significantly different according to LSD at $P < 0.05$.
[2] NS = nonsignificant.

In recent years, the effects of bud load applications, alone or together with irrigation, on yield and quality in viticulture have gained some more importance (Terry and Kurtural, 2011). In addition, the number of studies looking for an appropriate irrigation strategy and sufficient bud load level for viticulture for different ecological conditions, grape varieties, and cultivation techniques have been increasing (Fawzi et al., 2010; Bowen et al., 2011).

In our study, a significant yield increase occurred in the deficit irrigated 2K bud load grapevines. Yield increased more than 50% with irrigation. This is most probably due to better development of the canopy than for the nonirrigated vines. It is thought that this improvement was a result of the increase in LAI and consequently in leaf area and shoot growth due to limited increase of soil water content from the RDI treatments. Stomatal conductance values were also found to be higher in the irrigated vines than in the nonirrigated ones. This situation can be explained by the fact that under water stress due to lack of water content in the soil, plants close their stomata in order to decrease the water loss from the leaf surface (Basinger and Hellman, 2006; Hellman and Basinger, 2009). Dry and Loveys (1999) indicated that drying of the root system reduces stomatal conductance of plants and decreases the total transpiration. The twofold bud load caused a yield increase of only about 42% within the 2 years, which could be attributed to the failure of bud shooting (30% bud failure) under this treatment compared the expected rate under this application (Table 6). The observed bud failure and low increase in yield indicate the need for further experiment investigating lesser bud load applications instead of twofold bud load.

An increase also occurred in cluster weight with irrigation. The fact that statistically significant differences were not found in the berry properties shows that the 2K bud load can be applied to Kalecik Karası in experimental conditions and quality can be preserved with irrigation. When the values for brix, acidity, pH, and the other berry properties obtained in this study are considered, it seems that sufficient wine quality can be reached in Kalecik Karası with bud load and irrigation treatments applied under the experiment conditions.

Finally, our results showed that grape yield could be increased without a significant decline in berry quality with higher bud load treatment applied together with an irrigation regime when needed in plateau viticulture conditions. In addition to aiding potential water conservation, these results are thought to be important in contributing to rural development based on the potential to increase the incomes of the grape growers.

Table 6. The effects of two regulated deficit irrigation (RDI) practices and two bud load levels on the shoot rate (%) of Kalecik Karası.

Source of variance	2013[1]	2014
Irrigation		
No irrigation	87.4	81.1
RDI-I	85.3	75.1
RDI-II	78.8	78.2
LSD 5%	NS[2]	NS
Bud load level		
K	96.1 a	93.6 a
2K	71.6 b	62.6 b
LSD 5%	6.94	7.1
Interaction		
No irr. × K	99.2	97.1
No irr. × 2K	75.7	65.1
RDI-I × K	96.3	91.6
RDI-I × 2K	74.4	58.6
RDI-II × K	92.8	92.2
RDI-II × 2K	64.8	64.1
LSD 5%	NS	NS

[1]Means followed by different letters in the same column are significantly different according to LSD at $P < 0.05$.
[2]NS = nonsignificant.

Acknowledgment

This study has been supported by a grant from the Scientific and Technological Research Council of Turkey (TÜBİTAK) (Project number: 112O059).

References

Basile B, Marsal J, Mata M, Vallverdú X, Bellvert J, Girona J (2011). Phenological sensitivity of Cabernet Sauvignon to water stress: vine physiology and berry composition. Am J Enol Vitic 62: 452–461.

Basinger AR, Hellman EW (2006). Evaluation of regulated deficit irrigation on grape in Texas and implications for acclimation and cold hardiness. Int J of Fruit Sci 6: 3–22.

Bowen P, Bogdanoff C, Usher K, Estergaard B, Watson M (2011). Effects of irrigation and crop load on leaf gas exchange and fruit composition in red wine grapes grown on loamy sand. Am J Enol Vitic 62: 9–22.

Bravdo B, Hepner Y, Loinger C, Tabacman H (1985). Effect of irrigation and crop level on growth, yield and wine quality of Cabernet Sauvignon. Amer J Enol Vitic 36: 132–139.

Çelik H, Ağaoğlu YS, Fidan Y, Marasalı B, Söylemezoğlu G (1998). Genel Bağcılık. Sun Fidan AŞ Mesleki Kitaplar Serisi 1 (in Turkish).

Çelik S (2007). Bağcılık (Ampeloloji). Vol. 1. Namık Kemal Üniv. Ziraat Fak. Bahçe Bitkileri Böl. Tekirdağ. Avcı Ofset, İstanbul. (in Turkish).

Chaves MM, Santos TP, Souza CR, Ortuno MF, Rodrigues ML, Lopes CM, Maroco JP, Pereira JS (2007). Deficit irrigation in grapevine improves water-use efficiency while controlling vigour and production quality. Ann Appl Biol 150: 237–252.

Costa JM, Ortuño MF, Chaves MM (2007). Deficit irrigation as a strategy to save water: physiology and potential application to horticulture. J Integr Plant Biol 49: 1421–1434.

Dokoozlian NK, Kliewer WM (1996). Influence of light on grape berry growth and composition varies during fruit development. J Amer Soc Hort Sci 121: 869–874.

Dry PR, Loveys BR (1999). Grapevine shoot growth and stomatal conductance are reduced when part of the root system is dried. Vitis 38: 151–156.

El-Ansary DO, Nakayama S, Hirano K, Okamoto G (2005). Response of Muscat of Alexandria table grapes to post-veraison regulated deficit irrigation in Japan. Vitis 44: 5–9.

Escalona JM, Flexas J, Medrano H (1999). Stomatal and non-stomatal limitations of photosynthesis under water stress in field-grown grapevines. Aust J Plant Physiol 26: 421–433.

Fawzi MIF, Shahin MFM, Kandil EA (2010). Effect of bud load on bud behavior, yield, cluster characteristics and some biochemical contents of the cane of Crimson Seedless grapevines. J Amer Sci 6: 187–194.

Fereres E, Soriano MA (2007). Deficit irrigation for reducing agricultural water use. J Exp Bot 58: 147–159.

Geller JP, Kurtural SK (2013). Mechanical canopy and crop-load management of Pinot gris in a warm climate. Am J Enol Vitic 64: 65–73.

Hellman E, Basinger AR (2009). Evaluation of regulated deficit irrigation in west Texas. In: Proceedings of the Texas Viticulture and Enology Research Symposium, 2–3 June, Granbury, TX, USA.

Kang S, Zhang J (2004). Controlled alternate partial rootzone irrigation: its physiological consequences and impact on water use efficiency. J Exp Bot 55: 2437–2446.

Keller M (2005). Deficit irrigation and vine mineral nutrition. Am J Enol Vitic 56: 267–283.

Keller M, Smithyman RP, Mills LJ (2008). Interactive effects of deficit irrigation and crop load on Cabernet Sauvignon in an arid climate. Am J Enol Vitic 59: 221–234.

Kurtural SK, Wessner LF, Dervishian G (2013). Vegetative compensation response of a procumbent grapevine (*Vitis vinifera* cv. Syrah) cultivar under mechanical canopy management. Hortscience 48: 576–583.

Lovisolo C, Hartung W, Schubert A (2002). Whole-plant hydraulic conductance and root-to-shoot flow of abscisic acid are independently affected by water stress in grapevines. Funct Plant Biol 29: 1349–1356.

Matthews MA, Anderson MM (1989). Reproductive development in grape (*Vitis vinifera* L.): responses to seasonal water deficits. Am J Enol Vitic 40: 52–60.

McCarthy MG, Loveys BR, Dry PR, Stoll M (2002). Regulated deficit irrigation and partial rootzone drying as irrigation management techniques for grapevines. In: Deficit Irrigation Practices. FAO Water Reports No. 22. Rome, Italy: Food and Agriculture Organization of the United Nations, pp. 79–87.

Romero P, Fernandez-Fernandez JI, Martinez-Cutillas A (2010). Physiological thresholds for efficient regulated deficit-irrigation management in wine grapes grown under semiarid conditions. Am J Enol Vitic 61: 300–312.

Santos TP, Lopes CM, Rodrigues ML, Souza CR, Maroco JP, Pereira JS, Silva JR, Chaves MM (2003). Partial rootzone drying effects on growth and fruit quality of field-grown grapevines (*Vitis vinifera*). Funct Plant Biol 30: 663–671.

Santos TP, Lopes CM, Rodrigues ML, Souza CR, Silva JR, Maroco JS, Pereira JS, Chaves MM (2005). Effects of partial rootzone drying irrigation on cluster microclimate and fruit composition of Castelão field-grown grapevines. Vitis 44: 117–125.

Terry DB, Kurtural SK (2011). Achieving vine balance of Syrah with mechanical canopy management and regulated deficit irrigation. Am J Enol Vitic 62: 426–437.

TÜİK (2011). Turkey in Statistics. Ankara, Turkey: Turkish Statistical Institute.

Wessner LF, Kurtural SK (2013). Pruning systems and canopy management practice interact on the yield and fruit composition of Syrah. Am J Enol Vitic 64: 134–138.

Williams LE, Matthews MA (1990). Grapevine. In: Stewart BA, Nielsen DR, editors. Irrigation of Agricultural Crops (Agronomy). Madison, WI, USA: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, 1019–1055.

Winkler AJ, Cook JA, Kliewer WM, Lider LA (1974). General Viticulture. Berkeley, CA, USA: University of California Press.