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Vine Water Relations and Quality of 'Muscat of Alexandria' Table Grapes Subjected to Partial Root-zone Drying and Regulated Deficit Irrigation

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The effects of several irrigation strategies on vine water relations and the quality of table grapes, *Vitis vinifera* L. 'Muscat of Alexandria', were evaluated from veraison to harvest. The treatments included: (1) standard practice irrigation (control): re-irrigation when the soil moisture tension reached 15 kPa; (2) regulated deficit irrigation (RDI): re-irrigation 4 to 7 days after reaching a soil moisture tension of 15 kPa; (3) fixed partial root-zone drying (FPRD): one half of the root system was re-irrigated when the soil moisture tension reached 15 kPa; and (4) alternate partial root-zone drying (APRD): one half of the root system was re-irrigated when the soil moisture tension reached 15 kPa, and every week the irrigated half was switched. Treatments were continued for 7 weeks until harvest. During the experiment, RDI vines received 58% less irrigation water than the controls, while 33% less irrigation water was applied to FPRD and APRD vines. The results showed that only RDI vines had a significantly lower midday stem water potential compared with the control. Vines of FPRD and APRD treatments had the highest efficiency of water use (photosynthetic rate/stomatal conductance). At harvest, RDI fruit had markedly higher TSS, sugars, and amino acids, a similar acidity, and lower firmness and smaller size compared with the control. FPRD and APRD fruits had slightly higher TSS, sugars, and amino acids, a similar firmness and size, and lower acidity compared with the control. Aroma concentrations were high in RDI and FPRD fruits.

Key Words: deficit irrigation, grape, partial root-zone drying, quality, water potential.

Introduction

Controlled irrigation management is essential in modern viticulture. The efficient application of strategic irrigation technologies near the end of berry development not only saves water but also can play a positive role in improving the quality and profitability of table grapes. Regulated deficit irrigation (RDI) is a strategy which relies on the precise control of irrigation cut-off in order to apply a mild stress (Goodwin and Jerie, 1992). We reported that post-veraison RDI enhances the ripening of 'Muscat of Alexandria' table grapes; but, if severely applied, it may have negative impacts on foliage and fruit (El-Ansary et al., 2005). Partial root-zone drying (PRD) is a strategy which requires that the roots are simultaneously exposed to both wet and dry zones, thus stimulating some of the responses associated with water stress but not resulting in changes in vine water status (Dry and Loveys, 1998). The first work reporting the effects of PRD on yield and berry composition using split-root grapevines was conducted in Australia by Dry et al. (1996), who found that the yield is maintained and fruit quality is either unchanged or improved. However, the application of such strategies across a range of climates and viticultural conditions is still limited and needs further experimentation. Okayama city, located in the southwest of Honshu Island, Japan, features a temperate climate with rainy summer seasons. Thus, viticulture is usually practiced under polyhouses and root-zone restriction conditions to maintain healthy vines. The objective of our study was to compare the effects of employing different irrigation strategies and schedules on the vine water status, water use efficiency, and quality of 'Muscat of Alexandria' table grapes from veraison to harvest under rain-protected non-heated vineyard conditions.

Materials and Methods

Plant material, growth conditions, and irrigation treatments

The experiment was conducted in 2004 at the Okayama University Experimental Vineyard in Okaya-

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ma city (long. 133.92°E, lat. 34.66°N), Japan. Nine-year-old grapevines of 'Muscat of Alexandria' (*Vitis vinifera* L.) grafted on SO4 rootstocks were used. Vines were grown individually in raised beds (1.2 m long, 1.1 m wide, and 0.25 m high) under a non-heated polyhouse and root-zone restriction condition by installing a water-permeable but root-proof polyester sheet (BDK Lovesheet, Unitica, Japan) below the root-zone. The medium was a mixture of sandy soil, peat moss, and horse manure (4 : 1 : 1 vol/vol). Vines were trained to a unilateral cordon (2.4 m length), and spur-pruned (20 spur per vine); each spur having one shoot carrying one cluster; a sloping shoot-positioned trellis system was used. Weekly fertigation with a complete liquid fertilizer (Ohtsuka House Ekihi, No. 1 + No. 2, Ohtsuka Kagaku, Japan), containing 60 ppm of N was applied, the level of which was reduced to one third at the onset of veraison. A regular pest management program was maintained. Soil moisture tension was monitored by placing tensiometers (DIK-8332, Daiki Rika Kogyo, Japan) at a depth of 15 cm. From bud break to veraison, all vines were irrigated to a soil moisture tension of 3 kPa and re-irrigated when the soil moisture tension approached 15 kPa. Starting at veraison (17 July), four irrigation practices were imposed: (1) standard practice irrigation (control): re-irrigation when the soil moisture tension reached 15 kPa; (2) regulated deficit irrigation (RDI): re-irrigation 4 to 7 days after reaching a soil moisture tension of 15 kPa; (3) fixed partial root-zone drying (FPRD): one half of the root system was kept un-irrigated while the other half was re-irrigated when the soil moisture tension reached 15 kPa; and (4) alternate partial root-zone drying (APRD): one half of the root system was allowed to dry while the other half was re-irrigated when the soil moisture tension reached 15 kPa, and every week the irrigated half was switched so that the dry half was irrigated and the wet allowed to dry. For FPRD and APRD, each side of the vine was irrigated independently by dual in-line dripper tubing 30 cm apart from vine trunk, whereas the control and RDI vines were irrigated on both sides at the same time. Each control and RDI vine received 30 L per irrigation, while each vine in PRD (FPRD and APRD) received half of that amount. In conjunction with soil moisture monitoring, we measured the stem water potential to fine tune the irrigation schedule. Control, RDI, and the wet side of PRD vines were irrigated approximately at 2 to 3, 7, and 2-day-intervals, respectively. Treatments were continued for 7 weeks until harvest on 31 August. The total amount of water supplied to the vines from veraison to harvest in the control, RDI, and PRD treatments were 495, 210, and 330 L per vine, respectively.

Sampling and analyses

1. Water status and gas exchange measurements

The midday stem water potential (Ψ) was measured 4 times during the course of the experiment. Measurements were made one day before irrigation was given. Two leaves per vine were selected from the canopy, close to the trunk; they were enclosed overnight, while still attached, in plastic bags covered with aluminum foil to allow equilibration with the stem Ψ; they were then detached and their Ψ was measured immediately in the field by a pressure chamber (DIK-PC40, Daiki Rika Kogyo). Midday measurements of the photosynthetic rate (A) and stomatal conductance (g_S) were performed with a portable infrared gas analyzer (LCA-4, ADC, Shimadzu, Japan). Leaf water use efficiency (WUE) was calculated dividing A by g_S.

2. Fruit quality measurements

At harvest, the fruit diameter was measured in 30 berries per treatment using a digital caliper. Another 15 berries per treatment were randomly sampled and their firmness was determined as the force inducing 10% deformation of the fruit diameter (30 mm·min^{-1}), using a deformation tester (flat steel plate UL-5LK, CAP.: 50 N, diameter: 30 mm, Orientec Corp., Japan) mounted on a Tensilon machine (STM-T-50, Toyo Baldwin, Japan).

To determine juice amino acids, sugars, and organic acid contents at harvest, 60 berries per treatment were collected and divided into 3 subgroups including 20 berries each. Berries of each subgroup were peeled, deseeded, and the flesh was homogenized. The homogenate was centrifuged at 6500 rpm for 10 min. The supernatant was used for the analysis of amino acids, sugars, and organic acids. As regards amino acids, a 0.5 mL aliquot of sampled juice was mixed with 1 mL of water and 0.5 mL of 40% TCA. After standing for an hour at 5°C, the mixture was centrifuged at 5000 rpm for 5 min at 4°C. The supernatant was washed 3 times with 2 mL of diethyl ether to remove excess TCA. After removing the diethyl ether from the mixture *in vacuo*, the sample solution was filtered and then analyzed by an automatic amino acid analyzer (JLC-300, JEOL, Japan). For sugars and organic acids, a 2 mL juice aliquot was loaded into a column of Amberlite CG-120 (H^+) ion-exchange resin. The column was eluted with 48 mL of deionized water. The eluate was collected and analyzed by HPLC (L-7100, Hitachi, Japan). HPLC conditions for sugars were: column, Asahipak NH2P-50 4E, 4.6 mm × 250 mm (Shodex, Japan); detector, RID-10A (Shimadzu); mobile phase, $CH_3CN : H_2O = 75 : 25$; flow rate, 1 mL·min^{-1}; and column temp, 40°C. HPLC conditions for organic acids were: column, Unisil C18 (5 μm), 4.6 mm × 250 mm; detector, UV-VIS Detector (L-7420, Hitachi); wave length, 210 nm; mobile phase, 0.1 M $NH_4H_2PO_4$ (pH 2.5 adjusted by H_3PO_4); flow rate, 0.6 mL·min^{-1}; and column temp, 40°C. Total soluble solids (TSS) of berry juice were measured by a hand refractometer (ATC-1E, Atago, Japan), and titratable acidity (% tartaric acid) by diluting the juice with deionized water and titrating with 0.1 N sodium hydroxide to the phenolphthalein end point.

For measuring the aroma volatiles at harvest, 15 berries per treatment were randomly sampled and divided into 3 subgroups comprising 5 berries each. Berries of each subgroup were deseeded and homogenized. Ten grams of the homogenate were poured into a separation funnel with 10 μL of 2-octanol 0.1% (as an internal standard) and 50 mL of n-pentane. Monoterpenes were extracted by shaking for 6 min. The supernatant was dehydrated with Na_2SO_4 anhydride and concentrated to 0.3 mL *in vacuo*. A 1 μL aliquot was injected into the GC port (GC-14 A, Shimadzu). GC analytical conditions were: CBJ-WAX capillary column, 0.5 mm × 30 m (Shimadzu); N_2 as a carrier gas at 40 mL·min^{-1}; and column temperature was held initially at 70°C, increased at 5°C·min^{-1} to 220°C, and held at the final temperature. Injection temperature was set at 170°C and the detector temperature was 230°C. Identification of aroma compounds was performed with a Varian 3000 GC-MS (Varian, Inc., USA). GC-MS analytical conditions were: mass spectrometer, FinniganMAT MAGNUM (Bremen, Germany); CBJ-WAX capillary column, 0.5 mm × 30 m (Shimadzu); He as a carrier gas at 1 mL·min^{-1}; column temperature was held initially at 70°C, increased at 5°C·min^{-1} to 220°C, and held at the final temperature; and ionization voltage, 70 eV. MS identifications were confirmed by injecting authentic standards and quantitative analysis was accomplished using a series of standard solutions.

Experimental design and statistical analysis

Three individual vine replicates were assigned for each treatment using a completely randomized block design. Data analysis was done by a one-factor ANOVA. Mean comparisons were performed using the Tukey-Kramer test to examine differences between treatments. Significance was determined at $P<0.05$ or $P<0.01$.

Results and Discussion

The midday stem Ψ of the control vines ranged approximately from −0.3 to −0.4 MPa during the course of the experiment, and approximately similar midday stem Ψ values were also observed in FPRD and APRD vines (Table 1). Stem Ψ of RDI vines continued to decrease till the last measurement on day 38 of the experiment and reached the minimum value of approximately −0.6 MPa, *i.e.*, it was significantly lower ($P<0.01$) than that of control, FPRD and APRD vines. Before irrigation, RDI vines had a significantly lower midday stem Ψ compared with the control and the other irrigation treatments at all dates measured. Several experiments showed that there was no significant difference between leaf Ψ from vines receiving water to the entire root system compared with leaves from vines where only half of the root system was watered (Düring et al., 1996; Loveys et al., 2000). In contrast, drying the whole root system where irrigation input is either reduced or withheld completely for specified periods of time results in a decreased leaf Ψ (El-Ansary et al., 2005). In split-root plants, when part of the root system was allowed to dry while the other part was well-watered, water relations are maintained by the supply of water from the hydrated parts of the root system (Davies and Zhang, 1991). In our study, stem Ψ was less variable and more sensitive to soil Ψ than leaf Ψ (data not shown). This is in agreement with other reports on apple (Naor et al., 1995), prune (McCutchan and Shackel, 1992), and grapevine (Choné et al., 2001; Naor and Wample, 1994), suggesting that midday stem Ψ is an appropriate index of plant water status for irrigation management.

The leaf photosynthetic rate of RDI vines decreased with time, *i.e.*, it was significantly lower ($P<0.05$) than that of the other irrigation treatments at the first and final measurements (Table 2). This was accompanied by a parallel reduction in stomatal conductance. Photosynthetic rates of control, FPRD, and APRD leaves remained unchanged from the first to the second measurements and decreased slightly thereafter. On the last measurement, the control vines had the highest photosynthetic rate, followed by APRD and FPRD; differences were significant ($P<0.05$) between the control and FPRD vines. Stomatal conductance was higher in the control

Table 1. Stem water potential (Ψ) of 'Muscat of Alexandria' grapevines which received different irrigation treatments from veraison to harvest.

Treatment[z]	Day after veraison			
	Day 0	Day 7	Day 17	Day 38
	Stem Ψ (MPa)			
Control	−0.33 ± 0.05a[y]	−0.40 ± 0.03a	−0.36 ± 0.03A	−0.43 ± 0.02A
RDI	−0.33 ± 0.05a	−0.52 ± 0.03b	−0.51 ± 0.03B	−0.58 ± 0.05B
FPRD	−0.33 ± 0.05a	−0.41 ± 0.01a	−0.35 ± 0.01A	−0.41 ± 0.02A
APRD	−0.33 ± 0.05a	−0.38 ± 0.05a	−0.38 ± 0.02A	−0.40 ± 0.04A

[z] Control = Standard practice irrigation; RDI = Regulated deficit irrigation; FPRD = Fixed partial root-zone drying; APRD = Alternate partial root-zone drying.

[y] Mean ± SD; separation within columns by the Tukey-Kramer Test at $P<0.05$ (lowercase letters) or $P<0.01$ (uppercase letters).

Table 2. Photosynthetic rate (A), stomatal conductance (g_s), and leaf water use efficiency (WUE) of 'Muscat of Alexandria' grapevines subjected to different post-veraison irrigation treatments.

Treatment	A (μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$)	g_s ($mol \cdot m^{-2} \cdot s^{-1}$)	WUE (A/g_s)
Day 6 after veraison			
Control	6.66±0.43a	0.25±0.01a	26.91±1.2b
RDI	5.10±0.39b	0.17±0.03b	29.99±3.5ab
FPRD	6.19±0.29a	0.18±0.03b	33.90±5.0a
APRD	6.10±0.62a	0.20±0.02ab	31.28±1.5ab
Day 17 after veraison			
Control	6.61±0.77A	0.25±0.03A	26.44±1.4b
RDI	5.02±0.44B	0.16±0.03B	30.61±3.7a
FPRD	6.09±0.50AB	0.18±0.02B	34.47±2.7a
APRD	5.88±0.54AB	0.17±0.03B	33.73±3.0a
Day 30 after veraison			
Control	5.94±0.71a	0.19±0.01A	31.28±1.5b
RDI	3.86±0.56c	0.11±0.02B	34.06±7.4ab
FPRD	4.93±0.46b	0.13±0.02B	37.10±2.3ab
APRD	5.24±0.71ab	0.13±0.02B	40.31±2.0a

Abbreviations as in Table 1.

Table 3. Effects of the post-veraison irrigation treatments on several quality aspects of fruit at harvest.

Treatment	Berry diam. (mm)	Firmness (N)	TSS (%)	Acidity (%)
Control	22.7±0.90A	6.9±0.88a	15.9±0.78b	0.25±0.02a
RDI	21.4±0.96B	6.0±0.61b	18.0±0.45a	0.25±0.02a
FPRD	22.6±0.86A	6.6±0.89ab	16.9±0.26ab	0.22±0.01ab
APRD	22.4±0.85A	6.8±0.68a	16.7±0.17b	0.20±0.01b

Abbreviations as in Table 1.

than the other treatments for any given measurement, and the differences were highly significant ($P<0.01$) at the second and third measurements (Table 2). Leaf water use efficiency tended to increase with time, but more markedly in FPRD and APRD than RDI and the control (Table 2). On the second measurement, all treatments had a significantly higher ($P < 0.05$) leaf water use efficiency compared with the control. Drying the whole root system of the grapevine decreases the photosynthetic rate and stomatal conductance, which is considered a drought avoidance mechanism (Düring, 1987, 1988; Padgett-Johnson et al., 2003). Stomatal conductance is highly correlated with midday stem Ψ (Choné et al., 2001; Naor et al., 1995). The mechanisms by which plants perceive soil water deficits include chemical and hydraulic signals (Davies and Zhang, 1991; Tardieu and Davies, 1993). Stomatal conductance was significantly reduced in response to the half-drying of the root system (PRD treatments) without any associated change in midday stem Ψ, indicating the involvement of a non-hydraulic signal stimulating this response. Our results are in agreement with those reported by Dry and Loveys (1999) using split-root potted grapevines. Droughted grapevines show a significant rise in the abscisic acid (ABA) content of roots and leaves (Loveys et al., 2000; Okamoto et al., 2004). The ABA signal affects the stomatal conductance of grapevine leaves; it reduces photosynthesis slightly, but transpiration is reduced more severely; this leads to an increase in water use efficiency (Düring et al., 1996).

The RDI strategy led to a significantly smaller fruit ($P<0.01$) compared with the control at harvest (Table 3). Previous investigations on grapes showed that early season water deficits are particularly effective in reducing fruit size at harvest rather than late season water deficits (Hardie and Considine, 1976; Matthews et al., 1987). Moreover, the magnitude of the reduction in berry size is proportional to both the duration and severity of water stress (Goodwin and Jerie, 1992; Reynolds and Naylor, 1994). However, fruit size was unaffected by wetting one half of the root system in FPRD and APRD vines, accounting for 67% of the amount of water given to the controls from veraison to harvest. At harvest, the firmness of RDI fruit reached 6 N and was significantly lower ($P<0.05$) than that of the control and APRD fruits. Differences in firmness were not significant between the RDI and FPRD fruits. In previous work (El-Ansary et al., 2005), we demonstrated that fruit firmness is responsive to the vine water status and that post-veraison RDI treatment accelerates fruit softening. Fruit softening could be due to the water loss from fruit to the atmosphere or to the plant, which results in a decreased turgor pressure and, consequently, reduced firmness (Bernstein and Lustig, 1981). PRD treatments maintained fruit firmness close to the control, indicating that there was an adequate supply of water in PRD treatments.

By the end of the experiment, juice TSS was approximately 18, 17, 17, and 16% for RDI, FPRD, APRD, and control fruits, respectively, (Table 3). Although the TSS was greater in all irrigation treatments than in the control, the difference was only significant between the RDI treatment and the control. As shown in Table 4, concentrations of glucose and fructose were higher in all treatments than in the control, but the differences were only significant in the fructose concentrations between the RDI treatment and the control. The marked increase in juice TSS as a result of preharvest irrigation deficits may occur by one of four reasons: (1) by the reduction in lateral shoot growth with a concomitant reallocation of carbohydrates to the fruit (Reynolds and Naylor, 1994); (2) by concentration during berry desiccation (Reynolds and Naylor, 1994); (3) by osmoregulation (Yakushiji et al., 1996); or (4): by the direct effect of the root ABA signal on fruit ripening (Coombe, 1989; Düring et al., 1978; Okamoto et al., 2004). Table 3 shows that PRD treatments had a lower acidity level at harvest than the control, although the difference was not significant for FPRD juice. The acidity level of RDI juice was similar to the control. All irrigation treatments led to a very significant decline in the malic acid concentration at harvest as compared with the control, indicating that fruit maturation was enhanced by those treatments (Table 4). Most of the acid loss during fruit ripening occurs in malate (Matthews and Anderson, 1988). Moreover, Lakso and Kliewer (1975) found that the malic acid-producing enzyme PEP carboxylase has a lower stability at high temperatures than the malic acid-degradating enzyme malic enzyme. Souza et al. (2005) attributed the marked decrease in the malic acid concentration of rain-fed grapevine juice, in part, to the increased cluster temperature associated with the reduction in vegetative growth.

The total amino acid concentration in juice at harvest was lowest in the control vines (9.6 mmol·L^{-1}), slightly higher in FPRD and APRD (11.1 and 10.1 mmol·L^{-1}, respectively), and greatest in RDI vines (13.7 mmol·L^{-1}); it was significantly higher ($P < 0.05$) in RDI juice than in that of control and APRD (Table 5). Arginine was the predominant amino acid in juice, and it was significantly higher ($P < 0.01$) in RDI juice compared to the other treatments. Okamoto et al. (2004) reported that total amino acids in grape juice at harvest increase as a result of stress from a post-veraison water deficit. The marked increase in amino acid concentrations in the juice of water deficient vines may be due to the decomposition of proteins in dehydrated leaves and the remobilization of nitrogenous compounds into other permanent organs of the vine such as canes, trunks, and roots, and also into clusters (Ndung'u et al., 1997; Okamoto et al., 2004).

The volatile aroma production in 'Muscat of Alexandria' grapes responded to the irrigation treatments (Table 6). The concentrations of linalool and citronellol were markedly higher in RDI and FPRD fruits than in control fruit. FPRD fruit showed a significantly higher geraniol concentration compared with the control. All irrigation treatments led to a highly significant increase in the α-terpineol concentration as compared to control fruit. An exception was the nerol concentration, which was slightly higher in control fruit than in RDI or PRD fruit. Environmental and cultural conditions such as soil moisture availability can influence the accumulation and production of aroma volatiles in fruit (Dudareva et al.,

Table 4. Sugars and organic acid contents in 'Muscat of Alexandria' berry juice at harvest as influenced by the post-veraison irrigation treatments.

Treatment	Glucose	Fructose	Tartaric acid	Malic acid
	(g/100 mL)			
Control	7.41 ± 0.84a	7.32 ± 0.46b	0.23 ± 0.03a	0.21 ± 0.01A
RDI	8.67 ± 0.44a	8.71 ± 0.49a	0.21 ± 0.03a	0.15 ± 0.00B
FPRD	7.81 ± 0.30a	8.22 ± 0.29ab	0.25 ± 0.02a	0.15 ± 0.02B
APRD	7.77 ± 0.25a	7.96 ± 0.27ab	0.24 ± 0.01a	0.14 ± 0.00B

Abbreviations as in Table 1.

Table 5. Amino acid concentrations in 'Muscat of Alexandria' berry juice at harvest as affected by the post-veraison irrigation treatments.

Treatment	ARG	ALA	GABA	PRO	GLU	SER	THR	ASP	GLN	HIS	Others	Total
	(mmol·L^{-1} juice)											
Control	4.38B	1.12b	0.95a	0.85a	0.39b	0.34B	0.32a	0.20a	0.23B	0.16b	0.67B	9.59 ± 0.53b
RDI	6.67A	1.81a	1.13a	0.91a	0.61a	0.46A	0.37a	0.26a	0.45A	0.22a	0.84A	13.72 ± 1.92a
FPRD	4.37B	1.49ab	1.15a	1.26a	0.54ab	0.38AB	0.35a	0.22a	0.28B	0.17ab	0.83A	11.05 ± 0.33ab
APRD	4.02B	1.36ab	0.93a	1.12a	0.55ab	0.38AB	0.36a	0.22a	0.21B	0.16ab	0.74AB	10.05 ± 0.50b

Abbreviations as in Table 1.

Table 6. Aroma concentrations in 'Muscat of Alexandria' grape berries at harvest as influenced by the post-veraison irrigation treatments.

Treatment	Linalool	α-Terpineol	Citronellol ($\mu g \cdot g^{-1}$ FW)	Nerol	Geraniol
Control	0.28±0.02C	Trace	0.16±0.00c	0.73±0.09a	1.48±0.12b
RDI	0.55±0.03B	0.18±0.0A	0.19±0.00b	0.66±0.06ab	1.61±0.13b
FPRD	0.64±0.02A	0.18±0.0A	0.21±0.01a	0.69±0.04ab	2.05±0.16a
APRD	0.33±0.02C	0.17±0.0B	0.16±0.01c	0.57±0.02b	1.42±0.15b

Abbreviations as in Table 1.

2004; Mattheis and Fellman, 1999). We reported that the RDI strategy after veraison enhances volatile aroma production by grapes of 'Muscat of Alexandria' at harvest (El-Ansary et al., 2005). This increased aroma production in RDI and FPRD fruits may be related, in part, to the advancement of ripening as a result of employing those irrigation strategies. FPRD and APRD fruits had approximately similar levels of maturity-related quality attributes such as sugars and organic acids, though they were significantly different in the concentrations of several aroma volatile contributors (linalool, α-terpineol, citronellol, and geraniol). This inconsistency in aroma production by FPRD and APRD fruits may be due to the greater degree of water stress-associated responses that developed in the FPRD vines where one portion of the root system was kept in dry conditions during the experiment. Our results indicated that the maturity and quality of table grapes of 'Muscat of Alexandria' can be manipulated by imposing RDI or PRD strategies from veraison to harvest. By implementing the RDI strategy throughout ripening, fruit quality was improved but fruit size was partially reduced with a water saving of 285 L per vine, whereas applying the PRD strategy using either the fixed or alternate technique maintained fruit quality with water savings of 165 L per vine. After harvesting, we investigated the conditions of the root system in both the wet and dry zones of the PRD treatments and didn't find any visual symptoms of root death. However, the development of the new secondary roots was considerably less on the dry side of the FPRD treatment. We concluded that PRD treatments applied from veraison to harvest do not seem to have negative effects on the growth and quality of fruit compared with the standard irrigation practice, although this would require additional testing, especially for the acidity level. Further experiments are warranted to examine the effects of PRD on the physiology, development, and survival of the water-stressed roots to maintain healthy grapevines year after year.

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