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Water use efficiency and fruit quality of table grape under alternate partial root-zone drip irrigation

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ABSTRACT

Two-year field experiments were conducted to investigate the effect of alternate partial root-zone drip irrigation on fruit yield, fruit quality and water use efficiency of table grape (*Vitis vinifera* L. cv Rizamat) in the arid region of northwest China. Three irrigation treatments were included, i.e. CDI (conventional drip irrigation, both sides of the root-zone irrigated), ADI (alternate drip irrigation, both sides of the root-zone irrigated alternatively with half the water) and FDI (fixed drip irrigation, only one side of the root system irrigated with half the water). Results indicated that compared to CDI, ADI kept the same photosynthetic rate (P_n) but reduced transpiration rate, thus increased leaf water use efficiency (WUE) of table grape. And diurnal variation of leaf water potential showed no significant differences during 7.00 a.m. to 14.00 p.m. in both years. ADI also produced similar yield and improved WUE_{ET} by 26.7–46.4% and increased the percentage of edible grape by 3.88–5.78%, vitamin C content in the fruit by 15.3–42.2% and ratio of total soluble solid concentration/titrated acid in both years as compared to CDI. Thus ADI saved irrigation water, improved the water use efficiency and fruit quality of table grape without detrimental effect on the fruit yield in arid region.

1. Introduction

Water shortage is an important limiting factor in crop production in the arid areas of Northwest China where agriculture relies heavily on irrigation (Kang et al., 2004). Table grape is one of the main horticultural crops in Shiyang River Basin, Gansu Province, northwest China. The acreage of the vineyard in this region reached 6700 hm^2 in 2003, occupying about 12.5% of national total area of vineyard (Liu et al., 2006). From an economical point of view, fruit quality of table grape is more emphasized than its yield in recent years. Much effort has been spent on developing APRI (alternate partial root-zone irrigation) or partial root-zone drying (PRD) in the literature to improve crop water use efficiency and fruit quality of horticultural crops (dos Santos et al., 2007; Dry and Loveys, 1998; Girona et al., 2006; Goldhamer et al., 2006; Kang et al., 1997, 1998, 2000; Loveys et al., 1998; McCarthy et al., 2000).

The PRD technique was originally conceived as a means of reducing vine vigour and the reduction in shoot growth and increase light entering the bunch zone. It was also found that yield was maintained and fruit quality was either unchanged or improved in the first work reporting the effects of PRD on wine grapes in Australia (Dry et al., 1996). Most earlier studies of APRI on wine grape in Mediterranean region had a positive effect of APRI on stomatal conductance, water use efficiency,

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the control of vegetative vigour as well as the wine quality (Kriedemann and Goodwin, 2003; Loveys, 2000; Santos et al., 2003, 2005; Stoll et al., 2000). However, the positive effect of APRI on yield and fruit chemical composition was not significant in the field experiment on wine grape in the dry growing season in the San Joaquin Valley of California (Gu et al., 2000, 2004). The inconsistent effect of APRI on WUE and fruit quality in field-grown wine grape under the semiarid conditions was also discussed (de la Hera et al., 2007). One reason may be that plants may effectively forage for water in different watering treatment by proliferating their roots into the wetted root-zones (Mingo et al., 2004) and this response mainly depends on the grapevine variety and the environmental conditions (de Souza et al., 2005a,b).

Water use efficiency, fruit yield and quality were the integrate response of crop to soil water distribution, physiological index and water relations. Experimental results showed that APRI had no significant yield reduction even though the amount of irrigation water is significantly reduced (Kang and Zhang, 2004; McCarthy et al., 2000; Santos et al., 2005). However, many reports showed no improvement in grapevine water use, crop yield or fruit quality compared to the conventional irrigation at the same irrigation amount (dos Santos et al., 2003; de Souza et al., 2005a,b; Gu et al., 2004). Although many positive or negative effects of APRI have been reported in earlier literatures, the effect of APRI on soil water distribution in different partial root-zones, physiological response and the improvement of yield component, fruit quality and water use efficiency in different climates, grape varieties and viticultural conditions still need to be investigated before it can be concluded whether APRI is practical in all conditions.

In this study, field experiments have been conducted to investigate the effect of alternate partial root-zone drip irrigation (ADI) on temporal and spatial variation of soil moisture, fruit yield, fruit quality and water use efficiency of table grape grown in an arid region. Our objectives are to investigate how APRI improve water use efficiency and fruit quality of table grape and to explore an optimal irrigation strategy of water saving and quality improving for table grape in arid conditions.

2. Materials and methods

2.1. Field conditions and plant material

Field experiments were carried out on a cultivated table grape (*Vitis vinifera* L. cv Rizamat) grown in a 1.75-ha vineyard during the year 2005–2006 in Shiyang River Basin, which locates in the typical continental temperate arid zone of northwest China (latitude 37°52′20″N, longitude 102°50′50″E, altitude 1581 m), with a mean annual precipitation of 164 mm. The soil type is a light sandy loam with a moderate permeability and organic matter content, with averaged field capacity of approximately 0.435 $cm^3\ cm^{-3}$ and the bulk density of about 1.45 $g\ cm^{-3}$. The groundwater table is consistently below 25–30 m.

The six-year-old table grapes had an east–west row orientation. The table grapes were spaced 2.9 m between rows and 1.8 m along rows and trained on a vertical shoot positioning with three pairs of wires and spur pruned on bilateral cordon system at a height of 60 cm. All table grapes were uniformly pruned to same nodes per tree. Standard cultural practices in the region were applied to all treatments. Shoots were trimmed at about 20 cm above the highest wire from veraison to harvest.

Table 1 – Rainfall and reference crop evapotranspiration (ET_0) at the experimental site in 2005–2006

Month	Rainfall (mm)		ET_0 (mm)	
	2005	2006	2005	2006
May[a]	11.0 (7.0[c])	26.0 (17.0[c])	118.75	91.27
June	4.0 (0.0[c])	3.0 (0.0[c])	156.20	122.48
July	16.0 (11.0[c])	91.0 (88.0[c])	129.66	97.88
August	30.0 (19.0[c])	36.0 (30.0[c])	111.78	89.95
September	21.0 (15.0[c])	18.0 (11.0[c])	75.29	60.29
October[b]	6.0 (0.0[c])	0.0 (0.0[c])	32.25	16.73
Total	88.0 (52.0[c])	174.0 (146.0[c])	623.93	478.60

[a] Rainfall and ET_0 were from May 7th to 31st of two years.
[b] Rainfall and ET_0 were from October 1st to 15th of two years.
[c] Rainfall was the sum of daily rainfall greater than 5 mm.

Meteorological data (air temperature, relative humidity, global radiation, rainfall and wind speed) were recorded hourly by a weather station (Weather Hawk Station, Campbell Scientific, USA), which was 200 m away from the experimental plots. Variation of reference crop evapotranspiration (ET_0) calculated using the Penman–Monteith equation (Allen et al., 1998) and rainfall measured during the experimental period in two years is presented in Table 1.

2.2. Irrigation and experimental design

The experiment was designed as a randomized complete block with three replications. Three partial root-zone drip irrigation methods were included, i.e. CDI (conventional drip irrigation, irrigated on both sides of the root system as the control), ADI (alternate partial root-zone drip irrigation, irrigated with 50% of the control, alternatively on the two sides of the root system during consecutive watering), FDI (fixed partial root-zone drip irrigation, irrigated with 50% of the control on only one side of the root system). In the drip irrigation system, irrigation water was applied with pressure-compensated drip emitters, two emitters per tree for CDI and one emitter per tree for ADI or FDI (Fig. 1), operating at 4 $L\ h^{-1}$ and positioned 40 cm from the vine trunk. Water amount per irrigation under CDI was calculated as:

$$m = \alpha \cdot (\theta_{\max} - \theta_{\min}) \cdot p \cdot H \times 1000 \quad (1)$$

where m is irrigation water amount per irrigation (mm); α is percentage of consumptive water to field capacity(θ_f), α = 40%; $\theta_{\max}$ is the upper limit of irrigation (72% θ_f); $\theta_{\min}$ is the lower limit of irrigation (60% θ_f); p is ratio of soil wet zone, p = 40% according to the pre-experimental data, H is depth that irrigation penetrates (1 m).

Water amount per irrigation under ADI and FDI was designed as 50% of that under CDI. Irrigation details are listed in Table 2.

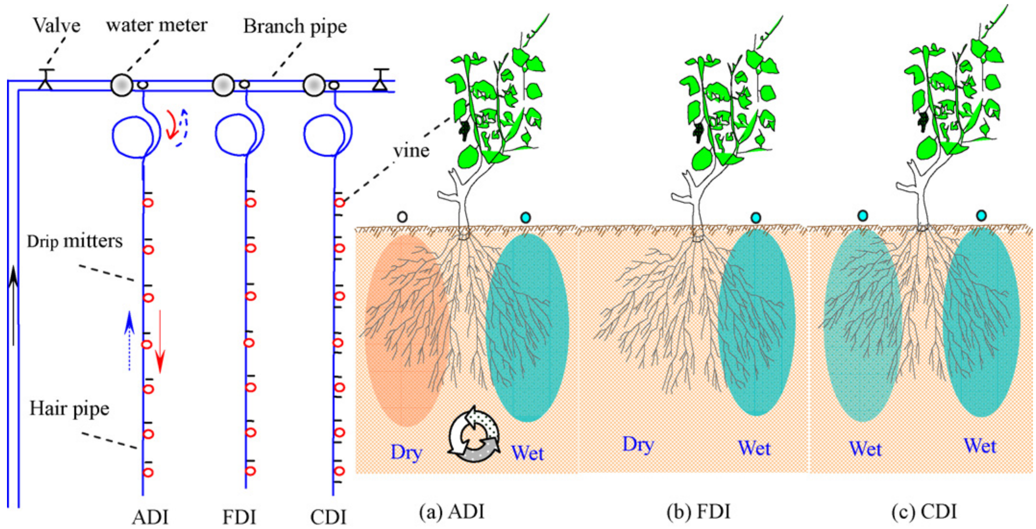

Fig. 1 – Layout of irrigation system for three drip irrigation methods in the experiment of field table grape. For ADI treatment, two root-zones of table grape were alternatively irrigated during the consecutive irrigation. For FDI treatment, only one of the two root-zones was irrigated during the whole growing season. For CDI treatment, both root-zones were irrigated in each watering.

2.3. *Soil water measurement*

To monitor soil water content of the different partial root-zones, two PVC access tubes (1.0 m in length) were installed at 45 cm from the trunk in the row. Soil water content was measured at 3–5 d intervals using a portable soil moisture monitoring system (Diviner, 2000, Sentek Pty Ltd, Australia). The vertical profile of soil water content in each tube was determined from measurements of soil water content at 0.1 m intervals. Readings were taken through the wall of a PVC access tube. Data was collected from a network of access tubes installed at selected sites.

The gravimetric sampling technique and steel rings were used to calibrate the Diviner 2000 display unit, and the following calibration equation was used in the three-year measurements:

$$SF = 0.2746 \cdot \theta^{0.3314} + 0.9876 \tag{2}$$

where θ is the volumetric soil water content ($cm^3\,cm^{-3}$), as determined by gravimetric sampling and bulk density of every 10 cm soil profile; SF is the scaled frequency (SF) readings which is calculated from the following equation:

$$SF = \frac{F_A - F_S}{F_A - F_W} \tag{3}$$

where F_A is the frequency reading in the access tube while suspended in air, F_S is the reading in the access tube in soil at a particular depth level, F_W is the reading in the access tube in the water bath.

The crop evapotranspiration (ET_c, mm) of each plot was determined by the following water-balance equation:

$$ET_c = P + I - F \pm Q + \theta_0 - \theta_h \tag{4}$$

where *P* is the effective rainfall in the growth period calculated as the sum of daily rainfall greater than 5 mm (Table 1); *I* is the irrigation water (mm); *F* is the surface runoff (mm), there is no runoff during the experiment, so *F* = 0; *Q* is the water loss by deep percolation (mm) either positive or negative, there is no remarkable difference between soil water content of 90 and

Table 2 – Details of irrigation treatments for table grape in 2005–2006

Year	Treatment	Irrigation detail		
		Times (No.)	Amount (mm/irrigation)	Irrigation date
2005	ADI	7	9.6	May 10, May 25, June 10, June 26, July 12, July 31, September 10
	CDI	7	19.2	May 10, May 25, June 10, June 26, July 12, July 31, September 10
	FDI	7	9.6	May 10, May 25, June 10, June 26, July 12, July 31, September 10
2006	ADI	6	9.9	May 16, May 30, June 12, June 25, July 18, August 17
	CDI	6	19.8	May 16, May 30, June 12, June 25, July 18, August 17
	FDI	6	9.9	May 16, May 30, June 12, June 25, July 18, August 17

ADI, CDI and FDI are alternate, conventional and fixed drip irrigation, respectively.

100 cm, and the groundwater table depth is consistently below 25–30 m, so Q = 0; θ_0 and θ_h is the amount of soil moisture stored at planting (mm) and harvesting (mm) based on the mean value from the dry and wet root-zones for ADI and FDI and the whole root-zone for CDI, respectively.

2.4. *Physiological index measurement*

Daily changes of net photosynthetic rate (P_n) and transpiration rate (T_r) of three leaves per treatment were measured with a portable photosynthesis system (ADC Bio-Scientific Ltd., UK) in two representative sunny cloudless days at veraison stage during 2005 and 2006. Leaf water use efficiency was calculated with the carbon gained per unit of water loss.

Leaf water potential (Ψ_L) was measured synchronously with a pressure chamber (3005 Plant Water Status Console, Soil Moisture Equipment Corp., Santa Barbara, CA). Pre-dawn and midday leaf water potential were also measured after the fifth irrigation in 2005.

2.5. *Yield components and fruit quality*

Five table grapes in each plot were chosen to investigate yield components and fruit quality; actual yield of each plot were also recorded at harvesting. Bunches were collected from upper, middle and lower position of the table grape to obtain bunch weight and percentage of edible grape. From the harvested grapes 2 kg berries were chosen randomly for analyzing berry weight and fruit quality. Total soluble solid concentration (TSSC) was measured by refractometer (WYT-II handheld refractometry, Chengdu Refractometer Ltd., China). Titrated acidity (TA) was determined by titration with NaOH with phenolphthalein as indicator. Vitamin C content (V_c) was measured by 2,6-dichlorophenol-indophenol titration (AOAC, 1990). Five samples were measured for each treatment. Yield water use efficiency was calculated and expressed as WUE_{ET} (total fruit yield per water amount consumed).

2.6. *Data analysis*

Data were statistically analyzed by a complete randomized model using SAS 6.12 (SAS Institute Ltd., USA). All the treatment means were compared in the same row for any significant differences using the Duncan's multiple range tests at a significance level of 0.05.

3. Results

3.1. *Temporal and spatial variation of soil water content*

Temporal variation of soil moisture under different partial root-zone drip irrigations is shown in Fig. 2. Results showed that the asymmetrical distribution of soil moisture in the two sides of ADI root-zone was achieved due to the alternate wetting and drying in arid fields (Fig. 2a). Soil moisture content in the drying side was relatively constant or increased slightly several days after irrigation as a result of redistribution of water through root systems, which was more significant in FDI (Fig. 2b).

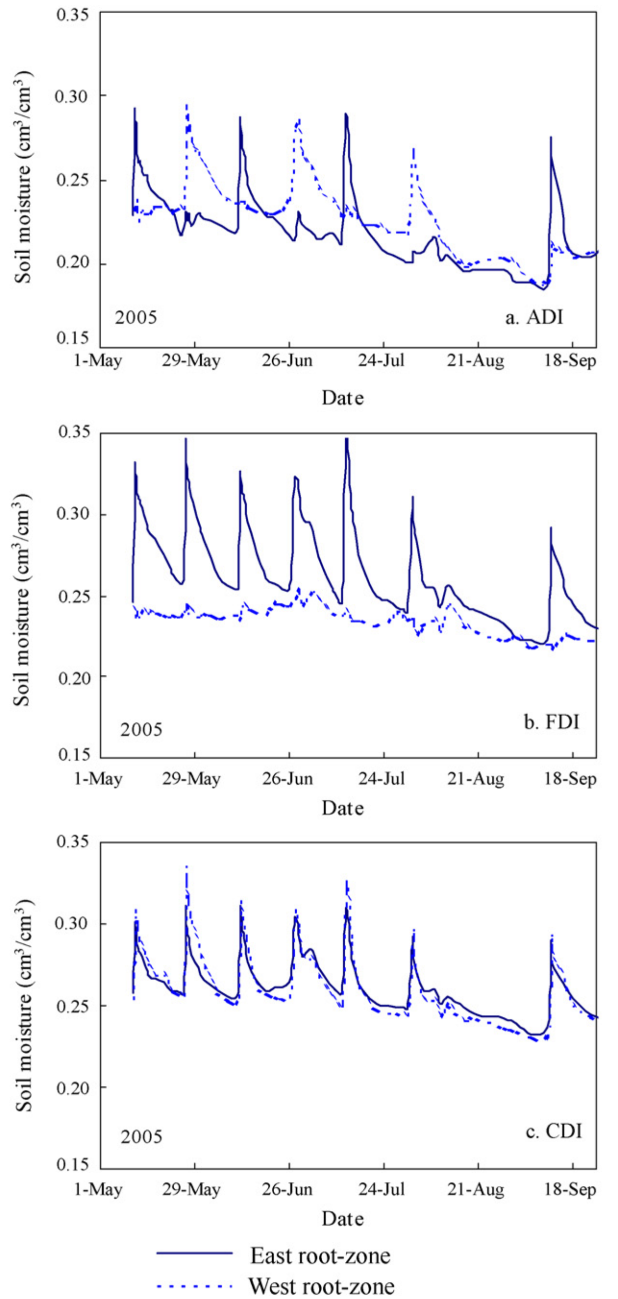

Fig. 2 – Temporal variation of soil water content in different root-zone under different partial root-zone drip irrigation in 2005. (a) ADI; (b) FDI; (c) CDI.

Spatial variation of soil moisture in different root-zones under ADI at 1.0 m soil profile during the second alternating cycle from 10 June to 11 July in 2005 is presented in Fig. 3. Soil water content in the two root-zones was different during the alternating cycles (Fig. 3a and b). Soil water content in the wetted side was higher than that of the drying side as a result of irrigation (Fig. 3a and d), but the soil water content was found to be relatively constant or increased slightly for several days after irrigation in the non-irrigated side (Fig. 3b and c). This may be caused by lateral infiltration or redistribution of water through the root systems. Moreover, water was

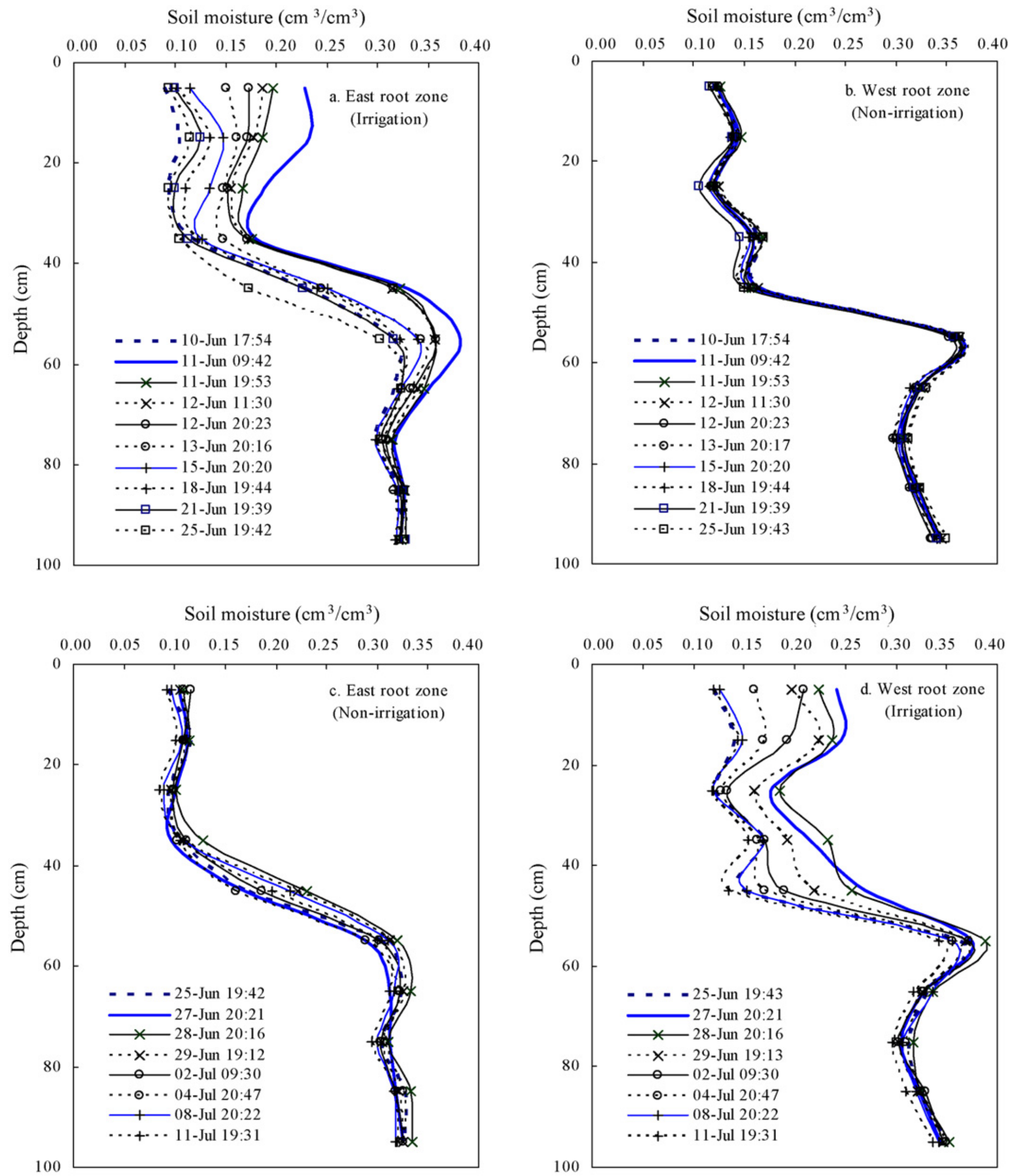

Fig. 3 – Spatial variation of soil water content in different root-zones under different partial root-zone drip irrigation during the second alternating cycle in 2005.

extracted mainly in the wetted soil profile of 0–60 cm. The results indicated that alternate partial root-zone irrigation could be more effective in the arid field.

3.2. *Physiological response*

Diurnal variation of leaf T_r and P_n in table grape under different irrigation treatments in 2005 showed ADI kept the similar photosynthetic rate (P_n) but reduced transpiration rate (T_r), thus increased leaf water use efficiency (WUE) compared to CDI. The data in 2006 also indicated that ADI kept same P_n but reduced T_r thus improved leaf WUE especially during 11.00 a.m. to 15.00 p.m. (Fig. 4).

Diurnal variation of leaf water potential (ψ_L) measured synchronously showed no significant differences during 7.00 a.m. to 14.00 p.m. in both years. However, ADI reduced the average ψ_L significantly during 14.00 p.m. to 19.00 p.m. in 2006, which indicated that table grape grown under ADI may experience a mild leaf water deficit after the midday (Fig. 4).

Pre-dawn leaf water potential (ψ_{pd}) after the fifth irrigation was slightly lower in ADI than that of CDI but no significant differences were observed during the irrigation cycle. However, the midday leaf water potential (ψ_m) in ADI was similar with CDI only in 7 days after irrigation in 2005 (Fig. 5).

3.3. *Fruit yield components and water use efficiency*

Fruit yield and its components of table grape under different irrigation treatments in 2005 and 2006 are shown in Table 3. ADI gained 44.8% more bunch number per tree than FDI in

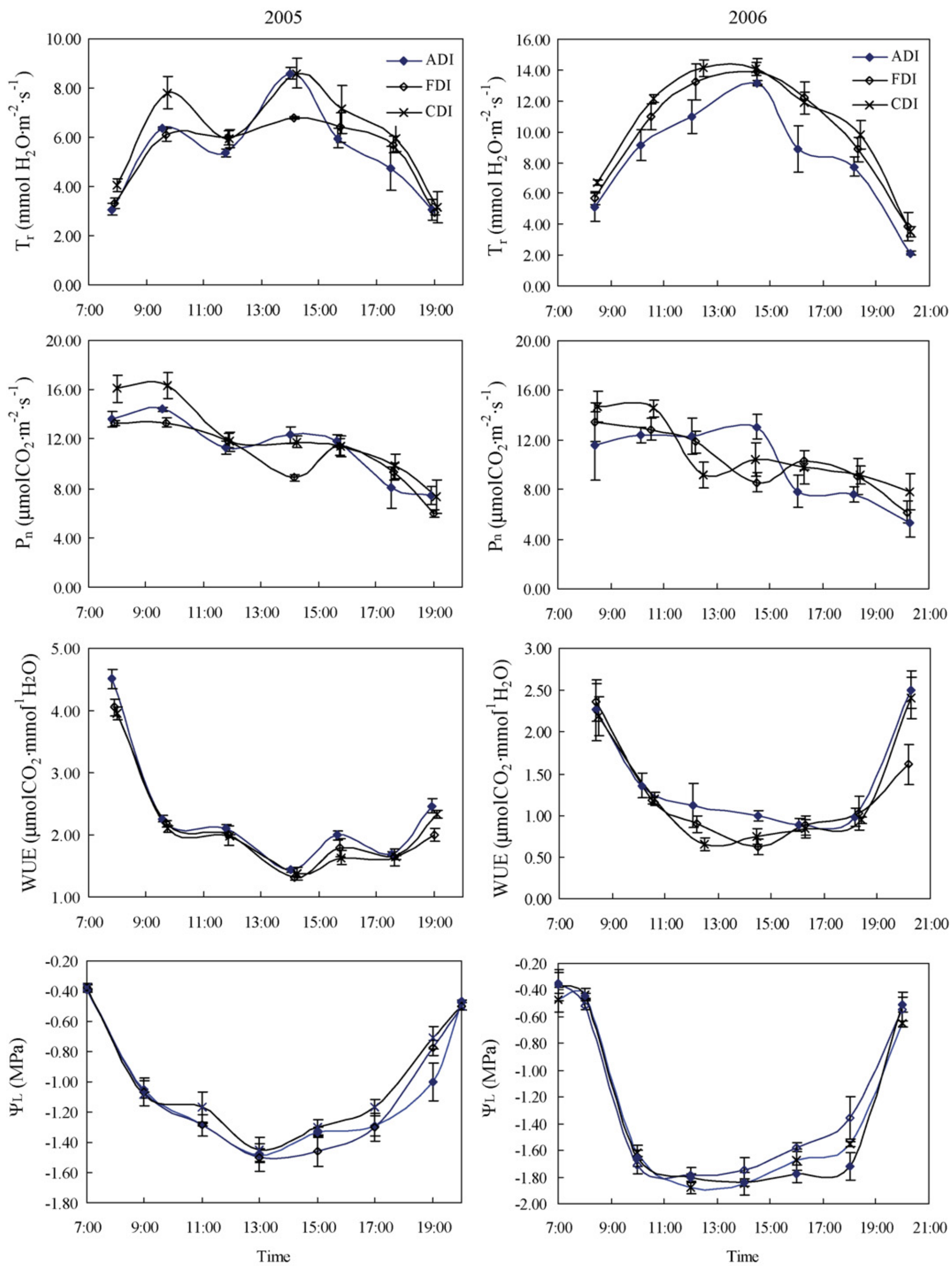

Fig. 4 – Diurnal change of transpiration rate (T_r, mmol H_2O m^{-2} s^{-1}), net photosynthetic rate (P_n, μmol CO_2 m^{-2} s^{-1}), water use efficiency (WUE, μmol CO_2 μmol^{-1} H_2O) and leaf water potential (ψ_l) of table grape in different stages under different partial root-zone drip irrigation on August 10th 2005 (10 days after the sixth irrigation) and August 4th 2006 (4 days after 29 mm rainfall on July 31 after the fifth irrigation). Vertical bars represent ±S.E. of measurements in each treatment.

2005, and it also improved bunch number per tree significantly as compared to CDI in 2006. Berry number per bunch was at the same level under the three irrigation treatments in 2005, but ADI gained 30.7% more berry number per bunch than FDI at the same irrigation level in 2006. Bunch weight and volume of ADI was kept at the same level with CDI in 2005, but it was reduced significantly in 2006. Furthermore, ADI increased the percentage of edible grape by 3.88–5.78% significantly at the same fruit yield level in both years.

As shown in Table 4, ADI produced similar yield with 69.9–79.9% of total evaportranspiration (ET), thus improved WUE_{ET} by 26.7–46.4% when compared to CDI in both years. On the other hand, ADI gained 94.7% more yield than FDI with similar ET and resulted in 94.1% more WUE_{ET} in 2005. However, ADI only gained 6.5% more fruit yield and 6.3% more WUE_{ET} in

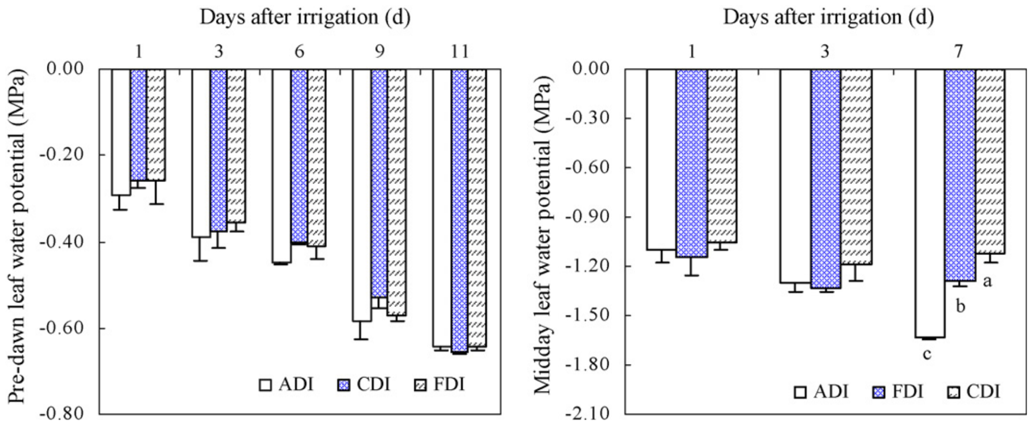

Fig. 5 – Pre-dawn (at 6:00 of local time) and midday (at 12:00 of local time) leaf water potential of table grape after the fifth irrigation on July 12th 2005. Vertical bars represent ±S.E. of measurements in each treatment.

2006. The two-year yield difference may result from the difference of weather condition such as ET_0 and rainfall.

3.4. *Fruit quality*

It should be noted that ADI improved the fruit V_c content by 15.3–42.2% in both years, but decreased the fruit TA by 13.2% at the same level of TSSC compared to CDI, therefore increased TSSC/TA by 22.5% at post-veraison in 2005. On the other hand, the results also showed that ADI improved TSSC at the similar level of TA with highest TSSC/TA significantly at harvest in 2006 (Table 5). The two-year fruit quality difference is resulted from the growth stage under different weather conditions.

4. Discussion

It was essential for APRI to provide a completely different soil moisture environment for the plant root-zone to improve WUE or fruit quality in the field. In this study, soil water content was monitored for its temporal and spatial variation. The results showed that the root-zone of grape plants under ADI always grew in a soil moisture environment where there was not only a temporal variation, but also a spatial 'active' controlled alternate drying and wetting. The buffering capacity of the soil under natural conditions where some processes such as water redistribution from wet to dry roots in response to water potential gradients can occur. This so-called hydraulic lift or hydraulic redistribution enables to maintain or even increase root growth in dry soil (Burgess et al., 1998). And soil moisture gradient between the wetting and drying root-zone allowed roots in dry soil to remain viable for extended periods (Kang and Zhang, 2004).

A physiological advantage of APRI is that it can keep plant relatively hydrated using about the half of the irrigated water. In our study, ADI reduced transpiration rate and increased leaf WUE, which is in agreement with the previous results on field-grown grapevines (Dry et al., 1996, 2000a,b; Dry and Loveys, 1998; Loveys et al., 1998; Stoll et al., 2000). But in the windy field with sparse table grapes, Our results on diurnal variation of ψ_L, ψ_{pd} and ψ_m do not completely support some earlier research in greenhouse or field that APRI maintained leaf water status and

Table 3 – Effect of different partial root-zone drip irrigation on yield components of table grape in 2005–2006

Parameter	Year	ADI	CDI	FDI
Bunch number per tree	2005	5.89 a	5.75 ab	3.25 c
	2006	25.30 a	19.75 b	23.50 ab
Berry number per bunch	2005	102.30 a	116.00 a	112.00 a
	2006	66.08 a	57.80 ab	50.56 b
Bunch weight (g)	2005	486.80 a	519.47 a	442.69 a
	2006	355.82 b	445.83 a	360.22 b
Bunch volume (cm^3)	2005	427.16 a	473.69 a	362.41 a
	2006	339.88 b	415.82 a	323.23 b
Berry weight (g)	2005	4.07 a	4.08 a	3.95 b
	2006	5.38 b	7.71 a	7.13 a
Percentage of edible grape (%)	2005	93.36 a	87.58 b	95.47 a
	2006	94.25 a	90.37 b	93.23 a

ADI, CDI and FDI are alternate, conventional and fixed drip irrigation, respectively. Each parameter means within the rows in the same year marked by different letters (a, b, c) are significantly different at $P_{0.05}$ level. Values are means of 5 plants for each plot.

Table 4 – Effect of different partial root-zone drip irrigation on water-balance components, yield and water use efficiency of table grape at harvest in 2005–2006

Parameter	Year	ADI	CDI	FDI
Rainfall (mm)	2005	52.0	52.0	52.0
	2006	146.0	146.0	146.0
Soil water variable (mm)	2005	38.7	39.5	38.2
	2006	37.9	39.7	37.5
Irrigation water (mm)	2005	67.2	134.4	67.2
	2006	59.4	118.8	59.4
ET_c (mm)	2005	157.9	225.9	157.4
	2006	243.3	304.5	242.9
Yield per tree (kg)	2005	2.68 a	2.62 ab	1.37 c
	2006	8.94 a	8.83 a	8.40 b
Yield per hectare (t)	2005	5.18 a	5.06 ab	2.66 c
	2006	17.30 a	17.08 ab	16.25 b
WUE_{ET} (kg/m^3)	2005	3.28 a	2.24 b	1.69 bc
	2006	7.11 a	5.61 c	6.69 b

Each parameter means within the rows in the same year marked by different letters (a, b, c) are significantly different at $P_{0.05}$ level. Values are means of 5 plants for each plot.

Table 5 – Effect of different partial root-zone drip irrigation on vitamin C content (V_c), total soluble solid concentration (TSSC), titrated acidity (TA) and TSSC/TA of table grape at post-veraison in 2005 and at harvest in 2006

Year	Treatment	V_c (mg/100 FWg)	TSSC (%)	TA (mg/100 FWg)	TSSC/TA
2005	CDI	0.268 b	13.56 b	5.16 a	26.28 c
	ADI	0.309 a	13.68 b	4.48 b	32.19 b
	FDI	0.162 c	15.00 a	4.25 c	33.48 a
2006	CDI	0.090 b	13.17 b	2.33 a	56.52 b
	ADI	0.128 a	13.65 a	2.33 a	58.58 a
	FDI	0.108 ab	13.10 b	2.47 a	53.04 c

Each parameter means within the rows in the same year marked by different letters (a, b, c) are significantly different at $P_{0.05}$ level. Values are means of 5 plants for each plot.

no serious leaf water deficit or loss of turgor occurred (Dry et al., 2000a,b; Kriedemann and Goodwin, 2003). The explanation is that stomatal resistance is only a small proportion of the whole diffusion resistance and evaporation from leaves is poorly coupled with the atmospheric condition (Kang and Zhang, 2004).

Some field experiments in Australia comparing ADI and CDI at the same water amount showed a significant increase in fruit yield for ADI grapevines (Dry et al., 2001). However, other research did not show significant differences in yield, its components and water use efficiency (de Souza et al., 2005a,b; dos Santos et al., 2003; Gu et al., 2004). All these experimental studies suggested that ADI did not increase yield relative to CDI when the same water amount is applied. Our results on table grape showed that ADI saved half of the irrigation water, produced similar yield and improved WUE_{ET} when compared to CDI in both years. It did not agree with the previous report in the APRI studies where same water amount was irrigated to APRI and conventional treatment (de la Hera et al., 2007; Gu et al., 2004). But it is in agreement with the yield response to APRI reported on wine grapes (dos Santos et al., 2003; Kriedemann and Goodwin, 2003; Loveys, 2000; Stoll et al., 2000). Thus the advantages of APRI would be more prominent under less irrigation and give more control of vegetative growth and partition more assimilated products into berry.

As for the required fruit quality of table grape, more percentage of edible grape indicated higher fruit quality and a better product price. Our results showed that ADI improved the percentage of edible grape significantly at the same yield level. How could this be achieved? We believed that the special watering pattern of APRI and the limited water amount is the main explanation. ADI alternated the wetted and dried sides of the root-zone with much less irrigation water, so it has the potential to reduce plant "luxury" water use, decrease canopy vigour and maintain the balance between vegetative and reproductive growth with reduced redundancy growth (Du et al., 2008). Therefore, the higher accumulation and export of assimilates for fruit development is possible under APRI.

Our results indicated that fruit V_c content of table grape under ADI was the highest in both years, indicating a higher nutrition value in the berry of ADI. The result of TSSC and TA was not in agreement with the report on wine grapes in some literatures (de la Hera et al., 2007; Gu et al., 2004). And as a result of higher TSSC/TA, ADI obtained higher total soluble solids concentration and medium titrated acid of grape, indicating sweeter and more delicious fruit in both years, which was in agreement with some previous reports on wine grape (Dry et al., 2000a,b; Dry and Loveys, 1998; Loveys et al., 1998; Stoll et al., 2000). The physiological explanation is that grape fruits can show no shrinkage even when the water potential of the leaves is lower than that of fruit, different soil moisture environment for the plant root-zone under APRI often shows high soil strength and alkaline pH values, which stimulate ABA deposit in root tissues and loaded into the xylem. Accumulation of ABA is mainly in expanded and mature leaves, but not in the fruit epidermis, this difference in ABA accumulation as a signal molecule may partly lie in the relative hydraulic and chemical isolation of the fruit (Davies et al., 2000), which may restrict fluxes of hormones (perhaps influence the anabolism of V_c, TSSC and TA) into fruits with the result that mild soil drying can restrict shoot growth with little effect on fruit growth and development (Sauter et al., 2001).

In addition, we also found that ADI advanced 5–7d ahead of scheduled harvest compared to CDI, which means better prices for farmers. The possible explanations were that the alternated drying and wetting soil surface may also influence the micro-meteorological conditions such as solar radiation, canopy temperature and relative humidity; and ADI inhibit canopy growth redundancy of grapevine and light micro-climate of canopy was changed, thus more sunlight reached to the fruit epidermis to make the fruit mature earlier. In addition, endogenous root ABA under ADI may improve fruit maturity and maintain shoot growth for an interaction with ethylene (Sharp et al., 2000; Sharp and LeNoble, 2002). Apparently, further experiments are still required to explain how APRI influence fruit yield and its quality in arid field.

In summary, our experiment tested the hypothesis that partial root-zone drip irrigation improved leaf WUE and WUE_{ET} of table grape in the arid region. Application of ARPI on table grape in the field had greater potential in saving irrigation water, maintaining economic yield and improving fruit quality. This is particularly important for the horticulture where all the crops almost completely rely on irrigation and water shortage in the arid region. Our result also has provided a practical irrigation strategy about the application of APRI in such arid areas.

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