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Full Length Research Paper

Effects of partial rootzone drying and conventional deficit irrigation on yield and quality parameters of "Williams Pride" apple cultivar drafted on M9 rootstock

Ulas Senyigit* and Fatmagul Ozge Ozdemir

Department of Agricultural Structure and Irrigation, Faculty of Agriculture,Suleyman Demirel University, TR 32260 Isparta, Turkey.

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Fruit yield and quality of 4 year old "Williams Pride" apple trees on M9 rootstock under partial rootzone drying (PRD) were studied over 2 years. Irrigation treatments were control irrigation (CI), conventional deficit irrigation (DI), and two different partial rootzone drying (PRDI and PRDII). In PRD, irrigation water was applied alternately on one side of the tree's rows and the other side was not irrigated. While the irrigated side was changed at every irrigation in PRDI, the side that was not irrigated was changed at every other irrigation in PRDII. Total irrigation water amount was 324.1 and 314.2 mm for CI in 2009 and 2010, respectively. Applied irrigation water amount for DI, PRDI and PRDII was 50% of the CI. The ranking of water use efficiency (WUE) and irrigation water use efficiency (IWUE) values was maintained as PRDII>PRDI>DI>CI in average, in 2009 and 2010. Consequently, minimal or no differences between PRDII and CI treatments were determined in vegetative growth, some yield components and fruit quality. These results recommended that PRD treatments are more effective water saving irrigation technology with a higher WUE and not reduce fruit quality for apple trees compared to regulated deficit irrigation.

Key words: Apple, yield, irrigation water, partial rootzone drying, water use efficiency.

INTRODUCTION

Turkey is the third biggest country after China and USA in apple production with 2.78 million tons (Fao, 2009). Isparta region that provides almost 20% of total apple production of Turkey, has an important role in apple production for Turkey (Tsi, 2009). Recently, dense planting orchards using new varieties drafted on dwarf (M9) rootstocks in the region have been started. Williams Pride variety drafted on M9 clonal rootstocks are commonly used in these orchards. While an average annual precipitation value is 520 mm in Isparta region, only 162 mm of the total precipitation occurred between May and October that is not met plant water requirement (Figure 1).

Due to the fact that a semi-arid climate condition occurs in the region, irrigation becomes a vital importance for an effective horticultural production among the growing season. Increase of population and insufficient water resources lead to the development of different irrigation strategies. Partial rootzone drying and deficit irrigation strategies are developed in order to increase efficiency of water use and water saving in agricultural production. Some crops including apple have high water requirements. In most countries, supplemental irrigation

*Corresponding author. E-mail:ulassenyigit@sdu.edu.tr. Tel: +90 246 2114697. Fax: +90 246 2371693.

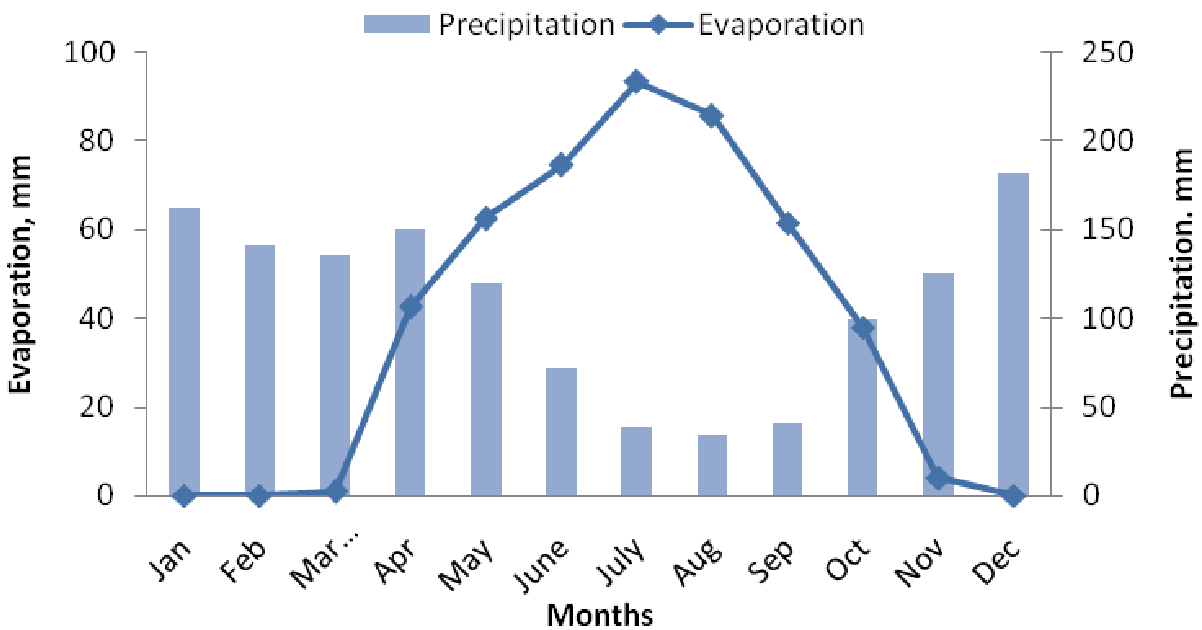

Figure 1. Relationship between class a pan evaporation and precipitation in Isparta region.

is necessary for successful crop production but water use for agriculture is reduced because of global climate changes and environmental pollution. Partial rootzone drying (PRD) is a new deficit irrigation strategy that was recently developed worldwide for different fruits such as mandarin (Kirda et al., 2007), grapes (Dry et al., 1996), pear (Kang et al., 2002) and apple (Talluto et al., 2008; Zegbe et al., 2008). With PRD, at each irrigation time, only one half of the rootzone is irrigated, whereas the other half left to dry. In addition, water consumption could be reduced by 50% compared to control irrigation without negative impact on product quality or yield in PRD (Santos et al., 2003). WUE is increased by a successful PRD with reduction of transpiration and PRD maintains plant water potential and yield. The proposed physiological mechanism of PRD is that roots in drying soil synthesise a hormonal signal abscisic acid (ABA) which is translocated to the shoots, indicating a developing soil-water deficit (Dry et al., 1996). ABA alerts partial stoma closure in the leaves, which reduces transpiration and raises WUE (O'Connell and Goodwin, 2007; Caspari et al., 2004; Talluto et al., 2008). The minimum irrigation and maximum fruit production can be regulated by PRD. Thus, many researchers on some apple varieties indicated that PRD may allow for considerable reduction in irrigation water with well fruit quality and yields. (Caspari et al., 2004; Lombardini et al., 2004; Leib et al., 2006). The aim of this study was examine the effects of partial rootzone drying, conventional deficit and control irrigation on yield and some quality parameters of "Williams Pride" apple cultivar drafted on M9 rootstock during the fourth and fifth years after planting in high-density apple orchard located in Isparta region.

MATERIALS AND METHODS

Experimental site and plant material

The experiment was established on 4 years-old "Williams Pride" apple cultivar drafted on M9 rootstock was planted in North-South row direction at 1×3 m spacing in the Agricultural Research and Experimental Center at the Campus of Suleyman Demirel University, Isparta, Turkey (lat. 37° 50' 2" N, long. 30° 32' 0"E, alt. 1010 m) during the 2009 and 2010 growing seasons.

Climatic and soil characteristics

The research area has a transition characteristic between the Mediterranean climate (precipitation regime) and Middle Anatolian continental climate (summer season is hot and dry, winter season is cold and snowy). Long-term average annual temperature, relative humidity and precipitation are 12°C, 61%, 520 mm, respectively (Tsms, 2008). During the experiments (from May to October) values of average monthly weather data belongs to 2009 and 2010 years were given in Table 1.

The experimental soil was clay-loam, the dry soil bulk density average was 1.41 g cm^{-3} throughout the 1.2 m deep profile. The total available soil water content within top 1.2 m of soil profile was 270.9 mm and no water problem was found. Some soil characteristics related to irrigation were presented in Table 2. Except for the irrigation, the orchard was received standard cultural

Table 1. Monthly mean climate values during 2009 and 2010 related to growing season.

Months	Maximum temperature (°C)		Minimum temperature (°C)		Maximum humidity (%)		Minimum humidity (%)		Duration of sunshine (h)		Precipitation (mm)	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
May	21.4	23.8	8.0	9.5	89	88	36	29	8.7	8.3	66.2	32.4
June	28.3	25.6	12.9	12.5	78	91	24	36	9.6	7.6	26.8	34.7
July	30.5	31.6	16.4	16.8	74	82	25	27	10.2	10.3	18.0	9.4
August	31.0	34.7	14.7	17.8	67	70	19	19	10.4	13.5	0.2	0.0
September	25.2	28.3	10.9	12.6	85	87	31	26	8.4	9.6	26.2	9.1
October	22.3	18.8	8.6	7.4	88	94	36	46	6.7	5.6	18.1	77.0

Table 2. Characteristics of the soil in the experimental area.

Soil depth (cm)	Structure	Bulk density (g cm^{-3})	Field capacity(m^3 m^{-3})	Wilting point(m^3 m^{-3})	Available soil water content (m^3 m^{-3})
0-30	CL	1.46	0.43	0.20	0.23
30-60	CL	1.41	0.45	0.22	0.23
60-90	CL	1.39	0.38	0.16	0.22
90-120	CL	1.36	0.37	0.16	0.21

practices according to the local commercial including fertilization, pest management, weed control and winter pruning.

Irrigation treatments and experimental design

There were four different irrigation treatments, including control irrigation (CI), conventional deficit irrigation (DI) and two different partial rootzone drying (PRDI and PRDII) were applied. Treatments were; CI (k_{cp}:1), the treatment was considered as the control irrigation and irrigation water amount was applied to the both sides of tree rows using two drip lateral at full rate of class a pan evaporation measured during the irrigation interval; DI (k_{cp}:0.50), the amount of water applied in the treatment was 50% of that applied to CI treatment and irrigation water was applied to the both sides of tree rows, similar to CI; PRDI, irrigation water was applied alternately on each one side of the tree rows with the other side left unirrigated and the irrigated side was changed every irrigation; PRDII, this treatment was similar to PRDI, irrigation water was applied alternately on each one side of the tree rows but the irrigated side was changed every other irrigation. Applied irrigation water amount for both of the PRDI and PRDII treatments was 50% of the CI (Figure 2).

Irrigation water was obtained from the hydrants on the irrigation network near the research area. Discharge rate of the irrigation water taken from the irrigation network was 7 L s^{-1}. Water is class C_3S_1 and can be used for irrigation. Plots were irrigated up to field capacity at the beginning of the irrigated growth period in each year. After the initial irrigation, all treatments were irrigated twice weekly by drip irrigation methods. Engineering characteristics and working principles related to the drip irrigation method were determined on the fundamentals given in Yıldırım (2008). Drip irrigation system consisted of PE laterals of 16 mm in diameter in-line type drippers with pressure regulators at 0.50 m distance. The drippers had a discharge rate of 4 L h^{-1} under an operational pressure of 4 atm. Two laterals were placed in each row and the percentage of the wetted area was determined as 33%.

Irrigation water amount was determined based on cumulative evaporation in daily values measured within each irrigation interval in the class a pan located in a meteorological station close to the orchard. Irrigation was maintained identically within the period of last frost and the first one for experimental period (From May to October). In

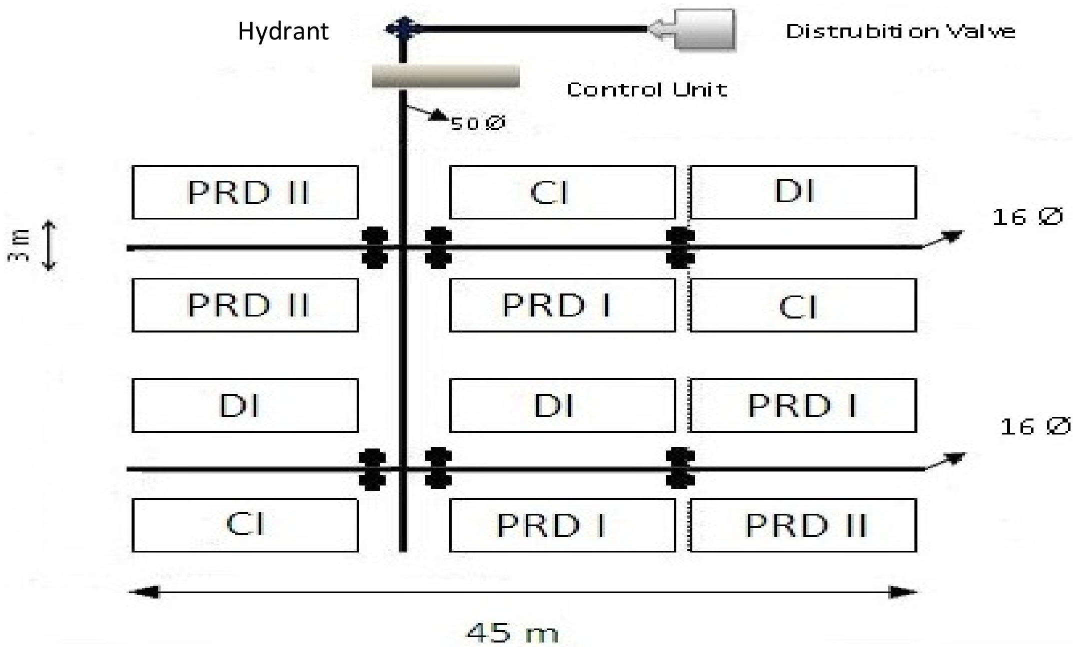

Figure 2. Irrigation treatments and experimental design.

calculating irrigation water volume, equation 1 described by Doorenbos and Pruitt (1977) was used:

$$I = Axk_{cp}xE_pxP \quad (1)$$

Where I is the volume of irrigation water applied (L), A is the plot area (m^2), k_{cp} is the plant-pan coefficient used in this study included pan coefficient and plant coefficient factors as indicated in Senyigit and Kadayifci (2007), E_p is the cumulative evaporation at class a pan in the irrigation intervals (mm) and P is the wetted area percentage.

Volumetric soil water content (m^3 m^{-3}) was measured by ΔT profile-probe before each an irrigation. ΔT probes were inserted between the tree trunks through the row in each plot. The probes were placed at soil depth of approximately 10, 20, 30, 40, 60, 100 cm to provide a depthwise profile of soil water content in each treatment. Evapotranspiration related to the treatments were calculated by the soil-water balance (James, 1988), considering the soil water content readings and effective rainfall.

A randomized complete plot design was used with three replicates in the study. Each plots consisted of fifteen trees and five central trees being considered as experimental and all the others as guard trees.

Parameters measured

Apples were hand-harvested two times at beginning of August. Amount of yield per unit area (t ha^{-1}), yield per unit canopy volume (kg m^{-3}), yield per trunk cross-sectional area (kg cm^{-2}), number of fruit per unit area (number ha^{-1}) and some quality characteristics of apple such as mean fruit weight, diameter, length, fruit firmness and amounts of the soluble solids were determined. Trunk cross-sectional area was determined from trunk diameter measures at 10 cm above the ground surface on five trees per plot. Also, ten fruits were sampled randomly from each tree to assess fruit quality parameters during 2009 and 2010. Mean fruit weight, diameter, length were measured using a precision scale and callipers. Fruit juice total soluble solids were measured with a digital refractometer and flesh firmness determinations were done on opposite sides of the equator of each fruit with a manual pressure tester mounting penetrometer an 11 mm tip (Talluto et al., 2008; Zegbe and Serna-Pérez, 2011).

Water use efficiencies

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) in the all treatments were calculated using the Equations 2 and 3 (Hillel and Guron, 1975):

$$\text{WUE} = 100\left(\frac{\text{Y}}{\text{ET}}\right) \quad (2)$$

$$\text{IWUE} = 100\left(\frac{\text{Y}}{\text{I}}\right) \quad (3)$$

Where WUE is the water use efficiency (kg m^{-3}), Y is the yield (kg ha^{-1}), ET is the evapotranspiration (mm), IWUE is the irrigation water use efficiency (kg m^{-3}) and I is the irrigation water (mm).

Data analysis

Statistical analysis were done applying the one way ANOVA analysis method. The Turkey test was used in determining the

Table 3. Number of irrigation, amounts of irrigation water, evapotranspiration and cumulative evaporation (2009, 2010).

Treatments	Number of irrigation		Irrigation water amount (mm)		Evapotranspiration (mm)		Cumulative evaporation (CAP*, mm)	
	2009	2010	2009	2010	2009	2010	2009	2010
CI	34	32	324.1	314.2	423.3	413.5	982	952
DI	34	32	162.0	157.1	259.7	252.5		
PRDI	34	32	162.0	157.1	262.7	256.5		
PRDII	34	32	162.0	157.1	255.0	244.2		

*Class A Pan

Table 4. Yield components related to treatments (averages of 2009 and 2010).

Yield components	Treatments			
	CI	DI	PRDI	PRDII
Yield (ton/ha)**	20.6^{a}	14.3^{b}	14.9^{b}	15.6^{b}
Yield per unit canopy volume (kg/m^3)**	2.00^{a}	1.23^{b}	1.40^{b}	1.74^{ab}
Yield per trunk cross-sectional area (kg/cm^2)^{ns}	0.48	0.41	0.45	0.40
Fruit number per tree *	66.3^{a}	44.6^{b}	49.2a^{b}	53.4a^{b}

ns, no significant; * P<0.01; ** P<0.05

differences between the averages of the groups and the differences of the treatments were indicated with the Latin letters.

RESULTS

Irrigation water and evapotranspiration

Evaporation values measured from class a pan were changed between 982 and 952 mm in 2009 and 2010, respectively (Table 3).

All plots were irrigated up to field capacity in the 0 to 120 cm soil depth prior to scheduled irrigation. Irrigation treatments were initiated at the beginning of the June. During the entire growing period, a total amount of irrigation water was 324.1 and 314.2 mm for CI treatment, 162.0 and 157.1 mm for the other treatments distributed over 34 and 32 events in 2009 and 2010, respectively.

Fruit yield and some quality parameters data

Apple yield parameters of averages of 2009 and 2010 were presented in Table 4. The highest yield was obtained from CI treatment. PRDI, PRDII and DI treatments fell in low yield group ($p<0.01$), whereas fruit numbers of PRD treatments were significantly higher than DI but not differ from CI ($p<0.05$). PRD treatments (PRDI and PRDII) saved water by 50% compared to CI but did not alter fruit quality such as mean fruit weight, fruit diameter and fruit length, whereas DI significantly decreased fruit length (Table 5).

Water use efficiencies

While the highest values were obtained from PRDII treatments (6.17 and 9.67 kg m^{-3}), the lowest WUE and IWUE (4.90 and 6.41 kg m^{-3})

Table 5. Some fruit quality and vegetative growth parameters related to treatments (averages of 2009 and 2010).

Quality and vegetative parameters	Treatments			
	CI	DI	PRDI	PRDII
Mean fruit weight (g)^{ns}	145.7	126.8	145.2	142.4
Fruit diameter (mm)^{ns}	67.4	67.0	70.6	69.0
Fruit length (mm)*	58.7^{ab}	57.2^{b}	60.2^{a}	59.3^{ab}
Flesh firmness (libre)*	18.6^{b}	20.7^{a}	19.9^{ab}	20.6^{ab}
Soluble Solid (%)**	12.9^{b}	14.2^{a}	13.8^{a}	13.6^{a}
Canopy volume (m^3)^{ns}	4.39	3.77	3.70	3.17
Trunk cross-sectional area (cm^2)*	13.6^{a}	10.7^{ab}	10.1^{b}	12.0^{ab}

ns, no significant; * $P<0.01$; ** $P<0.05$

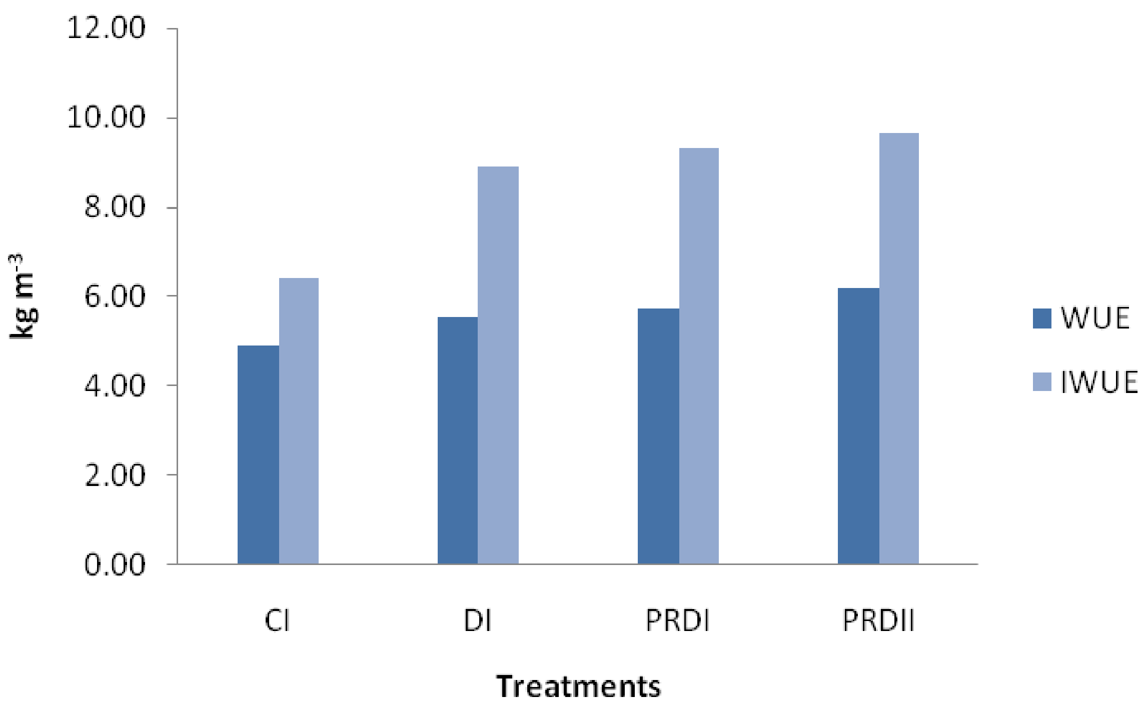

Figure 3. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) related to the treatments.

were obtained from control irrigation (CI) treatment (Figure 3).

DISCUSSION

Trees were irrigated at 50% of water amount in all deficit treatments compared to CI. Amount of applied irrigation water increased ET. While the highest ET was calculated in CI treatment, ET values obtained from PRDI, PRDII and DI treatments were similar according to experimental years. The obtained amount of the irrigation water and ET values were similar to the findings given by Girona et al. (2010), Fallahi et al. (2008) and Talluto et al. (2008). However, differences of applied irrigation water in this study compared to studies stated above may be explained by the climatic condition, duration of irrigation season and wetting percentage (33%) of the drip irrigation method used.

Although both deficit irrigation practices such as PRD and DI had same effect for saving of irrigation water, DI where the roots were irrigated uniformly in same level of water deficit, had proportionally lower yield than PRD treatments. While yield per unit canopy volume was lower in PRDI and DI, differences between PRDII and CI treatments were non-significant. Also, statistically significant differences were not obtained among the treatments for yield per trunk cross-sectional area. Generally, different responses for apple yield were observed by many authors depending on season, location, climatic and soil condition. For example, Einhorn and Caspari (2004) observed apple yields were not affected by PRD. However, O'Connell and Goodwin (2007) detected a reduction in fruit yields for apple under PRD according to CI. Caspari et al. (2004) reported also higher fruit yields for apple under PRD compared to commercial DI as similar with this study.

The results of fruit quality are in agreement with the results of Caspari et al. (2004). Zegbe and Serna-Pérez (2011) also reported that there was no difference in fruit quality between PRD and CI treatments. However, in this study, the entire water deficit treatments (DI, PRDI and PRDII) resulted in significantly higher flesh firmness and soluble solid during the experimental years compared to CI. This is in agreement with other studies (Caspari et al., 2004; Leib et al., 2006; Zegbe et al., 2008). On the other hand, although trunk cross-sectional area values were generally reduced by PRDI and partially reduced by DI and PRDII compared with CI, canopy volume of apple trees among all treatments was similar. These results were in agreement with Fallahi et al. (2008) who reported that trunk cross-sectional area of Autumn Rose Fuji apple reduced by PRD and DI treatment compared to CI. Talluto et al. (2008) also determined that irrigation treatments (PRD, DI and CI) did not affect canopy size of Pink Lady apple.

While the lowest WUE and IWUE were achieved from CI treatment where the most irrigation were applied, the highest values were obtained from PRDII treatments (6.17 and 9.67 kg m^{-3}) where 50% reduced irrigation water amount was applied. Although ABA content was not measured, this result might be explained by root to shoot which may result of too long drying period (one week) of one side of tree rows under PRDII compared to PRDI. Similar findings were reported by Kirda et al. (2007) in mandarin. Generally, PRD treatments with 50% less amount of water applications gave proportionally higher WUE and IWUE compared to DI and CI treatments. In the study, higher WUE in PRD might be explained by following studies found in literature. Green and Clothier (1999) indicated that apple trees quickly adjust root water uptake in response to changing soil water by increasing uptake from the moisture part of rootzone, while reducing uptake from the drying part. O'Connell and Goodwin (2007) also reported that reduced transpiration in PRD thought to be due to ABA root-signal derived from the drying rootzone. In addition, Leib et al. (2006) concluded that one of the most important advantage of PRD compared to DI is the lower evaporation from the soil surface.

Conclusions

The PRD used 50% less irrigation water than CI in two years of the experiment. PRD practices can be also more advantageous for yield and quality parameter compared to conventional DI where same water amount were applied. For apple trees, differently from regulated deficit irrigation, PRD is more effective water saving irrigation technology with a higher WUE and not reduce fruit quality rather than to contain excessive vegetative growth. Therefore, especially PRDII practice can be suggested for commercial use and can be adapted successfully for the regions in similar soil and climate conditions.

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