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RESEARCH ARTICLE

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Effects of regulated deficit irrigation on physiology, yield and fruit quality in apricot trees under Mediterranean conditions

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Abstract

Scarce water resources mainly in arid and semi-arid areas have caused an increasing interest for applying irrigation protocols aiming to reduce water spends. The effects of regulated deficit irrigation (RDI) on the performance of apricot trees (*Prunus armeniaca* L. cv. "Búlida") were assessed in Murcia (SE Spain), during three consecutive growing seasons (2008-2010). The hypothesis was that RDI would not restrict yield but increase fruit quality while saving water. Two irrigation treatments were established: i) control, irrigated to fully satisfy crop water requirements (100% ET_c) and ii) RDI, that reduced the amount of applied water to: a) 40% of ET_c at flowering and stage I of fruit growth; b) 60% of ET_c during the stage II of fruit growth and c) 50% and 25% of ET_c during the late postharvest period (from 60 days after harvest). Stem water potential, gas exchanges, trunk cross-sectional area (TCSA), fruit diameter, yield and fruit quality traits were determined. Vegetative growth was decreased by the use of RDI (12% less TCSA on average for the three years), whereas yield was unaffected. In addition, some qualitative characteristics of the fruits, such as the level of soluble solids, sweetness/acidity relation and fruit colour, were improved by the use of RDI. These results and average water savings of approximately 30%, lead us to conclude that RDI strategies are a possible solution for irrigation management in areas with water shortages, such as arid and semi-arid environments.

Additional keywords: fruit growth; photosynthesis; *Prunus armeniaca* L.; regulated deficit irrigation; stomatal conductance; water stress.

Abbreviations used: C (control); C* (chroma); ET_0 (reference evapotranspiration); ET_c (crop evapotranspiration); H° (hue angle); L* (lightness); RDI (regulated deficit irrigation); SSC (soluble solids content); TA (titratable acidity); TCSA (trunk cross-sectional area); TDR (time-domain reflectometry); VPD (vapour pressure deficit). **Parameters:** g_s (stomatal conductance); P_n (photosynthesis rate); S_Ψ (water stress integral); θ_v (soil water content); Ψ_s (midday stem water potential); Ψ_l (midday leaf water potential)

Authors' contributions: Conceived and designed the experiments: EN, OM and JJA. Obtained funding: EN and JJA. Performed the experiments: FPS, RA, OM and EN. Analyzed the data: EN, JMMA, FPS, RA and OM. Contributed reagents/materials/analysis tools: EN, JJA and OM. Wrote the paper: JMMA, EN and FPS. Critical revision of the manuscript: EN, JJA, JMMA and OM.

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Introduction

Mediterranean regions are characterized by the shortage of water resources (Ruiz *et al.*, 2015). This situation is aggravated by the strong competition for water between agriculture and other users such as industry or increasing population. It is therefore necessary to develop and implement techniques that optimize agricultural water use without affecting crop yields (Fereres & Soriano, 2007), being the regulated deficit irrigation (RDI) one of the most promising to attain this objective. This technique consists of applying water in quantities below those necessary to fully satisfy crop evapotranspiration (ET_c) requirements during certain periods of the crop cycle when yield and crop quality are hardly affected, applying all the water needed during the rest of the cycle, especially at critical periods when the yield and/or quality would be greatly affected by a lack of water. RDI is normally applied when reproductive growth is relatively slow and when vegetative growth and other plant processes may be affected, such effects frequently being translated into improved fruit quality (Ruiz-Sanchez *et al.*, 2010).

In this sense, RDI has been successfully used, maintaining yield and fruit quality, in many fruit species (Buendía *et al.*, 2008; López *et al.*, 2008), including citrus (González-Altozano & Castel, 2000) and olives (Moriana *et al.*, 2010).

Apricot (*Prunus armeniaca* L.) is one of the most important fruit species worldwide because its fruit is highly appreciated by consumers (Roussos *et al.*, 2011). Apricot world production is about 2.5 million tonnes per year (http://faostat.fao.org). Spain produces about 132,000 tonnes from a cultivation area of 20,000 ha. Apricot trees are highly sensitive to drought stress at particular phenological stages, such as stage III of fruit growth and during the 2 months after harvest (early postharvest) (Torrecillas *et al.*, 2000; Pérez-Pastor *et al.*, 2009). In contrast, researches about RDI strategies applied to apricot trees reported benefits such as higher values of total soluble solids, titratable acidity and hue angle in apricot fruits grown under RDI (Pérez-Pastor *et al.*, 2009, 2014), although these results came from experiments undertaken during less than three years and, consequently, they need to be confirmed.

In this context, the aim of this paper was to evaluate the effects of an RDI protocol established as appropriate for Mediterranean conditions (Pérez-Pastor *et al.*, 2009) and validate it for three growing seasons. Therefore, the RDI effects on plant-water relations, yield and fruit quality in adult apricot trees (*Prunus armeniaca* L. cv. 'Búlida') were assessed over three consecutive growing seasons (2008-2010) under semi-arid conditions. The main hypothesis of our study was that a rational RDI protocol would allow growers to save water without compromising yield, and even obtain improvements in fruit quality.

Material and methods

Description of the study site and plant material

The experiment was conducted over three consecutive years (2008–2010) in a 1-ha commercial plot located in Mula valley, Murcia, SE Spain (37°55'N, 1°25'W, 360 m above sea level).

The soil is clay-loam textured, highly calcareous (pH = 7.8), with low organic matter content and cationic exchange capacity. The available water capacity is 0.31 m^3/m^3. The climate of the region is semiarid Mediterranean with hot and dry summers (the averages for mean temperature and annual rainfall for the 1981-2010 period are 18.2 ºC and 290 mm, respectively); annual reference crop evapotranspiration (ET_0) and rainfall during the growing season (after full bloom, 12 March, to end November) were, respectively, 899 and 277 mm in the first year of experiments (2008), 912 and 375 mm in 2009 and 868 and 239 mm in 2010.

The plant material consisted of apricot trees (*Prunus armeniaca* L. cv. 'Búlida') grafted on Real Fino apricot rootstock, spaced 8 × 6 m and planted in 1999. At the beginning of the experiment, apricot trees had a similar trunk cross sectional area (TCSA), approximately 240 cm^2. Trees were drip irrigated using one drip irrigation line per row and five emitters per tree (each delivering 4 L/h).

Irrigation treatments and experimental design

Crop irrigation requirements were scheduled weekly according to daily ET_0, calculated using the Penman-Monteith equation (Allen *et al.,* 1998), and a local crop coefficient based on the time of the year (Abrisqueta *et al.,* 2001): 0.5 February, 0.75 March, 0.8 April, 0.9 May, 0.6 June, 0.5 July-November. According to Fereres & Goldhamer (1990), these coefficients were corrected considering ground cover. All trees received the same fertilization through the irrigation system: 110 kg N, 62 kg P_2O_5 and 117 kg K_2O per hectare and year. Pest control was that commonly used by growers, and no weeds were allowed to develop within the orchard. A total of 192 trees were used in this study. The experiment was laid out in completely randomized blocks with 4 replications (24 trees each). The four central trees from each replication were used for measurements, and the other trees acted as guard.

Two irrigation treatments were applied: i) Control (C), daily irrigated to fully satisfy the estimated crop evapotranspiration (ET_c) and ii) RDI irrigated at 100% ET_c during the critical periods (stage III of fruit growth and 2 months after harvest) and subjected to water shortage during the non-critical periods of crop development by reducing the amount of applied irrigation water to: a) 40% of ET_c from flowering until the end of the first stage of fruit growth; b) 60% of ET_c during the second stage of fruit growth and c) 50% and 25% of ET_c during the late postharvest period (that starts 60 days after harvesting), for the first 30 days and until the end of tree defoliation, respectively (Fig. 1).

This distribution of applied water during non-critical periods was based on previous studies (Torrecillas *et al.*, 2000). Irrigation water had good quality, with a very low electrical conductivity (0.6 dS/m). Irrigation was controlled by an automatic head unit programmer. In-line flowmeters, placed in each experimental plot, measured the amounts of water applied to each treatment.

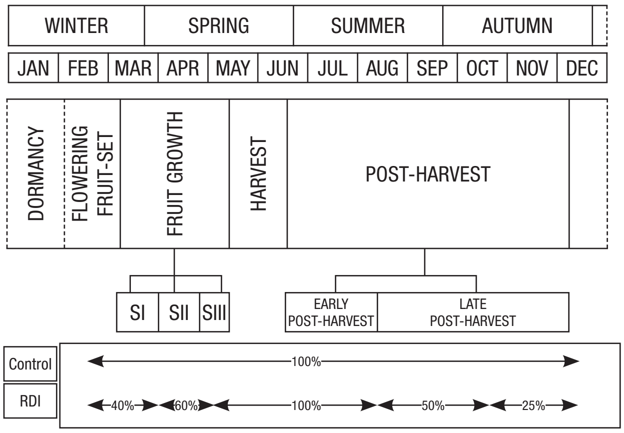

Figure 1. Diagram of the irrigation scheduling used for the current study. The numbers indicate the percentages of crop evapotranspiration (ET_c) applied at each phenological stage of apricot trees 'Búlida' over the experimental period. RDI: Regulated Deficit Irrigation; SI, SII and SIII refer to the stages I, II and III of fruit development.

Measurements

Climate data. Climate data were recorded at an automatic weather station placed within the experimental orchard. Data on air temperature (maximum, minimum and average), solar radiation, air relative humidity, rainfall and wind speed 2.5 m above the soil surface, were collected every 15 min and used to calculate vapour pressure deficit (VPD), ET_0 and to establish crop water requirements. The evolution of these parameters over the study period is shown in Fig. 2.

Soil water content. The volumetric soil water content (θ_v, m^3/m^3) of the topsoil (0.2 m) was determined by time domain reflectometry (TDR) (Model 1502C, Tektronix Inc., OR), as reported by Moreno *et al.* (1996). The θ_v content of the soil from 0.2 m to 1.0 m depth was measured at 0.1 m intervals using a neutron probe (Model 4300, Troxler Electronic Laboratories Inc., NC, USA), in access tubes installed 1.0 m from the trees and beside the emitters. Measurements using one neutron probe and TDR per experimental plot (4 replications per treatment) were taken in the morning, every 7 to 15 days, during the experimental period.

Stem and leaf water potential. Midday (12:00 h solar time) stem water potential (Ψ_s) was measured fortnightly in one mature leaf per tree, taken close to the trunk, in the four central trees of each experimental plot (16 measurements/treatment). Leaves were enclosed in a small black plastic bag covered with aluminum foil for at least 2 h before measurements were made with a pressure chamber (Soil Moisture Equip. Corp, model 3000, Santa Barbara, CA, USA). Additionally, leaf water potential (Ψ_l) was measured in the same trees used for Ψ_s measurements, sampling one mature and sunny-exposed leaf per plant. These measurements were made according to Scholander *et al.* (1965) and following the recommendations of Turner (1988).

Water stress integral. In order to assess the water stress intensity over the growing season, we calculated the water stress integral (MPa-days) from the Ψ_s data, using the following equation (Myers, 1988):

$$S_\Psi = \left| \sum_{i=0}^{i=t} \left(\bar{\Psi}_{i,i+1} - c \right) n \right|$$

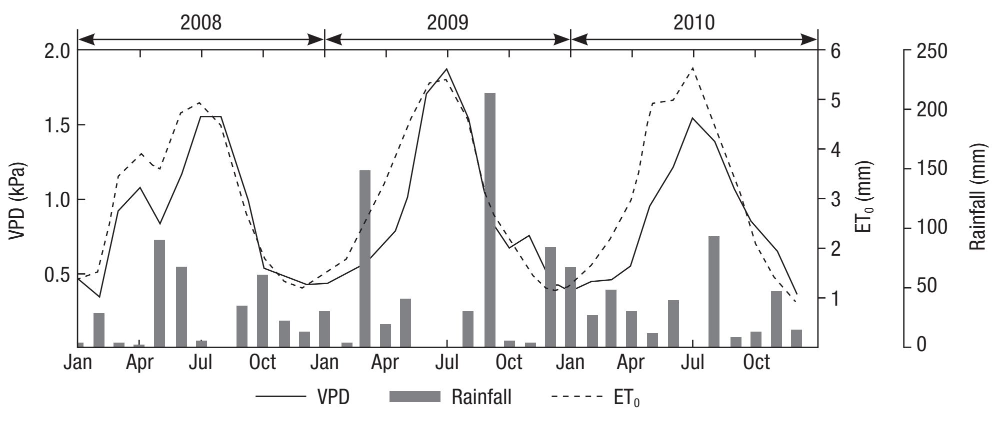

Figure 2. Reference evapotranspiration (ET_0), rainfall (mm) and vapour pressure deficit (VPD, kPa) at the experimental site. Monthly values from data collected during 2008, 2009 and 2010.

where $\bar{\Psi}_i$ is the average Ψ_s for each time interval, c is the value of the maximum (least negative) Ψ_s in all seasons (-0.4 MPa), and n is the number of days in the interval.

Gas exchange parameters. Net photosynthesis (P_n) and stomatal conductance (g_s) were measured fortnightly at solar midday, in one fully expanded sun-facing leaf in the four central trees of each experimental plot (16 measurements/treatment), in the same days that Ψ_s was recorded, using a field-portable photosynthesis system (LI-6400, Li-Cor, Lincoln, NE, USA) equipped with a LI-6400-01 CO_2 injector. The CO_2 concentration in the cuvette was maintained at 390 µmol/mol (approx. the ambient CO_2 concentration). Light, temperature and relative humidity conditions were those of the ambient.

Vegetative and fruit growth. Trunk diameter was measured at the end of each growing season in 96 trees per treatment with a sliding calliper, 0.20 m above the soil surface. Trunk cross-sectional area (TCSA) was calculated from these data.

Over the growing season, fruit diameter was measured perpendicularly to the fruit suture on 200 fruits per treatment (50 fruits/replication). Each sampling was carried out every 7-10 days, randomly measuring 12-13 fruits in the four inner trees per experimental plot using a digital calliper (Powerfix model Nr Z22855F, Milomex Ltd, Bedfordshire, UK). The measurements commenced when fruits have attained a diameter of 10 mm.

Yield, water productivity and fruit quality. Fruits from eight inner trees per replicate were individually harvested (32 trees/treatment). Water productivity was calculated as the ratio between yield and total irrigation water applied, expressed in kg/m^3.

At harvest, 200 fruits per treatment (50 fruits per experimental plot) were randomly selected for quality assessment. Skin and flesh colour, firmness, pH, soluble solids content (SSC) and titratable acidity (TA) were evaluated as quality indices.

Fruit firmness was evaluated using a Durofel penetrometer DFT100 (Agro-Technologie S.A., Paris, France). Juice was extracted from combined samples of longitudinal unpeeled slices. Total soluble solids concentration (SSC, ºBrix) was determined by refractometry (Atago, Co., Japan). Juice pH was measured using a pH-meter (Crison, Barcelona, Spain). TA was measured by titration and expressed as g malic acid/L (AOAC, 1984). The maturity index was calculated as the SSC/TA ratio.

Colour values, on the surface (ground skin colour) and after peeling in the flesh, were measured with a Minolta chromameter (CR-300, Minolta, Ramsey, NJ). The colour space coordinates L*, a*, and b*, hue angle [Hº = arctg (a*/ b*)], and Chroma $(a^*2/ b^*2)^{1/2}$ were determined around the equatorial region in three different positions (with an average of nine times for each apricot).

Statistical analysis

A weighted analysis of variance (ANOVA; statistical software IBM SPSS Statistics v. 21 for Windows, Chicago) was used in order to assess the effects that irrigation protocols exerted on the considered variables. Normality of the data was evaluated through the Shapiro-Wilk test. Unless otherwise stated, the significance level was $p \leq 0.05$.

Results

Soil water content and irrigation

Volumetric soil water content during the 2008-2010 period (Fig. 3), from 0 to 1 m depth, in the C treatment was nearly constant, with values close to field capacity. In the RDI treatment, θ_v decreased in all phenological periods before stage III of fruit growth, and recovered in this stage and early postharvest, when full irrigation was restored.

During the late postharvest period, the θ_v decreased because of the deficit irrigation applied. The soil moisture profile in the RDI treatment was characterized by the fact that, during the water deficit periods, the θ_v values at depths greater than 0.6 m were clearly below field capacity (data not shown).

Significant differences in θ_v values between treatments were observed during flowering and fruit set, stage I and II and late postharvest until the end of the experiment in 2008. The following year, these differences were only observed in stage II and at the beginning of stage III until the soil water content was recovered due to the restoration of full irrigation in the RDI treatment and in the last point of measurements in late postharvest. During 2010, no significant differences between treatments were detected, although slightly lower soil water contents were measured in stage II of fruit development and early post-harvest stages (Fig. 3).

The amounts of water applied during the 2008 growing season (March to November) were 574 and 385 mm in C and RDI, respectively. In 2009, these amounts were 437 and 333 mm, whereas in 2010 they were 520 and 366 mm for C and RDI, respectively (Table 1). The average water saved over the three years in the RDI treatment was 43% (flowering and fruit set), 44% (stage I of fruit growth), 55% (stage II of fruit growth) and 51% and 74% during the first and second late posthar-

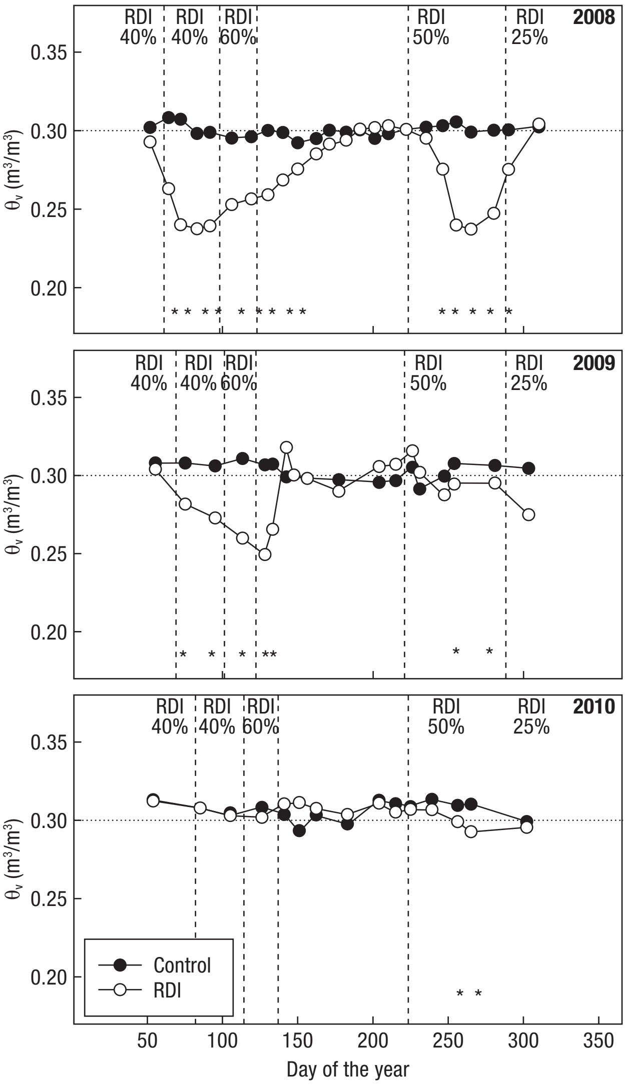

Figure 3. Volumetric soil water content down to 1 m depth (θ_v), in control and RDI treatments for the three growing seasons studied (2008-2010). Each data point is the mean of four values. Asterisks indicate significant differences between treatments ($p < 0.05$). The intervals between vertical lines from left to right represent the beginning of the different phenological stages for apricot trees during the experimental period. Horizontal lines represent soil field capacity.

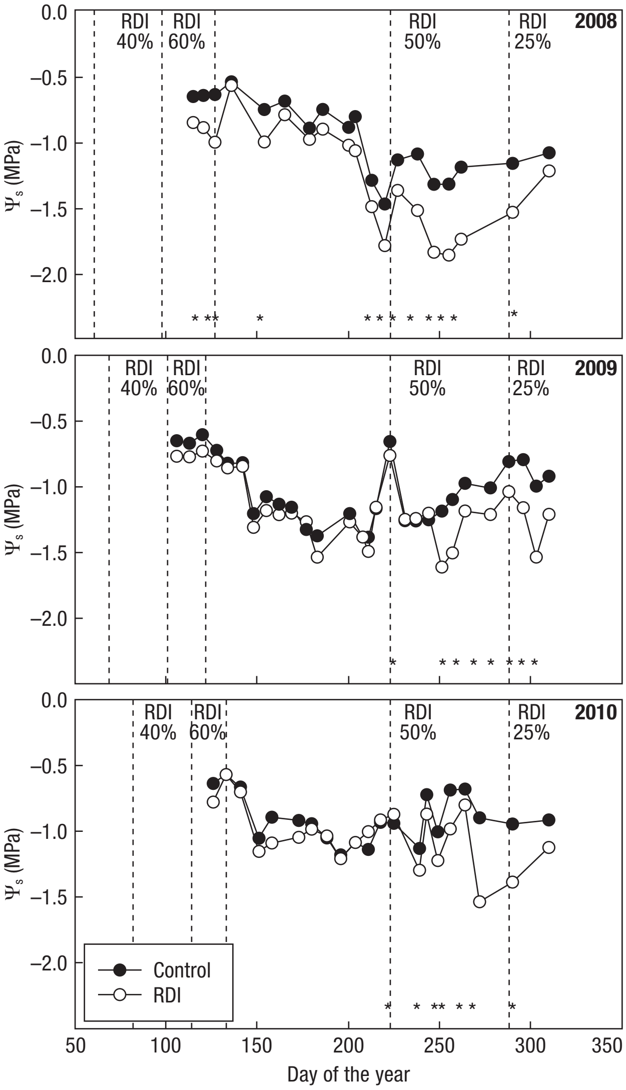

Figure 4. Midday stem water potential (Ψ_s) in control and RDI trees for the three studied growing seasons. Each data point is the mean of sixteen values. Asterisks indicate significant differences between treatments ($p < 0.05$). The intervals between vertical lines from left to right represent the beginning of the different phenological stages for apricot trees during the experimental period.

vest periods, respectively. Overall, for the entire growing season, RDI saved 29% water as compared to C.

Plant water relations

The evolution of Ψ_s showed a decreasing trend in all treatments due to increased climate demand with the advent of warmer months (Fig. 4). The RDI treatment induced significant reductions in Ψ_s in all the stages during which water deficit was imposed in 2008. Nevertheless, during 2009 and 2010, these differences were only significant in the postharvest period.

The RDI treatment induced significant reductions in the average values of midday Ψ_s in all the stages during which water deficit was imposed, similarly to soil water content (Table 2). During fruit development, the values of Ψ_s were nearly constant in C treatment and were about –0.64 MPa in stage II. The reduction of Ψ_s in the RDI treatment during this stage was significant and about 19% respect to C plants at stage II of fruit development (–0.79 MPa). During the postharvest period, Ψ_s values in C plants were lower due to increased evaporative demand, reaching an average of –1.04 MPa and –1.14 MPa during early and late postharvest periods, respectively.

Table 1. Cumulative applied water (mm) during the different stages of fruit growth for the three studied growing seasons, in Control and RDI trees. The lack of water savings on a given stage is represented as —.

Year	Treatment	Flowering & fruit set	Stage I	Stage II	Stage III	Early post-harvest	Late post-harvest I	Late post-harvest II	Total
2008	Control	14.2	29.7	43.0	49.5	190.4	185.4	61.8	574.0
	RDI	7.5	15.9	21.2	49.5	190.4	85.4	14.6	384.6
2009	Control	11.7	14.6	16.1	62.3	166.4	135.8	30.1	437.0
	RDI	7.1	7.5	9.2	62.3	166.4	70.7	9.3	332.5
2010	Control	5.4	15.5	35.5	93.9	151.4	168.6	50.1	520.4
	RDI	3.2	10.1	11.9	93.9	151.4	82.7	12.5	365.6
2008-2010	Control	10.4	19.9	31.5	68.6	169.4	163.3	47.3	510.5
	RDI	6.0	11.2	14.1	68.6	169.4	79.6	12.1	360.9
Water savings (%)		42.8	43.9	55.3	—	—	51.2	74.4	29.3

Table 2. Average values of midday stem water potential (Ψ_s), leaf water potential (Ψ_l), net photosynthesis (P_n) and stomatal conductance (g_s) for each phenological period during the three years of experimental period, as a function of the irrigation treatments.

2008-2010	Ψ_s (MPa)			Ψ_l (MPa)			P_n (µmol/m²·s)			g_s (mmol/m²·s)		
	Control	RDI		Control	RDI		Control	RDI		Control	RDI	
Stage I	-0.61	-0.75	*	-1.26	-1.45	ns	10.20	8.10	ns	144.10	107.30	ns
Stage II	-0.64	-0.79	***	-1.24	-1.46	*	8.23	8.12	ns	100.74	92.71	ns
Stage III	-0.85	-0.98	ns	-1.74	-1.86	ns	9.42	9.64	ns	132.60	130.66	ns
Early post-harvest	-1.04	-1.10	ns	-2.22	-2.33	ns	6.07	5.14	ns	78.93	59.75	ns
Late post-harvest I	-1.14	-1.33	*	-2.40	-2.55	ns	6.71	5.14	ns	89.90	70.01	ns
Late post-harvest II	-0.98	-1.39	***	-2.19	-2.48	*	6.00	1.10	***	76.60	22.20	***

Values are the mean of all values in the different stages. ns: non-significant. * $p < 0.05$. *** $p < 0.001$.

The decrease of Ψ_s in RDI was significant and about 14% and 30% compared to C plants during the first and second periods of late postharvest (–1.33 and –1.39 MPa), respectively. RDI showed the highest values of water stress integral (Fig. 5), which coincides with the evolution of Ψ_s, when significant differences between treatments were detected in all the stages were deficit irrigation was imposed in 2008.

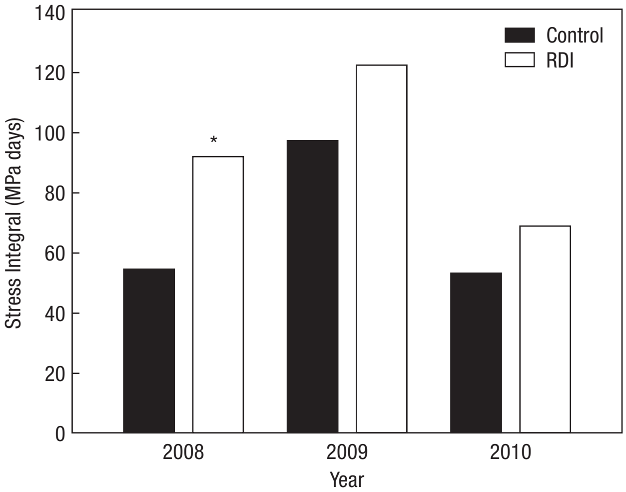

Figure 5. Stress integral values for each irrigation treatment, control and RDI in the 2008, 2009 and 2010 growing seasons. Asterisk indicates significant differences between treatments ($p < 0.05$).

However, the RDI treatment induced significant reductions in the average values of the three years for midday Ψ_l only during stage II and the second period of late postharvest (Table 2). Similar behaviour to that observed in Ψ_l was also detected for gas exchange parameters during the postharvest period, with a significant reduction in P_n and g_s values only at the end of the second period of late postharvest (Table 2). The decrease in P_n and g_s for the RDI treatment was 82 and 72%, respectively during this second period of late postharvest.

When each growing season is separately considered, lower values of both P_n and g_s were detected in all the stages during which water deficit was imposed in 2008. In 2009 and 2010, these differences were only significant for P_n in late postharvest in 2009. However, on average for the three years studied, RDI trees showed significantly lower P_n and g_s values than control trees (Fig. 6).

Vegetative and fruit growth

Cumulative shoot growth was limited by water deficit with trees from RDI showing lower values than

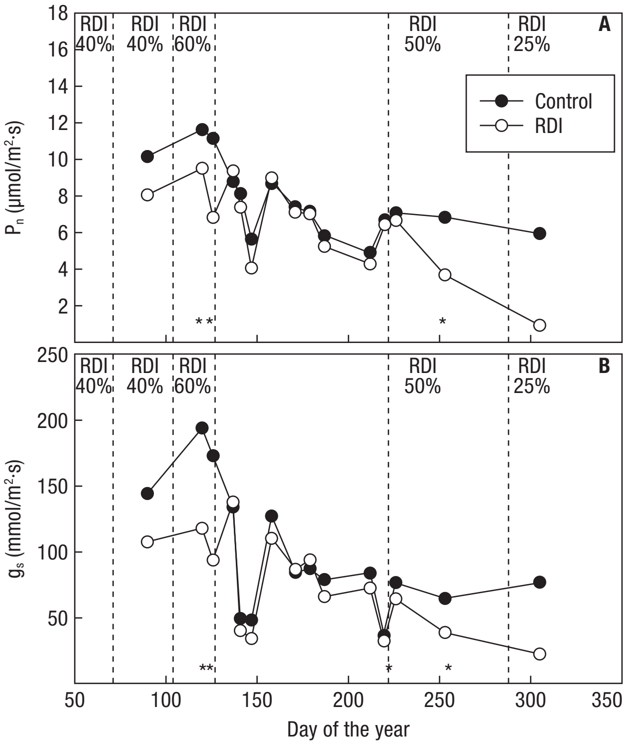

Figure 6. Net photosynthesis (P_n, A) and stomatal conductance (g_s, B) in control and RDI trees averaged for the three studied growing seasons. Asterisks indicate significant differences between treatments ($p < 0.05$). The intervals between vertical lines from left to right represent the beginning of the different phenological stages for apricot trees during the experimental period.

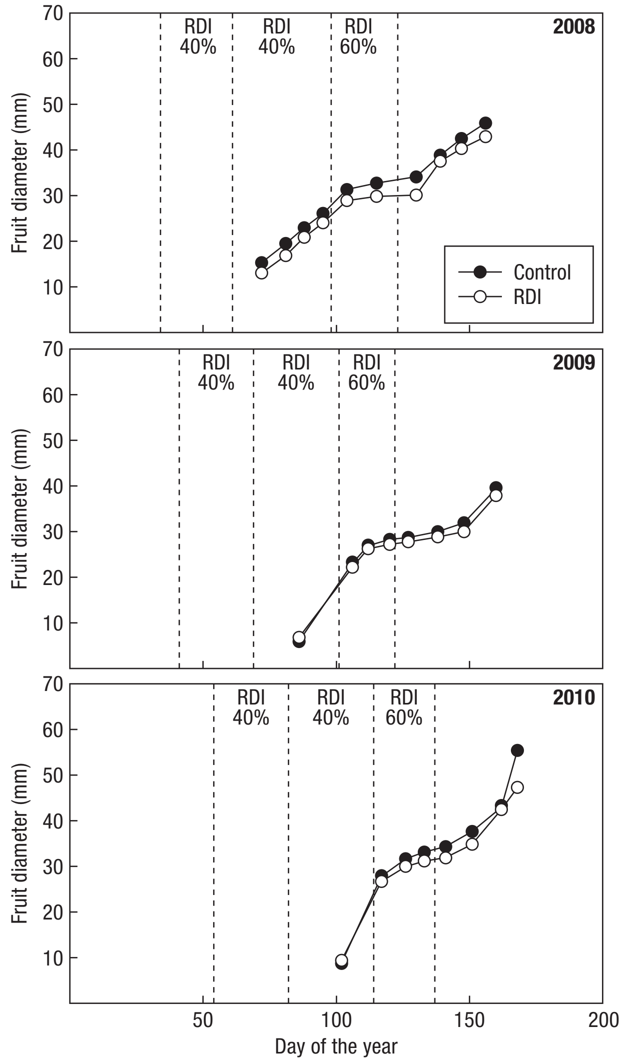

Figure 7. Fruit diameter (mm) evolution in control and RDI treatments for the three studied growing seasons. Each data point is the mean of 200 values. The intervals between vertical lines from left to right represent the beginning of the different phenological stages for apricot trees during the experimental period.

those observed in the control treatment (data not shown). Significant differences were observed for TCSA (Table 3), with lower values in the RDI treatment (~ 14% reduction in average for the three years studied).

Fruits exposed to RDI had a lower but non-significant fruit diameter at the end of stage II of fruit development. When irrigation was restored in the RDI treatment, fruits rapidly reached similar diameter values to those obtained in the C treatment. At harvest, the fruit equatorial diameter was similar in both treatments for the three years (Fig. 7).

Yield, water productivity and fruit quality

No significant differences in yield were observed between treatments for the three growing seasons considered (Table 3), despite of the significantly lower values of fruit set observed in RDI trees during 2008. In contrast, water productivity was significantly higher for RDI in the three years considered in this study. Regarding water savings, the percentages were 33, 24 and 30% respect to ET_c (Control) for 2008, 2009 and 2010, respectively.

In relation to fruit quality, fruit firmness decreased significantly (30%) in fruits from the RDI treatment only in 2008, while SSC and maturity index values were significantly increased (8.6 and 18.3%, respectively) in this treatment with respect to C (Table 4). However, there were no significant differences between treatments for pH and TA. In the other two years, no significant differences among treatments were detected in any parameter with the exception of maturity index in 2009 (12.8% increased under RDI). When averaged for the three years, SSC and maturity index were significantly increased in the RDI treatment by 5.7% and 11.1%, respectively.

The lightness factor, L*, in flesh was similar for both treatments during the three years (Table 5). However, in the skin significantly higher values were observed for the RDI treatment in 2009 and 2010. The hue angle

Table 3. Fruit set, trunk cross sectional area (TCSA), yield, water productivity (WP) and water savings as a function of the irrigation treatments for the experimental period 2008-2010.

Treatment	Fruit set (%)	TCSA (cm^2)	Yield (kg/tree)	WP (kg/m^3)	Water savings (%)
			2008		
Control	35.86	306.77	157	5.70	
RDI	19.71	278.46	153	9.79	33
	*	***	ns	*	
			2009		
Control	37.19	345.84	104	4.96	
RDI	38.46	309.26	106	6.45	24
	ns	***	ns	*	
			2010		
Control	45.97	379.60	92	3.68	
RDI	41.31	321.42	89	5.07	30
	ns	***	ns	*	
			2008-2010		
Control	39.67	344.07	118	4.78	
RDI	33.16	303.04	116	7.10	29
	ns	***	ns	*	

Values are the mean of 160 (fruit set), 96 (TCSA) and 16 measurements (yield). ns: non-significant. * $p < 0.05$, *** $p < 0.001$.

Table 4. Fruit firmness, pH, soluble solids content (SSC), titratable acidity (TA) and SSC/TA ratio at harvest as a function of the treatment for the three experimental seasons.

	Firmness (N)	pH -	SSC (ºBrix)	TA (g/100 mL)	Maturity index (SSC/TA)
			2008		
Control	52.90	3.71	9.47	1.07	9.02
RDI	36.50	3.75	10.28	0.98	10.67
	**	ns	*	ns	**
			2009		
Control	52.53	3.60	10.56	1.21	8.81
RDI	49.39	3.62	11.28	1.17	9.94
	ns	ns	ns	ns	***
			2010		
Control	69.97	3.94	10.33	0.96	10.89
RDI	71.83	3.94	10.53	0.95	11.15
	ns	ns	ns	ns	ns
			2008-2010		
Control	58.47	3.75	10.12	1.11	9.38
RDI	52.57	3.77	10.70	1.06	10.42
	ns	ns	*	ns	***

Values are the mean of 200 measurements. ns: non-significant. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

(Hº) in skin and flesh was significantly higher in the fruits from the RDI treatment during 2008, whereas it was significantly greater for skin in 2009 and for the flesh in 2010. Respect to Chroma (C*), the fruits from the RDI treatment showed significantly higher values in both skin and flesh than those from C during 2008 and 2009. These differences were not significant in 2010. When averaged for the three studied years, the skin colour attributes were significantly increased in the RDI fruits, as well as flesh Chroma.

Table 5. Skin and flesh colour values (reflectance measurements: L*, lightness factor; Hº, Hue value; C*, colour intensity (Chroma)) at harvest in the control and regulated deficit irrigation (RDI) treatments, for the three experimental seasons.

		L*		Hº		C*	
		Skin	Flesh	Skin	Flesh	Skin	Flesh
2008	Control	67.1	62.6	78.8	78.6	48.1	44.7
	RDI	69.2	63.9	85.3	82.9	50.6	46.6
		ns	ns	**	**	**	*
2009	Control	64.7	61.4	71.6	72.5	44.5	41.2
	RDI	66.1	61.7	77.1	73.0	47.9	43.9
		***	ns	***	ns	***	***
2010	Control	62.7	59.6	65.4	65.6	43.4	40.0
	RDI	63.8	59.5	67.3	63.2	44.2	40.8
		*	ns	ns	***	ns	ns
2008-2010	Control	64.8	61.2	71.9	72.2	45.3	42.0
	RDI	66.4	61.7	76.6	73.0	47.6	43.8
		***	ns	***	ns	***	***

Values are the mean of 200 measurements. ns: non-significant. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Discussion

The water applied in the C treatment maintained high values of θ_v, close to field capacity, indicating that plants under this treatment did not suffer from water deprivation (Fig. 3). The drainage was low in both treatments, indicating that a suitable irrigation scheduling in C treatment was applied (Abrisqueta *et al.*, 2001). During the phenological periods of water deficit in the RDI treatment, θ_v decreased significantly, reaching values which caused stress conditions for apricot trees (Ruiz-Sánchez *et al.*, 2000), especially in 2008. The higher spring rainfall amount registered in 2010 caused that no differences were observed between treatments during flowering and fruit set, stage I and stage II of fruit development.

The annual water savings averaged 29% for the three-year study period and were in accordance with those reported by Pérez Pastor *et al.* (2009) and Pérez-Sarmiento *et al.* (2010) for the same cultivar. Although Pérez-Pastor *et al.* (2009) observed significant reductions in plant production for the first two years of their study; in our case, yield was similar between treatments for the three years considered (Table 3), being of the same order of magnitude as that observed by Pérez Pastor *et al.* (2009). This aspect can be explained by the highest water restrictions designed by these authors during fruit development in the initial two years (75% until the end of stage II) in contrast with our experimental conditions (50%), which were based on the last two years designed by those authors (Fig. 1), in which they did not find significant differences in yield for control and RDI trees. Apart from this, the RDI treatment was more efficient than the control, as observed from the values of water productivity. These results are in agreement with previous reports for different fruits under water deficit conditions (*e.g.,* Romero *et al.*, 2004; Perez-Pastor *et al.*, 2009).

Water savings during fruit development did not affect fruit growth in the RDI treatment, since fruits from this treatment had a slightly lower but non-significant fruit diameter at the end of the stage II of fruit development, which were more marked in 2008. When irrigation was restored in the RDI treatment, a compensatory fruit growth occurred and allowed to reach a diameter similar to that of fruits from the C treatment (Chalmers *et al.*, 1986), as a consequence, apricot fruits were of «extra» size in both treatments (> 40 mm in diameter) at harvest. The reason for this observation is that fruits act as strong sinks of photosynthates, which become available when irrigation is restored; thus promoting higher fruit growth rates (Torrecillas *et al.*, 2000). This compensatory fruit growth during a recovery period of water deficit and the relative separation between shoot and fruit growth periods in apricot plants (Pérez-Sarmiento *et al.*, 2010) are essential for the successful application of RDI strategies (Goldhamer, 1989), since it indicates that deficit irrigation may be applied to limit shoot growth without detrimental effects on fruit growth and yield (Chalmers *et al.*, 1981; Mitchell & Chalmers, 1982).

Our results showed that the stress imposed in the RDI treatment significantly reduced TCSA compared to trees under full irrigation conditions. This suggests that the vegetative growth of the tree was significantly reduced by RDI, a fact of great interest for controlling canopy size since this would reduce the costs associated with specific agricultural practices (Ruiz-Sánchez *et al.*, 2010), such as pruning.

Although plant water status (Ψ_s and Ψ_l) and gas exchange (P_n and g_s) parameters were affected by the RDI treatment, not all these discontinuous water stress indicators performed in the same way. In this sense, only Ψ_s reflected well the effects of the different water restrictions on plant water status, even under mild levels of water deficit associated with low VPD (stage I of fruit growth) (Table 2). For this reason, the use of Ψ_s has been adopted for irrigation scheduling in stone fruits, establishing a threshold of -1.5 MPa during the post-harvest period for a moderate RDI strategy (Mirás-Avalos *et al.,* 2016). Moreover, this indicator shows high sensitivity to water deprivation (Remorini & Massai, 2003) and has been reported to provide good predictions of the yield response to deficit irrigation (Intrigliolo & Castel, 2006). The remaining water stress indicators (Ψ_l, P_n and g_s) depend more on the meteorological conditions (Ruiz-Sánchez *et al.*, 2004) and in our case only presented significant differences when water amounts for the RDI treatment were very low with respect to the C treatment (25% ET_c in the post-harvest period).

Despite being higher in the deficit treatment over the 3 years, the values of S_Ψ were only significant in 2008. Pérez-Pastor *et al.* (2014) confirmed that RDI led to yield reductions when water deficits were severe (>140 MPa-days of water stress integral) during non-critical periods. The maximum value obtained in the current study was ~ 120 MPa-days. For this reason, reductions in yield might have not been detected in our experiment.

One of the benefits of RDI is an improvement in fruit taste and quality due to increasing SSC (Mpelasoka *et al.*, 2000; López *et al.*, 2011; Alcobendas *et al.*, 2013; Mirás-Avalos *et al.*, 2013). In the present study, SSC values increased in all years for the RDI treatment although this difference was significant only in 2008, when a higher level of water stress was observed. No differences were found in pH and titratable acidity. Our data showed a similar fruit hardness in both treatments, with the exception of 2008, indicated by the significant differences in firmness, being lower in RDI fruits. Higher ratios of SSC/TA (maturity index) were observed for RDI during the three years, being significant in 2008 and 2009. This ratio affects taste perception (sweetness and acidity) by the consumer, thereby influencing buying decisions (Scandella *et al.*, 1997). Overall, fruits from the RDI treatment can be considered of high quality since SSC increased without affecting acidity (Scandella *et al.*, 1997).

These significant differences in fruit quality were in accordance with the previous figures in which no differences were observed neither in yield, or reproductive and vegetative growth, although the average water savings were close to 30% in the RDI treatment. These savings and the absence of impacts on fruits and trees reinforce the idea that the irrigation strategy used in the current study is optimal from an environmental and economic standpoint.

As for other parameters of fruit quality, lightness factor was significantly affected by RDI in 2009 and 2010 only for fruit skin. The Hº is considered a suitable and understandable colour index (Arias *et al.*, 2000). The increase in this parameter in apricot fruits under RDI can be associated to a reduction in carotenoids accumulation attributed to the oxidation caused by sunlight exposure (Ruiz *et al.*, 2005). This is usually related to a significant reduction in the vegetative growth of the trees during fruit development (Gelly *et al.*, 2003; Buendía *et al.*, 2008), leaving fruits more exposed to sunlight. In our study, the lower TCSA values observed under RDI suggest that vegetative growth was reduced in this treatment; hence, fruits from these trees might have been more exposed to sunlight than those from C trees.

In summary, our results indicated that apricot is an appropriate species to apply RDI because of its clear separation between vegetative and reproductive growths and its ability to recover the fruit diameter reduction suffered during RDI application. In fact, vegetative growth was decreased by RDI, whereas yield remained unaffected. Furthermore, some fruit qualitative attributes such as the level of soluble solids, sweetness/acidity ratio and colour were enhanced by the use of RDI. These reasons, together with average water savings of about 30%, emphasize the RDI strategies as a possible solution for water shortage.

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