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Effect of Deficit Irrigation on Apricot (*Prunus armeniaca* L.) cv. 'Amor El Euch' Trees Grown in the Mediterranean Region of Tunisia

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ABSTRACT

The response of apricot trees (*Prunus armeniaca* L.) to deficit irrigation (DI) was studied in two cropping seasons using a local cultivar 'Amor El Euch' in a Mediterranean region of Tunisia. The specific objectives were to evaluate the effects DI on 1) the soil-water availability in the tree root zone, 2) the plant and fruit growth parameters including leaf proline content, various fertility variables, fruit quality, and fruit yield, and 3) the water use efficiency (WUE) and water savings for mature 'Amor El Euch' apricot trees. Regulated irrigation (RI) treatments included: RI-1: irrigation to fulfill 100% crop consumptive use or evapotranspiration (ET_C) from phenological stage I through IV (control); RI-2: irrigation to fulfill 50% ET_C from stage I through IV; RI-3: irrigation to fulfill 100% ET_C during stages I and II, and 50% ET_C in stages III and IV; and RI-4: irrigation to fulfill 100% ET_C during stages I, II, and III (preharvest) and 50% ET_C in stages III (postharvest) and IV. Results showed that soil-water content were within the readily available water (RAW) level in the 2003 cropping season and below the RAW level during the 2004 season most probably due to 50% more total rainfall received during the prior season. The DI resulted in a significant increase in the leaf proline content during both seasons probably due to the developed response of trees to drought stress. Fruit diameter, length, and degree of firmness increased with an increase in water stress. On the other hand, fruit yield was significantly lower for RI-2 (2003, 2004) and RI-3 (2004) treatments than that for the control treatment. There was no significant decrease in fruit yield for RI-3 (2003) and RI-4 (2003, 2004) compared with the control treatment. Increased WUE resulted in up to 50% irrigation water savings during the DI treatments.

Keywords: drought stress, fruit quality and yield, leaf proline content, water savings, water use efficiency

INTRODUCTION

In 2006, apricot cultivation in Tunisia occupied 10,400 ha with an annual commercial fruit production of over 24,000 Mg, 52% of which came from the Kairouan region. Over 90% of the land under apricot production in Kairouan is irrigated and the rest of it is rainfed. Kairouan is famous for producing local and foreign cultivars of apricot (Khadari *et al*. 2006). A local variety 'Amor El Euch' accounts for approximately one-third of the total cultivated apricot varieties in this Mediterranean region. This cultivar has been increasingly adopted by growers because of its high fruit quality and increasing demand in the international market. However, the expansion of this cultivar to other regions of Tunisia has several obstacles, including water scarcity.

Since fruit trees experience water stress during drought spells, especially in the dry summer season, water is supplied to the orchards as supplemental irrigation for sustainable fruit yield. Although the importance of adequate irrigation during the rapid fruit growth stage has been advocated for enhanced yield (Domingo *et al*. 1999), DI can still be beneficial, especially for optimum fruit yield (Fereres *et al*. 2003). In fact, the importance of water stress has been judged for long-lasting fruit quality (Uriu and Magness 1967). Many studies have reported the positive results of DI for water saving and fruit quality of apple (Ebel *et al*. 1993), almond (Goldhamer and Viveros 2000), apricot (Ruiz-Sánchez *et al*. 2000; Torrecillas *et al*. 2000), citrus (Goldhamer and Salinas 2000), pistachio (Goldhamer and Beede 2004), wine grapes (McCarthy *et al*. 2002), and olive (Moriana *et al*. 2003). Ruiz-Sánchez *et al*. (2000) evaluated the response of apricot trees (cv. 'Búlida') to DI and reported a significant reduction in fruit yield but water saving of 25 to 40% over a period of 4 years (1996-1999). However, fruit quality was not reported to be adversely affected by DI treatments except when 50% of the seasonal ET_C demands were fulfilled. Pérez-Pastor *et al*. (2004) described different phenological stages of mature apricot trees (cv. 'Búlida'), grown under typical Mediterranean conditions and drip irrigation. Based on the assessment of the annual pattern of root, shoot and fruit growth, they found variations in root and shoot growth and characterized the DI as advantageous for shoot and fruit growth. Pérez-Pastor *et al*. (2007) studied the effect of DI on the fruit quality of apricots (cv. 'Búlida') at harvest and during storage at 1°C and reported that the DI resulted in higher values of total soluble solids (TSS), titratable acidity, and hue angle than in the control treatment. They reported that fruit diameter, fresh weight, firmness, and maturity index values were similar to those in the control treatment. They concluded that the DI was commercially advantageous to maintain the fruit quality and achieve water saving.

One of the major objectives of DI is to increase the water use efficiency (WUE) of a crop by eliminating irrigation events that have little impact on fruit yield. The WUE is defined as the ratio of crop yield to the total crop consumptive water use or ET_C, which is the loss of water to the atmosphere by the combined processes of evaporation from the soil and plant surface, and transpiration through plants (Allen *et al*. 1998). Several studies suggested that re-

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ducing water applications during non-critical phenological stage results in higher WUE and longevity of fruits, e.g., peach, nectarine, and apricot trees (Ruiz-Sánchez *et al.* 2000; Naor *et al.* 2001). The major purpose of supplying irrigation water to the plants is to meet their evapotranspiration demands (English 1990). Accurate estimation of irrigation requirements depends on accurate and consistent determination of potential evapotranspiration (ET_O) for which a number of methods have been proposed over the past 50 years after the introduction of Penman's (1948) ET_O equation.

Compared with field crops, apricot tree stomata are less conductive and canopies are rough (Alarcon *et al.* 2000). This results in reduced ET_C and stomatal conductance (Jarvis and McNaughton 1986) and presents favorable conditions for DI during specific growth stages. Since during some developmental stages, many fruit trees are not sensitive to water stress (Johnson and Handley 2000), DI may be applied during that period, e.g., between harvest and leaf fall (Johnson *et al.* 1992). The effects of water stress depend on the timing, duration, and magnitude of the deficits (Bradford and Hsiao 1982; Marsal and Girona 1997).

Before implementing a DI program, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole cropping season (Kirda and Kanber 1999). Studies have been conducted and reported on the effect of DI on growth and yield of various cultivars of apricot (e.g., Torrecillas *et al.* 2000; Ruiz-Sánchez *et al.* 2000; Pérez-Pastor *et al.* 2004; Ruiz-Sánchez *et al.* 2006; Pérez-Pastor *et al.* 2007). No studies to date have evaluated the response of cv. 'Amor El Euch' to DI with regards to different growth parameters at root, shoot, and fruit development stages, fruit quality and yield, and WUE and water savings. Therefore, the objective of this study was to evaluate the effects of DI on 1) the soil-water availability in the tree root zone, 2) the plant and fruit growth parameters including leaf proline content, fertility variables, fruit quality, and fruit yield, and 3) the WUE and water savings for mature 'Amor El Euch' apricot trees.

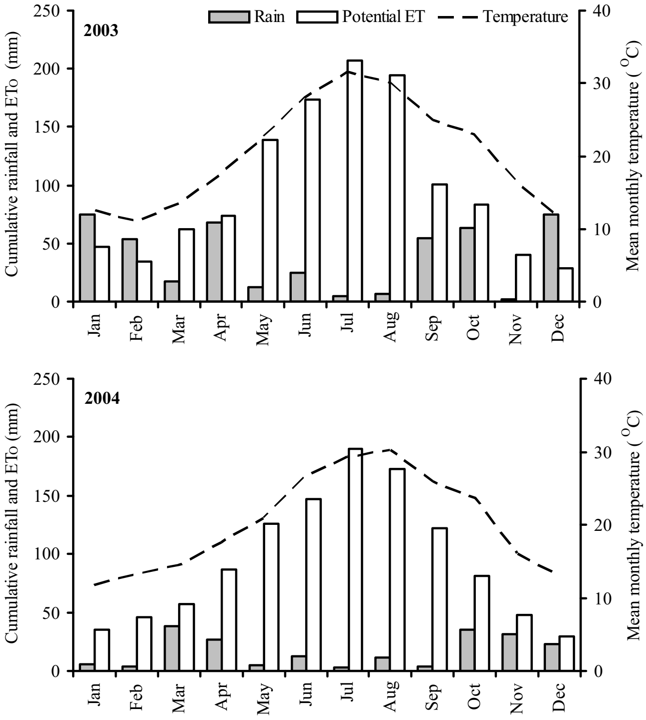

Fig. 1 Cumulative monthly rainfall received, cumulative monthly potential evapotranspiration (ET_O) calculated from class A pan evaporation, and mean monthly temperature recorded during the 2003 and 2004 cropping seasons.

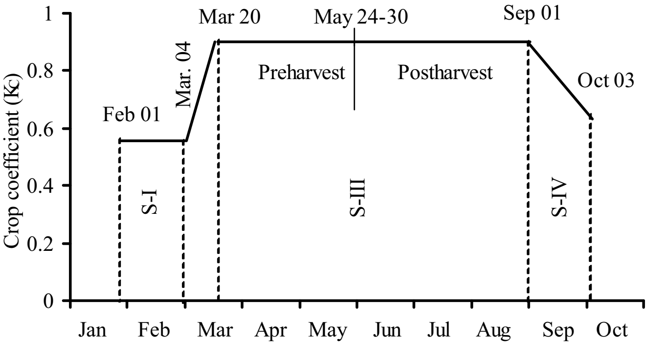

Fig. 2 Crop coefficient (K_C) values at the four phenological stages of apricot tree; S-I, S-II, S-III, and S-IV in a cropping season. Pre-and postharvest stages are also shown.

MATERIALS AND METHODS

The study site

This study was carried out on a private orchard in Chebika located 13 km East of Kairouan city (35° 36′ 35″ N; 9° 55′ 10″ W; altitude 124 m asl). Kairouan region is a plain zone under arid and Mediterranean conditions. The soil at the location is sandy loam texturing >80% sand. Selected physical and chemical properties of this soil are given in **Table 1**. Soil-water contents at field capacity and permanent wilting point are 0.12 and 0.05 cm^3 cm^{-3}, respectively and available soil-water (ASW) calculated for the 90 cm rooting depth is 63 mm.

This study was conducted during the two cropping seasons from Feb. 2003 to Sept. 2004. Maximum temperatures at the site were 48.5 (June 30, 2003) and 45°C (Aug. 10 and 19, 2004). The minimum temperatures were 1 (Feb. 08, 2003) and 0°C (Jan. 31, 2004). The 2003 cropping season was relatively wet as the site received 236 and 104 mm of total rain in 2003 and 2004, respectively (**Fig. 1**). The daily Class A pan evaporation (E_p) that were measured at a nearby meteorological station ranged from 0 (Jan. 31) to 14 mm (July 23) in 2003 and 0 (Jan 31) to 12.5 mm (Aug. 14) in 2004. Cumulative Class A pan evaporation values were 1422 and 1377 mm in the 2003 and 2004 cropping seasons, respectively. The E_p values were converted to ET_O as $ET_O = E_p \times K_p$, where K_p is pan coefficient and is equal to 0.7 (**Fig. 1**). The ET_C estimates were obtained from $ET_C = ET_O \times K_C$. For the purpose of irrigation scheduling and for most water balance studies, average crop coefficient (K_C) values for the four phenological stages of apricot (**Fig. 2**) were adopted from Allen *et al.* (1998).

Table 1 Selected physical and chemical properties of the soil at the study site.

Depth (cm) Soil composition	0-30	30-60	60-90
Clay (<0.002 mm) %	9	6	7
Silt (0.002-0.05 mm) %	6	5	11
Sand (>0.05) %	85	89	82
pH	7.86	8.56	8.37
Conductivity P.S mS/cm)	2.47	1.67	1.82
Total calcareous %	17.7	15.8	25.1
Active calcareous %	3.0	4.0	3.5
Organic carbon %	0.61	0.26	0.14
Organic matter %	1.05	0.45	0.24
Total nitrogen ‰	0.28	0.21	0.43
C/N	21.8	12.4	3.25
Potassium (K_2O, mg kg^{-1})	184	183	209
Phosphorus (P_2O_5, mg kg^{-1})	4.0	2.0	2.0

Field activities and deficit irrigation treatments

Seventeen-year-old apricot trees (*Prunus armeniaca* L. cv. 'Amor El Euch') on 'Oasis-Mechmech' rootstocks were planted at 5 m × 5 m spacing. This variety is self-sterile and was planted with other varieties including 'Ouardi' and 'Sayeb' for cross-pollination. For the 2003 and 2004 cropping seasons, the apricot trees produced new leaves during late March and completed full leaf growth during the last week of April. Fruit harvest was started on May 24

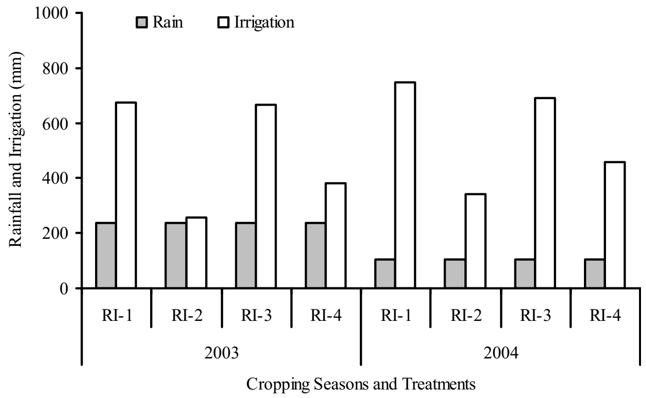

Fig. 3 Total annual rainfall, supplemental irrigation for the experimental treatments (RI-1 through RI-4) during the two cropping seasons.

and continued until May 30, and the end of the irrigation period was in early October during both growing seasons. The four phenological growth stages of apricot include stage I (early February to early March) when floral buds swell, open, and bloom into flowers. Stages II (early March to early May) and III (early May to early June) comprise shuck development, fruit growth from the opening of the shuck, and fruit expansion. Stage IV prolongs early postharvest (early June to early July) and late postharvest (early July to end September). Phenological growth stages I, II, III, and IV are referred as S-I, S-II, S-III, and S-IV, respectively (**Fig. 2**) from here onward.

The experimental design was a complete randomized (CRD) with trees as the experimental unit. Twenty five trees were selected based on i) vigor, ii) representativeness of the orchard and (iii) uniformity of the soil. There were a total of five treatments each comprising five trees (replicates). A buffer of 5 m (one tree row around the selected study area) was considered during this study. Five regulated irrigation (RI) treatments were set with respect to the phonological stages and/or growth periods, i.e., leaf initiation or development, leaf and fruit development, preharvest, and postharvest periods. The treatments include:

RI-1: Irrigation to fulfill 100% ET_C from S-I through S-IV (control);
RI-2: Irrigation to fulfill 50% ET_C from S-I through S-IV;
RI-3: Irrigation to fulfill 100% ET_C during S-I and S-II, and 50% ET_C during S-III and S-IV;
RI-4: Irrigation to fulfill 100% ET_C during stages I, II, and III (preharvest) and 50% ET_C during stages III (postharvest) and IV.

The orchard was irrigated with a drip irrigation system using two rows and six emitters per tree (three emitters per row), each with a flow rate of 8 L h^{-1}. Cumulative rainfall received and RI applied during each treatment is shown in **Fig. 3** for both cropping seasons. In addition to the surface-applied organic manures, liquid fertilizers (i.e., nitrogen, phosphorus, potassium, and magnesium) were applied through the irrigation system following the results of the soil analysis and plant nutrient requirements. As per visual observations, all the necessary steps were taken for pest and disease control by applying fungicides including copper oxychloride (10 g L^{-1}), Pelt 44 (thiophanate methyl) (1 g L^{-1}), and Sumisclex® (1 g L^{-1}) and insecticides, including Citrole® (0.02 L L^{-1}) and Talstar® (8×10^{-4} L L^{-1}).

Soil-water content

Volumetric soil-water contents at various stages were determined using a neutron probe (Solo 25, S^t Avertin, Nardeux, France) that had been calibrated for the experimental site. Gravimetric water content was also determined on a weekly basis from soil samples collected at 10 cm intervals to 90 cm rooting depth. Undisturbed soil cores were collected randomly from each treatment, carefully trimmed, sealed with caps, placed in labeled zip-lock plastic bags, kept in a cooler, and taken to the laboratory. The moist samples were weighed, oven dried at 105°C for 48 hrs, and weighed again. Measurements of soil-water content over time allowed the determination of readily available water (RAW) for plant uptake (Allen *et al.* 1998). For this experiment, allowable water depletion (p) was assumed as 0.5. With an ASW of 63 mm and rooting depth of 90 cm, the RAW was calculated to be 31.5 mm.

Leaf proline content

Leaf proline content (μg g^{-1}) of fresh matter (FM) was determined (Troll and Lindsley 1955) at the fruit growth stage (S-III) in 2003 and 2004. Leaf proline contents are also among the indicator of the effect of DI on a plant's performance. Proline is probably the most widely distributed metabolite accumulated under stress conditions (Delauney and Verma 1993). Many studies (e.g., Hanson *et al.* 1977; Ferreira *et al.* 1979; Hasegawa *et al.* 1994; Yeo 1998) reported the increase of proline concentration in response to DI. Some of the studies (e.g., Van Rensburg and Krüger 1994) reported a positive correlation between proline accumulation and enhanced tolerance to drought and others (e.g., Liu and Zhu 1997) attributed proline accumulation as a symptom of stress injury rather than an indicator of stress tolerance. Proline works as a source of energy, carbon and nitrogen and also protects several enzymes against the inactivating effects of heat during water stress (Paleg *et al.* 1981). At the harvest stage during S-III, five random leaves from each replicate were sampled to determine leaf proline content. The samples were prepared for analysis following their arrival to the laboratory. The proline concentration was determined from a standard curve and calculated on a FM weight basis.

Fertility variables

The observed fertility variables included floribondity, potential fertility and floral fertility. Floribondity is assessed as the ratio of number of floral buds to the total number of vegetative and floral buds. Potential fertility is defined as the ratio of number of blown floral buds to the total number of floral buds. Floral fertility is estimated as the ratio of the number of fruit set to the total number of blown floral buds (Alburquerque *et al.* 2003). Five shoots were randomly selected from each tree in the treatments to measure the aforementioned fertility parameters during S-II (for short shoots) and S-III (for long shoots) in the 2003 cropping season.

Fruit quality assessment

At fruit maturity, fruit quality was measured by determining fruit diameter, weight, firmness (Instron Lloyd Instruments LR-10 K), TSS (hand refractometer ATC-1 Atago), percent of edible dry weight, percent of non edible part, and pH (Crison pH-meter) using 20 randomly selected fruits per treatment. These measurements were made at the late postharvest period in S-III during both cropping seasons.

Fruit yield and water use efficiency

Fruit yield was calculated as weight of the harvested fruits (kg) per tree for each treatment. As mentioned earlier, there were five trees in each treatment planted at 5 m × 5 m spacing and hence the area under each treatment was calculated to be 125 m^2. Fruit yield was converted to kg m^{-2} for WUE (kg m^{-3}) calculations. The WUE was taken as the ratio of fruit yield (kg m^{-2}) to the total crop water consumptive use (mm) convertd to m.

Statistical analysis

Analysis of variance (ANOVA) was performed using SPSS 11.0.1 for Windows (SPSS 2001). When ANOVA indicated a significant effect of DI (i.e. $P < 0.05$), the treatment means were compared and separated using Student-Newman-Keul's multiple range tests. Standard deviations from the mean values were also calculated and plotted with other results.

RESULTS AND DISCUSSION

Soil-water availability

Due to a relatively wet 2003 cropping season (**Fig. 1**), soil-water was continuously available for plant uptake within the level of RAW for the treatments RI-1 and RI-4 (**Fig. 4**). However, the water contents were below the RAW level during most of the phenological stages III and IV for RI-2 treatments due to 50% less supplemental irrigation as compared with the control treatment. For the RI-3 treatment, the water contents were within the RAW level for the first half of the third stage and was below the RAW level for the next half of S-III and throughout S-IV. During the whole 2004 cropping season, soil-water availability was below the RAW level for all treatments. This was mainly due to less than 50% precipitation (104 mm in 2004 as compared with 236 mm in 2003) received during the 2004 cropping season. Water stress was particularly significant for RI-2 and RI-4 during S-III and S-IV in 2003 and during all stages in 2004 cropping seasons. The DI resulted in diminishing of soil-water, especially in the shallow soil layer, are similar to those reported by Silber *et al.* (2006), who examined the response of 'Safari Sunset' plants to various levels of DI. Since soil-water availability to the plants is affected by soil-water level/storage in the soil layers, tree growth and fruit parameters may be affected with such variations in soil-water levels as observed in different DI treatments.

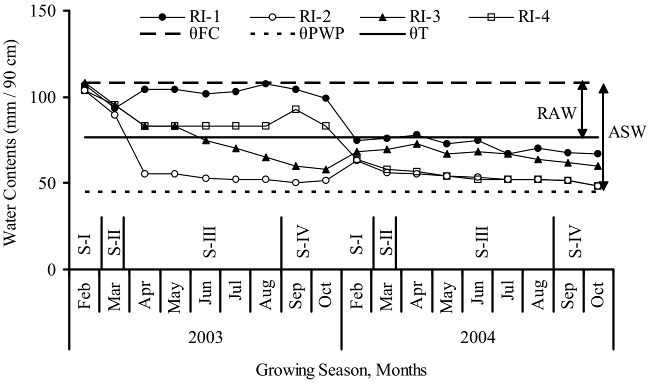

Fig. 4 Soil-water contents affected by rainfall events and irrigation treatments during the two growing seasons.

Leaf proline content

The DI treatments enhanced leaf proline concentration in accordance with water stress and growth stages. Mean values of leaf proline content for RI-4 treatment were significantly ($P < 0.05$) larger than the other three treatments during the 2003 cropping season (**Fig. 5**). During the 2004 cropping season the leaf proline content of the RI-4 treatment was significantly larger than that in the RI-3 treatment; however, there was no statistically significant difference in the leaf proline content in the rest of the treatments. The highest value of leaf proline content was recorded for RI-4, i.e., 94 µg g^{-1} during the 2003 cropping season. Proline accumulation under water stress helps the plant to resist drought (Paul *et al.* 2006). The increased accumulation of proline content within cell tissue appears to maintain osmotic pressure within cells and is considered a response to drought stress (Claussen 2002). The lack of a statistical difference between the mean leaf proline content in most of the treatments during the two cropping seasons during S-IV (2004) reflects that the biosynthesis of proline, perceived as an osmoregulator, was stimulated by enzymes controlled by genes conferring tolerance to drought stress (El Jaafari 1993).

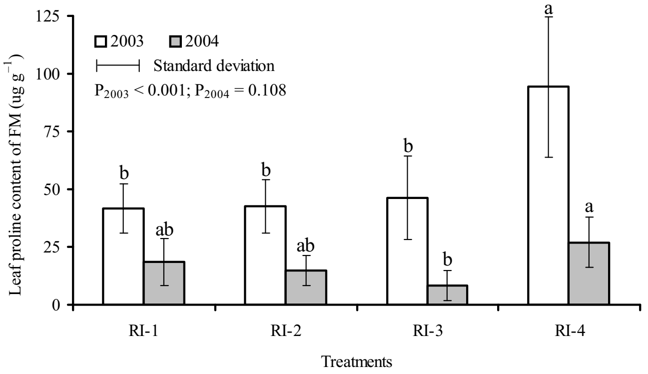

Fig. 5 Leaf proline content for different deficit irrigation treatments measured during postharvest period of S-III in the two cropping seasons. Mean separation by ANOVA followed by SNKMRT at P < 0.05.

Fertility parameters

There was no significant effect of DI on floribondity (**Fig. 6**). However, DI significantly affected the potential fertility in all the treatments as compared with the control treatment. These results suggest that DI applied during primary and secondary fruit growth stages (i.e., S-II and S-III, respectively) created more conducive conditions for flower bud abscission. There was a significant effect of DI on floral fertility where the mean values of floral fertility under RI-2 treatment were significantly different from those of the control treatment. Because of the prolonged and severe water stress that restricts flower bud formation and flowering processes (Kozlowski and Pallardy 2002), some researchers (Stern *et al.* 1998; Goldhamer and Viveros 2000; Stern *et al.* 2003; Goldschmidt and Samach 2004) have advocated periodic DI in order to sustain the flowering activity of plants.

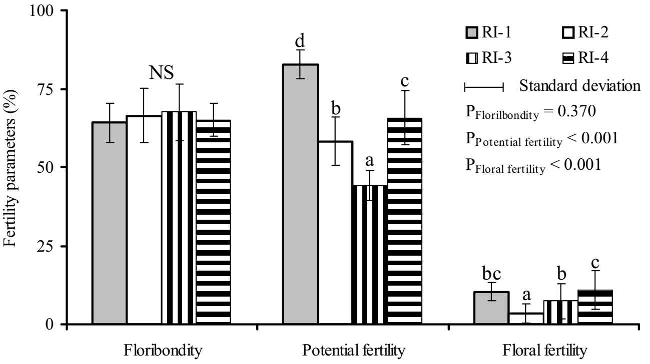

Fig. 6 Fertility parameters at return bloom affected by the regulated irrigation treatments during the 2003 cropping season. Mean separation by ANOVA followed by SNKMRT at P < 0.05.

Fruit quality

Fruit physical and chemical characteristics, including fruit diameter, fruit weight, degree of firmness, TSS, dry weight rate of edible part, rate of no edible part, and pH observed at the end of cropping seasons 2003 and 2004 are given in **Table 2**. These results indicate that DI significantly increased fruit diameter, fruit weight, and the degree of firmness. A significant increase in fruit dry weight was also observed in the 2003 harvest in the RI-4 treatment. The rest of the studied fruit characteristics were not significantly affected by DI. Results presented in **Table 2** support the findings of previous studies about DI's effect on the quality of fruits other than apricot as Kuriyama *et al.* (1981) and Bielorai (1982) reported DI to increase TSS and titratable acidity (TA) in citrus fruits. An improvement in fruit quality (e.g., higher values of TSS, TA, and hue angle) was also reported by Pérez-Pastor *et al.* (2007) who studied, at harvest and

Table 2 Physical and chemical characteristics: diameter, weight, degree of firmness, total soluble solids, dry weight rate of edible part, rate of non-edible part, and pH for 2003 and 2004 harvest for the different irrigation treatments.

Yield parameters	Treatments	Growing seasons	
		2003	2004
Diameter (mm)	RI-1	42.20 ± 2.45 a	42.00 ± 2.72 a
	RI-2	44.55 ± 3.32 b	42.69 ± 3.04 a
	RI-3	44.95 ± 2.44 b	45.77 ± 2.54 b
	RI-4	45.67 ± 2.68 b	46.79 ± 2.29 b
Weight (g)	RI-1	38.40 ± 3.30 a	30.93 ± 5.77 a
	RI-2	41.07 ± 4.85 ab	36.37 ± 6.08 ab
	RI-3	46.73 ± 3.11 b	42.53 ± 9.10 bc
	RI-4	45.16 ± 2.58 b	41.71 ± 5.13 bc
Degree of firmness (penetration: 1/10 mm)	RI-1	0.56 ± 0.22 a	1.03 ± 0.27 a
	RI-2	0.53 ± 0.19 a	1.14 ± 0.33 ab
	RI-3	0.80 ± 0.37 b	1.32 ± 0.41 b
	RI-4	0.81 ± 0.40 b	1.14 ± 0.45 ab
Total soluble solid (%)	RI-1	14.57 ± 1.08	12.88 ± 0.11
	RI-2	14.84 ± 0.46	12.66 ± 0.96
	RI-3	15.02 ± 0.88	11.84 ± 0.61
	RI-4	14.88 ± 0.86	11.86 ± 0.85
		NS	NS
Dry weight rate of edible part (%)	RI-1	13.35 ± 0.38 b	14.04 ± 1.68
	RI-2	13.10 ± 0.60 b	15.37 ± 0.82
	RI-3	12.76 ± 0.42 ab	15.99 ± 4.74
	RI-4	12.14 ± 0.44 a	13.47 ± 1.45
			NS
No edible part rate (%)	RI-1	5.84 ± 0.37	5.45 ± 0.40
	RI-2	5.91 ± 0.45	5.27 ± 0.53
	RI-3	5.92 ± 0.38	5.24 ± 0.33
	RI-4	6.18 ± 0.41	5.40 ± 0.23
		NS	NS
pH	RI-1	3.25 ± 0.09	2.64 ± 0.05
	RI-2	3.27 ± 0.07	2.66 ± 0.06
	RI-3	3.20 ± 0.05	2.63 ± 0.05
	RI-4	3.27 ± 0.09	2.64 ± 0.04
		NS	NS

Mean separation by ANOVA followed by SNKMRT at P < 0.05.

during storage, the effect of DI levels on the quality of apricot (cv. 'Búlida') fruits. Our results are also in concurrence with the findings of Pérez-Pérez *et al.* (2009) who assessed DI for its potential to improve the final fruit quality in 10-year-old 'Lane late' sweet orange grafted on Carrizo citrange (*Citrus sinensis* L. Osb. × *Poncirus trifoliata* L.). They did not find any significant changes in fruit yield although mean fruit weight was slightly reduced. However, they reported that the DI in their study increased TSS and TA and decreased juice percentage without altering the final maturity index of the fruit.

Fruit yield and water use efficiency

Water stress significantly reduced fruit yield for the RI-2 treatment during 2003 and for RI-2 and RI-3 treatments in 2004 (**Fig. 7**). However, the fruit yield for RI-3 and RI-4 and that for RI-4 was not significantly different from control treatments in 2003 and 2004 cropping seasons, respectively. The least yield per tree was recorded for RI-2 and RI-3 in the 2003 and 2004 cropping seasons, respectively. The overall reduced yield in the 2004 cropping season as compared with that of 2004 cropping season resulted in lower WUE for all the treatments with the highest water use efficiency shown by RI-2 treatment in 2003 (**Fig. 8**). The lowest WUE was recorded for RI-3 in both cropping seasons. However, the WUE values for RI-4 were higher than those of the control treatment in the both cropping seasons. The higher calculated WUE, especially for the DI treatments, is of great importance as in addition to the optimum fruit quality, it resulted in up to 50% water saving. González-Altozano and Castel (2000) studied the effects of DI on 'Clementina De Nules' citrus trees growth, yield, and fruit quality and reported that the DI treatments resulted in water savings from 6 to 22% without affecting yield and quality of the fruit. In a four-year study on the effect of DI on apricot trees, Ruiz-Sánchez *et al.* (2000) reported that during the first two years of the study, when water saving was higher than 40%, total yield obtained in DI treatment was reduced; however, when irrigation water saving was around 25%, the yield obtained was similar to that of the control treatment (i.e., irrigation at 100% of seasonal ETc). Similarly, for a mandarin (*Citrus reticulata* cv. 'Marisol') orchard, Kirda *et al.* (2007) reported only a marginal yield reduction (i.e., 10 to 14%) under the DI (irrigation equivalent to 60% Class-A pan evaporation), but more than a 2-fold increase in irrigation WUE compared with the traditional practice of full irrigation.

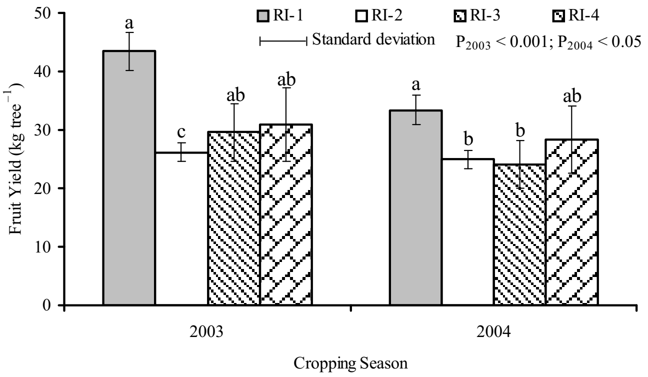

Fig. 7 Fruit yield for the regulated irrigation treatments at two harvests of 2003 and 2004 cropping seasons. Mean separation by ANOVA followed by SNKMRT at P < 0.05.

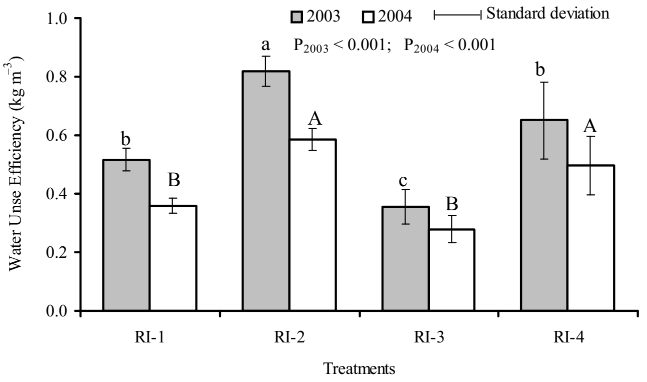

Fig. 8 Water use efficiency for the four treatments calculated from the total fruit yield per unit of total consumptive water use per unit area. Mean separation by ANOVA followed by SNKMRT at P < 0.05.

CONCLUSIONS

During the 2003 cropping season, the DI used during this study resulted in soil-water availability in the deeper available soil-water zone as compared with control and RI-3 treatments during which the water content was available for plant uptake in the readily available water zone. Dry conditions during the 2004 cropping season forced soil-water content below the readily available water level. Despite the negative effect of DI on fruit yield and physiological and plant growth variables (number of vegetative and floral buds, floribondity, potential yield, and leaf proline content), fruit quality (i.e., fruit diameter, weight, and degree of firmness) improved. DI during the postharvest stages S-III and S-IV could save up to 50% of irrigation water without significantly affecting fruit yield. The DI not only resulted in increased WUE but also resulted in approximately 50% water saving in treatments RI-2 during 2003 and 2004. A significant water saving was also recorded for treatments

RI-4 during 2003 (44%) and 2004 (39%). There was less than 25% water savings in the rest of the treatments. Our research findings show that the deficit irrigation has some benefits to cv. 'Amor EL Euch' grown under the conditions resembling to those reported in this paper.

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