

Response of early-peach [*Prunus persica* (L.)] trees to deficit irrigation

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Abstract

The effect of different irrigation strategies in water relations, vegetative growth and yield of early maturing peach trees, growing in Murcia, (Spain) was studied during two years. Treatments consisted on: a control T1, full irrigated (150% of ETc); T2, continuous deficit irrigation at 50% of ETc; T3, regulated deficit irrigation (RDI), irrigated at 100% of ETc only during stage III of fruit growth and 25% the rest of the growing season; and T4, with automatic control of irrigation based on capacitance FDR-type probe data, varying threshold values. The results indicated that irrigation deficits in T2 and T3 treatments induced the lowest soil water content and stem water potential (Ψ_{stem}) values during the postharvest period (e.g. Ψ_{stem} up to -1.8 MPa in T3 during summer 2008); thus, a reduction in trunk growth and pruning weight, respect to control treatment values, was noted in both years. Also, peach yield was significantly reduced in both deficit irrigated treatments. The greatest irrigation water saving in T3 treatment ($\approx 60\%$) caused the higher water use efficiency values in this treatment. For these reasons, water deficit during the postharvest periods (extended in the early maturing varieties) must be limited if fruit yield is not to be reduced. Irrigation scheduling based on capacitance probes have become a useful tool in the control of soil water content. When threshold values were precisely defined, the slight water deficits limited only vegetative growth while maintaining similar peach yield to that of well irrigated trees.

Additional key words: automatic irrigation; capacitance probes; neutron probe; soil water content; stem water potential; vegetative growth; yield.

Resumen

Respuesta del melocotonero extra-temprano al riego deficitario

Se estudió el efecto de distintas estrategias de riego deficitario en las relaciones hídricas, crecimiento vegetativo y producción de melocotoneros extratempranos 'Flordstar' en Murcia (España) durante dos años. Los tratamientos fueron: T1, control, riego diario al 150% ETc; T2, riego deficitario continuo (50% ETc); T3, riego deficitario controlado (100% ETc sólo durante la fase III de crecimiento del fruto y 25% ETc el resto del ciclo) y T4, control automático del riego basado diferentes umbrales de contenido hídrico del suelo con sondas de capacitancia. El déficit hídrico en los tratamientos T2 y T3 indujo los valores más bajos de contenido de agua del suelo y de potencial hídrico de tallo (Ψ_{tallo}) durante la poscosecha ($\Psi_{\text{tallo}} = -1,8$ MPa en T3, verano 2008); lo que provocó una reducción del crecimiento del tronco y peso de poda, respecto a los valores del tratamiento control, en los dos años. Además, la producción se redujo significativamente en ambos tratamientos. El tratamiento T3 resultó ser el más eficiente en el uso del agua debido al mayor ahorro de agua de riego ($\approx 60\%$). Por estas razones, los déficits hídricos en poscosecha (muy larga en variedades tempranas) deben ser limitados si no se quiere afectar la producción. Las sondas de capacitancia son una herramienta útil para el control del contenido hídrico del suelo, permitiendo una programación eficiente del riego. Cuando los valores umbrales se definen con precisión, se generan déficits hídricos ligeros que limitan sólo el crecimiento vegetativo manteniendo la producción similar a la de árboles bien regados.

Palabras clave adicionales: contenido de agua en el suelo; crecimiento vegetativo; potencial de tallo; producción; riego automático; sondas de capacitancia; sonda de neutrones.

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Introduction

Agriculture in semi-arid zones faces a quasi-permanent situation of water scarcity and low quality water resources. Besides a structural water deficit, tourist and residential development, as well as competition from other uses add to the problem. In these areas, new strategies which decrease water consumption and limit environmentally adverse effects are necessary. These strategies include the aimed to reduce the amount of water used in irrigation applications with a minimum impact on yield, so called deficit irrigation strategies (Chalmers *et al.*, 1981; Goldhamer, 1989; Ruiz-Sánchez and Girona, 1995).

Other strategies include improvements in water application systems by means of irrigation scheduling. During recent years, developments in new equipment have led to irrigation management practices based on the continuous monitoring of climatic variables (Allen *et al.*, 1998), plant-based parameters (Cohen *et al.*, 2001; Jones, 2004; García-Orellana *et al.*, 2007) or soil water content (Dane and Topp, 2002). The equipment used for soil water content monitoring includes devices to measure soil water potential, which is used for high-frequency irrigation management (Phene and Howell, 1984) and those based on electromagnetic techniques, which allow rapid, non-destructive and automatic measurements (Topp and Davis, 1985; Dean *et al.*, 1987; Paltineanu and Starr, 1997). Capacitance probes provide data on the soil water dynamics from the continuous and real-time measurements of soil water content variations throughout the root zone, facilitating decision-making for precise irrigation scheduling (Starr and Paltineanu, 1998; Goldhamer *et al.*, 1999).

Peach [*Prunus persica* (L.) Batsch] is the fourth more important fruit crop in the world and the second in Europe. Spain is the second largest producer. Most peach tree plantations are located in the Mediterranean area with its attendant low rainfall (≈ 300 mm year⁻¹). The province of Murcia is ranked third in peach production in Spain, with an average annual yield for the last 5 years of about 250,000 t, representing about 20% of the Spanish total (Anuario Estadístico de la Región de Murcia, 2008).

The main objective of the work was to study the effect of deficit irrigation (continuous and regulated)

on drip-irrigated early maturing peach trees, as well as to compare irrigation scheduling based on the soil water content, as measured by capacitance probe, with traditional scheduling based on ETc calculations. Plant and soil water relations, vegetative and fruit growth, and yield were evaluated during two growing seasons in the different irrigation treatments.

Material and methods

The experiments were performed in two growing seasons corresponding to the harvests of 2007 and 2008 in an experimental 0.8 ha plot located in Santomera-Murcia (S.E. Spain): 38° 06' N, 1° 02' W. The soil is highly calcareous, rocky and shallow, with a clay-loam texture and low organic matter and cationic exchange capacity values; it is classified as Lithic xeric haploxeroll (Soil Survey Staff, 2006). The bulk density of the soil was 1.45 g cm⁻³ down to 0.5 m, but higher values (1.67 g cm⁻³) were found at deeper levels. The mean values of soil water content at field capacity (θ_{FC}) and at permanent wilting point (θ_{PWP}), as determined in undisturbed soil samples by the Richards pressure plate technique (Richards, 1965), were 0.29 and 0.15 m³ m⁻³, respectively, which implied an available soil water content of 140 mm m⁻¹.

The plant material consisted of five-year-old peach trees cv. Flordastar, on GF-677 peach rootstock), spaced 5 × 5 m. The trees were irrigated by a drip irrigation system consisting of a single lateral line per tree row, with eight emitters per tree, placed 0.5 m from tree trunk, providing 2 L h⁻¹. The irrigation water used was considered to be of low salinity (electrical conductivity = 1.5 dS m⁻¹) with negative Langelier index, for that did not represent a risk to the soil structure stability or pose infiltration problems (Oster and Schroer, 1979).

Four irrigation treatments were applied: T1 (control), irrigated above estimated crop evapotranspiration (average 150% of ETc in both years), determined according to daily crop reference evapotranspiration (ET₀), calculated using the Penman-Monteith equation (Allen *et al.*, 1998) and crop coefficients from the FAO, corrected for the percentage of ground area shaded by the tree (Doorenbos and Pruitt, 1977; Fereres and Goldhamer, 1990); T2, continuous deficit irrigation,

Abbreviations used: ETc (crop evapotranspiration), ET₀ (reference crop evapotranspiration), FC (field capacity), FDR (frequency domain reflectometry), RDI (regulated deficit irrigation), SWC (soil water content), TCSA (trunk cross sectional area), TDR (time domain reflectometry), Ψ_{stem} (stem water potential).

irrigated at 50% of ET_c during the growing season; T3, regulated deficit irrigation (RDI), irrigated to fully cover 100% ET_c only during stage III of fruit growth, with the irrigation water reduced to 25% ET_c during the rest of the growing season; and T4, irrigation automatically scheduled using the capacitance probe and radio transmission system, following different criteria each year. In 2007, irrigation started at 22:00 h, and 100% of daily water requirements (computed with FAO-Penman-Monteith's method) were provided. In 2008, irrigation was automatically managed by monitoring the soil water content (SWC) at 22:00 h, and irrigation only started if the SWC in the top 0.5 m layer at this time was below 90% of field capacity (FC), stopping when the sensor at 0.8 m depth showed an increase of 2% over its value recorded at 22:00 h.

Treatments were distributed in a completely randomized design with four repetitions, each consisting of one row of 13 trees. The central nine trees were used for experimental measurements and the others served as guard trees. Root distribution studies revealed no active roots more than 1.5 m from drip line (I. Abrisqueta, unpublished results).

Irrigation was controlled by a head unit programmer operating on electro-hydraulic valves and the irrigation water volumes for each treatment were measured with in-line flowmeters.

Agro-meteorological data were recorded by an automated station located within the peach orchard with real-time access via Web. Rainfall was 309.1 mm for the 2006/07 growing season and 341 mm for 2007/2008, mostly occurring in spring and autumn.

The volumetric water content through the soil profile (SWC) was monitored in continuous real time, using two multisensor capacitance probes (C-probe, v.1, Agrilink Inc., Australia) per treatment, placed 10 cm from the emitter, inside a PVC access tube installed within the wetted area. The probe had sensors at 10, 20, 30, 50 and 80 cm depth. Each probe were connected to a radio transmission unit which read data every 5 min and stored an average value every 15 min. Capacitance probe readings were converted to volumetric soil water content using a local calibration equation (Vera *et al.*, 2009).

The SWC was also evaluated with discrete (every 7-10 days) measurements using a neutron probe (Troxler[®], mod. 4300; Troxler Electronic Laboratories Inc., Research Triangle Park, NC, USA), previously calibrated for the site. Access tubes were installed in the wetted area (1 m from the tree trunk) in one tree of

each replication and treatment. Soil moisture was determined at 0.1 m intervals from 0.2 to 0.8 m. Soil moisture in the top 0.1 m of the soil was determined by time domain reflectometry (TDR) (Tektronix[®], mod. 1502B; Tektronix Inc., Beaverton, OR, USA) following Topp *et al.* (1980).

Leaf water relations were determined by measuring stem water potential (Ψ_{stem}), using a pressure chamber (Soil Moisture Equip. Crop. Model 3000, Santa Barbara, CA, USA) on mature leaves on the north face of the tree near the trunk. These were placed in plastic bags covered with aluminum foil for at least 2 h prior to the measurements, which were carried out at midday every 7-15 days from April to October. Four leaves per treatment (one leaf per tree and one tree per replication) were cut and immediately placed in the chamber following the recommendations of Hsiao (1990).

Vegetative growth was evaluated by measuring the extension shoot length monthly in four tagged shoots per tree, one from each compass direction on four trees per treatment (one tree per replicate). Trunk diameter was determined with a forest caliper in all the experimental trees about 30 cm above the graft union during dormancy of both years. Trunk cross-sectional area (TCSA) was estimated as equivalent to a circle. Trees were pruned in winter each year and the pruning of five experimental trees of each replication and treatment was weighed. A sample was dried at 70°C to a constant weight.

Peaches were hand-thinned 0.2 m apart in March and harvested during the first week of May. The total weight of the fruits and the total number of fruits per tree were recorded in five experimental trees of each replicate and treatment.

Data were analyzed using the SPSS software (SPSS, 2002). Analysis of variance (ANOVA) was used to discern treatment effect. Statistical comparisons were considered significant at $p \leq 0.05$.

Results

The amount of water applied in the 2006/2007 growing season was 295 mm in the continuous deficit irrigation treatment (T2), 269 mm in RDC (T3) and 266 mm in SWC-based treatment (T4). For the 2007/2008 growing season the respective amounts applied were 294, 313 and 545 mm for T2, T3 and T4. The control treatment was irrigated ($\approx 1,200$ mm) above crop water requirements (ET_c, FAO-Penman-Monteith), which amounted to 741 mm in 2006/07 and 733 mm in 2007/08.

In the control treatment, the soil water content (SWC) in 0-0.8 m soil profile remained above field capacity values during both irrigation seasons and decreased during the dormancy period when no irrigation was applied (Fig. 1). High values were observed in SWC in all treatments during spring 2007 and autumn 2008 due to the rainfall, which prevented the appearance of a soil water deficit situation. In the RDI treatment, SWC decreased in stages I and II of fruit growth during

the deficit period of 2008, and recovered in stage III, when full irrigation was applied. During the postharvest period, the SWC decreased as a result of the deficit irrigation applied, reaching lower values in the RDI treatment (T3) irrigated at 25% of E_{Tc} than in the continuous deficit treatment (T2) irrigated at 50% E_{Tc} (Fig. 1).

In the T4 treatment, the SWC values measured with the capacitance probes remained around field capacity

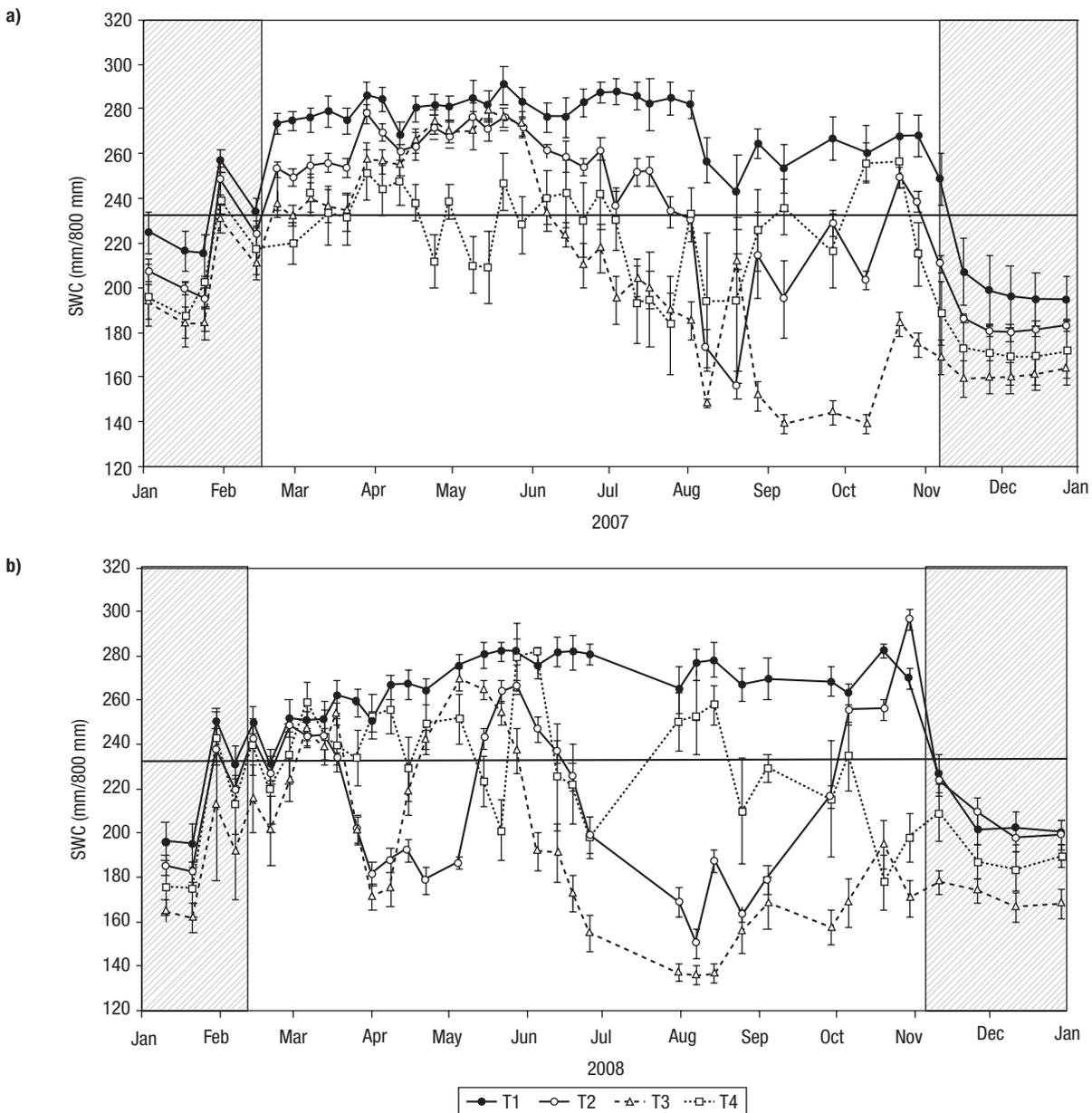


Figure 1. Soil water content (SWC) in 0-0.8 m soil profile measured with neutron probe in 2007 (a) and 2008 (b) in different irrigation treatments of Flordastar peach trees. Each point is the mean of 4 replications \pm standard error. Stripped areas indicate non irrigation period.

in 2007 but below the control treatment values most of the time, except during late summer in 2007, reflecting the dynamics of ET_c . In 2008, the SWC values were fairly constant and remained around the imposed threshold value (90% FC), which triggered irrigation (Fig. 2). Note that in 2007 irrigation was applied daily, whereas in 2008 the automatic irrigation scheduling induced a frequency of about 3-5 irrigations per week during the fruit growth period and less frequency (2-3

irrigations per week) was applied during the postharvest period.

During both years, deficit irrigation caused a decrease in Ψ_{stem} values with respect to the control, in which Ψ_{stem} varied between -0.4 and -0.8 MPa during the growing season (Fig. 3). The more pronounced Ψ_{stem} differences were found during the postharvest period, plants from the RDI treatment showing the greatest plant water deficits (lowest Ψ_{stem} values ≈ -1.8 MPa).

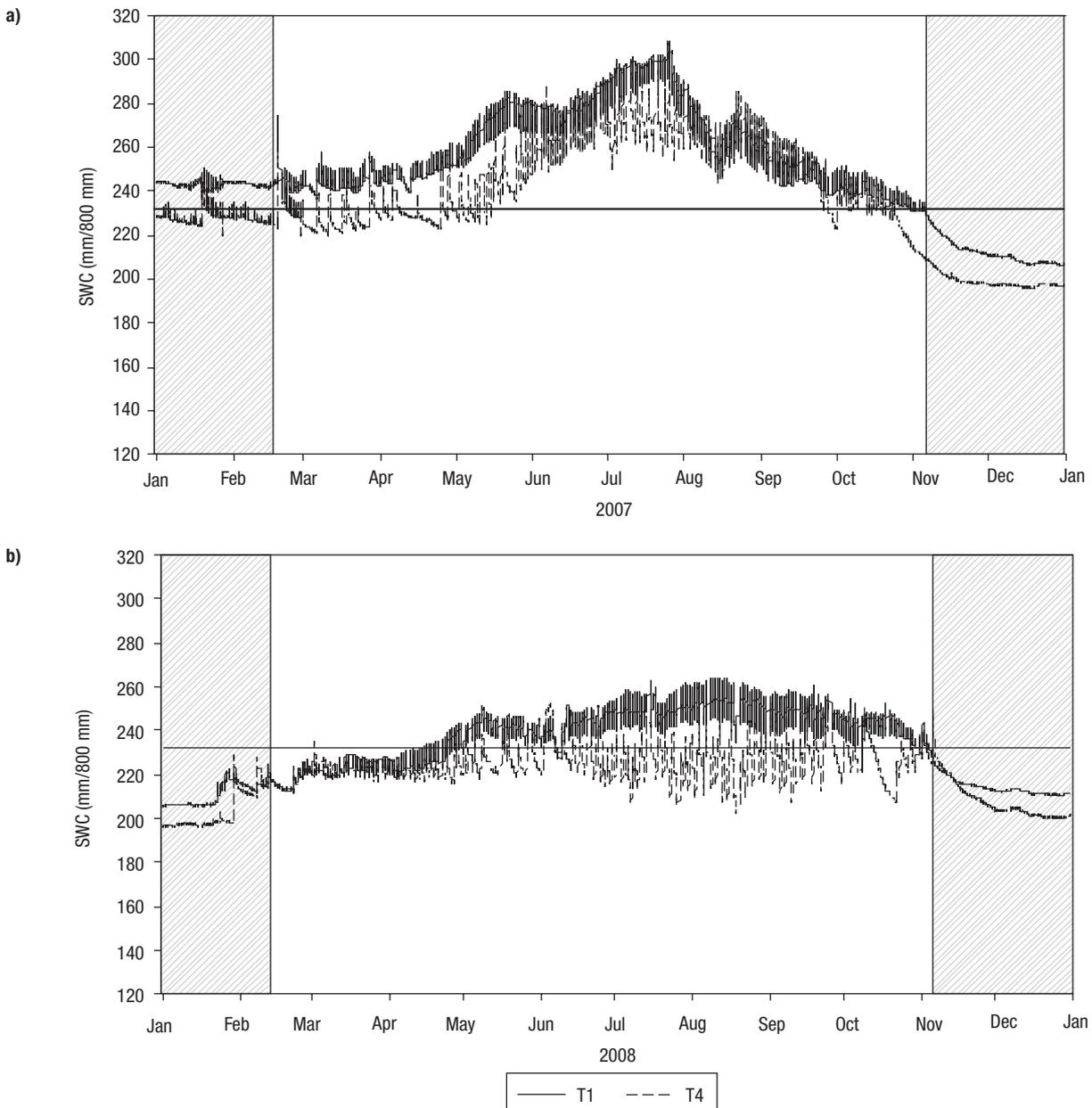


Figure 2. Soil water content (SWC) in 0-0.8 m soil profile measured with capacitance probes in 2007 (a) and 2008 (b) in irrigation treatments T1 (control) and T4 (soil-based) of Flordastar peach trees. Each point is the mean of 2 replications. Stripped areas indicate non irrigation period.

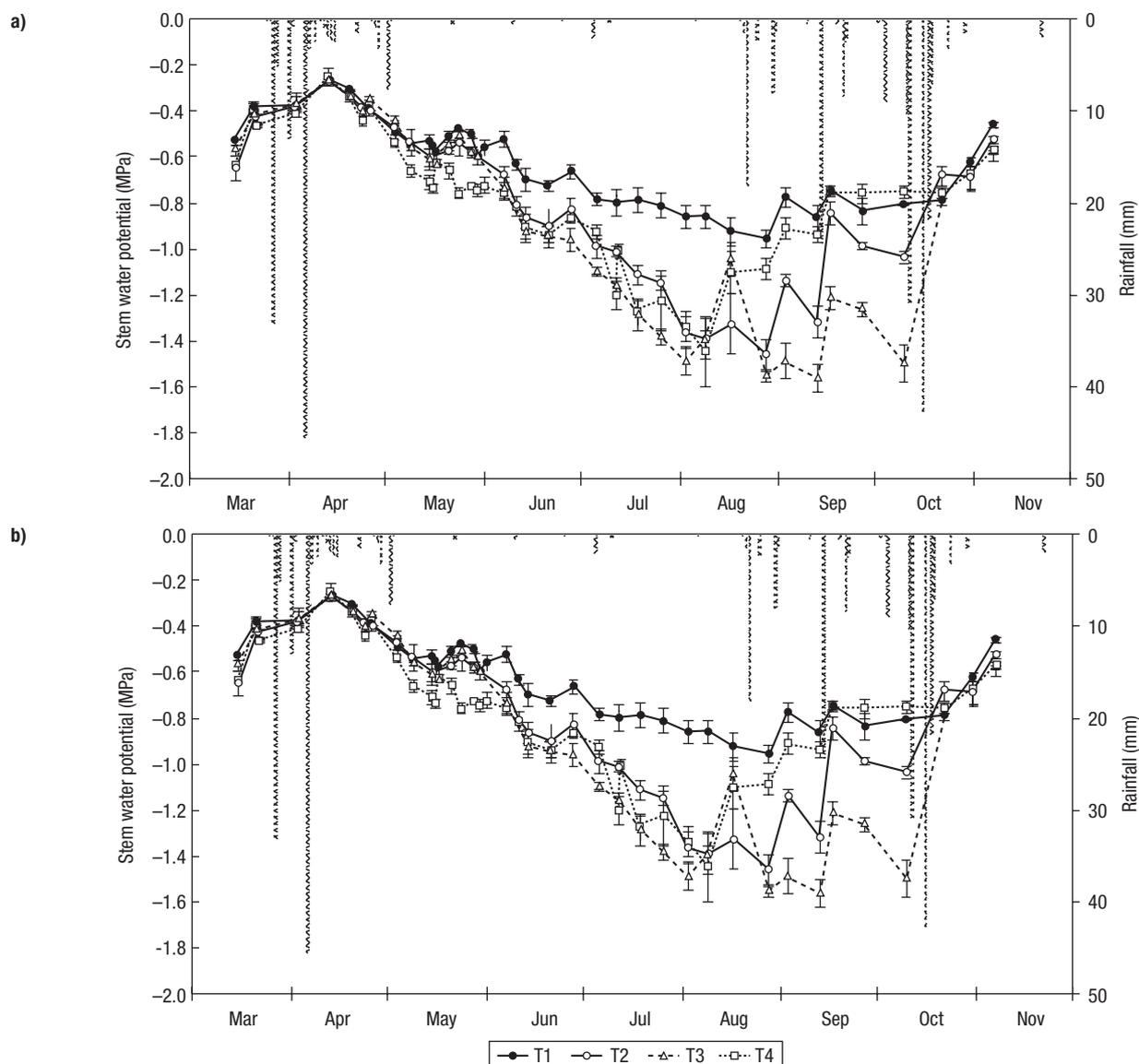


Figure 3. Stem water potential (Ψ_s) in different irrigation treatments of Flordastar peach trees and rainfall (vertical bars) during 2007 (a) and 2008 (b). Each point is the mean of 4 replications \pm standard error.

Ψ_{stem} in the SWC-based treatment was slightly lower than that of the control treatment during 2008 (Figure 3B), whereas a water deficit situation was observed at the beginning of the summer of 2007, when Ψ_{stem} decreased to -1.4 MPa (Fig. 3a).

Vegetative growth was limited by the water deficits, which affected the annual trunk growth in both growing seasons. TCSA in deficit irrigated treatments was reduced by 35% with respect to the control treatment (Table 1). Shoot elongation was affected in a lesser extent by deficit irrigation, with trees from RDI showing a slightly lower increase in annual shoot elongation values in 2007 than observed in the control treatment;

the same reduction was observed in shoots from T2 treatment in 2008 (data not shown). The winter pruning weights were statistically higher in the control treatment than in the deficit irrigated treatments (T2, T3 and T4), which showed similar values in 2007, whereas in 2008 the lowest pruning weights were recorded in both continuous and regulated deficit treatments, the SWC-based treatment showing an intermediate value (Table 1).

However, fruit diameter growth was less affected by water deficits, with similar values for all treatments in 2007 (Fig. 4a); whereas in 2008 fruits from the continuous deficit and RDI treatments showed lower fruit diameter than the control (Fig. 4b).

Table 1. Effect of different irrigation treatments on vegetative growth: trunk cross sectional area (TCSA) (cm²) and winter pruning (dry matter), on Flordastar peach trees during the experimental period

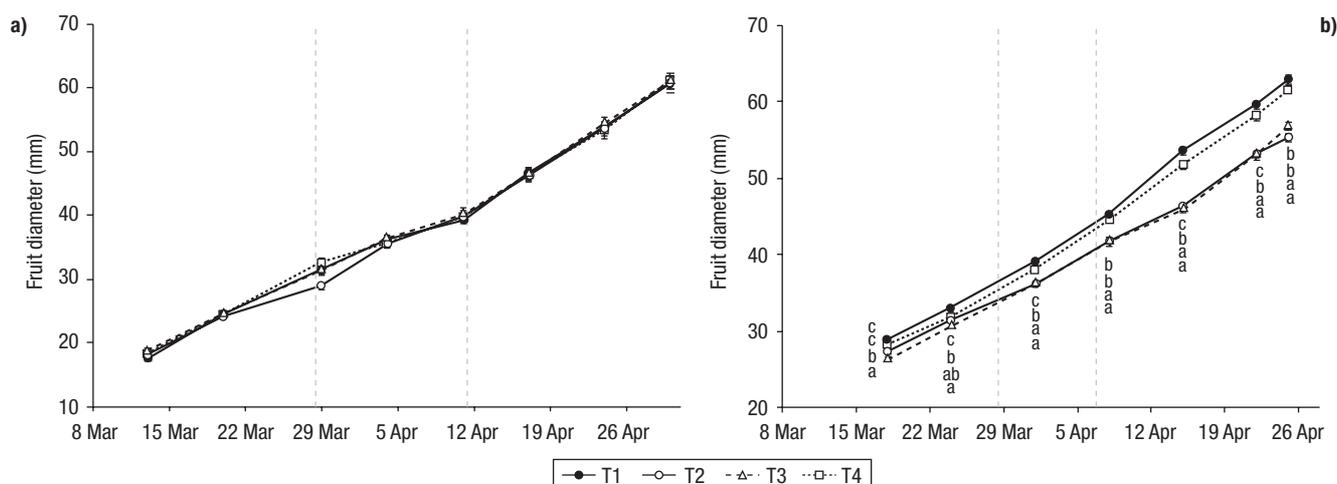
Treatment	Trunk cross sectional area (cm ²)		Pruning (kg tree ⁻¹)	
	2007	2008	2007	2008
T1 (control)	115.62 ^b	153.66 ^b	6.05 ^b	12.10 ^c
T2 (50%)	78.30 ^a	103.87 ^a	3.57 ^a	4.67 ^a
T3 (RDI) ¹	75.94 ^a	101.62 ^a	3.16 ^a	5.49 ^{ab}
T4 (soil-based)	70.77 ^a	102.52 ^a	3.31 ^a	7.19 ^b

¹ RDI: regulated deficit irrigation. Values are mean of 4 replications. Average values followed by different letters are statistically significant different according to LSD_{0.05} test.

Compared with the control, peach yield was reduced in both continuous and regulated deficit irrigation treatments during both seasons (Table 1), although to a greater extent in 2007 (around 45% reduction) than in 2008 (around 30% reduction). In the SWC-based treatment the fruit yield was significantly lower than in the control treatment in 2007, although the reduction observed (29%) was lower than that observed for both

deficit treatments, whereas similar yields were recorded in 2008 (Table 1).

Fruit size at harvest was similar in all the studied treatments in 2007 as indicated by the parallel reduction in total fruit weight per tree and number of fruits per tree in deficit treatments with respect to control treatment (Table 2). However, this variable was affected by deficit irrigation in 2008, with a statistically signi-

**Figure 4.** Fruit diameter growth (mm) in 2007 (a) and 2008 (b) in different irrigation treatments of Flordastar peach trees. Each point is the mean of 4 replications \pm standard error. Different letters indicate statistically significant different values according to LSD_{0.05} test.**Table 2.** Effect of different irrigation treatments on Flordastar peach yield (kg tree⁻¹ and number of fruits tree⁻¹) during the experimental period

Treatment	Yield (kg tree ⁻¹)		No. fruit tree ⁻¹	
	2007	2008	2007	2008
T1 (control)	24.29 ^b	50.13 ^c	213 ^b	420
T2 (50%)	14.03 ^a	33.23 ^a	116 ^a	401
T3 (RDI) ¹	13.49 ^a	35.95 ^{ab}	115 ^a	336
T4 (soil-based)	17.27 ^a	45.51 ^{bc}	142 ^a	392 ^{ns}

¹ RDI: Regulated deficit irrigation. Values are mean of 4 replications. Average values followed by different letters are statistically significant different according to LSD_{0.05} test. ns: non significant.

ficant lower individual fruit weight measured in continuous and regulated deficit irrigated trees (T2 and T3) than in control trees (Table 2).

Discussion

The seasonal values of the soil water content varied in response to the deficit irrigation applied (Fig. 1). The SWC values were proportional to the deficit irrigation applied, especially during the postharvest period, when lowest values were recorded in the more severe stressed treatment (RDI).

In the SWC-based treatment a different SWC dynamics was observed in each year, depending on the threshold used to trigger irrigation. During 2007 the SWC values followed the same trend as ET_c dynamics, whereas they remained between the thresholds imposed during 2008 (Fig. 2).

The capacitance-SWC data were closely related with the discrete measurements of SWC made using the neutron probe (Figs. 1 and 2). However, the continuous soil water content measurements using capacitance FDR-type probes allow access to data in real time (Fig. 2), so that variations can be analyzed taking into account the soil characteristics, root uptake, climatic conditions and limitations of the capacitance probe itself. These data allowed an optimal moisture range to be set for the crop, from which it was possible to precisely adjust the irrigation dose and frequency and automatic irrigation.

The rapid peach fruit growth stage is highly sensitive to water deficit, for which reason it is considered to be a critical period for most stone fruit trees, whereas stages I and II are less sensitive (Li *et al.*, 1989; Ruiz-Sánchez *et al.*, 1999; Naor *et al.*, 2001). The early maturing nature of the studied cultivar implies that water deficits applied during the non-critical periods of fruit growth coincide with low evaporative demand periods in Mediterranean climate areas, thus inducing slight to moderate plant water stress most of the time. This was the case in the experimental conditions of spring 2007, when similar Ψ_{stem} values were recorded in plants from all the treatments (Fig. 3).

Water deficit affected vegetative growth in the deficit irrigated treatments (Table 1) as follows: trunk diameter growth > winter pruning > shoot elongation. This behavior resulted in smaller trees in deficit treatments than in the control treatment (Table 1). The high sensitivity of vegetative growth to water deficit was

clear (Hsiao, 1973), as has been widely documented in peach trees in response to different irrigation deficit strategies (Johnson *et al.*, 1992; Boland *et al.*, 2000; Girona *et al.*, 2005).

Vegetative growth was lower in the SWC-based treatment than in the control; however, mention should be made of the change in the threshold in the 2007/08 growing season, which caused a lower reduction (both in trunk increase and winter pruning weights) in the last season (Table 1).

No effect of water deficit on fruit growth was observed in 2007 (Fig. 4), which can be attributed to the absence of any soil (Fig. 1) or plant (Fig. 3) water deficit situation during spring 2007 because of the rainfall which occurred; however, water deficit in 2008 was more severe than in 2007, inducing a statistically significant reduction in fruit diameter during the last stage of rapid fruit growth in both continuous and regulated deficit treatments. In the RDI treatment this effect may also have been due to the fact that, even though irrigation was reestablished to fully cover crop water requirement at stage III of fruit growth (by mid April), the harvest date was quite advanced this year (30 April) so that there was insufficient time to reach control values (Fig. 4b). This statement was supported by the slightly lower Ψ_{stem} values registered at this time in RDI treatment (−0.6 MPa), respect to the control values (−0.4 MPa) (Figure 3). So, even though the high soil water content values (≈240 mm in 0.8 m depth) in RDI treatment (Fig. 1), the delayed recovery of stem water potential induced a mild plant water deficit which caused a reduction in fruit size at harvest time.

The peach yield in 2007 was abnormally low for mature peach trees (Table 2). Indeed, the lowest yields of the last five year period was recorded in 2007 in the whole province of Murcia, although this only affected early maturing cultivars of *Prunus* sp. (peach and apricot trees) (Anuario Estadístico de la Región de Murcia, 2008). It also must be pointed out that during the postharvest period of 2006 the water deficits applied were severe and induced low stem water potential values in the deficit irrigation treatments as well as in the SWC-based treatment, with Ψ_{stem} values around −1.8 MPa (data not shown). These facts induced lower yields in 2007 in the deficit irrigated and SWC-based treatments compared with the control treatment. However, in 2008, when the irrigation protocols were adjusted to 0.9 of FC, similar peach yields were registered in the SWC-based treatment (Table 2).

If the data for fruit yield are normalized according to trunk size, non-significant differences were observed between treatments (data not shown). It should be mentioned that trees were submitted to deficit irrigation conditions (continuous and regulated) from the time the plantation was established (2002); thus, vegetative growth was clearly limited by the accumulated water deficit that resulted in smaller trees than in the control trees.

In terms of water use efficiency (defined as the ratio between yield and total irrigation applied water) it was clear that the deficit irrigation treatments were more efficient than the over-irrigated trees of the control treatment. The RDI treatment, with the greatest irrigation reduction (64 and 57% with respect to ET_c, for 2006/07 and 2007/08, respectively), were the most efficient in this respect (data not shown).

From the results obtained, it can be concluded that deficit irrigation strategies in peach trees must be adjusted to limit water deficits during the postharvest period of early maturing cultivars, which is very long in the case of 'Flordastar', if fruit yield is not to be reduced.

Irrigation scheduling based on capacitance probes has proved itself to be a useful tool for monitoring the soil water status, allowing automatic and efficient irrigation management. When the thresholds were precisely defined, an adequate plant water status was favored, slight water deficits limiting only vegetative growth while maintaining similar fruit yields.

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