Fruit yield and quality response of a late season peach orchard to different irrigation regimes in a semi-arid environment

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Abstract

Some degree of deficit irrigation is normally applied to orchards in semi arid environments in order to reduce unwanted vegetative growth and to increase water productivity. In this study the effect of three irrigation treatments on the yield and quality of the fruit production was evaluated during five consecutive years (2008-2012) in a commercial drip irrigated late season peach (*Prunus persica* (L). Batsch cv ´Calrico´) orchard. Irrigation treatments consisted in a full irrigation (FULL) with irrigation applications covering the crop water requirements, a sustained deficit irrigation during the whole irrigation season (SDI) with irrigation applications of 62.5 % of the FULL treatment and a regulated deficit irrigation (RDI) with a reduction of water applied to 50 % of the FULL treatment in the stone hardening period. The differential irrigation treatments created negligible differences in the stem water potential of the trees. Results showed that fruit production was only significantly higher in the FULL treatment than in the other two treatments in 2008 but in the rest of the years no significant differences were found between treatments. The average fruit weight was significantly smaller in the SDI treatment than in the FULL and RDI treatments. Firmness of the fruits in the SDI treatment was significantly lower than that of the FULL and RDI treatments and the total soluble solids of the SDI was significantly higher than the FULL and RDI treatments. Color parameters of the fruit skin and flesh were also affected by the irrigation treatments. The higher values of the soluble solids content (SSC) and the relation SSC/TA (total acidity) and the slight decrease in fruit diameter found in the SDI treatment suggest that irrigation water saving can be achieved without affecting the commercial profitability in the semi arid conditions of the Lower Ebro Valley in Northeast of Spain.

Keywords: drip irrigation, water deficit, trunk growth, irrigation strategies, Calanda peach, bagging

1. Introduction

In 2009 the peach and nectarine orchard area in the world was around 1.5 million ha, China is the country with the highest peach production which represents over half of the world peach production. Another important peach production area is located in southern Europe which includes the countries of Spain, France and Greece (FAO, 2011). The peach orchards in Spain covered an area of 50,000 ha in 2010 (MAGRAMA, 2011). Around 50% of the peach and nectarine orchard area is cultivated in the regions of Aragón and Cataluña in Northeast of Spain. Most of these orchards have early season cultivars in order to put the fruit production in the markets as soon as possible at the beginning of the summer season and obtain high economic profit. However in recent years the late season peach orchards which are harvested at the end of the summer and early fall are getting a higher relevance since this kind of peach characterized by its very firm flesh and sweetness is highly appreciated by the consumers. In an area of Aragón of around 5000 km^2 in the Northeast of Spain, a group of late season peach cultivars has been grown for a long time with a great acceptance by the consumers because of their excellent aspect and organoleptic characteristics. Peaches of these late season cultivars grown in this area have a unique and special denomination named “Calanda peach”. These peaches reach significant higher prices than the regular peaches and nectarines. The most important cultivars included in the “Calanda peach” denomination are ‘Jesca’, ‘Calante’ and ‘Evaisa’ (Espada et al., 1991). The fruit of these clingstone cultivars has round shape; the skin is light yellow without red spots and very low pubescence. The fruit flesh is yellow, non-melting and firm with high sugar content. Maturation is between middle of September and the beginning of November. At present new cultivars have been added to the denomination of “Calanda peach” and the demand of this type of peaches is increasing.

One of the most characteristic agronomic practices of “Calanda peach” is introducing the fruit into a paper bag during the stone hardening phase in order to protect the fruit against the Mediterranean fly (*Ceratitis capitata*), contact with pesticides, climatic incidences and other external physical damages (Sharma et al., 2014). The paper bag remains on the fruit until the harvest. The fruit acquires a homogeneous yellow color very appreciated by the consumers.

The production areas of the “Calanda peach” are semi-arid with low and irregular precipitation. Usually these orchards are located in flat areas with calcareous soils and high carbonate and gypsum content and drip irrigation is used in the modern peach orchards. Under this high frequency irrigation a high plant water status is maintained and the orchard does not suffer any water stress.

At present some problems of lack of quality in the “Calanda peach” have been reported. The farmers consider that this lack of quality can be due to inadequate agronomic practices such as excessive irrigation and nitrogen application and imbalance of nutrients in the fertilization. One of the most important problems that has been identified in peaches and other deciduous fruits is the appearance of the vitrescent dark spot. This physiological disorder affect the flesh of the peach and it is not visible in the fruit skin. According to the findings of Fernandez et al. (2009) this disorder seems to be related to calcium (Ca)-nutrition imbalances.

Different irrigation strategies and agronomic practices can be used to optimize the yield and quality of peach fruit production. Reviews of literature have shown that reducing the irrigation applications below the crop water requirement can be an useful tool to reduce unwanted vegetative growth, improve fruit quality and increase water productivity in orchards (Fereres and Soriano, 2007; Geerts and Raes, 2009; Ruiz-Sanchez et al., 2010). These reductions can be applied during the crop cycle (i.e. sustained deficit irrigation, SDI) or they can be applied in specific phenological phases where the deficit irrigation does not affect the fruit production (i.e. regulated deficit irrigation, RDI). The response of fruit orchards to different deficit irrigation strategies has been widely studied in many fruit species and areas of the World (Girona et al., 2003; Lopez et al., 2008; Moriana et al., 2003; Ruíz-Sanchez et al., 2010; Ramos and Santos, 2010). Different studies have showed that RDI saves irrigation water, increases water use efficiency and reduces tree vigor while the fruit yield remains constant or even increases (Chalmers et al., 1981; Boland et al., 2000; Geerts and Raes, 2009). Normally the RDI in peach orchard is applied in the stone hardening phase of the fruit development. In this phase the growth of the fruit is very slow and the shoots grow very fast. Most RDI studies have been made in early peach cultivars (Mounzer et al., 2008; Gelly et al., 2004) and very few results are available for late season peach cultivars.

The need to increase the water use efficiency in the irrigated areas of Spain and the vulnerability of the peach fruit quality to irrigation has moved the authors to study the effect of different irrigation regimes in the yield and quality of a late season peach orchard. Therefore the aim of the study is to ascertain the effect of different irrigation strategies including full irrigation (FULL), a sustained deficit irrigation during the whole irrigation season (SDI) and a regulated deficit irrigation (RDI) with a reduction of irrigation during the stone hardening period on the fruit production and quality of a late season peach orchard in northeast of Spain.

2. Material and methods

2.1. Experimental orchard

The experiment was started in 2008 in a 3-year old late season peach cultivar (*Prunus persica* (L.) Batsch cv ´Calrico´) drip irrigated orchard located in the AFRUCCAS experimental farm in the county of Caspe in northeast of Spain (41.16°N, 0.01°W). The experiment was conducted from 2008 to 2012. The cultivar Calrico, included in the Calanda peach denomination, was grafted on GF-677 rootstock (*Prunus amygdalus x*

Prunus persica). This rootstock is tolerant to Fe deficiency; it is well adapted to calcareous and arid soils but is sensitive to anaerobic conditions in the roots. The trees in the experimental orchard were planted at a spacing of 6 m by 2 m and pruned in Y formation system with two main branches starting at around 0.5 m from the soil surface. The soil of the plot has an average depth of 1.5 m and is a sandy-loam soil. It is classified as calcic haploxerept, fine loamy, mixed, thermic (Soil Survey Staff, 2006). The gravimetric average soil field capacity and permanent wilting percentage are 21 % and 12 %, respectively. Soil bulk density is 1600 Mg m^{-3}.

The peach orchard was managed according to the normal cultural practices in the region: Irrigations were applied daily with an automated drip system with two laterals per tree row located at 0.5 m from the rows with 1 m spaced self compensating emitters of 2, 3 and 4 L h^{-1}, depending on irrigation treatment. With this drip laterals disposition, each tree was in the center of 1 m square where the four emitters located in the corners. Irrigation water is pumped directly from the Mequinenza reservoir in the Ebro River. The average value of the electrical conductivity of the irrigation water (EC_w) during the five study years was 1.1 dS m^{-1}. In general the EC_w was low at the beginning of the irrigation season with values around 0.7 dS m^{-1} and increased to about 1.6 dS m^{-1} by the end of the irrigation season with the exception of year 2012 where EC_w remained below 1.2 dS m^{-1} throughout the season. According to Ayers and Westcot (1985) the quality of the irrigation water does not affect the production of a peach orchard with a high-frequency drip irrigation system.

Soluble fertilizers were applied with the drip irrigation system along the irrigation season. The seasonal fertilizer amounts per year included 87 kg ha^{-1} of N, 47 kg ha^{-1} of P_2O_5 and 120 kg ha^{-1} of K_2O.

Fruits were thinned in early June to a target crop load of about 140 fruits per tree and then the fruits were covered with individual paper bags. Each tree of the experimental units was harvested individually in two harvesting events performed during the month of September.

2.2. Experimental design

The experiment design was a complete randomized block with five replicates and three differential irrigation treatments: 1) control or fully irrigated treatment (FULL) with 100% of the Gross Irrigation Requirements (I) estimated by the own farmer according to the irrigation recommendations from the Irrigation Advisory System of Aragón (http://servicios.aragon.es/oresa/) for the experimental orchard in the county of Caspe. This irrigation advisory system uses the FAO methodology (Allen et al., 1998) with data of agrometeorological stations of the SIAR network (National Network of Agrometeorological Stations for Irrigation of the Ministry of Agriculture, Food and Environment of Spain, http:www.magrama.gob.es/es/); 2) sustained deficit irrigation (SDI) with the irrigation application reduced to 62.5 % of the FULL treatment throughout the irrigation season; and 3) regulated deficit irrigation (RDI) with the same irrigation applications as the FULL treatment except in the stone hardening phase of fruit development, when the trees were irrigated at 50 % of the FULL treatment. The length of the stone hardening phase was around one month and started by early or mid May, depending on the specific year. Each block consisted of a row of 35 trees. The experimental unit consisted in a row of 7 trees.

In the FULL treatment each tree was irrigated with four emitters of 4 L h^{-1}. In the SDI treatment two emitters of 3 L h^{-1} and two of 2 L h^{-1} were used along all the irrigation season and in the RDI treatment the 4 L h^{-1} emitters were removed and substituted by emitters of 2 L h^{-1} during the stone hardening phase. Irrigations were applied daily and the three treatments were irrigated simultaneously and with the same duration. Irrigation season started in late March or early April and finished by late September or early October depending on the specific year.

2.3. Measurements

Water applications were measured with volumetric water meters installed in June of 2008 in each drip line in the three irrigation treatments. Samples of irrigation water were taken to determine its electrical conductivity (EC).

Disturbed soil samples in the 0-60 cm soil layer were taken in April and September with a 6 cm diameter soil auger near a tree in the different irrigation treatments from 2009 to 2012. Samples were taken in two positions: one adjacent to the emitter (0 cm) and the other one at 25 cm from the emitter between the emitter lateral and the tree row (25 cm). For each position, sub-samples were taken in both sides of the tree row and the two sub-samples of each position were mixed together to get one single sample at 0 cm and another sample at 25 cm from the emitter. The auger holes were refilled with soil after each sampling. The soil samples were weighed and oven dried and weighed again to determine its gravimetric water content (GWC) in the laboratory. A total of 120 soil samples were analyzed every year (10 trees treatment^{-1} x 3 treatments x 2 positions x 2 dates of sampling).

Daily meteorological data was collected in the nearby automated agrometeorological station “El Suelto-Plano Espés” of the SIAR network. The station is located in Caspe County at UTM coordinates: UTMX 745309, UTMY 4576848 (41.19ºN, 0.05ºW) and altitude of 150 m. This station stores data on air temperature, air relative humidity, wind speed and direction, solar radiation and precipitation every 30 minutes. The daily meteorological data was used to estimate daily values of the reference evapotranspiration (ET_o) computed using the FAO Penman-Monteith (Allen et al., 1998).

In addition, the average ET_c of the experimental peach orchard was also estimated using the daily values of ET_o and the crop coefficient (K_c) derived from the relation found by Ayars et al. (2003).

$$K_c = 1.59 \, IPAR + 0.082 \quad (1)$$

where IPAR is the fraction of the intercepted photosynthetic active radiation.

Ayars et al. (2003) developed K_c values for late season peach orchards in California. Since no K_c curves were available specifically developed for the experimental peach orchard, the K_c obtained with the equation (1) was used because the general climatic conditions of the experimental area (low rainfall, hot summer and mild winter) are relatively similar to those found in the California area where Ayars et al. (2003) developed their K_c equation.

The IPAR was measured at weekly intervals in the experimental peach orchard with a ceptometer (SunScan Canopy Analysis System, SS1 type, Delta-T Devices Ltd., Cambridge, England) in 2010 and 2011. In each measurement of IPAR the ceptometer was located in 18 positions in the spacing of a tree (6 m x 2 m) in one tree per irrigation treatment. Once full cover was reached measurements were made monthly. Average curves of IPAR were adjusted to the experimental data by regression analysis in both years. These equations were used to calculate the K_c with equation (1) and the monthly values of the average ET_c in the experimental peach orchard in the different years. In the years where IPAR was not measured, the K_c curves were determined by adapting the average K_c curves of 2010 and 2011 to the phenology of the specific year. The K_c curve of 2010 was used in years 2008 and 2009 and the K_c curve of 2011 was used to estimate it in 2012. An average value of the Kc of 0.15 was used for the period between the complete leaf fall in late autumn and the starting of leaf emergence in spring.

Midday stem water potential (ψ_{stem}) of the trees was measured with a portable pressure chamber (model 3005 Soil Moisture Equipment Corporation, Santa Bárbara, CA, USA) in exposed developed leaves in the different treatments. The measured leaves were covered with aluminum foil around twenty minutes before measuring to equilibrate the leaf water potential to the stem water potential.

The initial trunk cross sectional area (TCSA, cm^2) was calculated from the perimeter values measured at 30 cm above the soil surface at the beginning and end of each growing season from 2008 to 2012. The TCSA was calculated assuming a circular cross sectional area of the trunk. The relative growth of the trunk cross sectional area (RGTCSA) was calculated using the following equation:

$$RGTCSA_i = (TCSA_f - TCSA_i) / TCSA_i \quad (2)$$

where the subindeces f and i represent the final and initial measurements made in October and March, respectively of every year.

Phenology by visual observation (Mounzer et al., 2008) was determined by frequent visits to the experimental orchard.

The fruits of each tree of the different irrigation treatments were individually harvested. All the fruits of each tree were weighed and the number of fruits was counted. The average weight of the fruit was determined from these data in each tree.

The fruit yield productivity (FYP) of each tree was calculated as the fruit yield divided by the initial trunk cross-sectional area (kg cm^{-2}) in the different irrigation treatments. Productivity of irrigation water (PIW) in the different irrigation treatments was calculated as the fruit yield divided by the irrigation depth (kg ha^{-1} mm^{-1}).

A subsample of 10 fruits per tree was processed in the laboratory to control the quality parameters; fruit weight, equatorial perimeter, skin color, firmness, flesh color, total soluble solids content and total acidity. The measurement of weight, equatorial perimeter and skin color of the fruit is non-destructive whereas flesh color and firmness were measured after removing approximately a 2.5 cm diameter slice of peel with a standard peeler on the two opposite sides of each fruit. Rest of fruit quality measures, were obtained from the sample flesh juice.

Fruit weight and equatorial perimeter were measured to assess the fruit size. Fruit diameter was deduced from equatorial perimeter measurements. Flesh firmness in kg/0.5 cm^2 was determined using a penetrometer equipped with 8 mm diameter plunger (0.5 cm^2). (Penefel, Setop Giraud –Technologie, 84300 Cauvaillon, France).

Fruit skin and flesh color was measured with a Minolta Chroma Meter CR-200 portable tristimulus colorimeter (Minolta Corp, Osaka, Japan) using CIE illuminant D65 and 8 mm measuring aperture diameter. Values were recorded in Commission Internationale d'Eclairiage (CIE) color space coordinates, defined by lightness (L*), range from red to green (a*), and range from yellow to blue (b*). The colorimeter was standardized by using the Minolta calibration plate CR.A43 before each measurement date. Color values for each fruit were computed as means of 2 measurements taken from opposite sides at the equatorial region of the fruit (Abbott, 1999). Flesh a* score has been reported to be a useful index for fruit maturity (Fuleki and Cook, 1976), however, a* scores may be too variable, and values of a* and b* should not be used alone because they are not independent variables (Francis, 1980) and because they are difficult to interpret. As a consequence, we calculated the chroma value (C*) by the expression [(a*2 + b*2)1/2] related with the brightness and color saturation and the hue angle (h*), the numerical value for color, as [tan-1 (b/a)]. Hue angle quantifies color, where 0º=red/purple, 90º= yellow and 180 =bluish/green (McGuire, 1992).

Representative juices of the different peach samples were obtained with a kitchen juicer, cleaning the appliance between samples. Juices were homogenized and clarified through the use of paper filters, retaining flesh particles bigger than 25 µm (CHM® Hardened Low Ash Filter F2054, Barcelona, Spain). Total soluble solids content (SSC) of the juices in ºBrix was assessed using a digital hand refractometer (PAL-1, Atago Co. Ltd., Tokyo, Japan), the total acidity (TA) expressed in meq/100 ml, and the pH were measured by automatic titration of 50 mL of juice with 0.1N NaOH solution (785 DMP Titrino, Metrohm AG, Herisau, Switzerland). The sugar-to-acid ratio (SSC/TA) was calculated from recorded data to assess the influence of the different irrigation strategies in this maturity index. SSC/TA is the fruit quality parameter that is ultimately most closely related with consumer acceptance of peaches (Crisosto et al., 2006).

2.4. Statistical analyses

Statistical analyses were performed using Analysis of Variance (ANOVA) and General Linear Model (GLM) procedure of the SAS 9.1 software (SAS Institute, 2004). Multiple comparisons among treatments were performed using Duncan test at *P* = 0.05.

3. Results

3.1. Meteorological variables, crop evapotranspiration (ETc) and irrigation (I)

Figure 1 presents the average monthly values of precipitation, air temperature, relative humidity and wind velocity recorded in the automated agrometeorological station “El Suelto-Plano Espés” during the five studied years. The rainfall distribution along the year differed between years but minimum values occurred in the summer months and maximum in the spring months. Average annual precipitation for the period 2008-2012 was 318 mm and ranged between 277 mm in 2009 and 355 mm in 2008.

Temperature regimes were very similar in the five study years. The average annual mean temperature (T_{mean}) for the period 2008-2012 was 15.4 ºC. Maximum monthly values of T_{mean} occurred in the months of July and August in all experimental years. The evolution of the air relative humidity was also very similar in the five studied years. The average annual relative humidity for the period 2008-2012 was 63 %. Minimum monthly values of the air relative humidity occurred in the summer months. An increase of the monthly values of air relative humidity was observed in the months of May 2008, April 2009, March 2011 and April 2012 corresponding with high precipitation values in these months. The evolution of the wind velocity showed that the monthly values were above 1.8 m s^{-1} along the five studied years and the average value was 2.7 m s^{-1}. In March 2008 and February and April of 2012 the monthly values of wind velocity reached values higher than 3.5 m s^{-1}.

The annual values of reference evapotranspiration (ET_0) were very similar during the five studied years (Figure 1). The average value for the period 2008-2012 was 1452 mm $year^{-1}$, ranging between 1369 mm in 2008 to 1538 mm in 2012. The maximum monthly values of ET_0 occurred in July with an average value for the 2008-2012 period of 239 mm $month^{-1}$.

Figure 2 presents the evolution of the IPAR in the in the three irrigation treatments of the experimental peach orchard during 2010 and 2011. In 2010 the evolution was similar in the three treatments until the middle of July. The maximum values were reached in the FULL and RDI treatments with values around 0.5 while the maximum values in the SDI were 0.4. In 2011 the maximum values of the IPAR were equal in the three treatments (around 0.6) but the IPAR of the SDI treatment was below the FULL and RDI treatments during most of the crop cycle. A quadratic polynomial equation fit the experimental data of all treatments in both years with high values of the determination coefficients (R^2 = 0.93 in 2010 and R^2 = 0.87 in 2011).

The seasonal values of the calculated peach orchard evapotranspiration (ET_c) using the Ayars et al. (2003) approach varied between 823 mm in 2008 to 1056 mm in 2012. The average value of ET_c for the period 2008-2012 was 933 mm $year^{-1}$. For the studied period the average monthly value of ET_c was maximum in July (194 mm) and minimum in the winter months (Figure 1). These ET_c values resulted very similar to the ET_c values provided by the Irrigation Advisory System of Aragón (data not presented).

The average seasonal depth of water applied in the 2009-2012 period was 712 mm, 430 mm and 658 mm in the FULL, SDI and RDI treatments, respectively. In 2008 the total irrigation water applied could not be calculated since the water meters were installed at the end of June of that year. The average difference between the seasonal water applied in the FULL and RDI treatment from 2009 until 2012 was only 54 mm. However the average difference of the seasonal water applied between the FULL and SDI treatments was much higher with an average value of 282 mm. For a more detailed analysis of the water applied in the three irrigation treatments, three periods were considered: 1) from blooming until the beginning of stone hardening (P1), during the stone hardening period (P2) and from the end of the stone hardening phase until the end of the irrigation season of the peach orchard (P3) (Table 1). Very slight differences in the depths of water applied were found between treatments FULL and RDI in the periods P1 and P3 that were due to the variability in the water meter readings. These differences were in all cases lower than 4 %. In the SDI treatment the depth of water applied in the P2 period was 61 % of that of the FULL treatment (Table 1). Seasonal irrigation in all treatments in 2009 was lower than the rest of the years. This was due to the lower development of the trees in the first two years.

The soil sampling performed from 2010 to 2012, showed that the average gravimetric soil water content (GWC) in the root zone of the trees (average values of soil samplings in April and September at the emitter position, at 25 cm of the emitter and for the average of both positions) was significantly higher in the FULL and RDI treatments than in the SDI treatment with values in the FULL and RDI treatments even higher than field capacity (21 %) in 2010 and 2011. The high values of GWC in 2011 were due to the high rainfall during the irrigation season. No significant differences in the GWC were observed between treatments in 2009. In all cases the GWC at the emitter position was higher than at 25 cm from the emitter. For the period 2009-2012, the average GWC was also significantly higher in the FULL and RDI treatments than in the SDI treatment s with average values considering both positions in the FULL, SDI and RDI treatments of 20.7 %, 17.9 % and 20.6 %, respectively (Table 2). These results showed that GWC was clearly reduced by the irrigation regime in the SDI treatment.

3.2. Tree growth, stem water potential and fruit production

Table 3 presents the initial dates of the different phenolological phases of the experimental peach orchard in the different studied years. A later emergence of leaves in years 2010, 2011 y 2012 created a delay in the beginning of the stone hardening phase. This phase lasted around 30 days in the five studied years. The initial date of harvest was affected by the meteorological conditions of the different years and varied between 2 September in 2011 and 24 September in 2008.

Figure 3 presents the evolution of the midday stem water potential (ψ_{stem}) in 2009 to 2011. The values of ψ_{stem} showed a similar behavior during the three years of measurements. Differences in ψ_{stem} were low between irrigation treatments and different years. In most measurements for the different treatments and years, ψ_{stem} was higher than -1.2 MPa indicating very low water stress in all irrigation treatments (Goldhamer et al., 1999; Girona et al., 2006). In 2009 the lowest values of ψ_{stem} (-1.3 MPa) were reached in the RDI and SDI treatments at the beginning of June. In 2010 and 2011 the lowest values of ψ_{stem} were reached in the SDI treatment but with values higher than -1.2 MPa. The lowest values of ψ_{stem} were reached at the end of July in 2010 and 2011 (-1.1 MPa). Rainfall events before the dates of ψ_{stem} measurements affected the ψ_{stem} values. For instance the higher ψ_{stem} values in all treatments in 2011 were probably due to the higher rainfall during the irrigation season in that year.

No significant differences between the three irrigation treatments were observed in the initial values of the peach trunk cross sectional area (TCSA) in the five studied years (Table 4). The initial average value of the TCSA of the trees was 49 cm^2 in 2008 and double in 2012 (98 cm^2). However significant differences were found in the relative growth of the trunk cross sectional area (RGTCSA) in 2008, 2009 and for the five years 2008-2012. The SDI treatment had a significantly lower value of RGTCSA than the FULL and RDI treatments. For the five years period the RGTCSA increased by 98 % in the SDI treatment while the increase in the FULL and RDI treatments were 119 and 127 %, respectively (Table 4). In 2010, 2011 and 2012 no significant effect of the irrigation treatments was found in the RGTCSA values.

Significant effect of the irrigation treatments in the fruit production (kg $tree^{-1}$) was found only in 2008. The fruit production was significantly higher in the FULL treatment (31 kg $tree^{-1}$) than in the SDI (23 kg $tree^{-1}$) and RDI (26 kg $tree^{-1}$) treatments. The rest of the years there were not significant differences in the fruit production between treatments. For the whole studied period (2008-2012) no significant differences between treatments (126 kg $tree^{-1}$ in the FULL treatment, 120 kg $tree^{-1}$ in the SDI treatment and 130 kg $tree^{-1}$ in the RDI treatment) were found for the cumulative production (Table 5). However significant differences between treatments in the average weight of the fruit were found in 2008, 2009 and 2012. In these three years the average weight of the fruit of the SDI treatment was significantly lower than that of the FULL and RDI treatments. In 2010 and 2011 no significant differences were found between treatments. For the whole studied period (2008-2012), the average weight of the fruit of the SDI (180 g) was significantly lower than that of the FULL (196 g) and RDI (194 g) treatments. The reduction in the fruit weight implies a decrease in the commercial value of the fruit. However the average reduction in the whole period of the SDI treatment in relation to the FULL treatment was only of 16 g.

The lowest values of the average fruit weight were obtained in the SDI treatment in 2009 (164 g) and 2012 (167 g).

The fruit yield productivity (FYP) expressed as the fruit production per unit of initial trunk cross sectional area ($TCSA_i$) was affected by the irrigation treatments only in 2008. The FYP was significantly lower in the SDI treatment (0.47 kg cm^{-2}) than in the FULL (0.66 kg cm^{-2}) and the RDI (0.61 kg cm^{-2}) treatments. For the rest of the experimental years and for the whole studied period (2008-2012) no significant differences in the FYP were found between treatments. The average value of FYP for the whole studied period and treatments was 0.38 kg cm^{-2} and year.

The productivity of irrigation water (PIW) of the SDI treatment was significantly higher than in the FULL and RDI treatments in 2009, 2011 and 2012. In these three years no significant differences were observed in the PIW between the FULL and RDI treatments (Table 5). For the period 2009-2012 the PIW of the SDI treatment (46 kg ha^{-1} mm^{-1}) was significantly higher than the FULL (29 kg ha^{-1} mm^{-1}) and RDI (32 kg ha^{-1} mm^{-1}).

3.3. Fruit quality

Tables 6 and 7 present the results of the quality parameters measured in samples of 10 fruits from each tree in the different irrigation treatments in the harvest of 2008, 2009, 2010 and 2012. Significant differences between treatments in the diameter of the fruit were found in all years. The diameter of the fruit in the SDI treatment was significantly lower than the FULL treatment in all years. No significant differences were found between the FULL and RDI treatments in all years except in 2012. For the four years the average diameter of the SDI treatment (71 mm) was significantly lower than that of the FULL (74 mm) and RDI (73 mm) treatments. These results are in total agreement with the values of the average weight of the fruit obtained in the harvest by dividing the total weight of the fruits by the number of fruits in each tree (Table 5).

The average values of firmness of the fruit flesh in all treatments and years varied between 3.3 and 3.9 kg/0.5 cm^2. The firmness of the SDI treatment in 2008 was significantly lower than that of the FULL and RDI treatments and no significant differences between treatments were observed in 2009 and 2010. For the period 2008-2010 the average value of the firmness in treatment SDI (3.5 kg/0.5 cm^2) was significantly lower than that of the FULL and RDI treatments (3.7 kg/0.5 cm^2).

Statistical differences between treatments were found in the total soluble solids content (SSC) in 2008, 2009 and 2010. In 2008 and 2009 the SSC in the SDI treatment was significantly higher than in the FULL and RDI treatments. For the whole studied period the average value of the SSC of the SDI treatment (14.9 ºBrix) was significantly higher than that of the FULL (13.9 ºBrix) and RDI (14.2 ºBrix) treatments. The higher SSC average contents were recorded during 2008 and 2009, and the lower during 2010.

No significant differences between treatments were found in the pH and acidity of the peach juice in all the years. The pH values in the different treatments and years ranged between 3.7 and 4.1 and the total acidity (TA) ranged between 6.1 and 7.1 meq/100ml of juice. Average acidities scored during 2008 were statistically higher than during the other years.

The statistical differences between treatments found in the SSC/TA maturity ratio, related with the gustative fruit quality, were similar to those obtained in the SSC analysis. The SSC/TA ratio obtained in the SDI treatment was generally higher than in the FULL and RDI treatments as is showed for the whole studied period (2008-2012) statistical analysis. As a whole, the higher ratios were measured in 2009, and the lowest in 2010.

A significant effect of the irrigation treatments in the CIELab color parameters of the peach fruit skin was observed. The color lightness (L*) of the SDI treatment was significantly higher than that of the FULL and RDI treatments in the year 2008, and for the whole data of the three years, but not differences were observed for 2010 and 2012. The chroma value (C*) of the fruit skin, parameter related with the brightness, was slightly higher in the SDI treatment than in the FULL and RDI treatments for the whole data of the three years. Similar results were found with the hue angle (h*) of the fruit skin, where the SDI treatment showed higher values than the FULL and RDI treatments for the whole data set of the three years. These differences in the three color parameters of the fruit skin for the whole studied period have been caused mainly for the data of 2008 since no statistical differences were observed in 2010 and only statistical difference in the C* was observed in 2012. The fruit skin of the SDI treatment had slightly higher lightness, brightness and closer to the yellow color than the other treatments.

The fruit flesh color parameters were evaluated only in 2010 and 2012. As it was expected, variability of flesh color parameters was lower than in skin. Very similar values were observed in the L* parameter ranging between 70 and 73. Although, lightness in RDI for the whole set of data was statistically higher than in the other two treatments. This trend was not consistent for 2012 where RDI and SDI treatments showed similar L* values but lower than the FULL treatment. The color brightness (C*) of the fruit flesh was similar in all treatments for all the years and for the whole studied period. On the other hand, the flesh hue angle (h*) value of the SDI treatment for the whole studied period was statistically higher than the FULL and RDI treatments, without differences between them. This general trend was observed for 2010 but not for 2012, where hue value was higher in the FULL treatment than in the other two treatments, which showed similar flesh hue values. In general, the flesh color of the fruits of the SDI treatment showed a color closer to yellow than the fruits of the other treatments.

4. Discussion and conclusions

The results showed that the lower amount of irrigation water applied in the SDI treatment significantly affected the average values of the soil gravimetric water content (GWC) in the area wetted by the emitters. However the small difference in irrigation water applied between the FULL and RDI treatments did not affect the values of the soil GWC. It is important to indicate that the GWC in all treatments was also affected by the different seasonal rainfall values during the irrigation season in the different years. The highest values of GWC in the three treatments were observed in 2011 that had the maximum seasonal rainfall value. The results of the ψ_{stem} showed that the differential irrigation treatments did not create high differences in water stress in the trees since ψ_{stem} was maintained above -1.2 MPa in the three irrigation treatments during most of the three irrigation seasons (Goldhamer et al., 1999; Girona et al., 2006). Probably rainfall events before the dates of ψ_{stem} measurements contributed to the lack of differences between treatments. In 2010 and 2011 the FULL treatment maintained ψ_{stem} values higher than -1.0 MPa. Vera et al. (2013) found in an early-maturing peach orchard that the average ψ_{stem} in summer should be maintained above -0.9 MPa to maintain yields.

The fruit production was only reduced significantly in the SDI and RDI treatments in 2008 but no significant differences were found between treatments in the rest of the experimental years or in the cumulative fruit production during the five experimental years. Probably the amount of irrigation water applied in 2008 was lower than in the other experimental years. Unfortunately the irrigation doses were only measured in the phase from the end of the stone hardening phase until the end of the irrigation season in 2008 and this irrigation dose in the FULL, SDI and RDI treatments was lower than in the other experimental years. The water shortage in the SDI treatment did not affect clearly the fruit yield probably because of a higher water extraction from the soil or an overestimation of the peach orchard evapotranspiration that caused an overestimation of the peach orchard irrigation needs. A more reliable determination of the orchard water requirements is of paramount relevance to optimize irrigation scheduling in late season peach orchards and more research is needed in the subject. The irrigation treatments did not affect the average trunk cross sectional area (TCSA) of the trees or the productivity expressed in fruit production per unit of TCSA. Recently, Perez-Pastor et al. (2014) studied continuous regulated deficit irrigation in apricot and they found that the TCSA was significantly reduced only under severe water deficit conditions. Probably the lack of significant differences in the TCSA in our experiment was due to lower water deficit than that of Perez-Pastor et al. (2014).

Fruit quality was affected by the different irrigation treatments. The average fruit weight in the SDI treatment was significantly lower than in the FULL and RDI treatments. These results were confirmed with the fruit diameter data. For the whole studied period (2008-2012), the average fruit diameter of the SDI treatment was significantly lower than that of the FULL and RDI treatments. For 2008-2012 the total soluble solids of the fruit in the SDI treatment was significantly higher than that of the FULL and RDI treatments. The pH and acidity of the fruit juice were not affected by the irrigation treatments. As a consequence, the SSC/TA ratio in the SDI treatment was significantly higher than in the FULL and RDI treatments, showing a slight better gustative quality and presumably a better consumer acceptance. For 2008-2012 the average value of the firmness of the fruit flesh in the SDI treatment (3.5 kg /0.5 cm^2) was significantly lower than in the FULL and RDI treatments. These appreciations are in general accordance with previous studies (Crisosto et al., 1994; Crisosto et al., 1997; Layne and Tan, 1984; Johnson and Jaine, 2000). These authors indicated that different irrigation regimes did not cause alteration in the yield, flesh firmness, acidity and pH whereas water stress caused a decrease in the average fruit size and an increase in SSC.

In the present study a significant effect of the irrigation treatments in the CIELab L*, C*, and h* color parameters of the peach fruit skin and flesh was observed. Delwiche et al. (1987) found that during the fruit maturity, the peach skin and flesh become darker, decreasing the L* value and the greenness, due to a decrease of the chlorophyll content and increasing the a* coordinate as maturity progress, but the b* coordinate, remains approximately constant. Fruits of the experimental orchard cv. "Calrico" and the other "Calanda peach" cultivars are grown inside special paper bags primarily to prevent the production damages caused by insects. However it was observed that the use of the bagging operation improved also the fruit appearance and decrease the pre-maturation fruit drop. Fruit bagging prevented the anthocyanin coloration of skin cells, produced in the portion of the fruit highly exposed to sunlight. As a consequence the "Calanda peach" varieties usually have fruits with uniform external light yellow color without any red blush in the fruit skin. In general the red blush in the peach skin is a distinctive sign that makes the fruit attractive to the consumer but this is not the case with the Calanda peach. The uniform fruit skin yellow color without any red blush is a very important characteristic for consumer quality perception of the Calanda peach. Jia et al. (2005) studied skin coloration in peach fruits bagged with paper of different sunlight transmission. They found that fruit weight, soluble solids content and total acidity were not affected by bagging treatments. However the area and intensity of the red color in the skin increased with increasing sunlight transmission. The non-bagged fruit accumulated the largest amount of anthocyanin, whereas the bagged fruit had the smallest amount of anthocyanin. In our experiment we observed that the skin fruit color of the SDI treatment had slightly higher lightness (L*), brightness (C*) and color hue value (h*) closer to yellow color than in the other treatments. Also the hue value (h*) of the flesh fruit color in the SDI treatment was significantly higher than in the FULL and RDI treatments. These results could indicate a slight advance in maturation in the SDI treatment in relation to the other two irrigation treatments, in spite of the higher SSC content and the lower firmness in the fruits of this treatment. The fact that the SDI treatment showed higher SSC content and lower firmness could also indicate an early fruit maturity in this treatment because all treatments were harvested in the same dates. However, the decrease in acidity linked to the earlier maturity was not observed in the SDI treatment. The color coordinates of the fruit skin of the SDI treatment showed a higher lightness, brightness and color closer to yellow than that of the other treatments and as a consequence, a more attractive external presence. Li et al. (2006) found that un-bagged peach fruit skin at maturation had higher L* and smaller h* as compared bagged fruit. They also found that flesh firmness of un-bagged fruit was higher than that of bagged fruit. Flesh firmness is considered a good indicator to predict the loss of fruit weight during postharvest handling, fruit potential storage and market life (Li et al. 2006). Therefore high firmness at harvest time is also an essential fruit characteristic in this type of fruits since an excellent external presence and fruit organoleptic quality are expected by ‘Calanda peach´s consumers.

In summary the results for the whole studied period showed that differences in fruit yield and quality production between the RDI and FULL irrigation treatments were insignificant. However the SDI treatment showed significant decreases of the average fruit weight, diameter and firmness and significant increases of the SSC and the ratio SSC/TA in relation to the FULL and RDI treatments. According to the findings of Berman and DeJong (1996), water stress in orchards with moderate fruit load, of cv. “Calrico” and other “Calanda peach” cultivars reduce the fruit fresh weight but not the dry weight. Also an increase in fruit sugar concentration was found in the SDI treatment of our experiment that has generally been associated with a decrease of the fruit water content (Crisosto et al., 1994). These results suggest that irrigation water in the late season peach orchards in areas of Northeast of Spain can be reduced significantly if a small reduction in fruit size is allowed without negative effects in the rest of fruit quality parameters, even it is possible to obtain a higher consumer acceptance due to the increase of gustative quality due to the increase of SSC and the ratio SSC/TA caused by a moderate water stress. Unfortunately, the water stress produced by the SDI treatment penalizes the fruit diameter, an attribute which defines the market prize and which is very appreciated by the “Calanda peach” consumers.

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Table 1. Irrigation water applied (mm) and precipitation (Prec, mm) in FULL, SDI and RDI treatments in the experimental peach orchard from blooming until the beginning of pit hardening (P1), during the stone hardening period (P2), from the end of the stone hardening phase until the end of the irrigation season (P3) and seasonal (Total) in 2008-2012.

		(mm)			
Year	Treatment	P1	P2	P3	Total
2008	FULL			293	
	SDI			156	
	RDI			255	
	Prec	28	105	148	281
2009	FULL	50	47	446	543
	SDI	27	26	252	305
	RDI	48	25	444	516
	Prec	80	14	67	161
2010	FULL	76	86	573	734
	SDI	49	57	382	489
	RDI	73	48	561	682
	Prec	79	30	58	167
2011	FULL	110	82	548	740
	SDI	67	47	314	429
	RDI	107	43	526	675
	Prec	171	57	23	251
2012	FULL	150	103	578	831
	SDI	94	64	341	499
	RDI	146	52	561	759
	Prec	75	18	72	165
2009-2012	FULL	96	79	536	712
	SDI	59	49	322	430
	RDI	95	42	523	658
	Prec	87	45	74	206

Table 2. Average gravimetric soil water content (%) of samples taken in April and September at two positions: close to the emitter (0 cm) and at 25 cm from the emitter (25 cm) and the average of the two positions (0 cm + 25 cm) in 2009-2012. Each value is the average of 20 soil samples taken in the 0-60 cm soil layer (10 samples in April and 10 samples in September) in FULL, SDI and RDI irrigation treatments of the experimental peach orchard in each year. Values followed by the same letter are not significantly different at P= 0.005.

		Position		
Year	Treatment	0 cm	25 cm	0 cm + 25 cm
2009	FULL	18.8 a	16.5 a	17.7 a
	SDI	17.2 a	15.3 a	16.2 a
	RDI	18.3 a	16.5 a	17.4 a
2010	FULL	24.8 a	21.2 a	23.0 b
	SDI	21.8 b	18.1 b	19.9 a
	RDI	24.8 a	20.9 a	22.8 b
2011	FULL	26.1 a	21.7 a	23.8 a
	SDI	23.0 b	18.2 b	20.6 b
	RDI	26.1 a	22.5 a	24.3 a
2012	FULL	19.8 a	16.8 a	18.3 a
	SDI	16.0 b	13.5 b	14.8 b
	RDI	19.2 a	16.6 a	17.9 a
2009-2012	FULL	22.3 a	19.1 a	20.7 a
	SDI	19.5 b	16.3 b	17.9 b
	RDI	22.1 a	19.1 a	20.6 a

Table 3. Starting dates of different phenological phases (month/day) in the experimental peach orchard in the farm AFRUCCAS, county of Caspe, Zaragoza, Spain in 2008-2012.

Phenological phase	Year				
	2008	2009	2010	2011	2012
First leaves emerging.	02/18	02/17	03/01	03/01	03/05
Full bloom, 50% of open flowers	03/14	03/13	04/07	03/31	04/03
Beginning of pit hardening	05/05	05/06	05/12	05/11	05/14
End of pit hardening	06/02	06/04	06/14	06/09	06/14
Beginning of fruit coloring	09/07	08/26	08/19	08/24	08/27
First harvest	09/24	09/14	09/15	09/02	09/11
More than 50% of leaves discolored and beginning of leaves fall	11/09	11/09	11/09	11/22	
All leaves fallen	12/05	12/05	12/02		

Table 4. Average values of the initial trunk cross sectional area ($TCSA_i$) of the peach trees (cm^2) and relative growth of the trunk cross sectional area (RGTCSA) measured at 30 cm above the soil surface in FULL, SDI and RDI irrigation treatments of the experimental peach orchard in 2008-2012. Values followed by the same letter are not significantly different at P= 0.005.

	$TCSA_i$ (cm^2)					
Treatment	2008	2009	2010	2011	2012	2008-2012
FULL	49 a	63 a	75 a	88 a	101 a	76 a
SDI	53 a	64 a	74 a	83 a	96 a	74 a
RDI	44 a	60 a	73 a	84 a	97 a	72 a
	RGTCSA					
Treatment	2008	2009	2010	2011	2012	2008-2012
FULL	0.28 a	0.23 a	0.13 a	0.15 a	0.09 a	1.19 a
SDI	0.21 b	0.16 b	0.14 a	0.15 a	0.08 a	0.98 b
RDI	0.32 a	0.22 a	0.13 a	0.15 a	0.08 a	1.27 a

Table 5. Average values of fruit production (kg tree^{-1}), average fruit weight (g), fruit yield productivity (kg cm^{-2} of trunk cross section) and productivity of irrigation water (kg ha^{-1} mm^{-1}) in FULL, SDI and RDI irrigation treatments of the experimental peach orchard in 2008-2012. Values followed by the same letter are not significantly different at P= 0.005.

	Fruit production (kg tree^{-1})					
Treatment	2008	2009	2010	2011	2012	2008-2012
FULL	31 a	26 a	21 a	27 a	20 a	*126 a
SDI	23 b	22 a	23 a	28 a	23 a	*120 a
RDI	26 b	25 a	25 a	29 a	23 a	*130 a
	Average fruit weight (g)					
Treatment	2008	2009	2010	2011	2012	2008-2012
FULL	197 a	198 a	205 a	197 a	184 a	196 a
SDI	179 b	164 b	190 a	194 a	167 b	180 b
RDI	200 a	195 a	202 a	199 a	176 ab	194 a
	Fruit yield productivity (kg cm^{-2})					
Treatment	2008	2009	2010	2011	2012	2008-2012
FULL	0.66 a	0.43 a	0.28 a	0.32 a	0.21 a	0.38 a
SDI	0.47 b	0.38 a	0.33 a	0.36 a	0.25 a	0.37 a
RDI	0.61 a	0.42 a	0.35 a	0.36 a	0.24 a	0.40 a
	Productivity of irrigation water (kg ha^{-1} mm^{-1})					
Treatment	2008	2009	2010	2011	2012	2009-2012
FULL		40 b	24 b	30 b	20 b	29 b
SDI		60 a	39 ab	54 a	38 a	46 a
RDI		40 b	31 a	36 b	25 b	32 b

* Accumulated fruit production in the five years

Table 6. Average values of fruit diameter (mm), fruit firmness (kg/0.5 cm^2), juice total soluble solids content (SSC, in º Brix), juice pH, juice total acidity (TA in meq/100ml) and SSC/TA ratio in FULL, SDI and RDI irrigation treatments of the experimental peach orchard in 2008-2012. Data was not available in 2011. Values followed by the same letter are not significantly different at P= 0.005.

	Diameter (mm)				
Treatment	2008	2009	2010	2012	2008-2012
FULL	73 a	76 a	74 a	71 a	74 a
SDI	71 b	71 b	72 b	68 b	71 b
RDI	74 a	76 a	74 ab	69 b	73 a
	Firmness (kg/0.5 cm^2)				
Treatment	2008	2009	2010	2012	2008-2012
FULL	4.0 a	3.8 a	3.3 a		3.7 a
SDI	3.4 b	3.8 a	3.3 a		3.5 b
RDI	3.8 a	3.9 a	3.5 a		3.7 a
	SSC (º Brix)				
Treatment	2008	2009	2010	2012	2008-2012
FULL	14.4 b	14.8 b	12.1 b	14.2 a	13.9 b
SDI	15.5 a	15.8 a	13.1 a	15.0 a	14.9 a
RDI	14.8 b	14.9 b	12.6 ab	14.0 a	14.2 b
	pH				
Treatment	2008	2009	2010	2012	2008-2012
FULL	3.8 a	4.1 a	4.0 a	4.0 a	3.9 a
SDI	3.8 a	4.1 a	4.0 a	3.9 a	3.9 a
RDI	3.7 a	4.0 a	4.0 a	3.9 a	3.8 a
	TA (meq/100ml)				
Treatment	2008	2009	2010	2012	2008-2012
FULL	6.9 a	6.4 a	6.8 a	6.6 a	6.7 a
SDI	7.2 a	6.4 a	6.2 a	6.5 a	6.6 a
RDI	7.1 a	6.6 a	6.6 a	7.0a	6.8 a
	Ratio SSC/TA				
Treatment	2008	2009	2010	2012	2008-2012
FULL	2.1 a	2.3 b	1.8 b	2.2 ab	2.1 b
SDI	2.3 a	2.5 a	2.1 a	2.4 a	2.3 a
RDI	2.2 a	2.3 b	1.9 ab	2.0 b	2.1 b

Table 7. Average values of the CIELab color parameters of lightness (L*), chroma value (C*) and hue angle (h*) of the fruit skin and flesh in FULL, SDI and RDI irrigation treatments of the experimental peach orchard in 2008, 2010 and 2012. Data was not available in 2009 and 2011. Values followed by the same letter are not significantly different at P= 0.005.

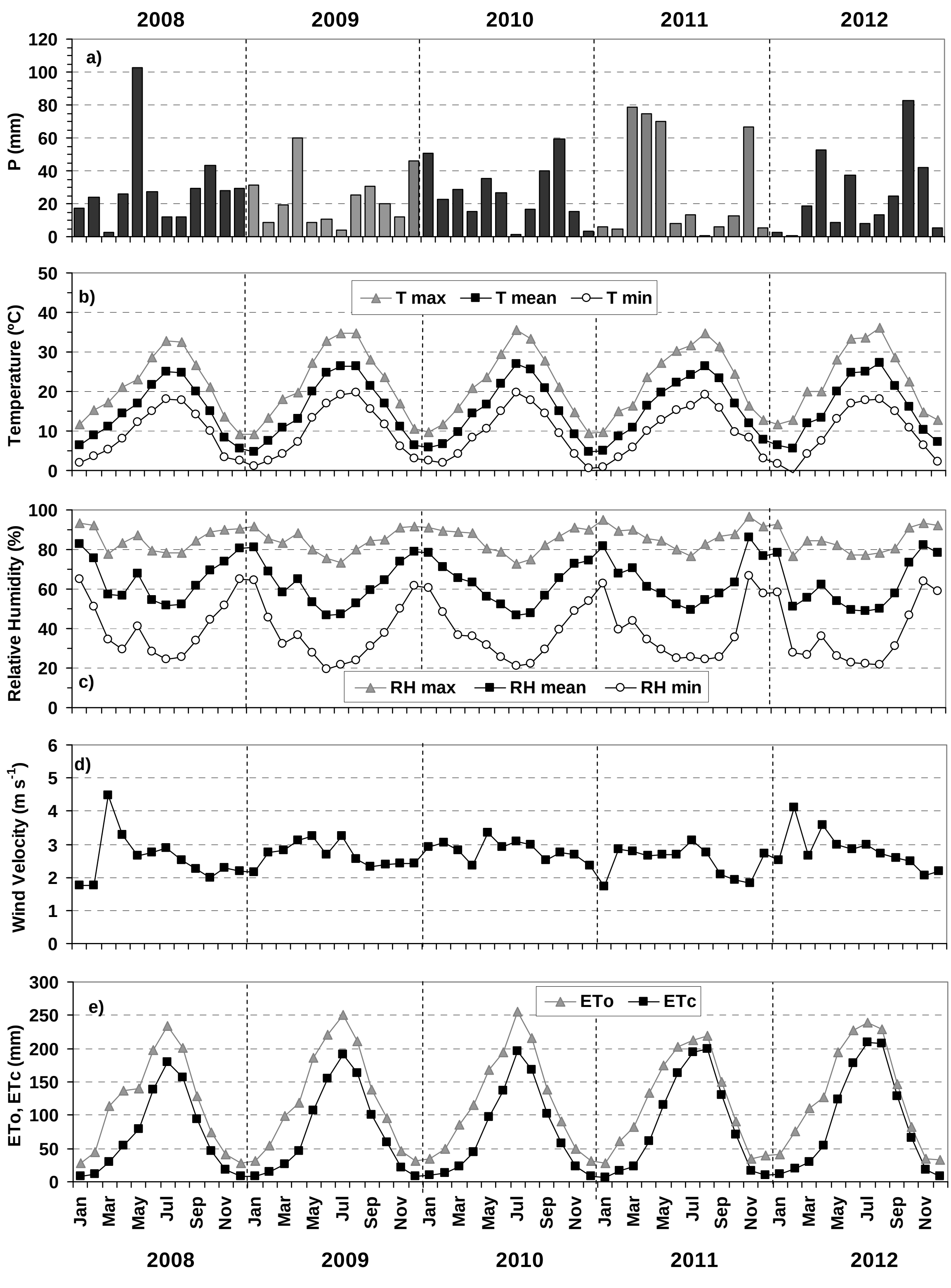
	Skin L*			
Treatment	2008	2010	2012	2008-2012
FULL	72 b	72 a	70 a	71 b
SDI	73 a	72 a	71 a	72 a
RDI	71 b	72 a	70 a	71 b
	Skin C*			
Treatment	2008	2010	2012	2008-2012
FULL	57.1 b	52.6 b	53.5 a	54.4 b
SDI	58.4 a	53.7 a	56.4 a	55.5 a
RDI	57.3 b	53.8 a	51.7 b	54.4 b
	Skin h*			
Treatment	2008	2010	2012	2008-2012
FULL	40.7 b	80.8 a	82.5 a	68.2 b
SDI	62.5 a	80.2 a	82.5 a	73.9 a
RDI	39.0 b	81.4 a	82.5 a	65.9 b
	Flesh L*			
Treatment	2008	2010	2012	2008-2012
FULL		71 b	70 b	71 b
SDI		71 b	71 a	71 b
RDI		73 a	71 a	72 a
	Flesh C*			
Treatment	2008	2010	2012	2008-2012
FULL		52.2 a	53.8 a	53.0 a
SDI		52.9 a	53.4 a	53.2 a
RDI		52.3 a	53.3 a	52.8 a
	Flesh h*			
Treatment	2008	2010	2012	2008-2012
FULL		67.0 b	84.8 a	75.1 b
SDI		81.4 a	83.1 b	82.5 a
RDI		69.9 b	83.1 b	77.3 b

Figure 1. Monthly average values of (a) precipitation (P), (b) maximum (T_{max}), mean (T_{mean}) and minimum (T_{min}) air temperature, (c) maximum (RH_{max}), mean (RH_{mean}) and minimum (RH_{min}) air relative humidity, (d) wind velocity and (e) reference evapotranspiration (ET_o) and peach orchard evapotranspiration (ET_c). Meteorological data was obtained in the SIAR meteorological station of “El Suelto-Plano Espés” located in Caspe, Zaragoza, Spain in 2008-2012.

Figure 2. Evolution of the fraction of intercepted photosinthetically active radiation (IPAR) measured in the peach trees of the full irrigation (FULL), sustained deficit irrigation (SDI) and regulated deficit irrigation (RDI) treatments in the peach orchard growing seasons of 2010 and 2011. The solid line indicates the quadratic polynomial equation fitted to the data of the three irrigation treatments.

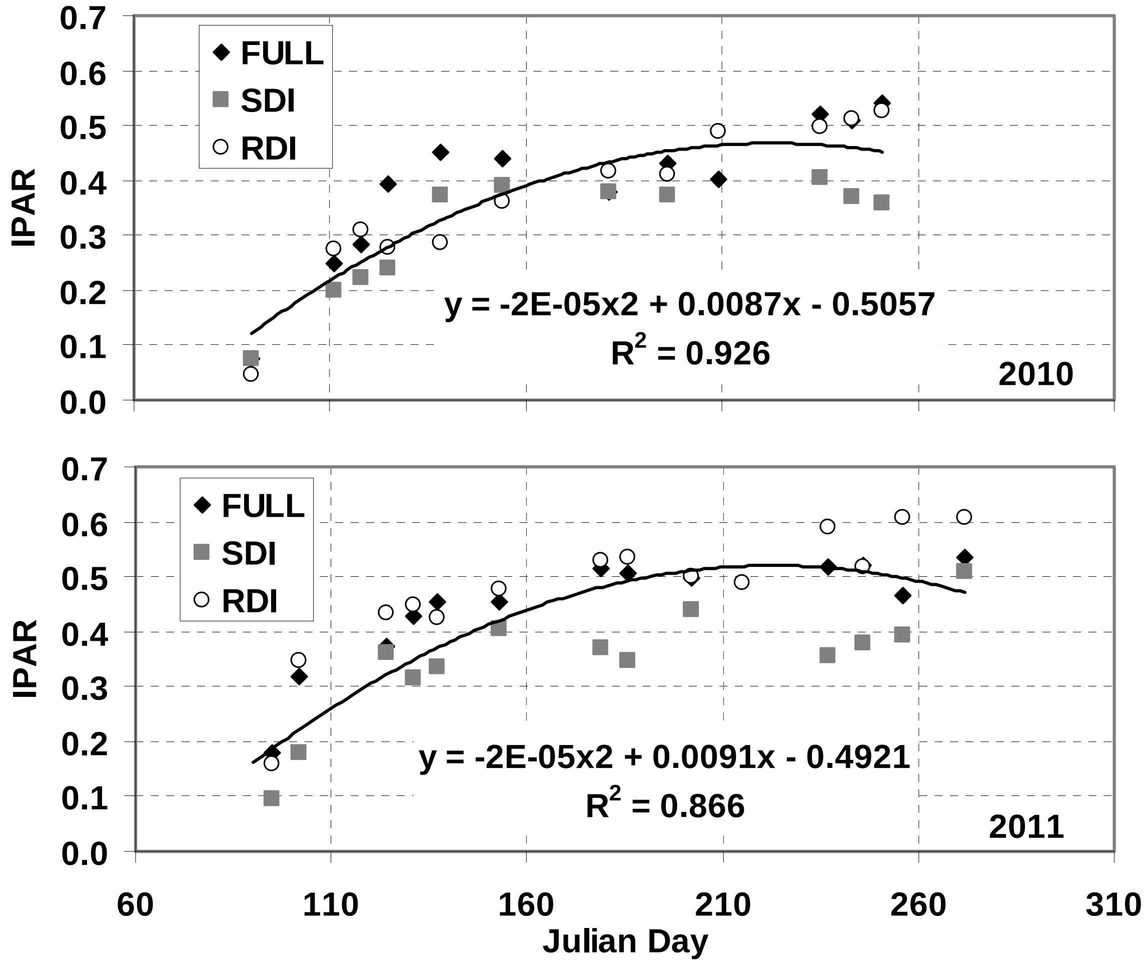
Figure 3. Evolution of stem water potential (ψ_{stem}) measured at solar noon in the peach trees of the full irrigation (FULL), sustained deficit irrigation (SDI) and regulated deficit irrigation (RDI) treatments in the growing seasons of 2009-2011. The vertical lines indicated the period when irrigation was reduced in the RDI treatment to 50 % of the FULL treatment. Each point is the average of 6 to 10 measurements.

Fig. 1



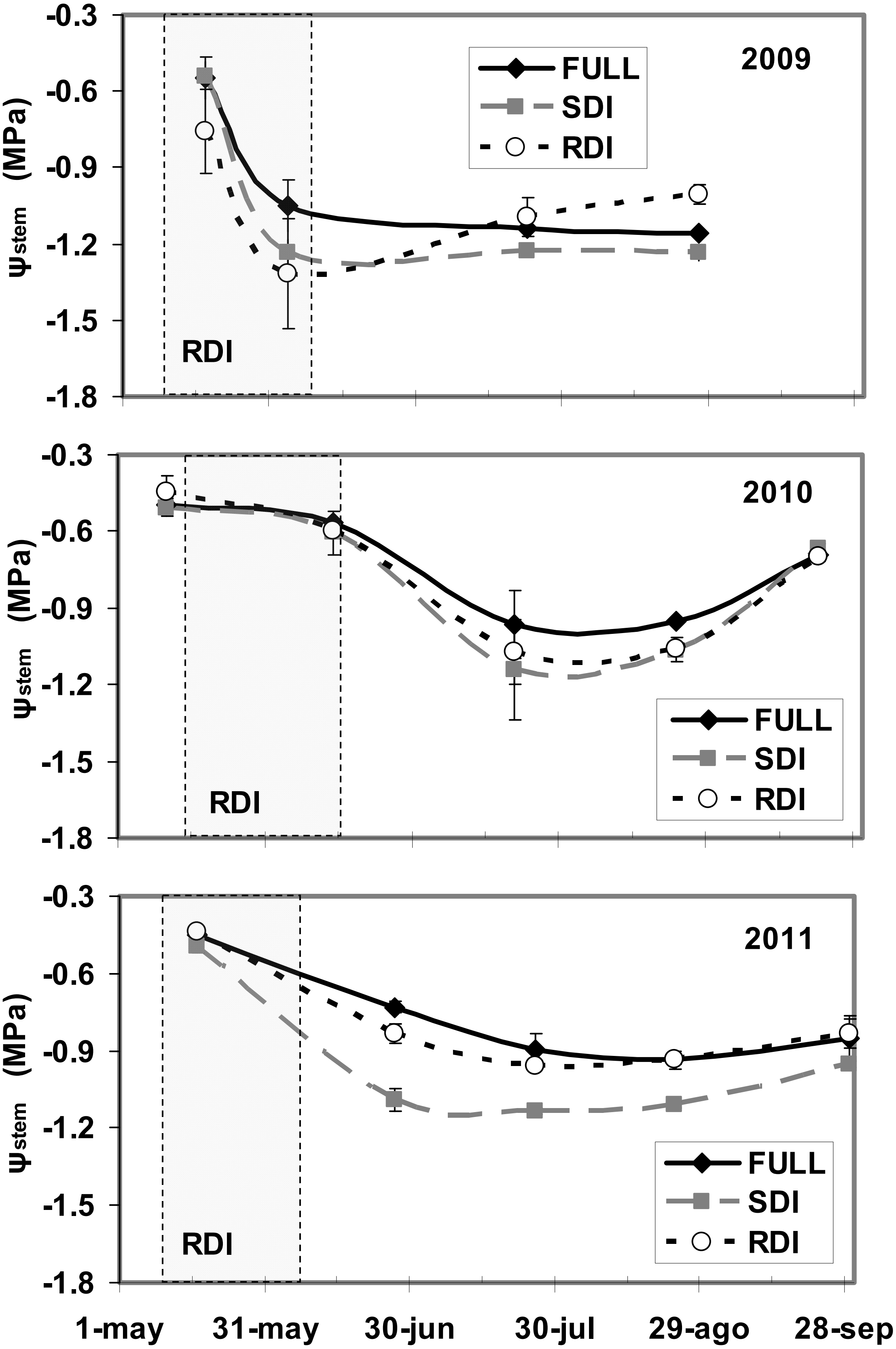
2008
2009
2010
2011
2012
a)
P (mm)
b)
T max
T mean
T min
Temperature (ºC)
c)
RH max
RH mean
RH min
Relative Humidity (%)
d)
Wind Velocity (m s-1)
e)
ETo
ETc
ETo, ETc (mm)
Jan
Mar
May
Jul
Sep
Nov

Fig. 2



0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
IPAR
FULL
SDI
RDI
y = -2E-05x2 + 0.0087x - 0.5057
R2 = 0.926
2010
y = -2E-05x2 + 0.0091x - 0.4921
R2 = 0.866
2011
60
110
160
210
260
310
Julian Day

Fig. 3



2009
2010
2011
FULL
SDI
RDI
RDI
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
ψstem (MPa)
1-may
31-may
30-jun
30-jul
29-ago
28-sep