

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

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21

22 **Abstract**

23

24 Some degree of deficit irrigation is normally applied to orchards in semi arid environments
25 in order to reduce unwanted vegetative growth and to increase water productivity. In this
26 study the effect of three irrigation treatments on the yield and quality of the fruit production

1 was evaluated during five consecutive years (2008-2012) in a commercial drip irrigated
2 late season peach (*Prunus persica* (L). Batsch cv 'Calrico') orchard. Irrigation treatments
3 consisted in a full irrigation (FULL) with irrigation applications covering the crop water
4 requirements, a sustained deficit irrigation during the whole irrigation season (SDI) with
5 irrigation applications of 62.5 % of the FULL treatment and a regulated deficit irrigation
6 (RDI) with a reduction of water applied to 50 % of the FULL treatment in the stone
7 hardening period. The differential irrigation treatments created negligible differences in the
8 stem water potential of the trees. Results showed that fruit production was only
9 significantly higher in the FULL treatment than in the other two treatments in 2008 but in
10 the rest of the years no significant differences were found between treatments. The
11 average fruit weight was significantly smaller in the SDI treatment than in the FULL and
12 RDI treatments. Firmness of the fruits in the SDI treatment was significantly lower than that
13 of the FULL and RDI treatments and the total soluble solids of the SDI was significantly
14 higher than the FULL and RDI treatments. Color parameters of the fruit skin and flesh
15 were also affected by the irrigation treatments. The higher values of the soluble solids
16 content (SSC) and the relation SSC/TA (total acidity) and the slight decrease in fruit
17 diameter found in the SDI treatment suggest that irrigation water saving can be achieved
18 without affecting the commercial profitability in the semi arid conditions of the Lower Ebro
19 Valley in Northeast of Spain.

20

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

23

24 **1. Introduction**

25

1 In 2009 the peach and nectarine orchard area in the world was around 1.5 million
2 ha, China is the country with the highest peach production which represents over half of
3 the world peach production. Another important peach production area is located in
4 southern Europe which includes the countries of Spain, France and Greece (FAO, 2011).
5 The peach orchards in Spain covered an area of 50,000 ha in 2010 (MAGRAMA, 2011).
6 Around 50% of the peach and nectarine orchard area is cultivated in the regions of Aragón
7 and Cataluña in Northeast of Spain. Most of these orchards have early season cultivars in
8 order to put the fruit production in the markets as soon as possible at the beginning of the
9 summer season and obtain high economic profit. However in recent years the late season
10 peach orchards which are harvested at the end of the summer and early fall are getting a
11 higher relevance since this kind of peach characterized by its very firm flesh and
12 sweetness is highly appreciated by the consumers. In an area of Aragón of around 5000
13 km² in the Northeast of Spain, a group of late season peach cultivars has been grown for a
14 long time with a great acceptance by the consumers because of their excellent aspect and
15 organoleptic characteristics. Peaches of these late season cultivars grown in this area
16 have a unique and special denomination named “Calanda peach”. These peaches reach
17 significant higher prices than the regular peaches and nectarines. The most important
18 cultivars included in the “Calanda peach” denomination are ‘Jesca’, ‘Calante’ and ‘Evaisa’
19 (Espada et al., 1991). The fruit of these clingstone cultivars has round shape; the skin is
20 light yellow without red spots and very low pubescence. The fruit flesh is yellow, non-
21 melting and firm with high sugar content. Maturation is between middle of September and
22 the beginning of November. At present new cultivars have been added to the
23 denomination of “Calanda peach” and the demand of this type of peaches is increasing.

24 One of the most characteristic agronomic practices of “Calanda peach” is
25 introducing the fruit into a paper bag during the stone hardening phase in order to protect
26 the fruit against the Mediterranean fly (*Ceratitis capitata*), contact with pesticides, climatic

1 incidences and other external physical damages (Sharma et al., 2014). The paper bag
2 remains on the fruit until the harvest. The fruit acquires a homogeneous yellow color very
3 appreciated by the consumers.

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

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

17 Different irrigation strategies and agronomic practices can be used to optimize the
18 yield and quality of peach fruit production. Reviews of literature have shown that reducing
19 the irrigation applications below the crop water requirement can be an useful tool to reduce
20 unwanted vegetative growth, improve fruit quality and increase water productivity in
21 orchards (Ferrerer and Soriano, 2007; Geerts and Raes, 2009; Ruiz-Sanchez et al., 2010).
22 These reductions can be applied during the crop cycle (i.e. sustained deficit irrigation, SDI)
23 or they can be applied in specific phenological phases where the deficit irrigation does not
24 affect the fruit production (i.e. regulated deficit irrigation, RDI). The response of fruit
25 orchards to different deficit irrigation strategies has been widely studied in many fruit
26 species and areas of the World (Girona et al., 2003; Lopez et al., 2008; Moriana et al.,

1 2003; Ruíz-Sanchez et al., 2010; Ramos and Santos, 2010). Different studies have
2 showed that RDI saves irrigation water, increases water use efficiency and reduces tree
3 vigor while the fruit yield remains constant or even increases (Chalmers et al., 1981;
4 Boland et al., 2000; Geerts and Raes, 2009). Normally the RDI in peach orchard is applied
5 in the stone hardening phase of the fruit development. In this phase the growth of the fruit
6 is very slow and the shoots grow very fast. Most RDI studies have been made in early
7 peach cultivars (Mounzer et al., 2008; Gelly et al., 2004) and very few results are available
8 for late season peach cultivars.

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

17

18 **2. Material and methods**

19

20 *2.1. Experimental orchard*

21

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

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

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

21 Soluble fertilizers were applied with the drip irrigation system along the irrigation
22 season. The seasonal fertilizer amounts per year included 87 kg ha⁻¹ of N, 47 kg ha⁻¹ of
23 P₂O₅ and 120 kg ha⁻¹ of K₂O.

24 Fruits were thinned in early June to a target crop load of about 140 fruits per tree
25 and then the fruits were covered with individual paper bags. Each tree of the experimental

1 units was harvested individually in two harvesting events performed during the month of
2 September.

3

4 *2.2. Experimental design*

5

6 The experiment design was a complete randomized block with five replicates and
7 three differential irrigation treatments: 1) control or fully irrigated treatment (FULL) with
8 100% of the Gross Irrigation Requirements (I) estimated by the own farmer according to
9 the irrigation recommendations from the Irrigation Advisory System of Aragón
10 (<http://servicios.aragon.es/oresa/>) for the experimental orchard in the county of Caspe.
11 This irrigation advisory system uses the FAO methodology (Allen et al., 1998) with data of
12 agrometeorological stations of the SIAR network (National Network of Agrometeorological
13 Stations for Irrigation of the Ministry of Agriculture, Food and Environment of Spain,
14 <http://www.magrama.gob.es/es/>); 2) sustained deficit irrigation (SDI) with the irrigation
15 application reduced to 62.5 % of the FULL treatment throughout the irrigation season; and
16 3) regulated deficit irrigation (RDI) with the same irrigation applications as the FULL
17 treatment except in the stone hardening phase of fruit development, when the trees were
18 irrigated at 50 % of the FULL treatment. The length of the stone hardening phase was
19 around one month and started by early or mid May, depending on the specific year. Each
20 block consisted of a row of 35 trees. The experimental unit consisted in a row of 7 trees.

21 In the FULL treatment each tree was irrigated with four emitters of 4 L h⁻¹. In the
22 SDI treatment two emitters of 3 L h⁻¹ and two of 2 L h⁻¹ were used along all the irrigation
23 season and in the RDI treatment the 4 L h⁻¹ emitters were removed and substituted by
24 emitters of 2 L h⁻¹ during the stone hardening phase. Irrigations were applied daily and the
25 three treatments were irrigated simultaneously and with the same duration. Irrigation

1 season started in late March or early April and finished by late September or early October
2 depending on the specific year.

3

4 2.3. Measurements

5

6 Water applications were measured with volumetric water meters installed in June of
7 2008 in each drip line in the three irrigation treatments. Samples of irrigation water were
8 taken to determine its electrical conductivity (EC).

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

20 Daily meteorological data was collected in the nearby automated
21 agrometeorological station “El Suelto-Plano Espés” of the SIAR network. The station is
22 located in Caspe County at UTM coordinates: UTMX 745309, UTM Y 4576848 (41.19°N,
23 0.05°W) and altitude of 150 m. This station stores data on air temperature, air relative
24 humidity, wind speed and direction, solar radiation and precipitation every 30 minutes. The
25 daily meteorological data was used to estimate daily values of the reference
26 evapotranspiration (ET_o) computed using the FAO Penman-Monteith (Allen et al., 1998).

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

$$4 \quad K_c = 1.59 \text{ IPAR} + 0.082 \quad (1)$$

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

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

12 The IPAR was measured at weekly intervals in the experimental peach orchard with
13 a ceptometer (SunScan Canopy Analysis System, SS1 type, Delta-T Devices Ltd.,
14 Cambridge, England) in 2010 and 2011. In each measurement of IPAR the ceptometer
15 was located in 18 positions in the spacing of a tree (6 m x 2 m) in one tree per irrigation
16 treatment. Once full cover was reached measurements were made monthly. Average
17 curves of IPAR were adjusted to the experimental data by regression analysis in both
18 years. These equations were used to calculate the K_c with equation (1) and the monthly
19 values of the average ET_c in the experimental peach orchard in the different years. In the
20 years where IPAR was not measured, the K_c curves were determined by adapting the
21 average K_c curves of 2010 and 2011 to the phenology of the specific year. The K_c curve of
22 2010 was used in years 2008 and 2009 and the K_c curve of 2011 was used to estimate it
23 in 2012. An average value of the K_c of 0.15 was used for the period between the complete
24 leaf fall in late autumn and the starting of leaf emergence in spring.

25 Midday stem water potential (ψ_{stem}) of the trees was measured with a portable
26 pressure chamber (model 3005 Soil Moisture Equipment Corporation, Santa Bárbara, CA,

1 USA) in exposed developed leaves in the different treatments. The measured leaves were
2 covered with aluminum foil around twenty minutes before measuring to equilibrate the leaf
3 water potential to the stem water potential.

4 The initial trunk cross sectional area (TCSA, cm²) was calculated from the perimeter
5 values measured at 30 cm above the soil surface at the beginning and end of each
6 growing season from 2008 to 2012. The TCSA was calculated assuming a circular cross
7 sectional area of the trunk. The relative growth of the trunk cross sectional area (RGTCSA)
8 was calculated using the following equation:

$$9 \quad \text{RGTCSA}_i = (\text{TCSA}_f - \text{TCSA}_i) / \text{TCSA}_i \quad (2)$$

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

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

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

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

21 A subsample of 10 fruits per tree was processed in the laboratory to control the
22 quality parameters; fruit weight, equatorial perimeter, skin color, firmness, flesh color, total
23 soluble solids content and total acidity. The measurement of weight, equatorial perimeter
24 and skin color of the fruit is non-destructive whereas flesh color and firmness were
25 measured after removing approximately a 2.5 cm diameter slice of peel with a standard

1 peeler on the two opposite sides of each fruit. Rest of fruit quality measures, were
2 obtained from the sample flesh juice.

3 Fruit weight and equatorial perimeter were measured to assess the fruit size. Fruit
4 diameter was deduced from equatorial perimeter measurements. Flesh firmness in kg/0.5
5 cm² was determined using a penetrometer equipped with 8 mm diameter plunger (0.5
6 cm²). (Penefel, Setop Giraud –Technologie, 84300 Cauvaillon, France).

7 Fruit skin and flesh color was measured with a Minolta Chroma Meter CR-200
8 portable tristimulus colorimeter (Minolta Corp, Osaka, Japan) using CIE illuminant D65 and
9 8 mm measuring aperture diameter. Values were recorded in Commission Internationale
10 d'Eclairage (CIE) color space coordinates, defined by lightness (L*), range from red to
11 green (a*), and range from yellow to blue (b*). The colorimeter was standardized by using
12 the Minolta calibration plate CR.A43 before each measurement date. Color values for each
13 fruit were computed as means of 2 measurements taken from opposite sides at the
14 equatorial region of the fruit (Abbott, 1999). Flesh a* score has been reported to be a
15 useful index for fruit maturity (Fuleki and Cook, 1976), however, a* scores may be too
16 variable, and values of a* and b* should not be used alone because they are not
17 independent variables (Francis, 1980) and because they are difficult to interpret. As a
18 consequence, we calculated the chroma value (C*) by the expression $[(a^*2 + b^*2)^{1/2}]$
19 related with the brightness and color saturation and the hue angle (h*), the numerical value
20 for color, as $[\tan^{-1}(b/a)]$. Hue angle quantifies color, where 0°=red/purple, 90°= yellow and
21 180 =bluish/green (McGuire, 1992).

22 Representative juices of the different peach samples were obtained with a kitchen
23 juicer, cleaning the appliance between samples. Juices were homogenized and clarified
24 through the use of paper filters, retaining flesh particles bigger than 25 µm (CHM®
25 Hardened Low Ash Filter F2054, Barcelona, Spain). Total soluble solids content (SSC) of
26 the juices in °Brix was assessed using a digital hand refractometer (PAL-1, Atago Co. Ltd.,

1 Tokyo, Japan), the total acidity (TA) expressed in meq/100 ml, and the pH were measured
2 by automatic titration of 50 mL of juice with 0.1N NaOH solution (785 DMP Titrino,
3 Metrohm AG, Herisau, Switzerland). The sugar-to-acid ratio (SSC/TA) was calculated from
4 recorded data to assess the influence of the different irrigation strategies in this maturity
5 index. SSC/TA is the fruit quality parameter that is ultimately most closely related with
6 consumer acceptance of peaches (Crisosto et al., 2006).

7

8 *2.4. Statistical analyses*

9

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

13

14 **3. Results**

15

16 *3.1. Meteorological variables, crop evapotranspiration (ET_c) and irrigation (I)*

17

18 Figure 1 presents the average monthly values of precipitation, air temperature,
19 relative humidity and wind velocity recorded in the automated agrometeorological station
20 “El Suelto-Plano Espés” during the five studied years. The rainfall distribution along the
21 year differed between years but minimum values occurred in the summer months and
22 maximum in the spring months. Average annual precipitation for the period 2008-2012 was
23 318 mm and ranged between 277 mm in 2009 and 355 mm in 2008.

24 Temperature regimes were very similar in the five study years. The average annual
25 mean temperature (T_{mean}) for the period 2008-2012 was 15.4 °C. Maximum monthly values
26 of T_{mean} occurred in the months of July and August in all experimental years. The evolution

1 of the air relative humidity was also very similar in the five studied years. The average
2 annual relative humidity for the period 2008-2012 was 63 %. Minimum monthly values of
3 the air relative humidity occurred in the summer months. An increase of the monthly
4 values of air relative humidity was observed in the months of May 2008, April 2009, March
5 2011 and April 2012 corresponding with high precipitation values in these months. The
6 evolution of the wind velocity showed that the monthly values were above 1.8 m s^{-1} along
7 the five studied years and the average value was 2.7 m s^{-1} . In March 2008 and February
8 and April of 2012 the monthly values of wind velocity reached values higher than 3.5 m s^{-1} .

9 The annual values of reference evapotranspiration (ET_0) were very similar during
10 the five studied years (Figure 1). The average value for the period 2008-2012 was 1452
11 mm year^{-1} , ranging between 1369 mm in 2008 to 1538 mm in 2012. The maximum
12 monthly values of ET_0 occurred in July with an average value for the 2008-2012 period of
13 $239 \text{ mm month}^{-1}$.

14 Figure 2 presents the evolution of the IPAR in the in the three irrigation treatments
15 of the experimental peach orchard during 2010 and 2011. In 2010 the evolution was
16 similar in the three treatments until the middle of July. The maximum values were reached
17 in the FULL and RDI treatments with values around 0.5 while the maximum values in the
18 SDI were 0.4. In 2011 the maximum values of the IPAR were equal in the three treatments
19 (around 0.6) but the IPAR of the SDI treatment was below the FULL and RDI treatments
20 during most of the crop cycle. A quadratic polynomial equation fit the experimental data of
21 all treatments in both years with high values of the determination coefficients ($R^2 = 0.93$ in
22 2010 and $R^2 = 0.87$ in 2011).

23 The seasonal values of the calculated peach orchard evapotranspiration (ET_c) using
24 the Ayars et al. (2003) approach varied between 823 mm in 2008 to 1056 mm in 2012.
25 The average value of ET_c for the period 2008-2012 was 933 mm year^{-1} . For the studied
26 period the average monthly value of ET_c was maximum in July (194 mm) and minimum in

1 the winter months (Figure 1). These ET_c values resulted very similar to the ET_c values
2 provided by the Irrigation Advisory System of Aragón (data not presented).

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

19 The soil sampling performed from 2010 to 2012, showed that the average
20 gravimetric soil water content (GWC) in the root zone of the trees (average values of soil
21 samplings in April and September at the emitter position, at 25 cm of the emitter and for
22 the average of both positions) was significantly higher in the FULL and RDI treatments
23 than in the SDI treatment with values in the FULL and RDI treatments even higher than
24 field capacity (21 %) in 2010 and 2011. The high values of GWC in 2011 were due to the
25 high rainfall during the irrigation season. No significant differences in the GWC were
26 observed between treatments in 2009. In all cases the GWC at the emitter position was

1 higher than at 25 cm from the emitter. For the period 2009-2012, the average GWC was
2 also significantly higher in the FULL and RDI treatments than in the SDI treatments with
3 average values considering both positions in the FULL, SDI and RDI treatments of 20.7 %,
4 17.9 % and 20.6 %, respectively (Table 2). These results showed that GWC was clearly
5 reduced by the irrigation regime in the SDI treatment.

6 7 *3.2. Tree growth, stem water potential and fruit production*

8
9 Table 3 presents the initial dates of the different phenological phases of the
10 experimental peach orchard in the different studied years. A later emergence of leaves in
11 years 2010, 2011 y 2012 created a delay in the beginning of the stone hardening phase.
12 This phase lasted around 30 days in the five studied years. The initial date of harvest was
13 affected by the meteorological conditions of the different years and varied between 2
14 September in 2011 and 24 September in 2008.

15 Figure 3 presents the evolution of the midday stem water potential (ψ_{stem}) in 2009 to
16 2011. The values of ψ_{stem} showed a similar behavior during the three years of
17 measurements. Differences in ψ_{stem} were low between irrigation treatments and different
18 years. In most measurements for the different treatments and years, ψ_{stem} was higher than
19 -1.2 MPa indicating very low water stress in all irrigation treatments (Goldhamer et al.,
20 1999; Girona et al., 2006). In 2009 the lowest values of ψ_{stem} (-1.3 MPa) were reached in
21 the RDI and SDI treatments at the beginning of June. In 2010 and 2011 the lowest values
22 of ψ_{stem} were reached in the SDI treatment but with values higher than -1.2 MPa. The
23 lowest values of ψ_{stem} were reached at the end of July in 2010 and 2011 (-1.1 MPa).
24 Rainfall events before the dates of ψ_{stem} measurements affected the ψ_{stem} values. For
25 instance the higher ψ_{stem} values in all treatments in 2011 were probably due to the higher
26 rainfall during the irrigation season in that year.

1 No significant differences between the three irrigation treatments were observed in
2 the initial values of the peach trunk cross sectional area (TCSA) in the five studied years
3 (Table 4). The initial average value of the TCSA of the trees was 49 cm² in 2008 and
4 double in 2012 (98 cm²). However significant differences were found in the relative growth
5 of the trunk cross sectional area (RGTCSA) in 2008, 2009 and for the five years 2008-
6 2012. The SDI treatment had a significantly lower value of RGTCSA than the FULL and
7 RDI treatments. For the five years period the RGTCSA increased by 98 % in the SDI
8 treatment while the increase in the FULL and RDI treatments were 119 and 127 %,
9 respectively (Table 4). In 2010, 2011 and 2012 no significant effect of the irrigation
10 treatments was found in the RGTCSA values.

11 Significant effect of the irrigation treatments in the fruit production (kg tree⁻¹) was
12 found only in 2008. The fruit production was significantly higher in the FULL treatment (31
13 kg tree⁻¹) than in the SDI (23 kg tree⁻¹) and RDI (26 kg tree⁻¹) treatments. The rest of the
14 years there were not significant differences in the fruit production between treatments. For
15 the whole studied period (2008-2012) no significant differences between treatments (126
16 kg tree⁻¹ in the FULL treatment, 120 kg tree⁻¹ in the SDI treatment and 130 kg tree⁻¹ in the
17 RDI treatment) were found for the cumulative production (Table 5). However significant
18 differences between treatments in the average weight of the fruit were found in 2008, 2009
19 and 2012. In these three years the average weight of the fruit of the SDI treatment was
20 significantly lower than that of the FULL and RDI treatments. In 2010 and 2011 no
21 significant differences were found between treatments. For the whole studied period
22 (2008-2012), the average weight of the fruit of the SDI (180 g) was significantly lower than
23 that of the FULL (196 g) and RDI (194 g) treatments. The reduction in the fruit weight
24 implies a decrease in the commercial value of the fruit. However the average reduction in
25 the whole period of the SDI treatment in relation to the FULL treatment was only of 16 g.

1 The lowest values of the average fruit weight were obtained in the SDI treatment in 2009
2 (164 g) and 2012 (167 g).

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

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

15

16 3.3. Fruit quality

17

18 Tables 6 and 7 present the results of the quality parameters measured in samples
19 of 10 fruits from each tree in the different irrigation treatments in the harvest of 2008, 2009,
20 2010 and 2012. Significant differences between treatments in the diameter of the fruit were
21 found in all years. The diameter of the fruit in the SDI treatment was significantly lower
22 than the FULL treatment in all years. No significant differences were found between the
23 FULL and RDI treatments in all years except in 2012. For the four years the average
24 diameter of the SDI treatment (71 mm) was significantly lower than that of the FULL (74
25 mm) and RDI (73 mm) treatments. These results are in total agreement with the values of

1 the average weight of the fruit obtained in the harvest by dividing the total weight of the
2 fruits by the number of fruits in each tree (Table 5).

3 The average values of firmness of the fruit flesh in all treatments and years varied
4 between 3.3 and 3.9 kg/0.5 cm². The firmness of the SDI treatment in 2008 was
5 significantly lower than that of the FULL and RDI treatments and no significant differences
6 between treatments were observed in 2009 and 2010. For the period 2008-2010 the
7 average value of the firmness in treatment SDI (3.5 kg/0.5 cm²) was significantly lower
8 than that of the FULL and RDI treatments (3.7 kg/0.5 cm²).

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

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

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

25 A significant effect of the irrigation treatments in the CIELab color parameters of the
26 peach fruit skin was observed. The color lightness (L*) of the SDI treatment was

1 significantly higher than that of the FULL and RDI treatments in the year 2008, and for the
2 whole data of the three years, but not differences were observed for 2010 and 2012. The
3 chroma value (C^*) of the fruit skin, parameter related with the brightness, was slightly
4 higher in the SDI treatment than in the FULL and RDI treatments for the whole data of the
5 three years. Similar results were found with the hue angle (h^*) of the fruit skin, where the
6 SDI treatment showed higher values than the FULL and RDI treatments for the whole data
7 set of the three years. These differences in the three color parameters of the fruit skin for
8 the whole studied period have been caused mainly for the data of 2008 since no statistical
9 differences were observed in 2010 and only statistical difference in the C^* was observed in
10 2012. The fruit skin of the SDI treatment had slightly higher lightness, brightness and
11 closer to the yellow color than the other treatments.

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

25

26

1 **4. Discussion and conclusions**

2

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

18 The fruit production was only reduced significantly in the SDI and RDI treatments in
19 2008 but no significant differences were found between treatments in the rest of the
20 experimental years or in the cumulative fruit production during the five experimental years.
21 Probably the amount of irrigation water applied in 2008 was lower than in the other
22 experimental years. Unfortunately the irrigation doses were only measured in the phase
23 from the end of the stone hardening phase until the end of the irrigation season in 2008
24 and this irrigation dose in the FULL, SDI and RDI treatments was lower than in the other
25 experimental years. The water shortage in the SDI treatment did not affect clearly the fruit
26 yield probably because of a higher water extraction from the soil or an overestimation of
27 the peach orchard evapotranspiration that caused an overestimation of the peach orchard

1 irrigation needs. A more reliable determination of the orchard water requirements is of
2 paramount relevance to optimize irrigation scheduling in late season peach orchards and
3 more research is needed in the subject. The irrigation treatments did not affect the
4 average trunk cross sectional area (TCSA) of the trees or the productivity expressed in
5 fruit production per unit of TCSA. Recently, Perez-Pastor et al. (2014) studied continuous
6 regulated deficit irrigation in apricot and they found that the TCSA was significantly
7 reduced only under severe water deficit conditions. Probably the lack of significant
8 differences in the TCSA in our experiment was due to lower water deficit than that of
9 Perez-Pastor et al. (2014).

10 Fruit quality was affected by the different irrigation treatments. The average fruit
11 weight in the SDI treatment was significantly lower than in the FULL and RDI treatments.
12 These results were confirmed with the fruit diameter data. For the whole studied period
13 (2008-2012), the average fruit diameter of the SDI treatment was significantly lower than
14 that of the FULL and RDI treatments. For 2008-2012 the total soluble solids of the fruit in
15 the SDI treatment was significantly higher than that of the FULL and RDI treatments. The
16 pH and acidity of the fruit juice were not affected by the irrigation treatments. As a
17 consequence, the SSC/TA ratio in the SDI treatment was significantly higher than in the
18 FULL and RDI treatments, showing a slight better gustative quality and presumably a
19 better consumer acceptance. For 2008-2012 the average value of the firmness of the fruit
20 flesh in the SDI treatment ($3.5 \text{ kg} / 0.5 \text{ cm}^2$) was significantly lower than in the FULL and
21 RDI treatments. These appreciations are in general accordance with previous studies
22 (Crisosto et al., 1994; Crisosto et al., 1997; Layne and Tan, 1984; Johnson and Jaine,
23 2000). These authors indicated that different irrigation regimes did not cause alteration in
24 the yield, flesh firmness, acidity and pH whereas water stress caused a decrease in the
25 average fruit size and an increase in SSC.

1 In the present study a significant effect of the irrigation treatments in the CIELab L*,
2 C*, and h* color parameters of the peach fruit skin and flesh was observed. Delwiche et al.
3 (1987) found that during the fruit maturity, the peach skin and flesh become darker,
4 decreasing the L* value and the greenness, due to a decrease of the chlorophyll content
5 and increasing the a* coordinate as maturity progress, but the b* coordinate, remains
6 approximately constant. Fruits of the experimental orchard cv. "Calrico" and the other
7 "Calanda peach" cultivars are grown inside special paper bags primarily to prevent the
8 production damages caused by insects. However it was observed that the use of the
9 bagging operation improved also the fruit appearance and decrease the pre-maturation
10 fruit drop. Fruit bagging prevented the anthocyanin coloration of skin cells, produced in the
11 portion of the fruit highly exposed to sunlight. As a consequence the "Calanda peach"
12 varieties usually have fruits with uniform external light yellow color without any red blush in
13 the fruit skin. In general the red blush in the peach skin is a distinctive sign that makes the
14 fruit attractive to the consumer but this is not the case with the Calanda peach. The
15 uniform fruit skin yellow color without any red blush is a very important characteristic for
16 consumer quality perception of the Calanda peach. Jia et al. (2005) studied skin coloration
17 in peach fruits bagged with paper of different sunlight transmission. They found that fruit
18 weight, soluble solids content and total acidity were not affected by bagging treatments.
19 However the area and intensity of the red color in the skin increased with increasing
20 sunlight transmission. The non-bagged fruit accumulated the largest amount of
21 anthocyanin, whereas the bagged fruit had the smallest amount of anthocyanin. In our
22 experiment we observed that the skin fruit color of the SDI treatment had slightly higher
23 lightness (L*), brightness (C*) and color hue value (h*) closer to yellow color than in the
24 other treatments. Also the hue value (h*) of the flesh fruit color in the SDI treatment was
25 significantly higher than in the FULL and RDI treatments. These results could indicate a
26 slight advance in maturation in the SDI treatment in relation to the other two irrigation

1 treatments, in spite of the higher SSC content and the lower firmness in the fruits of this
2 treatment. The fact that the SDI treatment showed higher SSC content and lower firmness
3 could also indicate an early fruit maturity in this treatment because all treatments were
4 harvested in the same dates. However, the decrease in acidity linked to the earlier maturity
5 was not observed in the SDI treatment. The color coordinates of the fruit skin of the SDI
6 treatment showed a higher lightness, brightness and color closer to yellow than that of the
7 other treatments and as a consequence, a more attractive external presence. Li et al.
8 (2006) found that un-bagged peach fruit skin at maturation had higher L^* and smaller h^* as
9 compared bagged fruit. They also found that flesh firmness of un-bagged fruit was higher
10 than that of bagged fruit. Flesh firmness is considered a good indicator to predict the loss
11 of fruit weight during postharvest handling, fruit potential storage and market life (Li et al.
12 2006). Therefore high firmness at harvest time is also an essential fruit characteristic in
13 this type of fruits since an excellent external presence and fruit organoleptic quality are
14 expected by 'Calanda peach's consumers.

15 In summary the results for the whole studied period showed that differences in fruit
16 yield and quality production between the RDI and FULL irrigation treatments were
17 insignificant. However the SDI treatment showed significant decreases of the average fruit
18 weight, diameter and firmness and significant increases of the SSC and the ratio SSC/TA
19 in relation to the FULL and RDI treatments. According to the findings of Berman and
20 DeJong (1996), water stress in orchards with moderate fruit load, of cv. "Calrico" and other
21 "Calanda peach" cultivars reduce the fruit fresh weight but not the dry weight. Also an
22 increase in fruit sugar concentration was found in the SDI treatment of our experiment that
23 has generally been associated with a decrease of the fruit water content (Crisosto et al.,
24 1994). These results suggest that irrigation water in the late season peach orchards in
25 areas of Northeast of Spain can be reduced significantly if a small reduction in fruit size is
26 allowed without negative effects in the rest of fruit quality parameters, even it is possible to

1 obtain a higher consumer acceptance due to the increase of gustative quality due to the
2 increase of SSC and the ratio SSC/TA caused by a moderate water stress. Unfortunately,
3 the water stress produced by the SDI treatment penalizes the fruit diameter, an attribute
4 which defines the market prize and which is very appreciated by the “Calanda peach”
5 consumers.

6
7

8 **Acknowledgments**

9

10 This work was financed by the CSD2006-00067 (CONSOLIDER-INGENIO 2010) and
11 INIA PET 2007-09-C05-01 projects. The authors thank the field and laboratory technicians
12 of the Soils and Irrigation Department and the Fruticulture Department (CITA) for their
13 valuable work. Authors also acknowledge J. L. Espada and the personnel of the
14 Experimental Farm AFRUCCAS for providing technical support.

15

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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.

Year	Treatment	(mm)			
		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.

Year	Treatment	Position		
		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 (cm²) 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 cm²), juice total soluble solids content (SSC, in ° 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 (° 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 photosynthetically 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

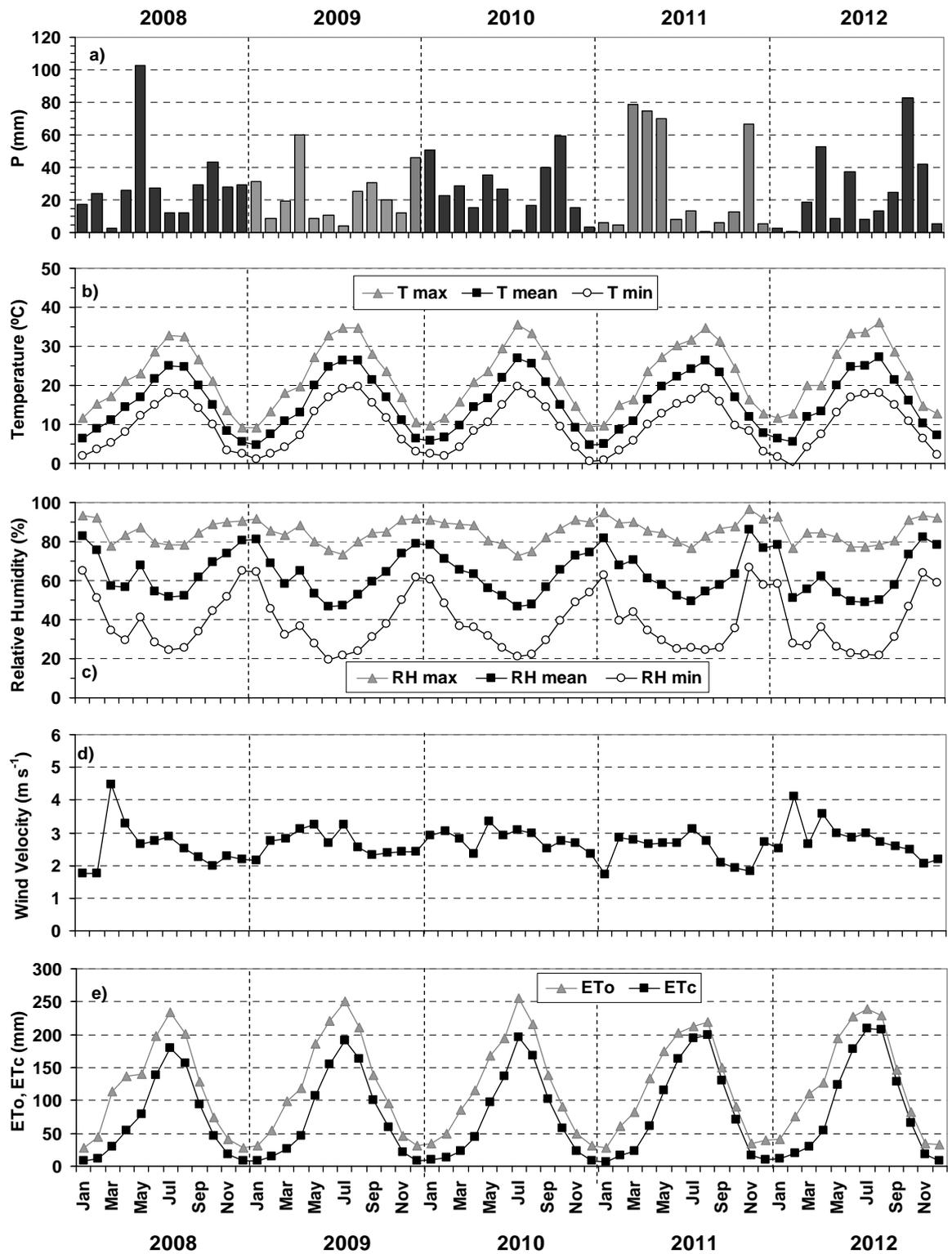


Fig. 2

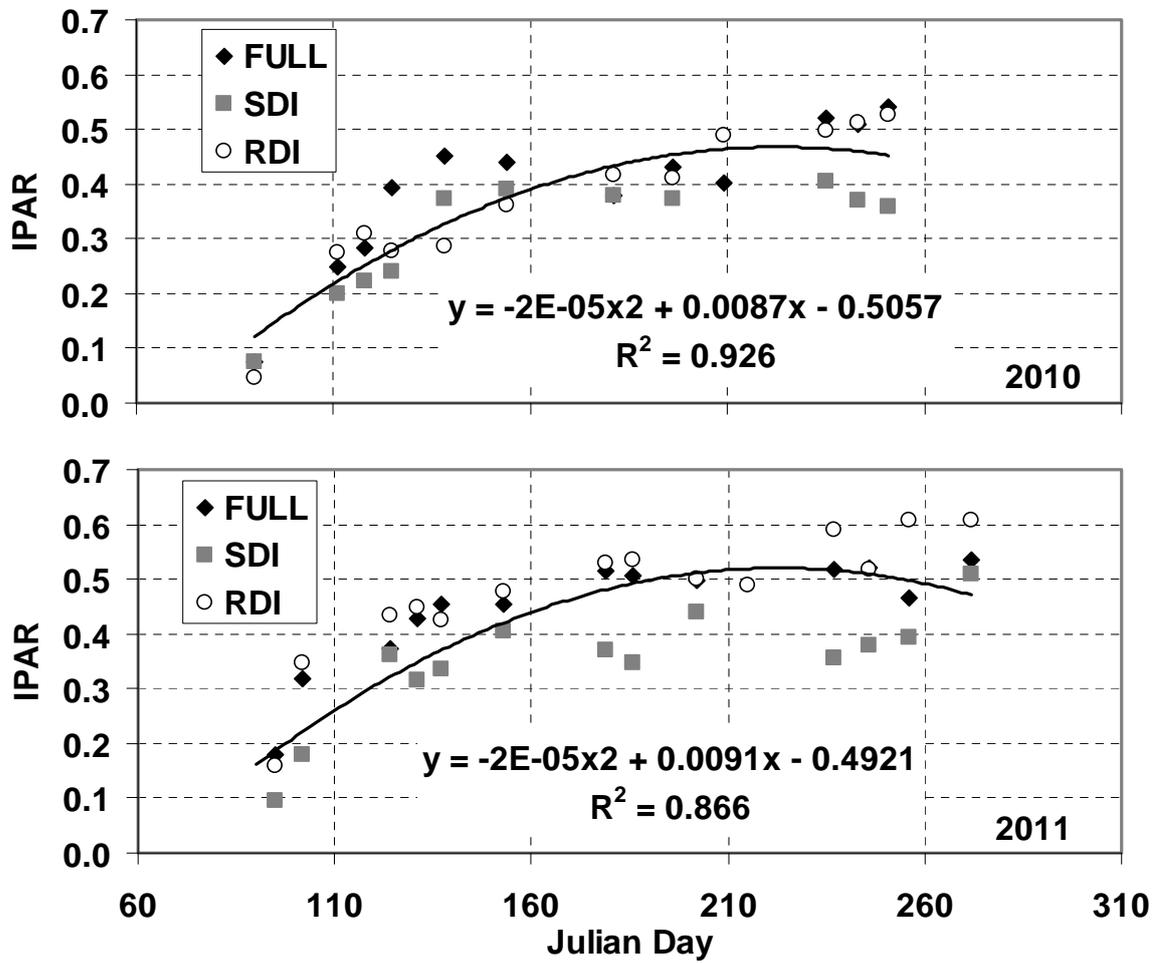


Fig. 3

