Extrapolating base-line trunk shrinkage reference equations across olive orchards

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Abstract

Maximum daily trunk shrinkage is a common measurement in irriation scheduling of fruit trees. But the strong relationship between these measurements and the environment severely limit field applications. Reference baselines are the solution for understanding the influence of environmental conditions. Nevertheless, the extrapolation out of the original conditions is not clear. The aim of this study was to compare several approaches to estimate a reference baseline in an olive orchard where there were no previous data from other seasons. Two orchards, separated 60 m, with different tree density were used. Orchard 1 had greater tree density than orchard 2, though the age and the cultivar were the same. Trunk diameters of both orchards were similar but the crown volume of orchard 2 was slightly lower than orchard 1. The current reference baselines of maximum daily trunk diameter in both orchards were not significantly different between them ($p<0.05$). In orchard 1, the previous reference baseline was calculated in a 5-year study (the so called multi-seasons approach). The multi-seasons approach was not significantly different in slope but it was in the y-interception to the current reference baselines in both orchards ($p<0.05$). This approach over-estimated the values in both orchards. Two additional approaches were tested. These latter approaches used data before massive pit hardening to estimate the current reference baseline. One of them used the early data to estimate a complete reference baseline (the so-called early approach). The other (the so-called y-early approach) used the same data only to estimate the y-interception and assumed that the slope was the same as in the multi-seasons approach. The early approach under-estimated the value of maximum daily trunk shrinkage. The early-y approach provided a satisfactory estimation of the reference baseline and improved those obtained with the multi-seasons approach. The limitations and uses in irrigation scheduling are also discussed.

Keyword: Irrigation scheduling, plant water status measurements, trunk diameter fluctuations, water relations.

1. Introduction

The Olive (*Olea europaea* L.) is a traditional rain-fed fruit tree in the Mediterranean basin. In the last 20 years, the intensification of olive cultivation has advanced greatly. These new orchards are irrigated and have higher tree density than traditional ones. The increase in cultivation has coincided with an increase in water demand for other uses (Fereres and Evans, 2006) and this strongly limits the amount of water available for irrigation purposes.

Regulated deficit irrigation (RDI) is a common irrigation scheduling technique in fruit trees, which saves water with low or null variations in yield (Behboudian and Mills, 1997; Naor, 2006). When RDI is applied, plant water status measurements are needed to control the intensity of the plant water stress imposed (Fereres and González-Dugo, 2009). In deficit irrigation scheduling, techniques of continuous measurement of plant water status allow adequate daily watering for control of water stress level (Ortuño et al., 2010). Trunk diameter fluctuations have been suggested in several fruit trees as a very efficient tool for RDI (i.e. almond, Goldhamer and Fereres, 2004; peaches, Conejero et al., 2011), but not in others such as olive trees (Moriana et al., 2003; Moriana et al., 2010). Trunk diameter fluctuations are a daily cycle of shrinkage (from the beginning of the day) and swelling (from mid-afternoon) which occurs in all plants (Klepper et al., 1971). This daily cycle provides two parameters which are used in irrigation scheduling: maximum daily trunk shrinkage and trunk growth rate.

Goldhamer and Fereres (2001) suggested the first approach for irrigation scheduling with a trunk diameter fluctuations parameter. In a young orchard, these authors suggested the comparison with maximum daily diameter to estimate trunk growth. However, although this parameter is presented in several studies (i.e. Goldhamer et al 1999) extrapolation to other locations is not easy. Moriana and Fereres

(2002), in olive trees, reported that maximum daily diameter would be difficult to extrapolate to other conditions and suggested trunk growth rate (the slope of maximum daily diameter) as easier to use in irrigation scheduling. However, only in young olive trees, a good relationship between TGR and temperature has been reported (Pérez-López et al., 2008). No strong relationship between either of these parameters and a meteorological variable has been found in mature orchards of any fruit species. This lack of results is probably related to the strong relationship between fruit development and both parameters (olive, Moriana et al., 2003; plum, Intrigliolo and Castel, 2007; olive, Pérez-López et al., 2008).

Maximum daily trunk shrinkage is the indicator derived from trunk diameter fluctuations most widely suggested in irrigation scheduling in several fruit trees (Ortuño et al., 2010; Fernández and Cuevas 2010). The increase in maximum daily trunk shrinkage has traditionally been associated with water stress conditions (Ortuño et al., 2010), though it is also strongly related to evaporative demand (Herzog et al., 1995). A reference is therefore needed in order to separate the effect of evaporative demand and soil water deficit. Reference baseline is a simple regression equation that estimates maximum daily trunk shrinkage in fully irrigated conditions from one meteorological parameter. Parameters such as temperature or vapor pressure deficit would provide an estimation of maximum daily trunk shrinkage in fully irrigated conditions and thus irrigation could be scheduled according to the water stress level previously decided. Goldhamer and Fereres (2001) suggested the maximum daily trunk diameter signal, which is the ratio between the measured and the estimated values, as an indicator of water stress level.

Previous studies conducted on olive trees have concluded that maximum daily trunk shrinkage is not a reliable water status indicator in moderate water deficit conditions (Moriana and Fereres, 2002; Moriana et al., 2010; Cuevas et al., 2012). However, Moriana et al (2000) reported a maximum daily trunk shrinkage vs. stem water potential relationship in olives that estimated a decrease in maximum daily trunk shrinkage in severe water deficit conditions. Olive trees are a very drought resistant species, in which severe water stress conditions during massive pit hardening (mid-summer) do not affect or only slightly reduce yield (Goldhamer, 1999). A reference baseline would therefore be useful in order to impose such stress conditions during this phenological period.

Several authors have reported reference baselines of maximum daily trunk shrinkage in relation to different meteorological data. The most commonly reported are vapour pressure deficit (VPD) and air temperature (amongst others, almond, Goldhamer and Fereres, 2004; lemon, Ortuño et al., 2009; mandarin, Pagán et al., 2008; peach, Conejero et al., 2011; plum, Intrigliolo and Castel, 2007). There are only three studies of olives that estimated a reference baseline (Moriana and Fereres, 2004; Moreno et al., 2006; Moriana et al., 2011). Moriana and Fereres (2004), with one season´s data, suggested VPD as the meteorological variable but without comparison to other meteorological data. Moreno et al (2006), with one season´s data, compared four different meteorological measurements (VPD, temperature, radiation and reference evapotranspiration) and reported that VPD and temperature presented the best agreement with maximum daily trunk shrinkage data. Moriana et al (2011), in a five-year study, showed that maximum daily temperature was beteewn others (VPD and temperatures at different time) the best fit with maximum daily shrinkage. These authors also considered that maximum temperature was easier to obtain than VPD and temperature measurements at different time of the day.

One of the main problems in the management of the reference baseline is validation in other places or seasons. In order to eliminate the influence of inter-season changes most studies use data from several seasons (i.e. Ortuño et al., 2009; Conejero et al., 2011; Moriana et al., 2011). However, Goldhamer and Fereres (2004) reported a reference baseline estimated only with the data of the beginning of the irrigation season. The extrapolation of the reference baseline to other places (with different cultivars or/and tree spaces) is more related to factors such as fruit load or tree dimensions and, from our knowledge, there are no studies in the literature. Fruit load has been reported as a significant factor that slightly varied the equations obtained (Intrigliolo and Castel 2007; Conejero et al., 2010; Moriana et al., 2011). However, such differences are small and, in a commercial orchard, fruit load could be not considered (Moriana et al., 2011). The influences of tree age (Moriana and Fereres, 2004) or trunk diameter (Genard et al, 2001; Intrigliolo and Castel, 2006) were also significant. Reference baseline would therefore probably need a previous local calibration.

The aim of this study is to compare several approaches to estimating a reference baseline in an orchard where there are no previous data. This reference baseline will be used during the massive pit hardening period. Two approaches use current season data before massive pit hardening. And a third approach uses a previous reference baseline (Moriana et al., 2011), calculated on the same experimental farm, but in an olive orchard with closer tree spacing.

2. Material and Methods

The experiment was performed in two orchards during the summer of 2011 at La Hampa, the experimental farm of the Instituto de Recursos Naturales y Agrobiología de Sevilla (IRNAS-CSIC). These orchards are located at Coria del Río near Seville (Spain)

(37º 17’’N, 6º 3’W, 30 m altitude). The sandy loam soil (about 2 m deep) of the experimental site was characterized by a volumetric water content of 0.33 m^3 m^{-3} at saturation, 0.21 m^3m^{-3} at field capacity and 0.1 m^3m^{-3} at permanent wilting point, and 1.30 (0-10 cm) and 1.50 (10-120 cm) g cm^{-3} bulk density.

The two olive orchards (*Olea europaea* L cv Manzanillo) were irrigated during the previous season with no water limitation. Orchard 1 was 41 years old and the tree spacing was 7 x 5 m. This orchard was the same where the reference baseline of Moriana et al (2011) was calculated, but the trees used in the present study were different. Orchard 2 was also 41 years old and tree spacing was 7 m x 7m. This orchard was beside orchard 1 and separated by around 60 m. The crown volume and trunk diameter of the experimental trees were not significantly different between orchards ($p<0.05$, Table 1). However, the trees in orchard 2 had markedly lower values of crown volume than orchard 1 (around 25% less) and lower ground cover (orchard 1 40%; orchard 2 24%). The beginning of the massive pit hardening was estimated according to Gijón et al (2010) at day of the year (DOY) 157 in the orchard 1 and 164 in the orchard 2.

Pest control, pruning and fertilization practices were those commonly used by growers and no weeds were allowed to develop in the orchard. Irrigation was carried out during the night by drip using one lateral pipe per tree row and five emitters per plant, delivering 8 L h-1 each. Micrometeorological 30 min data, namely air temperature, solar radiation, relative humidity of air and wind speed at 2 m above the soil surface were collected by an automatic weather station located some 40 m from the experimental site. Daily reference evapotranspiration (ET_o) was calculated using the Penman-Monteith equation (Allen et al., 1998).

Irrigation requirements were determined as the difference between crop evapotranspiration (ET_c) and rainfall. Soil moisture was not considered in the water balance in order to obtain no water stress conditions. ET_c was determined according to daily reference evapotranspiration (ET_o) and a crop factor based on the time of the year and the percentage of ground area shaded by the tree canopy (Fereres and Goldhamer, 1990). The crop coefficient values (K_c) considered were 0.76 in May, 0.70 in June, 0.63 in July and August, 0.72 in September and 0.77 in October (Fernández et al., 2006). The values of the coefficient in relation to the percentage of ground covered by the crop (Kr) were 0.8 in orchard 1 and 0.48 in orchard 2. The values of crop evapotranspiration (ET_c) and total amount of applied water (rainfall not included) during the experimental period (from the end of April until the middle September) are shown in Table 2.

Trunk diameter fluctuations (TDF) are a daily cycle of shrinkage and swelling. TDF were measured throughout the experimental periods, using a set of linear variable displacement transducers (LVDT) (model DF±2.5 mm, accuracy ±10 μm, Solartron Metrology, Bognor Regis, UK) attached to the main trunk, with a special bracket made of Invar, an alloy of Ni and Fe with a thermal expansion coefficient close to zero (Katerji et al., 1994). Measurements in 6 trees in orchard 1 and 5 trees in orchard 2 were taken every 10 s and the datalogger (model CR10X with AM 416 multiplexer, Campbell Sci. Ltd., Logan, USA) was programmed to report 15 min means. Maximum daily trunk shrinkage (MDS) was calculated as the difference between the maximum daily diameter, which occurs at the beginning of the day, and the minimum daily diameter, which occurs at mid-afternoon (Goldhamer et al., 1999).

The determination of the reference baseline supposed fully irrigated conditions. Several parameters were measured in order to establish the water status of the tree (soil moisture, maximum trunk diameter, stem water potential). Soil moisture was measured with a portable FDR sensor (HH2, Delta-T, U.K.) with a calibration previously obtained. The access tubes for the FDR sensor were placed in the irrigation line around 30 cm from the emitter. The data were obtained at 1 m depth and 10 cm intervals.

Maximum daily diameter of TDF daily cycle showed the trunk growth (Goldhamer et al 1999) and it was initially suggested as an indicator in water status measurements (Goldhamer and Fereres, 2001). However, trunk growth rate (TGR), the slope of maximum daily diameter, was considered a better parameter to describe the cycle of stress and re-watering (Moriana and Fereres, 2002). TGR in day "n" was calculated as the difference between the maximum daily diameter of day "n+1" minus the ones from the day "n" (Cuevas et al 2010). In order to characterize the trunk growth, maximum daily diameter was represented and also average TGR values were presented.

The stem water potential was measured at midday in one leaf per tree, using the pressure chamber technique (Scholander et al., 1965). Leaves near the main trunk were covered with aluminium foil at least one hour before measurements were taken.

The reference baseline of maximum daily trunk shrinkage would be used during pit hardening. The aim of this study was to establish a methodology for estimating a reference baseline in a current season before the massive pit hardening period. Reference baseline was estimated with maximum temperature. According to the literature maximum temperature is the best meteorological parameter (Moriana et al., 2011). Three different approaches were used to estimate the reference baseline:

1) Multi-seasons approach. This approach used the 5-year reference baseline calculated previously in orchard 1 (Moriana et al. 2011). Moriana et al (2011) reported that the low fruit load season´s equations were significantly different to the high fruit load season´s equations. However, according to this author such differences were small

and a general equation with all the seasons is suggested for commercial purposes. This general equation is the one used in this approach in both orchards.

2) Early approach. This approach was based on the methodology suggested in Goldhamer and Fereres (2004). The hypothesis is that data at the beginning of the season would allow the estimation of the reference baseline for the current season. The reference baselines in each orchard were estimated with data measured in the current season before the beginning of massive pit hardening.

3) Early-y approach. This approach is a mix of approaches 1 and 2. Moriana et al (2011) reported differences in the y-interception of the reference baseline due to fruit load, but not in the slope. The hypothesis is that changes in the reference baseline would be only in y-interception and not in the slope. Therefore, in this approach, data before massive pit hardening would estimate y-interception of the reference baseline. The slope used was the same as the multi-seasons approach.

In all three cases reference baseline was obtained by linear regression analysis, between the two variables. Differences between regression lines were determined with T-test of the slope and y-intercept. The comparisons between early-y approach and the current reference baseline and the early approach were done with confidence intervals (95%) of the slope and y-intercept. Equations were validated with the measured data of Maximum daily trunk shrinkage. And statistical differences with the 1:1 line were determined with T-test.

3. Results.

The experiment was performed from day of the year (DOY) 100 to 260 in 2011. Environmental variables fluctuated widely during this period, as is customary in the area. Mean daily air temperature (T_m) and maximum air temperature (T_{max}) presented a similar trend, reaching maximum values in August (Fig. 1A). Average T_m and average T_{max} were 25.6 and 33.5ºC respectively. The pattern of daily ET_o fluctuated widely, showing maximum values in late June and early July, and minimum values in early September (Fig. 1B). Total ET_o during the experimental period was 637 mm (Fig. 1B). Rainfall was very scarce, 87.1 mm during the experimental period, and occurred in June and late August (Fig. 1B). During the experimental period the volumetric soil water content in the profile (0-1m) was almost constant in the two orchards, with values close to field capacity content (Fig 1C). Soil water content in orchard 2 was always slightly higher than in orchard 1, average values were 0.23 $m^{-3}m^{-3}$ and 0.26 $m^{-3}m^{-3}$ in orchard 1 and 2 respectively (Fig 1C).

Stem water potential presented a similar pattern in both orchards, with an almost steady pattern throughout the experimental period (Fig. 2A). In orchard 1, stem water potential varied from -0.8 MPa to around -1.2 MPa, the average value was -1.13 MPa. In orchard 2, values varied from -0.7 MPa to -1.4 MPa, the average value was -1.17 MPa. Maximum daily trunk shrinkage (MDS) showed a similar pattern in both orchards, as shown in Figure 2B. Maximum daily trunk shrinkage increased slightly from the beginning of the experiment. The highest values of maximum daily trunk shrinkage in both orchards were observed during August (around 779 μm). Maximum daily diameter increased during the season in both orchards; Orchard 2 had the highest growth (Fig. 2C). The periods of sharp increase and decrease of maximum daily diameter (orchard 1, DOY 118-129; DOY 138-143; DOY 241-250; orchard 2, 136-143; DOY 237-250) were related to rainfall events (Fig. 1B), probably strongly influenced by the increased trunk moisture content. If these periods of rain are excluded, trunk growth was almost constant with a slight increase from DOY 187 in orchard 1 and at DOY 183 in orchard 2. In orchard 1, trunk growth rate (TGR), the slope of the maximum daily diameter figure, was lower than in orchard 2. (TGR was 8.4±2.3 in orchard 1 and 33.7±4.6 μm day^{-1}, in orchard 2).

Crop evapotranspiration (ET_c) and applied water in orchard 1 was 30% higher than in orchard 2 (around 30% in both parameters), due to tree spacing (Table 2). Yields were very low in both orchards: with a yield of 2.5 t ha^{-1} in orchard 1 and 0.6 t ha^{-1} in orchard 2.

The relationships between maximum daily trunk shrinkage (MDS) and maximum air temperature (T_{max}) for both orchards are shown at Fig. 3. The best fit, when all the data are considered, was $MDS=-667+34T_{max}$ (equation 1), in orchard 1 and $MDS=-757+37T_{max}$ (equation 2) in orchard 2 (Fig 3). The last two, equations 1 and 2, were therefore the reference baselines for this season. The equations were not significantly different ($p<0.05$). Equations 1 and 2 were slightly displaced compared to the multi-seasons approach (Fig. 3a; $MDS=-640+36T_{max}$, Moriana et al., 2011). The y-interception was significantly different between equations 1 and 2 and the multi-seasons approach ($p<0.05$). However, there were no significant differences in the slope between the two equations and the multi-seasons approach ($p<0.05$).

The early approach estimated the reference baseline only with the early data (before massive pit hardening, solid symbols at Figure 3b). The best fit with the early approach was $MDS=-137+13T_{max}$ in orchard 1 and $MDS=-478+26T_{max}$ in orchard 2. Both latter equations obtained with the early approach were significantly different from equations 1 and 2 respectively ($p<0.05$).

Finally, the Early-y approach estimated only the y-interception with the data before massive pit hardening (Fig. 3c). The equation estimated was $MDS=-792+36T_{max}$ in orchard 1 and $MDS=-760+36T_{max}$ in orchard 2. In both orchards, the slope and the y-interception of the early-y approach were in the confidence interval (95%) of equations

1 and 2, respectively. In orchard 1, the slope was also in the confidence interval (95%) of the early approach but not in orchard 2.

The equations calculated in the three approaches were validated with the data measured from the beginning of massive pit hardening (Fig. 4). In both orchards, all the approaches were significantly different to the 1:1 line ($p<0.05$). The multi-seasons approach clearly over-estimated in all the ranges of maximum daily trunk shrinkage (Fig. 4a). The early approach underestimated the measured values (Fig. 4b). In the early approach, the differences were greater in orchard 1 than in orchard 2 (Fig. 4b). The early-y equation is the nearest to the 1:1 line in both orchards, especially with maximum daily trunk shrinkage values lower than 500 μm (Fig 4 c).

4. Discussion

Deficit irrigation scheduling based on water status measurements such as trunk diameter fluctuations had a very significant advantage in comparison with the traditional water balance (Ortuño et al., 2010). This is that the control of water stress level instead of applied water permit an easier extrapolation to different conditions. However, the great variability of the indicators of trunk diameter fluctuations (Naor et al., 2006) and the strong relationship with the environment probably limit the use in places different to those where the experiments were performed. According to the present study, tree spacing was not an important factor and almost the same reference baseline could be used (Fig. 3). Although an important parameter as trunk diameter were similar (Table 1), the changes in tree environment, mainly radiation, due to the tree spacing (ground covers were clearly different, Table 1) would be enough to produce significant changes in the maximum daily trunk shrinkage. Trunk diameter fluctuations are mainly produced by hydration and dehydration of the bark (Brough et al., 1986) and had been associated with changes in trunk water content (Simmoneau et al., 1993). Therefore, maximum daily trunk shrinkage has been considered a good indicator in fully irrigated conditions of tree transpiration (Herzog et al., 1995). So according to the reference baseline of orchard 1 and 2, tree transpiration was similar in both orchards. However, the interception radiation of the trees was different and, therefore, the canopy transpiration was also likely different. On the other hand, the soil allotted per tree is larger in the wider tree spacing orchard, probably the more water transpired by the canopy is compensated by the larger root water uptake capacity. Then maximum daily shrinkage would not be associated to transpiration as strong as other authors suggest and, in fact, estimates the difference between root uptake and canopy transpiration.

Fruit load is a factor that, in olives trees, could also affect the extrapolation of the reference baseline. Alternate bearing could be produced by climatic and biotic conditions, or, which is most common in table olives, excessive pruning. The multi-season approach did not consider this effect, though fruit load produced significant changes in water relations and transpiration in olive trees (Martín-Vertedor et al., 2011). This approach over-estimated maximum daily trunk shrinkage mainly with values lower than 500 μm (Fig. 4). These variations were probably produced by the very low fruit load conditions. Moriana et al (2011) suggested that the variations when fruit load were not considered would be small. However, according to the present study deviations greater than 25% than the measured value would be obtained, mainly with low values of maximum daily trunk shrinkage (Fig. 4). Intrigliolo and Castel (2007) reported a similar decrease (around 34%) in maximum daily trunk diameter due to fruit load in plums. The yield in the present study was very low and should be considered even as null (Table 2). Martín-Vertedor et al (2011) in olive trees reported that the significant variations in stomata conductance occurred between off-season (when no yield was recorded) and the rest of seasons (with medium and high yield). Therefore, the multi-season approach could be useful in conditions of significant yield.

Although significant yield would be expected an estimation of the reference baseline with current season data and with the local conditions would be a better approach than the multi-season approach. The approach suggested by Goldhamer and Fereres (2004) in almonds (the so-called early approach) was used in this way. However, the early approach was the worst in both orchards (Figs. 3 and 4). These disagreements with the results in almonds of Goldhamer and Fereres (2004) are probably related to the differences between the water relations of both fruit species. The daily cycle of stomatal leaf conductance in full irrigated conditions is not limited by evaporative demand in almond (Marsal and Girona, 1997) while in olive trees there is a reduction at midday (Angelopoulos et al., 1996). Such differences in the daily pattern stomata could suggest different respond to high transpiration conditions. According to the present study, maximum daily trunk shrinkage greater than 400 μm was under-estimated with the early approach (Fig. 4). Therefore, the greatest conditions of transpiration likely changed the amount of water that the trunk transferred to the transpiration stream. In olive, the tree could increases the amount of water from the trunk more than in almond and then maximum daily shrinkage was higher than expected, Such increase could be related to the greater capacity of dehydration in olive trees (Fereres, 1984).

Maximum daily trunk shrinkage is affected by several factors which would change the pattern of its relationship with temperature in the long term, water status conditions (Genard et al., 2001) and wood composition (Drew and Dones, 2009) are probably the most important. Such changes would probably vary the reference baseline even though fully-irrigated conditions were performed during the current or previous season. The present study confirmed that these changes occurred, but only in the y-interception, while the slope of the equation was not affected (Fig. 4). The early-y approach made it possible to obtain the reference baseline before massive pit hardening with only the estimation of the y-interception. The extrapolation to other Manzanillo orchards is probably possible, but further work is needed to study the influence of the cultivar. Moriana and Fereres (2004) reported reference baseline using vapor pressure deficit (VPD) with different cultivars and age orchards, but similar environmental conditions. When VPD is considered for the same fruit load an almost equal slope was found between mature cv Manzanillo (Moriana et al. 2011) and mature cv Picual (Moriana and Fereres, 2004). The influence of tree age is probably different, young cv Arbequino showed a different slope and y-interception than mature cv Picual (Moriana and Fereres, 2004) and mature cv Manzanillo (Moriana et al., 2011). Goldhamer and Fereres (2001) suggested that the maximum daily trunk shrinkage would be smaller in young trees than in mature because of the greater growth in the former. In almonds, the reference baseline reported in several studies for young orchards was similar with different cultivars (Fereres and Goldhamer, 2003; Goldhamer and Fereres, 2004). Egea et al. (2009) with three season´s data in a young almond orchard suggested that the reference baseline could be estimated every 1-2 years with the data of the beginning of the season, though slight differences due to phenological stage were reported.

5. Conclusions

The extrapolation of reference baseline of maximum daily trunk shrinkage to other orchards was possible in mature cultivar Manzanillo. The reference baselines were similar between orchards, though spacing and ground cover were different. Slight variations in the y-interception were found in both reference equations. The multi-season approach, a general equation previously calculated, over-estimated both reference baselines. Such results were probably related to the extremely low fruit load in both orchards in comparison with the ones obtained when the multi-season approach was calculated. A multi-season approach would be useful in conditions of significant yield. An early approach that estimated the complete (slope and y-interception) reference baseline was not possible because significant variations in the slope were found with the increase in maximum daily trunk shrinkage. This result is not consistent with the ones reported in almond. The differences in the stomata leaf conductance pattern between both species were probably related to the lack of results. The reference baseline in all the estimations was similar in slope but different in y-interception. The early-y approach that only estimated this latter component of the reference baseline presented a good fit between observed and measured data during the period of pit hardening. According to the present results and literature the early-y approach would be useful in the estimation of reference baseline in mature orchards even when different cultivars were considered.

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Table 1. Dimensions and distance in the orchard of the experiment. There were no significant differences between orchard 1 and orchard 2 in crown volume or trunk diameter.

	Distance (mxm)	Ground cover	Crown Volume (m^3 $tree^{-1}$)	Trunk Diameter (m)
Orchard 1	7x5	40%	31.3±4	0.24±0.01
Orchard 2	7x7	24%	23.6±2	0.23±0.01

Table 2. Crop evapotranspiration, irrigation applied and yield components: yield (Yield (kg tree^{-1}) and harvest (t ha^{-1}).

	ETc (mm)	Irrigation applied (mm)	Yield (kg tree^{-1})	Yield (t ha^{-1})
Orchard 1	299.7	285.4	8.9 ± 6.0	2.5 ± 1.7
Orchard 2	214.0	196.7	2.9 ± 1.4	0.6 ± 0.3

Figure captions

Fig. 1. Daily mean(T_m, solid line) and maximum (T_{max}, dotted line) air temperature (A), reference evapotranspiration (ETo, solid line) and daily rainfall (vertical bars) (B) and volumetric soil water content (θ_v) down to 1m depth (Orchard 1: open symbols, Orchard 2 solid symbols) values during the experimental period (C). Horizontal lines (C) represent volumetric soil water content at permanent wilting point (WP), at field capacity (FC) and at saturation (S), respectively.

Fig. 2. Midday stem water potential (Ψ_{stem}) (A), maximum daily trunk shrinkage (MDS) (B) and maxium daily dimater during experimental period (C) (Orchard 1: open symbols and Orchard 2 solid symbols). Each point is the average of 6 measurements at Orchard 1 and 5 measurements at orchard 2.

Fig. 3. Relationship between maximum daily trunk shrinkage (MDS) and maximum temperature at orchard 1 (□) and orchard 2 (△). In the figure different reference baselines are presented. In all of them, the best fit for each orchard is presented. Orchard 1, MDS=-667+34T_{max} (bold solid line, R^2=0.60***, RMSE=107 µm, n=132). Orchard 2, MDS=-757+37T_{max} (bold dash line, R^2=0.67***, RMSE=84 µm, n=91) (A) Comparison between the best fit and the multi-seasons approach (solid line, MDS=-640+36 T_{max}, Moriana et al, 2011). (B) Comparison between the best fit and the early approach in orchard 1 (gray line, MDS=-137+13T_{max}, R^2=0.52***, RMSE=52 µm, n=30) and orchard 2 (gray dash line, MDS=-478+26T_{max}, R^2=0.58***, RMSE= 64µm; n=21). (C) Comparison between the best fit and the early-y approach in orchard 1 (gray line, MDS=-792+36T_{max}) and orchard 2 (gray dash line, MDS=-760+36T_{max}).

Fig. 4. Relationship between measured and estimated maximum daily trunk shrinkage (MDS) data from the beginning of the massive pit hardening. In all the figures the 1:1 line is represented. The graph compares the results in orchard 1 (□) and orchard 2 (△) using the multi-seasons (A), early (B) and early-y (C) approaches. (A) Orchard 1(gray line, Y=265+0.6X, R^2=0.65***; RMSE=70 μm, n=101) and orchard 2(gray dash line, Y=272+0.6X, R^2=0.61***, RMSE=67 μm, n=70). (B) Orchard 1 (gray line, Y=190+0.2X, R^2=0.65***, RMSE=25μm, n=101) and orchard 2 (gray dash line, Y=181+0.43X, R^2=0.61***. RMSE=48 μm, n=70). (C) Orchard 1(gray line, Y=114+0.6X, R^2=0.65***, RMSE=70 μm, n=101) and Orchard 2 (gray dash line, Y=152+0.6X, R^2=0.61***, RMSE=67μm, n=70).