Determining evapotranspiration in an olive orchard in southwest Spain

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Abstract

The aim of this work was to evaluate, for an olive orchard in the Aljarafe county, the method developed by Orgaz et al. (2005) for determining the crop evapotranspiration (ET_c). We compared the calculated ET_c ($ET_{c\ Orgaz}$) values with those determined by the crop coefficient approach ($ET_{c\ crop\ coef}$), as described by Fernández et al. (2006), who used coefficient values previously calibrated for our orchard conditions. In addition, we compared the tree transpiration (E_p) values estimated with the mentioned Excel application ($E_{p\ Orgaz}$) with those simulated by a transpiration model ($E_{p\ sim}$) based on Penman-Monteith, validated for our orchard conditions. Results showed that the Excel application is a user-friendly tool valid for calculating reasonably accurate values of ET_c from very few easy-to-measure inputs. The crop coefficient approach does not have this limitation, but years with unusual leaf area density may lead to errors on the calculated ET_c. $E_{p\ sim}$ is highly affected by variables difficult to measure in commercial orchards, such as the leaf area and the available soil water. In addition, processes related to leaf aging, soil temperature and recovery after drought are not include yet in the model, which affects the reliability of the $E_{p\ sim}$ values at the end of the irrigation.

INTRODUCTION

A correct irrigation management involves a precise determination of the crop water needs. For olive orchards, as well as for orchards of many other fruit tree species, the water crop coefficient method (Allen et al., 1998) has been widely used with that purpose (Fernández and Moreno, 1999). Still, the method has limitations derived from its empirical character, which makes difficult to extrapolate the crop coefficient (K_c) values to orchards different from those in which the existing values have been obtained. Recently, Orgaz et al. (2005) described a more mechanistic method for calculating K_c in any type of olive orchard, based on basic features easy to quantify in commercial orchards. Later, Testi et al. (2006) and Orgaz et al. (2006) described with detail this approach, an included a new component in the calculation of K_c, accounting for the evaporation of the water intercepted by the canopy. The Orgaz et al (2005) method was used to develop a user-friendly Excel application intended to calculate crop water requirements in commercial orchards, which was delivered with the book by Pastor et al. (2005). Our aim was to evaluate the method by Orgaz et al. (2005) in an olive orchard representative of the commercial orchards in the Aljarafe county, the main production

area for 'Manzanilla de Sevilla'. We compared the $ET_{c\ Orgaz}$ values with the $ET_{c\ crop\ coef}$ values. Results from the soil water balance carried in the same orchard by Palomo et al (2002) show that the K_c values suggested by Fernández et al. (2006) are reasonably precise for our orchard conditions. In addition, we compared the $E_{p\ Orgaz}$ values with the $E_{p\ sim}$ values.

MATERIALS AND METHODS
Orchard characteristics

The experiments were made at 'La Hampa', the experimental farm of the *Instituto de Recursos Naturales y Agrobiología* (IRNASE-CSIC). The farm is located in the Aljarafe county, close to Coria del Río, at 15 km to the southwest of Seville (37º 17' N, 6º 3' W, 30 m a.s.l.). The olive orchard was planted in 1969 with 'Manzanilla de Sevilla' olive trees at 7 m × 5 m spacing. The orchard is representative of those in the area. The trees have a single trunk with two main branches from 0.7 to 1.5 m above ground. The effective depth of the root system is about 0.9 m (Fernández et al., 1991). The canopy is spherical and open at the top. Average values of canopy volume and leaf area density (LAD) at the end of the growing season were 36 m^3 and 1.6 m^2 m^{-3}, respectively. The ground covered by the canopies was about 34%. Herbicides were used during the irrigation season to keep the soil free of weeds.

The soil is a sandy loam of about 1.6-2.0 m depth, depending on the location. The texture is quite homogeneous, with average values of 14.8% clay, 7.0% silt, 4.7% fine sand and 73.5% coarse sand. The volumetric soil water contents (θ, cm^3 cm^{-3}) at 0 MPa and -1.5 MPa are 0.33 cm^3 cm^{-3} and 0.10 cm^3 cm^{-3}, respectively. Filed θ values for field capacity are about 0.21 cm^3 cm^{-3}. The climate is typically Mediterranean, with a mild, wet season from October to April. The rest of the year is hot and dry. The average precipitation (P) and ET_o values in the area are 499 mm and 1165 mm, respectively (period 1971-2007). Main weather records for the irrigation season of 2007, the experimental period, are shown in Figure 1. The experimental orchard was irrigated daily to replace the crop water needs, with a lateral per row with five 3 L $hour^{-1}$ drippers per tree, 1 m apart. The irrigation season went from May 14 to October 2.

Calculation of ET_c

We used the crop coefficient method (Allen et al., 1998) to determine daily values of ET_c as $ET_c = K_c\ K_r\ ET_o$. We used the K_c values determined by Fernández et al. (2006) for the orchard conditions (0.76 in May, 0.70 in June, 0.63 in July and August, 0.72 in September and 0.77 in October). The value of the coefficient related to the percentage of ground covered by the crop (K_r), calculated after Fereres and Castel (1981), was 0.71. We used the REF-ET software (Allen 2000) and the records of the weather station next to the orchard to calculate daily ET_o values with the FAO56 Penman-Monteith equation (Allen et al., 1998).

We also calculated the ET_c values with the method described by Orgaz et al. (2005). More precisely, we used the Excel application delivered with the book by Pastor (2005). With this tool, monthly values of ET_c, E_p and soil evaporation (E_s) , both from the dry and wetted ground areas, are easily determined. The required inputs are related to the irrigation system and management, the weather conditions and the tree size and spacing, as described above.

Transpiration model

We used the Penman-Monteith equation to model daily E_p values in the orchard, for the whole irrigation season. We followed the approach described by Moreno et al. (1996):

$$\lambda E_{p\,sim} = f_1 \frac{s R_{n,1}}{s + \gamma\left(2 + g_{b,1}/g_{c,1}\right)} + f_1 \frac{\rho c_p D_a g_{b,1}}{s + \gamma\left(2 + g_{b,1}/g_{c,1}\right)} + f_s \frac{\rho c_p D_a g_{b,s}}{s + \gamma\left(2 + g_{b,s}/g_{c,s}\right)} \quad ,$$

where $E_{p\,sim}$ is in s^{-1} m^{-2} leaf plan area; $f_1 = A_1/A$ and $f_s = A_s/A$, being A (m^2) the total (one-side) leaf area. This comprises the area of sunlit leaves (A_1) and that of shade leaves (A_s). The values of A_1 and A_s were estimated with the RATP model (Sinoquet et al., 2001), which calculates the radiation transfer through the canopy (Diaz-Espejo et al., 2002); $R_{n,1}$ (W m^{-2} of leaf plan area) is the net, all-wave radiation of the lit leaves (assumed to be zero for the shade leaves); D_a (Pa) is the vapour pressure deficit of the air; λ is the latent heat of vapourisation (2.454 J kg^{-1}); g_c is the leaf stomatal conductance (m s^{-1}) and g_b is the leaf-canopy boundary-layer conductance (m s^{-1}); the values of g_c were calculated as $g_c = g_m\, f(\text{PPF})\, f(T_1)\, f(D_a)\, f(\theta)$, where PPF is the incident photosynthetically active photon flux, T_1 is the leaf temperature and g_m is the reference stomatal conductance measured under standard conditions (PPF = 1600 μmol m^{-2} s^{-1}, T_1 = 25 °C, D_a = 1 kPa, θ at field capacity = 0.21 m^3 m^{-3}). The f functions, described in Diaz-Espejo et al. (2006), were validated for our orchard conditions.

Measurements

The volumetric soil water contents (θ) in the soil around three representative trees were measured every 7-10 days with a Profile probe, at 0.1, 0.2, 0.3, 0.4, 0.6 and 1.0 m depths, and at 1, 2, and 3 m from the tree trunk. From the θ values we calculated the relative extractable water (REW) of the soil as REW = $(R - R_{min})/(R_{max}-R_{min})$, being R (mm) the actual soil water content, R_{min} (mm) the minimum soil water content measured during the experiments, and R_{max} (mm) the soil water content at field capacity (Granier, 1987). The leaf area (LA, m^2 one side) of the three trees in which θ was measured was estimated as described by Fernández et al. (2006). Half-hour values of the main meteorological variables were continuously recorded by an automatic weather station next to the olive orchard.

RESULTS AND DISCUSSION

Most of the 2007 irrigation season was dry and hot. The first significant precipitation amounts were recorded from mid September (Fig. 1), as usual in the area. The weather records showed a yearly value of P (411,1 mm) below average, and a yearly value of ET$_o$ (1235.0 mm) above average.

The irrigation volumes (IA, mm) were enough to keep soil water contents close to field capacity for most of the irrigation season (Fig. 2). This surely contributed to the increase in leaf area recorded during the growing season, which extended until late August (Fig. 3). Later we observed a slight decrease, caused by the oldest leaves falling from the trees. The LA values shown in Fig. 3 are similar to those recorded by Palomo et al. (2002) during the experiments in which they evaluated the crop coefficient method for our orchard conditions.

The time course of ET$_o$ for the whole irrigation season, ET$_{c\ crop\ coef.}$ and ET$_{c\ Orgaz}$, are shown in Fig. 4. The figure also shows the $E_{p\ sim}$, as well as $E_{p\ Orgaz}$. For the whole irrigation season, ET$_{c\ crop\ coef.}$ and ET$_{c\ Orgaz}$ amounted to 3413 m^3 ha^{-1} and 3839 m^3 ha^{-1},

respectively. Differences were greater in July and August, in which the monthly $ET_{c\ Orgaz}$ values were 21% and 18% greater, respectively, than those of $ET_{c\ crop\ coef}$. The REW values (Fig. 2) recorded on those months suggest that the IA estimated with the crop coefficient method were reasonably correct. Therefore, the $ET_{c\ Orgaz}$ values for July and August can be too high for the orchard conditions. Pruning practices in the Aljarafe, that led to trees with low leaf area density, may account for this. The dynamics of $ET_{c\ crop\ coef.}$ echoed that of ET_o, as expected, showing that the crop coefficient method can be useful to control high frequency irrigation. The $ET_{c\ Orgaz}$ values varied, from month to month, according to ET_o, showing also their utility for controlling irrigation, although with a lower resolution. The $E_{p\ sim}$ values also echoed ET_o, although not always were lower than $ET_{c\ crop\ coef.}$. This was especially evident late in the season (Fig. 4, bottom graph). We expected a lower precision of the model at that time of the year, since some aspects related to leaf aging, leaf gas exchange recovery after drought, or the influence of soil temperature in g_c, are not considered in the current version of the model. In addition, some disagreement between actual and $E_{p\ sim}$ values must be expected, because the transpiration model is sensitive to variables difficult to estimate precisely. This is the case of θ and LA. Thus, the calculation of the available water it is difficulted by the high spatio-temporal variability both of θ and root density; and, for LA, our experience shows that errors may easily amount to $\pm$ 20% or more. Concerning the $E_{p\ Orgaz}$ values calculated in July and August, two dry months, those amounted to 78% of $ET_{c\ Orgaz}$, being the remaining 22% the E_s. For mid September to mid October, a wet period (Fig. 1), the estimated $E_{p\ Orgaz}$ amounted to 56% of $ET_{c\ Orgaz}$ (E_s = 44% of ET_c, since this approach does not takes into account the water intercepted by the canopy). Testi et al. (2006) estimated, for an intensive olive orchard of similar characteristics, the annual value of E_s amounted to 35% of ET_c.

CONCLUSIONS

For the Aljarafe conditions, where the trees are severely pruned, the $ET_{c\ Orgaz}$ values could be too high, especially at the summer months. Using properly evaluated K_c values for the orchard conditions is not enough to get accurate estimations of ET_c when using the crop coefficient approach: among other factors, variations in LA from year to year, caused by differences on the pruning intensity or the impact of fungal diseases, may lead to erroneous ET_c estimations. Cautions taken, the approach may provide reliable ET_c values with the required resolution for high frequency irrigation. The tested transpiration model is valid for research purposes, but it has limitations for determining E_p in commercial orchards.

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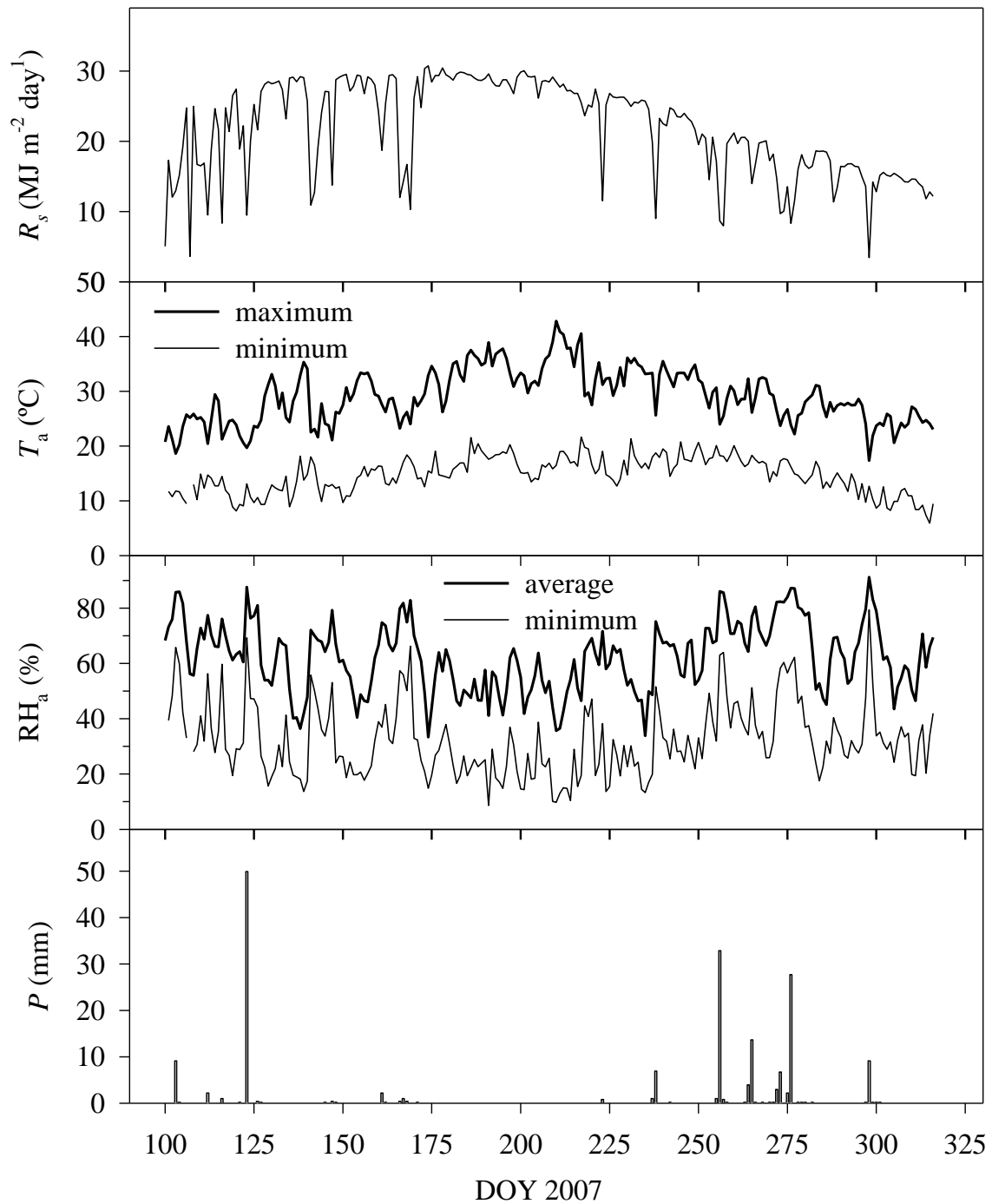
Fig. 1. Weather records collected during the experimental period by the water station next to the experimental olive orchard. R_s = solar global radiation, T_a = temperature of the air; RH_a = relative humidity of the air; P = precipitation amounts; DOY = day of year.
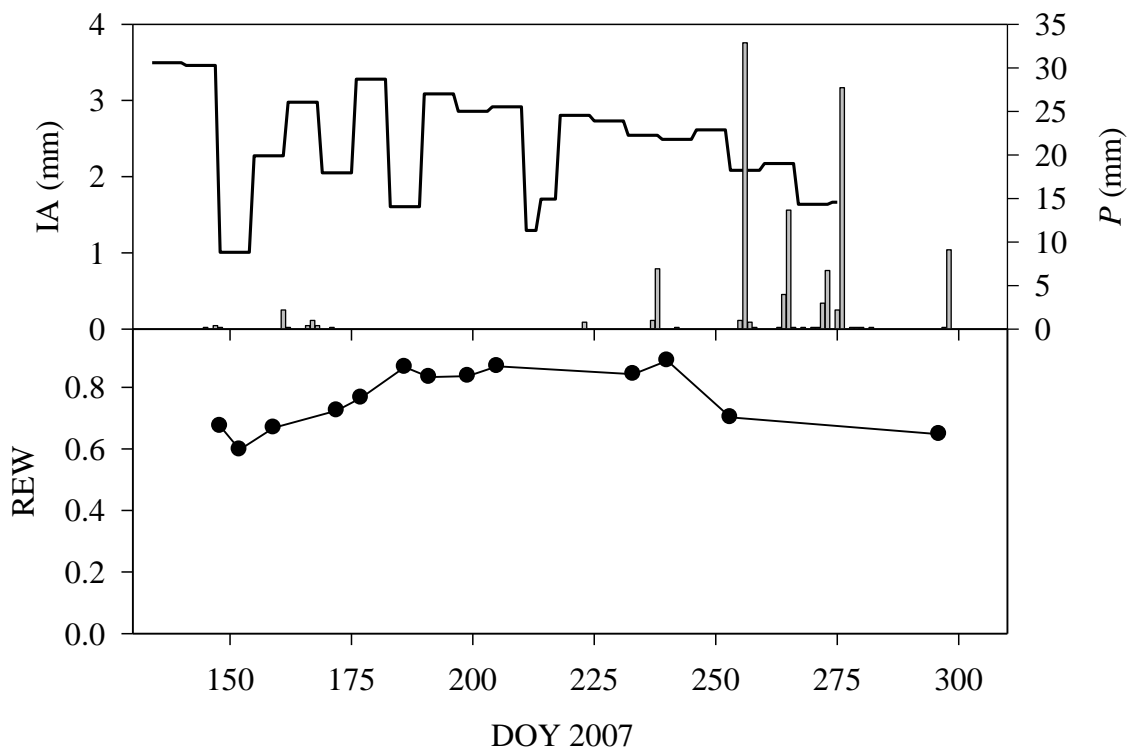
Fig. 2. Irrigation amounts (IA) supplied to the olive orchard during the experimental period. These amounts were calculated using the crop coefficient method by Allen et al. (1998) (see text for details). Also shown are the precipitation (*P*) amounts recorded by the weather station next to the orchard, as well as the resulting relative extractable water (REW) values calculated from the soil water contents recorded in the orchard. DOY = day of year.
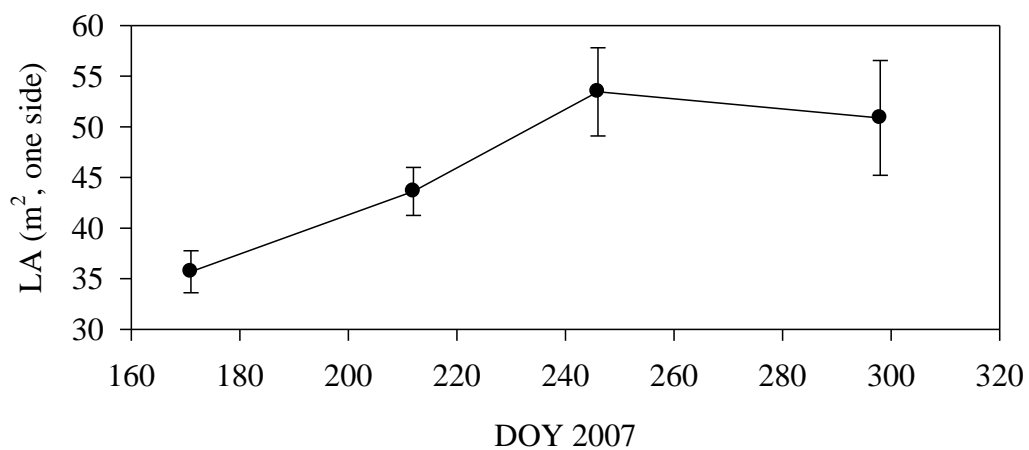

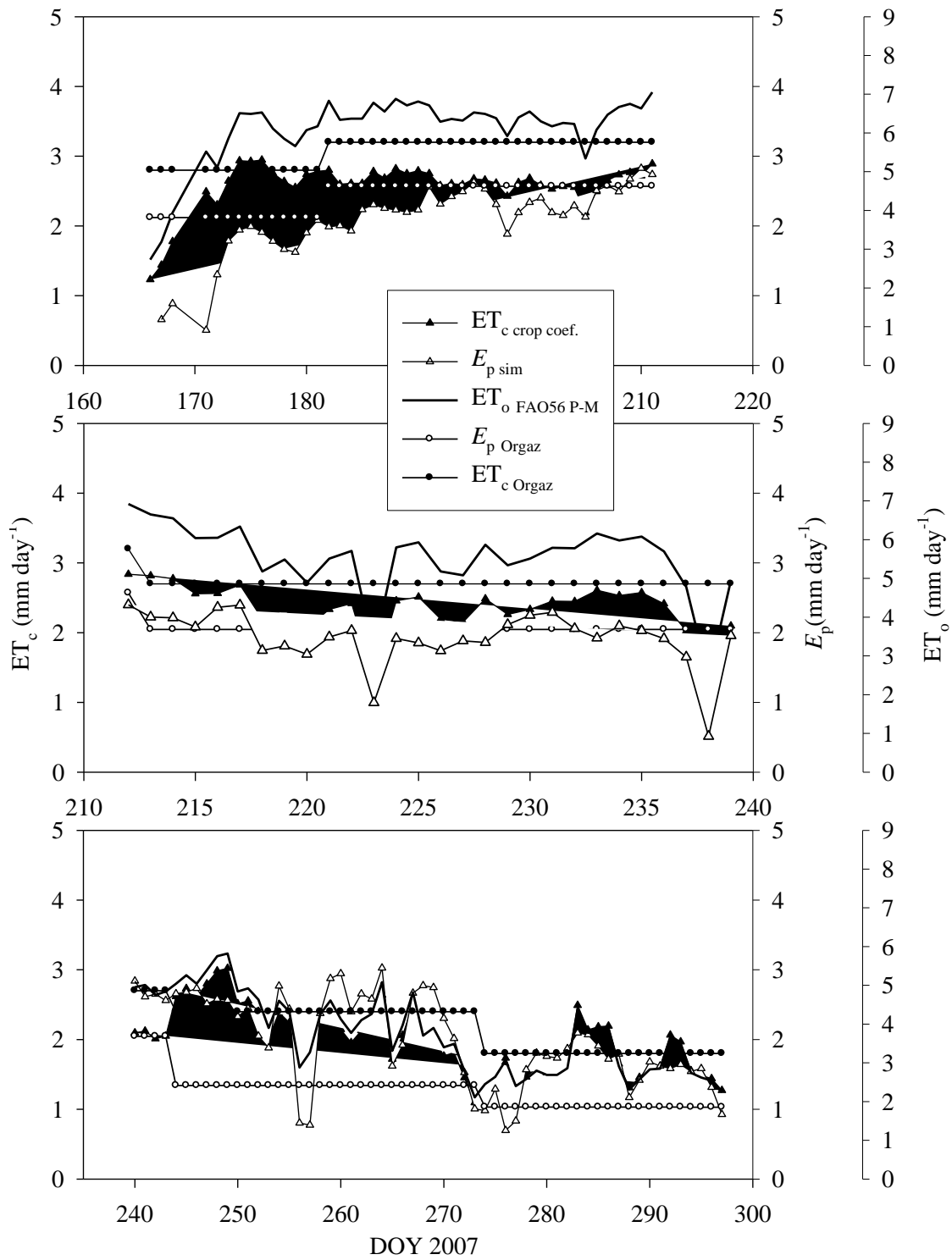Fig. 3. Leaf area (LA) values recorded during the experimental period (mean ± SE, *n* = 2). DOY= day of year.

Fig. 4. Time courses of the potential evapotranspiration (ET$_{o\ FAO56\ P\text{-}M}$) and crop evapotranspiration calculated both by the crop coefficient method (ET$_{c\ crop\ coef.}$) and after Orgaz et al. (2005) (ET$_{c\ Orgaz}$). Also show are the daily tree transpiration values simulated with our model ($E_{p\ sim}$) and estimated by the Orgaz et al. (2005) approach ($E_{p\ Orgaz}$). See text for details.