

Crop coefficient (K_c) for apple: comparison between measurements by a weighing lysimeter and prediction by CropSyst

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Abstract Accurate prediction of crop coefficient (K_c) is necessary for proper irrigation management. We explored CropSyst for determining irrigation requirements of apple trees and for accuracy of K_c prediction. Values of K_c were compared to those obtained, over 2002–2010, from lysimeter-grown trees. Over these years, trees had different ratios of height (H) to width (W). CropSyst predicted irrigation requirements using tree light interception and water uptake sub-model components. Parameters of the model were adjusted using data obtained from the lysimeter in 2010. Tree light interception sub-model was verified by 2007 data. After parameterization, good agreement was found between simulated and measured K_c over different seasons. The porosity coefficient of the canopy was related to changes in tree's H/W ratio and leaf overlapping. Accordingly, different porosity values could be estimated for each year. When yearly changes in canopy porosity was considered, CropSyst improved K_c prediction and generated relevant information for managing irrigation under changing canopy shape for apple trees.

Introduction

Since water resources are limited and the impending climate change will not help reverse the situation, there is sustained pressure for more efficient use of water in agriculture. Knowledge of crop water requirement is a prerequisite for irrigation efficiency. Obtaining this knowledge is still a difficult issue in fruit trees. Water requirements are often calculated using the following equation: $ET_c = K_c \times ET_o$ (Allen et al. 1998), where ET_c is crop evapotranspiration, ET_o is the reference evapotranspiration (Allen et al. 1998), and K_c is a crop-specific coefficient. ET_o is calculated from weather data, and K_c is empirically determined for a given crop and location. Determination of site-specific K_c is complicated because many factors can influence it in different ways across a season. Fruit tree canopies are not uniform, and their shape depends on the way they are trained. In deciduous trees, canopies are highly coupled with the atmosphere and can have different degrees of coupling from bud-break to full development (Franks and Farquhar 1999). Stomatal behaviour also changes as a tree grows across the season and the years (Marsal and Girona 1997; Olivo et al. 2009).

The work of Ayars et al. (2003) showed encouraging results of K_c determination based on noon intercepted radiation for peach growing in a weighing lysimeter. Girona et al. (2011), using a weighing lysimeter, indicated that it is not easy to determine K_c from midday light interception data for pear and apple. This difficulty could, at least partially, arise from the fact that apple and pear trees are grown in hedgerows and have a more heterogeneous surface canopy covering than the peach trees used by Ayars et al. (2003). Goodwin et al. (2006) showed constraints, and possible ways to overcome them, by extending measurements of intercepted radiation beyond noon. Tree

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size is one factor to consider, and a significant advancement has been made by Allen and Pereira (2009) by including tree height and canopy groundcover in the prediction of K_c . However, there are more factors to consider. For example, leaf overlapping in a canopy with marked vertical arrangements may change the possible influences of canopy volume or groundcover on K_c .

We hypothesized that consideration of tree size, shape, and leaf area will make substantial improvement in the prediction of canopy K_c in comparison with empirical intercepted radiation methods used by other researchers (e.g. Ayars et al. 2003). These three parameters are included in models, such as CropSyst (CS), that consider tree canopy properties. CS is a general crop growth model as described by Stöckle et al. (2003) that has incorporated tree canopy property effects on solar radiation interception (Oyarzun et al. 2007). In this study, we will use CS to predict K_c for apple trees, which will be compared with K_c values obtained from an 8-year research programme using a weighing lysimeter.

Materials and methods

Lysimeter and the measured data

Data on crop evapotranspiration were recorded from an apple lysimeter for the period 2002–2010. The data for 2002–2006 and a description of the lysimeter are found in Girona et al. (2011). Briefly, the lysimeter housed three ‘Golden Smoothee’ apple (*Malus domestica* Borkh) trees and was positioned within a 1-ha orchard. The lysimeter was installed in 1999 and the orchard planted in the same year with a spacing of 4 m between rows and 1.6 m within rows in a north–south row orientation at the IRTA-EEL in Mollerussa (41°37' N; 0°52' E; 260 m a.s.l.), Catalonia, Spain. The trees were grafted onto M9 dwarfing apple rootstock (EMLA) and trained to a modified central leader system.

We excluded the lysimeter evapotranspiration data for rainy days as well as for some days following rain. If rain was more than 1 mm, the day after the rainy day was excluded. If rain was more than 10 mm, 2 days after the rainy day were excluded. Data were also excluded when irrigation was stopped such as in 2007. In 2010, evapotranspiration and intercepted radiation were measured daily from bud-break until harvest following Girona et al. (2011). Data on the trees’ daily intercepted radiation in 2010 were obtained using six fixed custom-built ceptometers. Five ceptometers were positioned equidistant across the tree spacing at the ground level. The remaining was placed above the tree canopy. Ceptometers were connected to Campbell CR10X dataloggers (CR10X, Campbell

Scientific Inc., Logan, UT, USA) using a multiplexer (AM16/32, Campbell Scientific Inc.). More information on the light interception measurements can be found in Casadesus et al. (2011). In 2007, and for 20 specific days, intercepted radiation was measured manually every 2 h by using a portable ceptometer (Accupar Linear PAR, Decagon Devices, Inc., Pullman, WA, USA). This was done as described by Auzmendi et al. (2011).

The data and the parameters mentioned hereafter were those used in the simulation model. Total leaf area for 2003, 2006, 2007, 2008 and 2010 was measured at leaf fall by trapping all the leaves from whole trees under covering nets before leaf shedding. LAI (leaf area index) was calculated as total leaf area per tree divided by the tree spacing (Table 2). For 2002, 2004, and 2005, LAI was estimated from canopy light interception measurements and following the model of Oyarzun et al. (2007) as described in Girona et al. (2011). Tree width (W) and height (H) were measured with a surveying rod each year at bud-break and at mid-summer. The following parameters could then be calculated: (1) tree slenderness as the H/W ratio at mid-summer, and (2) leaf overlapping as LAI multiplied by H/W . Soil water content at water potentials of -33 and $-1,500$ kPa was determined using a pressure plate for samples taken at every 0.20 m to a depth of 1.2 m. Rooting depth was estimated from soil water uptake patterns, as described by Green and Clothier (1999) for fully irrigated field trees growing adjacent to the lysimeter trees. Data for Penman-Monteith reference crop evapotranspiration ($PM-ET_0$) (Allen et al. 1998) and all other necessary weather data were recorded from an automated weather station equipped with all the necessary sensors and located over grass 40 m apart from the lysimeter.

Model description

CropSyst is integrative comprehensive computer-based cropping systems model that covers a broad range of production and environmental aspects (Stöckle et al. 2003). A manual of CropSyst with full description of input parameters and file management is available at http://www.bsye.wsu.edu/CS_Suite/CropSyst/manual/index.htm. In its recent development, CS has been made applicable to deciduous trees. Although species-specific applications need to be calibrated, it has been successful at simulating plant water stress in pear trees during short periods of time (Marsal and Stöckle 2011). The most recently released version (v.4.13.09) was used for the simulations in this study. Input parameters are introduced in the model in separate files grouped by their common nature as in weather, soil, crop, and management files. Since CropSyst runs on a daily basis, daily weather data are required.

A phenology component of the model simulates the vegetative growth and updates daily changes in tree size which is later used by the light interception component to calculate canopy light interception and ground cover according to Oyarzun et al. (2007). Plant water consumption is modelled as described by Jara and Stöckle (1999). Crop transpiration is separated from the soil evaporation using the fraction of the intercepted solar radiation (f_{IR}) as a multiplier coefficient of maximum evapotranspiration. Top limits to crop water vapour transfer are imposed by a defining maximum crop transpiration, which is parameterized by supplying values representative of the highest evaporative demand of the site. Crop coefficients were calculated by dividing crop evapotranspiration by the ET_0 provided by the weather station.

Model parameterization

Model parameterization was carried out in the 2010 season and validations done by comparing with lysimeter data measured from 2002 to 2008. Parameters in the crop phenology component of CropSyst were defined using the accumulated degree days needed to fulfil each crop developmental phase requirements. Degree days were calculated on a daily basis using a base temperature of 4°C and cut-off temperature of 25.5°C (Lakso and Johnson 1990). A summary of the estimated parameters is given in Table 1.

The model of Oyarzun et al. (2007) for light interception uses canopy porosity instead of light extinction coefficient. The latter is the default option for the other models available in CropSyst. Parameterization for the canopy light interception component of CropSyst requires information on geographical coordinates of the orchard, canopy size and porosity. Tree height and width before bud-break and at the end of the season were used for initial and final values of canopy size simulation. Porosity coefficient for the canopy (K_{por}) was chosen by finding the best match between the simulations provided with CropSyst for the 1 week of July in 2007 and 2010 (after trees reached maximum size for the year) and actual measured values. LAI was set by choosing the stem/leaf partition coefficient that produced, after full canopy development, identical LAI values to those measured. The values of canopy porosity obtained in these 2 years differed slightly, and consequently, the adjustment for 2007 was used for simulation period of 2002–2007 and the value obtained in 2010 was used for the simulations performed in 2008–2010. A maximum theoretical LAI was assumed at full canopy shading of the ground. In our particular case and for the conditions of 2010, a maximum LAI was set at 6.0. This would correspond to the LAI at mid-season in which the ground was totally shaded by the full canopy.

Table 1 Crop parameters used in CropSyst simulations for apple other than tree dimension and orchard layout

Parameter	Value
<i>Measured</i>	
Specific leaf area ($m^2 kg^{-1}$)	10.5
Rooting depth (m)	0.6
<i>Adjusted to experimental lysimeter data</i>	
Thermal time to bud-break (gdd °C)	242
Begin flowering (gdd °C)	76
Begin initial fruit growth (gdd °C)	368
Begin rapid fruit growth (gdd °C)	1,112
Physiological maturity (gdd °C)	2,657
Leaf duration (gdd °C)	3,260
Canopy porosity coefficient (2002–2008)	0.33
Canopy porosity coefficient (2010)	0.23
Maximum expected LAI	6.0
Crop coefficient at full canopy- K_{cfc}	1.52
Maximum water uptake_rapid fruit growth ($mm day^{-1}$)	8.5
Maximum water uptake_postharvest ($mm day^{-1}$)	7.0
<i>Estimated from other experiments or literature</i>	
Transpiration use efficiency when VPD = 1 kPa ($g BM kg^{-1} H_2O$) ^a	7.8
Scaling coefficient of transpiration use efficiency ^a	−0.99
Leaf water potential at the onset of stomatal closure ($J kg^{-1}$)	−800
Wilting leaf water potential ($J kg^{-1}$) ^b	−2,000

^a Estimated from Auzmendi et al. (2011)

^b Estimated from pressure volume curves as in Marsal and Girona (1997)

For the ET component of CropSyst, we had to make a correction in estimating soil evaporation. Since the model only considered flood irrigation, it assumed that all applied water was evenly distributed over the soil surface. Therefore, simulated soil evaporation data produced substantially higher estimates than what would have occurred using drip irrigation. To correct this for full irrigation, soil evaporation was calculated independently from CropSyst and its value added to CropSyst simulated transpiration to obtain CropSyst simulated evapotranspiration. The independent calculation of soil evaporation was performed according to an empirical relationship obtained in 2007 from 15 measured days across crop development. These were rain-free days between late April and late September. Transpiration (T) was measured in these days by covering the lysimeter soil with a plastic sheet, and T/ET_0 ratio was calculated. For 2 days before and 2 days after transpiration measurements, the lysimeter soil was not covered and the ratio of lysimeter water use over ET_0 for the 4 days was calculated and averaged. The fraction of soil evaporation relative to ET_0 (fE) was calculated as the decrease in relative transpiration ratio for the days the lysimeter was covered as

compared to their corresponding four uncovered day averages. To facilitate management with CropSyst, fE was expressed in relation to T instead of ET_o , and it was found that fE was linearly related to f_{IR} and day of the year (DOY) ($r^2 = 0.52$, $n = 15$). Therefore, simulated E (mm day^{-1}) was calculated according to the following with f_{IR_CS} and T_{CS} being outputs obtained after CropSyst's previous simulation.

$$E = (-0.559f_{IR_CS} + 0.0004 \text{ DOY} + 0.543)T_{CS}. \quad (1)$$

Tree transpiration was parameterized by first setting the values corresponding to the crop coefficient at full canopy (K_{cfc}) and maximum water uptake. The canopy was assumed to have fully covered the ground, and trees assumed to have been unstressed. K_{cfc} was found by fitting simulated CropSyst in 2010 with the measured tree lysimeter ET for that year (Table 1). Maximum water uptake represents a theoretical value of plant water consumption for a fully developed green crop, completely covering the ground, unstressed, and fully watered with unrestricted root growth and under environmental conditions providing large atmospheric evaporative demand. This parameter was used for the calculation of plant hydraulic resistance and required different values depending on the developmental stage. Values were derived from maximum daily transpiration measured in the lysimeter (Table 1).

Soil hydraulic properties required to run CropSyst (volumetric soil water content at water potentials of -33 and $-1,500 \text{ J/Kg}$) were estimated using regression equations based on soil texture (Saxton et al. 1986). The soil varied from silty loam to loamy texture.

Because simulations did not consider water stress, potential T was the same as actual simulated T (T_{CS}). Daily K_c was therefore simulated according to:

$$K_C = \frac{T_{CS} + E}{ET_o} \quad (2)$$

where T_{CS} represents CropSyst simulated transpiration, E is the empirically estimated soil evaporation, and ET_o

represents Penman-Monteith reference ET measured in the weather station.

Evaluation of simulations

Crop Coefficients from CropSyst simulations were evaluated against apple lysimeter K_c data collected from 2002 to 2008. The year 2009 was not considered because of load cell malfunctioning in the lysimeter. Part of the lysimeter data has already been published (Girona et al. 2011), and we refer to it for more methodological details of lysimeter functioning. Irrigation was by a dripper system, and daily irrigation requirements were calculated according to the water used in the previous day. Trees were lightly pruned from 2002 to 2006 so that the canopy became unusually wide for a central leader system. After 2006, canopy width was reduced to a more normal size for the training system as evident in the trees' H/W ratios (Table 2). In 2010, trees were pruned to be even thinner (Fig. 1; Table 2). These manipulations in tree shape were performed to test the effect on K_c . Regression curves of K_c as a function of time normally have a plateau representing mid-season values ($K_{c_{mid}}$). To explore year-to-year changes of K_c , we calculated the mid-season values according to the following procedure.

Daily K_c 's were adjusted throughout the year to DOY by using a modified hyperbola III function as defined in SigmaPlot v.11 software (Systat Software Inc, Germany)

$$K_c = a - \frac{b}{(1 + cDOY)^{\frac{1}{d}}} \quad (3)$$

where a , b , and c and d are parameters of the function. $K_{c_{mid}}$ corresponded to the saturation value (a) of the fitted hyperbolic function.

Starting the simulation

Yearly simulations always started on 1st of January (hence, the chill requirement option of the model was disabled) and finished at harvest. Soil water content was assumed at field capacity and maintained as such thereafter. Simulation was

Table 2 Mid-season measured LAI, tree height (H) and width (W), tree slenderness (H/W), leaf overlapping ($LAI \cdot H/W$), and simulated daily fraction of intercepted radiation (f_{IR_CS}) during the different years of the study

Year	LAI	Tree height (m)	Tree width (m)	Slenderness (H/W)	Leaf overlapping ($LAI \cdot H/W$)	f_{IR_CS}
2002	0.94	3.00	1.40	2.14	2.01	0.35
2003	1.06	3.30	1.68	1.96	2.08	0.39
2004	1.29	3.65	1.80	2.02	2.61	0.45
2005	1.43	3.61	2.10	1.71	2.45	0.50
2006	1.90	3.61	2.20	1.64	3.11	0.60
2007	2.20	3.00	2.00	1.50	3.30	0.63
2008	2.45	4.40	2.05	2.15	5.25	0.66
2010	3.00	4.10	1.60	2.56	7.68	0.63

not extended to after harvest because K_c decreases at this time (Girona et al. 2011), and CropSyst is not yet ready to simulate this postharvest decrease. The counting of thermal time to bud-break started from 1st of January.

Results

Model verification

In 2010, an adequate agreement was found between the seasonal patterns of measured f_{IR} and that simulated with CropSyst (Fig. 2). The value of porosity coefficient found for 2007 ($K_{por} = 0.33$) was a reflection of the hedgerow training system with general high tree H/W values (Table 2) giving an indication of ‘slenderness’ and the degree of leaf overlapping. Slenderness and leaf overlapping were especially apparent in 2010 (Table 2; Fig. 1), and perhaps for this reason, the porosity coefficient in 2010 ($K_{por} = 0.23$) was lower than that in 2007. Simulated canopy ground cover for 2010 at mid-season was 0.50. The canopy parameterization and water uptake parameters were enough to show an adequate agreement between simulated and measured evapotranspiration (Fig. 2). Therefore, it was assumed that the use of CropSyst for forecasting daily K_c would be adequate with the porosity coefficient derived in 2010 for the period 2008–2010 and with the porosity coefficient derived in 2007 for the period 2002–2007. Linear regressions in 2010 between observed f_{IR} and ET_c had a slope of 1.17 and that of simulated $f_{IR_{CS}}$ and ET_c had a slope of 0.99. The respective coefficients of determination were 0.86 and 0.84. For 2007, linear regression between observed and simulated f_{IR} had a slope of 1.04 with 0.93 being the coefficient of determination.

Field simulations

Trees in 2002 had a low LAI of 0.94 and a low leaf overlapping compared to the other years, but by 2010, the LAI was approximately three times higher than in 2002 (Table 2). This increase occurred with the expansion in tree size (Fig. 1; Table 2). Simulated canopy $f_{IR_{CS}}$ increased progressively from the mid-season value of 0.35 for 2002 until reaching a maximum of 0.66 for 2008 (Table 2). Evaporation was derived directly from $f_{IR_{CS}}$, and consequently, E expressed as a ratio over ET decreased from 0.26 in 2002 to the estimated minimum value of 0.16 in 2008. Although not identical, K_c simulations produced with CropSyst agreed reasonably well with the seasonal patterns observed in the lysimeter (Fig. 3). The expression of tree phenology in terms of degree days for beginning of rapid fruit growth that

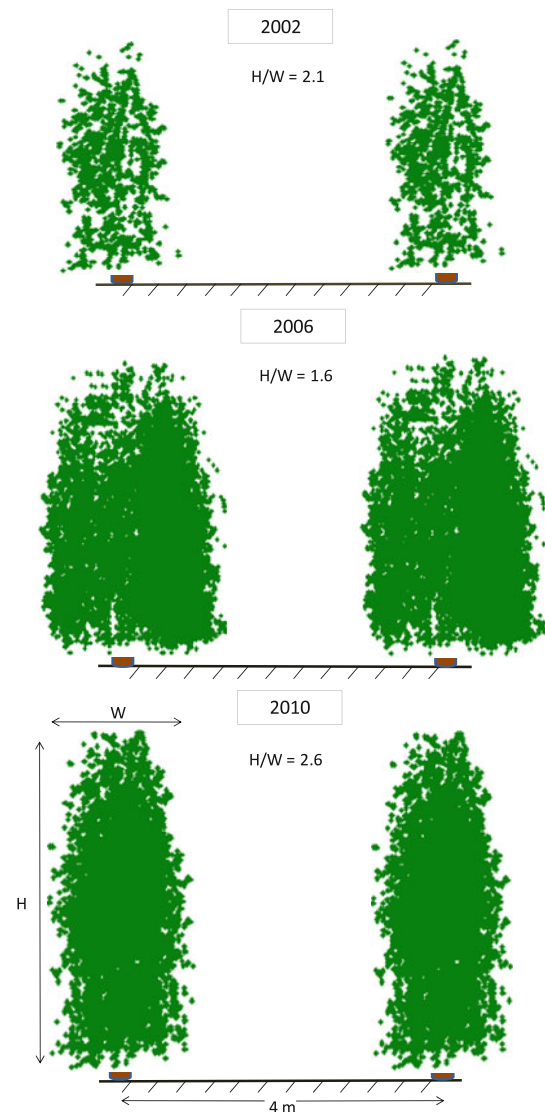


Fig. 1 Schematic representation of tree shapes for 3 years of the 8-year study. H/W describes the ratio of tree height to tree width

coincides with the cessation of shoot growth and provision of the measured LAI and canopy size at mid-season was sufficient input for CropSyst to predict increases in daily K_c that matched reasonably well with the increase in lysimeter K_c 's during the final phase of vegetative growth (Fig. 3). Lysimeter-measured K_c varied markedly from 2002, when it had the lowest value during mid-season ($K_{c_{mid}}$ of 0.55), up to the maximum value of 0.96 in 2006 and 2010 (Fig. 4). A linear regression between observed and simulated $K_{c_{mid}}$ was highly significant and had a slope of 1.004 (Fig. 4a). The $K_{c_{mid}}$ yearly patterns indicated higher values in 2006 and then fluctuated around this value until 2010 (Fig. 4b). CropSyst simulations produced a similar yearly pattern, but the maximum $K_{c_{mid}}$ value was observed from 2007 onwards (Fig. 4b).

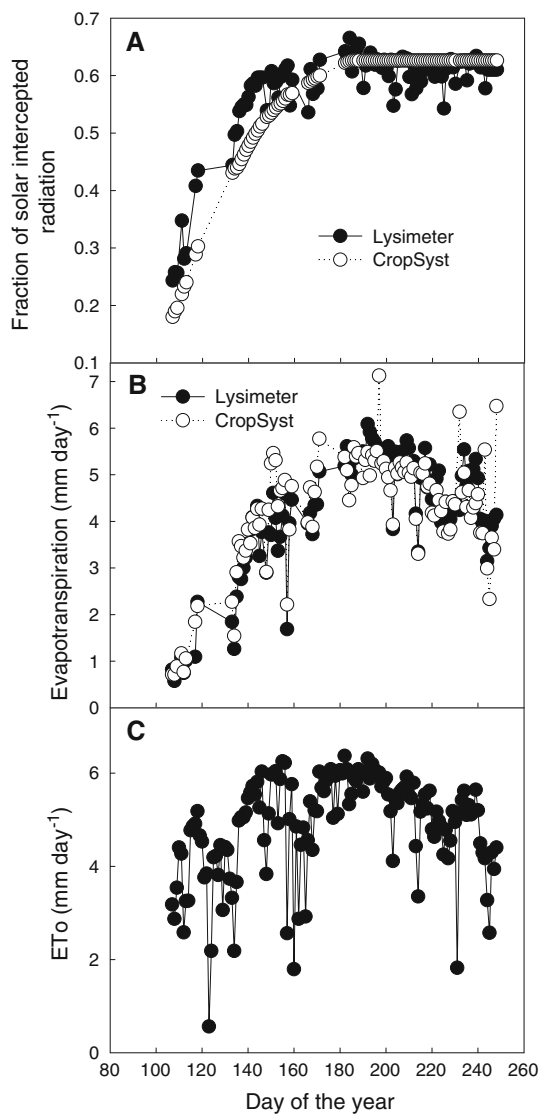


Fig. 2 Seasonal patterns of fraction of trees' daily intercepted radiation as measured in the lysimeter or simulated with CropSyst (a), measured lysimeter evapotranspiration (ET) in 2010 and the values simulated with CropSyst (b), and reference evapotranspiration (ET_0) (c)

Discussion

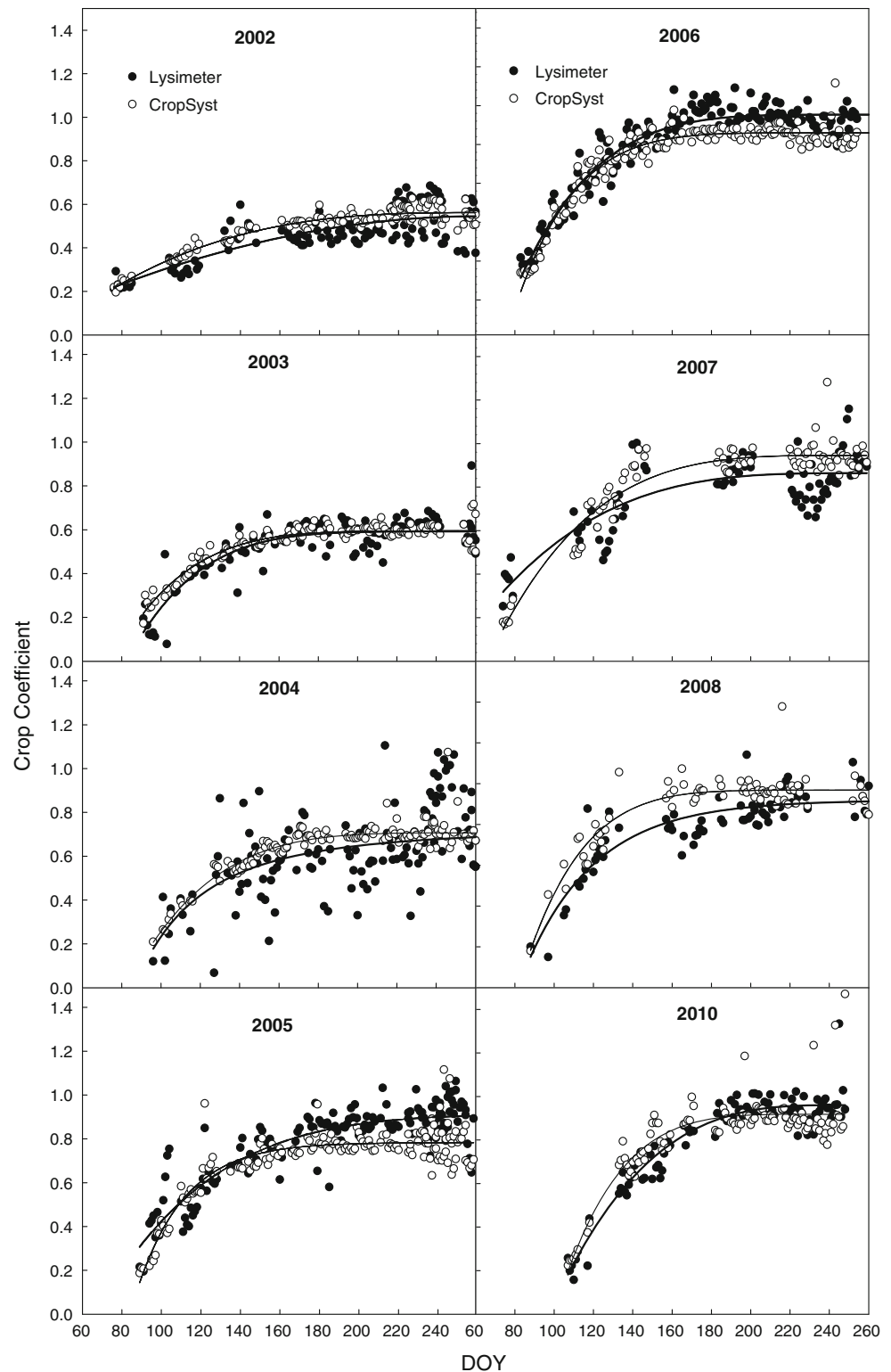
Although Ayars et al. (2003) found a linear relationship between K_c and noon f_{IR} , Girona et al. (2011) had difficulty confirming this relationship. They suggested that this difficulty arises from heterogeneity of the canopy with a more irregular arrangement of elements. CropSyst may have the capacity of overcoming some of these limitations because it combines tree light interception with a water uptake sub-model. An important parameter in the tree light interception component is the porosity coefficient which had to be adjusted to experimental data for best results. However, once adjusted for each species and training system, it should

be reasonably constant. In this study, canopy was subjected to different pruning intensities so that CropSyst could be tested for various canopy dimensions shown in Table 2.

In the light of the results obtained and considering the variation in tree size and LAI over the years, it seems that for apple the CropSyst approach to predict K_c was adequate (Fig. 4). It is interesting to note that LAI increased proportionally with tree volume, but it was negatively proportional to trees' H/W from 2002 to 2007 ($LAI = -1.84H/W + 4.84$; $r^2 = 0.88$). However, this relationship was lost after 2007 because of narrowing of tree width (Table 2) with increased pruning. It was after 2007 that the porosity coefficient needed readjustment, and this was because of changes in H/W in relation to LAI. For ratios higher than 2.15 and a leaf overlapping higher than 5, a porosity coefficient of 0.23 was used compared for 0.33 for previous years.

Although this reduction in porosity coefficient was considered after 2007, it is noteworthy that during 2007–2010 the correlation between simulated and lysimeter measured $K_{c_{mid}}$ was weaker than for the period 2002–2007 (Fig. 4a, b). The exponential function found by Girona et al. (2011) that related the f_{IR} at noon with K_c worked well for estimating $K_{c_{mid}}$ during 2002–2006. But such relationship was not maintained for the period 2008–2010. For this reason, the linear relationships between noon f_{IR} and measured $K_{c_{mid}}$ had a lower r^2 value (0.75) for the period 2002–2010 than for the period 2002–2006 ($r^2 = 0.88$). The two periods were distinctively different with respect to the way LAI developed. In the first period, LAI increased at low H/W values (Table 2). But in the second period, the LAI increased with tree slenderness ($H/W > 2.15$) (Table 2). As a consequence, leaf overlapping also increased (Table 2), and thus, leaf light exposure should have been reduced. In fact, the ratio of LAI over $f_{IR_{CS}}$ for 2008–2010 was twice as high as that for the period 2002–2006 (Table 2). This may indicate that during 2007–2010, there were more shaded interior leaves in a tree that was progressively increasing in slenderness and leaf overlapping (Fig. 5; Table 2). Although these interior leaves did not contribute to light interception, it is likely that they contributed to some transpiration, and this may have shifted the relationship between the f_{IR} at noon and daily canopy water consumption. Simulations with CropSyst of $K_{c_{mid}}$ for the period 2002–2010 worked better ($r^2 = 0.86$) than the $K_{c_{mid}}$ prediction from noon f_{IR} regression for the same period ($r^2 = 0.75$). The advantage of CropSyst is that it has a true tree light interception model and changes in tree's H/W and/or leaf overlapping can be accounted for by the readjustment in the porosity coefficient. This allowed prediction of reasonable values of K_c when leaf distribution was not uniform.

Fig. 3 Seasonal patterns of crop coefficients simulated by CropSyst and measured in the lysimeter for the period 2002–2010. Fitted nonlinear regression lines correspond to a modified hyperbola III as defined in SigmaPlot v11 software ($f = a - b / (1 + c \cdot x)^{(1/d)}$). Thin fitted lines correspond to CropSyst simulated values and the thick lines to lysimeter measured values



Since consideration of changes in porosity coefficient with leaf overlapping improved prediction of $K_{c_{mid}}$, it was of interest to find out whether year-to-year adjustment in the porosity coefficient would lead to further improvement in the correlation with measured $K_{c_{mid}}$. This adjustment was

done according to a linear relationship between leaf overlapping and porosity coefficient derived from the 2 years in which both of them were independently derived (2007 and 2010). This produced the following relationship: $K_{por} = -0.0228 \cdot \text{leaf overlapping} + 0.0405$. By exploring data

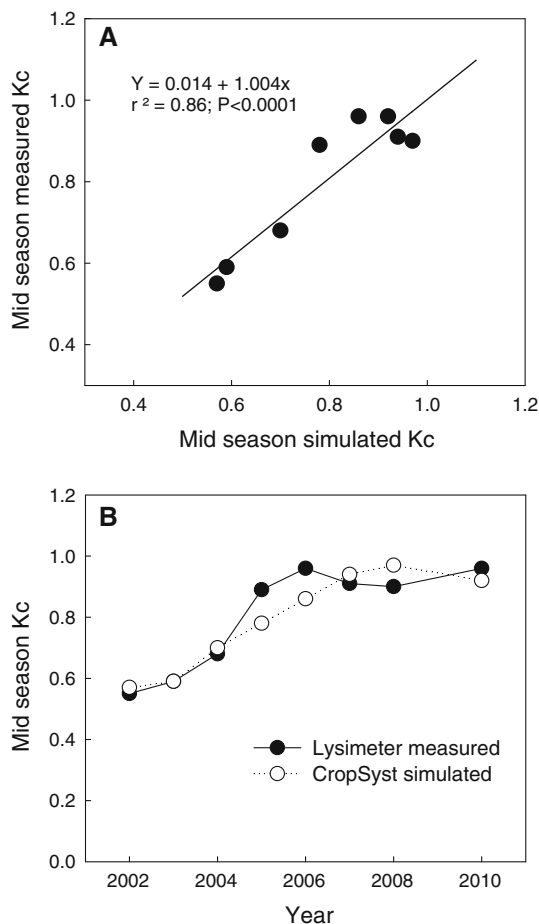


Fig. 4 **a** Linear relationships between mid-season crop coefficient values measured with the lysimeter and those simulated with CropSyst. The fitted *regression line* is the result of the contribution of all eight considered years (2002–2010). **b** Yearly patterns corresponding to both parameters

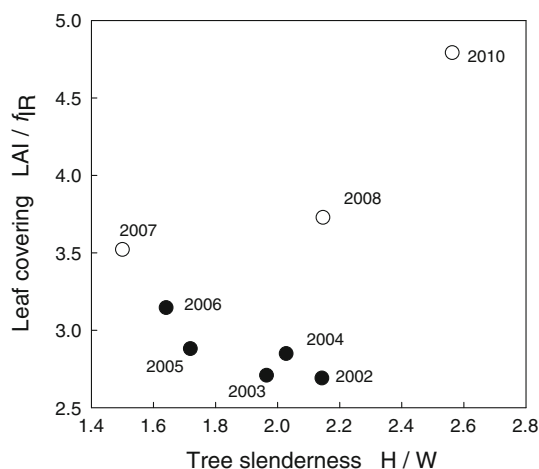


Fig. 5 Relationship between tree slenderness (H/W) and leaf covering (LAI/f_{IR_CS}) over the different years of the experiment

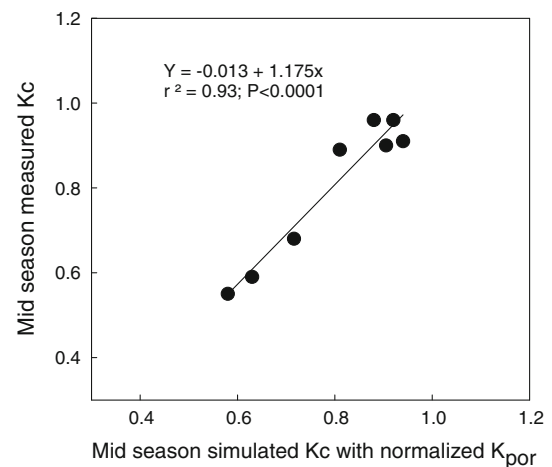


Fig. 6 Linear relationship between simulated mid-season crop coefficient with crop extinction coefficient being normalized each year according to leaf overlapping, and measured mid-season crop coefficient with the lysimeter

from other experiments, we found that this equation applies to other growing conditions (results not shown). Yearly porosity coefficients estimated in this way varied slightly and the maximum K_{por} value of 0.36 occurred in 2002. Interestingly, new simulated $K_{c_{mid}}$ with year-to-year adjustment in K_{por} increased the correlation coefficient between simulated and measured $K_{c_{mid}}$ up to a value of $r^2 = 0.93$ (Fig. 6). This highlights the importance of considering a measure of leaf overlapping in the estimation of K_c if canopy cover is heterogeneous.

There could still be room for further improvement in forecasting K_c . For instance the approach to estimate E was empirical, was only derived for 2007 conditions, and was not re-evaluated afterwards. Other factors that could play a role and that CropSyst does not account for are the effect crop load has on tree water consumption (Mpelasoka et al. 2001).

For the present state of CropSyst development, the parameterization done here is mostly valid for the conditions of this study. To run CropSyst in another site two aspects should be contemplated: (1) re-evaluation of porosity coefficient, and (2) availability of a new CropSyst version in which an irrigation system component would permit the E estimation for orchards irrigated with drip systems. This last implementation would probably increase the capacity of CropSyst to predict K_c and improve its practical application for potential users.

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