



Fraction of canopy intercepted radiation relates differently with crop coefficient depending on the season and the fruit tree species



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ABSTRACT

It is commonly assumed that the fraction of canopy intercepted radiation (f_{IR}) should be well correlated with irrigation crop coefficients (K_c) throughout the season. However, in fruit trees there is some evidence that such a correlation is different between pre-harvest and postharvest periods. Over two different years, basal K_c (K_{cb}) data from three different weighing lysimeters (one in California growing peach trees, and the other two in Catalonia growing apple and pear trees) were analyzed using two parameters of the CropSyst growth model: full canopy K_c (K_{fc}) and maximum plant hydraulic conductance (C_{max}). In CropSyst, K_{cb} is approximated as f_{IR} times K_{fc} . The latter is usually seasonally fixed, but for this study it was made variable so that it could be adjusted every fortnight throughout the season. Variable K_{fc} implies the possibility that the K_{cb} relationship with f_{IR} is not constant. The objective of this study was to evaluate possible seasonal patterns in the K_{fc} . The results indicated that K_{fc} was variable in all species and it followed a distinctive pattern in three different time periods: (i) initial rise (spring), (ii) plateau or slight decline (mid-summer), and (iii) decline (autumn). However, the magnitude of K_{fc} fluctuation was different among the three species. It fluctuated the most in the slowest growing species (pear), and the least in the fastest growing species (peach). Apple had an intermediate response. In conclusion, K_c is not a fixed function of f_{IR} . Assumption of a fixed function will introduce errors in plant water use estimation, which could be especially large in pears and apples. This will be by 50% in pears during postharvest.

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1. Introduction

Modern fruit production is facing the challenge of limited water resources. In order to optimize irrigation it is necessary to improve the accuracy of irrigation scheduling programmes. Water requirements can be calculated using the following equation: $ET_c = (K_{cb} + K_e) \times ET_o$ (Allen et al., 1998), where ET_c is crop evapotranspiration, ET_o is the reference evapotranspiration, K_{cb} is basal crop-specific coefficient that primarily represents plant transpiration, and K_e accounts for soil evaporation. Accurate determination of K_c ($K_{cb} + K_e$) is a prerequisite for sound irrigation scheduling. It is widely acknowledged that the fraction of crop intercepted radiation (f_{IR}) is a major determinant of K_c (Suay et al., 2003). It represents the energy that can be absorbed by the canopy and therefore be used for transpiration, and it has been assumed that the relationship between absorbed energy and transpiration does not change throughout the season (Pereira et al., 2007). This is

supported by the literature published on peach growing in lysimeters in California reporting that noon intercepted radiation produced a significant linear relationship with K_c (Ayars et al., 2003, Johnson et al., 2005). However, experiments done in apple and pear lysimeters in Catalonia indicated that K_c showed moderate declines after harvest without changes in canopy foliage (Girona et al., 2011). Auzmendi et al. (2011) explained such declines after apple harvest by a reduction in the ratio of transpiration to intercepted radiation. This seems to emphasize that there are also other factors to consider such as canopy conductance. Therefore, there seems to be some basis for challenging the assumption of constancy in the relation between f_{IR} and K_c . For instance it has been found that fruit sinks are related to leaf conductance which decreases when fruit are thinned or harvested in peach (Marsal and Girona, 1997). In terms of tree transpiration, this has also been shown in apple (Reyes et al., 2006).

Such a principle of constancy has been successfully used in modelling to calculate evapotranspiration for annual crops in CropSyst (CS) (Stöckle et al., 2003). In CS the f_{IR} is used as a multiplier coefficient of maximum evapotranspiration to separate crop transpiration from soil evaporation. This maximum ET is calculated as

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ETo times $K_{c_{fc}}$, where $K_{c_{fc}}$ is a parameter of the model which corresponds to Kc for a canopy that is fully covering the ground. In simulations for annual crops, $K_{c_{fc}}$ has one single value for the season. However, for deciduous fruit trees, our hypothesis is that $K_{c_{fc}}$ may be variable depending on the species and time of the year. Our objective was to find out if $K_{c_{fc}}$ fluctuated according to a clear seasonal pattern and if this occurred similarly for three different deciduous tree species. Eventually, $K_{c_{fc}}$ optimization in CS would serve to adequately simulate crop ET throughout the season for the species studied.

2. Materials and methods

2.1. Model description

CropSyst is a comprehensive cropping systems model that covers a broad range of production and environmental factors (Stöckle et al., 2003). A manual of CropSyst with full description of input parameters and file management is available at <http://www.bsyse.wsu.edu/CS.Suite/>. In recent modifications, 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, 2012; Marsal et al., 2013). 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 (air temperature, relative humidity, solar global radiation, and wind speed).

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 Stockle (1999). ET at full canopy (assuming total canopy cover) is calculated as:

$$ET_{fc} = K_{c_{fc}} ETo \quad (1)$$

where $K_{c_{fc}}$ represents the Kc for total canopy cover.

ET at any stage of canopy development is separated into transpiration and soil evaporation components by using the fraction of the intercepted solar radiation (f_{IR}) as a multiplier coefficient.

$$ET = T + E = f_{IR} K_{c_{fc}} ETo + (1 - f_{IR}) K_{c_{fc}} ETo \quad (2)$$

Since we have experimental data to independently estimate soil evaporation (E), ET is calculated by:

$$ET = f_{IR} K_{c_{fc}} ETo + E \quad (3)$$

Rearranging terms:

$$f_{IR} K_{c_{fc}} = \frac{ET - E}{ETo} \approx K_{cb} \quad (4)$$

and,

$$T = f_{IR} K_{c_{fc}} ETo \quad (5)$$

K_{cb} is the basal crop coefficient from the dual crop coefficient approach, which essentially represents transpiration plus a residual evaporation (Allen et al., 1998). In our modelling study K_{cb} includes only tree transpiration. $K_{c_{fc}}$, and therefore K_{cb} , are not only a function of the ratio of aerodynamic resistance of the orchard canopy to the reference crop canopy but also of the ratio of the respective canopy resistances. The canopy resistance of the reference crop is fixed to 70 s m^{-1} (Allen et al., 1998), but the canopy resistance of a stress-free orchard may fluctuate throughout the season.

A boundary condition for the onset of water stress is established by the simulation of plant water uptake and plant hydraulic conductance. Maximum plant hydraulic conductance (C_{max}) can be calculated according to an analogue Ohm's law for a full canopy cover as:

$$C_{max} = \frac{U_{max}}{\Psi_{fc} - \Psi_{Lsc}} \quad (6)$$

where U_{max} is a parameter of the model that represents the maximum water uptake of the crop, Ψ_{Lsc} is the lowest plant water potential that does not limit transpiration, and Ψ_{fc} is soil water potential at field capacity. Values for Ψ_{Lsc} change throughout the season and for this study we adopted those suggested by Fereres et al. (2012) for fruit trees (from -0.5 to -0.9 MPa). Values for Ψ_{fc} are those simulated from the soil module of the model. Plant hydraulic conductance (C) can be scaled down to the actual canopy size by:

$$C = f_{IR} C_{max} \quad (7)$$

and thus, water uptake (U) would be:

$$U = (\Psi_{fc} - \Psi_1) C \quad (8)$$

where Ψ_1 is the daily plant water potential.

Because our data only considered fully irrigated conditions, and simulations run on a daily basis, transpiration and water uptake are made equal and Ψ_1 can be solved as:

$$\Psi_1 = \Psi_{fc} - \frac{T}{C} \quad (9)$$

For this study we have used a version of CropSyst that allows the use of multiple $K_{c_{fc}}$ and plant hydraulic conductance parameterization throughout the season (version 4.15.14).

2.2. Approach

The study was based on lysimeter data obtained under non-water stress conditions and complementary data on tree f_{IR} , stem water potential, and data from a few days during the season with the lysimeter's ground covered. We have used CropSyst as a tool to expand the study to the entire irrigation season (from late April to the end of October). Rather than a simulation/predictive tool, CropSyst has been used following an inverse modelling approach. There were two parameters to optimize: $K_{c_{fc}}$ and C_{max} . To avoid random day-to-day variation, parameter optimization was done in two-week periods. This corresponds to an average of 17 periods for each year. The crop water demand was adjusted in two sequential steps for each of the considered periods. Firstly, $K_{c_{fc}}$ was optimized by reducing the error of model predictions in ETc. Secondly, C_{max} was optimized by minimizing the error of model predictions in midday stem water potential. The model estimates in intercepted radiation were performed by having information on canopy porosity, stem/leaf partitioning coefficient and layout characteristics (tree spacing, row orientation, tree height, tree width, branch insertion height), which were measured or field estimated. A complete description of these parameters is out of the scope of this study (see Marsal et al., 2013, and CropSyst manual <http://www.bsyse.wsu.edu/CS.Suite/> for more details). Validation of optimized CropSyst $K_{c_{fc}}$ parameter for other years has already been done in a previous study for the specific case of apple (Marsal et al., 2013). However, such study focused only on midseason and for that single species.

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