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Review

Use of CropSyst as a tool to predict water use and crop coefficient in Japanese plum trees

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ABSTRACT

The development of a method to estimate the seasonal crop coefficient (K_c) would be of great benefit to irrigated agriculture. We examined the simulation capacities of CropSyst for determining crop water use of Japanese plum under varying growing conditions. These conditions involved weather changes occurring during a period of three years (2010–2012), different pruning intensities, and the use of two cultivars having different vigor and maturity time (*Prunus salicina* Lindl. 'Angeleno' and 'Red Beaut'). Crop evapotranspiration (ET_c) was determined using the soil water balance method. Midday stem water potential (Ψ_{stem}) was determined using a pressure chamber. Two parameters of the CropSyst crop model: crop coefficient at full canopy ($K_{c,fc}$) and maximum plant hydraulic conductance (C_{max}) were parameterized in 2010 season to predict K_c, while 2011 and 2012 were used for validation. In 2011 and 2012, 'Angeleno' trees were subjected to severe summer pruning so that tree size would be smaller than in 2010. The influence of the high vigor and early harvest of 'Red Beaut' was tested in 2011. The results of 2010 parameterization revealed that $K_{c,fc}$ and C_{max} had a distinctive seasonal pattern. This parameterization was adequate to simulate K_c and Ψ_{stem} for 'Angeleno' in other seasons and smaller trees than in 2010. The parameters adjusted in 2010 were not adequate to simulate the behavior of the more vigorous cultivar of 'Red Beaut'. In 'Red Beaut', the factor that best explained the need to adapt CropSyst parameters was the difference in vigor but not the time of the removal of fruit sinks. To accurately simulate K_c and Ψ_{stem} in 'Red Beaut' it was required to use slightly higher values of $K_{c,fc}$ and C_{max} during a specific midsummer period.

Contents

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1. Introduction

Irrigation in commercial fruit orchards can be scheduled by using the water balance method for estimating crop evapotranspiration (ET_c) (Allen et al., 1998), the product of reference evapotranspiration (ET_o) and crop coefficient (K_c). However, there is no infallible technique for accurate determination of ET_c as K_c is dependent upon crop phenological stage, canopy height, cover and architecture (Allen et al., 1998). In annual crops, averaged values that are found in the literature could be used to estimate mean ET_c values. In fruit trees, the dependency of K_c on crop characteristics and management practices such as crop load adds uncertainty to its use wherever these factors are widely variable. Lower crop load levels typically reduce stomatal conductance and photosynthetic rate in peach, apple and pear (Chalmers et al., 1975; Crews et al., 1975; DeJong and Goudriaan, 1989; Reyes et al., 2006; Marsal et al., 2008) and therefore reduce transpiration rate and water uptake due to the decrease in demand of assimilates (Chalmers et al., 1983) or by restricted root growth (Williamson and Coston, 1989). In addition, it should be considered that K_c assessment can be improved when two separate coefficients are considered as ($K_{cb}+K_e$), where K_{cb} is the basal crop coefficient which represents the transpiration of the crop and K_e is the soil water evaporation coefficient which considers evaporation from the soil surface (Allen et al., 1998).

The development of a simple method to estimate the seasonal K_{cb} for different crops, including woody, perennial horticultural crops would be of great benefit to the agricultural industry (Williams and Ayars, 2005). The most direct method for estimating ET_c is through lysimeters, although these are expensive and are not generally available to growers. In the case of Japanese plum trees there is no information available on crop ET with the precision offered by lysimeters. Other alternatives such as the water balance method have been proposed to estimate irrigation needs. The soil water balance method uses the law of mass conservation (Faures et al., 1995; Moreno et al., 1996; Sanchez-Cohen et al., 1997) as $\Delta S = P + I - D - R - ET_c$, where ΔS is the change in soil water storage between two consecutive dates, P is effective rainfall, I is irrigation, D is drainage, R is runoff and ET_c is crop evapotranspiration. Although this method can be employed to estimate ET for longer time periods than a day (e.g., week-long or ten-day periods), it has also been widely used to quantify seasonal ET_c of different crops such as almonds (Fereres et al., 1981a,b; Andreu et al., 1997), olive (Moreno et al., 1988), apricot (Abrisqueta et al., 2001) or citrus (Castel et al., 1987; García-Petillo and Castel, 2007).

In the last few years, the development of crop models has received renewed attention because of their value when analyzing the behavior of agricultural systems under a variety of climatic and geographical conditions. CropSyst is a general crop growth model (Stöckle et al., 2003) that can have many applications. The development of CropSyst started in the early 1990s to simulate crop productivity, development, soil water budget, soil–plant nitrogen budget and management strategies for both arable and horticultural crops. Presently, CropSyst is being supplemented with developments for tree crop applications. Although its application to specific species requires the calibration of certain specific parameters, it has been successful at simulating plant water stress in pear trees during short periods of time (Marsal and Stöckle, 2012) and at predicting crop coefficient for apple (Marsal et al., 2013).

CropSyst considers daily changes in tree size to calculate canopy light interception and ground cover (Oyarzun et al., 2007). Tree transpiration is related to the amount of radiation intercepted by the canopy and soil evaporation is separated from the transpiration by using the fraction of intercepted radiation as a multiplier coefficient of maximum evapotranspiration ($ET_{c,\,max}$) (Stöckle et al., 2003). This $ET_{c,\,max}$ is calculated as $ET_o \times K_{c,fc}$, where $K_{c,fc}$ is a model parameter which corresponds to K_c for a canopy that is fully covering the ground. It has been reported that this parameter for deciduous fruit trees is variable depending on the species and the time of the year (Marsal et al., 2014). In the case of plum, there is no information on seasonal patterns of $K_{c,fc}$. In addition, whole season validations of CropSyst simulations to other years and cultivar within the same species have not yet been published. Our objective was to carry out a model parameterization for 'Angeleno' plum during 2010 and validate these CropSyst parameters for the seasons 2011 and 2012. Another aim was to validate 'Angeleno-2010′ parameters adjusted to another cultivar with notable differences in vigor and maturity time. The purpose of the work was to provide useful parameter values so that CropSyst could be used as a tool for irrigation scheduling in Japanese plum orchards.

2. Materials and methods

2.1. Model description

CropSyst is a multi-year, multi-crop, daily time-step cropping system simulation model developed to serve as an analytical tool to study the effects of climate, soil and management on cropping system productivity and the environment (Stöckle et al., 2003). Simulation scenarios are divided into separate input data files: simulation options, climate, soil, crop and management files, providing daily or annual results of soil and crop. Details on the use, parameterization and execution of the model are given in the user's manual (Stöckle and Nelson, 2000) and definitions, usage, and range of variation of all parameters required by CropSyst can be found in the Help facility of the model interface.

The model uses the following protocol: the simulation of crop phenology and daily updates in tree size are based on thermal time. A light interception component of the model is used to calculate solar radiation interception and ground cover according to Oyarzun et al. (2007). Plant water potential and tree transpiration are related and calculated at the same time using an Ohm's law analogy. ET at full canopy (ET_{fc}) is determined by multiplying ET_o by crop coefficient for total canopy cover ($K_{c,fc}$).