Validation of On-Farm Crop Water Requirements (PrHo) Model for Horticultural Crops in an Unheated Plastic Greenhouse.

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Abstract

Most greenhouse crop transpiration models presented in the literature have been calibrated and validated over short periods, sometimes less than a week, with the same conditions for calibration and validation. The objective of this paper is to analyse the performance of the PrHo v 2.0 (Ó2008 Cajamar; www.fundacioncajamar.com) model during the entire cropping season in an unheated plastic greenhouse.

PrHo is a software that estimates crop evapotranspiration (ETc) using the FAO model (Doorenbos and Pruitt, 1975), previously calibrated for use with greenhouse crops (Fernández, 2000). It includes two sub-models, the reference evapotranspiration sub-model (ETo) and the sub-model for the crop coefficients (Kc). The ETo sub-model estimates greenhouse ETo values from exterior solar radiation values, using a radiation model previously calibrated for local conditions. With this model is possible to adjust the irrigation to particular crop conditions, such as white washing. The Kc sub-model calculates Kc values from sowing/planting to effective full cover as a function of thermal time, calculated using greenhouse air temperature (Fernández, 2000; Orgaz et al., 2005). Therefore the evolution of Kc values includes the variability in crop growing cycles and planting dates.

PrHo v 2.0 calculates the ETc for the main greenhouse horticultural crops in real time (ETc REAL) or using average climatic data (ETc AVERAGE). The calculated PrHo values of ETc in real time were compared with average ETc values measured during entire cycles of pepper crop. There was very good agreement between the estimated and measured ETc values, even for low ETc values of 1 mm d^{-1}. The calculated ETc values closely followed the evolution of measured values.

INTRODUCTION

The greenhouse industry has expanded extraordinary in the Mediterranean basin. Nowadays, in Almería, in the Southeast of Spain, there are 27.000 ha of greenhouses dedicated to intensive horticultural production (Sanjuán, 2004). Most of these are low-cost structures covered with plastic film, without any climate control systems and with sand mulched soil-grown crops (Pérez-Parra et al., 2004).

Transpiration models of different complexity have been developed for predicting irrigation requirements of greenhouse crops (Baille et al., 1994; Jolliet and Bailey, 1992; Medrano et al., 2005; Montero et al., 2001;Möller et al., 2004; Stanghellini, 1987). Most greenhouse crop transpiration models have been calibrated and validated over short periods, sometimes less than a week, with the same conditions for calibration and validation. However, numerous input parameters are required to describe crop parameters and stomatal response, as well as radiation relationships, which might limit the routine use of the models by small farm growers.

In 1975, the United Nations Food and Agriculture Organization (FAO) proposed a methodology for computing crop evapotranspiration based on the use of reference evapotranspiration (ETo) and crop coefficients (Kc) (Doorenbos and Pruitt, 1975), which is commonly used to calculate crop evapotranspiration (ETc) for outdoor conditions. In order to improve greenhouse irrigation efficiency, FAO method has been calibrated over the entire cropping season (Fernández, 2000; Orgaz, 2005) and validated in several crops (Bonachela et al., 2006). Based on this method, daily irrigation water requirements for the major greenhouse crops can be estimated with a computer program (PrHo v 2.0, © 2008 Cajamar; www.fundacioncajamar.com), with the inputs of daily solar radiation and temperature data (Fernández et al., 2001).

The PrHo v 2.0 (© 2008 Cajamar) software was developed with the aim of providing technical advisers and growers with a tool that would allow them the optimization of irrigation supply to greenhouse horticultural crops, which would also be easy to use.

The objective of this paper is to analyse the performance of the PrHo v 2.0 (©2008 Cajamar) model during the entire cropping season in an unheated plastic greenhouse.

MATERIALS AND METHODS

PrHo is a software that estimates crop evapotranspiration (ETc) using the FAO model (Doorenbos and Pruitt, 1975), previously calibrated for use with greenhouse crops (Fernández, 2000; Fernández et al., 2001; Orgaz et al., 2005). It includes two sub-models, the reference evapotranspiration sub-model (ETo) and the sub-model for the crop coefficients (Kc).

ETo Sub-model

The evaporative demand under greenhouse in Mediterranean conditions depends mainly on the solar radiation (Fernández et al., 2001). Therefore, a radiation model was calibrated to estimate ETo and derived from the FAO-Radiation model (Doorenbos and Pruitt, 1975). The ETo sub-model estimates greenhouse ETo values from exterior solar radiation values (G_o, in mm d^{-1}) and greenhouse transmissivity (τ, in %). With this model is possible to adjust the irrigation to particular crop conditions, such as white washing.

For Julian days (JD) = 220

$$ETo = (0.288 + 0.0019 * JD) * Go * t \qquad (1)$$

For Julian days (JD) > 220

$$ETo = (1.339 - 0.00288 * JD) * Go * t \qquad (2)$$

Kc Sub-model

Kc values for major greenhouse horticultural crops were determined by Fernández (2000) and Orgaz et al. (2005). The duration of the major growth stages varies substantially depending on weather, planting dates, etc. Daily Kc values from sowing/planting to effective full cover were determined as a function of thermal time, calculated using greenhouse air temperature (Fernández, 2000; Orgaz et al., 2005).

For the sweet pepper crop, the empirical regression equation obtained between Kc and TT values during the partial crop cover stage was:

$$Kc = Kc_{ini} + 0.00176 * (TT - 200) \quad (3)$$

This equation was used for estimating Kc for pepper during the initial and crop development stages.

Software description

PrHo v 2.0 allows for the estimation of ETc of the main greenhouse horticultural crops on real time (ETc real) or using average climatic data (ETc average). The average ETc is calculated from the average daily values of solar radiation measured outside the greenhouse (1983 to 2007) and maximum and minimum temperatures measured inside the greenhouse (1988 to 2007). The real ETc is calculated from actual daily values of solar radiation measured outside the greenhouse and maximum and minimum temperature measured inside the greenhouse.

The program allows adjusting the irrigation to particular growing conditions such as white wash, salinity on the irrigation water and uniformity coefficient of the irrigation system. The white wash is a usual technique in the area during certain periods of the year, with the aim of decreasing the temperatures inside the greenhouse. The white washing of the plastic cover decreases the amount of solar radiation entering the greenhouse, and therefore, a proportional decrease in water use. In Almería, with a white washed plastic cover (average dose: 25 kg of calcium carbonate per 100 L of water) a decrease on solar radiation of 30% has been measured (own data) in relation to a reference greenhouse without any shading. However, this value may change depending on the amount of product used. Therefore, a relation was incorporated between the amount of product used and the decrease on solar radiation transmission adapted from Nisen (1975, in Baille, 1988).

Measurements

The estimations of the ETo sub-model and the Kc sub-model have been validated, as well as the ETc.

The experiments were carried out in the Foundation Cajamar Research Station (El Ejido, Almería, Spain) in two typical Mediterranean greenhouses: low-cost structures covered with plastic film (0.2 mm-thick thermal polyethylene sheet), without heating equipment, passively ventilated by opening side panels and roof vents and artificially layered soils, typical of the region and known as *enarenados* (Pérez-Parra et al., 2004).

The ETo sub-model was calibrated using measured values of ETo and solar radiation outside the greenhouse from 1993 and 1994 years. ETo was measured in two drainage lysimeters in greenhouse sown with perennial grass (*Cynodon dactylon* L.), which was maintained at 0.1-0.2 m height by regular mowing. This model was verified using the ETo data measured from 1999 to 2002.

Greenhouse air temperatures were measured within the greenhouse sown with perennial grasses with a ventilated aspiro-psychcrometer mounted at 1.5 m. The global radiation was measured with a pyranometer in an automatic agro-meteorological station ware placed in fallow land.

The pepper crop (*Capsicum annuum* L., Lamuyo type) was transplanted in September in a plastic greenhouse (58 m long x 24 m wide) in a sand mulched soil (enarenado) and drip irrigation, and two drainage lysimeters for the ETc measurements.

ETc and ETo were weekly measured in the lysimeters by the soil water balance (Fernández, 2000; Orgaz et al., 2005). The Kc values were calculated for weekly periods as the ratio between ETc and ETo values. The Kc values of the different stages were determined during the 1996/19997 growing season (Fernández, 2000; Orgaz et al., 2005), and the validation of the Kc sub-model was performed with the Kc values measured during the 1997/98 growing season.

The estimations of REAL ETc (ETc=ETo*Kc) of the PrHo v 2.0 software were validated against ETc measured values in a pepper crop. Besides, the PrHo estimated ETc value was compared with the transpiration values measured in a perlite grown pepper crop during season 2004/05. The multitunnel greenhouse (630 m^2) with passive climate was white washed from 21/07/04 to 18/09/04 (from transplant to 59 dat) with a dose of 25 kg calcium carbonate per 100 L of water. The temperature was measured with a ventilated aspiro-psicrometer located above the canopy.

RESULTS AND DISCUSSION

Validation of the ETo sub-model

The ETo sub-model was verified under non white washing conditions (Fig. 1a). The agreement between estimated and measured ETo data was very good as most data were narrowly distributed around the 1:1 line. The coefficient of determination (R^2) of the best-fit line was 0.98 and values of the intercept and the slope of the regression line were not significantly different from zero and unity, respectively, at the 0.05 probability level.

Verification of the Kc sub-model

Figure 1b presents measured and estimated Kc values of pepper. Measured Kc values were correctly estimated using these models throughout an entire pepper growth cycle (Fig. 1b), and most data were closely distributed around the 1:1 line.

In Almería region, planting dates of greenhouse crops vary substantially from year to year depending on agronomic, weather and, especially, on market conditions. As result, the length of the growth stage considered in the FAO model (Doorenbos and Pruitt, 1975) could differ significantly between seasons and growers. The Kc sub-model used to estimate ETc offer a simple method to calculate Kc with different climate or crop management conditions in relation to other methods such as, a time scale, or the percentage of shielded soil.

Verification of the ETc model

Figure 2a shows the evolution of the average daily ETc measured values and those simulated on real time for the pepper crop. The real time estimations showed an excellent agreement with the measured ETc (Fig. 2a) during the whole growing cycle, both in periods of low climatic demand (winter), and periods of high demand (spring). Although the highest overestimation of the model occurred during the winter period, it was never above 0.5 mm d^{-1}.

The regression analysis between measured and estimated ETc indicates that both the ordinate and the slope of the regression line did not differ significantly from cero and 1 respectively. The slope of the regression line was 0.98, which indicates that the estimations were precise for a wide range of ETc values (r^2=0.97). The precision of the model on a short term (Root Means Square Error, RMSE) was 0.26 mm d^{-1}.

PrHo also estimated correctly the average transpiration of a pepper crop grown in perlite (Fig. 2b). The estimated values adapted well to different management conditions, with white wash (from transplant to 59 dat) and without whitewash (from 60 dat to the end of the crop cycle).

The PrHo software estimated accurately the measured values of ETc or transpiration during a whole growing cycle and showed a high sensitivity to predict low values (lower than 1 mm d^{-1}), and adapted well to different management conditions. Besides, its simplicity and friendly environment as well as the few input parameters required make this software a standard of the area used widely both by technical advisers and growers for irrigation scheduling. With this software, irrigation calendars have been produced using average climatic data (average ETc) which have been distributed amongst the growers, also published periodically on specialized media of the area.

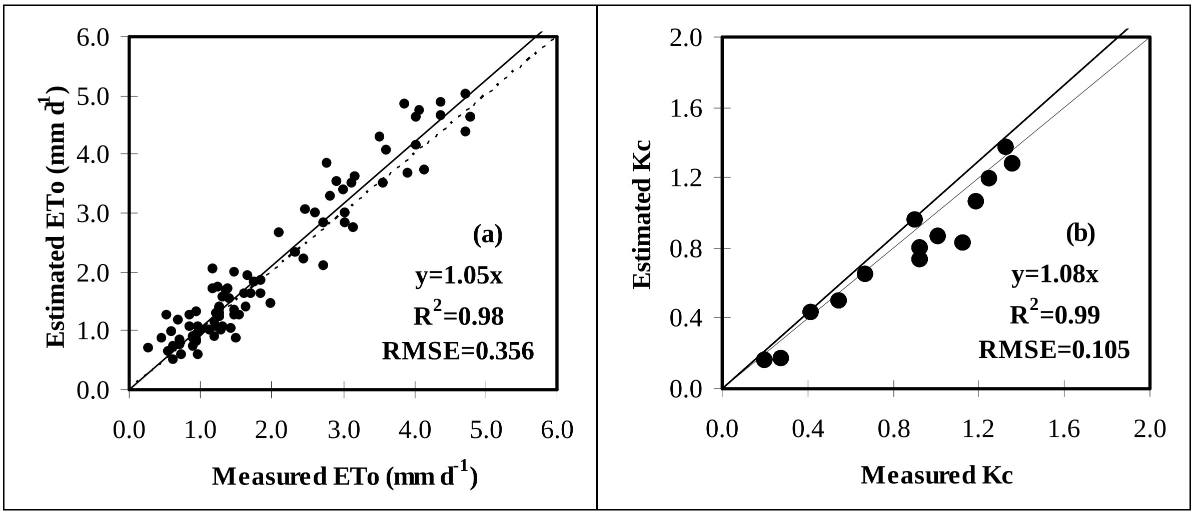

Figure 1: Comparison of measured against estimated ETo values of grass (a) and Kc values of pepper (b).

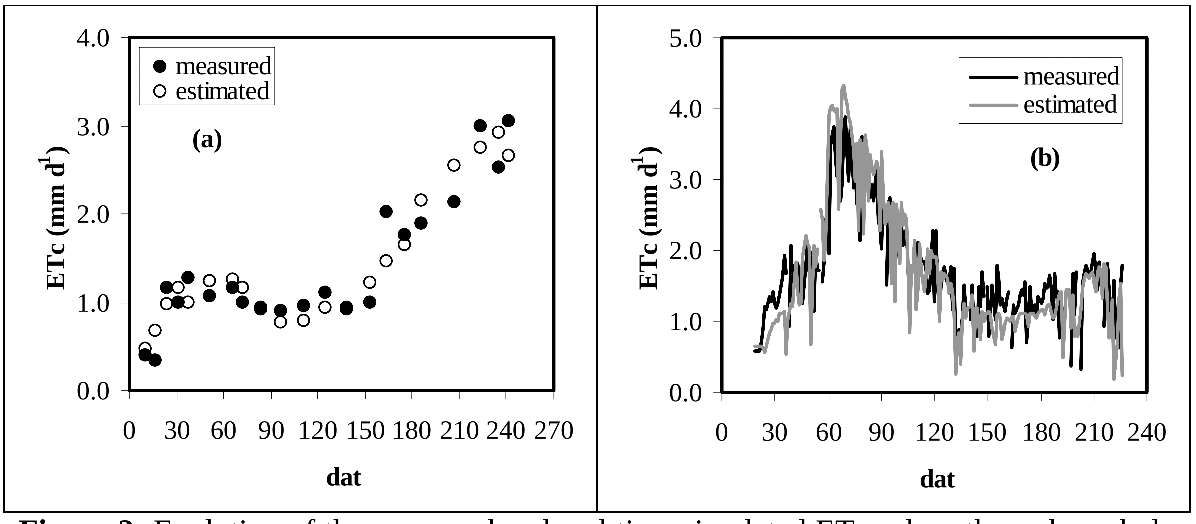

Figure 2: Evolution of the measured and real time simulated ETc values through a whole growing cycle of pepper crop grown in a sand mulched soil (a) and perlite (b).

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