MEASUREMENT AND ESTIMATION OF TRANSPIRATION OF A SOILLESS ROSE CROP AND APPLICATION TO IRRIGATION MANAGEMENT

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Abstract

Drained nutrient solution of soilless culture crops in many countries, is rejected to waste, producing undesirable polluting effects and reducing the water and fertilizer use effciency of the cropping system.

Current irrigation practices in protected soilless culture, are based either on fixed interval scheduling, corrected by means of EC monitoring in drainage or substrate extract, or on crop transpiration estimations by means of solar radiation integration.

Closed soilless culture systems help to improve water and fertilizer use efficiency, but irrigation management needs to be optimized, and properly operated in relation to crop requirements, and needed proportions of air and water in the substrate.

A study has been carried out, where the transpiration of a heated rose crop, conducted by the shoot bending system, is continuously measured by means of an electronic balance, and estimations are calculated with a simplified Penman-Monteith equation, adjusted by weekly LAI estimations, as well as outside solar radiation and inside water vapour saturation deficit recordings.

Based on these transpiration estimations, an irrigation strategy has been tested and compared to current irrigation practices used in commercial holdings.

1. Introduction

During recent years, a number of authors are paying attention to the improvement of irrigation of protected crops. The control equipment for irrigation has improved considerably, but growers of the mediterranean regions are mostly managing irrigation on the basis of empirical criteria and rules. Fixed volumes of water supply at regular time intervals, or a partial use of solar radiation integration, is the most common way of automatic irrigation. Microclimate in mild winter greenhouses can be a strong source of water stress for crops and the risk is increased by the fact that soilless culture has very much increased, and substrate physical properties of low water retention force the grower to look for a reliable automatic system based on optimum decision criteria. Otherwise either the crop can be under water stress danger or the system can be working on the basis of extra expenses of water and fertilisers.

More or less complex models of transpiration based on the Penman-Monteith equation (Monteith, 1973) have been proposed and validated under different conditions (Bailey et al., 1993; Gonzalez, 1995; Lorenzo et al., 1998; Medrano et al., 2001). A simplified version (Stanghellini, 1987; Boulard and Jemaa, 1993; Baille et al., 1994a; Medrano, 1999) that takes into account both, solar radiation and air saturation deficit as variables could be very useful for the implementation of irrigation algorithms in a soilless culture system.

The present paper aims at adjusting and validating a simple model of crop transpiration for a rose soilless crop. A model-based algorithm has been integrated in a control system, and has been tested for the complete management of crop irrigation needs, in order to check the real possibilities and degree of reliability for practical applications

2. Materials and methods

A soilless rose crop (cv. Dallas) is grown in an acrylic covered greenhouse of 250 m^2. Heating is supplied for a minimum of 16 ºC, by means of air forced aerotherms, and humidity is kept at 50 % minimum with a high pressure fog system. Two 30 plants units, located at the central position of the greenhouse, are grown in a NFT type system, where transpiration is measured at short time intervals (15 seconds), by means of an electronic balance (resolution ± 0.1 g). Nine hundred plants grown in a perlite hydroponic system complete the rest of the greenhouse. All plants are grown following the local standard commercial technics, using the stem bending technique and all-year-round production.

Short time soilless rose crop transpiration has been recorded and compared with a simplified transpiration model during a winter cropping period from November to February. A simplified transpiration model based on the simplified Penman-Monteith equation has been derived:

$$E = \mathrm{A} * \left[1 - e^{(-k*LAI)}\right] * G + \mathrm{B} * LAI * VPD$$

Where:
E = crop transpiration rate (g m^{-2} h^{-1})
G = outside solar radiation, w m^{-2}
VPD = inside air vapour pressure deficit, kPa
k = radiation extinction coefficient, 0.64
A,B = equation parameters (A dimensionless, B g m^{-2} h^{-1} kPa^{-1})

This simplified model considers that the transpiration is mainly explained by two components or terms: a radiative part (directly related to the radiation G absorbed by the crop) and an advective part (directly related to the inside greenhouse vapour pressure deficit). The advective term has shown to be really important, especially in winter nights when heating is working on with no radiation or in cloudy days.

In order to implement a real-time irrigation management, short time (15 seconds) estimations of crop transpiration have been used. A and B coefficients have been calculated by statistical identification (multi-parameter lineal regression or multiple regression model) for transpiration versus radiation and vapour pressure deficit real-time records. Taking into account that commercial greenhouses may have an outside weather station and an inside psychrometer, the models obtained by both, outside and inside solar radiation have been compared, finding that there is no difference in the fitting of their prediction (R^2 = 0.92 for both). Thus, the model with the outside solar radiation has been adopted. Leaf area index has been estimated weekly. Leaf area is composed by two terms, the arched shoots part, considered as constant for the term of a month, and the flowering shoots part. The arched shoots part has been measured monthly (4 plants samplings) and the flowering shoots part has been estimated on a weekly basis, as a linear function of the length of the shoots, entered as input to the transpiration model. In the period considered, LAI has varied between 2.12 and 2.51 and the flowering shoots part has represented from 22 % to 27 % of the total LAI. The following relation for the leaf area of the flowering shoots has been obtained:

LA shoots (cm^2)= 22.272 * L (cm) – 468.548 (R^2 = 0.85, n=67),

L= flowering shoots length

It has also been found that only 11 shoots are needed to estimate the leaf area of the flowering shoots, with an error less than 5 %, but usually some more have been used.

The radiation extinction coefficient (k) has been considered constant throughout the period and equal to 0.64 (Stanghellini, 1987).

Results and discussion

Transpiration Flux in Relation to the Microclimate

When transpiration (E) is considered in relation to values of outside solar radiation (figure 1) between 100 and 400 wm^{-2}, a positive correlation is observed, with lower scattering than in the range of 400 to 600 wm^{-2}. Estimation of E when solar radiation is very low or cero is improved if the saturation deficit of air is considered, particularly when required time intervals are short (Jolliet and Bailey, 1992; González, 1995). The scattered values of transpiration for radiation values higher than 400 wm^{-2}, could be associated to stomatal conductance variations in response to VPD changes, depending on fog system capacity.

Transpiration Model

The fitting of estimated and measured values of transpiration is shown in (figure 2) and is quite good all along the measured transpiration flux, which range is fairly wide, between 20 and 230 $g/m^2.h$ (5 and 58 g/plt.h). Some degree of underestimation is observed for the higher transpiration values, and an overestimation for the lower values, though very acceptably fitted in the measured range. Similar or bigger deviations are reported by Baille et al. (1994b) for a number of pot plants.

A very good prediction is obtained in the 24 h cycle when the course of the measured crop transpiration values is compared to the estimated one for Autumn and Winter (figure 3). The observed deviations betweeen the two sets of values, correspond to model underestimations in the hours when the flux is maximum. Also an overestimation is shown along the morning hours and, again, underestimation towards the sunset.

In general terms the prediction is considered good. The model works on a real time basis, and performs with a high level of accuracy the reactions of the transpiration flux to the climatic variations, solar radiation and VPD, during the day and the night. In the night hours, when forced air heating equipment is not working during longer intervals, due to milder temperatures, and measured crop transpiration flux is showing wider oscillations, the model has been able to perform this evolution. These conditions can be distinguished from the ones when aerotherms have been working more continuously, due to lower temperature levels (figure 4). Also during the night there is a very good behaviour of the estimated transpiration in relation to the course of VPD. Transpiration values follow in real time the evolution of VPD, which oscillates depending on air forced heating equipment on and offs (figure 4). A small anticipation of some minutes is obtained for the model in relation to the measured crop transpiration. For instance, on a sunny day, the quantity of supplied water has been about 1000 litres versus 2280 l supplied by means of the time scheduling policy. This difference is much more important when a cloudy day is considered, with only 520 l watering with the algorithm control.

Predictive Control of Water Supply

When the algorithm based on the studied transpiration model, has been implemented and tested for the irrigation scheduling of the rose soilless crop on perlite, a good performance has been obtained in the different conditions along Autumn and Winter. Two different insolation days are shown (figure 5). Watering is supplied at variable intervals, when the estimated transpiration integral reaches the set value. During the night the crop transpiration rate and integral are estimated by the model, and the required waterings are supplied to the crop. Measured crop transpiration all along the night hours is significant, particularly due to force air heating, ranging from 24% in a clear day to some 46% for an overcast day. Jolliet and Bailey (1992) report on some 22% the night transpiration fraction of the 24 hours period, for young tomato plants, under heated greenhouse, and Medrano (1999) obtained 10 to 20% for cucumber in Spain, in a cold greenhouse in Autumn. Figure 5 shows a good fitting of the model in the short time intervals, for two very different solar radiation days in Winter.

Water supply can be very well adapted, in this way, to actual plant requirements all the time. Estimations made by the model have been very acceptable, at the practical level, for irrigation control, in soilless growing systems that have a high level of fragility due to the very low buffer capacity for water and minerals.

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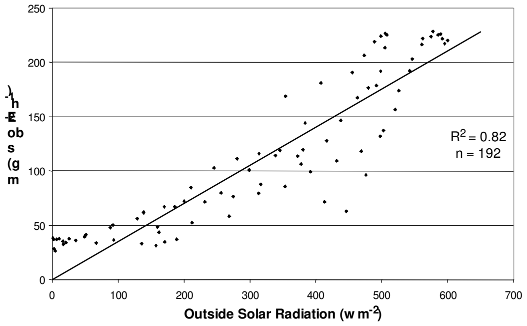

Figure 1. Observed crop transpiration vs. Outside solar radiation

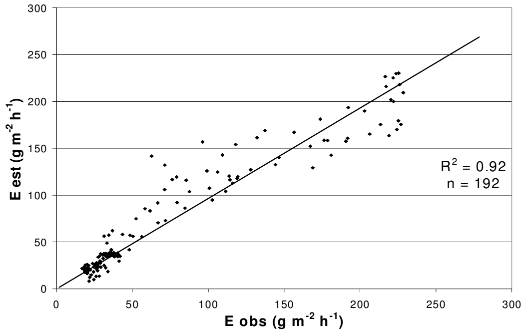

Figure 2. Estimated vs. Observed rose crop transpiration rates

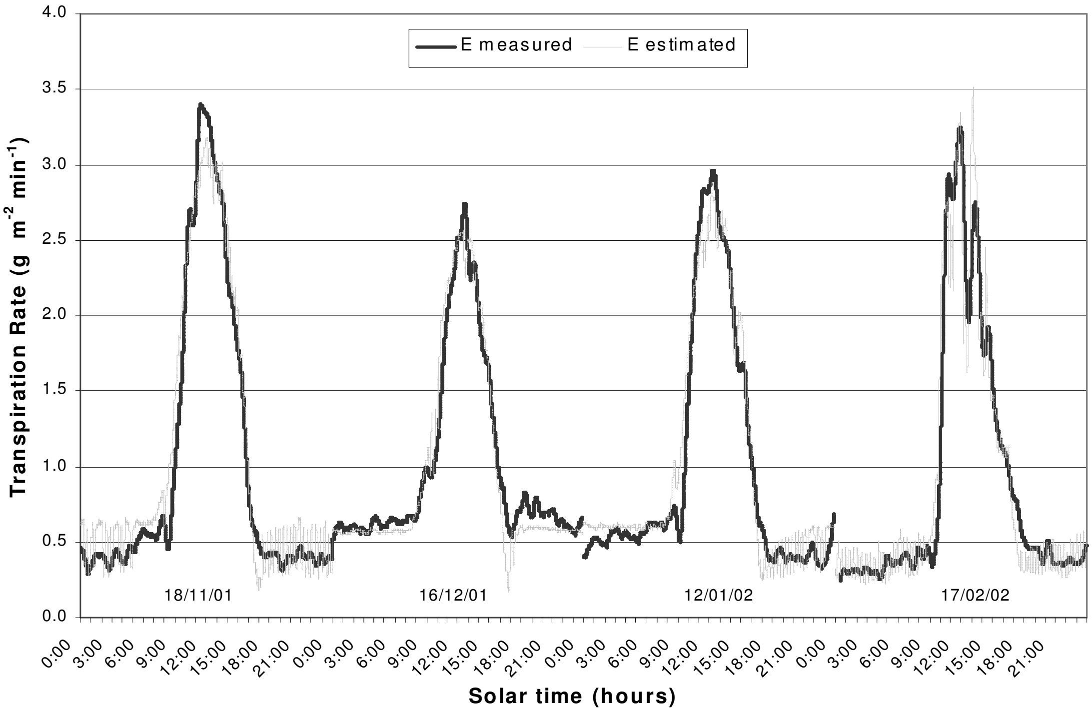

Figure 3. Comparison between estimated and observed rose crop transpiration rates during four days in Autumn and Winter

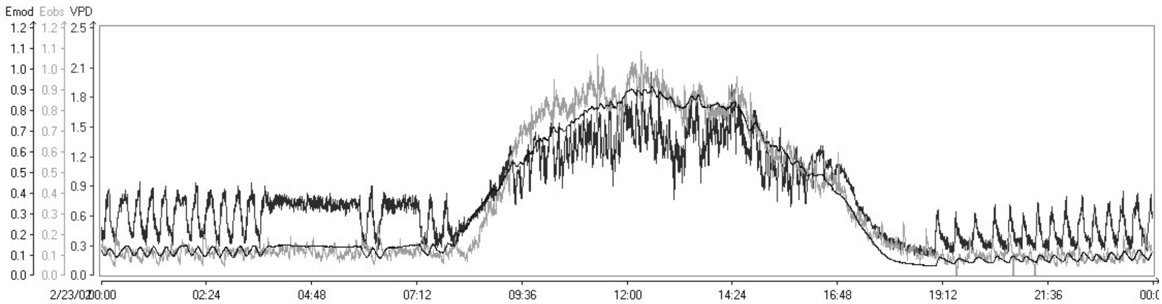

Figure 4. Daily course of observed and estimated rose crop transpiration rates in relation to VPD

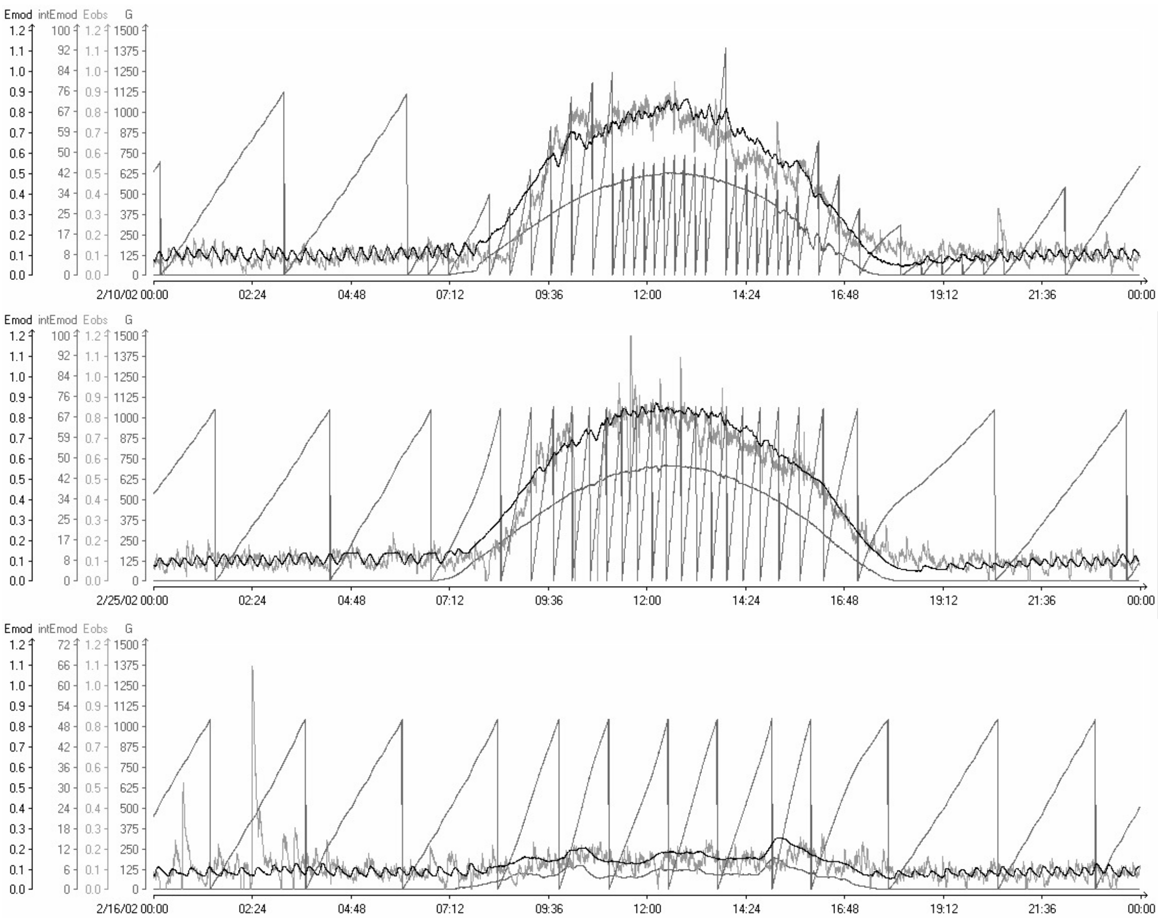

Figure 5. Comparison between irrigation strategy based on a time scheduling programmer (a), and the optimization of the irrigation management obtained with the use of the model based algorithm integrated in the control system for (b) clear day ; (c) cloudy day