Reference evapotranspiration of screenhouse-grown crops

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ABSTRACT

The reference evapotranspiration E_{ref} was measured under three screenhouses and compared to outside E_{ref}. The reduction with respect to outside E_{ref} was quantified by means of two factors, ζ_{rad} and ζ_{adv}. ζ_{rad} was found to depend linearly on transmittance (τ), and ζ_{adv} on wind ratio (ω). A model was proposed for screenhouse E_{ref} based on outside weather data, τ and ω

Palabras clave: Solar radiation, net radiation, transmittance, advective component, radiative component

1. Introduction

Screenhouses, also called net-houses, are becoming popular among growers in arid and semiarid regions like the Mediterranean area, due to the environmental, economic and agronomic benefits they offer [1]. Insect proof screenhouses are environmental friendly as they reduce the amount of chemical inputs in pesticides and their associated costs, health risks for workers and potential environmental pollution [2]. Economically, screenhouses have lower cost compared to conventional greenhouses [3]. The reduction of solar radiation due to net-covering allows alleviating conditions of stress-induced limitations of the physiological fluxes [4] which are a major constraint in the productivity and quality of greenhouse-grown crops. The positive impact of a net-covering on plant behaviour can be mostly explained by the more favourable microclimate under a screenhouse than outdoors.

In particular, the reduction in both radiation load (net radiation) and wind speed due to the presence of the cover material leads to a reduction of the climatic demand with respect to the open field. This reduction of the climatic demand – generally expressed in terms of the evapotranspiration of a reference crop, E_{ref}, as proposed by the FAO [5], hereafter FAO-56-PM method - leads to a concomitant reduction of the actual evapotranspiration rate of screenhouse crops with respect to the open field. This was demonstrated by several studies performed in the last decade [6, 7],

However, whereas irrigation scheduling of open field crop by means of the calculation of the FAO-56-PM method and subsequent application of a crop coefficient (K_c) is used worldwide, it is not possible to apply this method to screenhouse crops, because the calculation of the crop net radiation, R_n, is based on formulae that are valid only for open field conditions. In particular, R_n of a screenhouse crop differs substantially from that of an open field crop, due to the presence of the cover, which changes both the net short-wave and net long wave radiation. To overcome this problem, we propose in this study to investigate the links between the advective and radiative components of $E_{ref,in}$ and $E_{ref,out}$ with the aim to propose a simple model of $E_{ref,in}$ based only on outside climate inputs. The specific objectives were to:

(i) demonstrate that the radiative component of $E_{ref,in}$ is mainly driven by the screenhouse global transmittance (τ), and the advective component by the screenhouse wind ratio (ω), and

(ii) use these findings to formulate and test the performance of a E_{ref}-model that enables predicting $E_{ref,in}$ from the radiative and advective components of $E_{ref,out}$ and from the knowledge of τ and ω.

2. Materials and Methods

2.1 Screenhouse and open field facilities

The experiments were performed in three experimental flat roof screenhouses, with the longer dimension oriented N–S, (36º declination clockwise from North), located at the University of Thessaly near Volos (Velestino: Latitude 39º 22', longitude 22º 44', altitude 85 m), on the continental area of Eastern Greece. The three screenhouses were 20 m long, 10 m wide and 3.2 m high.

Three screens were tested. Two were insect-proof (IP) screens manufactured by Meteor Ltd., Israel: (1) a pearl 50 mesh (20/10) AntiVirus^{TM} screen, hereafter IP-1; and (2) a white 50 mesh BioNet^{TM} (BN), hereafter IP2. The third one was a green shade screen (Thrace Plastics C S.A. Xanthi, Greece) hereafter GS. The insect proof nets have a regular mesh netting of 0.27mm x 0.27 mm, while the green shading net, due to its different knitting, present meshes that are irregular in size and arrangement, with dimensions varying in the range 0.5 mm to 3.0 mm.

Sweet pepper plants (*Capsicum annuum L.*, cv. Dolmi) were transplanted in the three screenhouses and in open-field on May 7, 2012. Plants were laid out 0.5 m apart in the row, in five double rows with a distance between the double rows of 1.2 m, resulting in a plant density of 1.8 plants per m^2.

2.2 Climate data

The following climatic data were continuously monitored outside (University weather station, 100 m distant of the screenhouses) and in the centre of each screenhouse: air temperature and relative humidity, solar radiation, net radiation and wind speed.

2.3 Calculations

The daily reference evapotranspiration E_{ref} (mm day^{-1}) was calculated by means of the FAO-56 Penman–Monteith equation [5], using the outside and inside measured meteorological data of air temperature (T_a) and vapour pressure deficit (D_a), net radiation (R_n) and wind speed, W. The daily integral of soil heat flux was assumed to be zero, leading to the following expression for E_{ref}:

$$E_{ref} = \frac{0.408\Delta R_n + \gamma \frac{900}{T_a + 273} W D_a}{\Delta + \gamma(1 + 0.34 W)} \quad (1)$$

where Δ is the slope of water pressure curve and γ is the psychrometric constant, both in kPa ºC^{-1}.

The use of Eq. 1 implicitly implies that crop albedo was fixed at 0.23, aerodynamic resistance r_a (s m^{-1}) was equal to 208/W, and bulk surface resistance, r_c, was 70 s m^{-1}. The radiative and advective components of E_{ref} were defined respectively as:

$$E_{rad} = \frac{0.408\,\Delta R_n}{\Delta + \gamma(1 + 0.34\,W)} \quad (2a)$$

and

$$E_{adv} = \frac{\gamma \frac{900}{T_a + 273} W D_a}{\Delta + \gamma(1 + 0.34\,W)} \quad (2b)$$

The ratios of screenhouse E_{rad} and E_{adv} (subindice 'in') to the respective outside values (subindice 'out') were calculated as:

$\zeta_{rad} = E_{rad,in}/E_{rad,out}$ = radiative reduction factor

$\zeta_{adv} = E_{adv,in}/E_{adv,out}$ = advective reduction factor

$\zeta_{tot} = E_{ref,in}/E_{ref,out}$ = overall reduction factor

We developed a model based on the hypothesis that the radiative reduction factor (ζ_{rad}) is a function of the screenhouse transmittance, and the advective reduction factor (ζ_{adv}) is a function of the wind ratio. $E_{ref,in}$ is therefore expressed as:

$$\begin{aligned} E_{ref,in} &= \zeta_{rad} E_{rad,out} + \zeta_{ad} E_{adv,out} \\ &= f(\tau) E_{rad,out} + g(\omega) E_{adv,out} \end{aligned} \quad \ldots(3)$$

3. Results and Discussion

The time evolution of daily reference evapotranspiration (Eq.1) for the open-field and screenhouses (Fig. 1) followed a similar time-pattern to that observed net radiation, R_n. Compared to $E_{ref,out}$, the absolute reduction (ΔE_{ref}, mm day^{-1}) observed in the screenhouses were -0.60, - 1.58 and -1.57 mm day^{-1} for IP1, IP2 and SG respectively in Aug, and – 0.41, -1.01 and -0.99 mm day^{-1} respectively in Sept. Over the two months periods, the mean relative reduction with respect to outside E_{ref} was 17.4%, 41.3% and 42.6 % in IP1, IP2 and SG respectively.

The time pattern of the radiative component, E_{rad}, (Eq. 2a) followed closely that of E_{ref}, (Fig. 2). On a monthly scale, $E_{rad,IP1}$ (3.61 and 2.43 mm day^{-1} in Aug. and Sept. respectively) was very close to $E_{rad,out}$ (3.68 and 2.54 mm day^{-1} respectively). $E_{rad,IP2}$ and $E_{rad,GS}$ were lower than $E_{rad,out}$ (2.71 and 2.50 mm day^{-1} respectively in Aug, 1.82 and 1.71 mm day^{-1} respectively in Sept). Over the whole period of observation, the reduction of E_{rad} amounted to 3.0%, 27.1% and 31.9 % in IP1, IP2 and SG respectively.

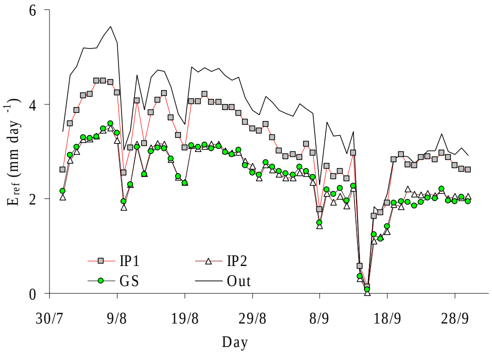

Figure 1. *Time evolution of reference evapo-transpiration (E_{ref}) outside and in the three screenhouses. Continuous line = outside; square = IP1; triangle = IP2; circle = GS)*

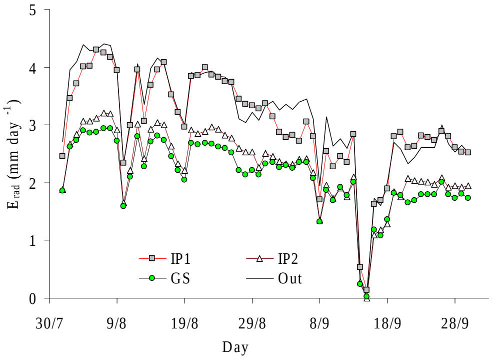

Figure 2. *Time evolution of the radiativecomponent (E_{rad}) outside and in the three screenhouses. Symbols as in Fig.1*

The advective component, E_{adv} (Eq. 2b) followed a distinct time evolution from E_{ref} and E_{rad}, showing maximum and minimum values (Fig. 3) that were concomitant with those of D_a and W_{out}. E_{adv} was the lowest in IP2 and SG, which have the lowest wind ratios (ω = 0.19 and 0.20 respectively), and was approximately doubled for IP1 (ω = 0.43). The latter provided E_{adv} values that were approximately half of $E_{adv,out}$. The mean relative reduction with respect to outside E_{adv} was 75.1%, 74.0% and 55.8 % in IP1, IP2 and SG respectively.

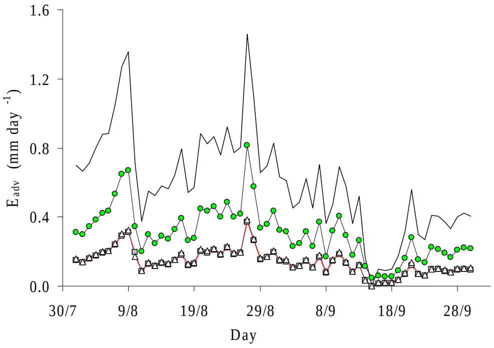

Figure 3. *Time evolution of the advective component (E_{adv}) outside and in the three screenhouses. Symbols as in Fig.1*

The respective contribution of the radiative and advective term with respect to E_{ref} was calculated as the ratio $\rho_{rad} = E_{rad}/E_{ref}$ and $\rho_{adv} = E_{adv}/E_{ref} = 1 - \rho_{rad}$. Over the observation period, ρ_{rad} was higher in the screenhouses with respect to the outside value, representing on average 96($\pm$3), 94($\pm$4) and 90($\pm$5) % for IP1, IP2 and GS respectively, while the mean outside value was 85($\pm$4) %.

Pooling the screenhouse daily data sets for the two-month period (n= 183), clear linear relationships were obtained between the parameters ζ_{rad} and τ on one hand and between ζ_{adv} and ω on other hand. The regression analysis provided the following relationships are:

$$\zeta_{rad} = 1.90\tau - 0.46 \quad (4a)$$

with R^2 = 0.85 and RMSE (root mean square error) = 0.055, and

$$\zeta_{adv} = 1.21\omega - 0.00 \quad (4b)$$

with R^2 = 0.95 and RMSE = 0.030.

Using these equations in the model of $E_{ref,in}$ (Eq. 3), the final model formulation was obtained as:

$$E_{ref,in} = (1.90\tau - 0.46)\, E_{rad,out} + 1.21 E_{adv,out} \quad (5)$$

The predicted values of $E_{ref,in}$, by means of Eq. 5, $[E_{ref.in}]_{est.}$, were in fair agreement with the values derived from Eq. 1 using *in situ* measurements of the screenhouse internal variables, $[E_{ref.in}]_{obs}$ (Fig. 4). The inside reference evapotranspiration was predicted from Eq. 5 with statistical indicators RMSE (root mean square error) = 0.11 mm day^{-1}, MBE (mean bias error) = -0.02 mm day^{-1} and R^2 = 0.97.

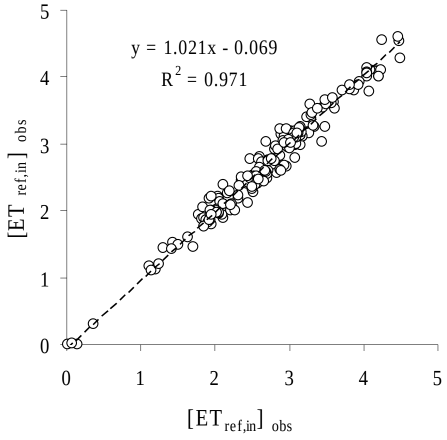

Figure 4. *Relationship between daily observed and estimated values of $E_{ref,in}$ (in mm day^{-1})..*

From the previous results, it can be deduced that the screenhouses enhanced the predominant role of the radiative component that was observed in open field conditions. The radiative component largely outweighed the advective component in all screenhouses, where E_{rad} contributed to 96, 94 and 90 % of E_{ref} in IP1, IP2 and GS respectively, against 85% outside.

This observation underlines that great care should be taken in assessing the radiative component of E_{ref}, for which small errors in the main driving variable – i.e. solar transmittance (Eq 4a) – could lead to significant errors in $E_{ref,in}$.. In corollary, the small weight of the advective component indicates that large uncertainties in the determination of the wind ratio would not be critical to the overall model performance (Fig. 4).

4. Conclusion

The two main inputs of the model, $E_{rad,out}$ and $E_{adv,out}$ can be provided by agricultural extension services without more computation requirements than those corresponding to the calculation of daily $E_{ref,out}$. The daily values of the radiative and advective components could therefore be supplied as specific information devoted to screenhouse-crops irrigation scheduling. Individual farmers could easily calculate $E_{ref,in}$ from the proposed model, provided they have a reliable estimation of the transmittance and wind ratio of their screenhouse. Other option would be that extension services provide farmers with a synthetic table where $E_{ref,in}$ is calculated for a range of values of τ and ω.

Screenhouse transmittance is a parameter of prime importance in predicting $E_{ref,in}$. The main reasons are that (i) the radiative component E_{rad} is the predominant contributor to total E_{ref} and (ii) the radiative reduction factor is highly sensitive to τ. A reliable estimate of τ is therefore required that should be based preferably on *in situ* measurements of the transmittance. This on farm 'calibration' could be carried out by research organisms, extension services or manufacturers, for the main cover materials and screenhouse structures that are presently used by farmers.

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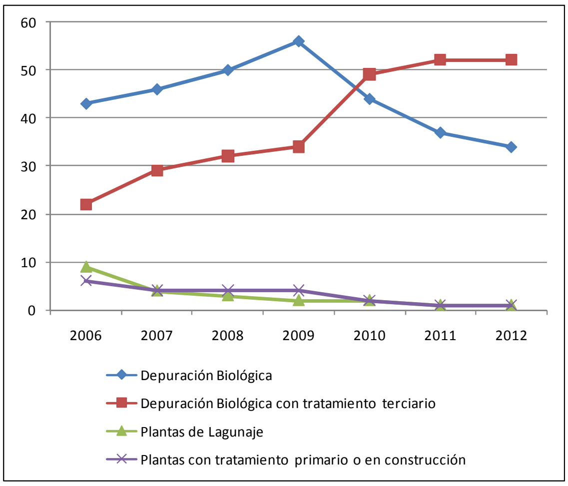

Figura 1. *Evolución de los métodos de depuración. 2012.*

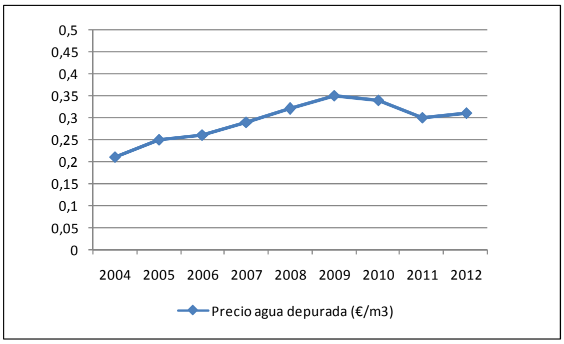

Figura 2. *Evolución del precio del agua depurada (€/m^3). 2012.*