Comparison of Transpiration Models in Tomato Soilless Culture

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Summary

A two-year greenhouse study was performed to determine the possibility of estimating the transpiration rate in hydroponically grown tomato on the basis of climate parameters. Transpiration rate, determined by the water balance method on different substrates, was compared to the transpiration rate calculated using the Penman-Monteith equation. Regression analysis of the comparison of two different approaches to water consumption determination confirmed that the transpiration rate of greenhouse grown tomato for the studied area can be estimated with high accuracy ($R^2 > 0.95$).

Key words

Penman-Monteith equation, water balance method, hydroponic substrates

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Received: April 13, 2006 | Accepted: February 7, 2007

Introduction

As the most intensive crop production, soilless culture requires large quantities of water, often over 10,000 m^3 ha^{-1} $year^{-1}$ (Voogt, 1992; Duchein et al., 1995). Total water consumption (TWC) in open soilless culture can be divided into two segments - physiological and technological consumption.

Technological part (ca 20-30% of TWC) is the amount of water leached from the substrate due to gravitation and providing optimal moisture and aeration of the substrate, as well as preventing salt accumulation (Schon and Compton, 1997).

Physiological segment (ca 70-80% of TWC) refers to the consumption by the plant, namely plant water uptake (PWU). Only a small part of absorbed water remains within the plant while the major part (> 90%) is released through the stomata as water vapour through the transpiration process (Li et al., 2001).

Since these are large amounts of water, knowledge of transpiration rates of different crops enables better and more rational management of water as a limited and inapplicable natural source. Transpiration models make it possible to estimate or calculate transpiration rates on the basis of climate and/or vegetative parameters.

The main goal of this study was to compare and test tomato transpiration rates calculated by the transpiration model according to Penman-Monteith (P-M), adapted to greenhouse conditions, using tomato transpiration on different substrates measured by the water balance method.

Material and methods

Experimental setting

The study of tomato grown in an open hydroponic system was conducted during 2001 and 2002 in a greenhouse (180 m^2) located at the experimental station of the Faculty of Agriculture, University of Zagreb, Croatia.

The greenhouse was equipped with an automatic heating, ventilation and fertigation system. Tomato seedlings (*Lycopersicon esculentum* Mill. F1 Bell) were planted into PE bags (100x15x7.5 cm) filled with one of the tested substrates.

Substrate bags were arranged in double rows with an average density of 3.1 plants per m^2. A dropper was set up by each plant (2 l h^{-1}) and the flow rate was checked monthly. Fertigation drip management (rate and frequency) was equally applied in all treatments and it was adjusted to plant phenology and climate conditions in the greenhouse.

The experiment was laid out according to the completely randomized block design in three treatments (rockwool, perlite and peat) and with three replicates. The experimental plot consisted of three bags and the accounting plot comprised one bag with three tomato plants.

The greenhouse was supplied with thermo- and hygrologgers, which recorded the values of air temperature and humidity at one hour intervals.

Water balance method

Transpiration measurements were carried out in 2001 (15.04.-30.11.) and 2002 (01.03.-01.11.). Transpiration rate (T) on particular substrates was determined by the water balance method on the basis of the difference between total water input (I) and output (O) (Romic, 1994; Romero-Aranda et al., 2001). Total I was measured by a flow meter installed on the main pipe, while drainage collectors were installed on each accounting plot for O calculation. Drainage quantity was measured twice a week. Disregarding the small evaporation area (0.006 m^{-2}) of the rockwool cube into which tomato was transplanted, the difference between I and O may represent the value of PWU, i.e. transpiration (T) (Romero-Aranda et al., 2001).

$$T = I - O \qquad (1)$$

Penman-Monteith equation

Besides direct measuring, transpiration rates were calculated using the Penman-Monteith model, adapted to greenhouse conditions (Stanghellini, 1987; Montero et al., 2001; Seginer, 2002):

$$T = \frac{0.408\Delta(R_S\tau)}{\Delta+\gamma(1+r_s/r_a)} + \frac{(\rho c/r_a)(e_s-e_a)}{\Delta+\gamma(1+r_s/r_a)} \qquad (2)$$

where

T - transpiration (mm day^{-1})
R_s - external solar radiation (MJ m^{-2} day^{-1})
r_a - aerodynamic resistance (m s^{-1})
r_s - stomatal resistance (m s^{-1})
e_s-e_a - saturation vapour pressure deficit (kPa)
Δ - slope of vapour pressure curve (kPa °C^{-1})
τ - cover transmissivity of solar radiation
γ - psychrometric constant (kPa °C^{-1})
ρ - mean air density at constant pressure (kg m^{-3})
c - specific heat of air at constant pressure (MJ kg^{-1} °C^{-1}).

R_s was calculated on the basis of insulation duration (n) using the program CROPWAT ver. 5.7 (Smith, 1992). Insulation duration data were obtained from the meteorological station Maksimir, Zagreb. It was assumed that the cover transmissivity of solar radiation (0.6) was constant and did not change during the trial period (Baille and Baille, 1994; Jolliet, 1994; Kittas et al., 1995). Mean air density (ρ), slope of saturation vapour pressure curve (Δ) for different temperatures and specific heat of air (c) were considered as constants, as well as the psychrometric con-

Table 1. Descriptive statistics of climatic (R_s-solar radiation, n-sunshine duration, RH-relative humidity, T-air temperature) and vegetative parameters (r_s- stomatal resistance)

Parameter	R_s (MJ/m²day)		n (h)		RH (%)		T (°C)		r_s (m/s)	
	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Minimum	5.5	4.7	3.3	2.2	41	30	9.8	9.6	201	202
Maximum	21.9	24.6	10.1	10.5	87.4	88.2	34.7	37.6	294	276
Mean	15.7	15.5	6.7	6.5	58.7	58.7	20.9	21.6	229	230
St. Deviation	6.3	6.7	2.5	2.7	5.5	5.3	4.5	4.7	38.9	28.4
C.V. %	41	43	37	41	11	15	31	32	17	12

stant (γ). Saturation vapour pressure deficit (e_s-e_a) represents the difference between the mean saturation vapour pressure (e_s), related to air temperature and actual vapour pressure (e_a), derived from relative humidity data according to Allen et al. (1998). In the P-M equation (Eq. 2), r_a and r_s represent the bulk aerodynamic and stomatal resistances of the leaves to vapour diffusion. The aerodynamic resistance value was considered as a constant (r_a=200 s m^{-1}) because of the comparatively large leaf area and low wind velocity in the greenhouse (Stanghellini, 1987; Kage et al., 2000). Stomatal resistance was calculated on the basis of external solar radiation (Boulard and Wang, 2000):

$$r_s = 200(1 + \frac{1}{\exp(0{,}05(\tau \times R_s - 50))}) \qquad (3)$$

Data processing

Transpiration values, estimated according to P-M and directly measured using the water balance method, were calculated per decade and compared using a simple linear regression. All descriptive and procedural data processing was done using a statistical software package (SAS, 2001).

Results and discussion

Since the nightly transpiration rate in the greenhouse can be negligible (Boulard and Wang, 2002), only daily values of climatic and vegetative parameters were used for research purposes (P-M equation), Table 1.

Results of descriptive statistics given in Table 1 indicate that the climate conditions were fairly uniform in both trial years. Among the observed parameters, solar radiation varied the most in the two-year research period (CV= 41 and 43%). Relative humidity in the greenhouse varied the least, CV being 11% in 2001 and 15% in 2002.

Data on directly measured transpiration were included into a simple linear regression model. In both trial years and with all three predictors, i.e. rockwool, perlite and peat, high coefficients of determination (R^2) with small differences between substrates were obtained (Figures 1 and 2).

The model involving rockwool achieved the highest r-square value in both years (R^2 = 0.98). This parameter, along with some others relating to macroelements and water balance (Ondrasek et al., 2004), confirms that irrigation management was best adapted to tomato grown on rockwool. Namely, irrigation applied in this trial involved the same amounts of water and identical irrigation intervals for all substrates. However, irrigation rates and intervals applied in soilless culture on substrates for the purpose of better water management should be adjusted not only to the plant growth, plant development stage, and climate parameters but also to the physical characteristics of the substrate. According to Biernbaum et al., (1999) and also

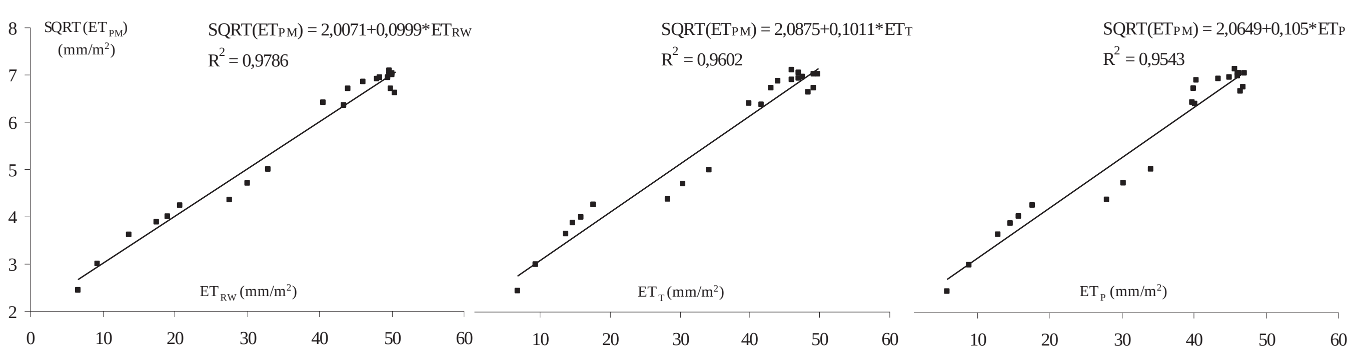

Figure 1. Comparison of the regression lines and associated statistical parameters between measured transpiration (T_T-on peat, T_{RW}-on rockwool, T_P-on perlit) and predicted by the P-M equation (T_{PM}) in 2001 (n=23)

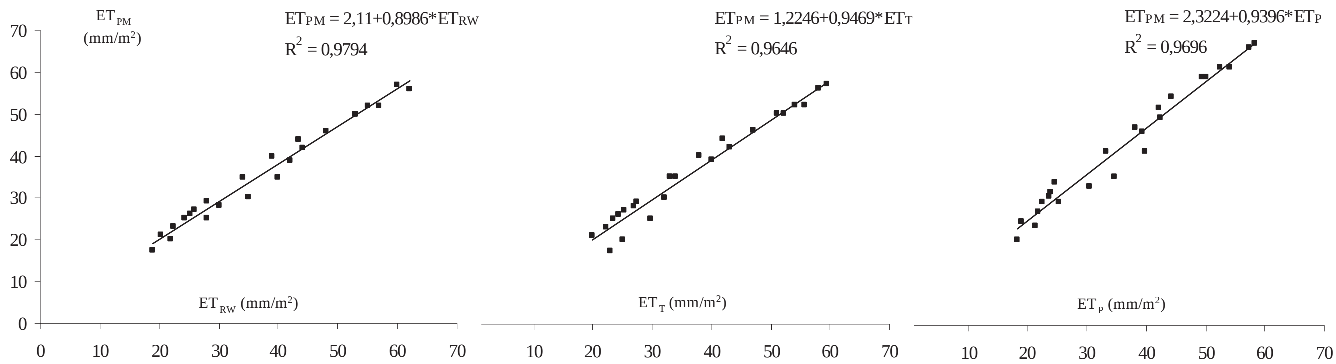

Figure 2. Comparison of the regression lines and associated statistical parameters between measured transpiration (T_T-on peat, T_{RW}-on rockwool, T_P-on perlit) and predicted by the P-M equation (T_{PM}) in 2002 (n=24)

confirmed by our results, fertigation frequency on peat should be increased compared to other substrates less capable of retaining available water. On the contrary, the amount and intervals of fertigation on perlite should be decreased compared to rockwool, which is more capable of accumulating water. According to Argo and Biernbaum (1995) and also confirmed by our results, growing media with relatively higher water-holding capacity (e.i. rockwool and peat) required fewer (fert)irrigations than those with a lower water-holding capacity, like perlite.

Conclusions

The two-year trial revealed that the same irrigation treatment in tomato hydroponic culture resulted in different transpiration rates on different substrates. It was also found that the external climate data in combination with the Penman-Monteith approach enable reliable prediction of water consumption by transpiration in tomato soilless culture in the studied area.

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