Transpiration of Glasshouse Rose Crops: Evaluation of Regression Models

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Abstract

Regression models of transpiration (T) based on global radiation inside the greenhouse (G), with or without energy input from heating pipes (E_h) and/or vapor pressure deficit (VPD) were parameterized. Therefore, data on T, G, temperatures from air, canopy and heating pipes, and VPD from both a lysimeter experiment and from a cut rose grower were analyzed.

Based on daily integrals, all T models showed good fits due to the dominant effect of global radiation G (solar + supplementary radiation) inside the greenhouse on T. Similar G-T relations on high-light and low-light days indicated identical effects of solar radiation and radiation from supplementary light on T.

For both data sets, similar regression coefficients of 0.3 l/MJ were obtained with models including G and VPD_{air}, G and E_h, or G and a constant intercept. Including the difference between saturated pressure at leaf temperature and air vapor pressure ($VPD_{leaf\text{-}air}$) did not improve the regression models. G accounted for 74% of latent heat transfer.

The contribution of heating underneath the canopy on T was investigated by switching off the heating on days during the winter period, and was on average 13% or 0.2 l/m^2.day for an extra energy input by heating pipes of 3 MJ/m^2.day. Therefore, the efficiency of sub-canopy heating was smaller than 0.07 l/MJ, less than 23% of the efficiency of global radiation.

INTRODUCTION

Transpiration models of greenhouse crops differ in their number of parameters. Complete energy balance models have been used to account for transpiration of the crop under different climatic conditions (Monteith, 1973; Stanghellini, 1987). The so-called Penman-Monteith model (P-M model) contains a number of parameters such as aero-dynamic and stomatal leaf resistances, which may be crop or even cultivar specific and require elaborate work to determine. A simplified P-M model T = a*G + b*VPD has been used to avoid parameterization of leaf resistances (Baille et al., 1994; Okuya and Okuya, 1988; Kittas et al., 1999; Medrano et al., 2005). For roses grown under Mediterranean winter conditions, the use of this simplified regression was justified since canopy resistance did not play a significant role in determining canopy transpiration (Kittas et al., 1999). In another study with roses under summer conditions in Israel, canopy resistance and ambient humidity also had only a secondary effect during the morning and noon, which means that the transpiration was 'decoupled'. In the afternoon, coupling of the conductance to transpiration did occur under high VPD values (Dayan et al., 2000). This coupling describes how saturation deficit at the leaf surface near the pores is linked to that of the air outside the boundary layer, or how conductance is related to transpiration (Jarvis, 1985). Because in greenhouses air velocity usually is low, boundary layer effects may be strong, and conductance and transpiration are largely uncoupled (Nederhoff, 1994).

For conditions occurring in the Netherlands, with low light levels and heating in the winter, a regression model for T was developed based on global radiation outside the greenhouse, and energy input from heating (de Graaf and Esmeijer, 1998; de Graaf, 1999): $T = (a*G + b*(t_{pipe} - t_{air})) * pf$, in which ($t_{pipe} - t_{air}$) = temperature difference between heating pipe and greenhouse in degree minutes, pf = plant factor, ranging between 0 and 1 depending on the relative length of the crop, and a and b are constants depending on the crop and the configuration of the heating system in the greenhouse. This model is used as an algorithm in climate computers for irrigation purposes in a continuous process by integration of radiation and degree sum in minutes. The transpiration model is frequently used by growers in combination with a drainage measurement, in which differences in T are compensated in following irrigations by taking into account measured differences between calculated drain (from T and irrigation amount) and realized drain.

Since increasing supplementary light levels are being used for the production of cut roses in the Netherlands, the need for additional heating has decreased. Heating underneath the canopy is however still promoted to ‘activate’ the crop, i.e. to increase T. This decreases the energy efficiency however, since excess heat is ventilated. More quantitative data on the contribution of heating to T are therefore required to optimise energy input.

Besides determining the influence of heating on T, the purpose of this study was to obtain a regression model which may be used for estimating T under different conditions. Therefore the climatic factors global radiation inside the greenhouse (G), energy from heating underneath the canopy (E_h) and vapor pressure deficit (VPD_{air} and $VPD_{leaf\text{-}air}$) were related to measured transpiration (T) for cut rose. The regressions were obtained from data of a lysimeter experiment and from data of a commercial rose grower.

MATERIALS AND METHODS

Data from Lysimeter Experiment

In a Venlo-type glasshouse (12 x 12.8 m) six 10 m long beds (width 1.1 m) were positioned. In two of the beds, lysimeter systems of 2 m^2 were placed in such a way that the plants were under identical conditions to the rest of the crop. Each lysimeter system, which consisted of load cells weighing an aluminium frame and a drain collection tank, contained 2 rows with 2 m rockwool slabs. In this set-up transpiration was calculated in 2-minute weighing intervals (Baas and Slootweg, 2004). The heating system at crop level consisted of 2 pipes underneath the canopy (1.2 pipes/m greenhouse; diameter 28 mm). Supplementary lighting was used at a level of 30 W/m^2 global radiation at canopy level during a maximum of 18 h/day. Lighting was switched off at global radiation levels outside the greenhouse higher than 150 W/m^2.

A rose crop (‘First Red’) was cultivated in the system from summer 2003-summer 2004. Besides transpiration, leaf temperature with four infrared sensors, global radiation (350-2500 nm), temperature of the heating pipes and air, and relative humidity were recorded. Data from 15 selected days were used for the regressions. The days were selected for their variability in transpiration, availability of complete data sets, and the size of the crop (directly before a harvest flush).

In the winter period, in weeks 46, 47, 48, 52 2003, and weeks 2, 7 and 12 2004 the heating pipes of 46°C underneath the canopy were switched of during 2 days in half the greenhouse, including one of the two lysimeter beds. By comparing transpiration with the control treatment the contribution of heating to total transpiration was determined.

Data from Rose Grower

Data from a grower were obtained in the period September 15 – November 14 2005. The cultivar ‘Ilios’ was grown in a greenhouse with supplementary lighting of 76 W/m^2 global radiation at canopy level, and 4 beds per greenhouse of 8 m with 12 heating pipes (diameter 51 mm). Transpiration was determined from the daily available quantities of irrigation minus drain. Global radiation (G) was not measured directly as in the lysimeter experiment, but estimated from global radiation outside the greenhouse and a greenhouse transmission of 75%. In addition, from the number of operating hours the extra input of supplementary lighting was calculated. Daily temperatures of heating pipes (1.5 pipes/m), greenhouse and crop canopy temperatures and relative humidity were available and used to calculate energy input and VPD.

Evaluation of Transpiration Models

For the purpose of evaluation of transpiration regressions, $VPD_{leaf\text{-}air}$ was calculated with the data of leaf temperature, relative humidity and greenhouse air temperature. Energy input from the heating pipes was calculated according to Nawrocki (1985), based on the configuration of the heating pipes.

The following multiple linear regressions were fitted with the available data sets:

$$T = (a1 * G + b * E_h) * pf \quad (1)$$
$$T = (a2 * (G + E_h)) * pf \quad (2)$$
$$T = (a3 * G)*pf \quad (3)$$
$$T = (a4 * G + d * VPD_{leaf\text{-}air}) * pf \quad (4)$$
$$T = (a5 * G + e * VPD_{air}) * pf \quad (5)$$
$$T = (a6 * G) * pf + c \quad (3a)$$

in which T = estimated daily (evapo)transpiration (l/m^2.day), G = global radiation at canopy level inside the greenhouse (J/cm^2.day), E_h = energy input from heating system (MJ/m^2.day), $VPD_{leaf\text{-}air}$ = vapor pressure deficit leaf-air (Pa), VPD_{air} = vapor pressure deficit air (Pa), a, b, d and e are coefficients for global radiation, energy input from heating, $VPD_{leaf\text{-}air}$ and VPD_{air}, respectively. Since all data were obtained from a full-productive crop, plant size factor pf was set to 1 in all regression models.

RESULTS AND DISCUSSION

The data used for the parameterization of the transpiration models from the lysimeter experiment showed a large variation in T, E_h and G during the year (Fig. 1 above). Lower T coincided with lower values of G (R^2=0.94), and higher values of E_h (R^2=0.87), but there was no clear correlation with $VPD_{leaf\text{-}air}$ (R^2=0.50) or VPD_{air} (R^2=0.06). Relative humidity (not shown) varied between 70 and 95% during the whole experiment.

The data from the grower showed a far lower input of E_h (on average 0.4 MJ/m^2.day, compared to 2.7 MJ/m^2.day in the lysimeter experiment), and less fluctuating VPD levels (Fig. 1 below). Lower T coincided with lower G (R^2=0.88) and lower VPD_{air} values (R^2=0.73), but not with $VPD_{leaf\text{-}air}$ (R^2=0.14) or E_h (R^2=0.50).

Despite the differences in growing circumstances (crop age, cultivar, heating system, supplementary light conditions) good fits were found for the relation between T and G for both data sets (Fig. 2), with similar global radiation coefficients of 0.3 l/MJ. Given a latent heat of vaporization of 2.454 MJ/kg (20°C), global radiation accounted for ca. 74% of the transpiration.

Two-minute-data (Fig. 3 and 4) measured on a high-light summer and a low-light winter day showed that T was related to G in a similar way as in the data based on daily integrals (Fig. 2). Under dark conditions, transpiration continued at a rate of between 0.5 ml/m^2.min on a high-light day, and ca. 1 ml/m^2.min on a low-light day, which would mean 0.36 l/m^2 for the night-time period of 6 hours, or 0.7-1.4 l/m^2.day, which is in line with the intercepts in Fig. 2.

From the similar G-T relationships found in Fig. 2 and 4 it is concluded that the crop was able to transfer G levels up to 600 W/m^2 into latent heat without significant delay. Moreover, radiation from supplementary lighting accounted for 70% on the low-light day and for only 4% on the high-light day. Since the relations on these contrasting days were similar (Fig. 4A compared to Fig. 4B) it is concluded that the transpiration of roses is similar under supplementary radiation and under solar radiation.

VPD_{air} showed a circular relation to G during the day under high-light conditions (Fig. 4C), which was due to the relatively high VPD in the afternoon, as T decreased in accordance with decreasing G. A similar relationship was found with $VPD_{leaf\text{-}air}$ which confirms that this parameter could not be used to predict G. At lower VPD under low-light conditions, no relation between VPD and G was found (Fig. 4D).

Table 1 gives coefficients for the calculated regressions. All models show high correlation coefficients and t-probability values for the lysimeter data set, particularly due to the dominant effect of G. For the data from the grower, regressions (1), (3a) and (5) showed highest R^2. Only regression (3a) showed similar coefficients for both data sets. Adding VPD_{air} or $VPD_{leaf\text{-}air}$ therefore did not improve the estimation of T under the climatic conditions of the data sets. VPD proved to be a significant factor under Mediterranean conditions in the simplified Penman-Monteith formula (5) for roses (Kittas et al., 1999). This might be due to the relatively high VPD values (500-2500 Pa) under Mediterranean winter conditions as compared to Dutch conditions (<1000 Pa).

The contribution of E_h on T was investigated in detail during the lysimeter experiment by switching of the heating in one lysimeter system, and measuring the effect in comparison to a control with heating pipes at 46°C (Fig. 5). The difference between the lysimeters on T ranged between 4 and 22%, or 0.2 l/m^2.day at most at a E_h of 3 MJ/m^2.day, or 0.07 l/MJ. The efficiency of heating energy compared to energy from solar radiation on T was therefore 0.7/3*100 = 23% at the most, which means that 16% of T could be contributed to heating.

From this study the following conclusions are drawn:

- Despite different growing circumstances, a global radiation coefficient of 0.3 l/MJ was found for two different rose cultivars in two differing datasets based on daily integrals. A similar linear relation between T and G was also found for 2-minute data within a day.
- Transpiration can be estimated from global radiation as measured or calculated inside the greenhouse (G), taking into account a constant intercept, or the contribution of heating (E_h). Including VPD_{air} or $VPD_{leaf\text{-}air}$ did not improve regression models of T under the conditions from the datasets.
- Similar G-T relations on high-light and low-light days indicated identical effects of solar radiation and radiation from supplementary light on T.
- Ca. 74% of G, and 16% of E_h was used for transpiration. Therefore, sub-canopy heating was quite ineffective in increasing transpiration.
- A site-specific and crop/cultivar specific T model can be obtained from daily light integrals and transpiration data as obtained from irrigation-drain amounts.

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Tables

Table 1. Regression coefficients and constants from transpiration data of cut roses.

Model	Coefficient	Lysimeter data		Grower data	
		estimate	R^2	estimate	R^2
(1) $T = a1 * G + b * E_h$	a1	.0034	0.91	.0034	0.85
(2) $T = a2 * (G + E_h)$	a2	.0033	0.91	.0042	0.72
(3) $T = a3 * G$	a3	.0038	0.91	.0043	0.65
(4) $T = a4 * G + d * VPD_{leaf\text{-}air}$	a4	.0029	0.89	.0028	0.61
(5) $T = a5 * G + e * VPD_{air}$	a5	.0028	0.85	.0021	0.88
(3a) $T = a6 * G + c$	a6	.0028	0.92	.0029	0.88
(1)	b	.0026		.022	
(3a)	c	1.04		1.40	
(4)	d	.0014		.0029	
(5)	e	.0017		.0038	

Figures

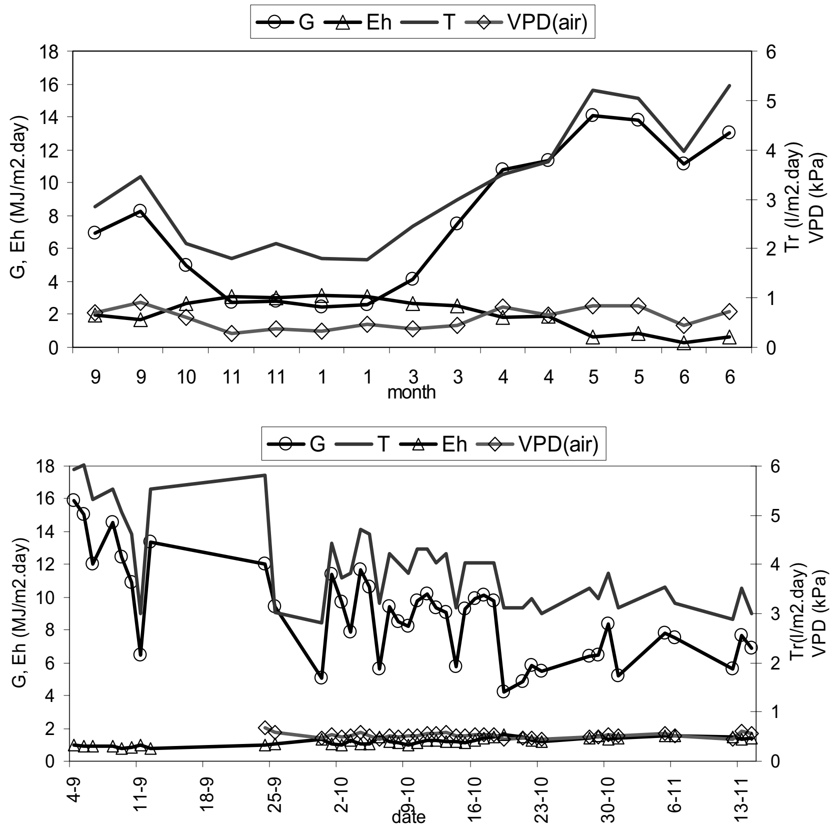

Fig. 1. Data from cut rose 'First Red' used for regression analysis from lysimeter experiment (above) and from 'Ilios' from grower (below).

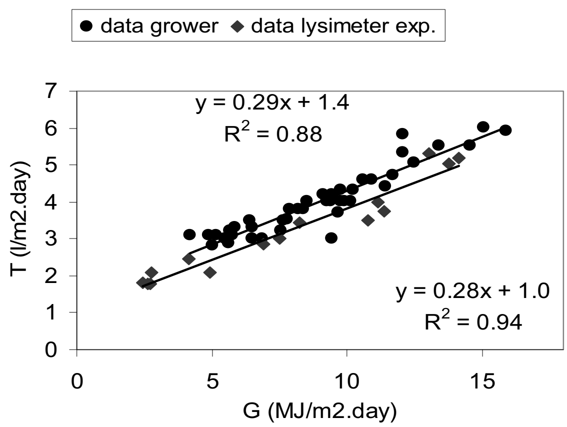

Fig. 2. Relation between G (measured at canopy level) and T for rose crop data from grower and data from experimental greenhouse.

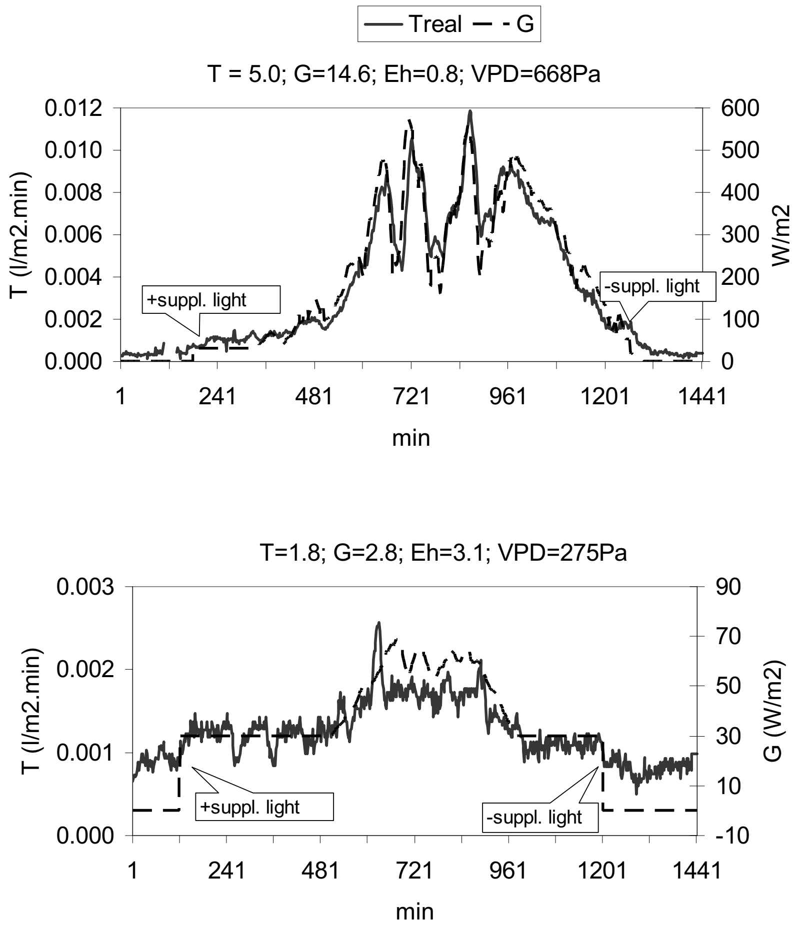

Fig. 3. Time-course of T and G on a high-light summer day (above) and a low-light winter day (below). All data are 2-minute data with a 20-minute running average.

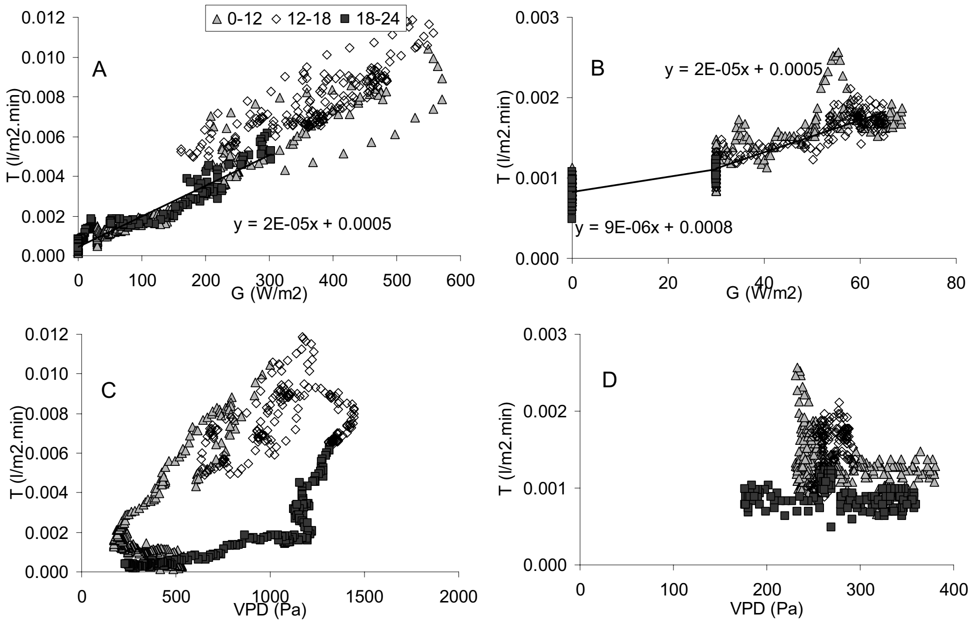

Fig. 4. Relations between T and G (A and B) and T and VPD_{air} (C and D) during different time-intervals (0-12 h, 12-18 h, 18-24 h) on a high-light summer day (A and C) and a low-light winter day (B and D).

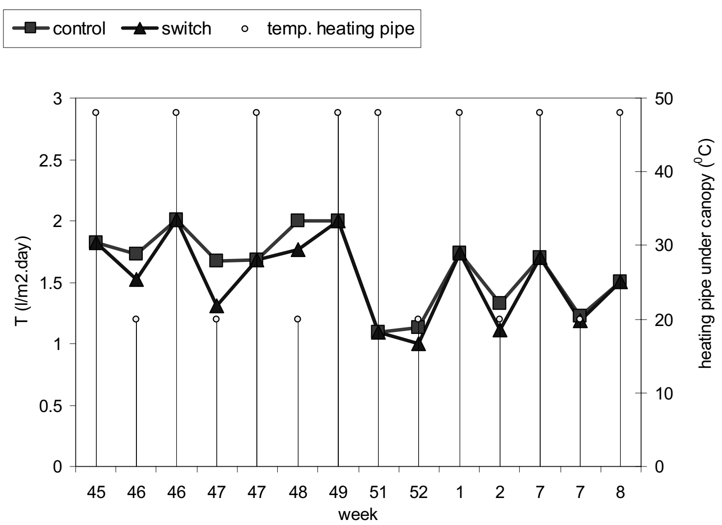

Fig. 5. Effect of switching off the heating pipe on T of cut rose 'First Red' during different weeks in the lysimeter experiment.