UAV-based infrared thermography reveals reduced transpiration in mistletoe-infected trees in an endangered eucalypt woodland

Wouter H. Maes, Alfredo R. Huete, Michele Avino, Matthias M. Boer, Remy Dehaan, Elise Pendall, Anne Griebel and Kathy Steppe

SUPPLEMENTARY MATERIALS: Estimation of transpiration from canopy temperature

S1 Estimation of transpiration of mistletoe, uninfected and infected canopy

In this section, we present a basic method to estimate transpiration from T_c using the observations of the flux tower nearby. Transpiration of the mistletoe, of the infected and uninfected canopy was estimated from the thermal measurements in combination with the flux tower measurements. The basic formula to calculate transpiration (Tr, mm s^{-1}) of the mistletoe, uninfected and infected canopy is

$$\lambda\,\mathrm{Tr} = S^* + \varepsilon\, L_{in} - \varepsilon\, \sigma\, T_c^4 - \frac{\rho_a\, c_p (T_c - T_a)}{r_{aH}} \quad \text{(S1)}$$

With λ the latent heat of vaporization, S^* the net shortwave radiation (W m^{-2}), L_{in} the incoming longwave radiation (W m^{-2}), ε the emissivity, ρ_a the air density (kg m^{-3}), c_p the specific heat capacity of the air (J kg^{-1} K^{-1}), T_a the air temperature, r_{aH} the aerodynamic resistance (s m^{-1}) and T_c the canopy temperature of either the mistletoe, uninfected or infected tree (T_{mist}, T_{uninf}, T_{inf}).

S^*, L_{in} and T_a are taken from the flux tower measurement and λ and ρ_a are calculated from T_a. The aerodynamic resistance (r_{aH}) is derived from flux tower measurements in a two-step approach. First, the measured sensible heat flux H from the flux tower measurements was corrected for energy balance closure using the Bowen Ratio method (i.e., $H_{corr} = \frac{(R_n - G)}{\left(1+\frac{1}{\beta}\right)}$, with R_n the net radiation, G the ground heat flux and β = H/λE the Bowen Ratio, with λE the measured evaporation, all as measured at the flux tower). The aerodynamic resistance r_{aH} is then calculated as

$$r_{aH} = \frac{\rho_a\, c_p\, (T_{s\_tower} - T_a)}{H_{corr}} \quad \text{(S2)}$$

With T_{s_tower} (K) the observed surface temperature of the flux tower, calculated as:

$$T_{s\_tower} = \sqrt[4]{\frac{L_{out} - (1-\varepsilon)\, L_{in}}{\sigma\, \varepsilon}} \quad \text{(S3)}$$

In equation S3, L_{out} is the outgoing longwave radiation (W m^{-2}) as measured at the flux tower and σ the Stefan-Boltzmann constant (5.675 10^{-8} W m^{-2} K^{-4}).
Finally, transpiration was converted from units of mm s^{-1} in Eq. 1 to mm $hour^{-1}$ by multiplying with 3600.

S2 Results

The estimated transpiration for the mistletoe, infected and uninfected eucalypt canopy is given in Table S1. Obviously, the trends are similar as for the T_c-comparison (Table 2). Transpiration of the infected canopy (Tr_{inf}) is always lower than that of mistletoe (Tr_{mist}) and ranges between 31% (30/01/2015) and 89% (16/06/2014) of Tr_{mist}. Transpiration from uninfected eucalypt canopy (T_{uninf}) is on average 90% of Tr_{mist} and is above 84% for all but one day (15/04/2015, 42%).

When plotting the differences in transpiration between the days for different climatic drivers (Figure S1), the same conclusions can be drawn as compared to the T_c-comparisons (Figure 6, Main text): both (Tr_{mist}-Tr_{inf}) and (Tr_{uninf}-Tr_{inf}) are particularly influenced by incoming radiation, but are not clearly higher under stressed conditions (low SW_{Can}, high VS-value, Fig 6d,f). No climatic driver or stress condition clearly influences (Tr_{mist}-Tr_{uninf}).

Table S1 – Overview of estimated transpiration of mistletoe (Tr_{mist}), infected eucalypt (Tr_{inf}) and uninfected eucalypt (Tr_{uninf}) canopy (in mm hour^{-1}).

Date	Tr_{mist}	Tr_{inf}	Tr_{uninf}
07/02/2014	0.72 ± 0.15	0.39 ± 0.25	0.68 ± 0.11
20/02/2014	0.96 ± 0.12	0.80 ± 0.17	0.86 ± 0.11
05/03/2014	0.93 ± 0.05	0.75 ± 0.08	0.79 ± 0.06
17/04/2014	0.41 ± 0.16	0.35 ± 0.21	0.44 ± 0.11
15/05/2014	0.58 ± 0.11	0.50 ± 0.12	0.50 ± 0.11
16/06/2014	0.53 ± 0.05	0.47 ± 0.07	0.52 ± 0.08
22/12/2014	0.68 ± 0.13	0.51 ± 0.16	0.73 ± 0.29
08/01/2015	0.79 ± 0.09	0.59 ± 0.16	0.79 ± 0.10
30/01/2015	0.53 ± 0.15	0.16 ± 0.15	0.46 ± 0.10
15/04/2015	0.31 ± 0.15	0.16 ± 0.13	0.13 ± 0.08

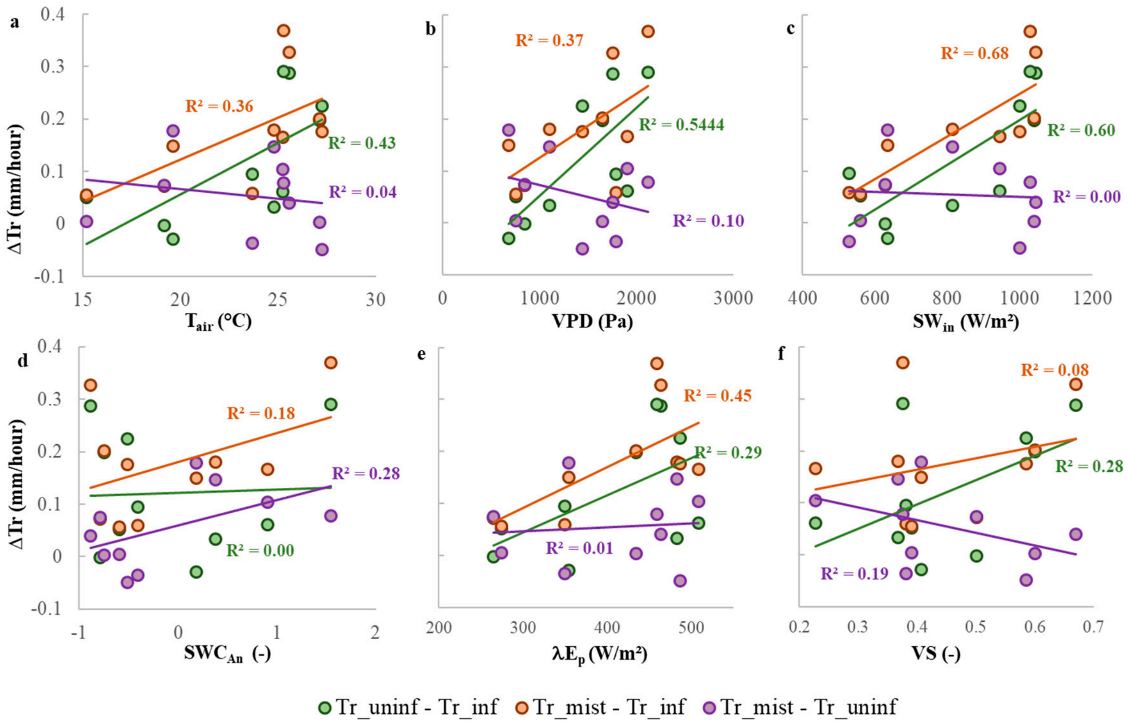

Figure S1. Distribution of the differences in estimated transpiration between infected (Tr_{inf}) and uninfected (Tr_{uninf}) eucalypt canopy, between infected eucalypt and mistletoe (Tr_{mist}) canopy and between uninfected and mistletoe canopy as a function of climatic drivers (**a.** air temperature, **b.** vapour pressure deficit and **c.** incoming shortwave radiation), **d.** the normalized anomaly in soil water content, **e.** potential evaporation and **f.** the vegetation stress factor.

S3 Discussion

A relatively straightforward method to derive transpiration from observed canopy temperature using flux tower data is presented. It is clear that this method depends on a few assumptions. First, by using L_{in} for calibrating T_{br} of the cameras (Eq. 1 in main text) and by deriving r_{aH} from Eq. S2, it was assumed that the observed surface temperature of the ecosystem, derived from L_{in}, is correct and is equal to the aerodynamic temperature T_0. We furthermore assume that, since all temperature measurements were performed at the top of the tree canopy, r_{aH} is the same, and is equal to the mean r_{aH} of the ecosystem. In Eq. S1, we assumed that the net shortwave radiation is the same for all the canopy types and is equal to the observed canopy of the overall ecosystem. This could be refined if multispectral imagery is available.

It is clear that the method would benefit from further testing, e.g. using sap flow measurements – and that the results need to be interpreted with the necessary precaution. Still, the range of estimated transpiration is reasonable, and the differences in estimated transpiration between mistletoe and infected host are very much in line with other studies using direct sap-flow measurements (see Section 4.3 main text).