Supporting information for “Optimization theory explains nighttime stomatal responses”

Yujie Wang, William R. L. Anderegg, Martin D. Venturas, Anna T. Trugman, Kailiang Yu, and Christian Frankenberg

Acceptance date: February 2021.

Notes S1 Derivation of nighttime marginal respiratory saving

We numerically computed marginal carbon gain in the daytime using

$$\frac{\partial A_{\mathrm{d}}}{\partial E_{\mathrm{d}}} \approx \frac{A_{\mathrm{d}}(E_{\mathrm{d}} + \Delta E_{\mathrm{d}}) - A_{\mathrm{d}}(E_{\mathrm{d}})}{\Delta E_{\mathrm{d}}} \tag{1}$$

While E_{d} and $A_{\mathrm{d}}(E_{\mathrm{d}})$ are experimentally measured, computing $A_{\mathrm{d}}(E_{\mathrm{d}} + \Delta E_{\mathrm{d}})$ required knowing how leaf temperature and stomatal conductance change with an incremental ΔE_{d}.

Leaf energy balance meets

$$2 \cdot c_{\mathrm{p}} \cdot g_{\mathrm{be}} \cdot (T_{\mathrm{leaf}} - T_{\mathrm{air}}) = R_{\mathrm{abs}} - f_{\mathrm{view}} \cdot \epsilon \cdot \sigma \cdot T_{\mathrm{leaf}}^4 - \lambda E \tag{2}$$

where c_{p} is the specific heat capacity of dry air at constant pressure (29.3 J mol^{-1} K^{-1}), g_{be} is the boundary layer conductance for heat ($g_{\mathrm{be}} = 0.189 \cdot \sqrt{\frac{u}{d}}$, where u is wind speed, and d is 0.72 leaf width), T_{leaf} is leaf temperature in K, T_{air} is air temperature in K, R_{abs} is total absorbed radiated energy from sun, air, and soil (not including other leaves), f_{view} measures the view factor of leaves (we assume that $f_{\mathrm{view}} = \frac{1}{\mathrm{LAI}}$), ϵ is the emissivity of leaf (0.97), σ is the Stefan-Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}), and λ is the latent heat of vaporization. As leaf cooling does not impact R_{abs}, differentiating equation 2 gives

$$\left(2 \cdot c_{\mathrm{p}} \cdot g_{\mathrm{be}} + 4 \cdot f_{\mathrm{view}} \cdot \epsilon \cdot \sigma \cdot T_{\mathrm{leaf}}^3\right) \cdot \frac{\partial T_{\mathrm{leaf}}}{\partial E} = -\lambda \tag{3}$$

Thus, $\frac{\partial T_{\mathrm{leaf}}}{\partial E}$ can be computed using

$$\frac{\partial T_{\mathrm{leaf}}}{\partial E} = -\frac{\lambda}{2 \cdot c_{\mathrm{p}} \cdot g_{\mathrm{be}} + 4 \cdot f_{\mathrm{view}} \cdot \epsilon \cdot \sigma \cdot T_{\mathrm{leaf}}^3} \tag{4}$$

A decline of T_{leaf} ought to result in a decline of nighttime respiration rate R_{leaf}, which is computed using

$$R_{\mathrm{leaf}} = R_0 \cdot \exp\left(\frac{\Delta H_{\mathrm{a}}}{RT_0} - \frac{\Delta H_{\mathrm{a}}}{RT_{\mathrm{leaf}}}\right) \tag{5}$$

where R_0 is the respiration rate at 25 °C ($T_0 = 298.15$ K), ΔH_{a} is activation energy, R is the ideal gas constant. The $\frac{\partial R_{\mathrm{leaf}}}{\partial T_{\mathrm{leaf}}}$ can be computed using

$$\frac{\partial R_{\mathrm{leaf}}}{\partial T_{\mathrm{leaf}}} = R_0 \cdot \exp(\frac{\Delta H_{\mathrm{a}}}{RT_0} - \frac{\Delta H_{\mathrm{a}}}{RT_{\mathrm{leaf}}}) \cdot \frac{\Delta H_{\mathrm{a}}}{RT_{\mathrm{leaf}}^2} = R_{\mathrm{leaf}} \cdot \frac{\Delta H_{\mathrm{a}}}{RT_{\mathrm{leaf}}^2} \tag{6}$$

Combing equations 4 and 6, we have

$$\frac{\partial R_{\mathrm{leaf}}}{\partial E_{\mathrm{n}}} = -\frac{\lambda}{2 \cdot c_{\mathrm{p}} \cdot g_{\mathrm{be}} + 4 \cdot f_{\mathrm{view}} \cdot \epsilon \cdot \sigma \cdot T_{\mathrm{leaf}}^3} \cdot R_{\mathrm{leaf}} \cdot \frac{\Delta H_{\mathrm{a}}}{RT_{\mathrm{leaf}}^2} \tag{7}$$

Supporting Figures

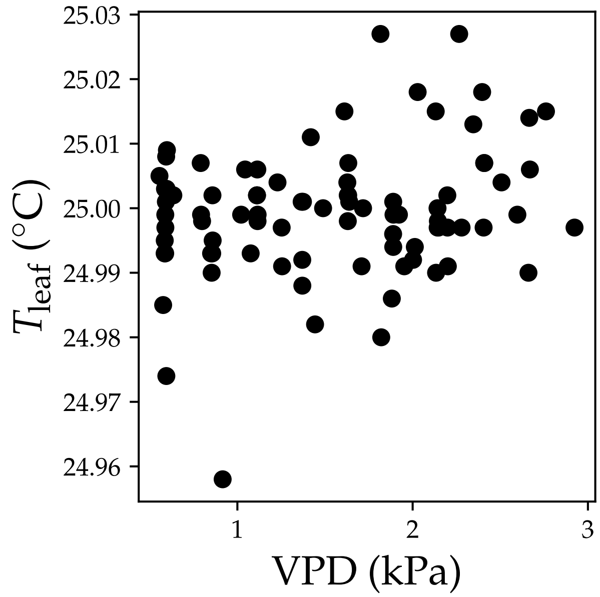

Fig. S1 Leaf temperature in the nocturnal transpiration response to atmospheric vapor pressure deficit (VPD). Data is from six individual leaves (each leaf from an individual tree).

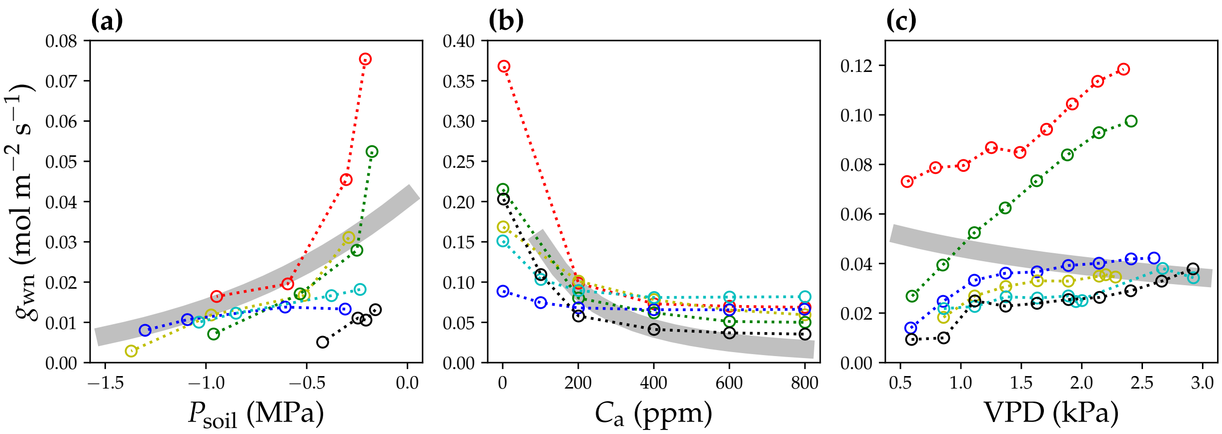

Fig. S2 Nighttime leaf diffusive conductance (g_{wn}) responses to the environmental cues. Each color represents a mature leaf from a tree. **(a)** The g_{wn} response to soil water potential (P_{soil}) in six drought-stressed trees. The light gray curve plots our model predicted g_{wn} using a constant fitness multiplier. **(b)** The g_{wn} response to atmospheric CO_2 (C_a) in six well-watered trees. **(c)** The g_{wn} response to atmospheric vapor pressure deficit (VPD) for the same six well-watered trees as in CO_2 response. The figure differs from Fig. 3 in the main text in that daytime air and leaf temperatures are 10 °C higher than nighttime temperatures.

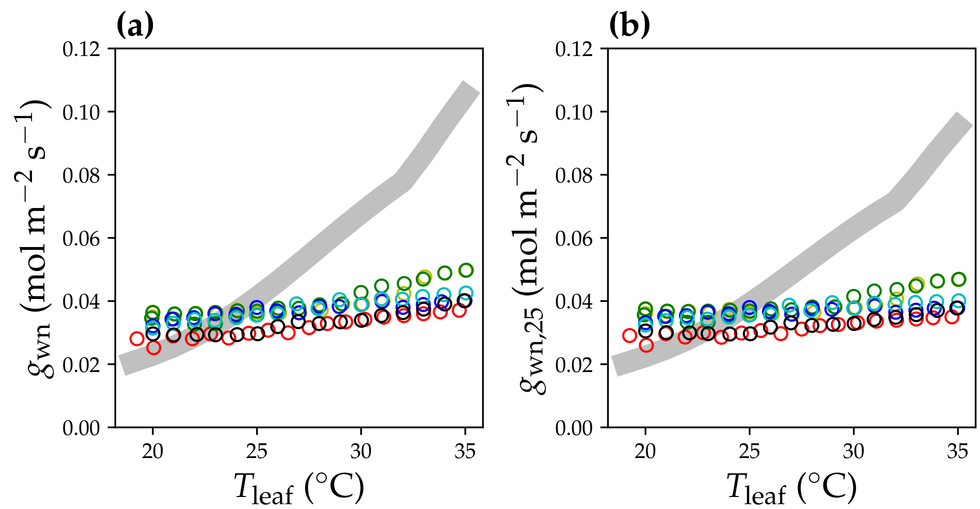

Fig. S3 Nighttime leaf diffusive conductance (g_{wn}) response to leaf temperature (T_{leaf}). Each color represents data from a mature leaf from a well-watered tree. **(a)** The g_{wn} is not corrected by temperature. The light gray curve plots our model predicted g_{wn} using a constant fitness multiplier. **(b)** The g_{wn} is normalized to 25 °C ($g_{wn,25}$). The figure differs from Fig. 4 in the main text in that daytime air and leaf temperatures are 10 °C higher than nighttime temperatures.

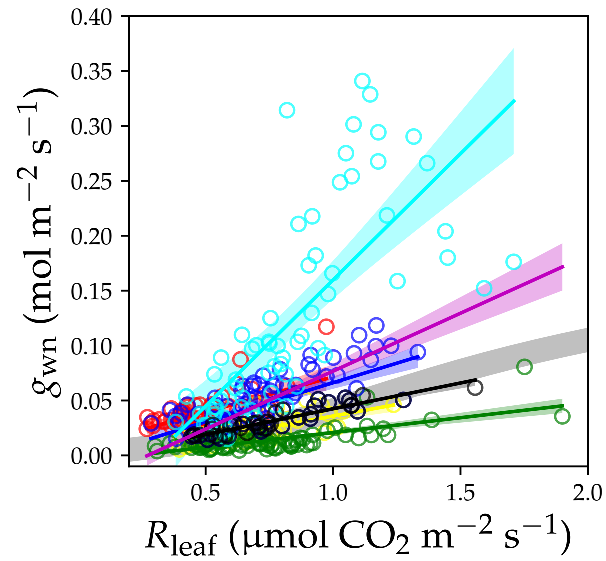

Fig. S4 Nighttime leaf diffusive conductance (g_{wn}) and leaf respiration (R_{leaf}) covary for mature leaves. Each symbol represents a leaf, and each corresponding color represents a well-watered tree. Each colored solid line plots the linear regression of $g_{wn} \sim R_{leaf}$ from each tree, and each shaded region indicates the confidence interval ($P < 0.05$ for all fittings). The light gray curve plots our model predicted g_{wn} using a constant fitness multiplier. The purple color line plots the linear regression of all leaves. The figure differs from Fig. 5 in the main text in that daytime air and leaf temperatures are 10 °C higher than nighttime temperatures.