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Supplementary information

Humidity gradients in the air spaces of leaves

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SUPPLEMENTARY INFORMATION

Supplement 1 List of abbreviations

Abbreviation	**Name**	**Units**
A	Net assimilation rate	mol m^{-2} s^{-1}
A_v	Assimilation rate per unit volume	mol m^{-3} s^{-1}
c_a	CO_2 concentration in the atmosphere	mol mol^{-1}
c_i	CO_2 concentration in the substomatal cavity	mol mol^{-1}
c_s	CO_2 concentration at the surface of a leaf	mol mol^{-1}
E_c	Rate of transpiration through the cuticle	mol m^{-2} s^{-1}
E_s	Rate of transpiration through the stomata	mol m^{-2} s^{-1}
E	Total transpiration rate	mol m^{-2} s^{-1}
J_m	Flux of water across cell membrane	mol m^{-2} s^{-1}
L_p	Hydraulic conductivity of the cell membrane	mol m^{-2} s^{-1} Pa^{-1}
r_b	Boundary layer resistance	m^2 s mol^{-1}
r_c	Cuticular resistance	m^2 s mol^{-1}
r_s	Stomatal resistance	m^2 s mol^{-1}
r_{unsat}	Unsaturated mesophyll air space resistance	m^2 s mol^{-1}
R_b	Boundary layer resistance (upper plus lower)	m^2 s mol^{-1}
R_c	Cuticular resistance (upper plus lower)	m^2 s mol^{-1}
R_s	Stomatal resistance (upper plus lower)	m^2 s mol^{-1}
R_{unsat}	Unsaturated mesophyll air space resistance (upper plus lower)	m^2 s mol^{-1}
R_{ias}	Internal air space resistance	m^2 s mol^{-1}
R_{H2O}	Uncorrected total resistance to water vapour	m^2 s mol^{-1}
cR_{H2O}	Corrected total resistance to water vapour	m^2 s mol^{-1}
R_x	Total resistance to diffusion of noble gas x	m^2 s mol^{-1}
t	Leaf thickness	m
w_a	Water vapour concentration in the air	mol mol^{-1}
w_i	Water vapour concentration in the substomatal cavity	mol mol^{-1}
w_s	Water vapour concentration at the surface of a leaf	mol mol^{-1}
w_{sat}	Water vapour saturated concentration at leaf surface temperature	mol mol^{-1}
z	Perpendicular distance from the abaxial plane	m
Ψ_{bulk}	Bulk leaf water potential	Pa
ψ_{cyt}	Cytosolic water potential	Pa
ψ_{wall}	Cell wall water potential	Pa
Subscript -l	The lower surface	--
Subscript -u	The upper surface	--

Supplement 2 Rough estimation of resistance to CO_2 diffusion within the leaf.

We follow the general approach of the Appendix to Parkhurst et al. 1988 and solve the differential equation that equates the CO_2 diffusion across any paradermal plane to the total assimilation rate below that plane. The flux in a negative direction, ie towards z=0, is given by $CD\frac{dc_\mathrm{i}}{dz}$ and the rate of assimilation below the plane is zA_v, so that

$$CD\frac{dc_\mathrm{i}}{dz} = zA_\mathrm{v}$$

where C mol m^{-3} is the density of air, D m^{2} s^{-1} is the diffusivity of CO_2 in air, modified by tortuosity, $c_\mathrm{i}(z)$ mol CO_2 mol^{-1} air is the local CO_2 concentration, z m is the perpendicular distance from the abaxial plane, t m is the leaf thickness, and A_v mol m^{-3} s^{-1} is the assimilation rate per unit volume, assumed constant.

Integrating, and using the boundary condition that just inside the lower surface $c_\mathrm{i}(0)=c_\mathrm{il}$

$$CD\left(c_\mathrm{i}(z)-c_\mathrm{il}\right)=\left(\frac{z^2}{2}\right)A_\mathrm{v}$$

So just inside the upper surface $z=t$ and $c_\mathrm{i}(t)=c_\mathrm{iu}$ so that

$$CD\left(c_\mathrm{iu}-c_\mathrm{il}\right)=\left(\frac{t^2}{2}\right)A_\mathrm{v}$$

The resistance of the intercellular air space is given by $R_{\mathrm{ias\text{-}CO_2}}=t/CD$ and the assimilation rate is $A_\mathrm{u}=A_\mathrm{v}t$ so that

$$R_{\mathrm{ias\text{-}CO_2}}=2\frac{c_\mathrm{iu}-c_\mathrm{il}}{A_\mathrm{u}}$$

In other words, the estimate of $R_{\mathrm{ias\text{-}CO_2}}$ is the internal [CO_2] difference, divided by the average assimilation rate (= A_u/2 given that A_l=0). $R_{\mathrm{ias\text{-}H_2O}}$ is then $R_{\mathrm{ias\text{-}CO_2}}/1.6$.

Assuming $R_{\mathrm{ias\text{-}CO_2}}$ constant for an individual leaf, the measurements performed under benign conditions of low Δw (B) can be used to estimate the target (c_iu-c_il) for a given assimilation rate at a greater Δw. The target (c_iu-c_il) is then

$$\left(c_\mathrm{iu}-c_\mathrm{il}\right)=\left(c_\mathrm{iu}-c_\mathrm{il}\right)_\mathrm{B}\frac{A_\mathrm{u}}{A_\mathrm{B}}\ .$$

Parkhurst, D. F., Wong, S. C., Farquhar, G. D. & Cowan, I. R. Gradients of intercellular CO_2 levels across the leaf mesophyll. Plant Physiology 86, 1032-1037, doi:10.1104/pp.86.4.1032 (1988).

Supplement 3 Gas exchange calculations for water vapour in the leaf accounting for unsaturation resistance

$$r_s=\frac{\left(w_i-w_s\right)}{E_s-E_s\frac{w_i+w_s}{2}}$$

$$r_{unsat}=\frac{\left(w_{sat}-w_i\right)}{E_s-E_s\frac{w_{sat}+w_i}{2}}$$

$$r_s+r_{unsat}=\frac{\left(w_i-w_s\right)}{E_s-E_s\frac{w_i+w_s}{2}}+\frac{\left(w_{sat}-w_i\right)}{E_s-E_s\frac{w_{sat}+w_i}{2}}$$

$$r_s+r_{unsat}=\frac{1}{E_s}\left[\frac{\left(w_{sat}-w_s\right)\left(1-w_i\right)}{\left(1-\frac{\left(w_i+w_s\right)}{2}\right)\left(1-\frac{\left(w_{sat}+w_i\right)}{2}\right)}\right]$$