BioCro Equations

Canopy Radiation

$$\delta = -23.5 \cdot \cos\left(\frac{360(D_j + 10)}{365}\right) \tag{1}$$

$$\cos(\theta) = \sin(\Omega)\sin(\delta) + \cos(\Omega)\cos(\delta)\cos(15 \cdot (t - t_{sn})) \tag{2}$$

$$I_{dir} = I_s \alpha^{\frac{(P/P_o)}{\cos(\theta)}} \tag{3}$$

$$I_{diff} = 0.5 \cdot I_s \cdot (1 - \alpha^{(P/P_o)/\cos(\theta)})\cos(\theta) \tag{4}$$

$$\frac{1}{2}\cos((15 \cdot t_{len}) = -\tan(\Omega)\tan(\delta) \tag{5}$$

$$t_{\text{len}} = \frac{2cos^{-1}(-\tan(\Omega)\tan(\delta))}{15} \tag{6}$$

$$t_{\text{down}} = 12 - t_{\text{len}}/2 \tag{7}$$

$$t_{\text{up}} = 12 + t_{\text{len}}/2 \tag{8}$$

> what is the relevance of equation 5? Steve H's thesis contains the original, below

Weather Downscaling

$$T_{\text{mean}} = \frac{1}{2}(T_{\text{max}} + T_{\text{min}}) \tag{9}$$

$$T_{\text{range}} = T_{\text{max}} - T_{\text{min}} \tag{10}$$

$$T_{\text{excursion}} = \sin\left(2\pi\frac{h_r - 10}{24}\right) \tag{11}$$

$$T_{\text{air}} = T_{\text{mean}} + T_{\text{range}} \cdot T_{\text{excursion}} \tag{12}$$

Canopy Radiation

> combine or use clearly distinguished titles for different sections on canopy radiation; energy balance, etc

$$q = \frac{n_r}{n} \tag{13}$$

$$N_{\text{eff}} = \frac{\frac{(1-q)}{q}}{C_{ov}^2} \tag{14}$$

$$r^{\sim} = \frac{m_r}{n} \tag{15}$$

$$h = \frac{r^{\sim}}{q} \tag{16}$$

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C4 Photosynthesis test

From Collatz 1992 Coupled Photosynthesis-Stomata1 Conductance Model for Leaves of C4 Plants. Aust. J. Plant Physiol. 19 519-538

$$V_{\max} = \frac{V_{\max_0} Q_{10}^{\frac{T_{\text{leaf}}-25}{10}}}{(1+\exp(0.3(T_{\text{lower}} - T_{\text{leaf}}))\,(1+\exp(0.3(T_{\text{leaf}} - T_{\text{upper}}))} \tag{17}$$

$$R_d = \frac{R_0 Q_{10}^{\frac{T_{\text{leaf}}-25}{10}}}{1+\exp(1.3(T_{\text{leaf}} - 55))} \tag{18}$$

$$k_t = k Q_{10}^{\frac{T_{\text{leaf}}-25}{10}} \tag{19}$$

$$c_i = c_a - \frac{1.6 A_n P}{g_s} \tag{20}$$

$$A_{\text{net}} = A_{\text{gross}} - R_d \tag{21}$$

$$M = \min\left[\frac{(V_{\max}+\alpha_{\text{slope}} I_{\text{abs}}) \pm \sqrt{(V_{\max}+\alpha_{\text{slope}} I_{\text{abs}})^2 - 4(V_{\max}\alpha_{\text{slope}} I_{\text{abs}})\theta_{\text{curve}}}}{2\theta_{\text{curve}}}\right] \tag{22}$$

$$A_{\text{gross}} = \min\left[\frac{\left(M + k_t \cdot \frac{c_i}{P}\right) \pm \sqrt{\left(M + k_t \cdot \frac{c_i}{P}\right)^2 - \left(4 \cdot M \cdot k_t \cdot \frac{c_i}{P} \cdot \beta\right)}}{2 \cdot \beta}\right] \tag{23}$$

C3 Photosynthesis

From Appendix 2 in Bernacchi et al 2003 Plant, Cell and Environment 26, 14191430 doi: 10.1046/j.0016-8025.2003.01050.x

$$A = (1 - \Gamma^*/c_i) \tag{24}$$

$$w_c = \frac{V_{c\max} c_i}{c_i + K_c(1 + O_a/K_0)} \tag{25}$$

$$w_j = \frac{J c_i}{4.5 c_i + 10.5\Gamma^*} \tag{26}$$

$$\Gamma^* = exp(19.02 - 37.83/(R(T_{\text{leaf}} + 273.15))) \tag{27}$$

$$K_c = exp(38.05 - 36.38/R(T_{\text{leaf}} + 273.15)) \tag{28}$$

$$K_0 = exp(20.30 - 36.38/R(T_{\text{leaf}} + 273.15)) \tag{29}$$

$$V_{c,\max} = V_{c,\max@25C} \cdot \exp(26.35 - 65.33/R(T_{\text{leaf}} + 273.15)) \tag{30}$$

$$J = \frac{Q_2 + J_{\max,\mathrm{T}} - \sqrt{(Q_2 + J_{\max,\mathrm{T}})^2 - 4\Theta_{PSII} Q_2 J_{\max,T}}}{2\Theta_{\text{PSII}}} \tag{31}$$

$$J_{\max,T} = J_{\max@25C} \exp(17.57 - 43.54/(R(T_{\text{leaf}} + 273.15))) \tag{32}$$

$$\Theta_{\text{PSII}} = 0.76 + 0.018 T_{\text{leaf}} - 3.7 \cdot 10^{-4} T_{\text{leaf}}^2 \tag{33}$$

$$Q_2 = Q \cdot k \cdot \Phi_{\text{PSII,max}} \cdot \beta_\Phi \tag{34}$$

$$\Phi_{\text{PSII,max}} = 0.352 + 0.022 T_{\text{leaf}} - 3.4 \cdot 10^{-4} T_{\text{leaf}}^2 \tag{35}$$

renamed β as to β_Φ; is this an appropriate naming?

From Appendix 1, Equations 7-9 in Long 1991 Plant, Cell and Environment 14, 729-739. doi:10.1111/j.1365-3040.1991.tb01439.x

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$$c_i = 0.7c_a\left(\frac{1.6740 - 6.1294\cdot 10^{-2}T_{\text{leaf}} + 1.1688\cdot 10^{-3}T_{\text{leaf}}^2 - 8.8741\cdot 10^{-6}T_{\text{leaf}}^3}{0.73547}\right) \tag{36}$$

$$c_i = 0.7c_a @25°C \tag{37}$$

$$O_i = 210\left(\frac{4.7000\cdot 10^{-2} - 1.3087\cdot 10^{-3}T_{\text{leaf}} + 2.5603\cdot 10^{-5}T_{\text{leaf}}^2 - 2.1441\cdot 10^{-7}T_{\text{leaf}}^3}{2.6934\cdot 10^{-2}}\right) \tag{38}$$

$$O_i = O_a @25°C \tag{39}$$

$$\phi = \frac{A_{\text{I=50}} - A_{\text{I=25}}}{25f} \tag{40}$$

is there a reason not to divide by the denominator when it is constant?

Water Stress

$$h_s = \frac{e_l - \rho_{va}}{e_l}\cdot 100 \tag{41}$$

$$g_s = g_0 + g_1\cdot A_{\text{gross}}\cdot\frac{h_s}{c_a} \tag{42}$$

$$\text{Four options for water stress model:} \tag{43}$$

$$g_{\text{ws, linear}} = \frac{W_s - W_p}{F_c - W_p} \tag{44}$$

$$g_{\text{ws, logistic}} = \frac{1}{1+\exp\left(\frac{\frac{1}{2}(F_c - W_p) - W_s)}{\phi_i}\right)} \tag{45}$$

$$g_{\text{ws, exponential}} = \frac{1-\exp\left(\frac{F_c - W_s}{F_c - W_p} + \frac{W_p}{1-W_p}\right)}{0.631206} \tag{46}$$

$$g_{\text{ws, none}} = 1 \tag{47}$$

$$\text{Calculate } g_s \text{ and } A_n \text{ under water stress:} \tag{48}$$

$$g_s^{\text{water stress}} = g_{\text{ws},*}g_s \tag{49}$$

$$A_n^{\text{water stress}} = g_{\text{ws},*}A_n \tag{50}$$

should there be only one equation for Anet(?) is either correct? The first seems strange in that it implies water limited Anet equals Anet times humidity

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Canopy Energy Balance

$$J_a = 2 \cdot I_{\text{abs}} \cdot \left(\frac{1-r-\tau}{1-\tau}\right) \cdot \ell \tag{51}$$

$$L_b = (2.126 \cdot 10^{-5} + 1.48 \cdot 10^{-7} \cdot T_{\text{air}})/0.004 \cdot \sqrt{L_w/u_{\text{layer}}} \tag{52}$$

$$u_a = \frac{u \cdot 0.41}{log((u-d)/z_o)} \tag{53}$$
I can not reconcile units

$$g_a = \frac{(u_a^2/u_{\text{layer}}) \cdot L_b}{(u_a^2/u_{\text{layer}}) + L_b} \tag{54}$$
I can not reconcile units

$$\rho_v' = 610.78 \cdot \exp(\left(17.269 \cdot \frac{T_a}{T_a + 237.3}\right)) \tag{55}$$

$$\Delta\rho_{va} = \rho_v' \cdot \left(1 - \frac{h_s}{100}\right) \tag{56}$$

$$\gamma = \frac{\rho \cdot c_p}{\lambda} \tag{57}$$

$$s = 18 \cdot (2501 - 2.373 \cdot T_a) \cdot \left(\frac{\rho_v'}{8.314 \cdot (T_a + 273)^2}\right) \tag{58}$$

$$R_{lc} = 4\sigma \cdot (273 + T_{\text{air}})^3 \cdot \Delta T \tag{59}$$

$$\Phi_N = J_a - R_{lc} \tag{60}$$

$$\Delta T = T_{\text{leaf}} - T_{\text{air}} = \frac{\Phi_n \left(\frac{1}{g_a} + \frac{1}{g_c}\right)}{\lambda\left[s + \gamma\left(1 + \frac{g_a}{g_c}\right)\right]} - \frac{\lambda\Delta\rho_{va}}{\lambda\left[s + \gamma\left(1 + \frac{g_a}{g_c}\right)\right]} \tag{61}$$
should thermal conductivity be in this equation?

$$E = \frac{s \cdot \Phi_N + \lambda \cdot g_a \cdot \Delta\rho_{va}}{\lambda \cdot [s + \lambda \cdot (1 + g_a/g_c)]} \tag{62}$$

$$\mathbf{E_c} = \sum_{\text{layer}N}^{\text{layer}1} (\mathbf{E}_{\text{sun}} \cdot l_{\text{sun}}) + (\mathbf{E}_{\text{shade}} \cdot l_{\text{shade}}) \tag{63}$$

$$\mathbf{E}_{\text{tot}} = \int_0^{365\text{days}} \int_0^{24\text{hours}} \mathbf{E_c} \tag{64}$$
why use $\int$ instead of $\sum$?

Sun / Shade Canopy

$$k = \frac{\sqrt{\chi^2 + \tan^2(\theta)}}{\chi + 1.744 \cdot [\chi + 1.183]^{-0.733}} \tag{65}$$

$$F_{\text{sun}} = \frac{1 - \exp[-k \cdot F_{\text{canopy}}]}{k} \tag{66}$$

$$F_{\text{shade}} = F_{\text{canopy}} - F_{\text{sun}} \tag{67}$$

$$I_{\text{sun}} = k \cdot I_{beam} + I_{\text{diff}} + I_{\text{scat}} \tag{68}$$

$$I_{\text{beam}} = I_{\text{dir}} \cos(\theta) \tag{69}$$

$$I_{\text{shade}} = I_{\text{diff}} + I_{\text{scat}} \tag{70}$$

$$I_{\text{diff}} = I_{\text{od}} \exp(-k_d F_{\text{canopy}}) \tag{71}$$

$$I_{\text{scat}} = I_{\text{beam}} \exp(-k\sqrt{\alpha_{\text{scat}}} F_{\text{canopy}}) - I_{\text{beam}} \exp(-k F_{\text{canopy}}) \tag{72}$$

$$\tag{73}$$

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Total Canopy Assimilation

$$A_c = (A_{c,\text{sun}} \cdot F_{\text{sun}}) + (A_{c,\text{shade}} \cdot F_{\text{shade}}) \tag{74}$$

$$F_{\text{sun}} = \sum_{\text{layer}N}^{\text{layer}1} l_{\text{sun}};\ l_{\text{sun}} = \frac{1 - e^{(-k \cdot F_{\text{sun}})}}{k} \tag{75}$$

$$F_{\text{shade}} = \sum_{\text{layer}N}^{\text{layer}1} \ell_{\text{shade}};\ \ell_{\text{shade}} = F_{\text{sun}} - \ell_{\text{sun}} \tag{76}$$

$$F_{\text{canopy}} = F_{\text{sun}} + F_{\text{shade}} \tag{77}$$

$$A_c = \sum_{\text{layer}N}^{layer1} (A_{c,\text{sun}} \cdot F_{\text{sun}}) + (A_{c,\text{shade}} \cdot F_{\text{shade}}) \tag{78}$$

$$A_{c,\text{tot}} = \sum_{\text{day}=1}^{365} \sum_{\text{hr}=1}^{24} A_c \tag{79}$$

$$g_c = \sum_{\text{layer}1}^{\text{layer}N} (g_{s,\text{sun}} \cdot l_{\text{sun}}) + (g_{s,\text{shade}} \cdot l_{\text{shade}}) \tag{80}$$

$$g_{c,\text{tot}} = \sum_{\text{day}=1}^{365} \sum_{\text{hr}=1}^{24} g_c \tag{81}$$

is $\ell_{\text{sun}} \equiv l_{\text{sun}}$? neither is defined

switch use of $\int$ over hr/yr to $\sum$?

Allocation

$$A_{\text{storage}} = |\min(0, \omega_{\text{storage}} \cdot k_{\text{storage}})| \tag{82}$$

$$A_{\text{total}} = A_{\text{leaf}} + A_{\text{stem}} + A_{\text{root}} + A_{\text{storage}} \tag{83}$$

$$\omega_{\text{leaf}} = \omega_{\text{leaf}} + (A_{\text{total}} \cdot k_{\text{leaf}}) \tag{84}$$

$$\omega_{\text{stem}} = \omega_{\text{stem}} + (A_{\text{total}} \cdot k_{\text{stem}}) \tag{85}$$

$$\omega_{\text{stroot}} = \omega_{\text{storage}} + (A_{\text{total}} \cdot k_{\text{storage}}) \tag{86}$$

$$\omega_{\text{root}} = \omega_{\text{root}} + (A_{\text{total}} \cdot k_{\text{root}}) \tag{87}$$

$$\Psi_{\text{adl}} < \Psi_{\text{pt}} \tag{88}$$

$$k_{\text{leaf}} = k_{\text{leaf}} \cdot k_{\text{mod}} \tag{89}$$

$$k_{\text{stem}} = k_{\text{stem}} \cdot k_{\text{mod}} \tag{90}$$

$$k_{\text{storage}} = k_{\text{storage}} \cdot k_{\text{mod}} \tag{91}$$

$$k_{\text{mod}} = (\Psi_{\text{adl}} - \Psi_{\text{pt}}) \cdot \Psi_g; 0 \leq k_{\text{mod}} \leq 1 \tag{92}$$

$$\Delta F_{\text{canopy}} = \frac{\omega_{\text{leaf}}}{Sp_{\text{leaf}}} \tag{93}$$

$$\Delta L_{\text{stem}} = \frac{\omega_{\text{stem}}}{Sp_{\text{stem}}} \tag{94}$$

$$\Delta L_{\text{sroot}} = \frac{\omega_{\text{sroot}}}{Sp_{\text{sroot}}} \tag{95}$$

$$\Delta L_{\text{storage}} = \frac{\omega_{\text{storage}}}{Sp_{\text{storage}}} \tag{96}$$

$$\text{Stem}_{\text{coppice}} = 0.95 - \omega_{\text{stem}} \tag{97}$$

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should restrictions on values of k in equations 82 and 92 be moved to the parameter definitions?

would it make sense to subscript values of ω with t, $t+1$ when updating them to avoid confusion?

Δt is the timescale for updating biomass.; need to define ΔT for both daily and hourly

Soil Evaporation

$$E_{\text{soil}} = \sum \frac{(\Psi_{\text{si}} - g \cdot z_i - \Psi_x)}{R_{\text{si}} + R_{\text{ri}}} \tag{98}$$

$$R_{\text{ri}} = R_r \cdot \frac{\sum L_i}{L_i} \tag{99}$$

$$\Psi_x = \sum \frac{(\Psi_{\text{si}} - q_w \cdot z_i)}{R_{\text{si}} + R_{\text{ri}}} \Big/ \sum \frac{1}{R_{\text{si}} + R_{\text{ri}}} \tag{100}$$

$$\Psi_L = \Psi_x - E \cdot R_L \tag{101}$$

$$E_d = \begin{cases} E_p, & \theta^* \geq \theta_1 \\ E_p\left(\frac{\theta - \theta_2}{\theta_1 - \theta_2}\right), & \theta_2 < \theta^* < \theta_1 \\ 0, & \theta^* \leq \theta_2 \end{cases} \tag{102}$$

$$\theta_{i+1} = \theta_i - \frac{E_i \cdot \theta_i}{\rho_w \cdot d_s} \tag{103}$$

$$g_{a,\text{soil}} = \frac{(2.126 \cdot 10^{-5}) + (1.48 \cdot 10^{-7}) \cdot T_{\text{soil}}}{\left(0.004 \cdot \sqrt{\frac{S_{size}}{u_{\text{soil}}}}\right)} \tag{104}$$

$$R_{lc,\text{soil}} = ((4\sigma) \cdot (273 + T_{\text{soil}})^3 \cdot \Delta T) \tag{105}$$

$$J_{a,\text{soil}} = 2 \cdot I_{\text{soil}} \cdot \left(\frac{1 - S_r - S_\tau}{1 - S_\tau}\right) \tag{106}$$

$$\Phi_{N,soil} = J_{a,soil} - R_{lc,soil} \tag{107}$$

$$E_{\text{soil}} = \frac{s \cdot \Phi_{N,soil} + \lambda \cdot g_{a,soil} \cdot \Delta\rho_{va}}{\lambda \cdot [s + \gamma]} \tag{108}$$

is “soil” subscript correct?

Respiration

$$R_{\text{total}} = aA_n + b_{\text{stem}}\Delta\omega_{\text{stem}} + b_{\text{root}}\Delta\omega_{\text{root}} + b_{\text{storage}}\Delta\omega_{\text{storage}} \tag{109}$$

Energy Balance

$$HS_{\text{soil}} = HO_{\text{soil}} \cdot exp\left[\frac{h_{\text{soil}}}{46.97 \cdot (T_{\text{soil}} + 273.16)}\right] \tag{110}$$

$$HO_{\text{soil}} = 1.323 \cdot exp\left[\frac{17.27 \cdot T_{\text{soil}}}{273.3 + T_{\text{soil}}}\right] \Bigg/ T_{\text{soil}} + 273.16 \tag{111}$$

$$G_{\text{soil}} = -\lambda_{\text{soil}} \frac{\delta T}{\delta x} \tag{112}$$

$$G_{\text{soil}} = -\lambda_{\text{soil}} \cdot \left[\frac{T_2 - T_{\text{soil}}}{\Delta z}\right] + (T_{\text{soil}} - T_l) \cdot C \cdot \frac{\Delta z}{(2 \cdot \Delta t)} \tag{113}$$

should denominator in equation 112 be δz?

what is t_l?

C in from equation 113 is undefined - is this the specific heat of soil?

Definition of Terms

Term	Units	Definition	Value	
A_{gross}	$\mu mol\, mol^{-1}$	Gross rate of CO_2 uptake per unit leaf area	-	
A_{net}	$\mu mol\, mol^{-1}$	Net rate of CO_2 uptake per unit leaf area	-	
$A_{net,\text{water stress}}$	$\mu mol\, mol^{-1}$	A_{net} under water stress		
A_c	$\mu mol\, mol^{-1}$	Net canopy rate of CO_2 uptake per unit ground area	-	
$A_{c,\text{tot}}$	$g\, m^{-2}\, yr^{-1}$	A_c integrated over the course of a year	-	
$A_{c,\text{sun}}$	$mol\, mol^{-1}$	Net rate of CO_2 uptake per unit area sunlit leaves	-	
$A_{c,\text{shade}}$	$mol\, m^{-2}\, s^{-1}$	Net rate of CO_2 uptake per unit area shaded leaves	-	
A	$\mu mol\, mol^{-1}$	Predicted rate of CO_2 uptake	-	
c_a	$\mu mol\, mol^{-1}$	Atmospheric CO_2 concentration	378	
a	Dimensionless	Coefficient for growth respiration	0.2	
α	dimensionless	Atmospheric transmittance	0.85	
α_{slope}	mol mol^{-1}	The quantum yield of CO_2 uptake determined by the initial slope of the response of A versus I_{abs}	0.04	
b_{leaf}	Dimensionless	Coefficient for maintenance respiration for leaf	0.03	
b_{stem}	Dimensionless	Coefficient for maintenance respiration for stem	0.015	
b_{root}	Dimensionless	Coefficient for maintenance respiration for root	0.01	
β		C_4 curvature parameter	0.93	
β_Φ	%	Fraction of absorbed quanta reaching PSII		
c_i	$\mu mol\, mol^{-1}$	Intercellular concentration of O_2 in air corrected for solubility relative to 25°C		
c_p	$J\, kg^{-1}\, K{-1}$	Specific heat capacity of dry air	1010	
C_{ov}	Dimensionless	Coefficient of Variation for probability of rain in each month	-	
d_s	m	Soil depth	-	
D_j	d	day of year	-	
D_{start}	d	Day of year on which the sinusoidal temperature function is assumed to start	45	
d	dimensionless	Zero plane displacement	0.77	
δ	degrees	Solar declination	-	
e_l	kPa	Saturated water VPD in the leaf	-	is “saturated VPD” an oxymoron?
E	$J\, mol^{-1}$	Activation energy	R_d = 66405 $V_{\max}$ = 6800	
E_d				undefined from equation 102
E_i				undefined from equation 103
E_c	$mmol\, m^{-2}\, s^{-1}$	Instantaneous canopy evapo/transpiration rate	-	
E_d	$g\, m^{-2}\, s^{-1}$	Potential soil evaporation	-	
E_l	$mmol\, m^{-2}\, s^{-1}$	Evapo/transpiration rate at sunlit/shaded leaves in a canopy layer	-	
E_p	$g\, m^{-2}\, s^{-1}$	Actual soil evaporation	-	
E_{R_d}	J mol^{-1}	Activation energy of R_d	-	
E_{tot}	$mmol\, m^{-2}\, yr^{-1}$	E_c integrated over the course of a year	-	
$E_{V_{\max}}$	J mol^{-1}	Activation energy of V_{cmax}	-	
f		fraction of light not absorbed by photosynthesis	0.23	
$f_{s,l}$		fraction of sunlit leaves at depth l (l is cumulative leaf area index from top)		
F_c	$m^3 m^{-3}$	Field Capacity		
F_{canopy}	$m^2\, m^{-2}$	Cumulative canopy leaf area index from top at depth	9	
F_{shade}	$m^2\, m^{-2}$	Canopy shaded leaf area index	-	
F_{sun}	$m^2\, m^{-2}$	Canopy sunlit leaf area index	-	
F_{sum}	$m^2\, m^{-2}$	Summed leaf area index from top of canopy to layer considered in calculation	-	
G_{soil}	$W\, m^{-2}$	Soil heat flux	-	
g	$m\, s^{-2}$	Gravitional constant	9.8	
g_a	$mmol\, m^{-2}\, s^{-1}$	Leaf boundary layer conductance	-	

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Table 1 – continued from previous page

Term	Units	Definition	Value	
g_c	$mmol\,m^{-2}\,s^{-1}$	Canopy conductance of CO_2	-	
$g_{\text{c, root}}$				undefined
g_s	$mmol\,m^{-2}\,s^{-1}$	Leaf stomatal conductance	-	
g_0	dimensionless	Stomatal slope factor	3	
g_1	dimensionless	Stomatal intercept factor	0.08	
$g_{s,\text{sun}}$	$mmol\,m^{-2}\,s^{-1}$	The sum of stomatal conductance of sunlit leaves	-	
$g_{s,\text{shade}}$	$mmol\,m^{-2}\,s^{-1}$	The sum of stomatal conductance of shaded leaves	-	
g_{ws}	dimensionless	Species-specific water stress sensitivity factor		
$g_{\text{ws*}}$	dimensionless	water stress stomatal conductance factor; see equations 43		
γ	Pa K^{-1}	psychrometer constant	-	
Γ^*	μmol mol^{-1}	CO_2 compensation point in the absence of dark respiration		
h_r	h	Hour of day	-	
h_s	%	Relative humidity	-	
h_{canopy}	m	Height of canopy	5	
h_{ms}	m	Wind speed measurement height	2	
h_{layer}	m	Height of canopy layer above ground	-	
I	$\mu mol\,m^{-2}\,s^{-1}$	Photon flux	-	
h	$mmday^{-1}$	The amount of water received on a given rainy day	-	
h_{soil}	m	Water pressure head	-	
HO_{soil}	$kg\,m^{-3}$	Saturated humidity of the air at the soil surface	-	
HS_{soil}	$Kg\,m^{-3}$	Humidity of the air at the soil surface	-	
I_{abs}	$\mu mol\,m^{-2}\,s^{-1}$	Photon flux absorbed by either sunlit or shaded leaves within a canopy layer	-	
I_{dir}	$\mu mol\,m^{-2}\,s^{-1}$	Photon flux in direct solar beam	-	
I_{diff}	$\mu mol\,m^{-2}\,s^{-1}$	Photon flux in diffuse radiation	-	
I_{total}	$\mu mol\,m^{-2}\,s^{-1}$	Total photon flux incident on canopy	-	
I_s	$\mu mol\,m^{-2}\,s^{-1}$	Solar constant, photon flux in a plane perpedicular to the solar beam above the atmosphere	2600	
I_d				undefined
$I_{\ell,d}$				undefined
I_{short}	$\mu mol\,m^{-2}\,s^{-1}$	Short wave radiation component of incident light	-	
I_{beam}		flux density of beam radiation on horizontal surface at top of canopy		
I_{od}		flux density of diffuse radiation on horizontal surface at top of canopy		
I_{soil}	$\mu mol\,m^{-2}\,s^{-1}$	Solar radiation incident upon soil surface	-	
I_{soil}	$W\,m^{-2}$	Solar radiation on soil	-	which units for I_{soil} are correct?
I_{sun}	$\mu mol\,m^{-2}\,s^{-1}$	Mean I for leaves which receive direct solar radiation, i.e. are sunlit	-	
I_{shade}	$\mu mol\,m^{-2}\,s^{-1}$	Mean I for leaves shaded from direct solar radiation	-	
I_{scat}	$\mu mol\,m^{-2}s^{-1}$	Direct beam radiation scattered by surfaces within the canopy	-	
J_{a}	$\mu mol\,m^{-2}\,s^{-1}$	Total solar radiation absorbed by either sunlit or shaded leaves within a canopy layer	-	
$J_{\text{a, soil}}$	$\mu mol\,m^{-2}\,s^{-1}$	Total solar radiation absorbed by soil	-	
k	dimensionless	Foliar absorption coefficient (α_ℓ in Bernacchi 2003)	-	
k_d	dimensionless	extinction coefficient for diffuse light		
K_c	$\mu mol\,mol^{-1}$	Michaelis Menton constant for the carboxylation of RuBISCO	460	
K_{CO_2}	$mol\,m^{-2}\,s^{-1}$	Initial slope of photosynthetic CO_2 response	0.7	
Kt		C_4 slope factor	-	
K_o	$mmol\,mol^{-1}$	Michaelis Menton constant for oxygenation of RuBISCO	330	
k_{slope}	Dimensionless	Initial slope of photosynthetic light response	0.04	
LN	$g\,m^{-2}$	Leaf nitrogen concentration	-	
k_{leaf}	Dimensionless	Partitioning coefficient for leaf	-	

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Table 1 – continued from previous page

Term	Units	Definition	Value	
k_{stem}	Dimensionless	Partitioning coefficient for stem	-	
k_{sroot}	Dimensionless	Partitioning coefficient for storage root	-	
k_t		temperature-dependent pseudo-first order rate constant with respect to P_i (Collatz 1992)		
k_{froot}	Dimensionless	Partitioning coefficient for fine root	-	
k_{stroot}	Dimensionless	Partitioning coefficient for structural root	-	
ℓ				undefined from Ja: equation 51
ℓ_{sun}				undefined from equation **??**
l_{sun}				undefined from equation 75
L_i	$cm\,cm^{-3}$	Root density of ith zone	-	
L_w	m	Leaf width in the direction of the wind	0.04	
ΔL_{stem}				undefined
ΔL_{sroot}				undefined
λ	MJ/Kg	Latent heat of vapourisation	-	
λ_{soil}	$W/(m°C)$	Thermal conductivity for the soil surface	-	
M			22	what is$M$?
m_r	mm month^{-1}	monthly precipitation rate		
N_{eff}	days/mo	effective length of rainy period		check units with equation 14
n	day	The number of days in a month	29, 30, or 31	
nr	day	The number of rainy days in a month	-	
O_a	$mmol\,mol^{-1}$	Atmospheric O_2 concentration	210	is this corected to 25C like O_i?
O_i	$mmol\,m^{-2}\,s^{-1}$	Intercellular concentration of O_2 in air corrected for solubility relative to 25°C	-	
ω_{leaf}	g	Leaf biomass	-	
ω_{stem}	g	Stem biomass	-	
ω_{sroot}	g	Biomass of storage root	-	
ω_{froot}	g	Biomass of fine root	-	
ω_{stroot}	g	Biomass of structural root	-	
ω_{storage}	g	Biomass of storage	-	
Ω	degrees	Latitude	-	
P	kPa	Atmospheric pressure		
P_o	kPa	Standard atmospheric pressure at sea level	101.324	
P_s	kPa	Leaf surface partial pressure of CO_2	-	
Ψ_{g}				undefined
Ψ_l	MPa	Leaf water potential	-	
Ψ_{L}				undefined
Ψ_t	MPa	Threshold leaf water potential for decreasing gs	-	
Φ_{N}	W m^{-2}	Net radiation	-	
$\Phi_{N,soil}$	W m^{-2}	Net radiation at soil surface	-	
ϕ_i		coefficient which controls spread of logistic function used to calculate water stress factor in 43		
Ψ_{adl}	MPa	Average daily plant water potential	-	
Ψ_{pt}	MPa	Threshold water potential	-	
Ψ_{si}	MPa	Soil water potential of the ith layer	-	
Ψ_x	MPa	xylem water potential	-	
q	Dimensionless	The probability that there is no rainfall	-	during a month?
q_w	kg s^{-1}	Flux of water	-	
Q_{10}	dimensionless	Is the proportional rise in a parameter for a 10°C increase in temperature	2	
r	dimensionless	Leaf reflection coefficient for total solar radiation	0.2	
$r^{\sim}$	mm day^{-1}	Mean daily rainfall in each month	-	
R	$J\,k^{-1}\,mol^{-1}$	Real gas constant	8.314	
R_L	$m^3\,kg^{-1}\,s^{-1}$	Leaf resistance	-	
R_{si}	$m^3 kg^{-1} s^{-1}$	Soil resistance of the ith zone	-	
R_{ri}	$M^3 kg^{-1} s^{-1}$	root resistance of the ith zone	-	
R_o	$mol\,m^{-2}\,s^{-1}$	Dark respiration rate at $25°C$	3	
R_d	$mol\,m^{-2}\,s^{-1}$	Dark respiration at a given temperature	-	

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Table 1 – continued from previous page

Term	Units	Definition	Value	
R_{lc}	$mol\,m^{-2}\,s^{-1}$	Longwave radiation	-	
$R_{lc,\mathrm{soil}}$	$mol\,m^{-2}\,s^{-1}$	Soil longwave radiation	-	
ρ_w	$kg\,m^{-3}$	Density of water	1000	
ρ_a	kPa	vapor pressure deficit in air		is this distinct from $\Delta\rho_{\mathrm{va}}$?
ρ_a'				undefined from equation 56
s	kPa K^{-1}	Slope of saturated water vapor pressure change with respect to temperature (look up table)	-	also defined by equation 58; is one correct?
s_p	dimensionless	Spectral imbalance	-	
S_{size}	m	Average size of soil particles	0.04	
S_r	Dimensionless	Soil reflectance	0.2	
S_τ	Dimensionless	Soil transmission	0.01	
Sp_{leaf}	gram m^{-2}	Specific leaf area	50	
Sp_{stem}	gram m^{-1}	Specific stem elongation factor	60	
Sp_{froot}	gram m^{-1}	Specific fine root elongation factor	10	
Sp_{stroot}	gram m^{-1}	Specific structural root elongation factor	60	
σ	$\mathrm{Wm}^{-2}\mathrm{K}^{-4}$	Stefan-Boltzmann constant	$5.67 \cdot 10^{-8}$	
t	h	Time of day	-	
t_{up}	h	time of dawn		
t_{down}	h	time of dusk		
t_{len}	h	day length	-	is this a constant, 24?
t_{sn}	h	Time of solar noon	12	
T_{leaf}	°C	Leaf temperature	-	
T_{air}	°C	Ambient air temperature	-	
T_{mean}	°C	Daily mean T_{air}		
T_{range}	°C	$\frac{T_{\mathrm{air}}-T_{\mathrm{mean}}}{T_{\mathrm{range}}}$		
$T_{\mathrm{excursion}}$	fraction	Difference between current T_{mean}		
T_{soil}	°C	Soil surface temperature	-	
T_{lower}	°C	Lower T limitation on photosynthesis		
T_{upper}	°C	Upper T limitation on photosynthesis		
T_1	°C	Annual mean air temperature	18	
T_2	°C	Annual range in air temperature	2	
T_3	°C	Average daily range in air temperature	7	
T_4	°C	Maximum daily range in air temperature	7	
ΔT	°C	Temperature difference between (leaf or soil) and air		
τ	Dimensionless	Leaf transmittance coefficient		
Θ_{curve}	dimensionless	Curvature parameter	-	
Θ^*	kgm^{-3}	Actual volumetric water content	-	
Θ_1	$kg\,m^{-3}$	The volumetric water content for maximizing Evaporation		
Θ_2	$kg\,m^{-3}$	The volumetric water content for wilting point	-	
Θ_i	$kg\,m^{-3}$	The volumetric water content of the ith day	-	
Θ	degrees	Solar zenith angle	-	
u	m s^{-1}	Measured wind speed at known height (2m)	2	
u_{layer}	m s^{-1}	Wind speed in a given canopy layer	-	
u_{soil}	m s^{-1}	Wind speed at soil surface	-	
v		Saturated water vapour concentration	-	
V_{max}	$mol\,m^{-2}\,s^{-1}$	Maximum rubP saturated rate of carboxylation at a given temperature	-	
V_{max_0}	$mol\,m^{-2}\,s^{-1}$	Maximum rubP saturated rate of carboxylation at a given temperature	-	
V_{c,max_0}	$mol\,m^{-2}\,s^{-1}$	Maximum rubP saturated rate of carboxylation at $25°C$	39	
VPD	kPa	Leaf-air water vapour pressure deficit	-	
V_T	$mol\,m^{-2}\,s^{-1}$	V_{max} at current T		
w_c	$mol\,m^{-2}\,s^{-1}$	RuBISCO limited rate of photosynthesis		units?
w_c	$mol\,m^{-2}\,s^{-1}$	RuBP limited rate of photosynthesis		units?

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Table 1 – continued from previous page

Term	Units	Definition	Value
W_p	m^3m^{-3}	Wilting point	
W_s	m^3m^{-3}	Soil water content	
z_o	m	Roughness length	0.234
χ	dimensionless	The ratio of horizontal:vertical projected area of leaves in the canopy segment	1
slope	$mol\, m^{-1}$	Initial slope of photosynthetic CO_2 response	0.7
curve	dimensionless	Curvature parameter	0.83
Z	m	Thickness of a soil layer	-

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