

BioCro Equations

Canopy Radiation

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

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

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

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

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

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

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

λ is defined as “specific heat of vaporization”; not sure what it is here. The original eqn. used Ω

Weather Downscaling

$$\text{Mean} = T_1 + T_2 \cdot \sin\left(2\pi \frac{D_j - D_{\text{start}}}{365}\right) \quad (7)$$

$$\text{Range} = T_3 + (T_4 - T_3) \cdot \sin\left(2\pi \frac{D_j - D_{\text{start}}}{365}\right) \quad (8)$$

$$\text{Excursion} = \sin\left(2\pi \frac{h_r - 10}{24}\right) \quad (9)$$

$$T_{air} = \text{Mean} + \text{Range} \cdot \text{Excursion} \quad (10)$$

Canopy Radiation

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

$$q = \frac{n_r}{n} \quad (11)$$

$$N_{\text{eff}} = \frac{\frac{(1-q)}{q}}{C_{ov}^2} \quad (12)$$

$$r^{\sim} = \frac{m_r}{n} \quad (13)$$

$$h = \frac{r^{\sim}}{q} \quad (14)$$

C4 Photosynthesis

$$V_{\text{max}} = V_{\text{max},o} \cdot Kt(E_{V_{\text{max}}}) \quad (15)$$

$$R_d = R_o \cdot Kt(E_{R_d}) \quad (16)$$

$$M = \min \frac{(V_{\text{max}} + \alpha_{\text{slope}} I_{\text{abs}}) \pm \sqrt{(V_{\text{max}} + \alpha_{\text{slope}} I_{\text{abs}})^2 - 4(V_{\text{max}} \alpha_{\text{slope}} I_{\text{abs}}) \theta_{\text{curve}}}}{2\theta_{\text{curve}}} \quad (17)$$

$$A_{\text{gross}} = \min \frac{(M + k_t \cdot \frac{c_i}{P}) \pm \sqrt{(M + k_t \cdot \frac{c_i}{P})^2 - (4 \cdot M \cdot k_t \cdot \frac{c_i}{P} \cdot \beta)}}{2 \cdot \beta} \quad (18)$$

$$A_n = A_{\text{gross}} - R_d \quad (19)$$

what are k_t and K_t in equations 15

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

$$A = (1 - \Gamma^*/c_i) \quad (20)$$

$$w_c = \frac{V_{cmax}c_i}{c_i + K_c(1 + O_a/K_0)} \quad (21)$$

$$w_j = \frac{Jc_i}{4.5c_i + 10.5\Gamma^*} \quad (22)$$

$$\Gamma^* = \exp(19.02 - 37.83/(R(T_{leaf} + 273.15))) \quad (23)$$

$$K_c = \exp(38.05 - 36.38/R(T_{leaf} + 273.15)) \quad (24)$$

$$K_0 = \exp(20.30 - 36.38/R(T_{leaf} + 273.15)) \quad (25)$$

$$V_{c,max} = V_{c,max@25C} \cdot \exp(26.35 - 65.33/R(T_{leaf} + 273.15)) \quad (26)$$

$$J = \frac{Q_2 + J_{max,T} - \sqrt{(Q_2 + J_{max,T})^2 - 4\Theta_{PSII}Q_2J_{max,T}}}{2\Theta_{PSII}} \quad (27)$$

$$J_{max,T} = J_{max@25C} \exp(17.57 - 43.54/(R(T_{leaf} + 273.15))) \quad (28)$$

$$\Theta_{PSII} = 0.76 + 0.018T_{leaf} - 3.7 \cdot 10^{-4}T_{leaf}^2 \quad (29)$$

$$Q_2 = Q \cdot k \cdot \Phi_{PSII,max} \cdot \beta_{\Phi} \quad (30)$$

$$\Phi_{PSII,max} = 0.352 + 0.022T_{leaf} - 3.4 \cdot 10^{-4}T_{leaf}^2 \quad (31)$$

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

$$c_i = 0.7c_a \left(\frac{1.6740 - 6.1294 \cdot 10^{-2}T_{leaf} + 1.1688 \cdot 10^{-3}T_{leaf}^2 - 8.8741 \cdot 10^{-6}T_{leaf}^3}{0.73547} \right) \quad (32)$$

$$c_i = 0.7c_a @ 25^{\circ}C \quad (33)$$

$$O_i = 210 \left(\frac{4.7000 \cdot 10^{-2} - 1.3087 \cdot 10^{-3}T_{leaf} + 2.5603 \cdot 10^{-5}T_{leaf}^2 - 2.1441 \cdot 10^{-7}T_{leaf}^3}{2.6934 \cdot 10^{-2}} \right) \quad (34)$$

$$O_i = O_a @ 25^{\circ}C \quad (35)$$

$$\phi = \frac{A_{I=50} - A_{I=25}}{25f} \quad (36)$$

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

Leaf Water Potential

$$h_s = \frac{e_l - \rho_{va}}{e_l} \cdot 100 \quad (37)$$

$$g_s = g_0 + g_1 \cdot A_{gross} \cdot \frac{h_s}{c_a} \quad (38)$$

$$A_{net, water stress} = A_{net} \cdot h_s \quad (39)$$

$$A_{net, water stress} = A_n \cdot g_{ws} \quad (40) \quad g_{ws} \text{ is undefined}$$

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

Canopy Light Transfer

$$J_a = 2 \cdot I_{\text{abs}} \cdot \left(\frac{1 - r - \tau}{1 - \tau} \right) \cdot \ell \quad (41)$$

$$L_b = (2.126 \cdot 10^{-5} + 1.48 \cdot 10^{-7} \cdot T_{\text{air}}) / 0.004 \cdot \sqrt{L_w / u_{\text{layer}}} \quad (42)$$

$$u_a = \frac{u \cdot 0.41}{\log((u - d) / z_o)} \quad (43) \quad \text{I can not reconcile units}$$

$$g_a = \frac{(u_a^2 / u_{\text{layer}}) \cdot L_b}{(u_a^2 / u_{\text{layer}}) + L_b} \quad (44) \quad \text{I can not reconcile units}$$

$$\rho'_v = 610.78 \cdot \exp\left(17.269 \cdot \frac{T_a}{T_a + 237.3}\right) \quad (45)$$

$$\Delta\rho_{va} = \rho'_v \cdot \left(1 - \frac{h_s}{100}\right) \quad (46)$$

$$\gamma = \frac{\rho \cdot c_p}{\lambda} \quad (47)$$

$$s = 18 \cdot (2501 - 2.373 \cdot T_a) \cdot \left(\frac{\rho'_v}{8.314 \cdot (T_a + 273)^2} \right) \quad (48)$$

$$R_{lc} = 4\sigma \cdot (273 + T_{\text{air}})^3 \cdot \Delta T \quad (49)$$

$$\Phi_N = J_a - R_{lc} \quad (50)$$

$$\Delta T = T_{\text{leaf}} - T_{\text{air}} = \frac{\Phi_n \left(\frac{1}{g_a} + \frac{1}{g_c} \right)}{\lambda \left[s + \gamma \left(1 + \frac{g_a}{g_c} \right) \right]} - \frac{\lambda \Delta\rho_{va}}{\lambda \left[s + \gamma \left(1 + \frac{g_a}{g_c} \right) \right]} \quad (51) \quad \text{should thermal conductivity be in this equation?}$$

$$E = \frac{s \cdot \Phi_N + \lambda \cdot g_a \cdot \Delta\rho_{va}}{\lambda \cdot [s + \lambda \cdot (1 + g_a / g_c)]} \quad (52)$$

$$\mathbf{E}_c = \sum_{\text{layer}1}^{\text{layer}N} (\mathbf{E}_{\text{sun}} \cdot l_{\text{sun}}) + (\mathbf{E}_{\text{shade}} \cdot l_{\text{shade}}) \quad (53)$$

$$\mathbf{E}_{\text{tot}} = \int_0^{365 \text{ days}} \int_0^{24 \text{ hours}} \mathbf{E}_c \quad (54) \quad \text{why use } \int \text{ instead of } \sum?$$

Sun / Shade Canopy

$$k = \frac{\sqrt{\chi^2 + \tan^2(\theta)} \cdot \cos(\theta)}{\chi + 1.744 \cdot [\chi + 1.183]^{-0.733}} \quad (55)$$

$$F_{\text{sun}} = \frac{1 - e^{(-k \cdot F_{\text{canopy}} / \cos(\theta))} \cdot \cos(\theta)}{k} \quad (56)$$

$$F_{\text{shade}} = F_{\text{canopy}} - F_{\text{sun}} \quad (57)$$

$$F_{\text{canopy}} = F_{\text{sun}} + F_{\text{shade}} \quad (58)$$

$$I_{\text{sun}} = I_{\text{dir}} \cdot k / \cos(\theta) + I_{\text{shade}} \quad (59)$$

$$I_{\text{shade}} = I_{\text{diff}} \cdot e^{(-0.5 \cdot F_{\text{canopy}}^{0.7})} + I_{\text{scat}} \quad (60)$$

$$I_{\text{scat}} = 0.07 \cdot I_{\text{dir}} \cdot (1.1 - 0.1 \cdot f) \cdot \exp(-\cos(\theta)) \quad (61) \quad \text{is this the same } f \text{ as Long}$$

$$I_{\text{total}} = I_{\text{dir}} + I_{\text{dif}} \quad (62) \quad \text{1991 "fraction of light not absorbed by photosynthesis"?$$

Total Canopy Assimilation

$$A_c = (A_{c,\text{sun}} \cdot F_{\text{sun}}) + (A_{c,\text{shade}} \cdot F_{\text{shade}}) \quad (63)$$

$$F_{\text{sun}} = \sum_{\text{layer}N}^{\text{layer}1} l_{\text{sun}}; \quad l_{\text{sun}} = \frac{1 - e^{(-k \cdot F_{\text{sun}})}}{k} \quad (64)$$

$$F_{\text{shade}} = \sum_{\text{layer}N}^{\text{layer}1} \ell_{\text{shade}}; \quad \ell_{\text{shade}} = F_{\text{sun}} - \ell_{\text{sun}} \quad (65)$$

$$F_{\text{canopy}} = F_{\text{sun}} + F_{\text{shade}} \quad (66)$$

$$I_d = I_{\text{diff}} \cdot e^{(-k \cdot F_{\text{sun}})} \quad (67)$$

$$I_{\ell,d} = k \cdot I_d \quad (68)$$

$$I_{\ell,s} = k \cdot I_{\text{dir}} + I_{\ell,d} \quad (69)$$

$$A_c = \sum_{\text{layer}N}^{\text{layer}1} (A_{c,\text{sun}} \cdot F_{\text{sun}}) + (A_{c,\text{shade}} \cdot F_{\text{shade}}) \quad (70)$$

$$A_{c,\text{tot}} = \int_0^{365\text{days}} \int_0^{24\text{hours}} A_c \quad (71)$$

$$g_c = \sum_{\text{layer}1}^{\text{layer}N} (g_{s,\text{sun}} \cdot l_{\text{sun}}) + (g_{s,\text{shade}} \cdot l_{\text{shade}}) \quad (72)$$

$$g_{c,\text{tot}} = \int_0^{365\text{days}} \int_0^{24\text{hours}} g_c \quad (73)$$

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

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

Allocation

$$A_{\text{storage}} = |\omega_{\text{storage}} \cdot k_{\text{storage}}; k_{\text{storage}} < 0 \quad (74)$$

$$A_{\text{total}} = A_{\text{leaf}} + A_{\text{stem}} + A_{\text{root}} + A_{\text{storage}} \quad (75)$$

$$\omega_{\text{leaf}} = \omega_{\text{leaf}} + (A_{\text{total}} \cdot k_{\text{leaf}}) \quad (76)$$

$$\omega_{\text{stem}} = \omega_{\text{stem}} + (A_{\text{total}} \cdot k_{\text{stem}}) \quad (77)$$

$$\omega_{\text{storage}} = \omega_{\text{storage}} + (A_{\text{total}} \cdot k_{\text{storage}}) \quad (78)$$

$$\omega_{\text{root}} = \omega_{\text{root}} + (A_{\text{total}} \cdot k_{\text{root}}) \quad (79)$$

$$\Psi_{\text{adl}} < \Psi_{\text{pt}} \quad (80)$$

$$k_{\text{leaf}} = k_{\text{leaf}} \cdot k_{\text{mod}} \quad (81)$$

$$k_{\text{stem}} = k_{\text{stem}} \cdot k_{\text{mod}} \quad (82)$$

$$k_{\text{storage}} = k_{\text{storage}} \cdot k_{\text{mod}} \quad (83)$$

$$k_{\text{mod}} = (\Psi_{\text{adl}} - \Psi_{\text{pt}}) \cdot \Psi_g; 0 \leq k_{\text{mod}} \leq 1 \quad (84)$$

$$\Delta F_{\text{canopy}} = \frac{\omega_{\text{leaf}}}{Sp_{\text{leaf}}} \quad (85)$$

$$\Delta L_{\text{stem}} = \frac{\omega_{\text{stem}}}{Sp_{\text{stem}}} \quad (86)$$

$$\Delta L_{\text{sroot}} = \frac{\omega_{\text{sroot}}}{Sp_{\text{sroot}}} \quad (87)$$

$$\Delta L_{\text{storage}} = \frac{\omega_{\text{storage}}}{Sp_{\text{storage}}} \quad (88)$$

$$\text{Stem}_{\text{coppice}} = 0.95 - \omega_{\text{stem}} \quad (89)$$

should restrictions on values of k in equations 74 and 84 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

$$E_{\text{soil}} = \sum \frac{(\Psi_{\text{si}} - g \cdot z_i - \Psi_x)}{R_{\text{si}} + R_{\text{ri}}} \quad (90)$$

$$R_{\text{ri}} = R_r \cdot \frac{\sum L_i}{L_i} \quad (91)$$

$$\Psi_x = \sum \frac{(\Psi_{\text{si}} - q_w \cdot z_i)}{R_{\text{si}} + R_{\text{ri}}} / \sum \frac{1}{R_{\text{si}} + R_{\text{ri}}} \quad (92)$$

$$\Psi_L = \Psi_x - E \cdot R_L \quad (93)$$

$$E_d = \begin{cases} E_p, & \theta^* \geq \theta_1 \\ E_p \left(\frac{\theta - \theta_2}{\theta_1 - \theta_2} \right), & \theta_2 < \theta^* < \theta_1 \\ 0, & \theta^* \leq \theta_2 \end{cases} \quad (94)$$

$$\theta_{i+1} = \theta_i - \frac{E_i \cdot \theta_i}{\rho_w \cdot d_s} \quad (95)$$

$$g_{a,\text{soil}} = \frac{(2.126 \cdot 10^{-5}) + (1.48 \cdot 10^{-7}) \cdot T_{\text{soil}}}{\left(0.004 \cdot \sqrt{\frac{S_{\text{size}}}{u_{\text{soil}}}}\right)} \quad (96)$$

$$R_{lc,\text{soil}} = ((4\sigma) \cdot (273 + T_{\text{soil}})^3 \cdot \Delta T) \quad (97)$$

$$J_{a,\text{soil}} = 2 \cdot I_{\text{soil}} \cdot \left(\frac{1 - S_r - S_\tau}{1 - S_\tau} \right) \quad (98)$$

$$\Phi_{N,\text{soil}} = J_{a,\text{soil}} - R_{lc,\text{soil}} \quad (99)$$

$$E_{\text{soil}} = \frac{s \cdot \Phi_{N,\text{soil}} + \lambda \cdot g_{a,\text{soil}} \cdot \Delta \rho_{va}}{\lambda \cdot [s + \gamma]} \quad (100) \quad \text{is "soil" subscript correct?}$$

Respiration

$$R_{\text{total}} = (a \cdot A_n) + (b_{\text{stem}} \cdot \omega_{\text{stem}}) + (b_{\text{root}} \cdot \omega_{\text{root}}) \quad (101)$$

Energy Balance

$$HS_{\text{soil}} = HO_{\text{soil}} \cdot \exp \left[\frac{h_{\text{soil}}}{46.97 \cdot (T_{\text{soil}} + 273.16)} \right] \quad (102)$$

$$HO_{\text{soil}} = 1.323 \cdot \exp \left[\frac{17.27 \cdot T_{\text{soil}}}{273.3 + T_{\text{soil}}} \right] / T_{\text{soil}} + 273.16 \quad (103)$$

$$G_{\text{soil}} = -\lambda_{\text{soil}} \frac{\delta T}{\delta x} \quad (104)$$

$$G_{\text{soil}} = -\lambda_{\text{soil}} \cdot \left[\frac{T_2 - T_{\text{soil}}}{\Delta z} \right] + (T_{\text{soil}} - T_l) \cdot C \cdot \frac{\Delta z}{(2 \cdot \Delta t)} \quad (105)$$

should denominator in equation 104 be δz ?

what is t_l ?

C in from equation 105 is undefined - is this the specific heat of soil?

Definition of Terms

Term	Units	Definition	Value
A_{gross}	$\mu\text{mol mol}^{-1}$	Gross rate of CO ₂ uptake per unit leaf area	-
A_{net}	$\mu\text{mol mol}^{-1}$	Net rate of CO ₂ uptake per unit leaf area	-
$A_{\text{net,water stress}}$	$\mu\text{mol mol}^{-1}$	A_{net} under water stress	-
A_c	$\mu\text{mol mol}^{-1}$	Net canopy rate of CO ₂ uptake per unit ground area	-
$A_{c,\text{tot}}$	$\text{g m}^{-2} \text{yr}^{-1}$	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	-
$A_{c,\text{shade}}$	$\text{mol m}^{-2} \text{s}^{-1}$	Net rate of CO ₂ uptake per unit area shaded leaves	-
A	$\mu\text{mol mol}^{-1}$	Predicted rate of CO ₂ uptake	-
c_a	$\mu\text{mol mol}^{-1}$	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	$\mu\text{mol mol}^{-1}$	Intercellular concentration of O ₂ in air corrected for solubility relative to 25°C	-
c_p	$\text{J kg}^{-1} \text{K}^{-1}$	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	-
E	J mol^{-1}	Activation energy	$R_d = 66405$ $V_{\text{max}} = 6800$
E_d			
E_i			undefined from equation 94
E_c	$\text{mmol m}^{-2} \text{s}^{-1}$	Instantaneous canopy evapo/transpiration rate	-
E_d	$\text{g m}^{-2} \text{s}^{-1}$	Potential soil evaporation	-
E_l	$\text{mmol m}^{-2} \text{s}^{-1}$	Evapo/transpiration rate at sunlit/shaded leaves in a canopy layer	-
E_p	$\text{g m}^{-2} \text{s}^{-1}$	Actual soil evaporation	-
E_{R_d}	J mol^{-1}	Activation energy of R_d	-
E_{tot}	$\text{mmol m}^{-2} \text{yr}^{-1}$	E_c integrated over the course of a year	-
$E_{V_{\text{max}}}$	J mol^{-1}	Activation energy of V_{cmax}	-
f		fraction of light not absorbed by photosynthesis	0.23
F_{canopy}	$\text{m}^2 \text{m}^{-2}$	Canopy leaf area index	9
F_{shade}	$\text{m}^2 \text{m}^{-2}$	Canopy shaded leaf area index	-
F_{sun}	$\text{m}^2 \text{m}^{-2}$	Canopy sunlit leaf area index	-
F_{sum}	$\text{m}^2 \text{m}^{-2}$	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}	Gravitational constant	9.8
g_a	$\text{mmol m}^{-2} \text{s}^{-1}$	Leaf boundary layer conductance	-
g_c	$\text{mmol m}^{-2} \text{s}^{-1}$	Canopy conductance of CO ₂	-
$g_{c, \text{root}}$			undefined
g_s	$\text{mmol m}^{-2} \text{s}^{-1}$	Leaf stomatal conductance	-

is “saturated VPD” an oxymoron?

undefined from equation 94
undefined from equation 95

Table 1 – continued from previous page

Term	Units	Definition	Value
g_{ws}			
g_0	dimensionless	Stomatal slope factor	3
g_1	dimensionless	Stomatal intercept factor	0.08
$g_{s,sun}$	$mmol\ m^{-2}\ s^{-1}$	The sum of stomatal conductance of sunlit leaves	-
$g_{s,shade}$	$mmol\ m^{-2}\ s^{-1}$	The sum of stomatal conductance of shaded leaves	-
g_{ws}	dimensionless	Species-specific water stress sensitivity factor	
g_{wmod}		water stress stomatal conductance factor	
γ	$Pa\ K^{-1}$	psychrometer constant	-
Γ^*	$\mu mol\ mol^{-1}$	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
$h_{m.s}$	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	$mm\ day^{-1}$	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 perpendicular to the solar beam above the atmosphere	2600
I_d			
$I_{\ell,d}$			
I_{short}	$\mu mol\ m^{-2}\ s^{-1}$	Short wave radiation component of incident light	-
I_{soil}	$\mu mol\ m^{-2}\ s^{-1}$	Solar radiation incident upon soil surface	-
I_{soil}	$W\ m^{-2}$	Solar radiation on soil	-
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	-
$J_{a, soil}$	$\mu mol\ m^{-2}\ s^{-1}$	Total solar radiation absorbed by soil	-
k	dimensionless	Foliar absorption coefficient (α_ℓ in Bernacchi 2003)	-
K_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	-
k_{stem}	Dimensionless	Partitioning coefficient for stem	-
k_{root}	Dimensionless	Partitioning coefficient for storage root	-
k_{froot}	Dimensionless	Partitioning coefficient for fine root	-
k_{stroot}	Dimensionless	Partitioning coefficient for structural root	-
ℓ			
ℓ_{sun}			
l_{sun}			
L_i	$cm\ cm^{-3}$	Root density of ith zone	-

undefined, modifies Anet during water stress

distinct from g_{ws} ?

undefined

undefined

which units for I_{soil} are correct?

undefined from Ja: equation 41

undefined from equation 69

undefined from equation 64

Table 1 – continued from previous page

Term	Units	Definition	Value	
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			17	what is M ?
m_r	mm month ⁻¹	monthly precipitation rate		
N_{eff}	days/mo	effective length of rainy period		check units with equation 12
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	-	
$\Phi_{N,\text{soil}}$	W m ⁻²	Net radiation at soil surface	-	
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	-	
R_{lc}	mol m ⁻² s ⁻¹	Longwave radiation	-	
$R_{\text{lc,soil}}$	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 $\Delta\rho_{\text{va}}$?
ρ'_a				undefined from equation 46
s	kPa K ⁻¹	Slope of saturated water vapor pressure change with respect to temperature (look up table)	-	also defined by equation 48; 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	

Table 1 – continued from previous page

Term	Units	Definition	Value
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	$\text{Wm}^{-2}\text{K}^{-4}$	Stefan-Boltzmann constant	5.67 10^{-8}
t	h	Time of day	-
t_{len}	h	day length	-
t_{sn}	h	Time of solar noon	12
T_{leaf}	$^{\circ}\text{C}$	Leaf temperature	-
T_{air}	$^{\circ}\text{C}$	Ambient air temperature	-
T_{soil}	$^{\circ}\text{C}$	Soil surface temperature	-
T_1	$^{\circ}\text{C}$	Annual mean air temperature	18
T_2	$^{\circ}\text{C}$	Annual range in air temperature	2
T_3	$^{\circ}\text{C}$	Average daily range in air temperature	7
T_4	$^{\circ}\text{C}$	Maximum daily range in air temperature	7
ΔT	$^{\circ}\text{C}$	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	kgm^{-3}	The volumetric water content for maximizing Evaporation	-
Θ_2	kgm^{-3}	The volumetric water content for wilting point	-
Θ_i	kgm^{-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	-
w_c	$\text{mol m}^{-2} \text{s}^{-1}$	RuBISCO limited rate of photosynthesis	-
w_c	$\text{mol m}^{-2} \text{s}^{-1}$	RuBP limited rate of photosynthesis	-
v		Saturated water vapour concentration	-
V_{max}	$\text{mol m}^{-2} \text{s}^{-1}$	Maximum rubP saturated rate of carboxylation at a given temperature	-
V_{c,max_o}	$\text{mol m}^{-2} \text{s}^{-1}$	Maximum rubP saturated rate of carboxylation at 25°C	39
VPD	kPa	Leaf-air water vapour pressure deficit	-
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	-

is this a constant, 24?

units?

units?