Description of 3-PG

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What is 3-PG?

- Simple, process-based model to predict growth and development of even-aged stands.
- Uses basic mean-monthly climatic data, and simple site factors and soil descriptors.
- Generates:

  foliage, woody tissue and root biomass,
  conventional stand attributes (volume, BA, stocking),
  soil water content and water usage.
- Runs on monthly time step.
- Parameterised using stand-level data.

Main Components of 3-PG

Production of biomass – Based on environmental modification of light use efficiency and constant ratio of NPP to GPP.

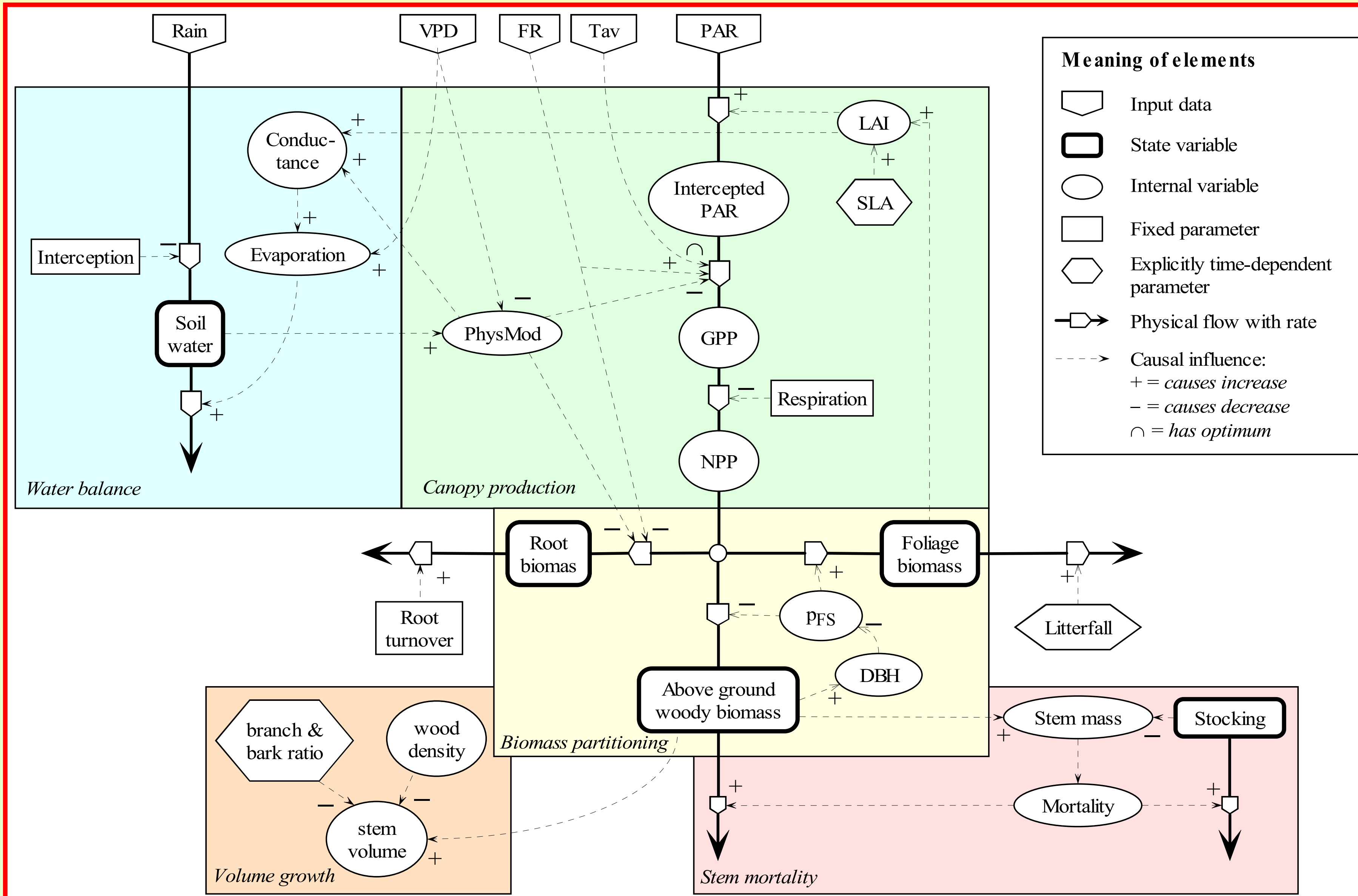
Biomass partitioning – Affected by growing conditions and tree size.

Stem morality – Based on self-thinning rule.

Soil water balance – A single soil layer model with evapo-transpiration determined from Penman-Monteith equation.

Stand properties – Determined from biomass pools and assumptions about specific leaf area, branch+bark fraction, and wood density.

Structure and Causal Influences



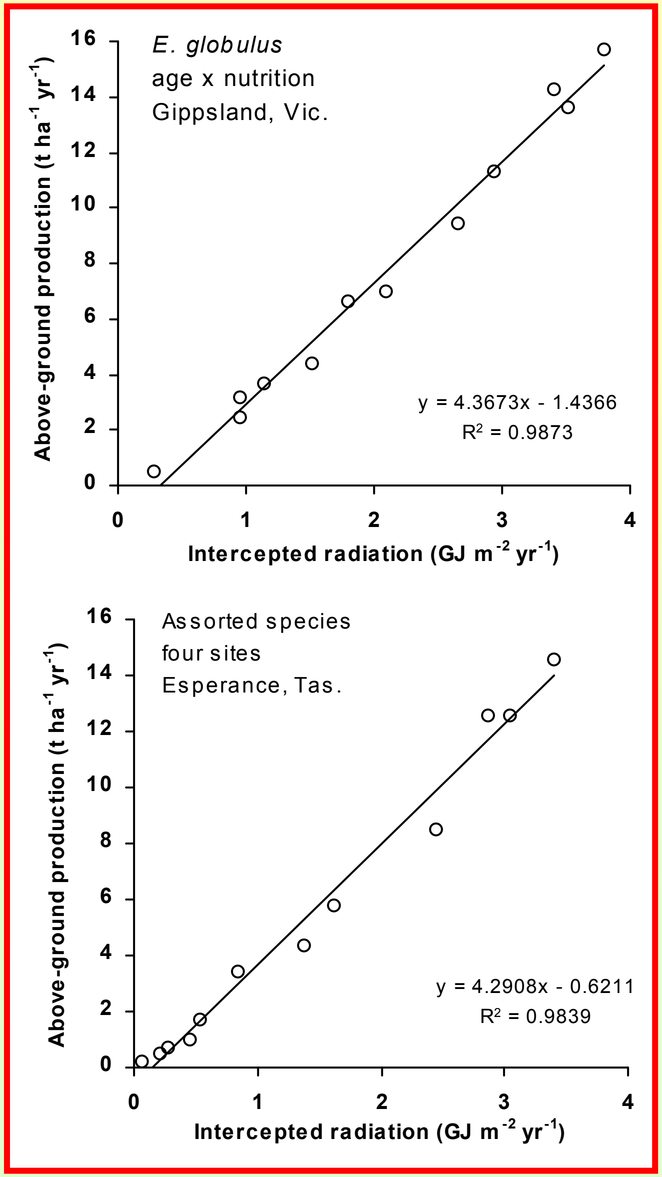
Biomass Production and Intercepted Solar Radiation

Observation shows:

- above-ground production linearly related to intercepted radiation
- gross production proportional to intercepted radiation.

Slope of these relationships is light use efficiency ε (g_{DM} MJ^{-1}).

This finding is the basis for many simple models.



Light Use Efficiency

Light use efficiency

- is affected by climatic factors (e.g. temperature) and site factors (e.g. soil-water status)
- varies seasonally, but annual values more stable.

This concept forms basis of many simple models, e.g.

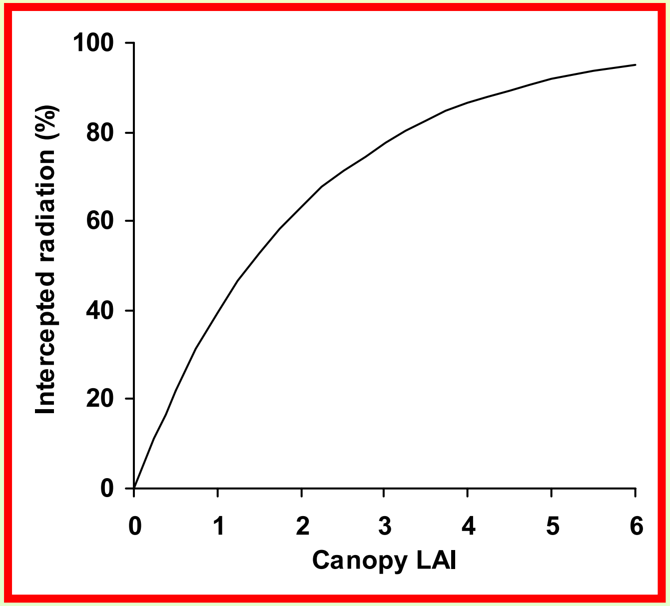
- ***GrowEst*** grasslands; based on T & soil water; multiplicative
- ***PlantGro*** many crops; many environmental & site factors; law of the minimum
- ***3-PG*** trees; based on T, VPD, soil water & nutrition; mainly multiplicative

Calculating Intercepted Radiation

Beer's law determines light transmitted through canopy. Thus radiation intercepted by the canopy is:

$$Q_{\text{int}} = (1 - e^{-kL})Q_0$$

Note diminishing returns from high leaf area indices ➔



Gross Canopy Production

Putting these together, total gross production by the canopy is

$$P_g = \alpha_C (1 - e^{-kL}) Q_0$$

where canopy quantum efficiency α_C (mol mol^{-1}) or light use efficiency ε, g_{DM} MJ^{-1}:

- measure efficiency of conversion of solar radiation into biomass
- depend on environmental and site factors.

Net Canopy Production

Respiration assumed to be constant fraction of gross canopy production. Thus net canopy production is:

$$
\begin{aligned}
P_n &= YP_g \\
&= \alpha_C Y(1 - e^{-kL})Q_0
\end{aligned}
$$

where Y ≈ 0.47.

This is a contentious assumption, which greatly simplifies treatment of respiration.

Growth Modifiers in 3-PG

Each environmental factor is represented by a growth modifier = function of factor which varies between 0 (total limitation) and 1 (no limitation).

Factor	Modifier	Parameters
Vapor pressure deficit	$f_{VPD}(D)$	k_D
Soil water	$f_{SW}(\theta)$	θ_{max} , c_θ , n_θ
Temperature	$f_T(T_{av})$	T_{min} , T_{opt} , T_{max}
Frost	$f_F(d_f)$	k_F
Site nutrition	$f_N(FR)$	f_{N0}
Stand age	$f_{age}(t)$	n_{age} , r_{age}

Effects on Canopy Production

All modifiers affect canopy production:

$$\alpha_C = f_T f_F f_N \min\{f_{VPD}, f_{SW}\} f_{age} \alpha_{Cx}$$

where α_{Cx} is maximum canopy quantum efficiency.

In 3-PG the combination of modifiers

$$\varphi = \min\{f_{VPD}, f_{SW}\} f_{age}$$

also affects canopy conductance, and is called *PhysMod* in the program.

Temperature Growth Modifier $f_T(T_a)$

$$f_T(T_a) = \left(\frac{T_a - T_{min}}{T_{opt} - T_{min}}\right)\left(\frac{T_{max} - T_a}{T_{max} - T_{opt}}\right)^{(T_{max} - T_{opt})/(T_{opt} - T_{min})}$$

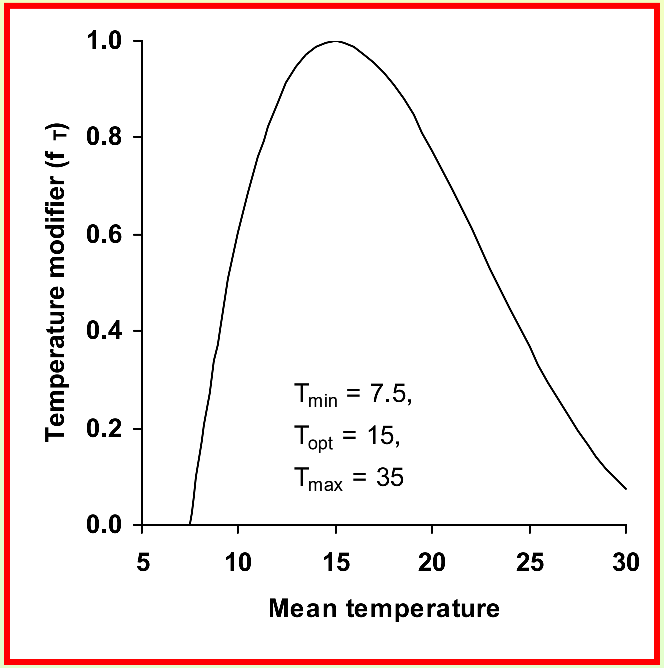
where

T_a = mean monthly daily temperature

T_{min} = minimum temperature for growth

T_{opt} = optimum temperature for growth

T_{max} = maximum temperature for growth



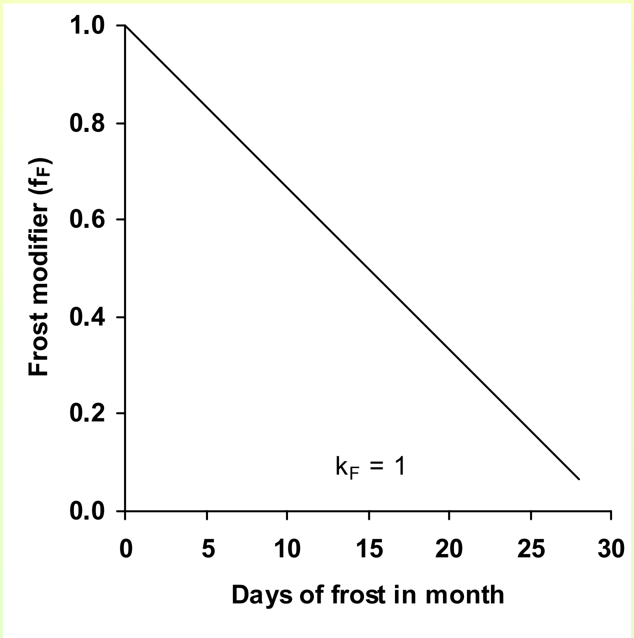
Frost Growth Modifier $f_F(d_F)$

$$f_F(d_F) = 1 - k_F(d_F/30)$$

where

d_F = number of frost days in month

k_F = number of days of production lost for each day of frost.



Soil-water Growth Modifier $f_{SW}(\theta)$

$$f_{SW}(\theta) = \frac{1}{1 + \left[(1 - \theta/\theta_x)/c_\theta\right]^{n_\theta}}$$

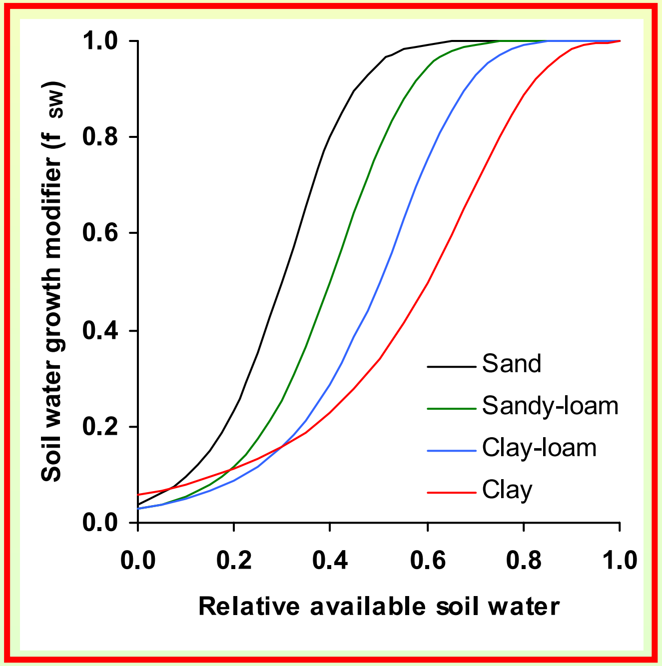
where

θ = current available soil water

θ_x = maximum available soil water

c_θ = relative water *deficit* for 50% reduction.

n_θ = power determining shape of soil water response.



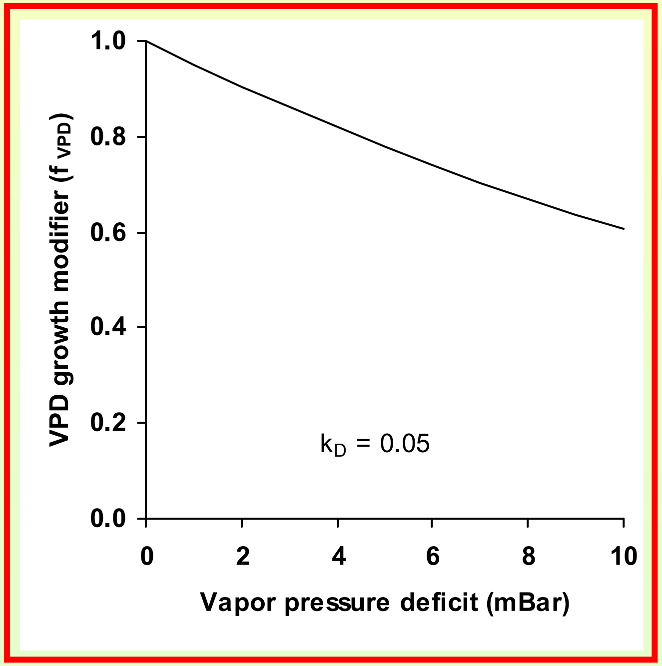
VPD Growth Modifier $f_{VPD}(d)$

$$f_{VPD}(D) = e^{-k_D D}$$

where

D = current vapor pressure deficit

k_D = strength of VPD response.



Age-related Growth Modifier $f_{age}(t)$

$$f_{age}(t) = \frac{1}{1 + (t / r_{age} t_x)^{n_{age}}}$$

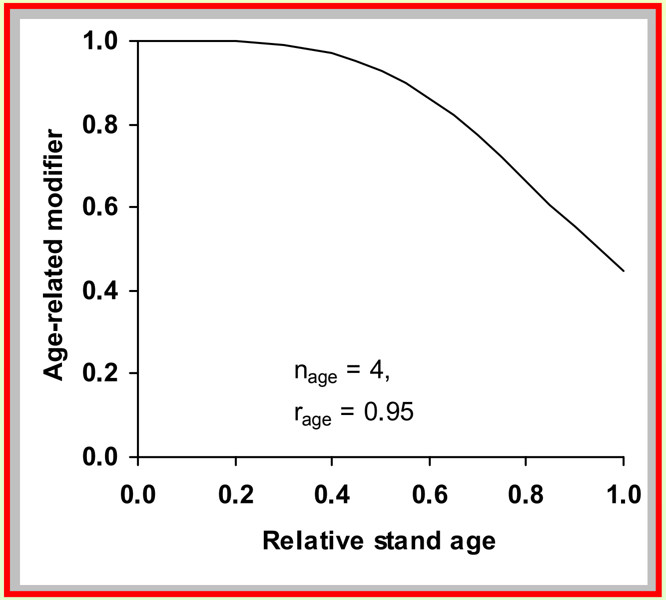
where

t = current stand age

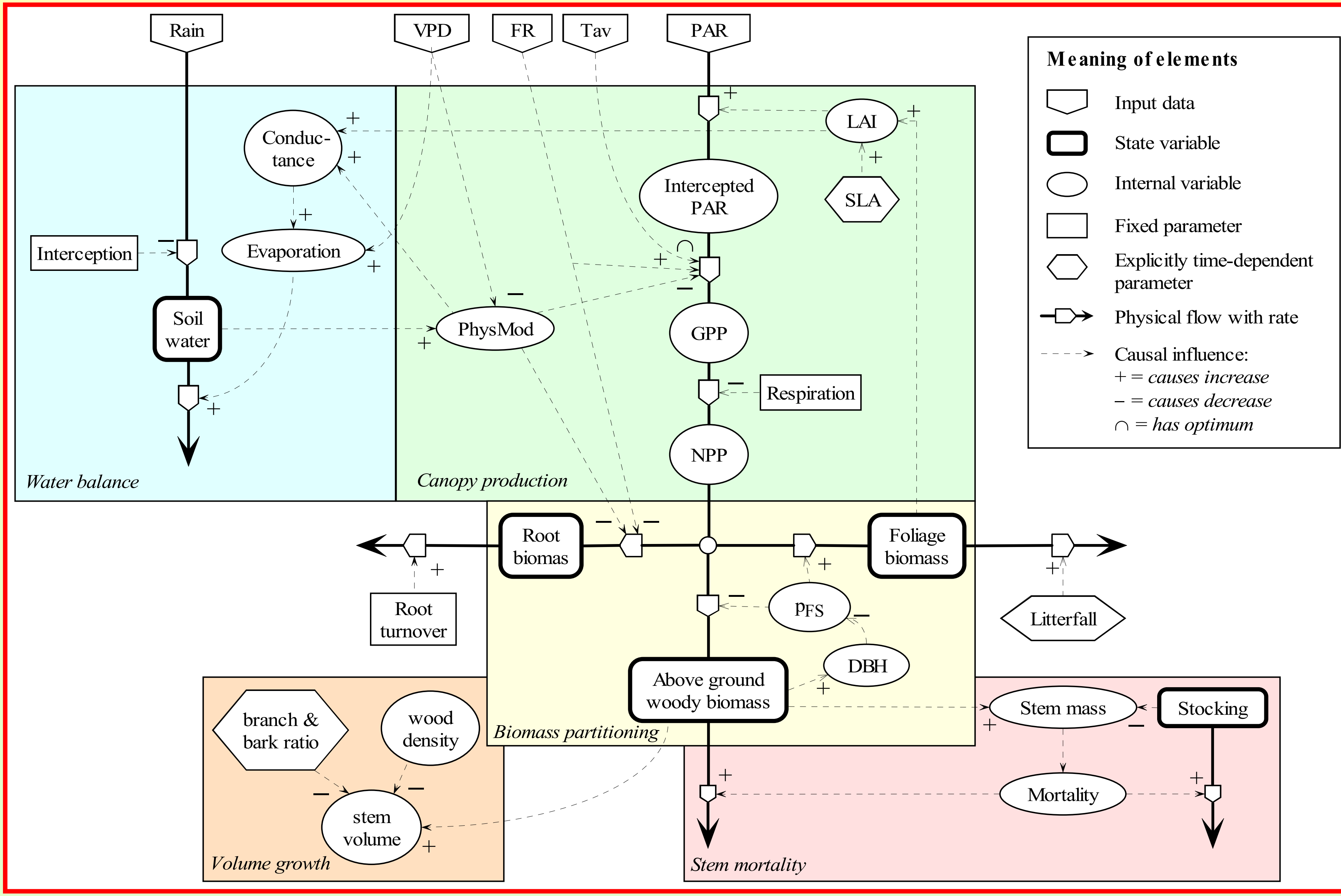
t_x = likely maximum stand age

r_{age} = relative stand age for 50% growth reduction

n_{age} = power determining strength of growth reduction



Structure and Causal Influences



Biomass Partitioning

NPP is partitioned into biomass pools (t_{DM} ha^{-1}):

- foliage (W_F),
- above-ground woody tissue (W_S)
- roots (W_R)

Partitioning rates (η_F, η_R and η_S) depend on growth conditions and stand DBH.

Litter-fall (γ_F) and root-turnover (γ_R) also taken into account. Thus:

$$\Delta W_F = \eta_F P_n - \gamma_F W_F$$

$$\Delta W_R = \eta_R P_n - \gamma_R W_R$$

$$\Delta W_S = \eta_S P_n$$

Root Partitioning

Partitioning to roots affected by growth conditions through φ (*PhysMod*) and by soil fertility:

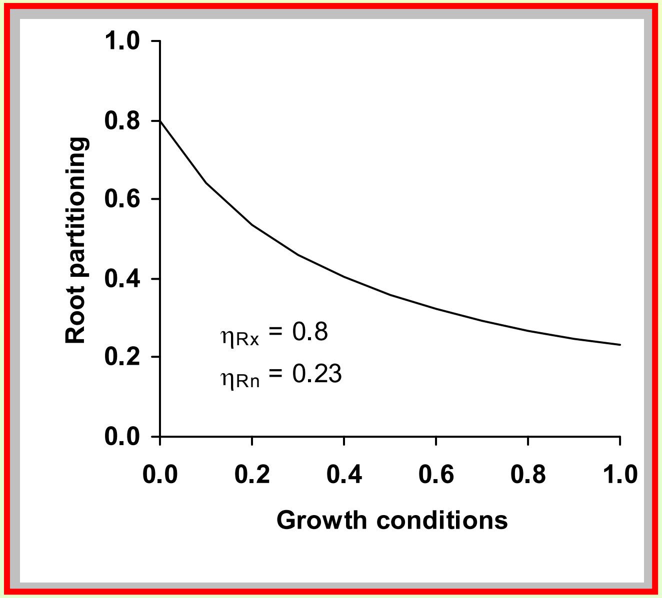
$$\eta_R = \frac{\eta_{Rx}\eta_{Rn}}{\eta_{Rn} + (\eta_{Rx} - \eta_{Rn})m\varphi}$$

where

$m = m_0 + (1-m_0)FR$

η_{Rx} = root partitioning under very poor conditions

η_{Rn} = root partitioning under optimal conditions



Foliage and Stem Partitioning

Above-ground partitioning based on foliage:stem partitioning ratio

$$p_{FS} = \eta_F / \eta_S = aB^n$$

- B is diameter at breast height determined from an allometric relationship between stem mass and B
- a, b are coefficients determined from p_{FS} at B = 2 and 20 cm.

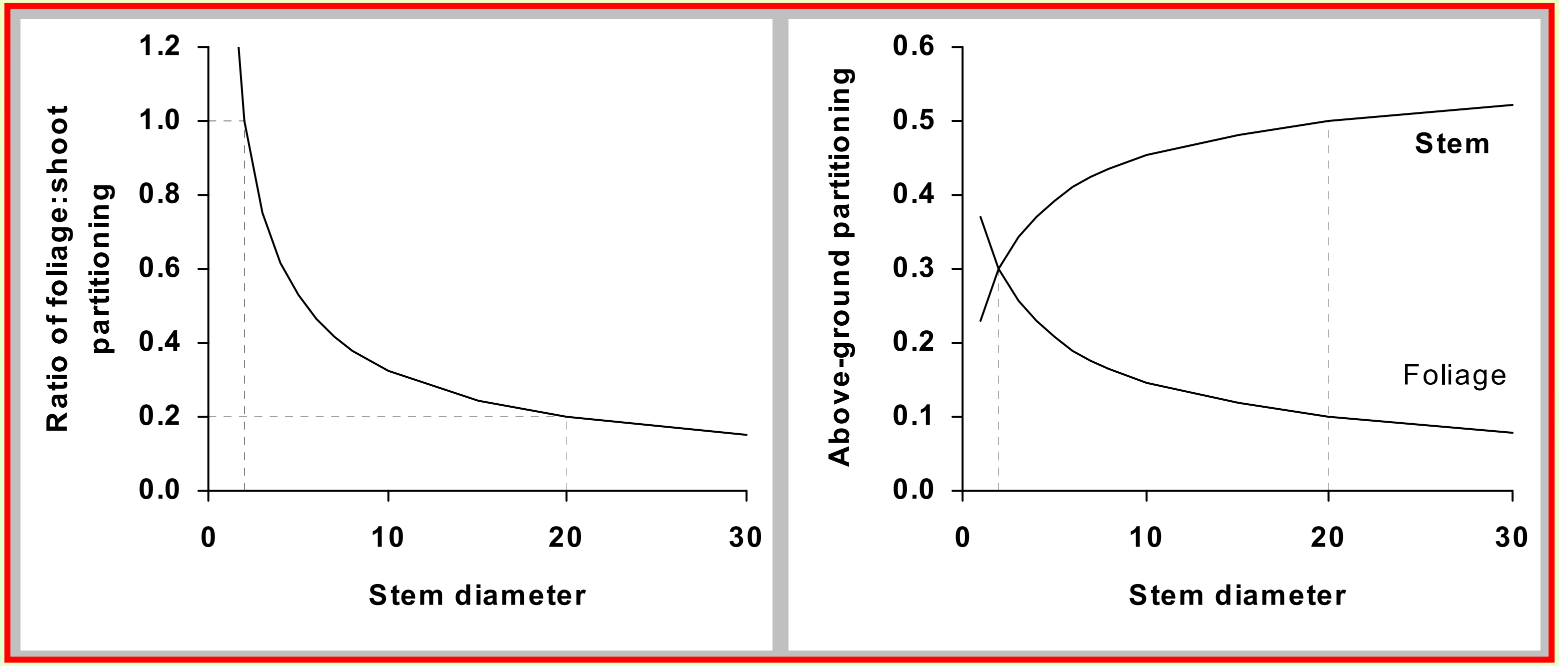
Then

$$\eta_S = \frac{1-\eta_R}{1+p_{FS}} \;, \quad \eta_F = p_{FS}\eta_S$$

Above-ground Partitioning *v* Tree-size

Increasing DBH decreases foliage partitioning and increases stem partitioning. Graphs show response when

$$p_{FS}(2) = 1, p_{FS}(20) = 0.25, \eta_R = 0.4$$



Root-turnover and Litter-fall

Root-turnover is a constant fraction of root biomass ($\gamma_R = 0.015$ month^{-1}).

Litter-fall is age-dependent fraction of foliage biomass:

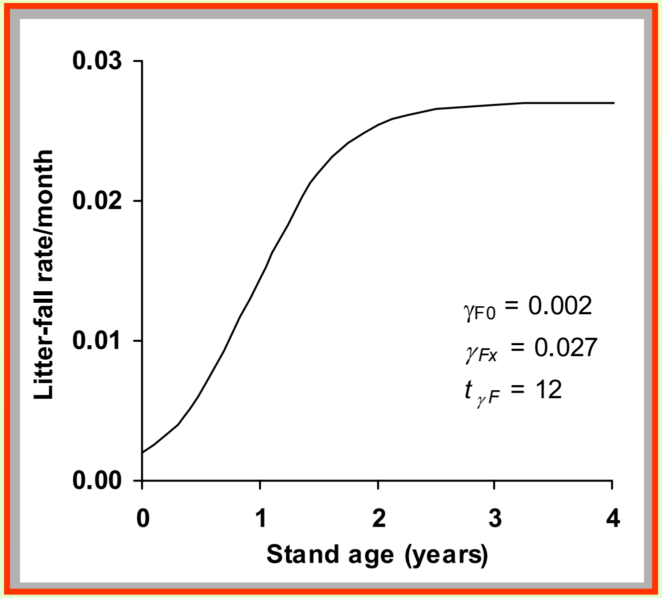
$$\gamma_F(t) = \frac{\gamma_{Fx}\gamma_{F0}}{\gamma_{F0} + (\gamma_{Fx} - \gamma_{F0})e^{-kt}} \quad , \quad k = \frac{1}{t_{\gamma F}} \ln\left(1 + \frac{\gamma_{Fx}}{\gamma_{F0}}\right)$$

where

γ_{F0} = litter-fall rate at age 0

γ_{Fx} = maximum litter-fall rate

$t_{\gamma F}$ = age when $\gamma_F = ½(\gamma_{F0} + \gamma_{Fx})$



Stem Mortality

Based on self-thinning where average stem weight for current stocking

$$w_{Sx}(N) \leq w_{Sx0}(1000/N)^{3/2} \quad \text{(kg/tree)}$$

and w_{Sx0} = max. stem weight at 1000 trees ha^{-1}.

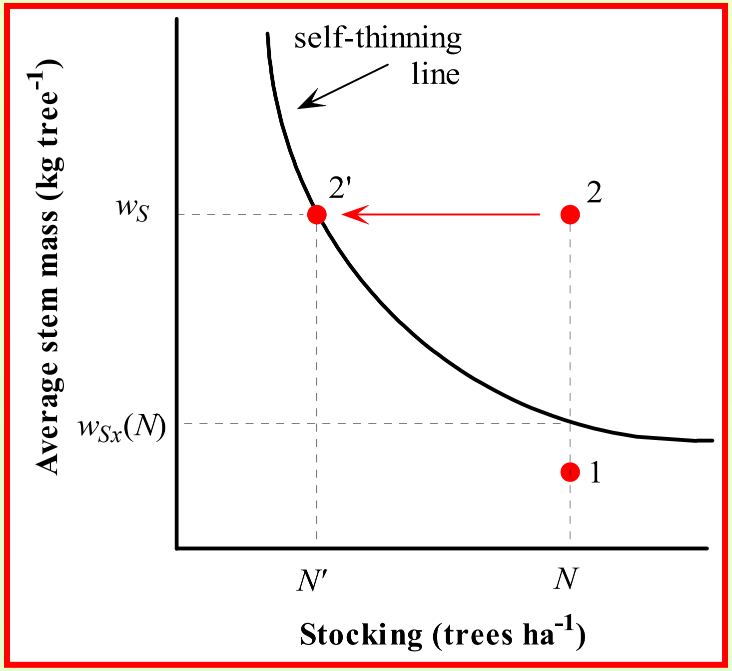
If at 1 *then* $w_S \leq w_{Sx}(N) \Rightarrow$ *no mortality*

If at 2 *then* $w_S > w_{Sx}(N) \Rightarrow$ *self-thin to* 2′

$$N' = 1000(w_{Sx0} / w_S)^{2/3}$$

$$\Delta W_S = -\gamma_S \frac{(N - N')}{N} W_S$$

where $\gamma_S \approx 0.2$ is a parameter.



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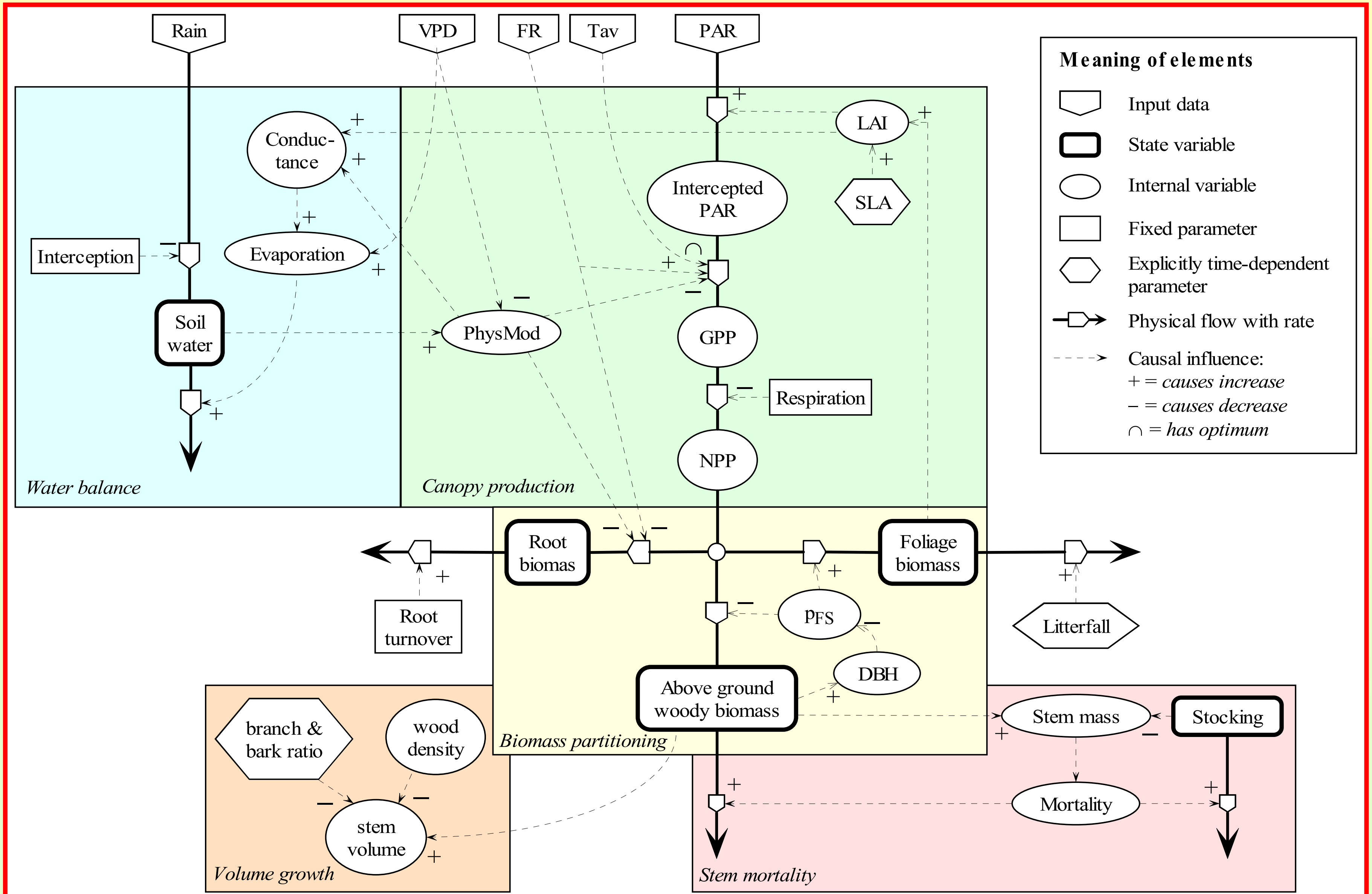


Soil Water Balance

Soil water balance model based on single soil layer.

Uses monthly time steps.

Inputs:

- rainfall and irrigation

Losses are:

- interception = fixed % of rainfall
- evapotranspiration – determined using Penman-Monteith equation
- excess over field capacity lost as run off

Evapotranspiration

Evapotranspiration is calculated using the *Penman-Monteith* equation.

Directly affected by VPD and radiation.

Canopy conductance:

- determined by LAI
- affected by growth conditions – VPD, soil water and age.

Boundary layer conductance:

- is assumed constant ($0.2\ m\ s^{-1}$)

Calculation of Stomatal Conductance

Canopy conductance is affected by VPD, soil water and stand age through φ (= *PhysMod* in 3-PG code), and increases with canopy LAI:

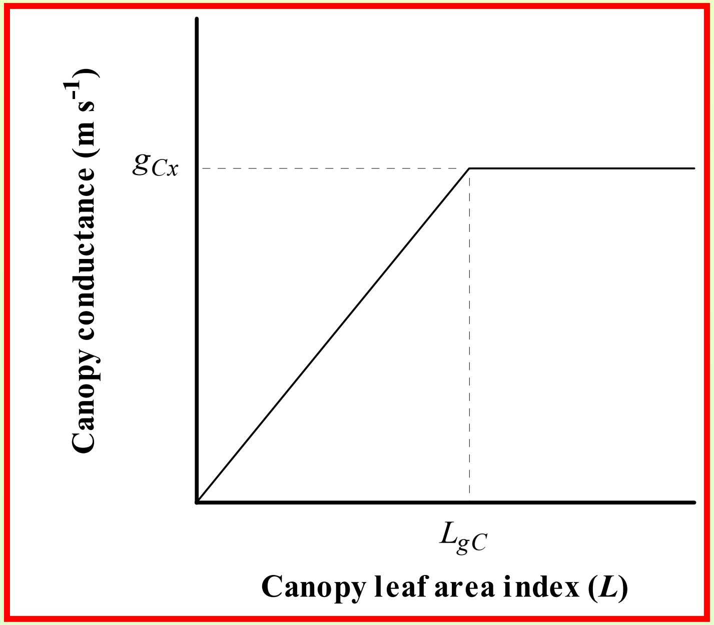
$$g_C = g_{Cx}\,\varphi\ \min\{L/L_{gC}\,,\,1\}$$

where

$\varphi = \min\{f_{VPD}, f_{SW}\}\, f_{age}$

g_{Cx} = maximum conductance

L_{gC} = LAI at max. conductance



Structure and Causal Influences