Toward a mechanistic modeling of nitrogen limitation on vegetation dynamics

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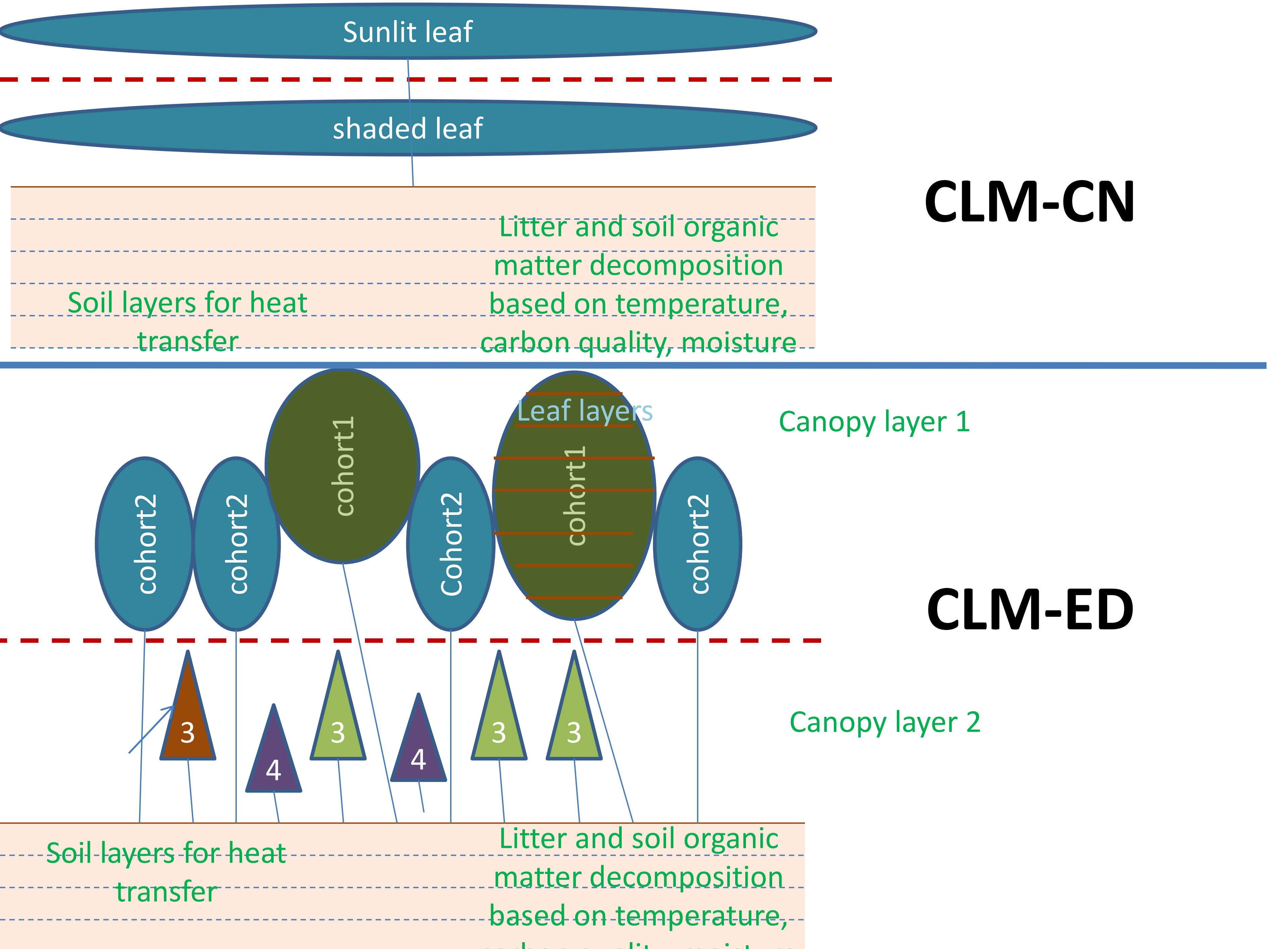
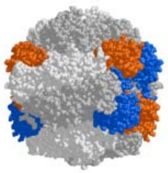


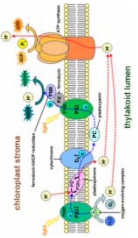
Sunlit leaf
shaded leaf
Litter and soil organic matter decomposition based on temperature, carbon quality, moisture
Soil layers for heat transfer
CLM-CN
Leaf layers
cohort1
cohort1
cohort2
cohort2
Cohort2
cohort2
Canopy layer 1
CLM-ED
3
4
3
4
3
3
Canopy layer 2
Soil layers for heat transfer
Litter and soil organic matter decomposition based on temperature,

Farquhar Photosynthesis Model for C3 plants

Photosynthesis rate $$A = \min(W_c, W_j, W_p)$$



Rubisco-limited carboxylation rate $$W_c = R_c V_{c,max}$$

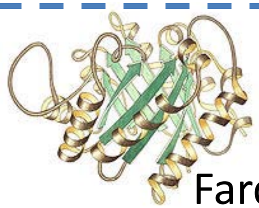


Light-limited carboxylation rate $$W_j = R_j J$$

L = light harvesting rate;

$J_{\max}$ = maximum electron transport rate

$$J = J_{\max} \frac{L}{\sqrt{J_{\max}^2 + L^2}}$$



Triose phosphate utilization(TPU)-limited rate $$W_p$$

Farquhar, G. D., S. Caemmerer, et al. (1980). Planta **149: 78-90.**

Harley & Sharkey. (1991).***Photosynthesis Research 27****: 169-178.*

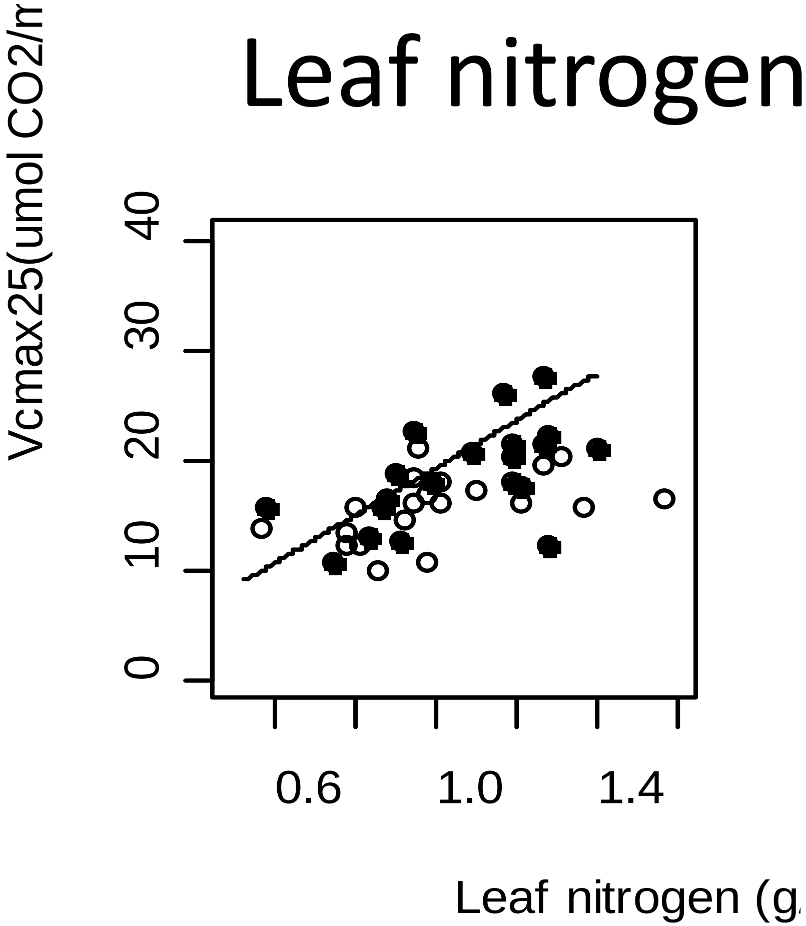
Approaches for simulating nitrogen limitation on photosynthesis

1. Down-regulation of NPP by nitrogen supply and demand;
2. Fixed relationship between Vc,max and leaf nitrogen content (LNC_a), without consideration differences in light, CO_2 and temperature conditions.

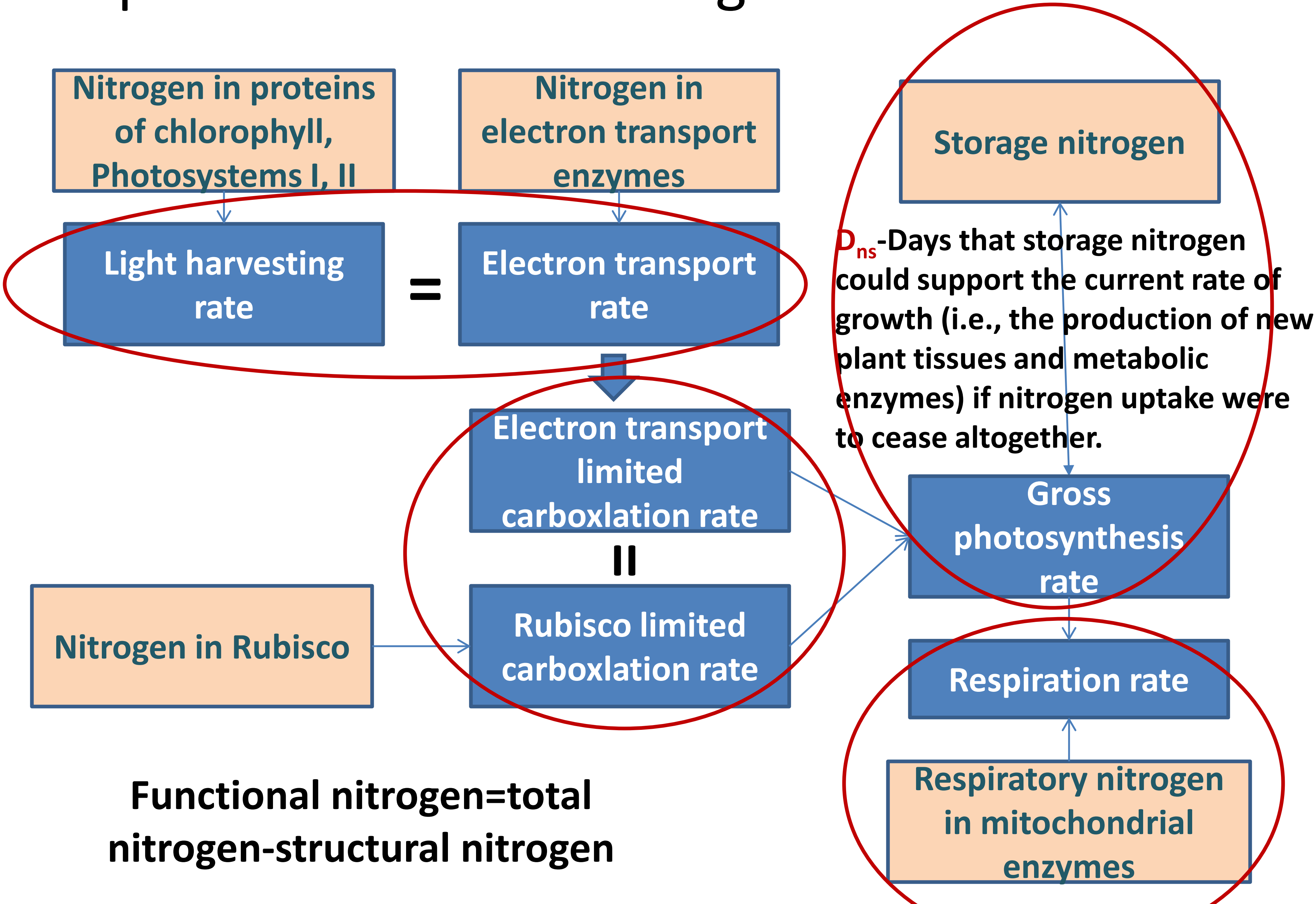
   $Vc,max = a + b\ LNC_a$
3. Simplified electron transport limitation;

   J= *u*PAR (photosynthetic active radiation)

Environmental conditions on Vc,max-Leaf nitrogen relationship change



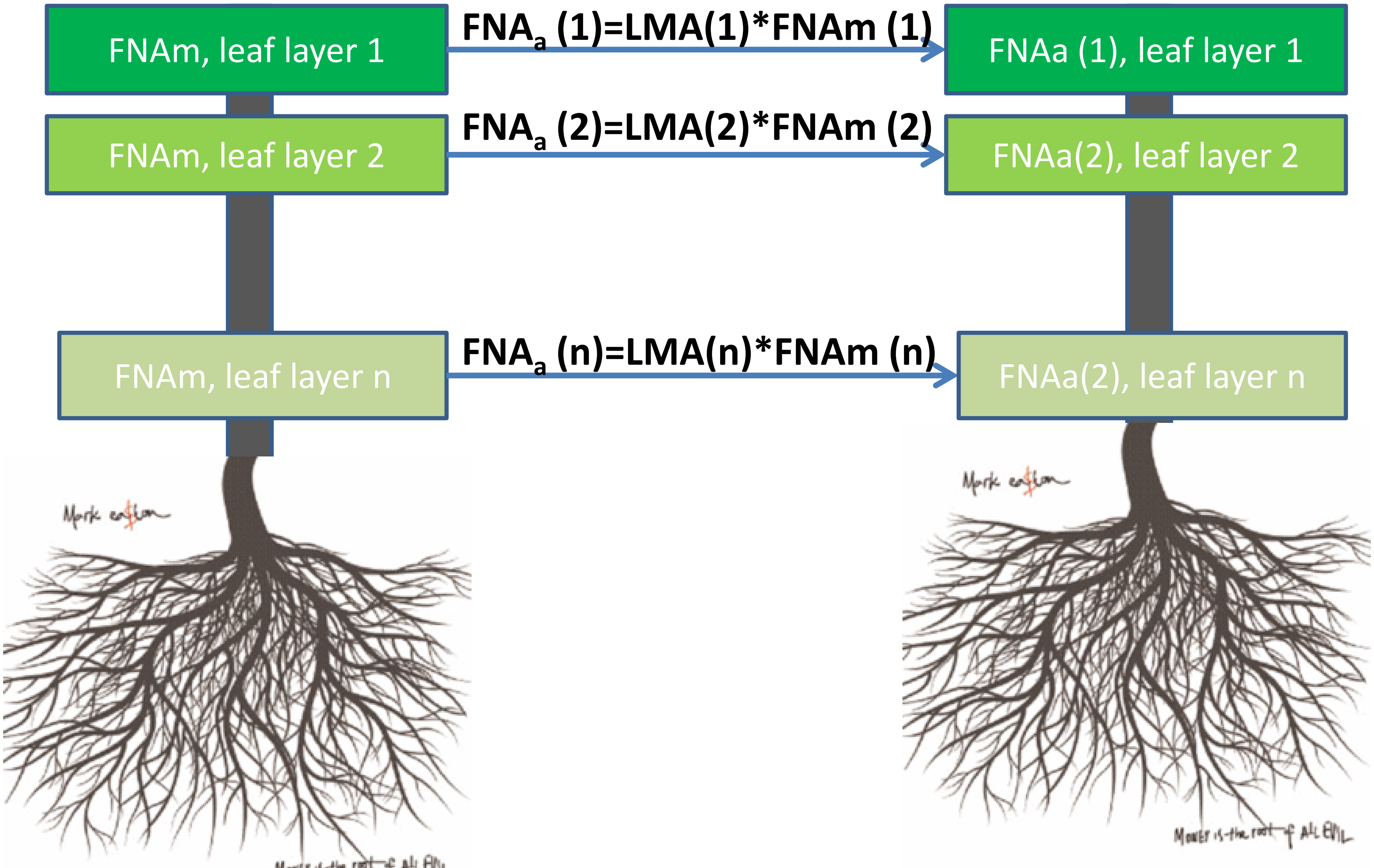
Optimal functional nitrogen allocation model



Functional nitrogen=total nitrogen-structural nitrogen

Leaf-mass-based functional nitrogen availability (FNA_m)=**Total plant functional nitrogen/total leaf biomass**

Leaf-area-based functional nitrogen availability (FNA_a)= FNA_m*Leaf mass per area (LMA)

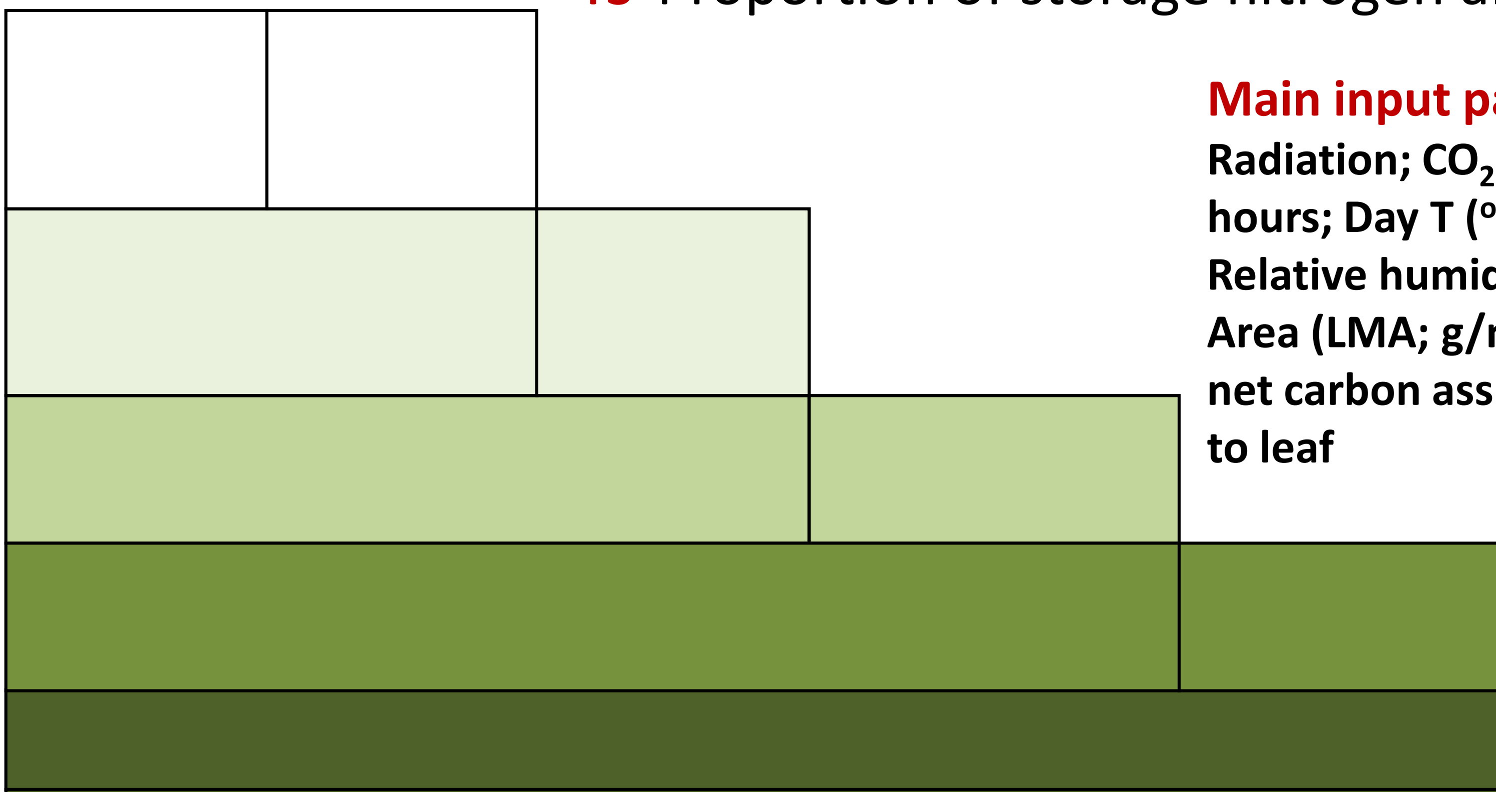


Mechanistic nitrogen allocation model

Tuning parameters:

D_{ns}-Days that storage nitrogen could support the current rate of growth (i.e., the production of new plant tissues and metabolic enzymes) if nitrogen uptake were to cease altogether.

fs-Proportion of storage nitrogen allocated to leaf.



Main input parameters:

Radiation; CO_2 (ppm); Daytime hours; Day T (°C); Night T (°C); Relative humidity; Leaf Mass per Area (LMA; g/m2); Proportion of net carbon assimilation allocated to leaf

Nitrogen investment parameters

Ntrogen use efficiency (NUE; *umol* CO_2/ *g* N/ s).

$$NUE_l = 1.78$$

$$NUE_c = 0.8 \times 33.3 \times 6.25 \times f_{V_{cmax}}(T)$$

$$NUE_J = 8.06 \times 156 \times f_{Jmax}(T)$$

$$NUE_r = 33.69\,[D_{day} f_r(T_{day}) + D_{night} f_r(T_{night})]$$

Niinemets and Tenhunen (1997).**Plant Cell and Environment 20:** 845-866;
Evans (1989 Oecologia **78(1): 9-19.**

$$LNC_a = PN_p FNA_a :\rightarrow \text{photosynthetic nitrogen}$$

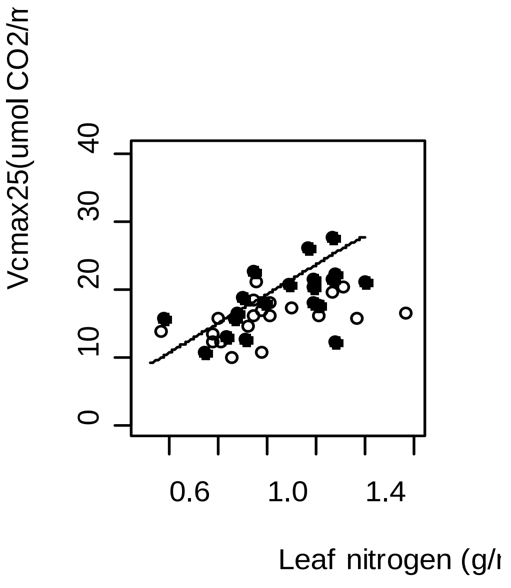
$$+ f_s(1 - PN_g) FNA_a :\rightarrow \text{storage nitrogen}$$

$$+ f_r(1 - PN_p) PN_g FNA_a :\rightarrow \text{respiratory nitrogen}$$

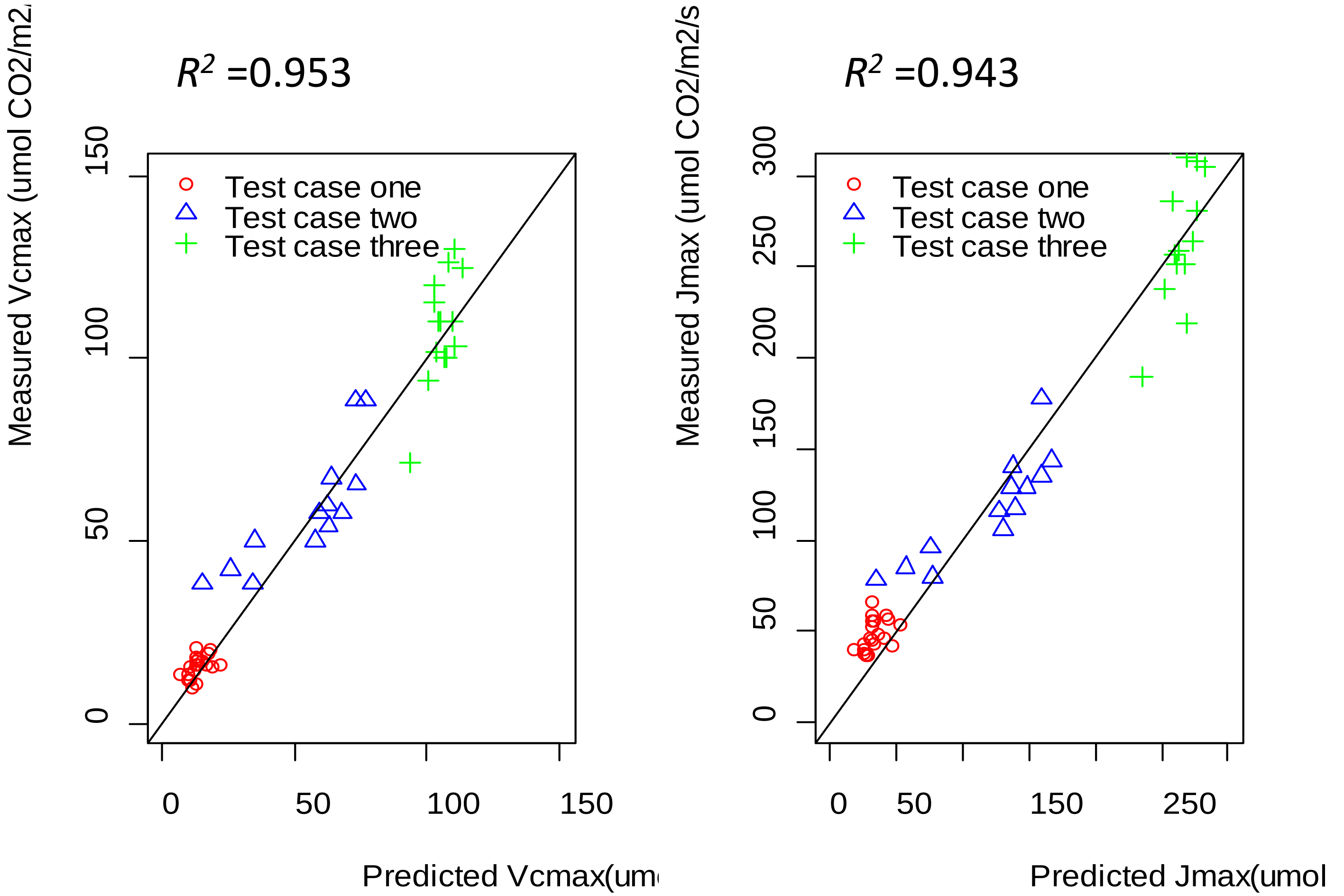
$$+ 0.001 LMA \quad :\rightarrow \text{structural nitrogen}$$

Leaf nitrogen content (LNCa; g/m2) estimation from FNC_a

Test case 1 [D_{ns}=85; fs=0.86]

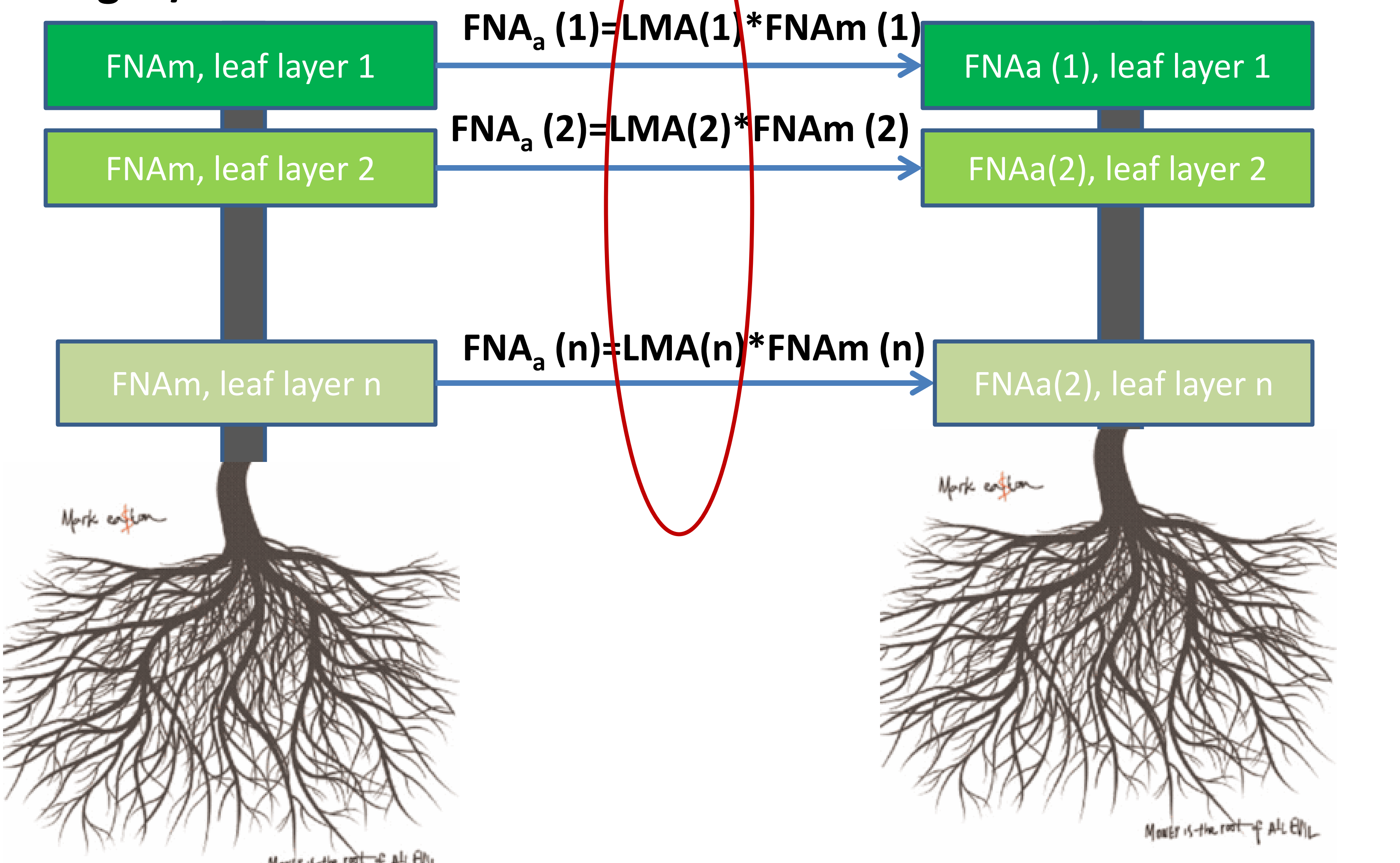


Model evaluations

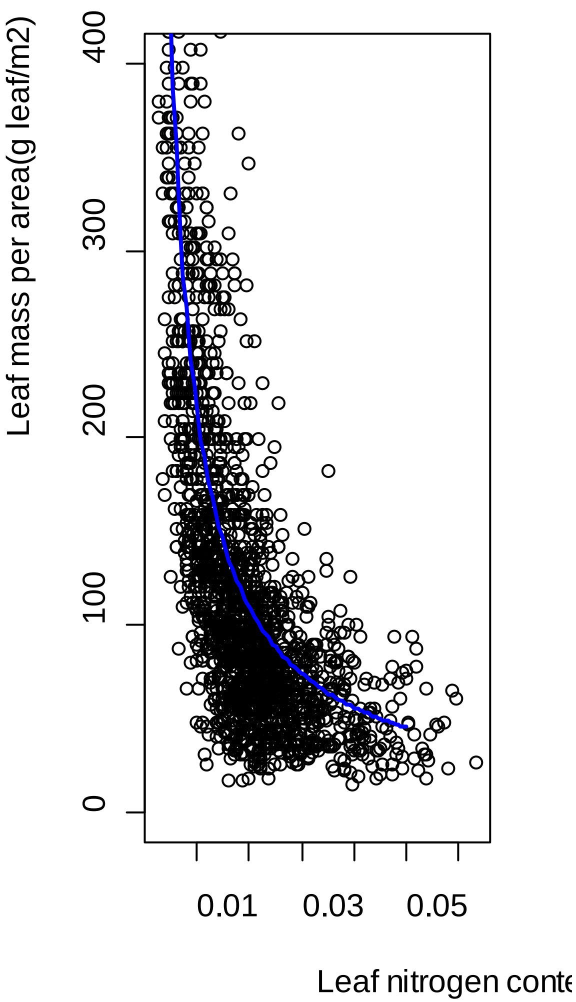


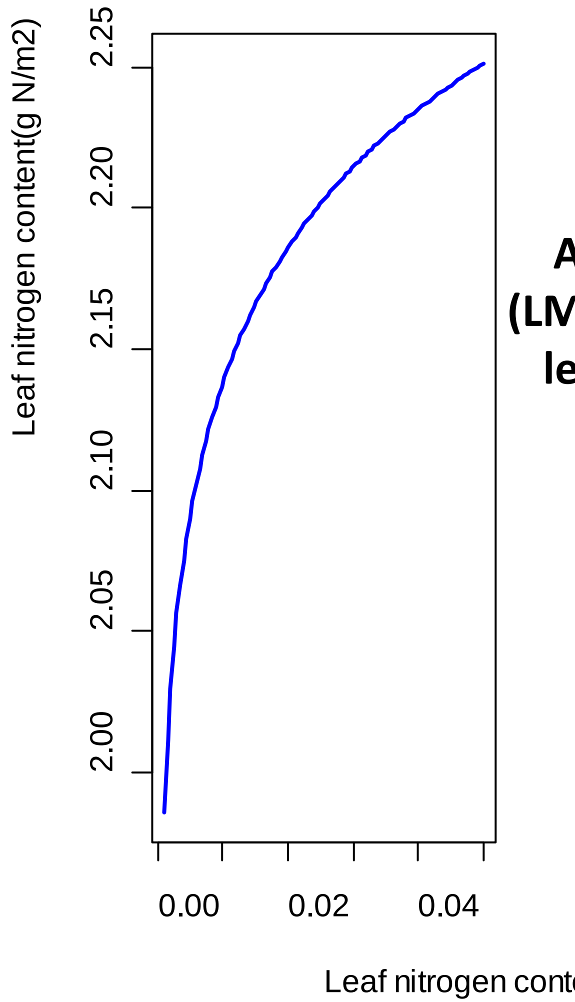
Leaf-mass-based functional nitrogen availability (FNA_m)=**Total plant functional nitrogen/total leaf biomass**

Leaf-area-based functional nitrogen availability (FNA_a)= FNA_m*Leaf mass per area (LMA)



Leaf nitrogen content

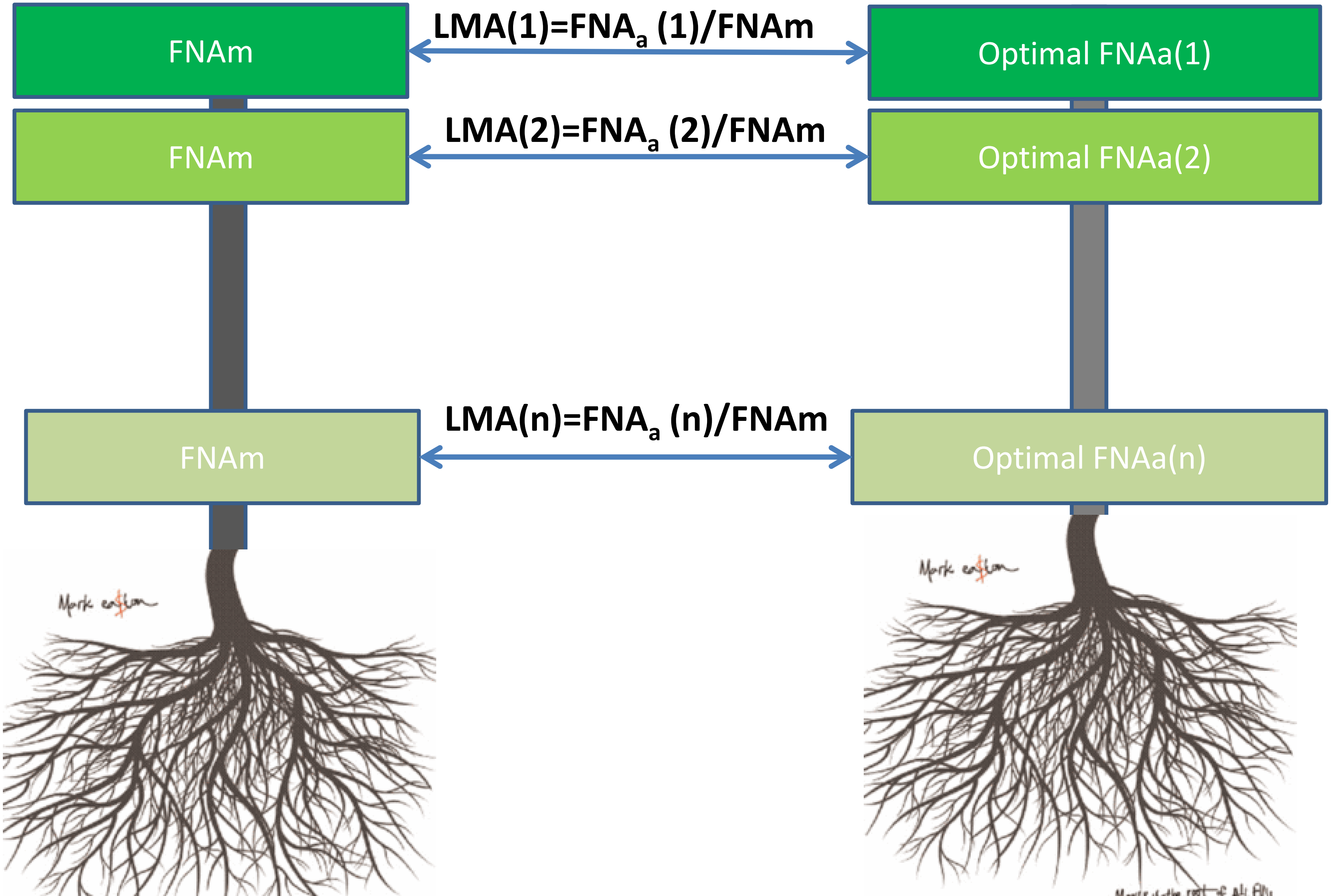




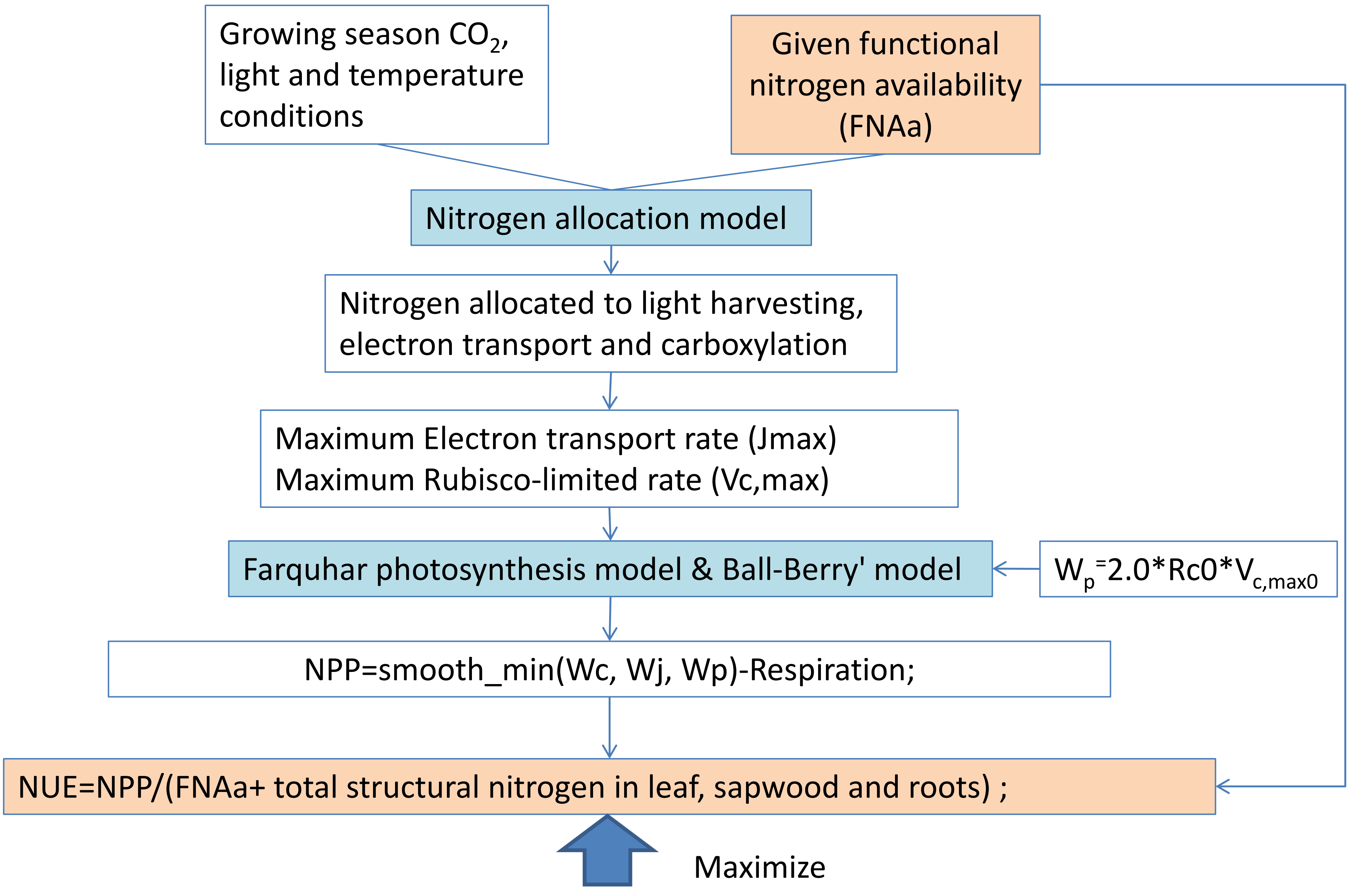
Assumption: Leaf mass per area (LMA) is always adjusted for optimal leaf-area-based nitrogen content

Wright, I. J., P. B. Reich, et al. (2004). Nature **428(6985): 821-827.**

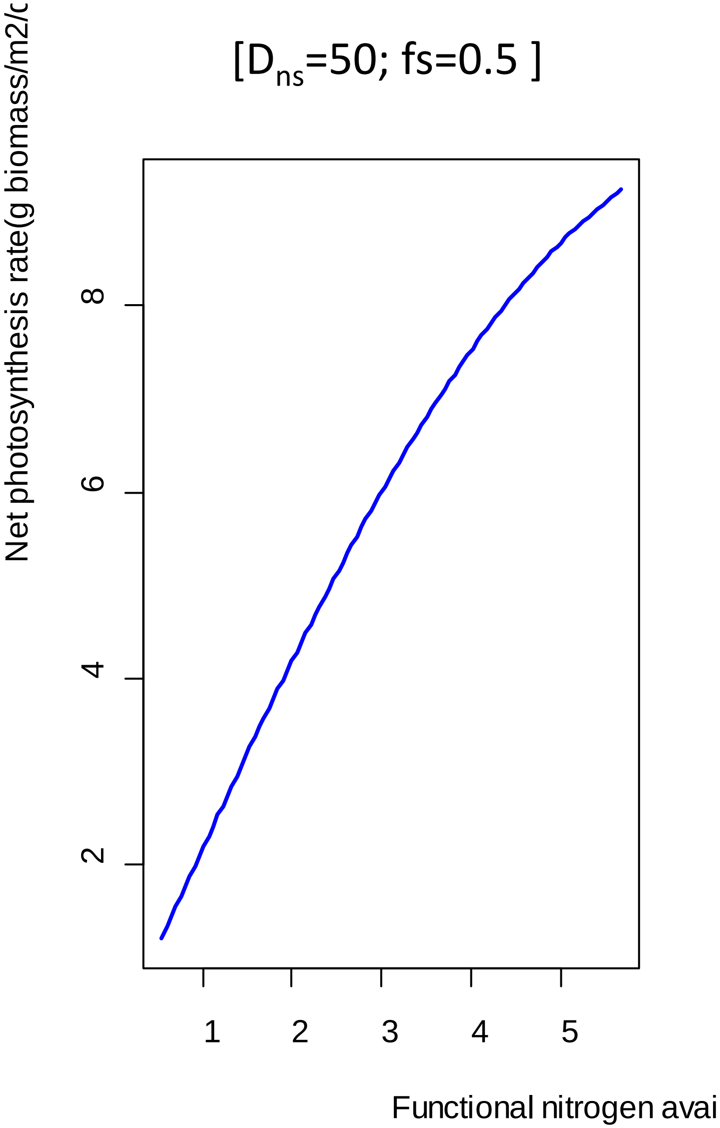
FNAm=Total functional nitrogen/total leaf mass

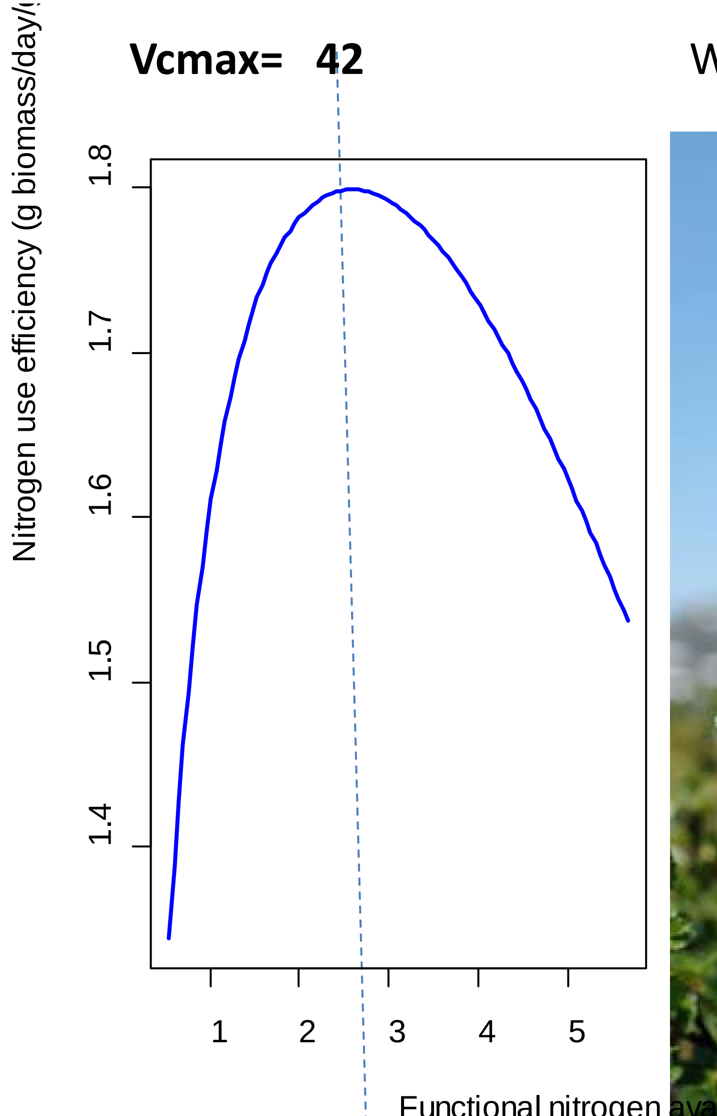


Optimal functional nitrogen availability model



$[D_{ns}=50; fs=0.5]$ **Vcmax= 42** Wp =33





Betula nana (Toolik lake)

Optimum LNCa=1.52 g N/m2

Observed=1.57 g N/m2

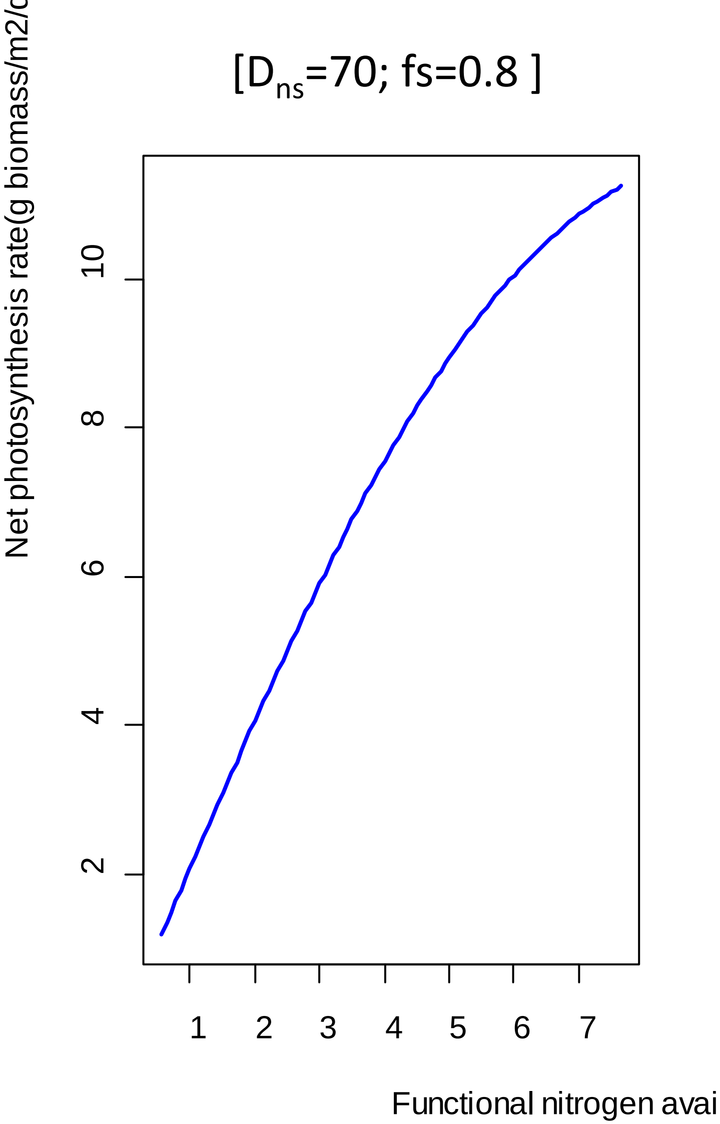
Leaf area/sapwood area=0.15 m^2 /cm2; height=0.5m

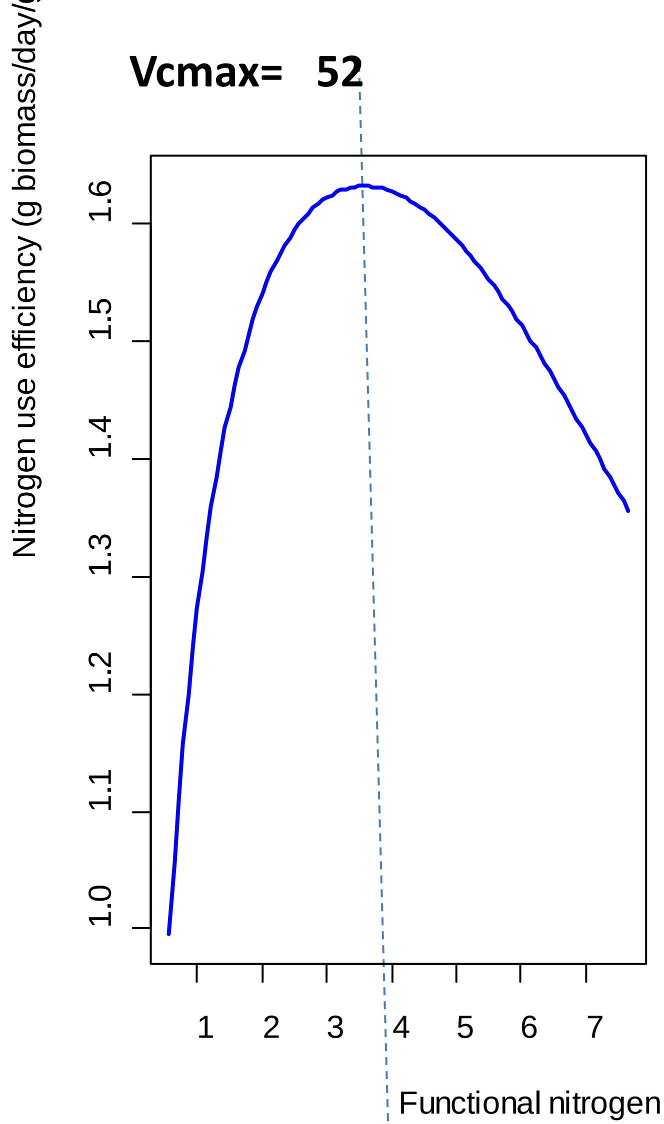
Limbach, et al. (1982). <u>Holarctic Ecology</u> **<u>5(2): 150-157;</u>** Shaver, et al. (2001). <u>Ecology</u> **<u>82(11): 3163-3181.</u>**

[D_{ns}=70; fs=0.8]

Vcmax= 52

Wp =41.6





Optimal LNCa=3.06 g N/m2

Observed=3.12 g N/m2

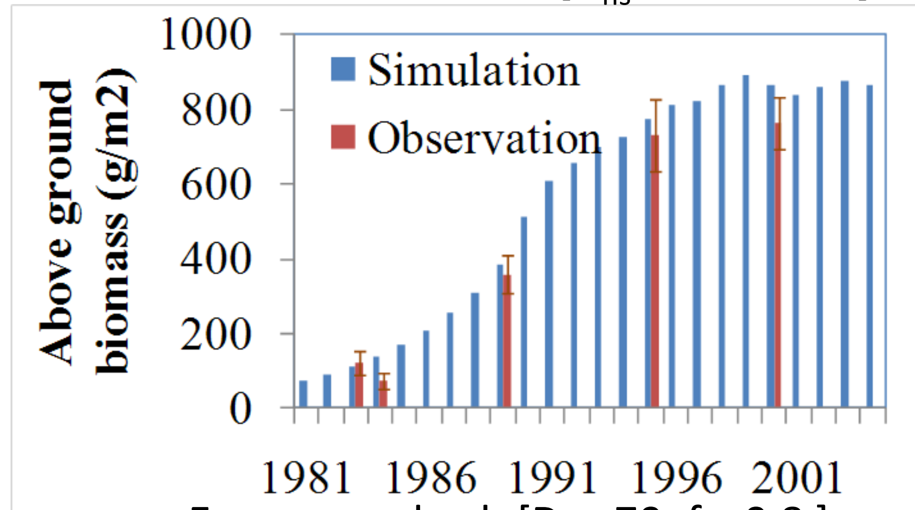
Ledum palustre (Toolik lake)

Leaf area/sapwood area=0.15 m^2 /cm2; height=0.5m

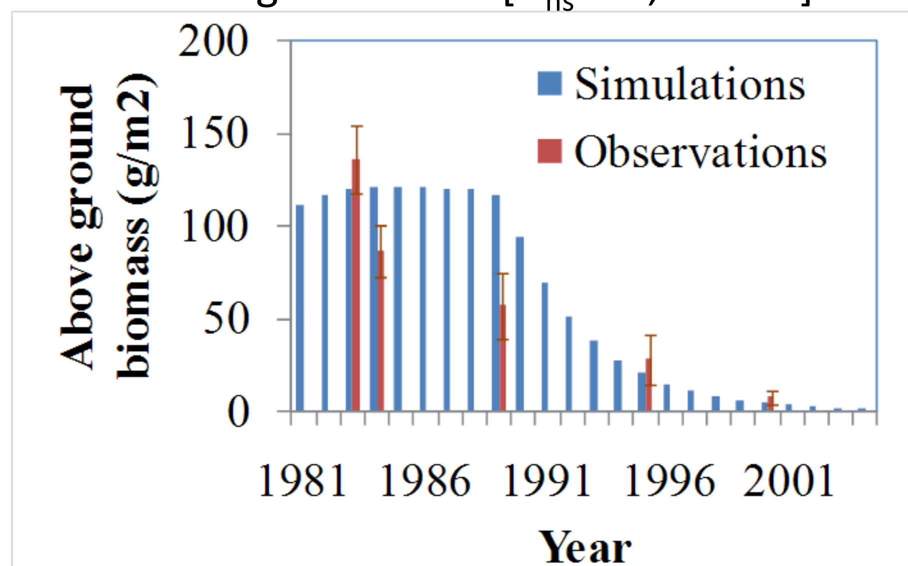
Limbach, et al. (1982). <u>Holarctic Ecology **5(2): 150-157;**</u> Shaver, et al. (2001). <u>Ecology **82(11): 3163-3181.**</u>

Test ED-N model against nitrogen fertilization observations in the arctic

Deciduous shrub [D_{ns}=50; fs=0.5]



Evergreen shrub [D_{ns}=70; fs=0.8]



Nitrogen	Control	Fertilized
Inorganic nitrogen	4.0[1]	7.6[3]
Organic nitrogen	3.0[2]	3.0

Soil nitrogen concentration (umol/L) for control and fertilized plot

Ratio of root biomass to leaf biomass: **1.5 for deciduous and 0.8 for evergreen**.

Limbach, et al. (1982). Holarctic Ecology **5(2): 150-157;** Shaver, et al. (2001). Ecology **82(11): 3163-3181.**

Summary & Next Step

- A *dynamic nitrogen allocation* model is developed for ED model to predict the light capture rate, Jmax and Vc,max change under different environmental conditions;
- An *optimal plant nitrogen model* is developed for ED to predict optimal level of nitrogen under different light, temperature, CO_2 and soil nitrogen availability conditions;
- The developed model will be linked with Rosie Fisher's *leaf optimization model* to have more robust predictions of leaf area index.
- Model limitations: acclimation time and acclimation ability.

Acknowledgements

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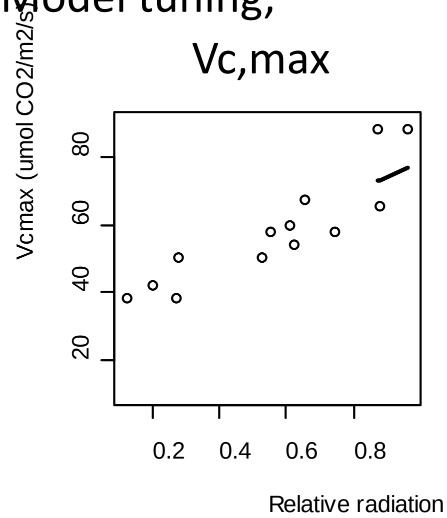
NCAR National Center for Atmospheric Research

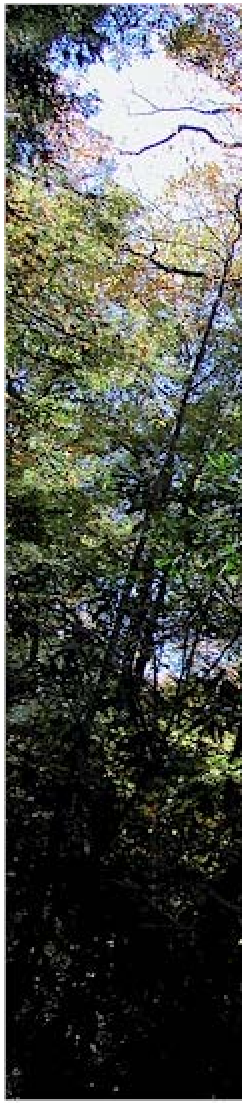
Test case 2 [D_{ns}=50; fs=0.5]

● Radiation >0.8 canopy top radiation; ○ Radiation <0.8 canopy top radiation;

——— Model tuning; - - - - - Model prediction

Vc,max Storage N Rubisco N



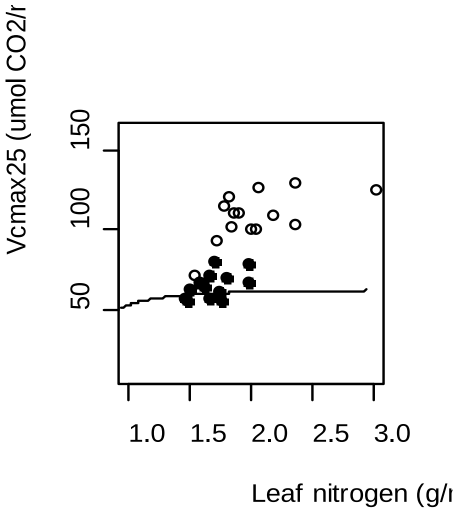


Poplar (*Populus tremula*)

Light capture N Electron transport N Respiratory N

Niinemets, Ü., O. Kull, et al. (1998). Tree Physiology **18(10): 681-696.**

Test case 3 [D_{ns}=4; fs=0.5]



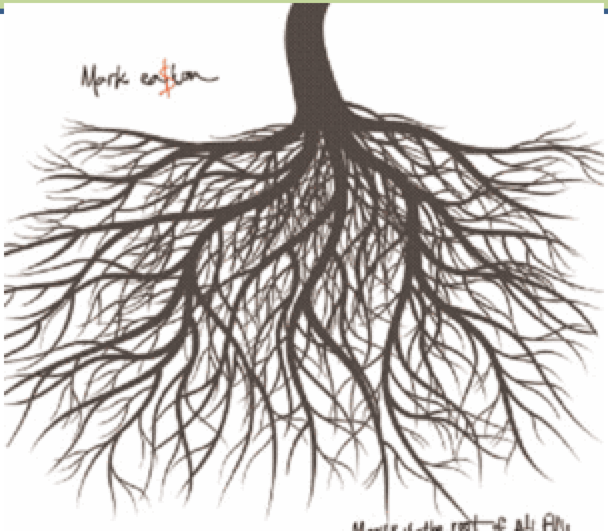
Leaf area index optimization

Optimal functional nitrogen availability, leaf area based (1)

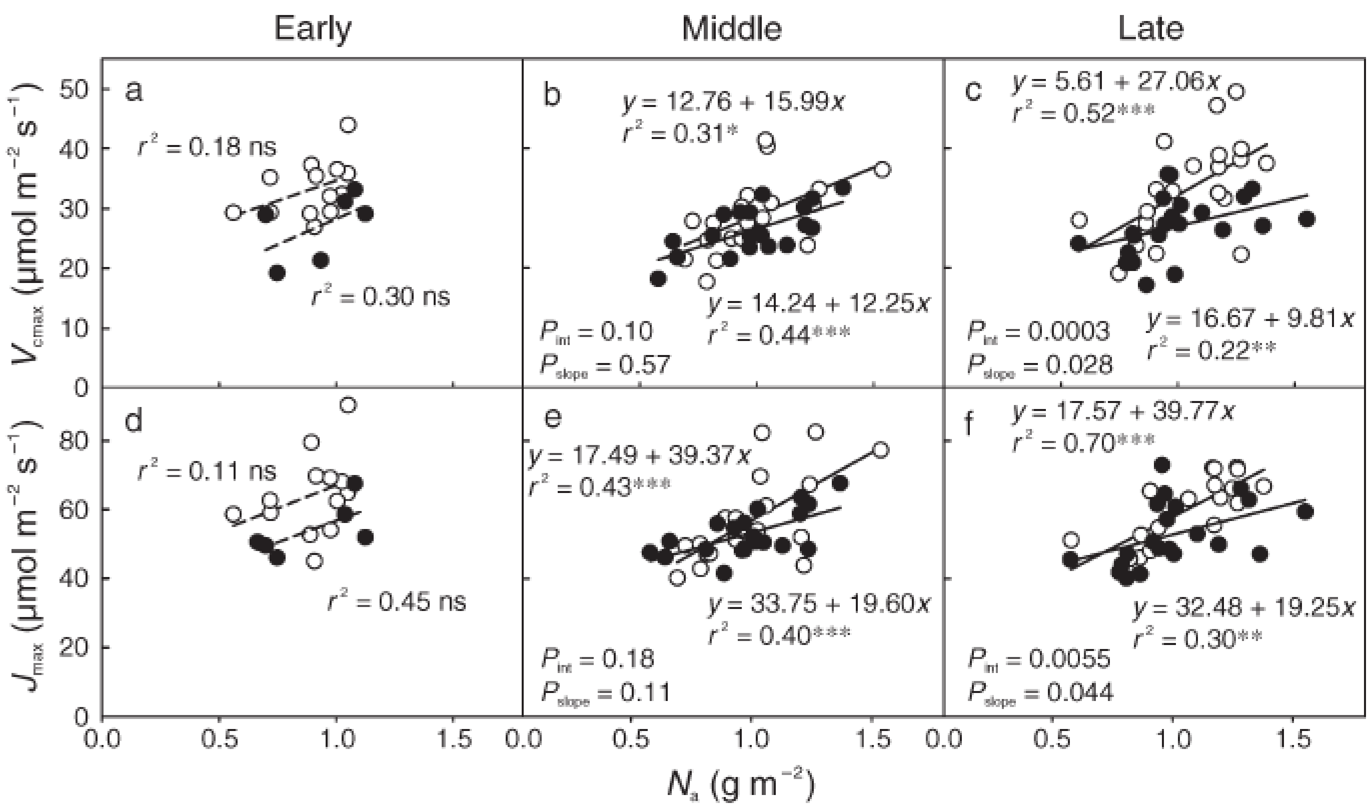
Optimal functional nitrogen availability, leaf area based (2)

Net Carbon Balance=Yearly NPP-construction cost-yearly respiration(n)

If Net Carbon Balance<0, then reduces active nitrogen uptakes

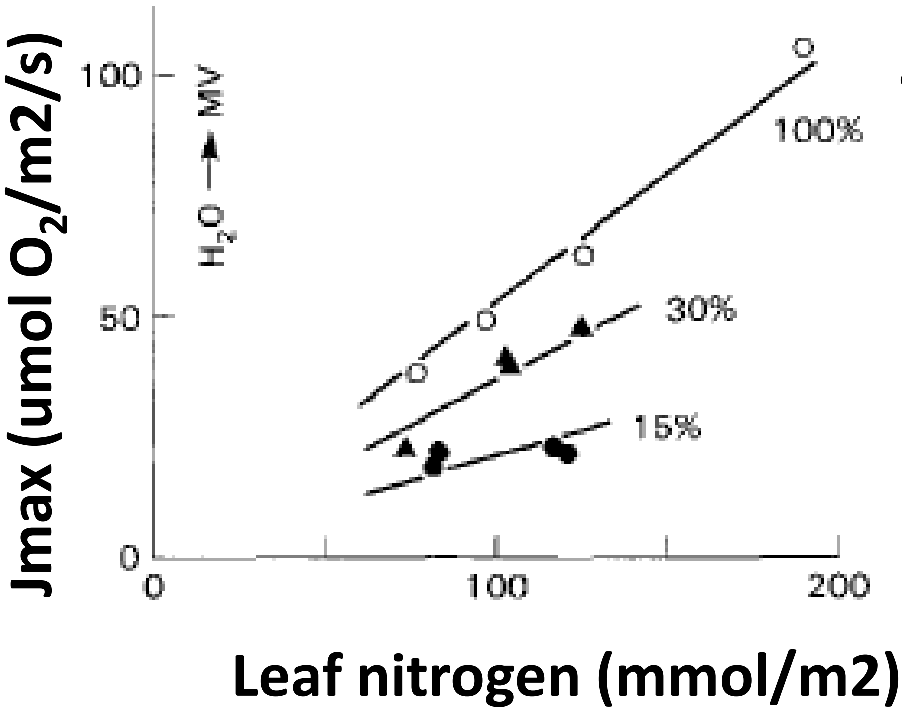


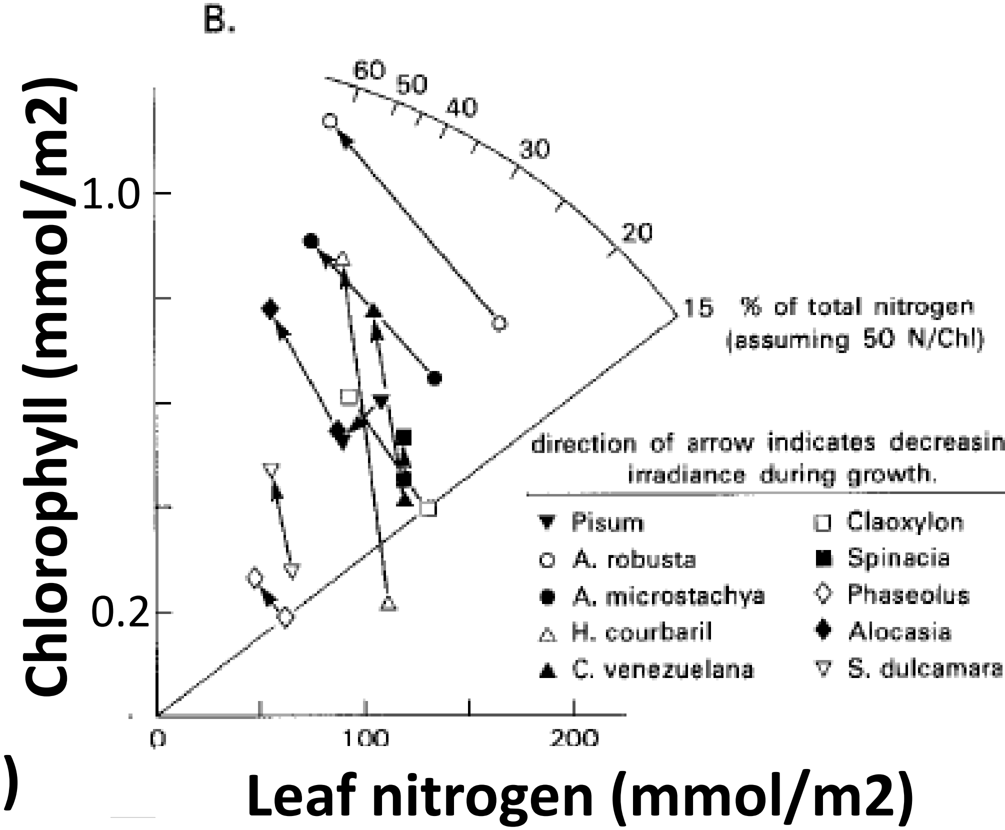
CO_2 enrichment effects on $V_{c,max}$ and J_{max}



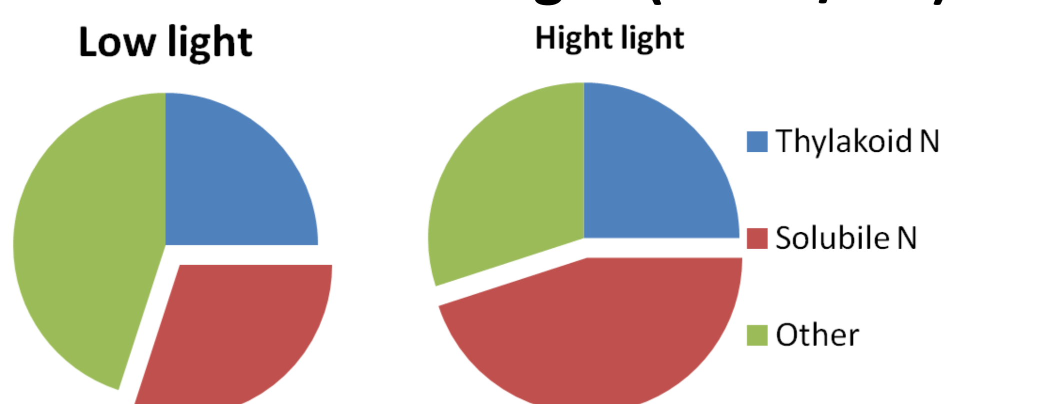
CROUS et al (2008). **Tree Physiology 28, 607–614.**

Irradiance effect on J_{max} and Chlorophyll

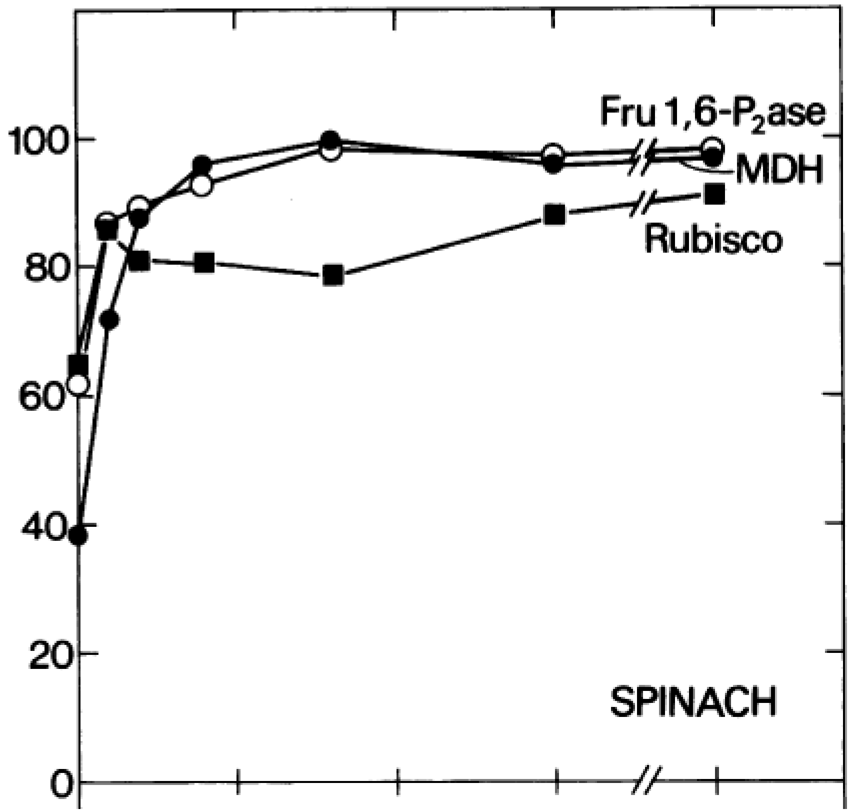


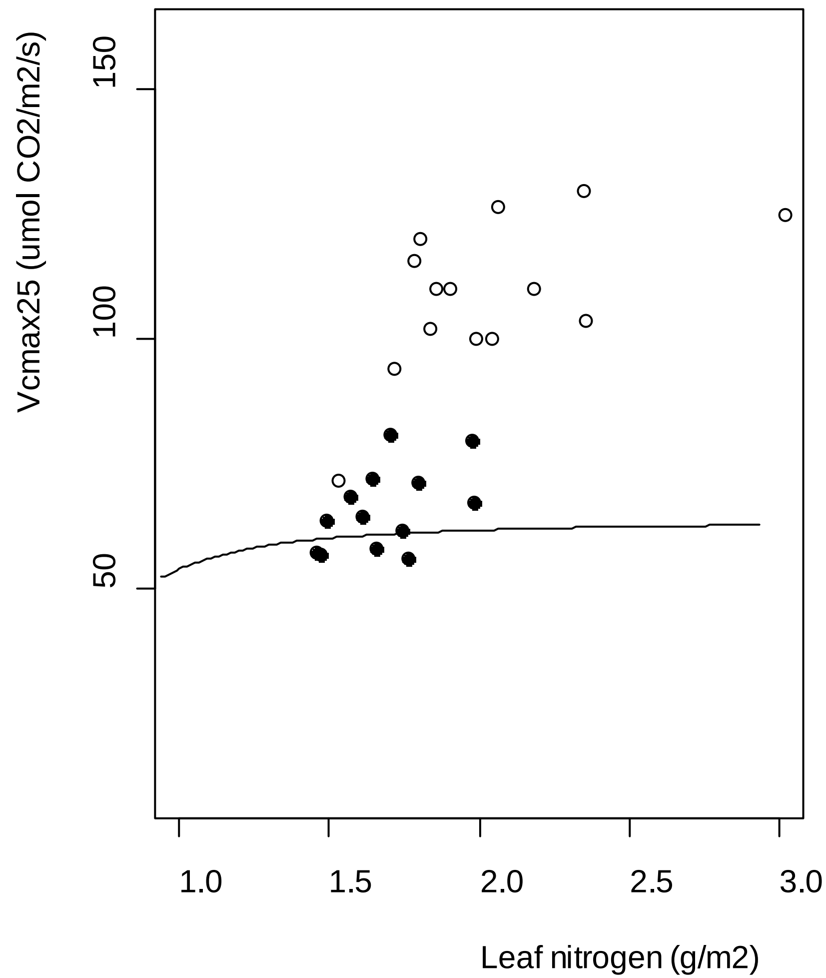


Evans 1989. Oecologia, 78: 9-19



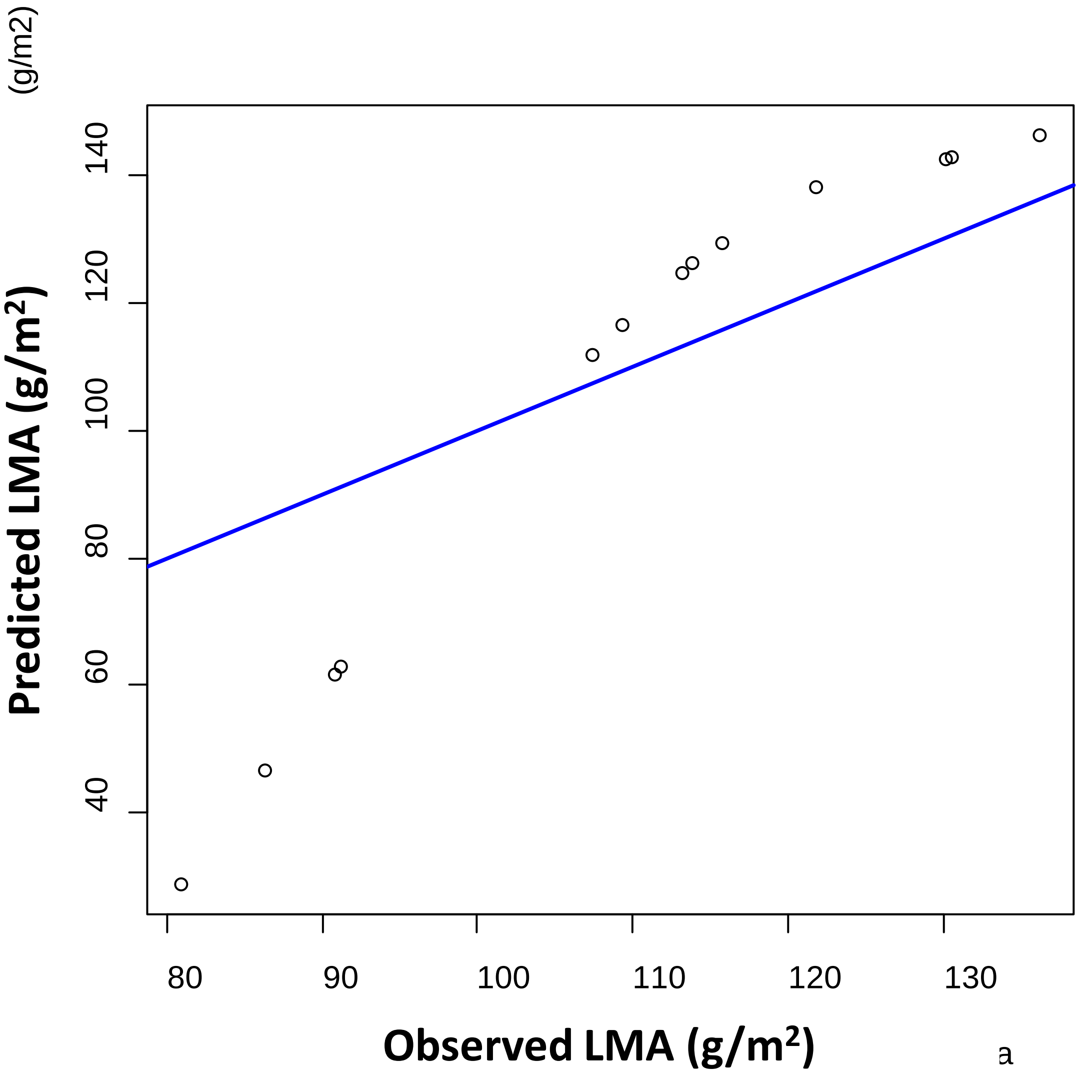
Temperature effects on Vc,max

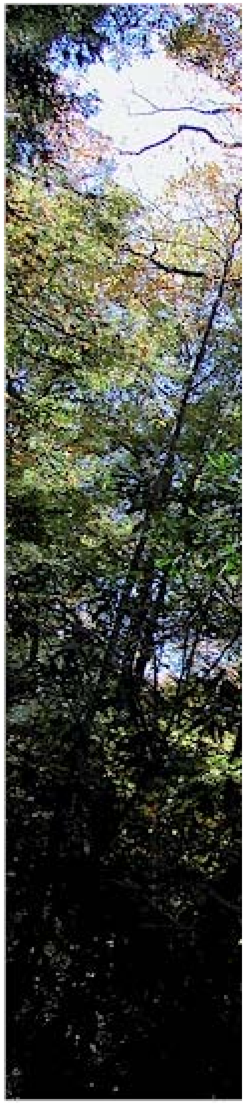




Evaluation of the model

Poplar (*Populus tremula*)





‘storage nitrogen’

- An ideal definition of storage nitrogen would be the nitrogen stored in plant tissues that is not involved in any metabolic processes or structural components (i.e., cell wall and DNA); however, it would be extremely difficult to quantify the nitrogen investment for all metabolic processes. Therefore, to facilitate the development of a relatively simple nitrogen allocation model, in this study, ‘storage nitrogen’ is defined as the total plant nitrogen pool minus the amount of nitrogen used in structural components, photosynthetic and respiratory enzymes.

Dynamic root change

Fn = 2MFNCm/(FNCm+MFNCm)