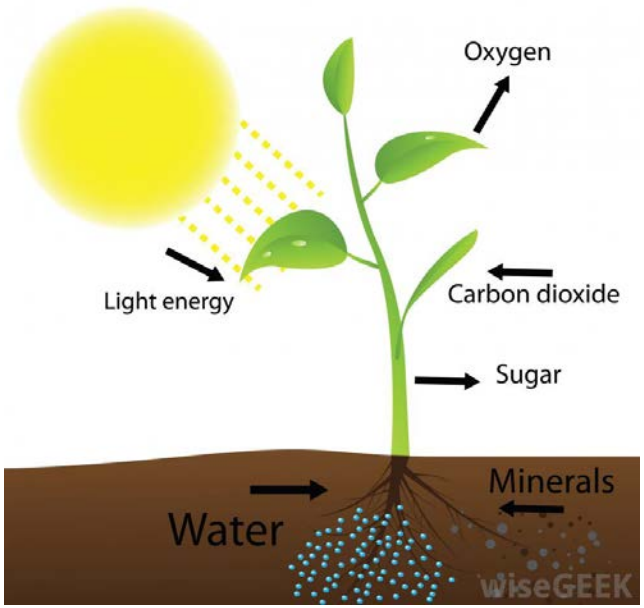
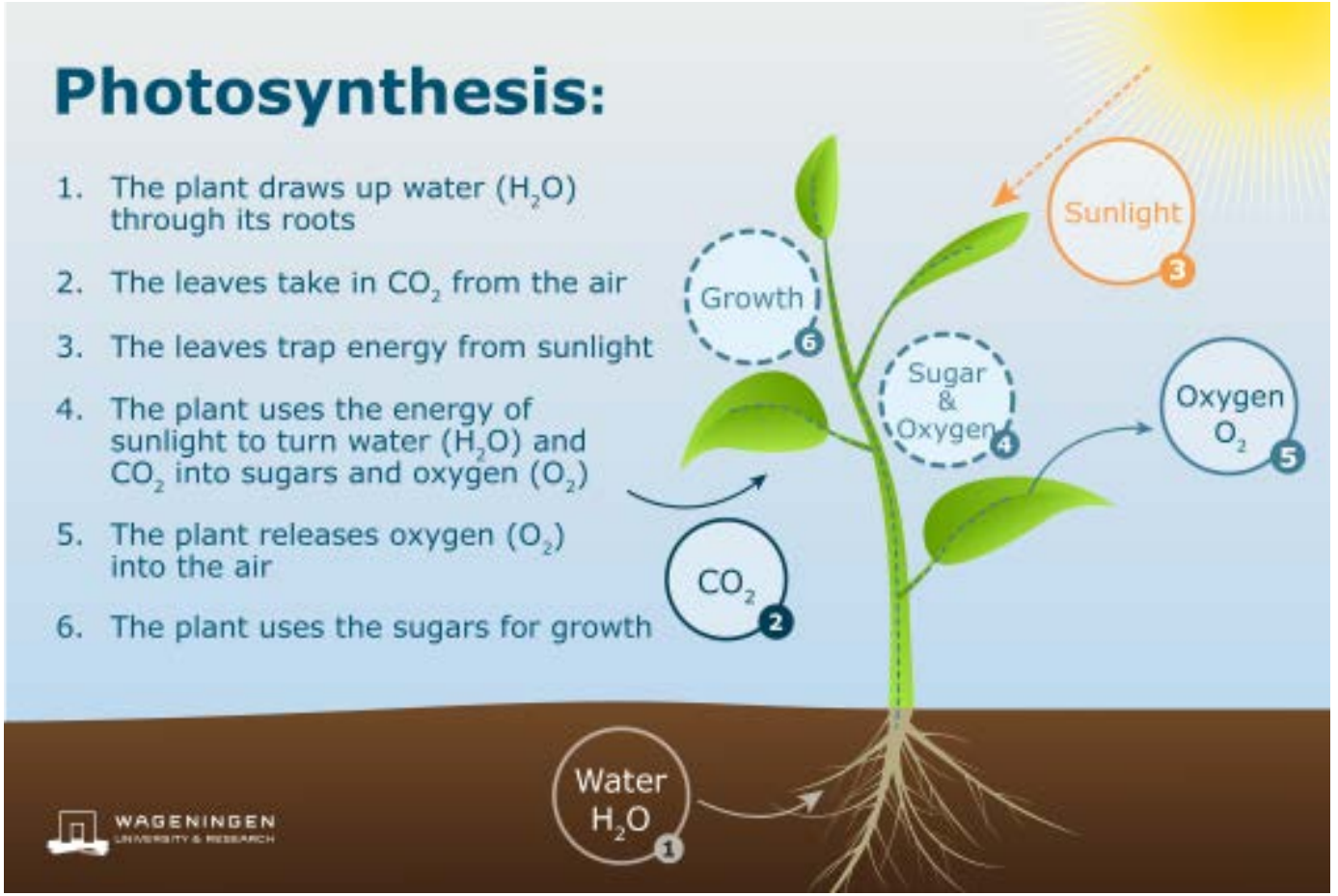
From leaf irradiance to plant photosynthesis

Christian Fournier



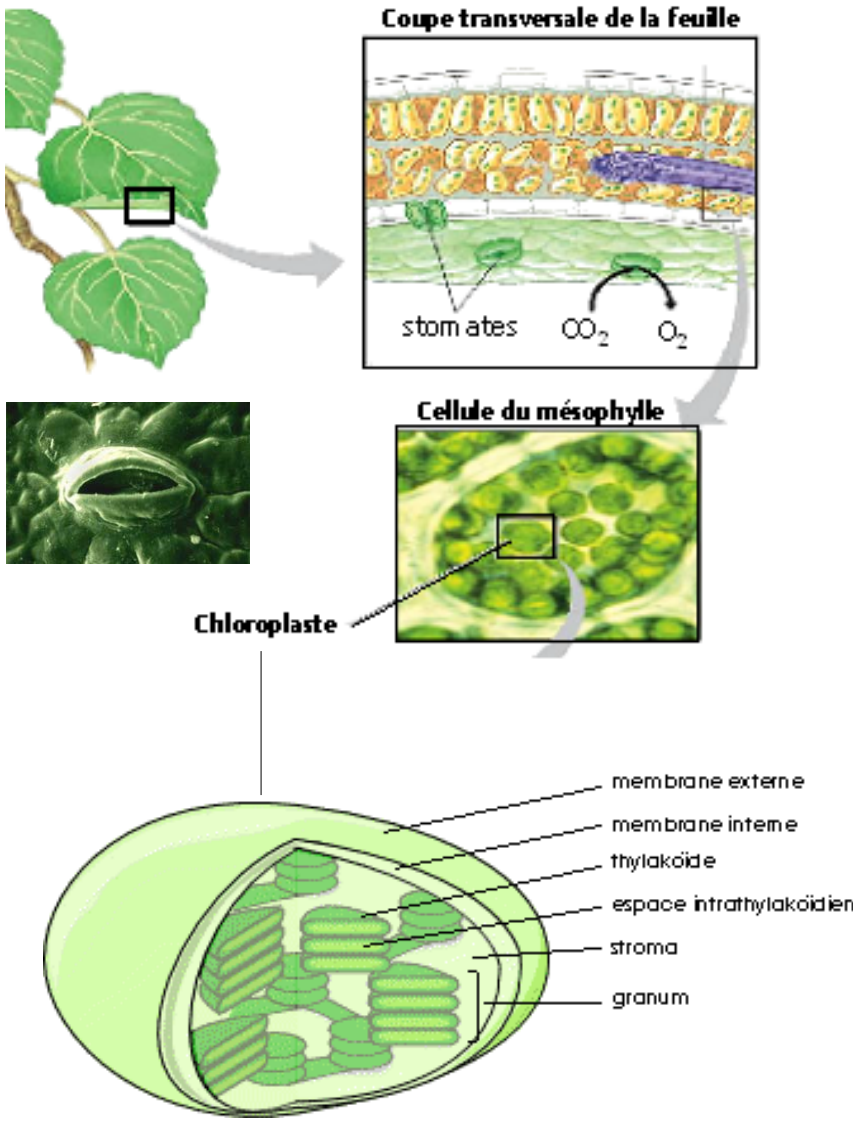
Photosynthesis

Photosynthesis = The process by which green plants and some other organisms use sunlight to synthesize nutrients from carbon dioxide and water. Light capture and conversion into chemical energy is done by pigments (chlorophylles, caroténoides, …)



$6\ CO_2 + 6\ H_20 \xrightarrow[chlorophylles]{lumière} C_6H_{12}0_6 + 6\ O_2$

Main actors



Leaves that are dedicated to this function.

Stomata, that are pores in the epiderm that allows CO2 / O2 exchange with outer air and transpiration (water pump)

Chloroplaste, that are organelles that conduct photosynthesis

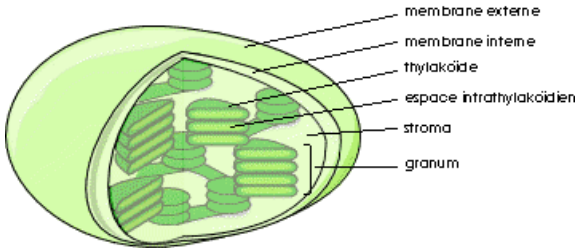
Chlorophylle, main pigment of light reaction centers is located in a internal, manyfold membrane, the tyllakoid, surounded by the stroma

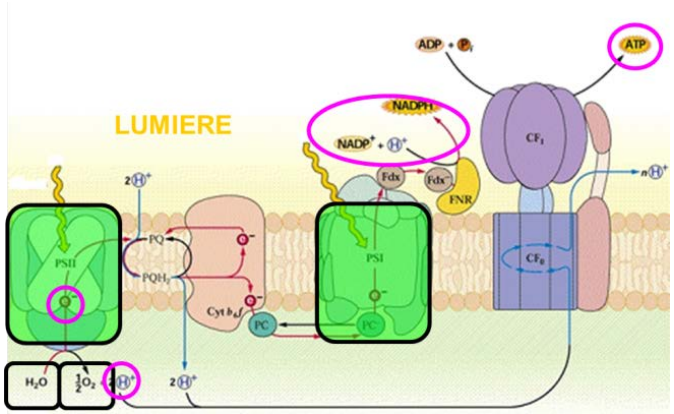
RuBP (Rubisco) is the main enzyme involved in CO2 fixation in organic compound

Main reactions

1. Phase « claire » (light dependent reactions):

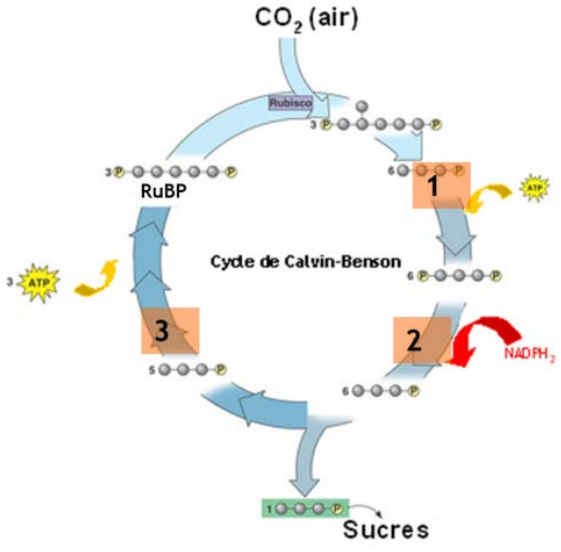
Reactions centers use light to strip electrons from water, produce chemical energy (ATP, NADPH) and liberate 02





2. Phase « sombre » (light independent reactions): Cycle de Calvin - Benson

Chemical energy is used to reduce C02 into sugar compounds



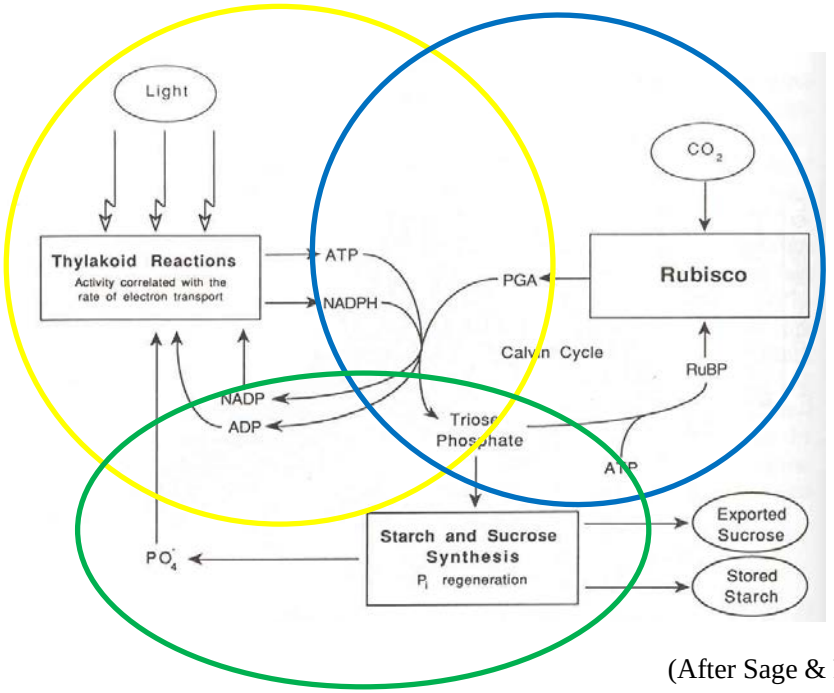
Modeling Framework (Farquhar extended)

- 3 sets of responses:
  - Light dependent reactions
  - [CO2] dependent reactions
  - Product dependant reactions

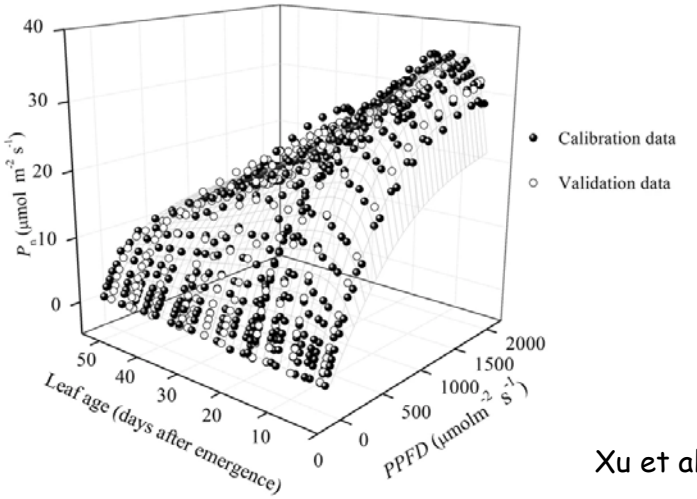
- Enzymatic kinetics (T°C dependant rates)

- Co-limitation mechanism :
  - Actual photosynthesis = Min (Light, CO2 , *Product*)

- Acclimation (extension):
  - Plant continuously adjust responses with space and time.
  - Explained by Enzyme (prodeins) production
  - Enviromentally driven (light, C02, T°C)



(After Sage & Reid, 1994)



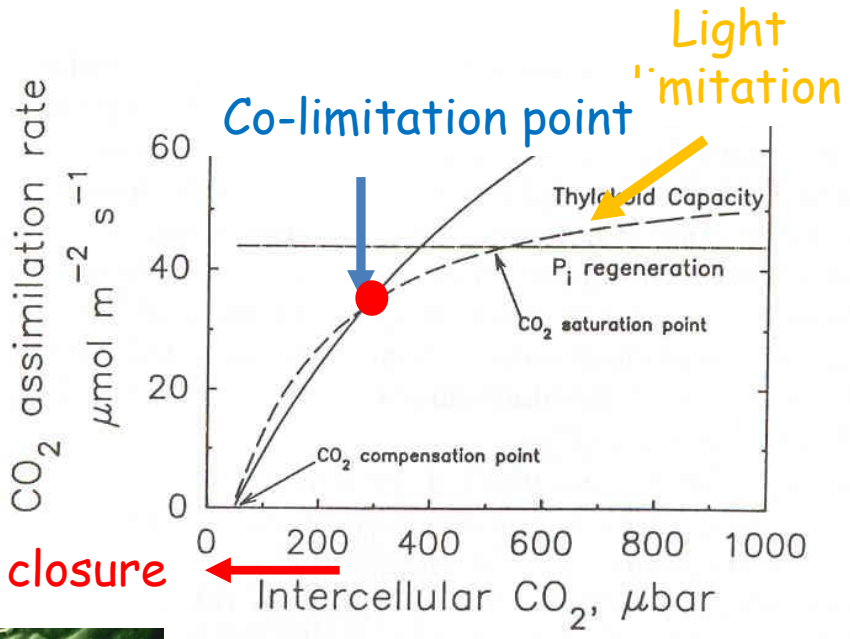
Xu et al. 2019

CO2 (Stomata) response

- Unstressed condition : Ci constant whatever An

- RuBP/Tylakoids level adjusted so that CO2 / light colimitation occur at Ci ('Functional adaptation')

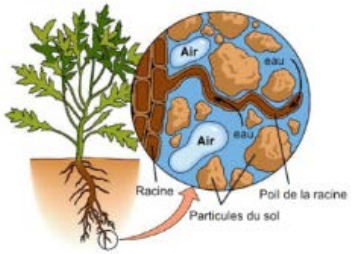
- Stomata are co-controled by transpiration



Stomata closure

Ball-Bery Index

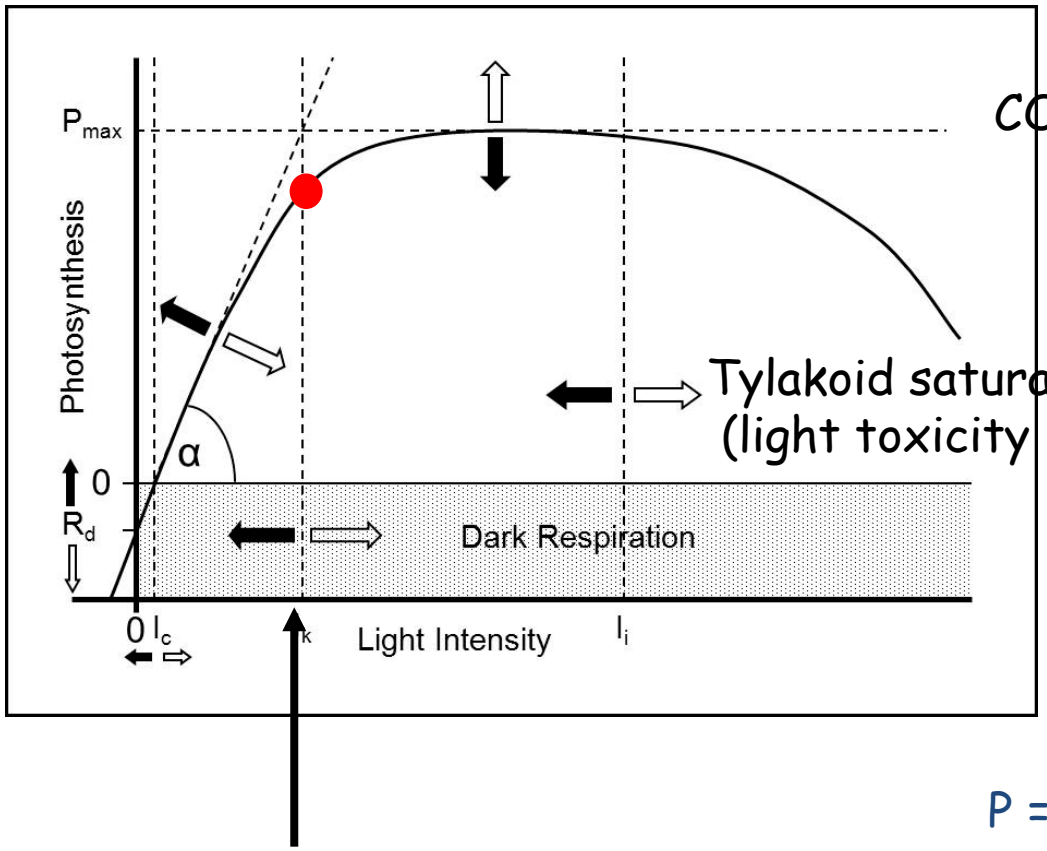
$$g_s = m^* A_n \frac{H_s}{C_s} + g_0.$$



Gs: stomatal conductance
Hs : humidity
Cs : CO2 ext.

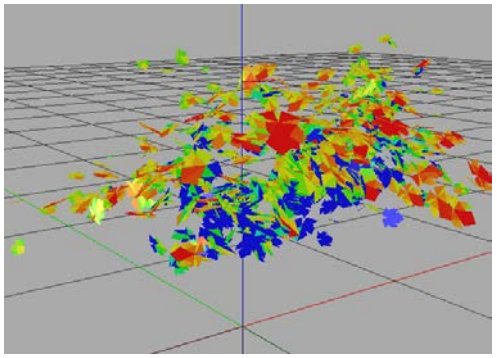
Light response

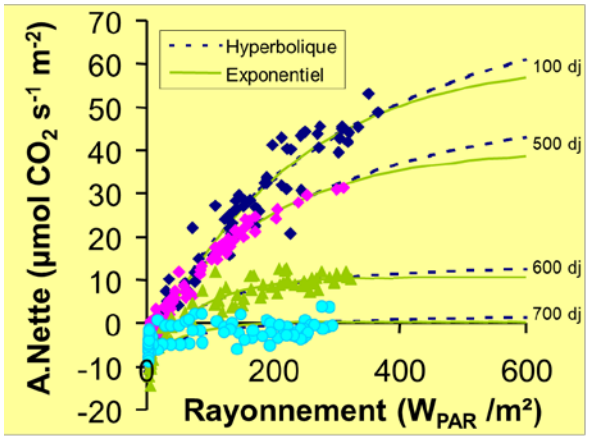
Light limitation



CO2 limitation

Tylakoid saturation
(light toxicity begins)



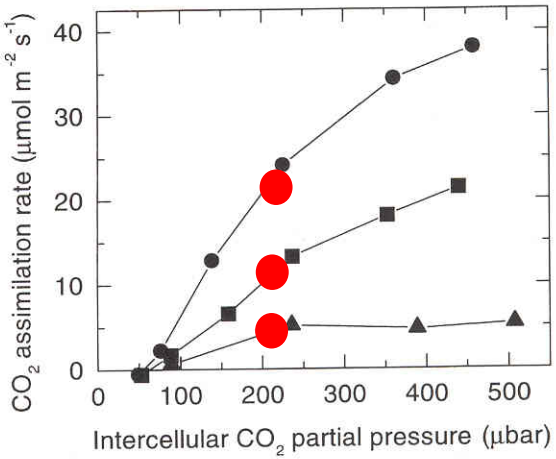


$P = P_{max} \cdot \alpha \cdot I / (P_{max} + \alpha \cdot I]) - Rd$

Mean irradiance on leaf
(light acclimation)

Nitrogen and Temperature effects

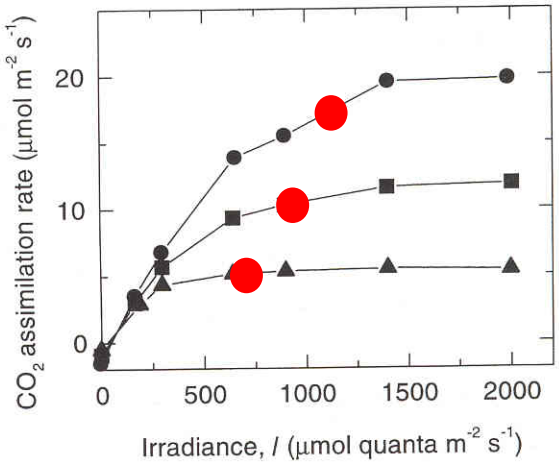
Coordinated changes of CO2 / Light capture processes

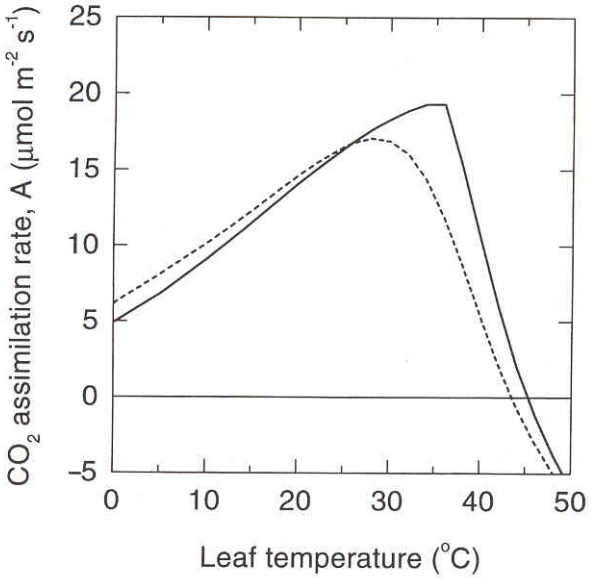


12 mM N

4 mM N

0.6 mM N

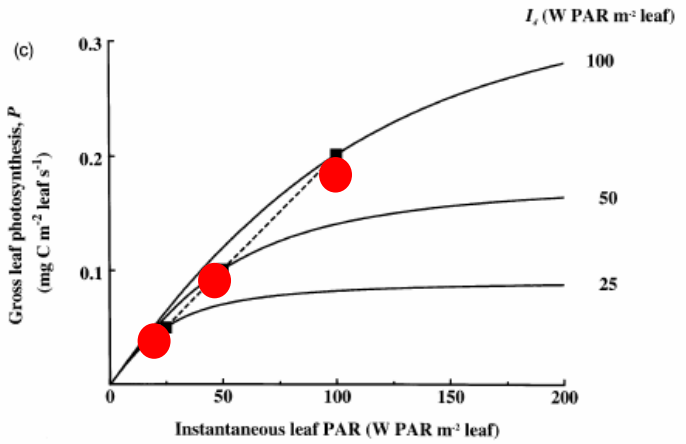




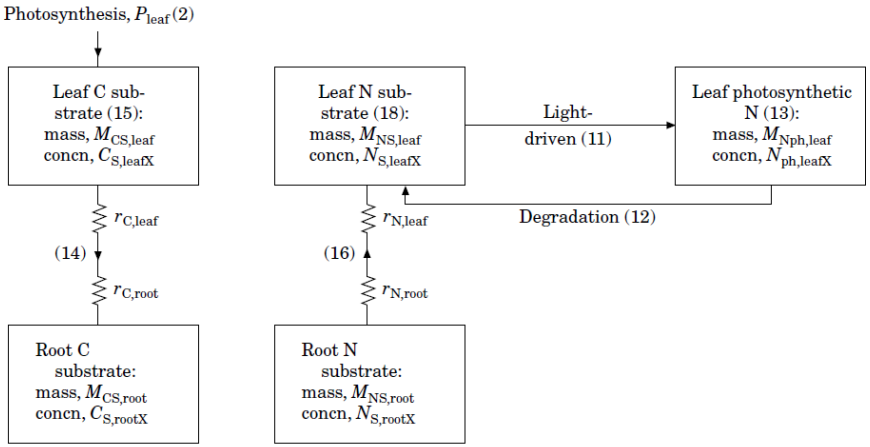
Acclimation to light mechanism

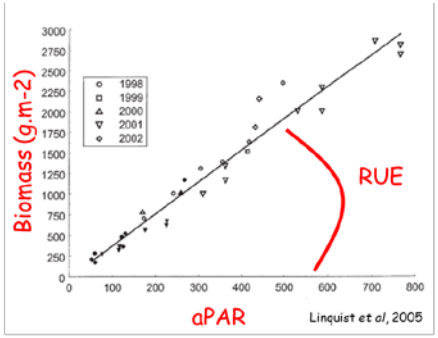
- Mean ambient light varies within canopy
- N repartition is optimised to have all leaves function at colimitation point
- mecanism :
  - Proteins constantly degrade into labile N
  - Biosynthesis increase with light

⇒ 'Canopy' optimisation
⇒ Linearisation of reponse to light

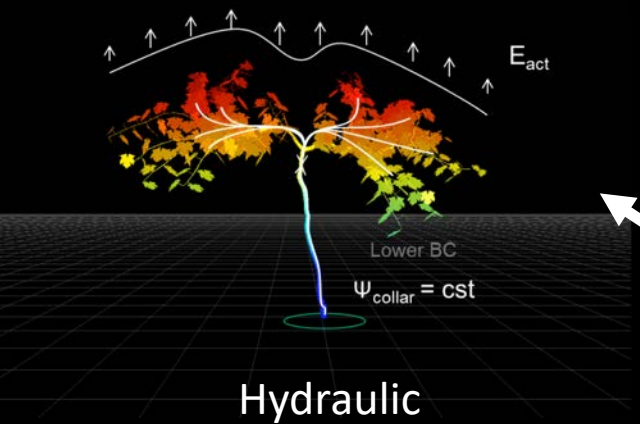


Thornley—Leaf Photosynthesis with Acclimation to Light and Nitrogen

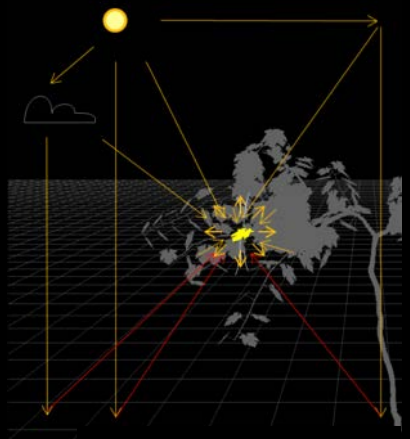




Bottom up integration

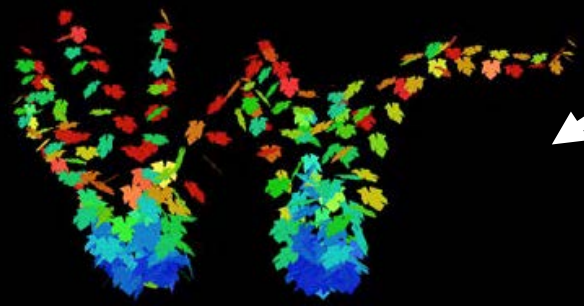


Hydraulic



Energy budget

Central Data Structure (MTG)



Light interception

$$g_s = g_0 + \frac{A_n + R_d}{C_i - \Gamma_*} m$$

A_n = min { A_c: Rubisco-limited; A_j: RuBP-limited; A_p: Export limited }

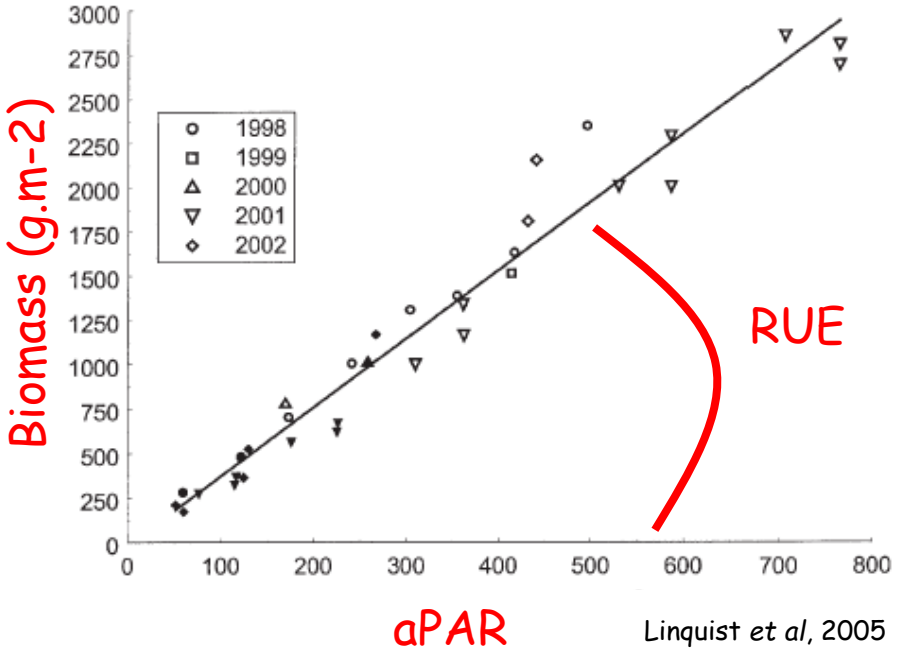
Gas exchange

Hydroshoot: Albasha, R., Fournier, C., C., Pradal, C., Alejando Prieto, J., Louarn, G., Lebon, E., HydroShoot: a new FSPM model for simulating hydraulic structure and gas-exchange dynamics of complex plants canopies under water deficit. 2016 IEEE International Conference on Functional-Structural Plant Growth Modeling, Simulation, Visualization and Applications (FSPMA 2016), Qingdao, China, 2016.

Top down approach

Biomass Production = Radiation Use Efficiency (RUE) * Intercepted Radiation

(* f(stress H20) * f(stress N) * …)



Linquist *et al*, 2005