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A modeling approach to determine the contribution of plant hydraulic conductivities to the water uptake dynamics in the soil-plant-atmosphere system

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Context

Water is central in agriculture

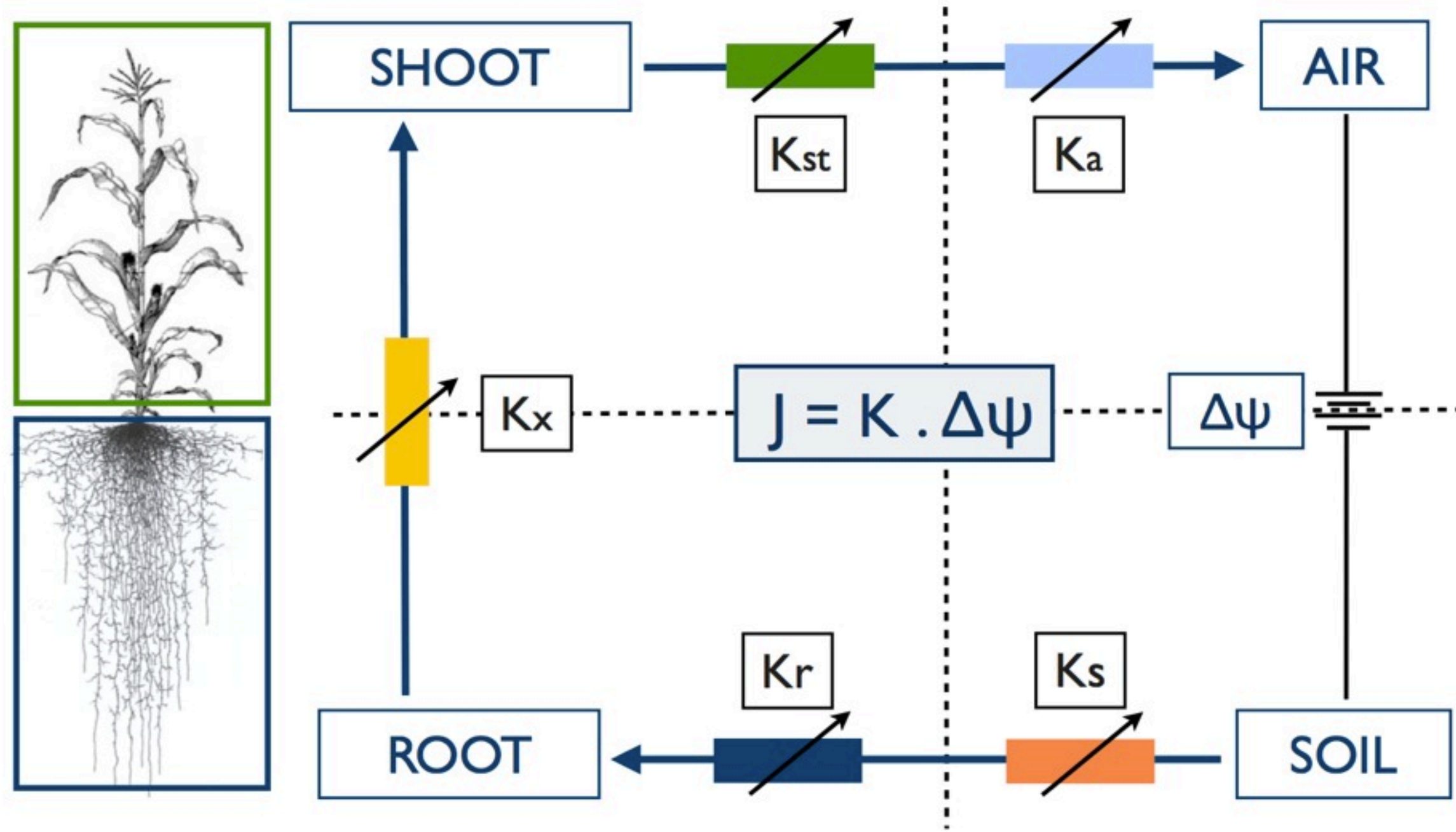
Photo credit: Sam Beebe @ Flickr

- Farming account for 70% over worlwide water use
- Global changes reduces water availability
- Better water use at the crop level (agricultural practices)
- Better water use at the plant level (physiology, genetics)

Why modeling water flow in the SPAC?

- Highly dynamic system
- Feed-back phenomena
- Heterogenous plant and soil properties
- Difficulty of observation

Water flow in the Soil-Plant-Atmosphere Continuum



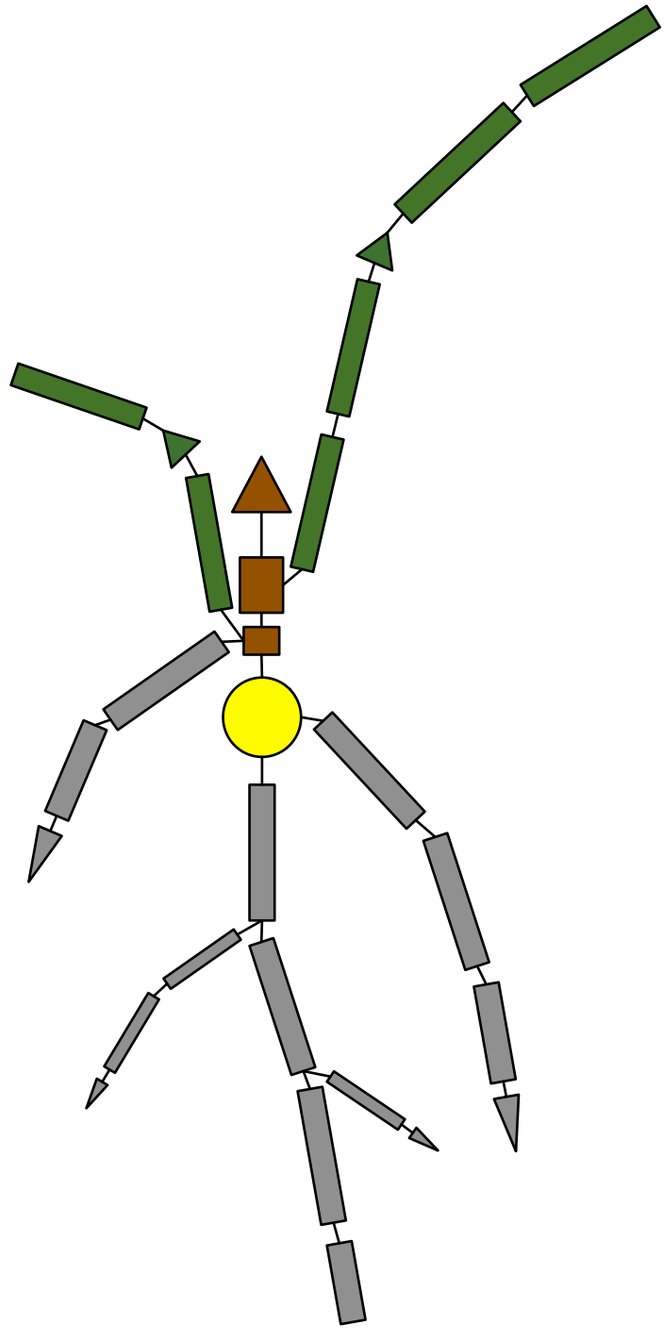
Root system picture from Kutschera et al. 1997

Model description

Plant architecture in PlaNet

- 4D growth and development
- Sub-organ resolution
- Based on “articles”
- Three article properties
  - Development
  - Exchange water with environment
  - Transport water in the plant

Plant architecture in PlaNet-Maize



Different article types:

- Root [meristem / segment]
  - Primary
  - Seminal
  - Adventitious
  - Laterals
- Stem [meristem / segment]
- Leaf [meristem / segment]

Resolution of water flow - I

Article level

Radial flow

$$Jr(z) = Kr\left[\Psi s(z) - \Psi x(z)\right]S$$

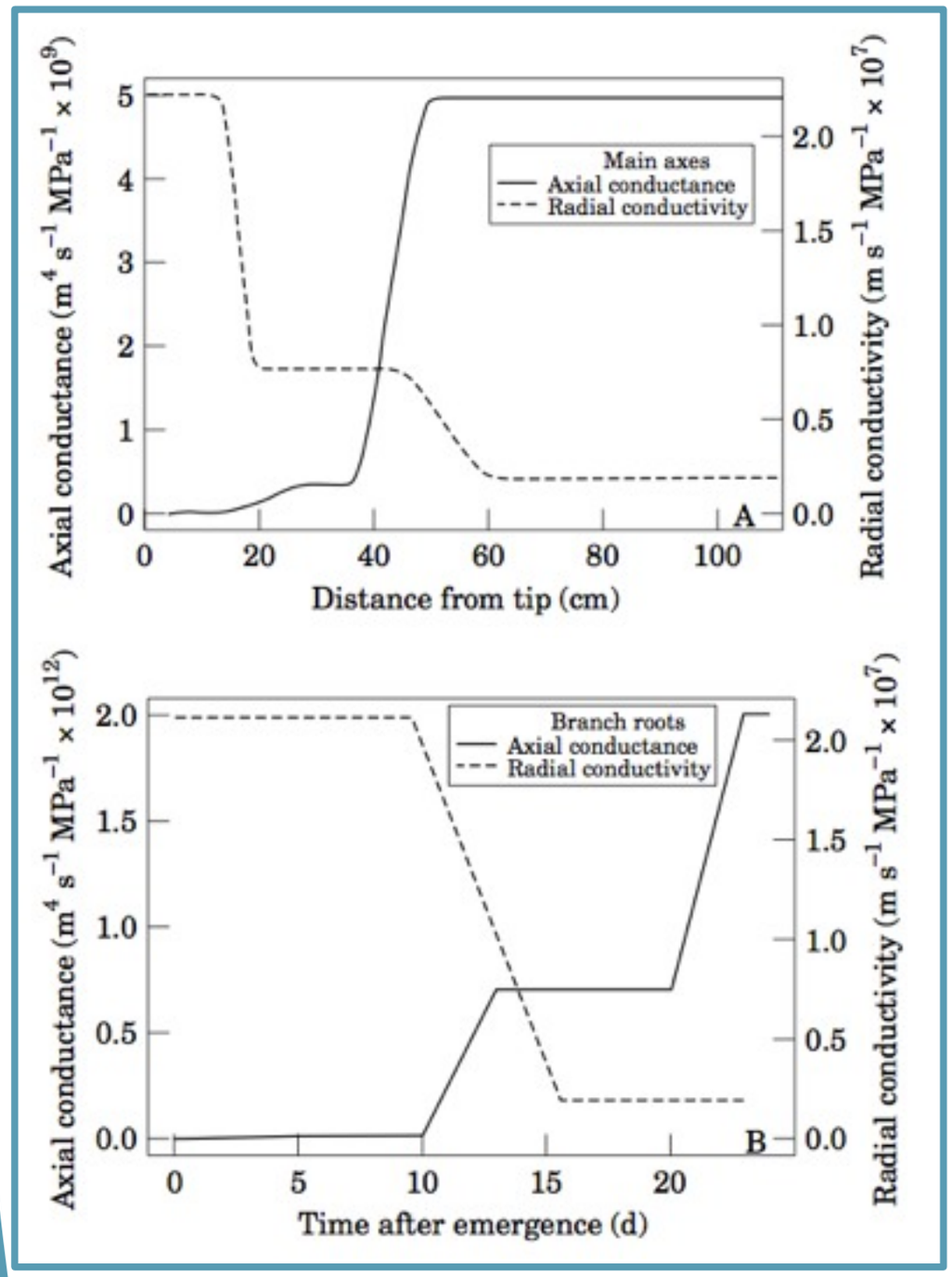
Axial flow

$$Jh(z) = -Kx\frac{\Delta\Psi x(z)}{\Delta z}$$

Landsberg, J. & Fowkes, N., 1978. *Annals of Botany*, 42, 493–508.

Resolution of water flow - II

Hydraulic properties

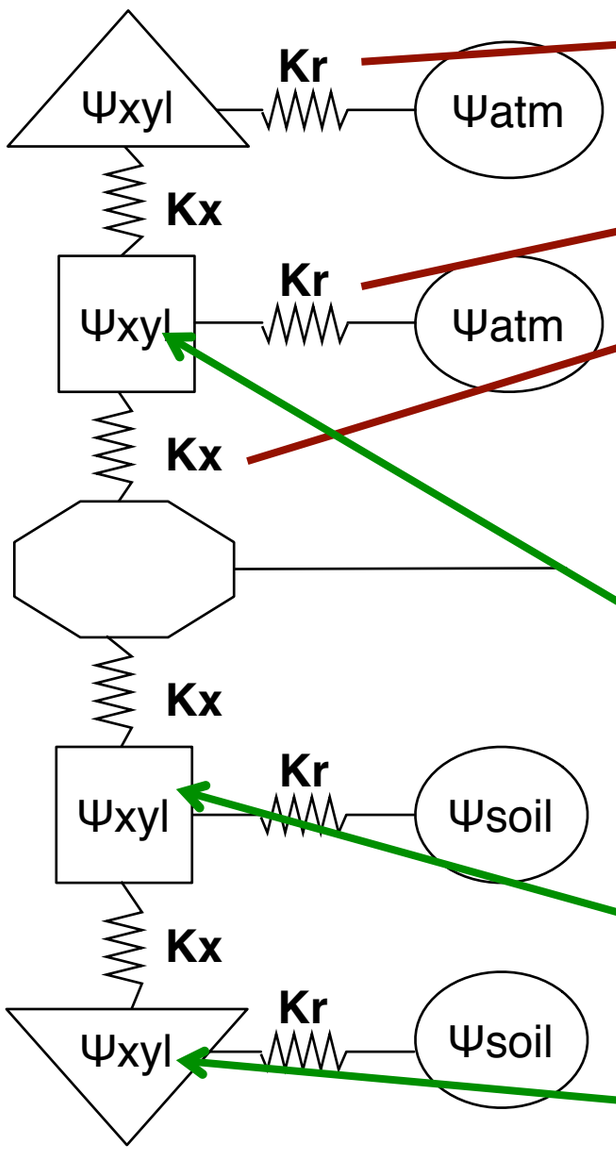


- Hydraulic properties depend on:
  - Root type
  - Root segment age
- Heterogeneous system
- Evolutive system

Doussan, C. et al. 1998. *Annals of Botany*, 81, pp.225–232.

Resolution of water flow - III

Plant level



$$\alpha = S^* Kr$$

$$\beta = \frac{Kx}{d}$$

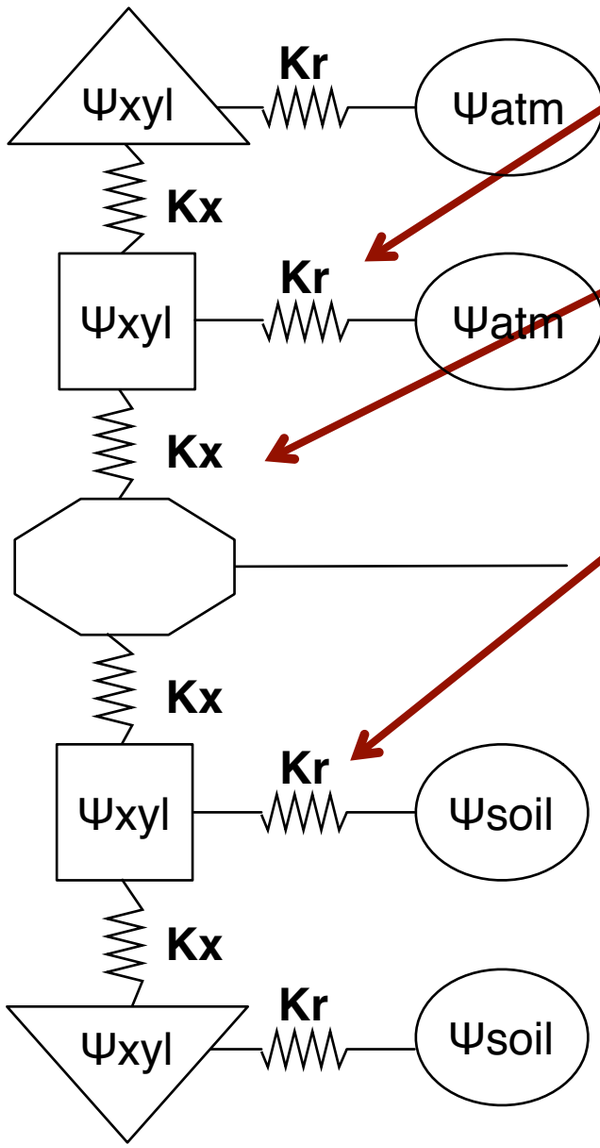
$$A = \begin{pmatrix} \beta_2 + \beta_4 & -\beta_2 & \cdots & 0 \\ -\beta_2 & \beta_2 + \beta_3 + \alpha_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \beta_5 + \alpha_5 \end{pmatrix} \quad b = \begin{pmatrix} 0 \\ K_{r2} S_2 \Psi_{exo2} \\ \vdots \\ K_{r5} S_5 \Psi_{exo5} \end{pmatrix}$$

$$A^* x = b$$

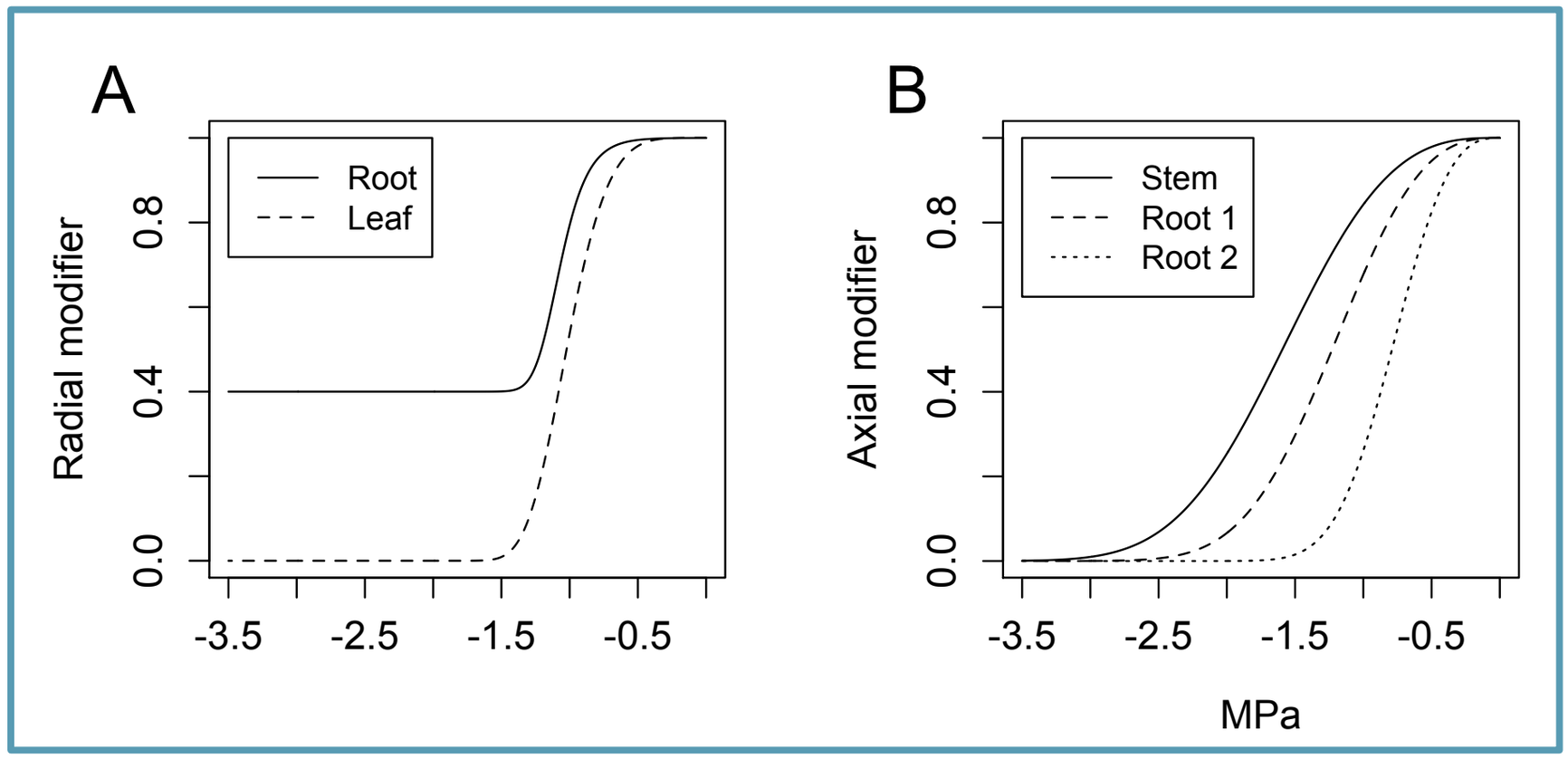
Matricial resolution

Doussan et al. 2006. *Plant and Soil*, 283, 99–117.

Regulation of water flow

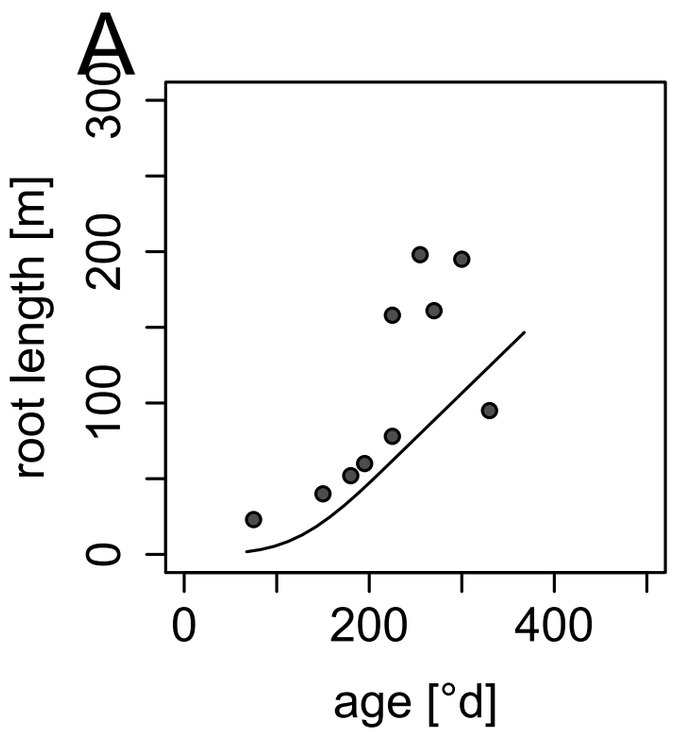


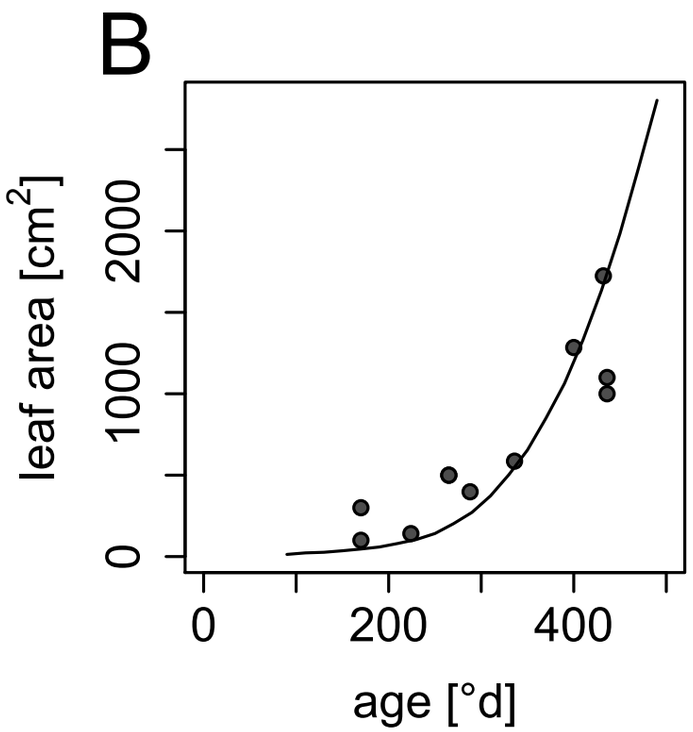
- Leaf conductance | stomata
- Axial conductivity | cavitation
- Root radial conductance | aquaporins



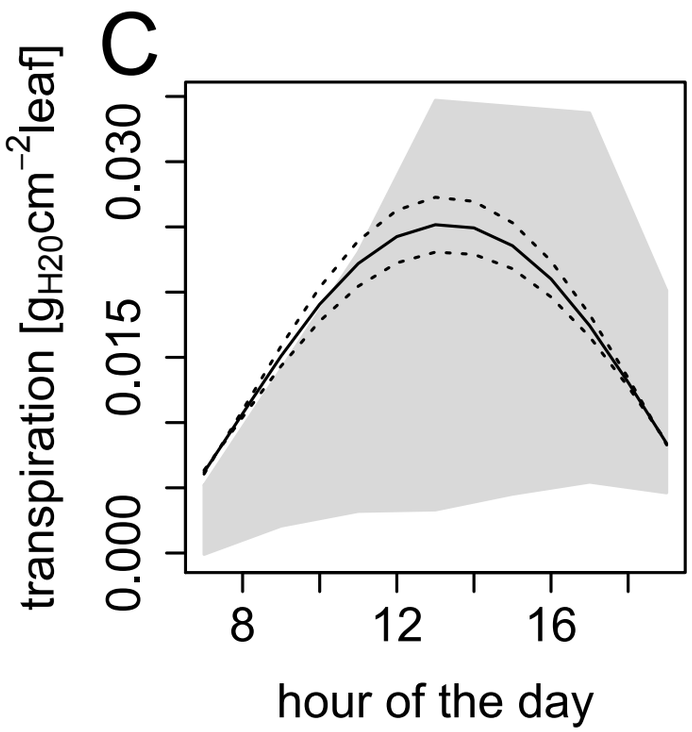
Results

Model validation



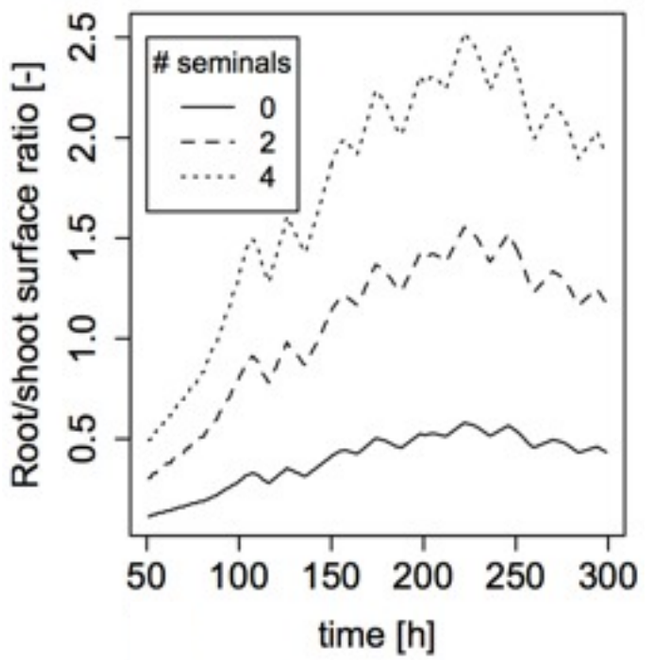


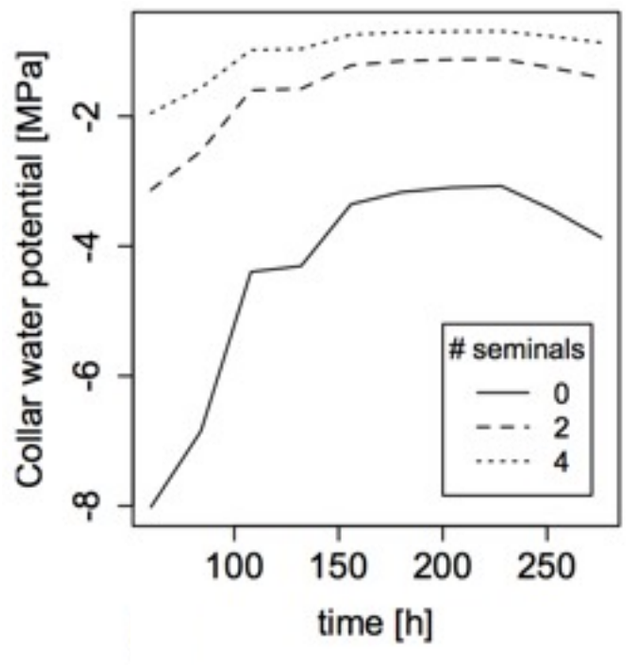
Architecture



Water fluxes

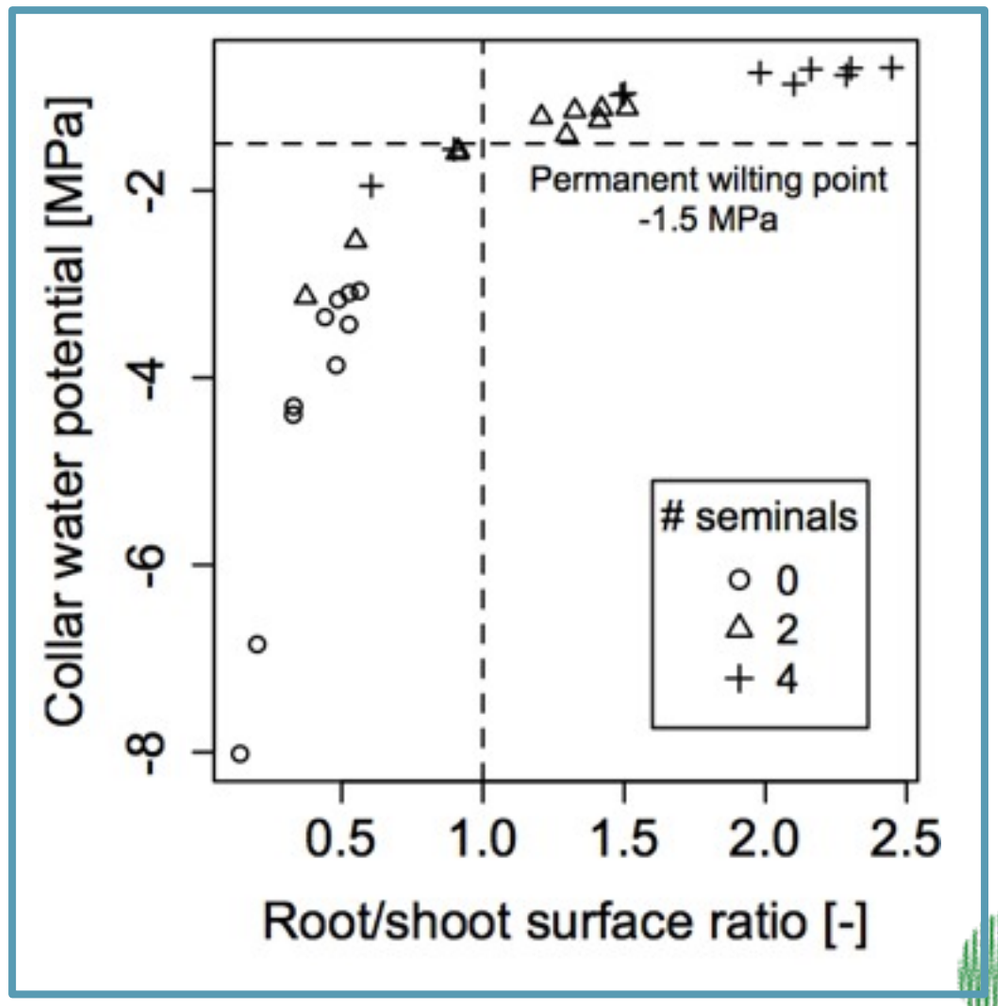
Effect of root system size (no regulation)





- Homogenous water supply
- Different root/shoot ratio

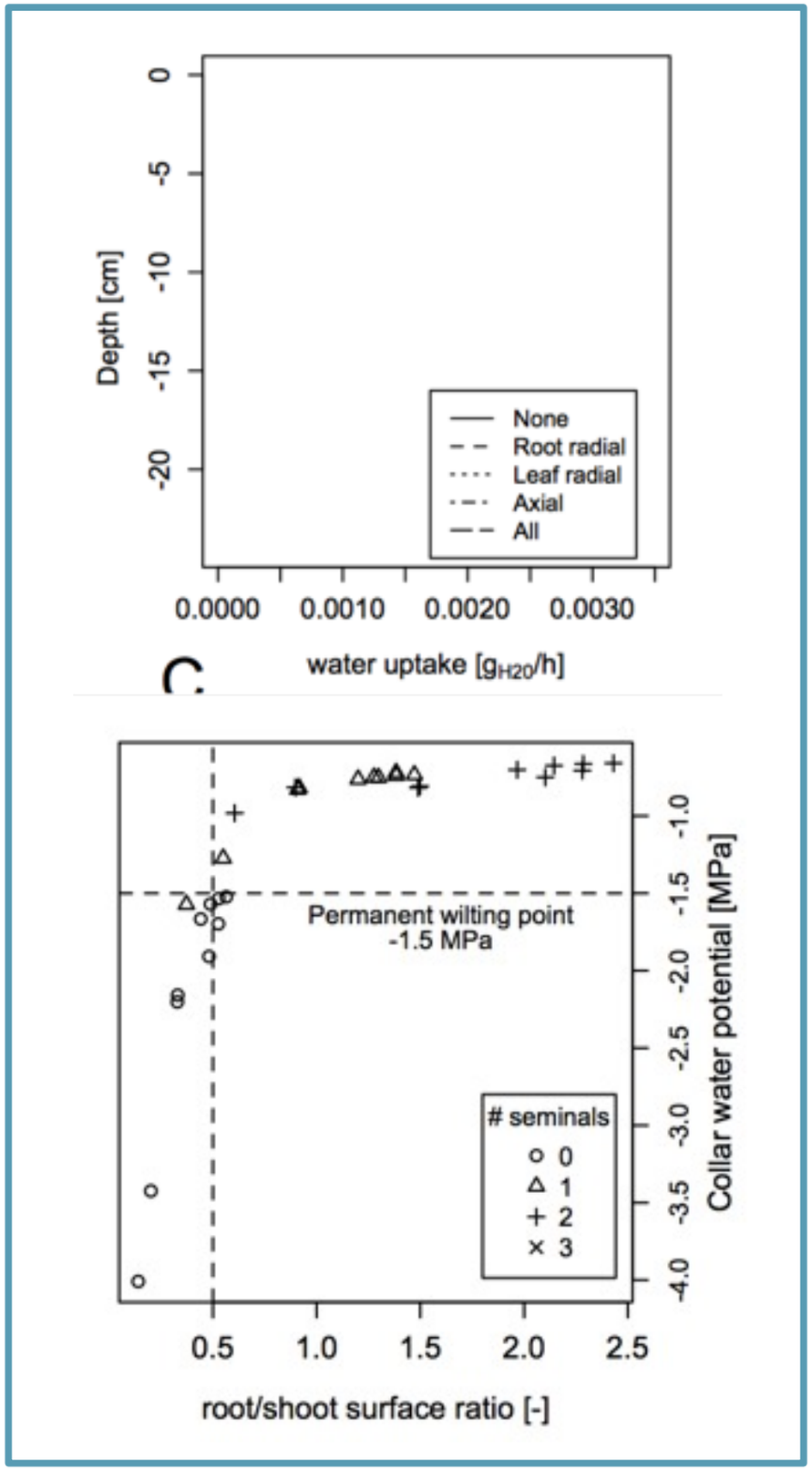
➢ Different water balance



Effect of hydraulic regulation

- Homogenous water supply
- Different root/shoot ratio
- Hydraulic regulation

➢ Modification of water uptake
➢ Better plasticity of the system



Conclusion

- PlaNet-Maize merges:
  - Maize plant growth and development
  - Water fluxes in the plant
  - Water fluxes regulations
- The model open new avenues for reseach.

Perspectives

- Carbon based growth
- Root-to-shoot signaling (ABA)
- Realistic soil module

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Departement Environnement et Agronomie

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