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

- Farming accounts for 70% of worldwide water use
- Global changes reduce water availability
- Better water use at the crop level (agricultural practices)
- Better water use at the plant level (physiology, genetics)

Photo credit: Sam Beebe @ Flickr
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


**Radial flow**

\[ J_r(z) = Kr\left[\Psi_s(z) - \Psi_x(z)\right]S \]

**Axial flow**

\[ J_h(z) = -K_x \frac{\Delta \Psi x(z)}{\Delta z} \]
Resolution of water flow - II

Hydraulic properties

- Hydraulic properties depend on:
  - Root type
  - Root segment age

- Heterogeneous system
- Evolutive system

Resolution of water flow - III

Plant level

\[ \alpha = S^* K_r \]
\[ \beta = \frac{K_x}{d} \]

\[ A = \begin{pmatrix}
\beta_2 + \beta_4 & -\beta_2 & \cdots & 0 \\
-\beta_2 & \beta_2 + \beta_3 + \alpha_2 & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
0 & 0 & \cdots & \beta_5 + \alpha_5 \\
\end{pmatrix} \]

\[ b = \begin{pmatrix}
0 \\
K_r S_2 \Psi_{exo2} \\
\vdots \\
K_r S_5 \Psi_{exo5} \\
\end{pmatrix} \]

\[ A^* x = b \]

Matricial resolution

Regulation of water flow

- Leaf conductance | stomata
- Axial conductivity | cavitation
- Root radial conductance | aquaporins
Results
Model validation

**Architecture**

- **A**: Root length [m] vs. age [°d]
- **B**: Leaf area [cm²] vs. age [°d]

**Water fluxes**

- **C**: Transpiration [g H₂O cm⁻² leaf] vs. hour of the day
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 research.
Perspectives

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