Modeling soil-root interactions: Effect of rhizosphere salinity on transpiration reduction

International Research Training Group nupus

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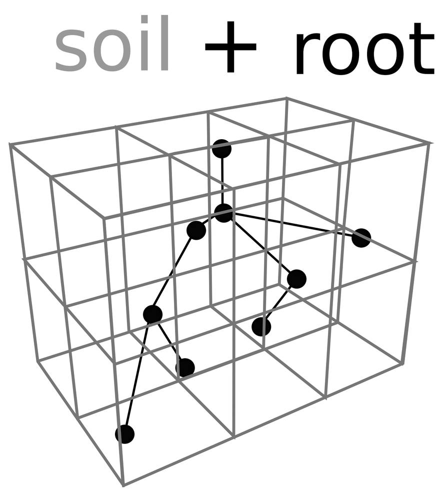
Motivation

Interactions between plant roots and soil are important for several agricultural problems since root water and nutrient uptake behavior have a crucial influence on soil physical processes. To understand these processes, we developed a model approach that couples water flow inside the root system with three-dimensional water flow and solute transport in the soil [1]. We used the model to investigate transpiration reduction processes due to soil salinity [2].



Model concept

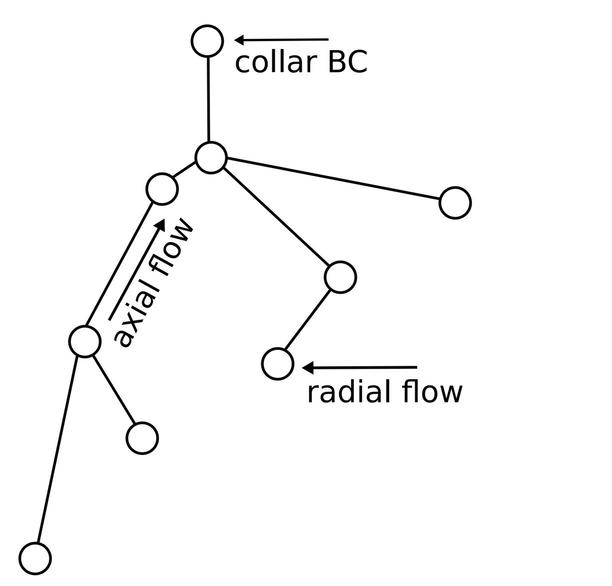
Our model couples three-dimensional soil domain with an one-dimensional network grid. Soil water flow is defined by **Richards equation**, root water flow by the **approach of Doussan** [3], and solute transport by **convection-dispersion equation**.

Soil Water Flow

Three-dimensional Richards equation:

$$\frac{\partial \theta}{\partial t} = \nabla \cdot [\mathbf{K}(h)\nabla(h+z)] - S(x,y,z,t)$$

Root Water Flow



Radial flow:

$$J_r^i = K_r^* A_r (H_{s,int} - H_{xylem}^i)$$

Axial Flow:

$$J_x^i = -K_x^* A_x \left(\frac{\Delta H_{xylem}}{l_{seg}} + \frac{\Delta z}{l_{seg}}\right)$$

Boundary conditions:
Transpiration rate or pressure head at root collar

Coupling

Sink term definition:

$$S_j = \frac{\sum_{k=1}^{n_k} J_r^k}{V_j},$$

Soil pressure head:

$$H_{int} = \frac{\sum_{i=1}^{8} H_i \frac{1}{dist_i}}{\sum_{i=1}^{8} \frac{1}{dist_i}},$$

Soil Solute Transport

Three-dimensional convection-dispersion equation:

$$\frac{\partial(\theta c)}{\partial t} = \nabla \cdot (\theta \mathbf{D} \nabla c) - \nabla \cdot (\theta \mathbf{u} c) - S' c,$$

with

$$D_{ij} = \lambda_T \|\mathbf{u}\| \delta_{ij} + (\lambda_L - \lambda_T)\frac{u_j u_i}{\|\mathbf{u}\|} + D_w \tau \delta_{ij},$$

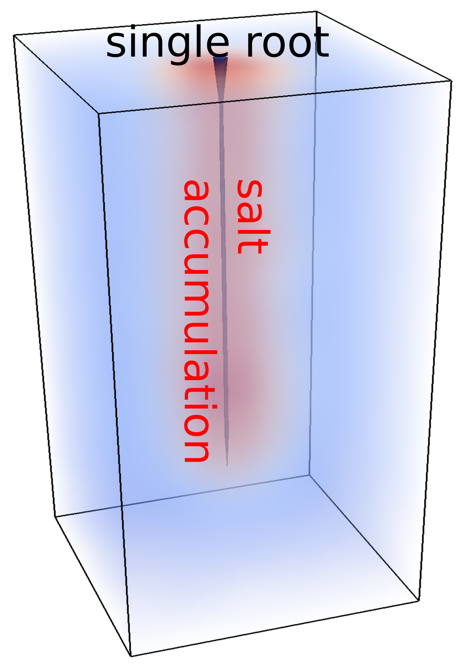
Stress definition

When the collar pressure head reaches $H_{collar}^{crit} = -15000$, the BC at the root collar switches from a flow BC (potential transpiration rate) to a pressure head BC with a constant head of $H_{collar} = -15000$ cm. After this switch, the actual transpiration rate T_{act} is reduced compared to the (applied) potential transpiration rate T_{pot}.

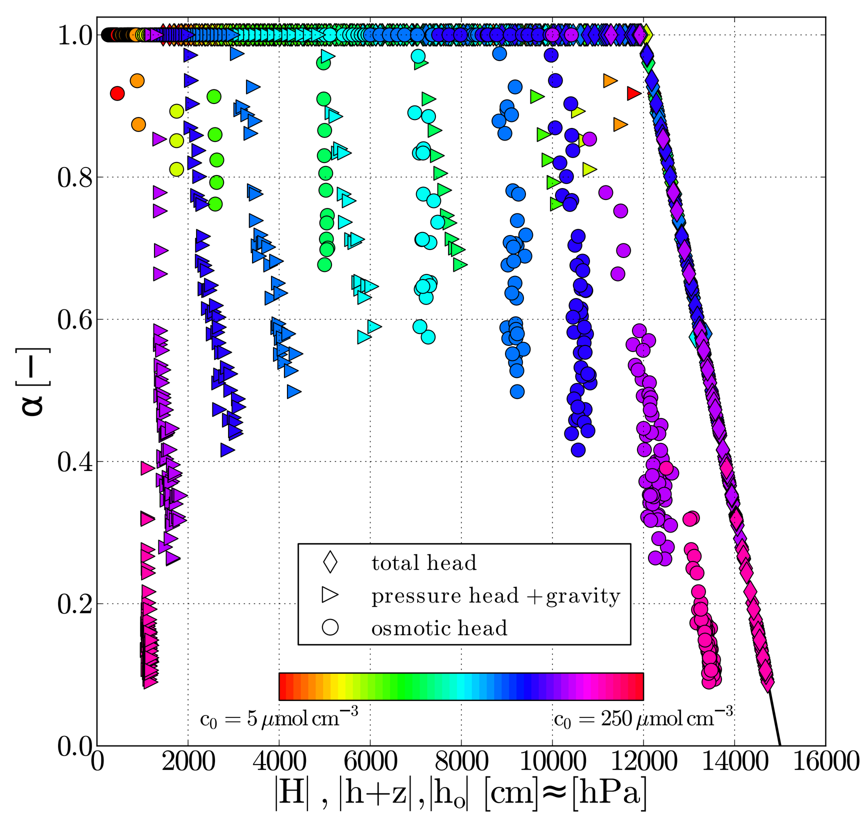
Numerical experiments

Simulation setup

- soil column 4.5 x 4.5 x 10 cm filled homogeneously with clay loam
- single lupine plant root (K_x, K_r^*)
- initial pressure head $h_{init} = -1000$ cm
- various inital concentrations
- various constant potential transpiration rates
- no flow condition boundary condition at all faces



Water potential at the soil-root interface



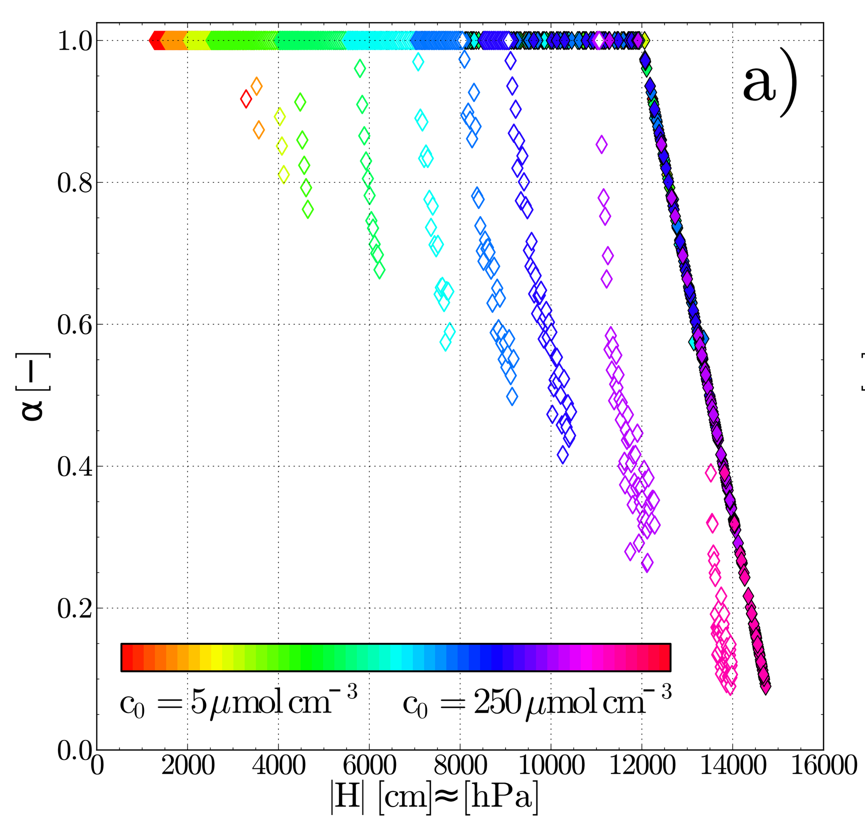
Stress reduction under constant potential transpiration rates are linearly linked to the total local water head (sum of matric, gravimetric and osmotic head) at the soil-root interface, which is consistent with the macroscopic model of Couvreur [4]:

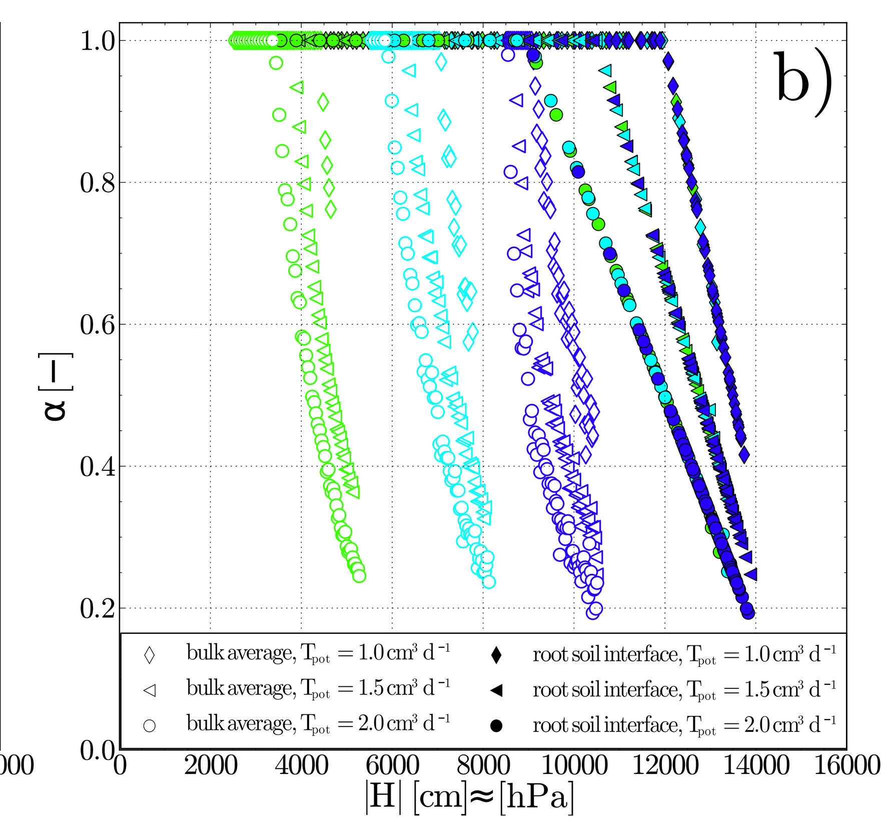
$$\alpha = \frac{T_{act}}{T_{pot}} = \frac{K_r s}{T_{pot}}\left(\sum_{j=1}^{M} H_{s,j} SSF_j - H_{collar}\right)$$

This approach is additive in terms of water potentials, but separation of pure water or salt stress response is not possible.

Water potential in the bulk soil

Using average bulk water heads leads to differences in the transpiration response to bulk soil water head dependent on the osmotic and matric head gradients in the root neighborhood.





Outlook

salinity stress functions:
sensitivity analysis on the parameters affecting the shift between bulk and root-soil interface by using 1D apparent data

new implementation:
include model approach into the framework DuMu^x, an open-source simulator for flow and transport processes in porous media [5]

References

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[5] B. Flemisch, M. Darcis, K. Erbertseder, B. Faigle, A. Lauser, K. Mosthaf, S. Müthing, P. Nuske, A. Tatomir, M. Wolff, and R. Helmig. Dumux: {DUNE} for multi-{phase, component, scale, physics,...} flow and transport in porous media. *Advances in Water Resources*, 34(9):1102 – 1112, 2011. New Computational Methods and Software Tools.