Soil-Root Interaction Simulation with DuMu^x

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 one-dimensional water flow inside the root system with three-dimensional water flow and solute transport in the soil [1]. We used the model to investigate root water uptake processes, transpiration reduction [2] and root growth.

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Model concept

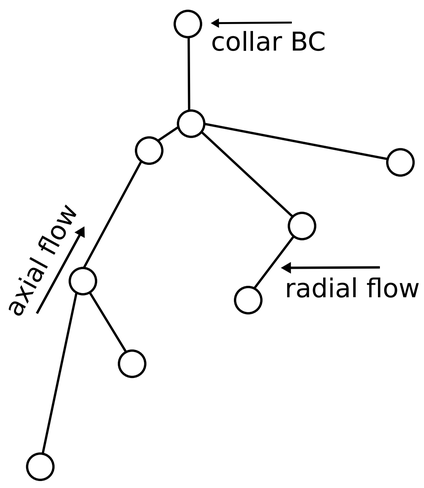
Our model couples a three-dimensional soil domain with a one-dimensional network grid. Soil water flow is governed by **Richards equation**, root water flow by the **approach of Doussan** [3].

Soil Water Flow

Three-dimensional Richards equation:

$$\frac{\partial\, \phi S_w \varrho_w}{\partial t} - \mathrm{div}\left\{\varrho_w \frac{k_{rw}}{\mu_w}\,\mathbf{K}\;(\mathbf{grad}\, p_w - \varrho_w \mathbf{g})\right\} = q_w,$$

Root Water Flow



Radial flow:

$$J_r = K_r^* A_r \left(p_{int} - p_{xylem}\right)$$

Axial Flow:

$$J_x = -K_x^* A_x \frac{\partial p_{xylem}}{\partial z}$$

Boundary conditions

Soil: Closed or open box with or without irrigation (Neumann). **Root:** Transpiration rate of the plant (Neumann) or a critical pressure (Dirichlet) at root collar.

Coupling

Sink term definition

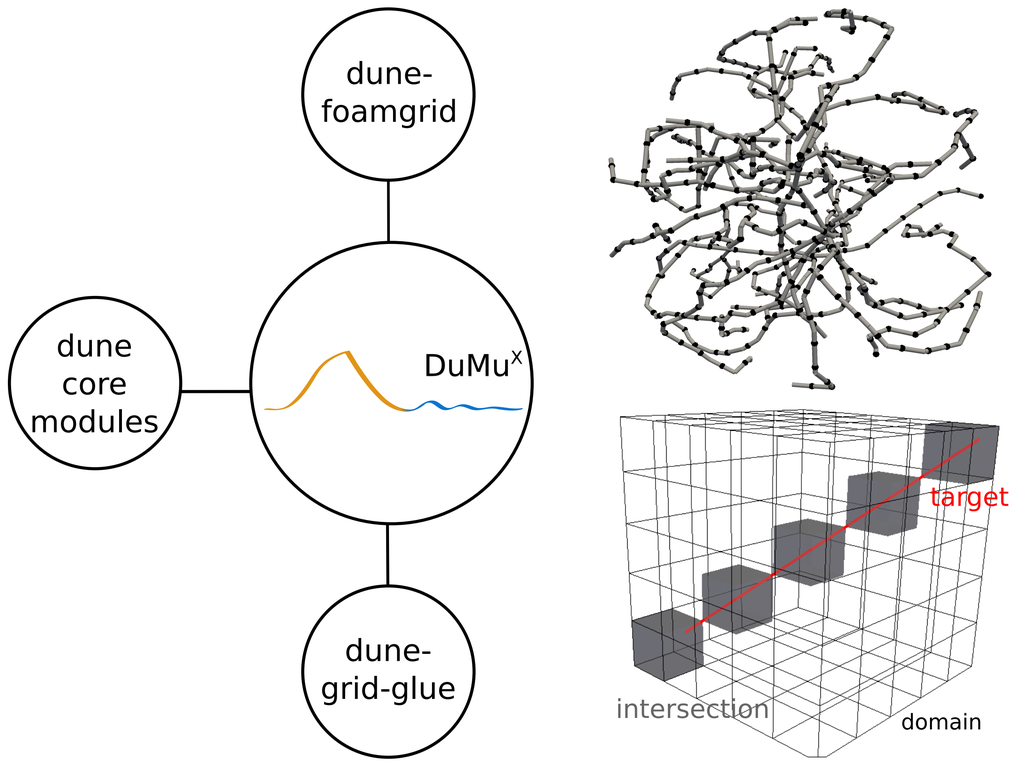
$$q_w = \frac{\sum_{k=1}^{n_k} J_r^k}{V_j},$$

Soil pressure

$$p_{int} = \sum_{i=1}^{N_i} p_i \,\mathrm{frac}_i,$$

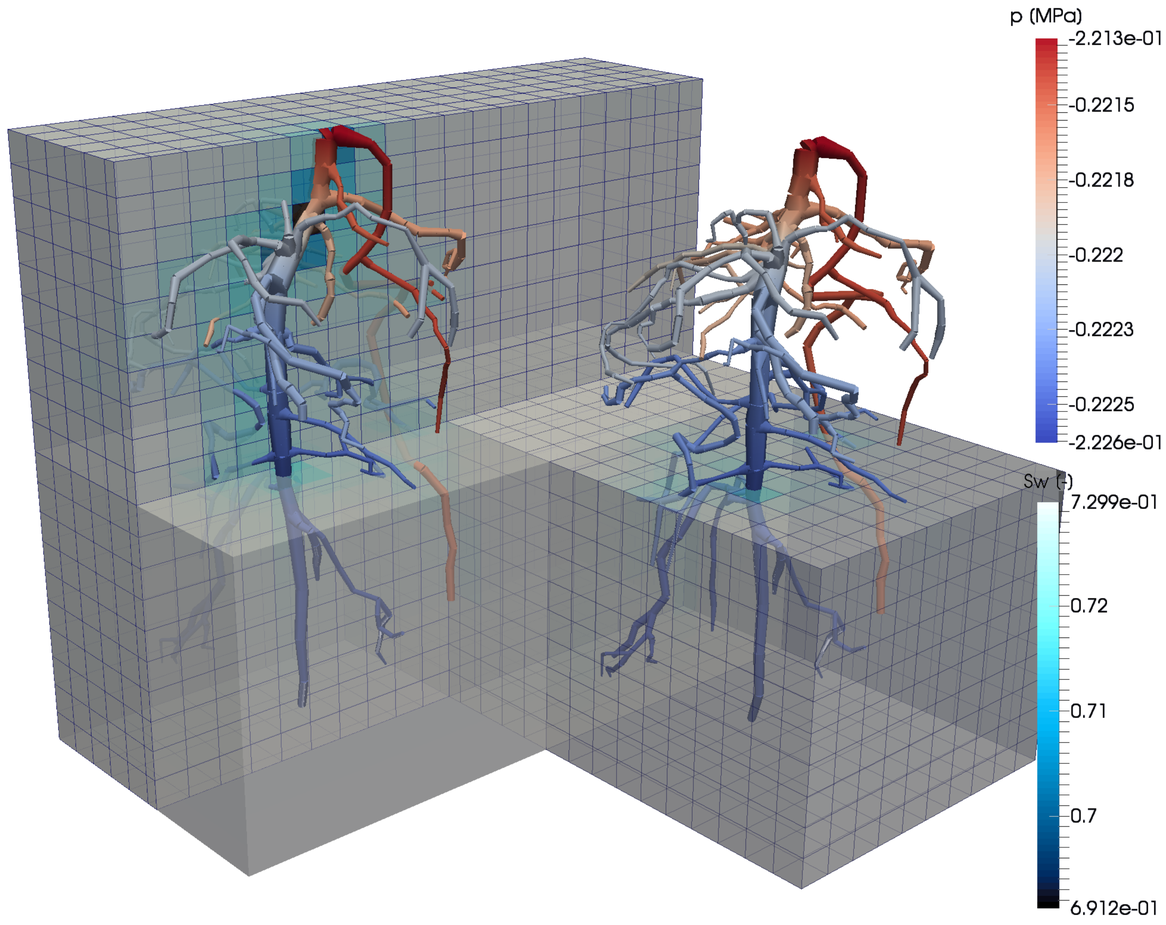
Implementation

We use the framework DuMu^x [4] for implementation with two additional dune modules to represent the 1D network grid (dune-foamgrid) and handling the grid coupling of the network grid to the 3D background grid (dune-grid-glue).



Results

Two lupine root systems taking up water from the surrounding soil. Soil cubes are dryer (darker color) where local root water uptake takes place. The color of the root systems represents the pressure inside the roots.



References

[1] Mathieu Javaux, Tom Schröder, Jan Vanderborght, and Harry Vereecken. Use of a Three-Dimensional Detailed Modeling Approach for Predicting Root Water Uptake. *Vadose Zone Journal*, 7(3):1079–1088, 2008.

[2] Natalie Schröder, Naftali Lazarovitch, Jan Vanderborght, Harry Vereecken, and Mathieu Javaux. Linking transpiration reduction to rhizosphere salinity using a 3d coupled soil-plant model. *Plant and Soil*, 377(1-2):277–293, 2014.

[3] Claude Doussan, Loïc Pagès, and Gilles Vercambre. Modelling of the hydraulic architecture of root systems: an integrated approach to water absorption - model description. *Annals of Botany*, 81:213–223, 1998.

[4] 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.

Outlook

Analysis of neighbor effects of root water uptake. Can plants benefit from the hydraulic water redistribution of their neighboring plants?

DuMu^x Simulations are performed using the open-source simulator DuMu^x.

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