Modelling soil-root interactions

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Plant roots are long and thin branched structures that interact with a porous medium, the soil, in multiple ways. Roots are necessary for plant anchorage and to forage for water and mineral nutrients that are stored in the soil. In the light of current challenges related to climate change and predicted fertilizer scarcity, understanding and making use of the underlying mechanisms becomes increasingly important (Lynch 2007). On the other hand, it becomes increasingly clear that roots are an essential component of soil science, significantly affecting soil's chemical, physical and biological properties (Gregory 2006).

We present a multidimensional model of root water and solute uptake from soil. Our approach is based on the "Multidimension" module of the DuMu^X framework (Flemisch et al. 2011) coupled with the root architectural model CRootBox (Leitner and Schnepf 2016). It is a numerical simulation model in which the soil is represented by a 3-dimensional grid, while the root system is composed of connected line segments. It is thus a branched 1-dimensional structure, however the coordinates of the nodes within the 3-dimensional coordinate system are known. Flow and transport equations are solved in both domains; water and solutes are exchanged via sink source and sink terms. Thus, roots are viewed as line sources or sinks in the soil.

Water flow along a root axis is described by the Poiseulle law; radial flow into each root segment is dependent on the water potential gradient between the soil and the root xylem. The conservation of incompressible water inside a single cylindrical plant root is given by the balance between the axial and radial fluxes. Water flow in soil is described by the Richards equation, with the sink term for water uptake being obtained by summing over the radial fluxes into all the root segments inside each soil element.

Solute movement in both soil and root is described by the convection-dispersion-equation, however with water content inside the xylem equal to 1, and the solute transport highly convection-dominated inside the roots. For the exchange of solutes between soil and root, we implemented several mechanisms: there can be advective uptake of solutes with the transpiration stream, passive uptake along a concentration gradient between roots and soil, active uptake, e.g. of nutrients, by Michaelis Menten kinetics as well as the excretion of root exudates into the soil.

For strongly sorbed solutes, the concentration gradients that develop around each root may be much smaller than the soil discretisation. In order to still capture those gradients, we estimate the concentration at the root surface according to Roose and Kirk (2009).

In order to benchmark the solution of the implemented equations, simulation results were compared with analytical benchmarks and against simulations by the R-SWMS model (Javaux et al. 2008). These comparisons showed a good agreement.

With our simulation results, we aim to increase our understanding of the complex soil-root system and to design management strategies for different purposes and in different environments.

References

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