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Three dimensional modelling of root water uptake for small scale soil-root interactions

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The coupling of water flow in the soil with the plant xylem network causes a mathematical problem. A root in the soil takes up water, due to the passive process of transpiration of the shoot of the plant (part of the plant that is above ground), which causes the soil to dry out. Because the conductivity of the soil is highly non-linear, meaning that small changes in soil conditions affect the hydraulic behaviour drastically, the uptake of water - physiological behaviour - around a root should therefore be described with large accuracy. This can be done by enhancing the derived numerical coupled 3D soil-root model or by analytical approximations applied to the continuity equation describing water flow in the soil (Richards equation). Enhancing the numerical model leads to a more accurate solution in which smaller elements are used to solve the derived system of equations describing water flow (and solute transport) in the soil. The computational time, however, will increase enormously. An analytical approach is favourable, because it is fast and the parameters can easily be monitored and handled.

To derive an analytical solution a domain much less complicated than a 3D domain should be chosen. A radial domain is sufficient and the Richards equation is solved by applying correct assumptions of the time derivative term and boundary conditions. The derived analytical solution is successfully compared to methods found in literature, which are always extreme cases of the common solution derived here. Furthermore, a numerical implicit finite difference model with implicit linearization of the non-linear terms is derived for the radial domain in order to compare the analytical solution to a numerical based approach as well. Within an error estimation of less than 1% both models give the same result to a similar scenario.

The analytical approach is built into the code of the 3D soil-root model. Comparisons are made by comparing the enhanced 3D model with the former 3D model which uses a simplistic coupling of the soil-root water flow without taking the soil conductivity around a root into account. Furthermore, the enhanced model is compared to the numerical enhancing method (smaller elements).