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Modelling root water uptake in heterogenous soils

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The spatial variability of hydraulic properties has long been subject of studies of water flow and solute transport in porous media at different scales. Experimental and theoretical approaches have been developed to predict the role of heterogeneity on water flow in both saturated and unsaturated porous media. In soils, particular attention focussed on preferential flow and transport during infiltration, while less attention was dedicated to the effects of soil heterogeneity on water flow under varying drying conditions, especially in the case of water uptake by plant roots. At the scale of a single root, heterogeneity within the soil matrix is commonly treated by using an effective hydraulic conductivity, representative of the bulk soil. Effective properties can be properly defined in steady state conditions, but it is not clear if they can be extended to drying soils exposed to variable boundary conditions.

Here we report on how heterogenous hydraulic conductivities along the root surface affect the emergent relationship between root water potential and water uptake. Numerical simulations of water flow towards a root surface were carried out in a two-dimensional domain with a randomised configuration of unsaturated hydraulic conductivities and variable boundary conditions – i.e. increasing and decreasing transpiration rates. By employing the Matheron's theorem, the soil hydraulic properties were varied to different degrees, while maintaining the same effective hydraulic conductivity (corresponding to the geometric mean).

The numerical simulations showed that: i) in domains with a large spatial variability in hydraulic properties, the resistance to water flow near the root surface was distinctly lower compared to the homogeneous case with the same effective conductance and, thus, higher water uptake rates could be sustained; ii) the root water potential after root water uptake was ceased recovered markedly slower in heterogeneous domains than in the homogeneous one. Our simulations show that spatial heterogeneity in soil hydraulic properties along the roots has a substantial influence on the emerging relationship between plant water potential and transpiration, inducing a strong hysteresis in this relationship. The problem that the impact of soil heterogeneity on water flow to roots could not be properly simulated using effective conductivities challenges existing root water uptake models. Our findings also provide new insights into the puzzling hysteresis that has been long observed in the relation between transpiration and xylem suction.