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Quantifying water flow across and hydraulic conductivity of the rhizosphere in coarse-textured soils using high-resolution X-ray CT

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Plants are major drivers of terrestrial water fluxes, transpiring 40% of the global terrestrial precipitation. This vast amount of water inevitably flows through the rhizosphere, the thin soil layer surrounding roots. This interface is, therefore, of great relevance for the hydrological cycle. Especially when considering coarse-textured soils such as sandy soils, existing soil-plant models significantly overestimate the water flow in the rhizosphere, consequently overestimating transpiration in drying soils. This discrepancy reflects the challenges in estimating the hydraulic properties of the rhizosphere, particularly in sandy soils where most of the losses in water potential directly occur in the first millimeter near the root-soil interface. At this small scale (< 1 mm), the existing definition of hydraulic conductivity falls short. Additionally, the contact area between root and soil water changes substantially as the soil dries. Currently, we lack a quantitative description to accurately estimate the water flow across the heterogeneous and dynamic rhizosphere.

By means of high-resolution synchrotron radiation-based X-ray computer tomography (act. pixel size 0.65 µm), we study the rhizosphere of 8-day-old maize (Zea Mays L.) roots grown in sandy soil (sample diameter 8 mm). Novel AI-based image segmentation and analysis techniques enable us to quantify the connectivity of the liquid phase across the rhizosphere at varying soil water potentials. The three-dimensional segmented images are used to simulate the flow of water and air in the rhizosphere. The simulations enable quantitative estimation of the effective hydraulic conductivity of the rhizosphere.

Our analysis shows an important loss in contact area between roots and soil water at relatively high soil matric potentials and decline in the connectivity of the liquid phase across the rhizosphere. This results in a restriction of water flow paths from the bulk soil to the roots and a reduction in hydraulic conductivity. To incorporate this observed behaviour of the rhizosphere hydraulic conductivity in upscaled models, we developed a scheme that allows us to estimate an effective rhizosphere hydraulic conductivity. This parameter is crucial, particularly in sandy soils, for accurately including the rhizosphere in upscaled root water uptake models.

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References

Primary author: DUDDEK, Patrick (ETH Zurich, Physics of Soils and Terrestrial Ecosystems)

Co-authors: Dr SEYBOLD, Hansjoerg (ETH Zurich); Mr STOLL, Florian (ETH Zurich); Dr LEHMANN, Peter (ETH Zurich); Dr LOVRIC, Goran (Paul Scherrer Institut, Villigen); Prof. CARMINATI, Andrea (ETH Zurich)

Presenter: DUDDEK, Patrick (ETH Zurich, Physics of Soils and Terrestrial Ecosystems)

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