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Novel 3D imaging of root systems grown in slab-shaped rhizotrons

Sarah Bereswill[1], Nicole Rudolph-Mohr[1], Christian Tötzke[1], Nikolay Kardjilov[2], André Hilger[2], and Sascha Oswald[1]
[1]University of Potsdam, Institute for Environmental Sciences and Geography, Water and Matter Transport in Landscapes, Germany (bereswill@uni-potsdam.de)
[2]Helmholtz Centre Berlin for Energy and Materials, Institute of Applied Materials, Berlin, Germany

Complex plant-soil interactions can be visualized and quantified by combined application of different non-invasive imaging techniques. Oxygen, carbon dioxide and pH gradients in the rhizosphere can be observed with fluorescent planar optodes, while neutron radiography detects small-scale heterogeneities in soil moisture and its dynamics. Respiration and exudation rates can vary between roots of different types, such as primary and lateral roots, as well as along single roots among the same plant. The 3D root system architecture is therefore a key information when studying rhizosphere processes. It can be captured in detail with neutron tomography, but so far only for plants grown in small, cylindrical containers.

Combined non-invasive imaging of biogeochemical dynamics, soil moisture distribution and 3D root system architecture is a technical challenge. Thin, slab-shaped rhizotrons with relatively large vertical and lateral extension are well suited for optical fluorescence imaging, allowing for spatially extended observation of biogeochemical patterns. This rhizotron geometry is, however, unfavorable for standard 3D tomography due to reconstruction artefacts triggered by insufficient neutron transmission when the long side of the sample is aligned parallel to the beam direction.

We therefore applied neutron laminography, a method where the rotational axis is tilted, to measure the root systems of maize and lupine plants grown in slab-shaped glass rhizotrons (length = 150 mm, width = 150 mm, depth = 15 mm) in 3D. In parallel, we investigated rhizosphere oxygen dynamics and pH value via fluorescence imaging and assessed soil moisture distribution with neutron radiography.

Neutron laminography enabled the 3D reconstruction of the root systems with a nominal spatial resolution of 100 µm/pixel. Reconstruction quality strongly depended on root-soil contrast and hence soil moisture level. After reconstruction of the root system and co-registration with the fluorescence images, first results indicate that observed oxygen concentrations and pH gradients depend on root type and individual distance of the roots from the planar optode.

In conclusion, neutron laminography is a novel 3D imaging method for root-soil systems grown in slab-shaped rhizotrons. The method allows for determining the precise 3D position of individual roots within the rhizotron and can be combined with 2D imaging approaches. Following experiments will address X-ray laminography as a possible attractive further application.