Experimental report

15/12/2022

Proposal: **1-05-12**

Council: 4/2020

Title: Studying the influence of root hairs on the microstructure of rhizosphere soil and its implication for root water uptake

Research area: Biology

This proposal is a new proposal

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Samples: root-soil system

Instrument	Requested days	Allocated days	From	To
NEXT	3	4	24/09/2021	28/09/2021

Abstract:

Roots interact in various ways with the surrounding soil to facilitate water and nutrient uptake. Thereby, they induce changes in the properties of rhizosphere soil. Besides root exudates, root hairs seem to play an important role in modifying the pore structure of the rhizosphere, which is thought to significantly contribute to its distinct hydraulic behaviour observed in various neutron experiments. To better understand the structural alterations of the rhizosphere soil induced by root hairs including its implications for the root water uptake, we propose a study on maize plants comparing a hairless mutant with a hairy wild type. We will apply a combination of high-resolution neutron (NT) and X-ray tomography (XCT) to visualize and quantify transport-relevant changes in the rhizosphere microstructure and relate this highly resolved soil water patterns around the root surface. We expect to gain new insights into the specific hydraulic behaviour of rhizosphere soil as well as into the mechanism triggering the formation of the rhizosheath.

Experimental Report

Title of Study: Studying the influence of root hairs on the microstructure of rhizosphere soil and its implication for root water uptake

Scientific Background. The layer of soil surrounding the roots, termed as rhizosphere, is subjected to numerous root-soil interactions. Root growth, root hair formation, rhizodeposition and the subsequent colonization with microorganisms alter the physicochemical properties of rhizosphere soil (1). Various neutron experiments showed that the hydraulic behavior of the rhizosphere differs significantly from bulk soil and the exudation of mucilage by roots is considered to be the major reason. The distinct rhizosphere hydraulics is assumed as a plant measure to improve the root water uptake under dry conditions (2). However, due to limited spatial resolution (> 100µm) of the neutron measurements and the intrinsic lack of mineral contrast, it could not be clarified to what extent changes in the microstructure of the rhizosphere soil and the presence of root hairs contribute to the modified hydraulic behavior of the rhizosphere. Root hairs are a valuable trait for plant growth and nutrients acquisition under combined soil stresses. Root hairs offer an advantage for root penetration into high-strength layers of soil (3). Anchoring the root surface to pore walls, they improve root-soil contact and aid the penetration of soil (4). Root hairs seem to play a major role in efficient phosphorus uptake, particularly under limited P availability (5). They furthermore help to sustain water uptake and transpiration in drying soils (6). Root hairs are important for the evolving rhizosphere as the can change porosity and connectivity of the soil pore space which implies consequences for the hydraulic behavior of the rhizosphere (7)

References

1. Bengough AG (2012) Water Dynamics of the Root Zone: Rhizosphere Biophysics and Its Control on Soil Hydrology. Vadose Zone Journal 11(2).
2. Carminati A, et al. (2011) How the Rhizosphere May Favor Water Availability to Roots. Vadose Zone Journal 10(3):988-998.
3. Haling RE, et al. (2013) Root hairs improve root penetration, root–soil contact, and phosphorus acquisition in soils of different strength. Journal of Experimental Botany 64(12):3711-3721.
4. Bengough AG, Loades K, & McKenzie BM (2016) Root hairs aid soil penetration by anchoring the root surface to pore walls. Journal of Experimental Botany 67(4):1071-1078.
5. Keyes SD, et al. (2013) High resolution synchrotron imaging of wheat root hairs growing in soil and image based modelling of phosphate uptake. New Phytologist 198(4):1023-1029.
6. Carminati A, et al. (2017) Root hairs enable high transpiration rates in drying soils. New Phytologist 216(3):771-781.
7. Koebernick N, et al. (2017) High-resolution synchrotron imaging shows that root hairs influence rhizosphere soil structure formation. New Phytologist 216(1):124-135

Objectives. The proposed experiment aims to study root hair interactions with rhizosphere soil. Complementary high-resolution neutron and X-ray scans of maize roots will be performed in order to visualize and quantify soil structural changes induced by roots with distinct root hair morphology, i.e. with and without root hairs (X-ray CT). Furthermore, neutrons will capture highly resolved water gradients at the root-soil interface including the fine structure of the root surface. This unique bimodal data set will allow us to relate structural features of the root surface and water gradients at the root-soil interface with alterations in microstructure induced by root hairs. Using hairless maize mutants and its hairy wild type, we will test the hypotheses that root hairs influence the pore structure in the rhizosphere leading to a more structured soil and that these changes imply a modified water distribution pattern around the roots.

Preliminary results

We combined high resolution neutron and X-ray tomography to gain 3D data about the fine root structure, the local water distribution around the roots and microstructure of surrounding soil matrix. We compared the patterns of soil porosity and water content in the rhizosphere at two different water saturation levels for two contrasting maize types, i.e. hairy wild type vs. hairless mutant. Fig. 1 demonstrates that the use of dedicated high-resolution set-up for neutrons was necessary to resolve the fine root structure of maize seedlings. The principal experimental setup is shown in Fig.2 a. Multimodal registration and an ad-hoc 3D image segmentation were performed to extract the root system, and to quantify the structural changes of root-soil interface induced by decreasing soil water content, for both maize types. While the detailed results will be discussed in separate publication (under preparation) we generally recommend dual-mode tomography as powerful tool to link the porosity profile of the rhizosphere with soil water gradients and to relate these patterns to the hydro-mechanical interaction of roots and soil.

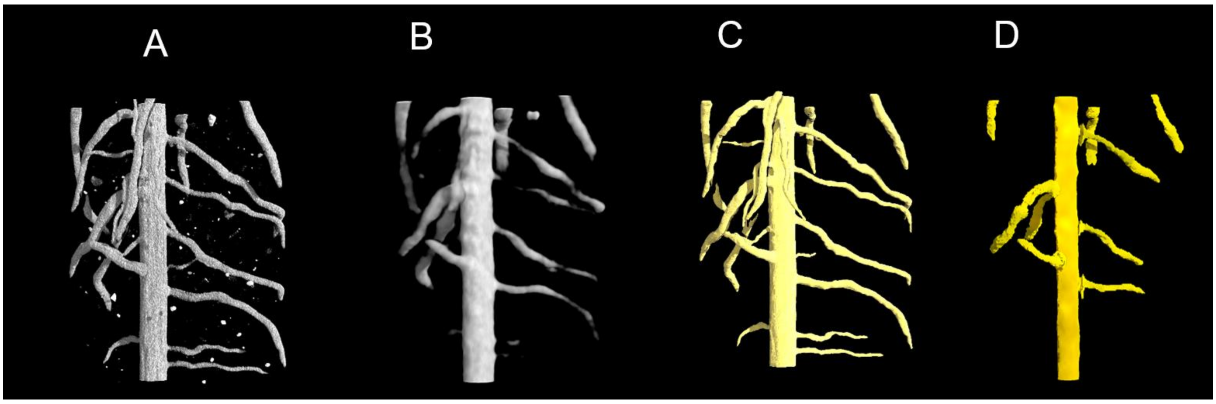

Fig.1 High resolution vs. medium resolution neutron tomography (A vs. B) of the same section of a maize root system(MM01_01) -> High resolution is required for reproduction and segmentation of small lateral roots.

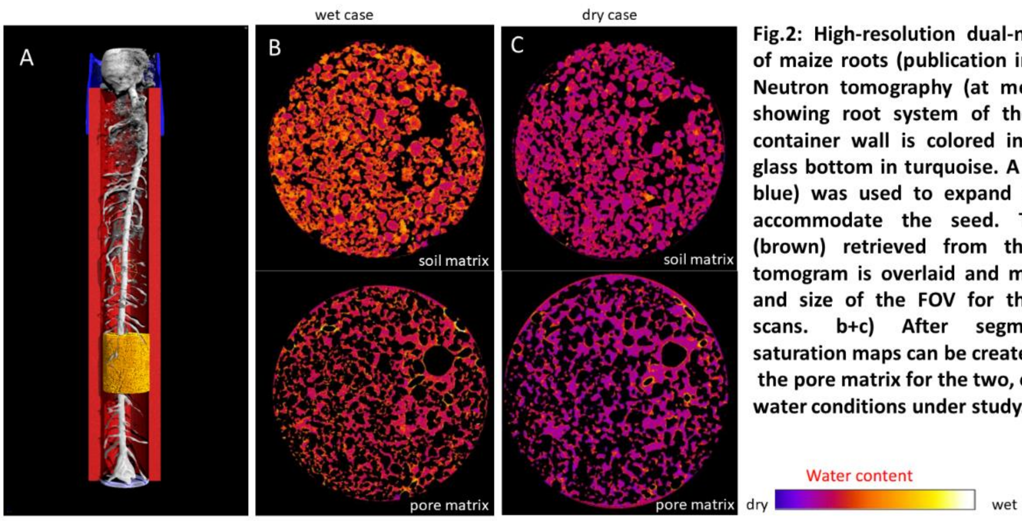

Fig.2: High-resolution dual-mode tomography of maize roots (publication in preparation). A) Neutron tomography (at medium resolution) showing root system of the seedling. PTFE-container wall is colored in red, the porous glass bottom in turquoise. A shrink tube (dark blue) was used to expand the soil space to accommodate the seed. The soil column (brown) retrieved from the high-res X-ray tomogram is overlaid and marks the position and size of the FOV for the high-resolution scans. b+c) After segmentation, water saturation maps can be created for the soil and the pore matrix for the two, contrasting soil water conditions under study.