BBSRC Multi-Soil 2018 Talk Abstracts:

Combining X-ray and Electrical resistivity tomography methods towards a new methodology of soil hydraulics properties assessment

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Developing a better understanding of soil hydraulic properties is of significant importance for such diverse fields as agriculture, soil and ecosystem management, civil engineering and geotechnics. Electrical Resistivity Tomography (ERT) and X-ray Computed Tomography (CT) are two state-of-the-art methodologies with great potential for applications in soil science. ERT allows time-lapse monitoring of solute transport. X-ray CT is sensitive to bulk density changes at high resolution. We obtain the functional dependence of soil electrical resistivity and x-ray absorption on moisture content in a laboratory controlled calibration experiment, therefore deriving the corresponding transfer functions. Experimental results were compared with existing models, such as Waxman-Smits and Bailly. The high degree of correlation ($R>0.85$) and low misfit ($\%RMS<12\%$) between measurements and model predictions confirm the validity of these models, subsequently formulating a new property relationship linking x-ray absorption and electrical conductivity. Furthermore, we conducted a column experiment, which takes advantage of the specific strength of both tomography methods. It aimed to assess the effect of zero tillage (ZT) by monitoring a 0.05 M KCl solution infiltration. ZT soils exhibited a slow solution infiltration correlated to an undeveloped porosity network and a significant ion binding effect. Our methodology opens the door for future assessments of soil hydraulic properties using X-ray CT and ERT and may serve as reference for future calibration studies between electrical and structural properties of materials.

Multi image based method for plant soil interaction

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Soil-root-fertiliser, or indeed any soil systems, cannot be fully examined through just one experimental method. Structure, chemistry, physics and biology all play important roles in many important functional properties of the system, such as root nutrient uptake, effective diffusion, hydraulic conductivity and microbe activity. To determine how roots respond to a P fertiliser pellet, such as struvite, how P is transported in the soil from the fertiliser towards the roots, and how this affects root P uptake, a suite of methods are used. X-ray micro-computed tomography (XCT) is used to visualise the undisturbed 3D structure root-soil-fertiliser systems and produce computational meshes for numerical modelling. Scanning electron microscopy with energy dispersive X-ray spectroscopy is used to obtain 2D P maps of planes within the image regions. These two imaging methods are aligned to verify that the process to obtain the P maps does not disturb the sample and to reveal the 3D context of the 2D P maps. Models describing the processes are then parametrised by the P maps. Image based models, where the model domain is extracted from 3D images obtained with XCT, are used to assess the effect of root architecture on plant P uptake.

Use and challenges of electrical resistivity tomography to study processes in agro-ecosystems

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Sustainable management of agro-ecosystems requires a thorough understanding of the interaction between physical, chemical and biological processes at play. In addition, processes at pore scale are linked to field scale phenomena, but this connection is often poorly understood. Electrical resistivity tomography (ERT) is increasingly used in the context of agriculture since the measured resistivity distribution can be linked to soil moisture, soil structural characteristics or pore water salinity. Due to its minimally invasive character, its spatial coverage and its monitoring abilities, ERT can be used to study field heterogeneity and competition between plants, quantify water fluxes throughout a growing season or distinguish preferential flow pathways in soils. Is resolution is well-below classical soil imaging techniques such as X-ray CT or MRI, but its spatial coverage much larger. This highlights the potential of ERT to link our knowledge obtained from pore scale data to field scale processes.
Nevertheless, a lot of challenges still remain. A Tikhonov-type regularization approach is often used to solve the ill-posed, inverse problem linked to ERT, resulting in a smoothed resistivity distribution. However, in reality strong contrasts can exist due to e.g. compacted soil layers due to ploughing, water infiltration fronts, etc. and in that case other operators have been proposed to regularize the inversion. Taking into account spatial heterogeneity of petrophysical characteristics and providing a realistic uncertainty estimation are additional challenges, which can be addressed using stochastic approaches. Monitoring data provides further elements to constrain the inverse problem: data can be replaced by data difference and regularization may incorporate the temporal dimension for instance. However, such constraints require their compatibility with the studied temporal process, which is not always straightforward. Several alternative strategies are being developed, such as coupled hydrogeophysical inversion, or stochastic approaches using a prior falsification/validation method following a Popper-Bayes philosophy. In this talk, we will address some of these challenges and give some recent applications in the field of agro-geophysics.

Percolation Theory and Soil Tomography

Diego Soto-Gómez, Paula Pérez-Rodríguez, Laura Vázquez Juíz, J. Eugenio López-Periago, John Koestel, and Marcos Paradelo*

Macropores in soils have a critical importance in preferential flow, allowing solutes and colloids to bypass the soil matrix. Some concepts from percolation theory can be used to study the morphology of those pores involved in transport. We determined the percolation threshold (pc) and the critical pore thickness for different soils. We also extracted the backbone of the samples and compared the results from soils under different tillage managements. The pc was 0.014 ± 0.003, and the average coordination number of the backbone is 1.74 ± 0.01. For the entire skeleton, the coordination number is 3.03 ± 0.15. Shallow-tilled samples presented backbones with more pore volume, branches, junctions and loops; while the soil not tilled after sowing (with root pores) has less tortuous backbones. The organic samples presented more variability intragroup. There is a correlation between the dry bulk density and the backbone volume, surface, fractal dimension and number of loops. These backbone properties were also correlated with the average surface stained by a particulate fluorescent tracer. The tortuosity of the backbone is correlated with the dispersion coefficient for particles, and the β coefficients (for particles and bromide) are correlated with the number of end-points of the backbone.

Magnetic Resonance Imaging of Root zone Processes

Sabina Haber-Pohlmeier and Andreas Pohlmeier*

The understanding of dynamic processes in soil root systems is highly advanced by the emergence of 3D non-invasive imaging techniques. Amongst these, Magnetic Resonance Imaging (MRI) is a powerful technique for imaging of the distribution and dynamics of fluids in situ. Beyond medicine, it finds more and more applications in material- and geoscience, where the behaviour of fluids in porous media is in the focus of interest. Its versatility results from the numerous possibilities of connecting the image signal with the pore size, various tracer substances or direct flow and diffusion processes [1]. Especially NMR relaxation times T1 and T2 are sensitive to the water status in porous media, i.e. to changes in pore size or presence of hydrogels. In this contribution we focus on the investigation of root-zone processes like water uptake, solute transport and changes in hydraulic properties using three examples. One of the most important but also challenging root-zone processes is solute transport. We show that MRI in combination with inversion-recovery preparation can quantitatively map in 3D concentration changes of a model solute, Gd-DTPA and thus allows to draw conclusions on the underlying solute uptake mechanisms. Water flow and uptake is strongly coupled to effective pore size distribution, and MRI offers the opportunity of monitoring both properties in time series. As example, water depletion in a 3 week old lupin / soil system is monitored over a period of 2 weeks. Heterogeneous depletion patterns were obvious, which coincide to patterns in T2 relaxation time maps. Zones in the neighbourhood of the roots with by lower T2 values reflecting smaller effective pore sizes correspond to delayed desiccation, whereas in zones of longer T2, typical for larger pore sizes, desiccation started first. The presentation concludes with first data from the complementary use of MRI and neutron imaging on the same plant. While neutron imaging is extremely sensitive to the total water content, MRI provides synergistic information about local water dynamics based on relaxation times and relaxation time contrast. The experiments focus on changes in hydraulic properties of the root zone occuring during drying and rewetting scenarios, which are relevant for root-water uptake.

Roots Redesign the Soils Physical Architecture and Function for Drought-Tolerant Plants

Sheikh M.F. Rabbi* and Ian M. Young

The rhizosphere drives plant productivity and is the “powerhouse” of soil function, regulates both water and nutrient uptake by plants. The interaction between the root zone and soil geometry affects water, nutrient and microbial dynamics within the soil. The root architecture and rhizodeposition (such as carbon rich mucilage and exudates) can dramatically alter water and solute flow towards the root. Using high-resolution (16μm) micro-computed x-ray tomography, and root metrics, we compared the geometry of soil around drought tolerant and normal chickpea varieties. We found that the drought tolerant varieties had the remarkable capability in redesigning the soil close to their roots by increasing total porosity and connected porosity. We also found that the drought tolerant variety despite exhibiting no increase in root hair length, increased the rhizosheath on the root surface. We linked this to an observed increase in root mucilage. Our results demonstrate the importance of examining the plants ‘hidden half’, which function as architects, micro-engineering their environment to improve water uptake at the root-soil interface.

Imagine the Complexity of Soil Microstructures

Stephen Peth*

In the presentation an overview will be given on the potential and limitations of X-ray microtomography (XRCT) to analyse and quantify soil microstructures on various scales. After shortly explaining the principles of XRCT different examples will be demonstrated showing a range of applications where we have utilized XRCT to visualize and quantify microstructures and their relation to soil functions. These include biopore networks, the structure of the rhizo- and drilosphere, biological soil crusts and soil aggregates/microaggregates. Methods will be introduced to quantitatively analyse the pore space morphology, to make the small scale organic matter and water distribution visible and to study the internal deformation behaviour of soils. An outlook on the perspectives of XRCT in soil research will end the presentation.

Combined Imaging of Dynamic Soil and Root Zone Processes

Sascha Oswald*

The water distribution in soil and resulting fluxes are key quantities for soil processes beyond soil physics, being relevant also for biochemistry, plant science, groundwater and agricultural practices. Neutron imaging has been established as a non-invasive method to quantitatively map the water distribution in laboratory plant-soil-systems. However, by combination with other imaging methods also other quantities and processes can be investigated. Thus, examples will be given and illustrated how this can be done and what can be obtained additionally. One example will show the combination of 3-D tomographies by neutron imaging and X-ray CT imaging on the same samples. Another one is the novel combination with a mobile Magnetic Resonance Scanner, aiming for root water uptake and rhizosphere water mobility. In quasi 2-D systems neutron radiography can be combined with fluorescence imaging for time-lapsed imaging of dynamic processes in rooted soil, namely pH and oxygen distribution. Here especially of interest is the influence of root activities that create spatially and temporally dynamic patterns. Finally, a newly developed tomography approach allows for the first time also fully investigating soil water movement via neutron imaging in 3-D on the time scale of minutes. First results of this will be presented and possible applications discussed.

Image-based modelling of root growth at cellular and particle resolution

Matthias Mimault, Daniel Patko, Yangminghao Liu, Felicity O'Callaghan, Mike MacDonald, Mariya Ptashnyk, Lionel Dupuy*

The growth of a crop is conditioned by multiple interactions with the soil environment, and macroscopic patterns and traits that are of importance to agriculture are dependent on processes taking place at the microscale. For example, rhizosphere bacteria colonise preferentially intercellular junctions and the surface of certain cell types. Limitations to soil strength have been linked recently to microscale variations in soil particle force. We are developing new theoretical frameworks to model, visualise and simulate the dynamics of the rhizosphere from cellular to organ level. The framework is based on microscopy image data collected in the lab and fast computational techniques using particle-based techniques and GPU accelerated simulations. Currently, we are able to extract microscopy information at cellular level and simulate growth of entire organs at cellular resolution. In the future, the framework could also include physical and chemical interactions with microbes and soil particles in the pore space.

Can microscale heterogeneity of the spatial distribution of organic matter favour soil microbial diversity?

Xavier Portell*, Valerie Pot, Patricia Garnier, Philippe C. Baveye, Wilfred Otten

We have developed a novel multi-species, individual-based, pore-scale model and used it to explore the hypothesis that the heterogeneous distribution of soil organic matter, in addition to the spatial connectivity of the soil moisture, might account for the observed microbial biodiversity in soils. In the study, we have considered bacteria of three Arthrobacter strains distributed in a 3D computed tomography image of a real soil under three spatial heterogeneity levels (high, intermediate, and low) in the distribution of the soil organic matter. We found that the total bacterial biomass and respiration are similar under the high and intermediate resource heterogeneity schemes. However, the key result of the simulations is that spatial heterogeneity in the distribution of organic matter influences the maintenance of bacterial biodiversity. For geodesic distances exceeding 5 mm between bacteria and organic matter, microbial colonies cannot grow. Our work suggest that microscale factors need to be considered to better understand the root causes of the high biodiversity of soils at macroscale.

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How life shapes the liquid phase in soils

Pascal Benard, Mohsen Zarebanadkouki and Andrea Carminati*

By modifying the physical properties of the soil solution plants and microorganisms create a network that mediates flow processes across the rhizosphere. Specifically, by increasing the extensional viscosity of the soil solution and decreasing its surface tension, plant mucilage and microbial EPS maintain the connectivity of the liquid phase, stretching the boundary of life in soils. The physics of such processes questions paradigms of soils physics, such as the dominant role of capillary and adsorption forces in shaping the liquid configuration in soils. In the rhizosphere the viscoelastic properties of the soil solution play a more important role and their fundamental physics as well as their implications are not well understood.