The role of connectivity for flow and transport in soils quantified using neutron imaging

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Soils are heterogeneous systems containing structures of various scales. These heterogeneities control the water distribution and hence flow and transport properties of soils. We will show that not only the amount of water but its spatial configuration as well determines the hydraulic properties. As soon as the water phase becomes continuous, transport mechanisms and hydraulic properties change abruptly. In a first part we give examples for the role of liquid phase continuity at different scales ranging from pore scale with continuous liquid films to hillslope subsurface flow dominated by the connectivity of wet patches.
To predict flow and transport processes, the spatial distribution of the liquid phase and its connectivity must be known. Due to intense interaction of neutrons with the hydrogen nucleus, neutron imaging is an optimal tool to map the distribution of the water phase. After a short introduction in principles of neutron imaging and its application in soil science, we will focus on two processes dominated by the continuity of the liquid phase.
(i) Drainage and wetting of heterogeneous porous media: Soils consist of materials differing in texture and hydraulic properties. In a soil column with coarse material embedded in fine sand material, the water content distribution was measured using speedy neutron tomography with less than one minute for a complete scan. We found that the water dynamics during a series of drainage and wetting processes were different for coarse sand structures connected to the surface and elements isolated by fine material. The experiment could not be reproduced by standard model approaches.
(ii) Evaporation: Compared to drainage and wetting processes, evaporation of water is a slow process driven by atmospheric conditions. Despite the slowness, drying processes show interesting dynamics with a period of high and constant evaporation rate followed by an abrupt decrease that is not fully understood. By means of neutron radiography, we measured the water content distribution during the constant stage of evaporation and could verify that drying rate is high as long as continuous liquid structures exist, supplying water from the wet soil to the surface. The water flow from the wet region to the surface is driven by capillary pressure difference between large and small pores.

With neutron imaging we could quantify the role of structure connectivity on water flow. Based on this knowledge we can make better predictions of flow and transport properties in soils. In addition, we can use the concept of structure connectivity to build porous media with well defined hydraulic properties by combining materials of different textures. We will close the presentation with an example of inserting continuous fine textured structures to control the water balance.