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Probing pore-scale modeling methods to determine saturated/unsaturated hydraulic properties of highly structured agricultural soils

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Novel pore-scale modelling methods are becoming popular in geophysical and petrophysical applications to determine single and multi-phase transport properties of sedimentary rocks (e.g., sandstones, carbonates, etc.). However, the implication of these techniques for soils is very limited to simple single phase flow simulations on small domains (without comparison to any laboratory measurements), or to simple pore-network approaches with more qualitative results which capture some important flow features (an especially strong limitation of these methods is usage of cylindrical pore-throats capable of containing only one fluid). In this contribution we try to determine saturated/unsaturated hydraulic properties and water retention curve (WRC) using computational fluid dynamics (CFD) and pore-network modelling approaches for three soil samples taken from different layers from an agricultural field in Suzdal area of Russian Plain.

Cylindrical samples with radius of 5 cm and volume of approximately 100 cubic cm were scanned using X-ray microtomography device SkyScan-1172 with the resolution of around 15 microns. After thresholding and bunarization the biggest possible cubes were subcropped and used for further analysis. At first, single-phase velocity fields and permeabilities were determined numerically solving Stokes equation directly on digitized 3D images. Same images were used for extraction of the pore-networks using maximal inscribed ball method. Single and two-phase (water-air) flow properties, including drainage curve (WRC) and relative permeabilities, were determined in these networks considering triangular and rectangular pore cross sections. Due to the unconventional samplers it was impossible to measure transport properties on the samples used for scanning and modelling. All measurements (bulk density, grain/aggregate size distributions, hydraulic conductivity and WRC, etc.) were performed using numerous (30-50 samples for each soil layer) conventionally obtained samples and used for comparison against scanning and modelling results.

Our results show that both modelling methods provide similar single-phase flow results, so that simplified pore-network geometry is representative for given soil samples. Comparison of simulated and measured values for unsaturated characteristics also showed very promising results. Finally, we compare simulated relative permeabilities to that obtained using conventional Mualem-van Genuchten approaches and its modifications (Durner's WRCs for multi-modal pore-sizes). Future prospects of the pore-scale modelling technique in soil science applications are outlined and current challenges are discussed.