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Understanding the influence of biofilm accumulation on the hydraulic properties of soils: a mechanistic approach based on experimental data

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The distribution, amount, and characteristics of biofilms and its components govern the capacity of soils to let water through, to transport solutes, and the reactions occurring. Therefore, unraveling the relationship between microbial dynamics and the hydraulic properties of soils is of concern for the management of natural systems and many technological applications. However, the increased complexity of both the microbial communities and the geochemical processes entailed by them causes that the phenomenon of bioclogging remains poorly understood. This highlights the need for a better understanding of the microbial components such as live and dead bacteria and extracellular polymeric substances (EPS), as well as of their spatial distribution. This work tries to shed some light on these issues, providing experimental data and a new mechanistic model that predicts the variably saturated hydraulic properties of bio-amended soils based on these data.

We first present a long-term laboratory infiltration experiment that aims at studying the temporal variation of selected biogeochemical parameters along the infiltration path. The setup consists of a 120-cm-high soil tank instrumented with an array of sensors plus soil and liquid samplers. Sensors measured a wide range of parameters in continuous, such as volumetric water content, electrical conductivity, temperature, water pressure, soil suction, dissolved oxygen, and pH. Samples were kept for chemical and biological analyses. Results indicate that: i) biofilm is present at all depths, denoting the potential for deep bioclogging, ii) the redox conditions profile shows different stages, indicating that the community was adapted to changing redox conditions, iii) bacterial activity, richness and diversity also exhibit zonation with depth, and iv) the hydraulic properties of the soil experienced significant changes as biofilm proliferated.

Based on experimental evidences, we propose a tool to predict changes in the hydraulic properties of bio-amended variably saturated soils. The new mechanistic model provides analytical equations for the water retention curve and the relative permeability. The approach consists in assuming that the porous media behaves as an ensemble of capillary tubes, which may be obtained from the experimental saturation profile. This premise is extended by considering the existence of biofilm bodies composed of bacteria and EPS. These compounds display a channeled geometry that reshapes the pore space at the pore-scale following specific geometrical patterns and changes its volume with suction. The hydraulic properties of the bio-amended soil can then be derived from the integrate contribution of the two biofilm compounds separately. Model can successfully reproduce displacements of the soil-water retention curve towards higher saturations and permeability reductions of distinct orders of magnitude.