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Preferential water and solute fluxes in a model macropored porous medium as a function of flow rate

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Macropores in soils can induce preferential flow and increase solute transport. Close to water saturation, most of the water flows through macropores at a much higher rate than it would in the same soil without any macropore. Preferential flow and water infiltration in soils with macropores have been investigated with different modeling approaches. Most of these are based on dual porosity or dual permeability approaches. These approaches consider that macropored soils are constituted by the association of two regions exchanging water, a matrix and a macropore domain, both of them obeying Darcy's law. Nevertheless, these approaches restrict preferential flow to the macropore domain and cannot simulate any enhancement of flow in the matrix surrounding the macropores. However, this hypothesis has been strongly questioned by several studies that had investigated solute transfer in macropored soils for which solute breakthrough curves (BTCs) were in complete disagreement with the flow restriction to the macropore domain. Thus, the understanding of water infiltration in soils requires more investigations regarding the effect of macropore and cracks in soils. The proposed paper aims at investigating water flow and tracer transport in a water saturated model macropored system as a function of the flow rate. Various solutes were injected in a 5 cm diameter, 14.5 cm high column filled with 425-800 μm diameter glass beads glued together. A 3 mm diameter Teflon rod inserted along the axis of the column during the preparation of the system was removed after the consolidation of the porous medium to create a macropore. Several flow rates - always ensuring a laminar flow - were tested, from values for which the diffusion transport rate is similar to the advective transport rate to values several orders of magnitude higher for which advection dominates. For all flow rates, solute BTCs were analyzed using the moment method and MIM model to quantify the volume of water visited by solutes and water fractionation between mobile and immobile zones. Besides, the column was imaged in an MRI device to track solute transfer within the model system. The experimental results clearly show that solute transfer depends on flow rate. At high flow rates, preferential flow is established, and solute BTCs are mono-modal curves. The amount of water visited in the system is roughly the same as the volume of water in the macropore. Apparently, solute and water flowed mostly through the macropore. For lower flow rates, BTCs present two peaks revealing bimodal transfer, with a fraction of the transport now occurring in the matrix. The analysis of these BTCs with the moment method and the dual permeability model allowed the quantification of the amount of water visited in the matrix and water exchange between the macropore and the matrix. These data and modeling results are compared with MRI observations and lattice-Boltzmann simulations. This study provides relevant data regarding the understanding of the effect of a macropore on water infiltration and solute fluxes in soils.