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Using multi-step outflow experiments to characterize structured soils: which model to choose?

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The multi-step outflow (MSO) method is a widely used tool for assessing soil hydraulic properties, whereas many soils exhibit preferential flow due to macropores and structural heterogeneity. We therefore investigated numerically the three following questions: (1) Do MSO data show the impact of soil structure on water flow? (2) If yes, to what extent are the common one-dimensional hydraulic models able to apprehend any preferential flow features? And (3) what are the predictive capabilities of these models parameterized with MSO data? We coupled the HYDRUS-1D model with the DiffeRential Evolution Adaptative Metropolis algorithm (DREAM) to infer common hydraulic models under virtual MSO conditions, for soil samples with different levels of heterogeneity. Regarding questions 1 and 2, our findings indicate that (i) large outflow observed during the first steps of MSO may express the behavior of a real macropore, or of structural heterogeneity inside the soil core; (ii) this behavior cannot be characterized with the MV (Mualem, 1976; van Genuchten, 1980) and DR (Durner, 1994) models whereas mobile-immobile (Philip, 1968; van Genuchten and Wierenga, 1976, MIM) and dual-permeability (Gerke and van Genuchten, 1993a,b, DUAL) preferential flow models can provide excellent fits depending on the soil architecture type; (iii) in the presence of macropores, the DUAL model performed excellently despite frequent convergence problems. Regarding question 3, a virtual infiltration front experiment revealed that predictive capabilities of the MIM parameterized with MSO are not satisfactory. This indicates that the MIM underlying concept induces excellent MSO fits for wrong reasons. Similar findings hold for the DUAL model and structured soil architectures other than macropores. For a macroporous soil, i.e., the conceptual structure for which the DUAL model was designed, the latter model parameterized with MSO data can provide consistent results under infiltration conditions. This, however, should be verified with real soils. Lastly, although neglecting the first MSO steps can result in a perfect match of the soil matrix behavior by the MV model, this methodology can induce significant errors when simulating the behavior of a macroporous soil under infiltration, because of the macropore-matrix water transfer.