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What are the respective effects of the protocol, the model and the spatial variability on uncertainty in MSO experiments?

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Multistep outflow (MSO) experiments have become a standard to characterize subsurface hydraulic properties. The main advantages of this transient approach are that the measurements are relatively quickly conducted, that both the retention and the hydraulic conductivity curves can be obtained simultaneously, and that several inputs can be used in the objective function for the inversion. However, the uncertainty on the saturated hydraulic conductivity, the potential ill-posedness of the inverse problem and the underlying hypothesis of homogeneity remain noteworthy drawbacks. Moreover users mention unexpected high flow rates close to saturation leading them to omit the first pressures step.

The objective of this study is to answer the following questions: (1) What is the most appropriate model to describe the hydraulic properties from an MSO experiment and what protocol is the most suitable to be as accurate as possible close to saturation without observing measurement artefacts? (2) What causes the largest variation in the inverted hydraulic properties: the spatial variability at the horizon scale; the choice of protocol or the choice of model? (3) Is the MSO apt to characterize the hydraulic behaviour of structured soils?

Three horizons close to the soil surface were sampled in the loamy region of Belgium under different land uses (Crop, Grass, Forest) and MSO experiments were conducted on triplicate undisturbed 1L soil cores. Fourteen suction and pressure steps were successively applied on the initially saturated samples ranging from +10 to -960 cm of equivalent pressure head at the lower boundary. Inversions were performed with AMALGAM-SO with an objective function combining the cumulative outflow, the pressure head halfway down the sample and points of the retention curve. The forward model, Hydrus-1D, was used in combination with the classical Mualem-van Genuchten (MV), the Durner (DR) and the Gerke (DUAL) models for the description of the hydraulic properties.

The variation in the cumulative outflow measurements is the greatest in the Forest horizon, followed by the Grass horizon and finally by the Crop horizon. The fitting performances of the different models are generally good on the cumulative outflow and the suction data, but less adequate on retention data. The results show that model DR using unsaturated data performs the best. It means that it is better to let the sample equilibrate with a water table levelled with the bottom of the sample before starting to simulate the water redistribution experiment. Comparing the variation observed in the measurements and the simulations, it appears that the variation in the Grass horizon is underestimated by the three models, especially close to saturation. The optimised hydraulic conductivity curves do not show the same variation at the horizon scale for the different models. The MV curves tend to be closer to each other than the ones from the other models. The ability of the MSO to provide relevant information on the hydraulic behaviour of structured soils is supported by the good fitting performances of model DR. However, the comparatively less good fits of DUAL tend to moderate this assertion. But the chosen parameterisation of DUAL might have hindered the flexibility of the model.