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Including swell-shrink dynamics in dual-permeability numerical modeling of preferential water flow and solute transport in soils

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The classical dual-permeability approach introduced by Gerke and van Genuchten for modeling water flow and solute transport in porous media with preferential flow pathways, was extended to account for shrinking effects on macropore and matrix domain hydraulic properties. Conceptually, the soil is treated as a dual-permeability bulk porous medium consisting of two dynamic interacting pore domains (1) the fracture (from shrinkage) pore domain and (2) the aggregate (interparticles plus structural) or matrix pore domain, respectively. The model assumes that the swell-shrink dynamics is represented by the inversely proportional volume changes of the fracture and matrix domains, while the overall porosity of the total soil, and hence the layer thickness, remains constant.
Swell-shrink dynamics was incorporated in the model by either changing the coupled domain-specific hydraulic properties according to the shrinkage characteristics of the matrix, or partly by allowing the fractional contribution of the two domains to change with the pressure head. As a first step, the hysteresis in the swell-shrink dynamics was not included. We also assumed that the aggregate behavior and its hydraulic properties depend only on the average aggregate water content and not on its internal real distribution.
Compared to the rigid approach, the combined effect of the changing weight and that of the void ratio on the hydraulic properties in the shrinking approach induce much larger and deeper water and solute transfer from the fractures to the matrix during wetting processes. The analysis shows a systematic underestimation of the wetting front propagation times, as well as of the solute travel times and concentrations when the volume of the aggregate domain is assumed to remain constant. The combined and interacting effects of the dynamic weight and the evolution of matrix pressure head in the shrinking approach is responsible for a bimodal behavior of the water exchange term, which in turn induces a bimodal behavior of the weight and the matrix pressure head.

Key words: Preferential flow and transport, Double permeability models, Shrinkage characteristics