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Two-phase simulation of a variable rate infiltration experiment

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Flow and transport processes in unsaturated soils are typically modeled through Richards' equation with retention and hydraulic conductivity curves obtained under static and stationary conditions, respectively. This model is commonly applied to quantify infiltration at the hillslope scale under strongly varying rainfall intensity, which leads to varying infiltration rates. To our knowledge detailed laboratory experiments reproducing this situation in large columns of length comparable with the soil thickness in Alpine hillslopes are lacking. In the present work we analyze and model variable rate infiltration experiments performed in a sand column accurately instrumented with tensiometers and TDR probes. Previous analyses revealed that data collected during transient experiments are not falling within the main wetting and drying curves obtained with careful analysis under static conditions. On the other hand, as expected, the same retention curves were able to reproduce with high accuracy experiments conducted under quasi-static conditions. As a consequence, the Richards' model was unable to reproduce the pressure distribution along the column during transient experiments conducted with variable rainfall rates. These findings have important consequences, e.g. for the prediction of runoff production and hill-slope stability. We propose that this discrepancy may be due to the influence of air flow on water pressure which is expected to be much higher under variable rainfall conditions when rapid saturation of the top soil may limit air to escape from above. In the present work, we numerically investigated this hypothesis using a two-phase air-water flow model. The numerical solver is based on a linear FEM-based pressure-pressure formulation where accurate mass balance is preserved by careful choice of spatial and temporal discretization of the nonlinear terms. The pressure-pressure formulation is chosen to ensure proper implementation of the pressure-based boundary conditions that need to be imposed at the top of the column under condition of infiltration in unsaturated soil. Simulation results show that including air dynamic into the modeling approach provides a better match between experimental and numerical simulations.