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Visualizing Macropore Flow Mechanisms using 4D X-ray Computed Tomography

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Project Abstract:
Transfer of mass between fast flow in macropores and slow flow in the soil matrix is an important control on the fate and transport of solutes. Time lapse X-ray Computed Tomography (CT) scans provide a non-invasive and non-destructive way to examine fate and transport phenomena in a heterogeneous material in 4D (i.e. transient three-dimensional imaging). Infiltration experiments were performed on a reference column of homogeneous soil and on a soil column with a substantial network of desiccation cracks running the length of the soil. The experiments were conducted by continuously dripping water containing a non-reactive NaI tracer at the top of the dry soil; the initial applied flow rate was 0.12 mL/min, but was increased to 0.33 mL/min after approximately 7 hours. Throughout the experiments the columns were located within a preclinical CT scanner (MILabs, Netherlands) and imaged with high resolution (i.e. 80 micron) at 7 minute intervals to visualize the flow pattern and evaluate mechanisms associated with flow in both the macropore and matrix domains. Quantitative, time-lapse images of water content were obtained from signal intensity changes between the dry and wet CT scans for each column.

The homogeneous column demonstrated an infiltration behavior consistent with standard concepts of unsaturated flow in soils. In contrast, however, complex flow behaviors were observed in the column containing the cracked soil. At low infiltration rates, the flow was dominated by film flow through the macropores (i.e., cracks) with comparatively little imbibition from macropore to matrix. At high infiltration rates, the macropores filled with water and a higher imbibition rate occurred within the soil matrix. A variety of features were also observed that demonstrate complex interactions between the macropores and matrix. For instance, water content increases were observed in the matrix prior to activation of macropore flow, which is consistent with the need to increase local matrix pressures above the threshold air entry pressure of the macropore. Also visible were the formation of flow networks where individual macropores were connected via short flow paths in the matrix. Overall, the results show that the wetting of the soil is a complex process reflecting different contributions from downward infiltration through the matrix and lateral wetting from vertical macropores. These complex filling processes will clearly impact the movement of radionuclides through the soil by advection, but they also have implications for the delivery of reagents that control the chemical environment of the soil, which in turn regulates the mobility of radionuclides.