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Simulation of flow patterns in soils

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Water flow in soils can be classified into two major categories: uniform and non-uniform (preferential) flow (In: Conceptual Models of Flow and Transport in the Fractured Vadose Zone, 2001, pp.149–187). The former describes a relatively slow movement of water through the porous soil matrix and can be modelled by the classical Richard's equation. The latter comprises all flow phenomena where water bypasses a portion of the soil matrix and flows through localised (i.e. preferential) paths: (i) macropore flow through root channels, earthworm borrows or fissures, (ii) unstable flow due to air entrapment, texture variability or water repellency and (iii) funnel flow along textural boundaries to name the most important ones. Unlike uniform flow, preferential flow is hardly predictable. The classical Richard's equation is based on the concept of a homogeneous representative elementary volume that is characterised by a single value of water potential, water content and hydraulic conductivity. This assumption is frequently violated especially for preferential flow through macropores (Eur J Soil Sci, 2007; 58:523–546).

As it is difficult to predict preferential flow, dye tracer studies are often done to visualise flow patterns in soils. In the process a dye solution is applied onto the soil surface. After infiltration of the tracer solution several vertical soil profiles are excavated and photographed. The images are rectified to correct any geometrical or color distortions. Thereafter, the classical image analysis consists of image classification into stained and non-stained pixels yielding binary images. The number of stained pixels per depth, the so-called dye coverage, is determined. Its shape is interpreted to identify dominant flow regimes. Weiler and Flühler (Geoderma, 2004; 120:137–153) used the width of stained paths to divide the flow regime in different classes of preferential and uniform flow. However, the class limits were specific to the experiment and cannot be generalized.

We propose a tool for simulation of stained patterns based on probabilistic transport of dye in a three-dimensional cellular automaton. Cellular automata have been studied as models of percolation, e.g. in rocks (J Rev Mod Phy, 1993; 65:1393–1534). We explore the possibility to combine different measures (classical dye coverage, width of stained objects, complexity and information measures etc.) in order (i) to compare simulated and real flow patterns and (ii) to classify the flow regime. The simulation tool could help to produce surrogate images similar to real ones thus increasing the amount of data for pattern analysis. Often, the number of experiments and/or profiles necessary to characterise a study site is chosen arbitrarily. Using the simulation tool, the number of experiments as well as the distance between profiles can be estimated.