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Visualization of subsurface preferential paths and biomat flows on forested hillslopes: experimental study

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Preferential flow paths (PFP) are known to cause rapid flux of water vertically or parallel to the slope. Animal burrows, root channels, pipes, cracks and fissures are classical types of PFPs. Recently, biomat flow was also recognized as a pathway that can rapidly transport solutes downhill with or without infiltration in the soil matrix, and, thus, can be considered as a special type of PFP. To visualize and assess the effect of PFPs on water flow we conducted five staining experiments within two different catchments in Japan: (1) landslide scar near Okaya city, Nagano Prefecture; and (2) Konohara catchment in Mie prefecture.

To visualize flow paths we used 100 L of a 2 g L-1 solution of Uranine, a fluorescent dye, and uniformly sprinkled this over a square area of 1 m2 on the hillslopes using a sprinkler with a known flow rate of 50 L h-1. After 8 h of infiltration vertical soil pits were excavated every 10-20 cm starting from 2-4 m downslope of the center of the irrigated area. Resulting staining configurations were recorded with digital photographs in UV light. All excavations were conducted during nighttime to eliminate any additional incident light. During excavation, undisturbed soil core samples were taken from both stained and unstained portions of soil. In total, 105 samples were collected at the five field tests. After the end of the experiment all core samples were transported to the laboratory and processed to assess hydraulic conductivity, grain size and other physical properties.

Quasi 3D visualization of tracer flow through the hillslope showed strongly heterogeneous percolation of fluid which occurred via clearly determinable preferential flow paths (PFP). However, only three cases of classical PFPs were observed: a macropore with diameter of about 1 cm and length of 8 cm and ant colony in one experiment, and a decayed root in another. Biomat flow was pronounced and transported tracer solution for about 0.5 m downslope before infiltrating. Laboratory analysis of undisturbed soil samples, taken from both stained and unstained portions of soil during field experiments, showed similar grain size distributions for the same catchment, while hydraulic conductivities for both stained and unstained portions had the same wide range of values (0.001 to 0.24 cm/s). Hydraulic conductivities and grain size distributions showed no strong correlation with the solute percolation into the soil both for stained and unstained samples. Grain size distributions within a large block of soil in the field did not affect soil hydrological properties; thus, packing of soil grains appears to be more important.

Solute flow through natural forested hillslopes was investigated in three dimensions via a series of staining and excavation experiments. As a result quasi 3D visualizations of tracer flow were obtained for all five experiments, representing excellent information for future modeling validations. Five soil blocks with characteristic sizes (meters in length) were studied in two different forested sites representing different soil and hydraulic conditions. The influence of biomat flow was recognized, as this uppermost soil layer conducted solute for longer distances than subsurface flow and even longer than overland flow when this occurred. No correlation between soil wetness and travel distance through the biomat was found, however, these data may be insufficient to make such general conclusions. Preferential flow dominated subsurface flow for all studied cases. Further investigations of biomat flow, influence of irrigation rates, and antecedent soil wetness on resulting staining patterns, as well as correlations with shapes of the staining patterns with other hydraulic parameters seems to be of great scientific importance.