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Particle facilitated transport of cadmium in soil macropores

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Numerous studies have shown that a part of cadmium and other strongly adsorbed chemicals adsorbed on particles < 0.01 mm, and mobilised by erosive impact of rain or irrigation could be transported via soil macropores. The objective of this study was to estimate both the share of cadmium adsorbed on soil particles < 0.01 mm, easily mobile in soil macropores, and the domain specific distribution coefficients, and use them to predict the Cd movement in response to rainstorm events.

The study was undertaken at the experimental site Kralovska luka, located in Danubian Lowland (southwest Slovakia), which is a large agriculturally managed area (1260 km^2). The area is characterized by a shallow groundwater table (0.5–3.8 m deep), and the underlying aquifer contains about 10 km^3 of freshwater. The earthworm-formed preferential paths were observed in the depths more than 1 m in the studied area.

Transport of cadmium was measured during a standard double ring ponded infiltration experiment by means of a radioactive tracer technique. The activity/concentration vs. depth distributions of the radioactive tracer ^{115m}Cd (with the halftime of 43 days and activity less than 10 MBq) and carrier $CdCl_2$ (with cadmium concentration about 2 mg l^{-1}) were estimated using the probe, in which a Geiger-Mueller detector can be lowered to any desired depth (up to 1.5 m).

Two distribution coefficients were estimated in the studied soil: the matrix distribution coefficient K_{dm}, equal to the equilibrium distribution coefficient K_d^{eq} and estimated using the conventional batch technique, and the macropore distribution coefficient K_{dM}, estimated using the modified batch technique. In both techniques, the radioactive tracer ^{109}Cd plus carrier solution (with the halftime of 330 days, chemical form $CdCl_2$, and initial cadmium concentration 50.9 mg l^{-1}) was used.

Two models, capable of simulating one-dimensional movement of cadmium in variably saturated soil profile, were applied to predict the Cd movement in response to rainstorm events. These are: the HYDRUS 5.0 code and the S1D Dual code. HYDRUS is based on the conventional single continuum approach and uses the single-domain Richards' equation and advection-dispersion equation to solve for the soil water velocity and solute concentration fields. S1D Dual is a dual-continuum model, which is based on dual-permeability approach and allows for simulation of preferential flow effects such as macropore flow and transport with domain specific sorption.

The use of single-continuum approach resulted in a significant under-prediction of the depth of cadmium penetration. The single-domain model with the equilibrium sorption, due to the fact that no preferential flow is considered, predicts that cadmium practically does not move below 10 cm depth, which contradicts the observed Cd penetration. The dual-permeability model only slightly under-predicts the measured penetration of cadmium. According to the model, 32% of the total Cd amount moves below the 10 cm depth. The dual-permeability model reveals Cd residua down to 75 cm beneath the surface, albeit in negligible concentrations.

An important feature of the presented dual-continuum approach is the consideration of the domain specific adsorption, which allows one to take into account the mobility of small soil particles (< 0.01 mm) in the macropores. It was experimentally confirmed that these particles may carry substantial amount of adsorbed cadmium. It is shown that the particle mobility can be incorporated in the dual-continuum transport model by decreasing the distribution coefficient in the macropore domain according to the results of the modified batch test.