Contribution ID: **388** Type: **Oral Presentation**

Contribution of soil structure and colloidal particles to the leaching of PFAS in undisturbed soil columns

Monday 19 May 2025 17:40 (15 minutes)

The term 'per- and polyfluoroalkylated substances'(PFAS) refers to a broad class of molecules containing at least one perfluorinated methyl (-CF3) or methylene (- CF2-) group1. Their properties have led to their use in a large number of applications since the 1940s. Unfortunately, they are persistent in the environment or metabolised into persistent substances, bioaccumulative and harmful to ecosystem health.
Soil plays a key role in the fate of PFAS: it delays their arrival in aquifers and allows them to be internalised by crops and biota. Since 20092, the transport of PFAS in soils has been studied by lab experiments, mainly in model soils: columns filled with sand or crushed and recompacted soil, saturated with water and artificially contaminated with one or more molecules. These experimental situations have limitations because: (i) soils are often contaminated by mixtures of PFAS3, which can lead to competitive adsorption phenomena; (ii) in situ, PFAS are present in soils for years, allowing slow processes to affect their fate 6,7 (e.g., metabolisation, transport to the microporosity by diffusion or during humidification/drying cycles); (iii) two modes of transport in structured soils have not been considered: (a) transport as colloidal phase, facilitating the mobility of molecules with a strong affinity for the soil constituents and which would otherwise have little mobility8. This mechanism could contribute to the mobility of long-chain PFASs, interacting strongly with organic matter, which is itself assumed to be immobile; (b) preferential transfer into the largest porosity in the soil (macropores linked to the action of soil fauna or roots), facilitating the vertical transfer of PFAS present in the colloidal or aqueous phase.
The mechanisms that determine the fate of PFAS in the experimental situations studied so far are not necessarily the same as those under field conditions. We have explored these in situ mechanisms by considering a more realistic experimental situation: simulated rainfall on columns of undisturbed soil from a former firefighting training site, contaminated by a cocktail of molecules.
The X-ray tomography reveals the diversity of pore size and connectivity even at column scale, mainly contributing to the hydrodynamics during rainfall (preferential flow and/or predominantly matrix flow, even ponding).These experiments showed that (i) the hydrodynamic conditions, linked to soil structure, had a moderate influence on the extent of colloidal-phase transport of PFASs, more related to the location on the hydrograph, (ii) when the perfluorinated chain length nc was ≤ 7, diffusion was the mechanism limiting transport, (iii) colloidal particles facilitated the mobility of certain fluoro-telomers and perfluorinated acids with n≥8, so far only shown with PFOA in model soils5. These results enabled us to refine the conceptual model of the fate of PFASs in soil and to propose the mechanisms that should be studied to improve it. Competitive sorption phenomena - rarely studied in soils - could be a mechanism that should not be overlooked in understanding the transport of PFAS in mixtures.

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Session Classification: MS08

Track Classification: (MS08) Mixing, dispersion and reaction processes across scales in heterogeneous and fractured media