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Modeling diffusion control on organic matter decomposition in unsaturated soil pore space

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Soil Organic Matter decomposition is affected by soil structure and water content, but field and laboratory studies about this issue conclude to highly variable outcomes. Variability could be explained by the discrepancy between the scale at which key processes occur and the measurements scale. We think that physical and biological interactions driving carbon transformation dynamics can be best understood at the pore scale. Because of the spatial disconnection between carbon sources and decomposers, the latter rely on nutrient transport unless they can actively move. In hydrostatic case, diffusion in soil pore space is thus thought to regulate biological activity. In unsaturated conditions, the heterogeneous distribution of water modifies diffusion pathways and rates, thus affects diffusion control on decomposition.

Innovative imaging and modeling tools offer new means to address these effects. We have developed a new model based on the association between a 3D Lattice–Boltzmann Model and an adimensional decomposition module. We designed scenarios to study the impact of physical (geometry, saturation, decomposers position) and biological properties on decomposition.
The model was applied on porous media with various morphologies. We selected three cubic images of 100 voxels side from μCT-scanned images of an undisturbed soil sample at 68μm resolution. We used LBM to perform phase separation and obtained water phase distributions at equilibrium for different saturation indices. We then simulated the diffusion of a simple soluble substrate (glucose) and its consumption by bacteria. The same mass of glucose was added as a pulse at the beginning of all simulations. Bacteria were placed in few voxels either regularly spaced or concentrated close to or far from the glucose source. We modulated physiological features of decomposers in order to weight them against abiotic conditions.

We could evidence several effects creating unequal substrate access conditions for decomposers, hence inducing contrasted decomposition kinetics: position of bacteria relative to the substrate diffusion pathways, diffusion rate and hydraulic connectivity between bacteria and substrate source, local substrate enrichment due to restricted mass transfer. Physiological characteristics had a strong impact on decomposition only when glucose diffused easily but not when diffusion limitation prevailed. This suggests that carbon dynamics should not be considered to derive from decomposers' physiology alone but rather from the interactions of biological and physical processes at the microscale.