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Self-organisation and emergent phenomena of the soil microbial decomposer system: do we need to account for it in soil organic matter turnover models?

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Soil organic matter turnover models traditionally represent organic matter and microbial biomass as aggregated pools, and soil processes as aggregated fluxes. While this is an inevitable simplification of reality, it also represents a reductionistic ‘upscaling’ approach, which neglects that the soil system behavior could be driven bottom-up by a self-organizing network of microscale interactions. In this talk, I would like to shed light on this latter option.
Microbial decomposition of organic matter requires the concerted action of functionally different microbes, which interact with each other in a spatially structured micro-environment. From complex systems theory, it is known that interactions among individuals at the microscale can lead to an ‘emergent’ system behavior at the macroscale. Such an emergent behavior, or self-organisation, adds a new quality to the system which cannot be derived from the traits of the interacting agents.

One way to analyse emergent behaviour of complex systems is individual-based modelling. Here, I will present examples from an individual-based microbial decomposer community model, which simulates production, diffusion and uptake of enzymatic products by individual microbes of different functional types in a spatially explicit micro-environment. At the same time the model computes element flows of C and N through the decomposer system in a stoichiometric explicit way. The model thus allows to explore collective system behavior emerging from interactions among microbial decomposers and to link it to system-scale turnover rates of organic C and N.

Applications of this model revealed insights into the potential of self-organisation within microbial decomposer communities and their effects on organic matter turnover. They showed, for example, the emergence of a community-regulated ‘buffering’ behaviour, which stabilises decomposition rates in the face of increasing extracellular enzyme efficiencies. They also demonstrated that, under certain conditions, spatial self-organisation of microbial decomposer communities leads to a spatial restructuring of nutrient pools at the microscale with fundamental consequences for C and N cycling. These spatial organization pattern, however, did not change gradually, but in an abrupt, step-wise fashion with changing environmental conditions, triggering a corresponding step-wise response of C and N cycling at certain tipping points.

Together, these results demonstrate that microbial interactions at the micro-scale have the potential to drive emergence of qualitatively new system properties at the macro-scale, which may not be foreseeable by traditional ‘top-down’ designed soil organic matter turnover models. I thus propose that mechanisms of community-driven regulation and emergent behavior of microbial decomposer communities need to be explored and better understood, to allow their future implementation into biogeochemical models.