MEPSOM

Multiscale modelling and Emergent Properties of Microbial degradation of Soil Organic Matter

UNDERSTAND MICROBIAL FUNCTIONS AT MICROSCOPIC SCALES IN ORDER TO PREDICT THE DYNAMICS OF CARBON IN SOIL

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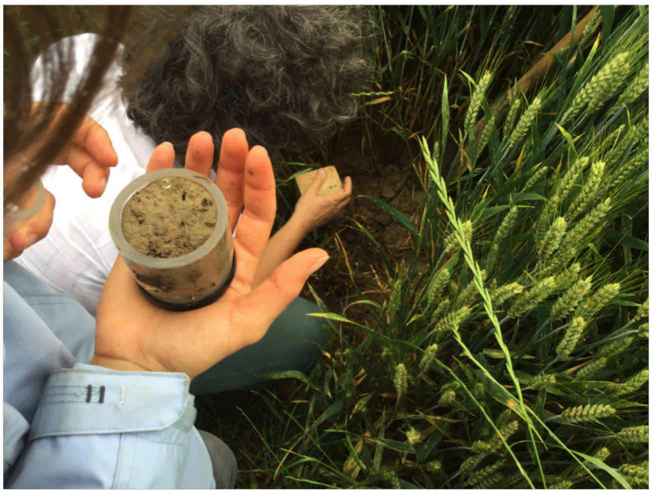
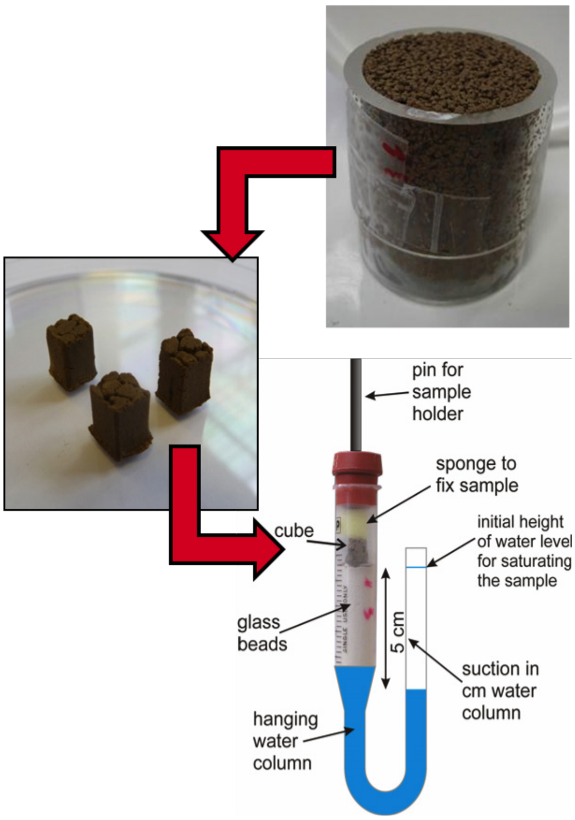
MICROBIAL HABITAT, A KEY TO UNDERSTANDING AND MODELING SOIL CARBON DYNAMICS

Soils contain three times more carbon than atmosphere, as organic matter emitting greenhouse gases. However, current models do not satisfactorily predict soil organic matter biodegradation, particularly in the context of climate change. A proposed explanation is that these models consider soil as a black box and do not take into account how organisms function in their habitat, which is a complex and heterogeneous network of pores, partially filled with water and air, with limited access to organic resources. MEPSOM aimed to establish a new approach for modeling organic matter biodegradation, based on an explicit representation of microorganisms environment, and prioritize certain biotic and abiotic factors of microbial activity in soils.





INNOVATIVE MODELS OF ORGANIC MATTER DEGRADATION, PRIORITIZING MICROBIAL ACTIVITY FACTORS

1. Soils are heterogeneous and structured environments, including micrometer scales,
2. Organic resources and microorganisms are spatially distributed heterogeneously,
3. Microbial communities are diverse, have contrasted physiological characteristics and ecological requirements.

We have developed three 3D models, representing the distribution of solids (mineral or organic), pores -partially filled with water or air- and microorganisms at the µm to mm scales. Microorganism growth and degrading activity depend on local conditions and physical access to organic substrates, which relies on diffusion. Description of sand or soils samples is based on X-ray micro-tomography. Experiments were performed to calibrate and test models or to analyze the hierarchy of biotic (microbial diversity) and abiotic (soil structure, water status) factors on biodegradation.

APPROACH

MEPSOM closely combines modeling and experimentation

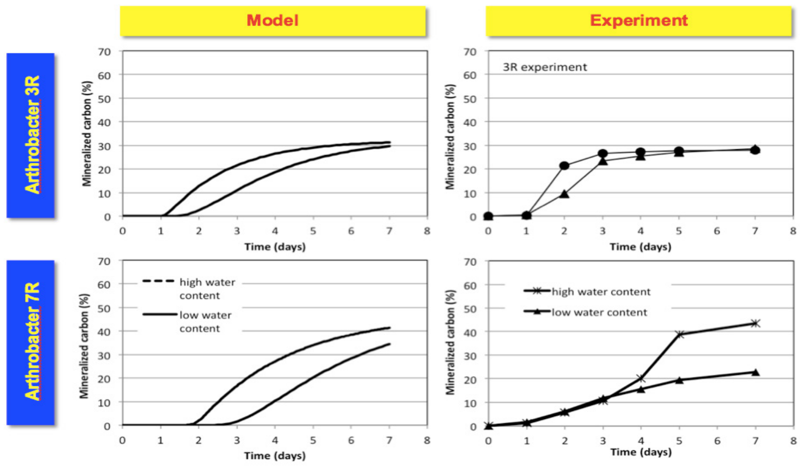
• The conceptual representation of what controls the microbial degradation of organic matter in soil led us to three models. These models are either focused on bacteria (MOSAIC, LBM) or on fungi (µFUN), because these microorganisms have very distinct growth and colonization patterns, as well as a distinct dependency to local conditions of their environment. The models also correspond to two different physical and mathematical approaches of the description of a 3D pore system, either a voxel based description (µFUN, LBM) or one based on geometrical primitives (MOSAIC).

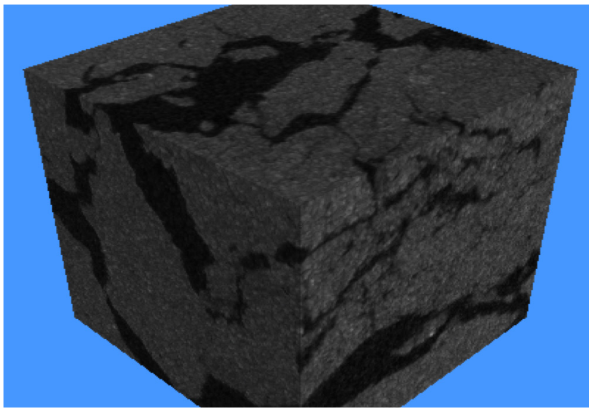
• These new models need to be parameterized for variables describing the system, but such information, at the microscopic scale is often not easily available (such as the spatial distribution of solid particles and pores). Experiments and modeling approaches were then devoted to test methods to obtain the relevant information concerning the spatial distribution of solids, voids, water and air, organic matter and microorganisms.

• Given the complexity of soil systems, the models were first tested in their ability to describe the biological functioning of simple systems. In these systems, the physical habitat was made of sand partially saturated with water. They contained only one category of organic matter: simple molecules or decomposing plant debris, named particulate organic matter (POM) and they harbored only either bacteria or fungi. Specific experiments were then implemented.

• Modeling complex systems like soils could not be done without obtaining further knowledge on the hierarchy of drivers of the microbial degradation of organic matter. A series of experiments was then devoted to test the relative importance of microbial diversity and microbial community structure versus that of their physical habitat in decomposition. The importance of the location of both microorganisms and substrates was also investigated at the pore scale (location of microorganisms and substrates in different pore size classes) and at the core scale (distance between substrates and microorganisms).

• So as to ensure the cohesion and efficiency of the project, all experiments were performed on the same simple systems and on the same soil.





MAIN RESULTS

Results of our experiments and modeling confirm that the high variability in CO2 evolution often reported in field situations can be explained from processes and interactions occurring at the microscopic scale in soils. This demonstrates the need for a new class of C models that accounts for microbial dynamics and accessibility of substrate as key drivers of C sequestration. Whereas it has been widely advocated in recent years that such an approach was required, this task seemed somehow impossible, and the MEPSOM project is the first one to our knowledge to undertake it. This was possible thanks to the set up of a multidisciplinary consortium working on a small number of experimental systems and models, combining closely modeling and experiments. This project has set the basis for a new interdisciplinary approach: a strong consortium has been built, novel mathematical tools and models are available and should be developed in the future, using additional dedicated experiments, and should be used through scenario modeling to identify the possible impacts of changes in water regime on the microbial decomposition of soil organic matter.

We have developed three original models, MOSAIC, LBM and µFUN. In µFUN and LBM the soil is discretized into voxels, formalisms based on partial differential equations or lattice Boltzmann. In MOSAIC II the soil pores are approximated with geometric primitives, which are also biological functional units and the calculation methods are algorithmic. The microorganisms are bacteria (MOSAIC, LBM) or fungi (µFUN) and organic solutes diffuse into the soil pores filled with water. We have shown that the characteristics of the microbial habitat had more impact on the biodegradation of organic matter than the diversity of microbial communities. Our results and the tools developed will allow to test the impact of changes in soil water regime, which might result from climate change, on the biodegradation of organic matter and soil CO2 emissions.

Results have been valued so far in 8 papers in international journals, 28 talks in conferences, including several invited ones, and 5 PhD theses.

FOLLOW-ON PROJECTS SIMUPOR & SOILMU-3D

MEPSOM was one of the first attempts to study the influence of the microscopic pore space heterogeneity on physical and biological dynamics within soils.

• Forthcoming project Soilmu-3D deals with upscaling and downscaling between micro-scale and field scale.

• Next project SIMUPOR investigates how the same methodological scheme can be applied in different specific applications.