Feedback of Belowground Processes to Global Change Mediated by Microbial Community Dynamics

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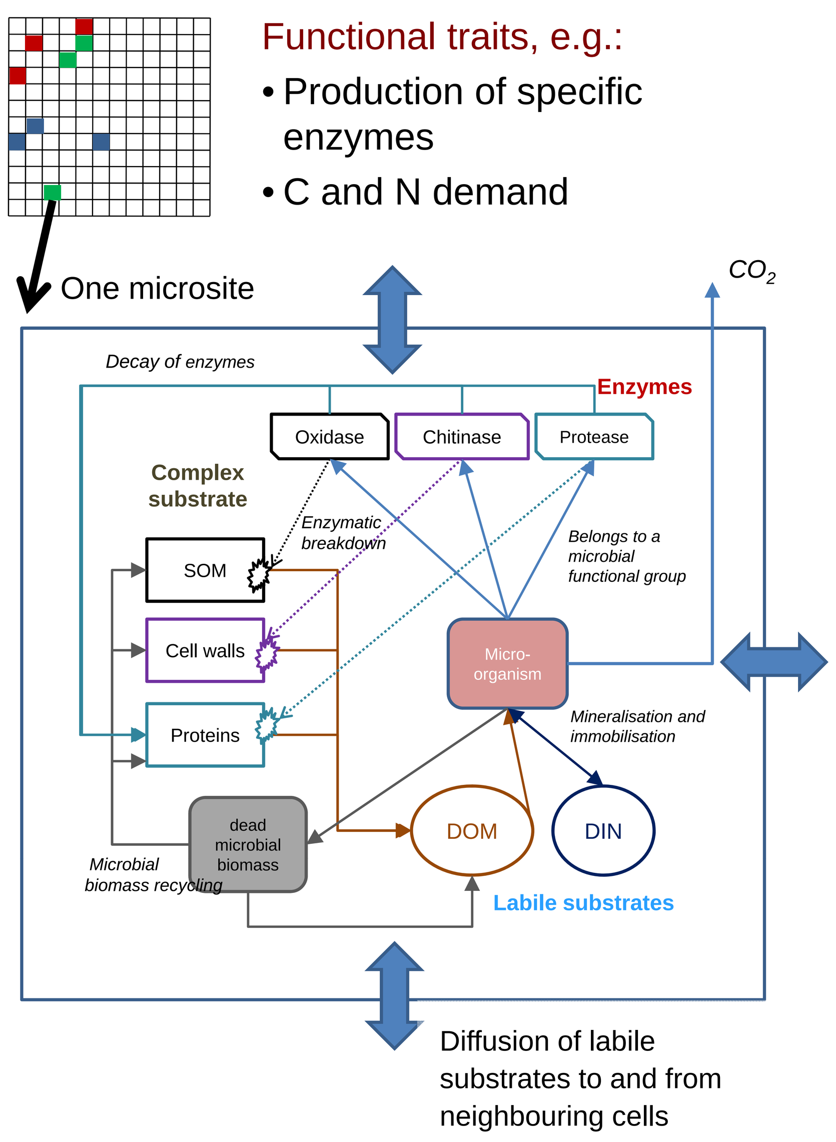
Background

Microbial degradation of plant litter and soil organic material ("soil respiration") causes an annual CO_2 flux equivalent to 8% of today's atmospheric carbon pool. Any changes in this rate may significantly influence the atmospheric carbon (C) budget. Soil respiration has been found to be sensitive to temperature, moisture as well as to C and nutrient availabilities. Recent studies have shown that changes in soil respiration rates were most often accompanied by changes in microbial community composition, pointing to a link between community structure and function. Despite its significance for the global C budget, the mechanisms underlying the degradation of soil organic material are still only poorly understood.

Modeling microbial functional groups

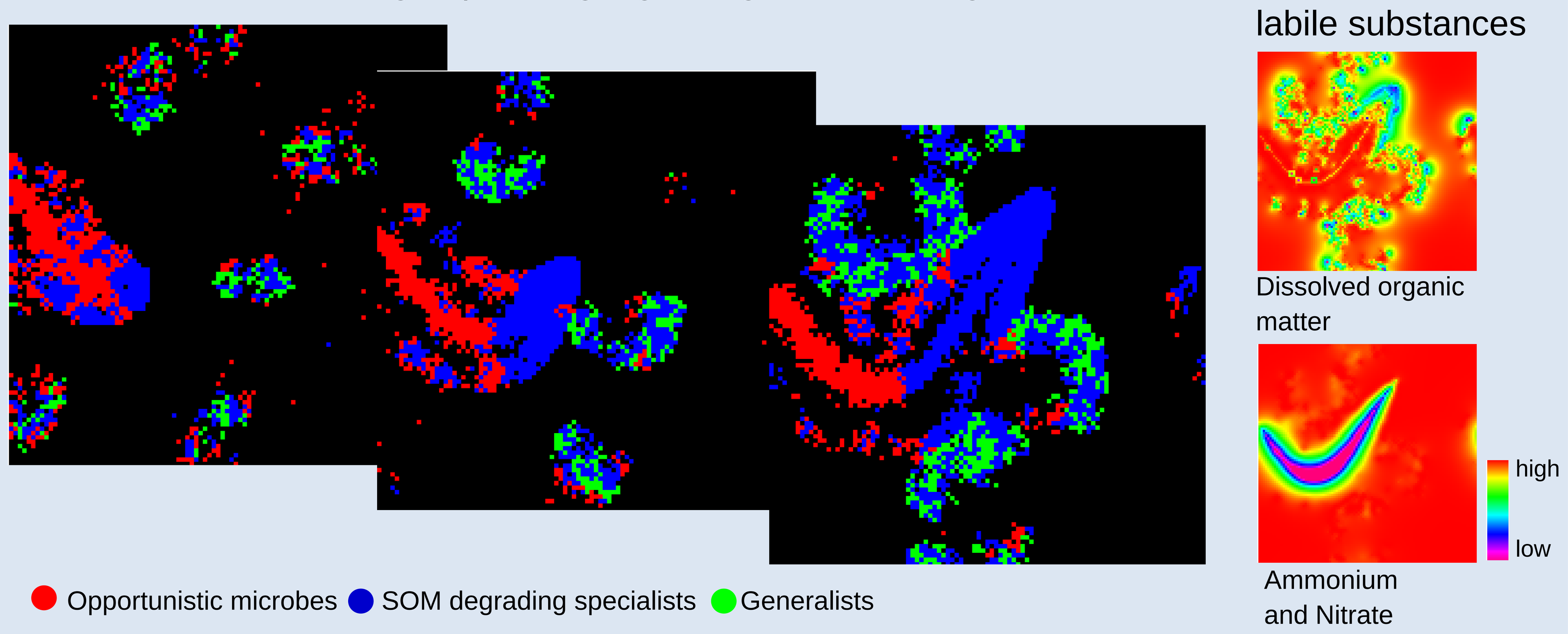
- Spatially structured: 10.000 microsites on a two-dimensional grid
- Each microsite can be inhabited by one microbe belonging to a specific functional group
- Functional groups are characterized by functional traits
- Microbes carry out carbon and nitrogen (N) transformations in each microsite
- Diffusion of labile substances across the grid enables competitive and synergistic interactions
- Microbial community dynamics emerge as a result and feed back on degradation processes and thus resource availability.



Rhizosphere priming

Labile C released by plant roots is known to enhance degradation of soil organic matter, a process called "rhizosphere priming". The mechanism behind it is still unclear, although priming is increasingly considered as a major factor governing the rate of soil C turnover. Recent studies have shown that the amount of C released by plant roots is increasing with increasing atmospheric CO_2 concentrations, which may affect soil C turnover on a global scale.

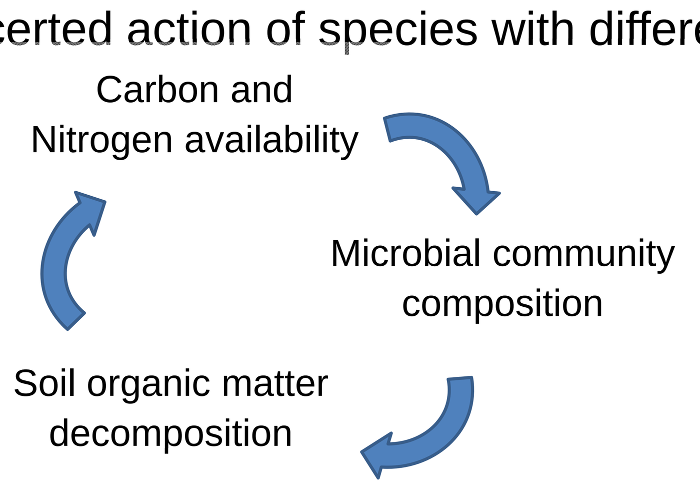
Distribution of microbial groups along a growing root releasing labile carbon



Our model results demonstrate that the local input of labile C along a growing root immediately structures the rhizosphere community. Fast growing, opportunistic microbes (red) thrive directly at the roots surface. Around them and especially at the growing root tip a layer of soil organic matter degrading microbes (blue) forms utilizing energy and nutrients being released from the root and the turnover of opportunistic microbes. This leads to higher rates of soil organic matter degradation around the growing root tip.

A soil ecological concept

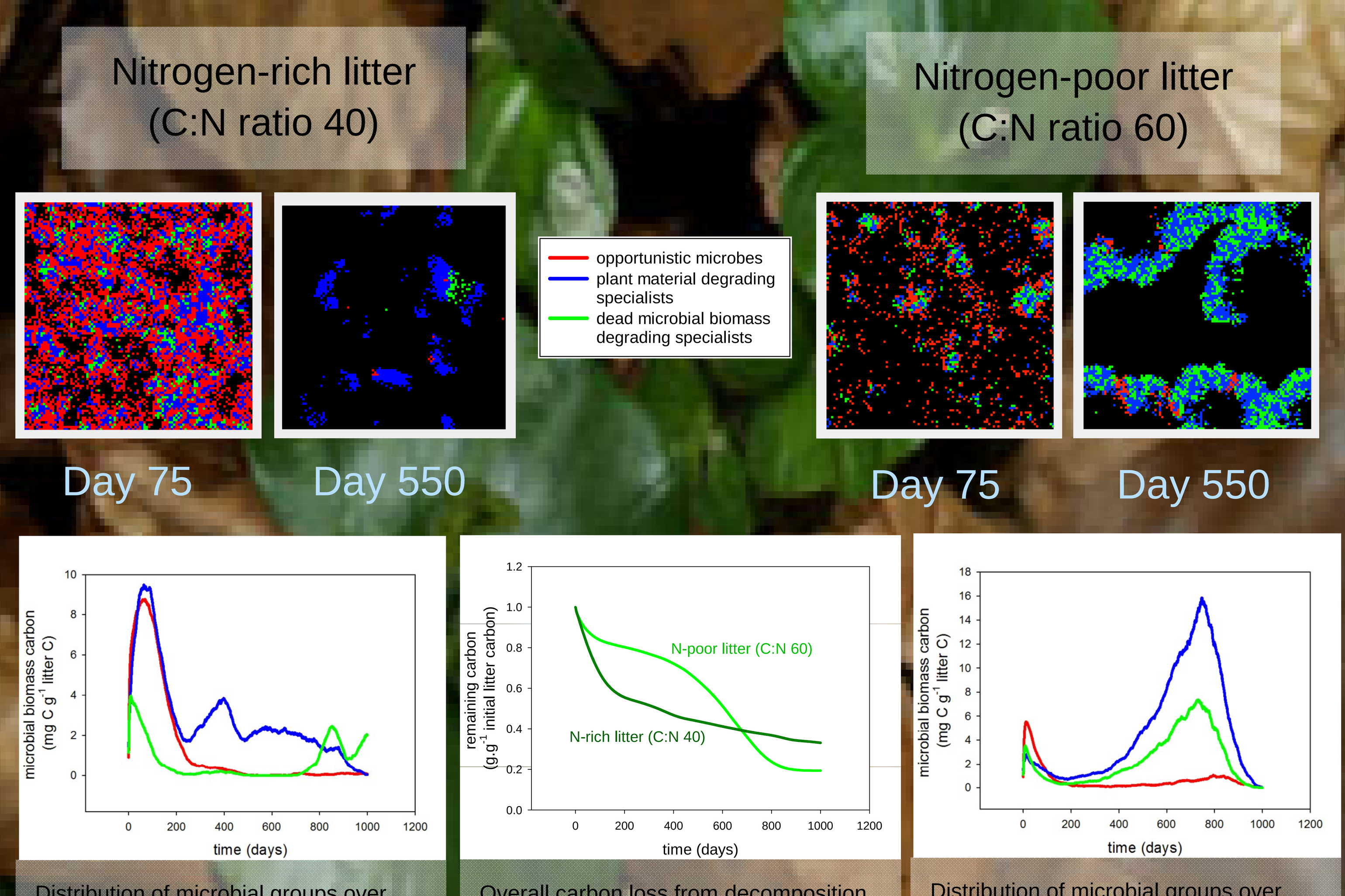
- Soil is a complex and heterogeneous environment consisting of a magnitude of microsites with different abiotic conditions and resource availabilities, which promotes the exceptionally high biodiversity of soil microbes
- Different microbial species fulfill different functions in the soil and have distinct nutrient and energy demands (functional diversity).
- The degradation of chemically complex organic material requires the concerted action of species with different functional traits.



Understanding mechanisms of soil carbon turnover requires understanding the link between resource availability, microbial community dynamics, and soil processes.

Litter decomposition

Plant litter decomposition comprises the largest part of the carbon(C) flux from terrestrial ecosystems to the atmosphere. Litter decomposition rates have been found to depend (amongst others) on nitrogen (N) availability for microbes. Increasing N input into natural ecosystems from industrial sources gradually increase N content in plant litter, which may affect its decomposition rate. Litter decomposition is usually accompanied by a succession of microbial groups.



Distribution of microbial groups over time with initial litter C:N=40

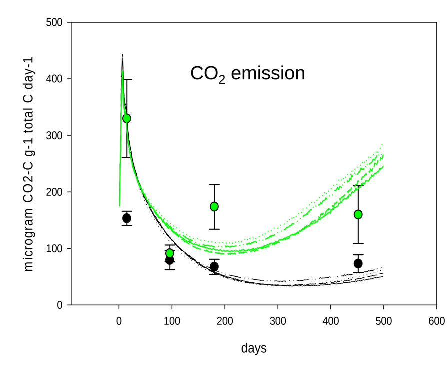
Overall carbon loss from decomposition in the two litter types.

Distribution of microbial groups over time with initial litter C:N=60

Our model shows strong interactions between the chemical transformation of litter and microbial community dynamics during the decomposition process. The initial C:N ratio determines the rate of decomposition by mediating a specific microbial community dynamics.

Model calibration

Model parameters were calibrated using a Bayesian approach (Markov-chain Monte Carlo): 15 model output variables were fitted to empirical measurements obtained during a long time litter decomposition experiment.



Model output versus data for microbial respiration during litter decomposition: circles: empirical measurements, lines: model output

Conclusion

We integrated microbial ecology into a biogeochemical model in a bottom-up approach. Soil respiration rates emerge as a result of ecological interactions between microbes at the individual level. Model results are consistent with empirical observations and provide insights into the mechanisms driving soil organic matter turnover. Our results demonstrate the importance of dynamic interactions between microbial communities and soil organic matter turnover at the microscale, which may drive the overall response of soil CO_2 emissions to changing environmental conditions.