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Modeling the survival responses of a multi-component biofilm to environmental stress

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Biofilms are consortia of microorganisms embedded in self-produced matrices of biopolymers. The survival of such communities depends on their capacity to improve the environmental conditions of their habitat by mitigating, or even benefitting from some adverse external factors. The mechanisms by which the microbial habitat is regulated remain mostly unknown. However, many studies have reported physiological responses to environmental stresses that include the release of extracellular polymeric substances (EPS) and the induction of a dormancy state. A sound understanding of these capacities is required to enhance the knowledge of the microbial dynamics in soils and its potential role in the carbon cycle, with significant implications for the degradation of contaminants and the emission of greenhouse gases, among others.

We present a numerical analysis of the dynamics of soil microbes and their responses to environmental stresses. The conceptual model considers a multi-component heterotrophic biofilm made up of active cells, dormant cells, EPS, and extracellular enzymes. Biofilm distribution and properties are defined at the pore-scale and used to determine nutrient availability and water saturation via feedbacks of biofilm on soil hydraulic properties. The pore space micro-habitat is modeled as a simplified pore-network of cylindrical tubes in which biofilms proliferate. Microbial compartments and most of the carbon fluxes are defined at the bulk level. Microbial processes include the synthesis, decay and detachment of biomass, the activation/deactivation of cells, and the release and reutilization of EPS. Results suggest that the release of EPS and the capacity to enter a dormant state offer clear evolutionary advantages in scenarios characterized by environmental stress. On the contrary, when the conditions are favorable, the diversion of carbon into the production of the aforementioned survival mechanisms does not confer any additional benefit and the population of active cells decline. The proposed model (including complex relations between active biomass and biofilm) has been proved useful to capture the most relevant processes involved in biofilm proliferation and its adaptation to environmental conditions. These aspects are largely neglected in biogeochemical models, but could be relevant in soils where strong feedbacks of microbial activity on hydraulic properties emerge.