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Physical protection of organic matter: a biophysical model

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Soils contain the largest terrestrial reservoir of organic carbon, and dynamics in soil organic matter (SOM) turnover will drive carbon-climate feedback over the coming century. To date, most SOM dynamics have been simulated with pool-based models, rather than explicit considering accessibility. These models have substantially advanced our understanding of soil organic matter dynamics, informed decision making and soil management. However, questions need to be asked if capturing physical protection this way reflects our increased understanding of the microscale environments in soils. An alternative way to look at accessibility is to focus on the pore geometry as the soil-phase where microbes reside, move, and gases, enzymes and dissolved organic matter diffuse. Pore geometry is a critical factor in affecting the accessibility of organic matter for microorganisms, and the challenge is to capture this accessibility explicitly in models thereby bringing more physical realism in our approach. Such an approach would allow for a process driven sliding scale of accessibility. We will demonstrate how such an approach can be developed and exemplify this for fungal mediated breakdown of SOM. First, we will empirically test how pore geometry affects fungal spread, and how this can lead to threshold like behaviour or tipping points. We will then capture this in a spatial explicit model and apply this to a 3-dimensional soil environment. As we gradually enhance the complexity of the soil environment, we will redefine pore accessibility as we seek to relate pore-connectivity on organic matter turn-over. For a complex system the question of what constitutes accessibility is not easy to address and needs to consider more than the pore sizes and exclusion. For example, for fungal mediated processes, accessibility may be determined by various characteristics, namely: (i) the total volume of the connected pore space; (ii) the connected air-filled pore volume, through which fungal spread predominantly occurs and gasses diffuse, (iii) the connected water phase volume, through which dissolved C diffuses, (iv) the distribution of particulate organic matter that fuels fungal growth, and (v) biological traits such as those enabling translocation through for example fungal hyphal networks. When we consider these various processes that have impact on SOM degradation we find the following: i) connectivity of the water phase is critical as it regulates diffusion of dissolved organic matter; this is even so for fungi that preferentially spread through air-filled pores, and ii) whether fungi behave as R or K strategists is not just determined by fungal traits but to a large extend depends on the physical environment. Consequently, selective pressures can be exerted by physical conditions. It was not possible to identify a key physical driver as the dynamics were mostly determined by interactions between the various types of connectivity. These different pathways tend to compensate each other, enhancing stability of the process against environmental variability. We argue that when multiple connected pathways underpin a soil function this leads to resilience of soils to perturbations and are that connectivity and interactions are key drivers of soil health.