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Identifying the drivers behind the respiration pulses and microbial activity observed after soil rewetting – A modelling analysis

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Most terrestrial ecosystems experience extended periods of drought followed by rainfall events. The response of soil microorganisms to such pronounced cycles of drying-rewetting (DRW) triggers some of the most dynamic patterns in microbial activity and soil respiration. The resulting biogeochemical reactions may even dominate the annual release of carbon to the atmosphere. Despite their great significance, the mechanisms underlying microbial metabolic dynamics induced by DRW in soils are still debated and several questions remain open – Which mechanisms control the intensity and duration of the respiration pulses? How are the activity, growth and respiration rates connected to DRW?

Recent experimental studies have identified two categorically different microbial responses to DRW. One results in a more efficient way of using carbon where microorganisms start synthesizing new biomass immediately upon rewetting, coinciding with respiration rates that peak immediately and then decrease exponentially ("Type 1"). A second one results in a more 'wasteful' response in which microorganisms grow exponentially after an extensive lag period while maintaining a sustained period of elevated respiration ("Type 2"). Empirical evidence and theoretical work point to several potential processes and mechanisms that control such dynamics. On the one hand, the amount of labile carbon is increased after rewetting because the organic matter accumulated during the preceding dry period becomes available, sourced from e.g. dead microbial biomass, exoenzymes, and/or previously physically protected soil aggregates. On the other hand, microbial physiological processes such as osmoregulation and dormancy/reactivation of cells are activated as a response to the extreme environmental changes.

In this work, we interrogate the mechanisms proposed and formalize them via a process-based soil microbial model. It assumes strong feedbacks between microbial activity and soil moisture at the pore-scale and determines the availability of carbon and water from the soil hydraulic properties – aspects that are largely neglected in most previous biogeochemical models. The proposed model has been proven useful to capture the general microbial patterns observed after rewetting of dry soils, unravelling the putative drivers of microbial activity, growth and respiration. Through calibration, we identified osmoregulation, dormancy and accumulation of carbon during drought as the three necessary processes to capture the dynamics observed. We found that the type of response to DRW can be explained entirely by the harshness of the disturbance experienced by the microbes, with more severe drying resulting in the type 2 response, and we determined the periodicity and intensity of the DRW cycles that can trigger a switch between response types. Finally, we could explore the implications for the global carbon cycle under scenarios of climate change.