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Mechanistically modeling the microbial growth and respiration responses to rewetting dry soils

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The terrestrial ecosystems in arid, semi-arid and Mediterranean areas are characterized by extended periods of drought followed by rainfall events, creating pronounced cycles of drying-rewetting (DRW). As a consequence, the resident microorganisms need to respond to these extreme dynamics in environmental conditions, which is known to induce some of the most dynamic patterns of microbial growth and respiration documented. Thus, DRW events can account for the dominant fraction of carbon dioxide emissions to the atmosphere in ecosystems affected by drought, with strong implications for the global carbon cycle and climate change.

Despite their great significance, the mechanisms underlying microbial metabolic dynamics induced by DRW in soils are still debated and several questions remain open – What is the carbon source sustaining the increased proliferation of microbes? Which mechanisms control the intensity and duration of the respiration pulses? How the growth and respiration rates are connected after rewetting? Specifically, two categorically different microbial responses to rewetting have been identified; a more efficient way of growing where microorganisms start growing immediately upon rewetting, coinciding with respiration rates that peak immediately and then decrease exponentially (“Type 1”), or more ‘wasteful’ response in which bacteria grow exponentially after an extensive lag period (up to 20 h), with a sustained period of elevated respiration, sometimes followed by a further increase coinciding with the emergence of bacterial growth (“Type 2”). Previous studies have suggested that the response upon rewetting could be related to the harshness of the disturbance as experienced by the microbes, with more “harsh” (i.e. longer or more severe) drying resulting in a Type 2 response. However, the specific underlying mechanisms remain unknown.

Empirical evidence and theoretical work point to several potential processes and mechanisms that strongly influence the nature of microbial 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 and extracellular microbial products such as exoenzymes and polysaccharides, and previously physically protected soil aggregates are disrupted during intense dry periods. On the other hand, microbial physiological processes such as osmoregulation, dormancy/reactivation of cells, and synthesis/reuse of extracellular polymeric substances are activated as a direct response to the extreme environmental changes from wet to dry, or dry to wet, conditions.

In this work, we address the hypotheses proposed and formalize them via a hierarchy of process models of different levels of complexity. Specifically, we evaluate the simplest modeling approach that allows capturing the general microbial patterns observed after rewetting of dry soils. We also identify the environmental and microbial factors that can trigger a switch from the type 1 to the type 2 response to rewetting, and vice versa. These scenarios allow disentangling the putative drivers of microbial growth and respiration pulses in a set of virtual experiments that subsequently can be interrogated by empirical experiments.