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Uncovering the diverging factors that control microbial carbon sequestration and respiration in soils exposed to moisture fluctuations

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Soils are continuously exposed to recurrent cycles of drying and rewetting, for instance, when extended periods of drought are followed by rainfall events. For nearly a century it has been known that the balance of the soil C budget is affected by these moisture fluctuations, which is characterized by very large mineralization losses when dry soils are rewetted. In some ecosystems, the soil C losses resulting from this phenomenon ("the Birch effect") even represent a dominant fraction of the annual C-transfer from soils to the atmosphere. However, to balance the soil C budget, the microbial control of C input to the soil during these events also needs to be known. It was recently discovered that the growth of microorganisms, driving C stabilization in soils, has a far slower response to rewetting than does respiration. This results in a pronounced and dynamic disconnection between the mechanisms controlling microbial respiration and growth. Despite the significance of this decoupling for the C budget and the long-term balance of soil C stocks, this feature has so far been entirely overlooked by biogeochemical models, potentially leading to a failure to capture the capacity of soils to mitigate the effects of climate change.

To close this knowledge gap, we developed a new process-based soil microbial model that includes a wide range of physical, chemical and biological mechanisms to explore the nature of soil C dynamics induced by moisture changes. The model was validated using respiration data from soils exposed to repeated cycles of drying and rewetting which has been frequently studied (Miller et al., 2005, Soil Biol Biochem) and compared to other models existing in the literature. The proposed model was able to capture, at once and for the first time, the respiration data and the decoupled behaviour of growth. Simulation results identified the drought-legacy effects on C use efficiency and microbial physiology as the main mechanisms controlling the soil responses to moisture fluctuations. This represents a critical step towards unravelling the C sequestration capacity of soils, its drivers and feedback on climate.