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Stoichiometric vs hydroclimatic controls on soil biogeochemical processes

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Soil nutrient cycles are controlled by both stoichiometric constraints (e.g., carbon to nutrient ratios) and hydroclimatic conditions (e.g., soil moisture and temperature).
Both controls tend to act in a nonlinear manner and give rise to complex dynamics in soil biogeochemistry at different space-time scales.

We first review the theoretical basis of soil biogeochemical models, looking for the general principles underlying these models across space-time scales and scientific disciplines. By comparing more than 250 models, we show that similar kinetic and stoichiometric laws, formulated to mechanistically represent the complex biochemical constraints to decomposition, are common to most models, providing a basis for their classification. Moreover, a historic analysis reveals that the complexity (e.g., phase space dimension, model architecture) and degree and number of nonlinearities generally increased with date, while they decreased with increasing spatial and temporal scale of interest.

Soil biogeochmical dynamics may be suitable conceptualized using a number of compartments (e.g., decomposers, organic substrates, inorganic ions) interacting among each other at rates that depend (nonlinearly) on climatic drivers. As a consequence, hydroclimatic-induced fluctuations at the daily scale propagate through the various soil compartments leading to cascading effects ranging from short-term fluctuations in the smaller pools to long-lasting changes in the larger ones. Such cascading effects are known to occur in dryland ecosystems, and are increasingly being recongnized to control the long-term carbon and nutrient balances in more mesic ecosystems.

We also show that separating biochemical from climatic impacts on organic matter decomposition results in universal curves describing data of plant residue decomposition and nutrient mineralization across the globe. Future extensions to larger spatial scales and managed ecosystems are also briefly outlined. It is critical that future modeling efforts carefully account for the scale-dependence of their mathematical formulations, especially when applied to a wide range of scales.