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Response of heterotrophic soil respiration to changes in moisture: what do data and theory tell us?

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Soil moisture strongly affects the dynamics of soil organic matter and is central to predict changes in soil carbon stocks from site to global scales. Despite its importance in controlling soil carbon transformations, the mechanisms involved are still poorly represented in models, mostly as highly simplified empirical relationships. To improve such representations we approached the problem in two ways: First, a synthesis analysis of laboratory data was performed to explore the variability of moisture effects on heterotrophic respiration across soil types. Second, we used theory and established relationships to build a semi-mechanistic model that predicts the response of soil heterotrophic respiration to changes in moisture and its dependence on soil properties.

With the first approach, statistical models of the response of soil heterotrophic respiration to moisture were obtained. The inclusion of soil properties (clay, bulk density and organic matter) as predictor variables improved the agreement between model results and observations. These models are useful to visualize the change in the response across different soil types. They thus improve over other commonly used empirical relationships, but because they remain a statistical approximation based on linear regressions they are potentially biased and could lead to systematic errors in predictions.

In the second approach we explored the theory linking gas diffusivity and heterotrophic respiration in soils, as well as the effect of soil clay content, pore space, organic matter and temperature. The advantage of a mechanistically based model is that it can be modified or expanded to test different theories or processes, and extrapolation of predictor variables will not usually lead to unrealistic predictions.

Observations and model predictions from the two approaches are shown to agree in many points, e.g. in the influence of soil clay content. But both the empirical and the more mechanistic model are unable to explain much of the variability in the data and fail to reproduce nonlinear responses such as the Birch effect. We conclude that a more complete theoretical basis is needed to represent the full range of soil moisture responses in a unifying model, further validated with new experimental data.