Unpacking soil carbon stabilization: From measurement to modelling

Jingjing Liu [a], Mark Farrell [a], Han Weng [b], Chiara Pasut [a]

[a] *CSIRO Agriculture & Food, Urrbrae, SA, Australia,* [b] *School of Agriculture, Food, and Wine, The University of Adelaide, Waite Campus, Urrbrae, SA, Australia*

Email: jingjing.liu1@csiro.au

Abstract: Understanding the mechanisms underpinning the stabilization of soil organic carbon (SOC)—particularly the formation and persistence of mineral-associated organic carbon (MAOC)—is critical for improving long-term predictions of carbon dynamics under different management regimes. In this study, we develop a conceptual modelling framework that integrates a structurally modified C–N coupled version of the BRTSim-BAMS2 model (Tang et al., 2019) with the phase-space approach (Manzoni & Cotrufo, 2024) to simulate SOC dynamics under three treatments—control, NPK (mineral nitrogen, phosphorus, and potassium fertilizer), and farmyard manure—using data from the >170-year Rothamsted Broadbalk experiment.

Our approach incorporates a phase-space representation of carbon dynamics that explicitly tracks carbon flows through microbial and direct sorption pathways into MAOC. This framework allows for the evaluation of how varying parameter configurations—such as microbial turnover and pathway allocation—can influence long-term stabilization patterns. While parameter values are informed by incubation studies and data from the previous literature, this work focuses on exploring the feasibility of using mechanistically derived parameters to improve model realism and alignment with observed SOC trends. We demonstrate that certain parameters derived from controlled conditions—especially those governing microbial turnover and MAOC formation—can be reliable and we can translate the methods into long-term modelling frameworks. Comparing RothC and the modified BRTSim model results, we simulate SOC dynamics across plots with contrasting organic inputs and compare the performance of different parameters.

By disentangling the relative contributions of microbial processing versus direct stabilization, this work highlights the importance of representing carbon flow pathways in SOC models. It provides a foundation for integrating short-term and theorical mechanistic model into long-term modelling to better capture the SOC stabilization under contrasting nutrient and organic input regimes.

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