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Density-dependent microbial turnover improves soil carbon model predictions of long-term litter manipulations

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Climatic, atmospheric, and land-use changes all have the potential to alter soil microbial activity via abiotic effects on soil or mediated by changes in plant inputs. Recently, many promising microbial models of soil organic carbon (SOC) decomposition have been proposed to advance understanding and prediction of climate and carbon (C) feedbacks. Most of these models, however, exhibit unrealistic oscillatory behavior and SOC insensitivity to long-term changes in C inputs. Here we diagnose the sources of instability in four models that span the range of complexity of these recent microbial models, by sequentially adding complexity to a simple model to include microbial physiology, a mineral sorption isotherm, and enzyme dynamics. We propose a formulation that introduces density-dependence of microbial turnover, which acts to limit population sizes and reduce oscillations. We compare these models to results from 24 long-term C-input field manipulations, including the Detritus Input and Removal Treatment (DIRT) experiments, to show that there are clear metrics that can be used to distinguish and validate the inherent dynamics of each model structure. We find that widely used first-order models and microbial models without density-dependence cannot readily capture the range of long-term responses observed across the DIRT experiments as a direct consequence of their model structures. The proposed formulation improves predictions of long-term C-input changes, and implies greater SOC storage associated with CO_2-fertilization-driven increases in C inputs over the coming century compared to common microbial models. Finally, we discuss our findings in the context of improving microbial model behavior for inclusion in Earth System Models.