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Site-level simulations of measurable soil fractions with the Millennium V2 soil model

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Soil carbon (C) models are used to predict C sequestration responses to climate and land use change. Yet, the soil models embedded in Earth system models typically do not represent processes that reflect our current understanding of soil C cycling, such as microbial decomposition, mineral association, and aggregation. Rather, they rely on conceptual pools with turnover times that are fit to bulk C stocks and/or fluxes. As measurements of soil fractions become increasingly available, it is necessary for soil C models to represent these measurable quantities so that model processes can be evaluated more accurately. Here we present Version 2 (V2) of the Millennium model, a soil model developed in 2018 to simulate C pools that can be measured by extraction or fractionation, including particulate organic C, mineral-associated organic C, aggregate C, microbial biomass, and dissolved organic C. Model processes have been updated to reflect the current understanding of mineral-association, temperature sensitivity and reaction kinetics, and different model structures were tested within an open-source framework. We evaluated the ability of Millennium V2 to simulate total soil organic C (SOC), as well as the mineral-associated and particulate fractions, using three independent data sets of soil fractionation measurements spanning a range of climate and geochemistry in Australia (N=495), Europe (N=176), and across the globe (N=716). Considering RMSE and AIC as indices of model performance, site-level evaluations show that Millennium V2 predicts soil organic carbon content better than the widely-used Century model, despite an increase in process complexity and number of parameters. Millennium V2 also reproduces between-site variation in SOC across gradients of climate, plant productivity, and soil type. By including the additional constraints of measured soil fractions, we can predict site-level mean residence times similar to a global distribution of mean residence times measured using SOC/respiration rate under an assumption of steady state. The Millennium V2 model updates the conceptual Century model pools and processes and represents our current understanding of the roles that microbial activity, mineral association and aggregation play in soil C sequestration.

