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Evaluation of dual carbon isotope constraints ($\delta^{13}C$ and $\Delta^{14}C$) on the parameterisation of a mechanistic, depth explicit soil organic carbon model

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Over the past years, many mechanistic soil organic carbon models have been developed. While these models offer a clear improvement in process representation compared to classic SOC models (e.g. of microbial mineralization and mineral protection of OC), the increase in model complexity, and thus the number of uncertain model parameters, is generally not supported by sufficient available data. Thus, model parameters can generally not be sufficiently constrained through a calibration with typically used data, like soil carbon contents, because multiple, similarly good solutions are possible (referred to as the equifinality problem).

A common approach to reduce equifinality in SOC models is to use ^{14}C isotopes of SOC as an additional constraint during model calibration. While this approach has shown to improve parameter identifiability (i.e., the identification of unique parameters that lead to optimal results), data on the $\Delta^{14}C$ of SOC is often not available due to high measurement costs. Therefore, we explored the potential of constraining a SOC model with the more widely available ratio of stable carbon isotopes of SOC ($\delta^{13}C$). While simulations of $\Delta^{14}C$ generally better constrain the turnover time of slowly cycling SOC pools, simulations of $\delta^{13}C$ allow to constrain additional processes, such as mixing of OC from aboveground and belowground sources and recycling of SOC through microbes. To do so, we developed a novel mechanistic, microbially driven model that simulates depth profiles of SOC (SOILcarb). In addition to total OC, the model simulates the $\delta^{13}C$ and $\Delta^{14}C$ value of SOC, by incorporating multiple processes affecting these isotopic ratios in soils.

Our results show that SOILcarb was able to accurately simulate depth profiles of total SOC, $\delta^{13}C$ and $\Delta^{14}C$ of a forest soil. To optimally explore the parameter space, we used a differential evolution calibration algorithm and extracted all parameter sets that led to a reliable simulation of depth profiles given a fixed error margin. The results showed that simulations calibrated only on total OC data did not results in a good fit of simulated depth profiles of either $\delta^{13}C$ or $\Delta^{14}C$. In contrast, simulations using either $\delta^{13}C$ or $\Delta^{14}C$ as an additional model constraint led to accurate simulations of depth profiles of total OC, $\delta^{13}C$ and $\Delta^{14}C$ by reducing the range in, and absolute value of, parameter values related to mainly vertical transport and protection rates of OC. Notably, parameters related to microbial OC uptake rates and microbial turnover were not better

constrained by either isotopic ratio. Our results show that additional constraints on parameter values, in addition to total SOC, are necessary to increase confidence in model parameters of mechanistic SOC models, while more work is needed to better constrain microbial processes in these models.