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How good is ^{13}C isotope analysis in assessing dynamics of organic compounds in soil? - The example of lignin

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Stable carbon isotope (^{13}C) data have been used for a few decades to study the dynamics of organic matter (both bulk organic matter and individual compounds on a molecular level) by natural labelling, i.e. after land use changes from C3 plants to C4 plants. All of these studies rely on the assumption of constant inputs for correct data interpretation. However, in reality, (i) annual biomass production varies approximately by ±20% between years, (ii) root/shoot ratios vary according to moisture and nutrient conditions, (iii) lignin content in plant litter can vary by a factor of two during the last month of growth, and (iv) isotopic label can differ by at least 1 ‰ V-PDB between plant parts. In this study we assess how these violations of the assumptions affect the precision of results from stable isotope studies.

We set up a model that simulates independent annual variation of biomass yield, root/shoot ratio, and lignin content of the biomass between individual years as well as isotopic differences between plant parts. Lignin-derived phenols are used as an example of plant-derived organic compounds in soil. These simulations are based on variation in actual yield and climate data from a case study of a Luvisol with 23 years of continuous maize cultivation. We used the simulated variable biomass inputs as input data for a decomposition model that calculates resulting soil lignin stocks and the percentage of newly introduced (labelled) organic compounds as output. It is this percentage that is analytically determined in field studies using the natural isotope labelling technique and that can be converted into apparent turnover time of the respective compound in the soil.

Our modelling study showed that for experimental periods < 5 a, isotope labelling experiments will not provide reliable turnover times, because the results are strongly affected by individual extreme years. However, uncertainty is reduced with increasing experimental time and at experimental periods of >20 a, apparent turnover times can be estimated with an uncertainty of $\pm 20\%$. Compared with this input variability, uncertainty introduced by isotopic differences between plant parts has a negligible effect on the turnover time estimates. From this modelling study, we conclude that turnover time estimates are robust to violations of the underlying assumptions when they are based on long-term field experiments.