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Quantification of isotopic turnover in agricultural systems

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The isotopic turnover, which is a proxy for the metabolic rate, is gaining scientific importance. It is quantified for an increasing range of organisms, from microorganisms over plants to animals including agricultural livestock. Additionally, the isotopic turnover is analyzed on different scales, from organs to organisms to ecosystems and even to the biosphere. In particular, the quantification of the isotopic turnover of specific tissues within the same organism, e.g. organs like liver and muscle and products like milk and faeces, has brought new insights to improve understanding of nutrient cycles and fluxes, respectively. Thus, the knowledge of isotopic turnover is important in many areas, including physiology, e.g. milk synthesis, ecology, e.g. soil retention time of water, and medical science, e.g. cancer diagnosis.

So far, the isotopic turnover is quantified by applying time, cost and expertise intensive tracer experiments. Usually, this comprises two isotopic equilibration periods. A first equilibration period with a constant isotopic input signal is followed by a second equilibration period with a distinct constant isotopic input signal. This yields a smooth signal change from the first to the second signal in the object under consideration. This approach reveals at least three major problems. (i) The input signals must be controlled isotopically, which is almost impossible in many realistic cases like free ranging animals. (ii) Both equilibration periods may be very long, especially when the turnover rate of the object under consideration is very slow, which aggravates the first problem. (iii) The detection of small or slow pools is improved by large isotopic signal changes, but large isotopic changes also involve a considerable change in the input material; e.g. animal studies are usually carried out as diet-switch experiments, where the diet is switched between C3 and C4 plants, since C3 and C4 plants differ strongly in their isotopic signal. The additional change in nutrition induces changes in physiology that are likely to bias the estimation of the isotopic turnover.

We designed an experiment with lactating cows which were successively exposed to the diet's natural isotopic variation and a diet-switch. We examined whether the same turnover information can be obtained from the natural (uncontrolled, short-term) isotopic variation as from the diet-switch experiment. Statistical methods to retrieve the turnover characteristics comprised multi-pool compartmental modeling for the diet-switch experiment as well as correlation analysis to perform wiggle-matching and quantification of autocorrelation (geostatistics) for the analysis of the natural variation. All three methods yielded similar results but differed in their strengths and weaknesses that will be highlighted. Combining the strengths of the new methods can make this tool even more advantageous than diet-switch experiments in many cases. In particular, the new approach empowers studying isotope turnover under a wider range of keepings, wildlife conditions and species, yielding turnover estimates that are not biased by changes in nutrition.