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^{13}C fractionation in transformations at the interface between roots, microorganisms, soil organic matter and soil respiration

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Introduction

Natural variations of the $^{13}C/^{12}C$ ratio have been frequently used over the last three decades to trace C sources and fluxes between plants, microorganisms, and soil. Most of these studies have used the natural ^{13}C labelling approach, i.e. natural $\delta^{13}C$ variation after C_3 – C_4 vegetation changes. In this mini-review, we focus on ^{13}C fractionation in processes at the interface between roots, microorganisms, and soil: root respiration, microbial respiration, formation of dissolved organic carbon by root exudation, as well as microbial uptake and utilization of soil organic matter (SOM).

Root respiration

Based on literature data (Wedin et al., 1995; Klumpp et al., 2005; Schnyder and Lattanzi, 2005; Werth et al., 2006; Werth and Kuzyakov, 2006; Gessler et al., 2007; Larsen et al., 2007; Werth and Kuzyakov, 2009), we estimated that, on average, the roots of C_3 and C_4 plants are ^{13}C enriched compared to shoots by -1.2±0.6‰ and -0.3±0.4‰, respectively. A very few studies showed that CO_2 released by root respiration was ^{13}C depleted by about +2.7±1.8‰ for C_3 plants and +1.3±2.4‰ for C_4 plants compared to root tissue. This urgently calls for further studies to reliably estimate ^{13}C fractionation by root respiration.

Microbial utilization

In soils developed under C_3 vegetation (Qian and Doran, 1996; Qian et al., 1997; Liang et al., 1999; Santruckova et al., 2000; Gregorich et al., 2000; Formánek and Ambus, 2004; Hamer et al., 2004; Kristiansen et al., 2004; Pelz et al., 2005; Stevenson et al., 2005; Piao et al., 2006; Dijkstra et al., 2006; Werth et al., 2006; Crow et al., 2006; Boström et al., 2007; Werth and Kuzyakov, 2009), the microbial biomass was ^{13}C enriched by -1.2±2.6‰ and microbial CO_2 was ^{13}C enriched by -0.7±2.8‰ compared to SOM (Fig. 1). This discrimination pattern suggests preferential utilization of a ^{13}C-enriched soil fraction by microorganisms, but a respiration of lighter compounds from this fraction. Preferential consumption of easily decomposable substrates and less negative $\delta^{13}C$ values were common for substances with low C/N ratios. For C_4 soils (Santruckova et al., 2000; Dijkstra et al., 2006), preferential substrate utilization was less important than for C_3 soils. This is because, here, microbial respiration strictly followed kinetics, i.e. microorganisms incorporated heavier carbon (Δ = –1.1‰) and respired lighter carbon (Δ = +1.1‰) than SOM (Fig. 1).

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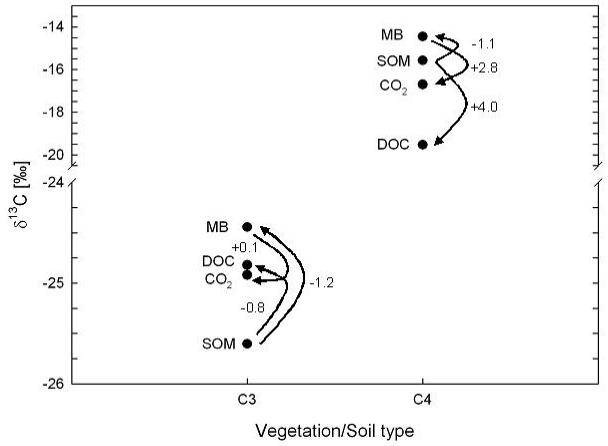

Fig. 1: ^{13}C discrimination processes between soil organic matter (SOM) and the soil carbon pools: dissolved organic carbon (DOC), microbial biomass (MB), and SOM-derived CO_2 for C_3 and C_4 soils.

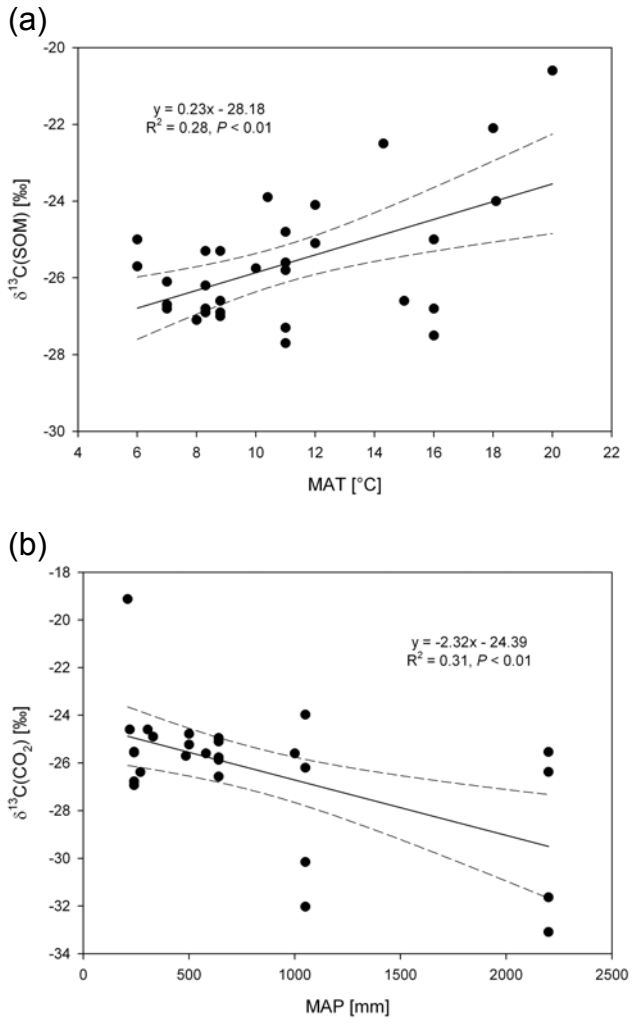

Fig. 2: Soil organic matter $\delta^{13}C$ vs. mean annual temperature (MAT) (a) and soil-derived CO_2 $\delta^{13}C$ vs. mean annual precipitation (MAP) (b) from sites with C_3 vegetation. The solid line shows the regression line, the dashed lines show the 95% confidence interval of the regression. For references see the beginning of this section.

Temperature and precipitation had no significant effect on the ^{13}C fractionation in these processes in C_3 soils. Increasing temperature and decreasing precipitation led, however, to increasing $\delta^{13}C$ values of soil C pools (Fig. 2).

CO_2 partitioning

In the framework of standard isotope mixing models, we calculated CO_2 partitioning using the natural ^{13}C labelling approach at a vegetation change from C_3 to C_4 plants. A root-derived fraction of 25%, 50%, and 75% to total soil respiration was assumed. Disregarding any ^{13}C fractionation processes (Eq. (13)), the calculated results deviated by between 2% and 7% from the presumed fractions (Fig. 3). Accounting for fractionation processes in the standard errors of the C_4 source pool and the mixing pool (Eq. (13) Fract. in SE) did not improve the exactness of the partitioning results; rather, it doubled the standard errors of the CO_2 pools. Including ^{13}C fractionations directly into the mass balance equations (Eq. (20) Fract. in SE) reproduced the CO_2 partitioning exactly.

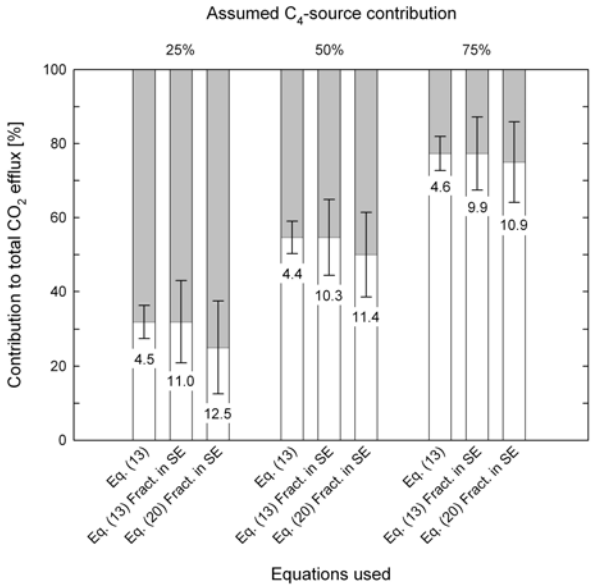

Fig. 3: Partitioning of soil CO_2 efflux into root-derived (grey) and SOM-derived (white) carbon. Natural ^{13}C labelling was used by planting a C_4 plant on soil developed under C_3 vegetation. Root-derived respiration from the C_4 plant (root respiration and rhizomicrobial respiration) was assumed to contribute 25%, 50%, and 75% to the CO_2 efflux. ^{13}C fractionation between root-derived sources and CO_2

was either disregarded (Eq. (13)), accounted for in the standard error of the C_4 'end member' and the mixing pool (Eq. (13) Fract. in SE), or accounted for in the partitioning equation and in the standard error of the C_4 'end member' and the mixing pool (Eq. (20) Fract. in SE). Standard errors of the contributions are shown in the centre of the columns with their values below.

Conclusions

Most C transformations such as root respiration, formation of DOC, microbial utilization of soil organic matter as well as microbial respiration are correlated with significant changes of C isotopic signatures compared to that of the C source. The ^{13}C fractionation within individual steps of C transformation is highly variable and is comparable with the $\delta^{13}C$ difference between the $\delta^{13}C$ values of 'end members' commonly used in natural ^{13}C labelling studies. This makes it inappropriate to accept literature data about possible changes of $\delta^{13}C$ within the processes. Rather, the discrimination should be measured for the specific conditions of the experiment.

Simple calculations of partitioning errors in studies based on the natural ^{13}C labelling approach showed high uncertainties of the results. This reflects small differences of $\delta^{13}C$ values between the 'end members', natural variation of $\delta^{13}C$ values within the 'end members' and the mixed pool, uncertainties of ^{13}C fractionation, and preferential substrate utilization. This calls for caution in interpreting the results obtained using the natural ^{13}C labelling approach.

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