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Do variations in the δ^{13}C of soil phospholipid fatty acids indicate changes in substrate use with climate warming?

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The effect of climate warming on the microbial mineralization of soil organic carbon (SOC) remains a key uncertainty in biogeochemical models. In particular, it remains unclear whether microbial substrate use patterns change with climate. The carbon isotopic signature (δ^{13}C) of soil microbial phospholipid fatty acids ($\delta^{13}C_{PLFA}$) can provide insight into substrate utilization patterns in situ without manipulations unavoidable in soil incubation experiments. The interpretation of $\delta^{13}C_{PLFA}$, however, is limited by gaps in our understanding of the isotopic fractionation associated with PLFA biosynthesis, and in particular, whether this fractionation changes with growth temperature. Characterizing the principles controlling $\delta^{13}C_{PLFA}$ under controlled laboratory conditions can help with the interpretation of field measurements of temperature effects on microbial SOC assimilation.

We measured $\delta^{13}C_{PLFA}$ from field soils in two regions along a boreal climate transect, which differ by 4.5 °C mean annual temperature. In each region, the organic (L, F, H) and mineral (B; top 10cm) soil horizons were sampled at three locations chosen for similar vegetation (balsam fir), stand age, elevation, and soil type (humo-ferric podzol).

Soils from both regions had similar bulk SOC δ^{13}C and exhibited an increase with depth from -29.5±0.4 to -26.5±0.6‰. Despite the similar δ^{13}C of SOC, PLFA in the organic horizons from the warmer region were more enriched in ^{13}C relative to those from the colder region.In a model that used region, horizon and the individual PLFA as predictors, we found that region had a subtle (0.7‰), but highly significant (p<0.001) effect on $\delta^{13}C_{PLFA}$. Substantial differences existed in the regional effect on δ^{13}C individual PLFA. For example, in the H horizon regional differences were highest for PLFA 18:2ω6,9 (fungi; 2.3‰) and PLFA i15:0 (Gram negative bacteria; 1.3‰) and lowest for PLFA 18:1ω7 (Gram negative bacteria; ±0.0‰). The $\delta^{13}C_{PLFA}$, however, did not differ between regions in the mineral horizons. The elevated $\delta^{13}C_{PLFA}$ in the organic horizons of the warmer region might be due to (1) the consumption of more ^{13}C-enriched (e.g. carbohydrate-rich) or less ^{13}C-depleted (lignin-derived) substrates, (2) the consumption of more processed, ^{13}C enriched SOC or (3) physiological effects impacting fatty acid biosynthesis and fractionation at a higher temperature.

To help assess whether this difference in $\delta^{13}C_{PLFA}$ between regions was due changes in substrate use or due to physiological effects of the distinct temperature regimes, we conducted a series of chemostat experiments to isolate the effect of temperature on $\delta^{13}C_{PLFA}$. We cultivated Pseudomonas fluorescens, a gram-negative bacterium common in soils, in continuous culture in a mineral medium amended with a single carbon substrate (cellobiose, $\delta^{13}C_{cellobiose}$=-24.2‰) at three temperatures (16, 21, and 26.5°C). We found similar $\delta^{13}C_{PLFA}$ in cultures at 16 and 21°C where the weighted mean of three PLFA were both -31.1±0.1‰, but lower $\delta^{13}C_{PLFA}$ at 26.5 °C where the weighted mean $\delta^{13}C_{PLFA}$ was -35.1±0.6‰. Laboratory findings from this simplified system thus contrast with those observed using more complex, environmental samples, suggesting that the climate-induced change in $\delta^{13}C_{PLFA}$ from the environmental samples is not likely dominated by a direct physiological effect of temperature on microbial metabolism. Rather our findings from intact soils suggest shifts in microbial substrate use occur with climate warming.