Moisture and Temperature Dependence of δ^{13}C and δ^{18}O of CO_2 from Heterotrophic Soil Respiration

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I. Background

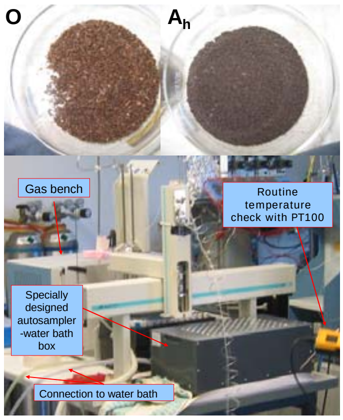
Understanding the role of terrestrial ecosystems in governing the isotopic composition of atmospheric CO_2 requires knowledge of environmental controls of δ^{13}C and δ^{18}O of CO_2 in biosphere-atmosphere CO_2 exchange. Heterotrophic respiration contributes approximately half of the total respiratory backflow of CO_2 from terrestrial ecosystems to the atmosphere, but too little is known about environmental controls of C and O isotopic signatures of CO_2 released from soils to be able to reliably quantify the contribution of different CO_2 flux components (photosynthesis, above- and belowground autotrophic as well as heterotrophic respiration) to net ecosystem CO_2 exchange.

II. Experiment

The dependencies of δ^{13}C and δ^{18}O of CO_2 from heterotrophic soil respiration on soil temperature and soil moisture were investigated. Samples of the organic layer (O) and humified A horizon (A_h) of a Norway spruce (*Picea abies* (L.) Karst) forest (Höglwald close to Augsburg, Germany) were incubated at different temperature and moisture levels in gas-tight incubation tubes (exetainers), followed by isotope-ratio mass spectrometer (IRMS) analysis of the CO_2 formed during heterotrophic soil respiration. The increase of CO_2 mixing ratios during the incubations, monitored by IRMS at different sampling times, allowed for calculation of the δ^{13}C and δ^{18}O of the respiratory source of the CO_2 by the Keeling plot methodology.

III. Method

Samples of the O layer below the needle litter and of the A_h horizon were taken on the 10th of May 2007 and 30th of August 2007, taken back to the lab on the same day, and kept refrigerated at 5°C until incubation and analysis. Preparation of refrigerated soil samples started two days prior to analytical determination of the δ^{13}C and δ^{18}O of soil-respired CO_2. First, samples were sieved at 4 mm in order to homogenate the sample material and to exclude fine roots. Subsequently, the sieved samples of O and A_h horizon were air-dried for one night. Then, some g of soil material, depending on the temperature and humidity treatment, were placed into 12 mL exetainers (Labco Ltd., UK). For each temperature and moisture level and each horizon 18 replicates were analyzed. The specific amount of water required to achieve the target soil moisture level was added to each exetainer. To avoid drying of samples, the exetainers were sealed with parafilm. Samples were then incubated for one night at the respective temperature, which was controlled with a custom-made sample tray connected to a water bath. The parafilm was removed and the samples were aerated for another 1–2 hours before sealing the exetainers with the appropriate septum screw caps prior to IRMS analysis with a gas bench coupled to a continuous-flow mass spectrometer (Delta^{Plus}XP, ThermoFisher, Bremen, Germany).



IV. Results

Values for δ^{13}C are given in ‰ vs. PDB, values for δ^{18}O in ‰ vs. SMOW; MWHC = maximum water holding capacity.

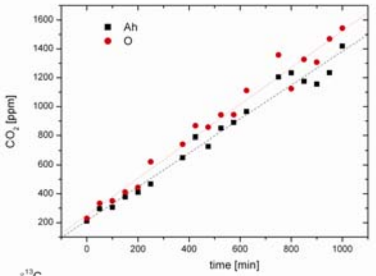


Fig. 1. Increase in headspace CO_2 mixing ratios above soil from the O layer and from the A_h horizon, respectively, during a 20 h measurement period.

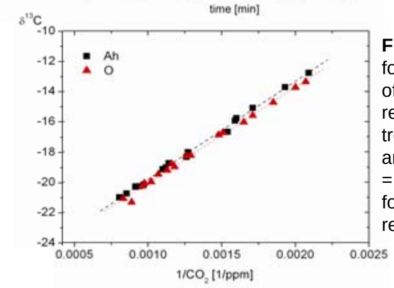


Fig. 2. Keeling plots for the determination of δ^{13}C of soil-respired CO_2; treatment at 10°C and 50% MWHC (R^2 = 0.966 and 0.998 for A_h and O, respectively).

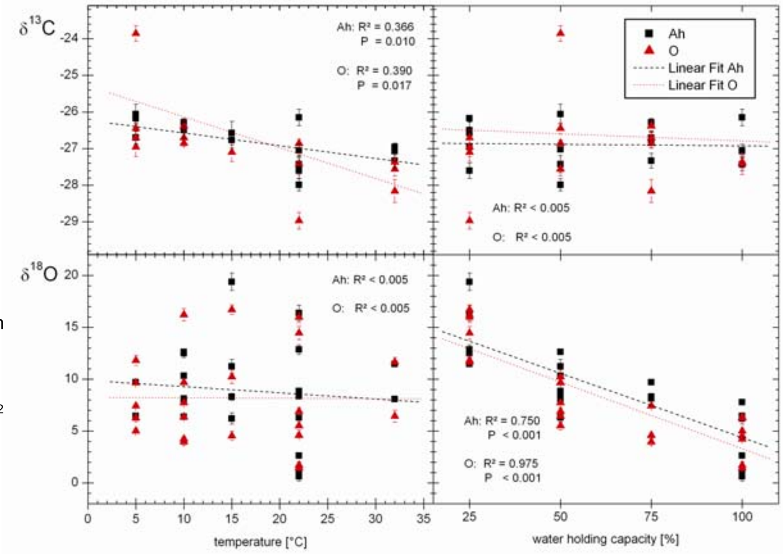


Fig. 3. δ^{13}C (top panels) and δ^{18}O (bottom panels) at different temperature (left panels) and soil moisture levels (right panels), expressed as % of MWHC, for soil samples of the organic layer and A_h horizon. Significant linear relationships between δ^{13}C and temperature as well as between δ^{18}O and water holding capacity were found.

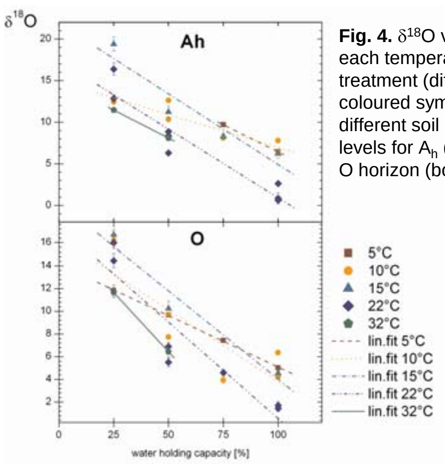


Fig. 4. δ^{18}O values for each temperature treatment (differently coloured symbols) at different soil moisture levels for A_h (top) and O horizon (bottom).

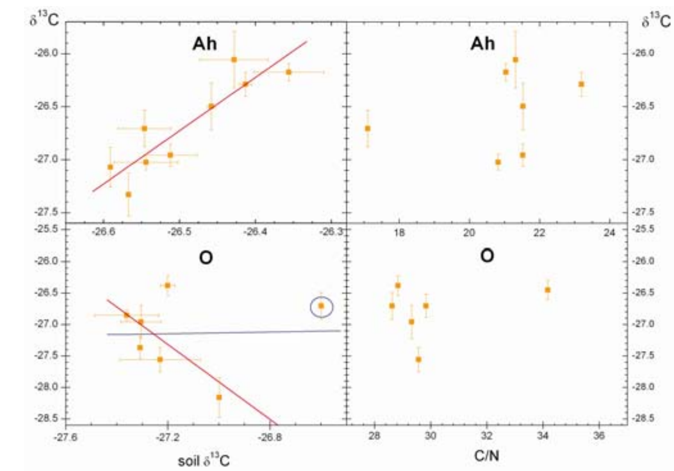


Fig. 5. Relationship between δ^{13}C of soil-respired CO_2 of A_h horizon (top panels) and organic layer (bottom panels) with δ^{13}C of soil carbon (left panels) and with soil C/N ratios (right panels). Red lines display best linear fit (blue encircled data point omitted); including all data results in a linear fit indicated by the blue line.

V. Summary

The δ^{13}C of the CO_2 respired from root-free organic layer and A_h horizon did not show any significant relation to soil water content. In contrast, δ^{13}C had a negative significant linear relationship with temperature. Data fluctuated around an average δ^{13}C of -25.6‰ for the A_h horizon and -26.4‰ for the organic layer, reflecting the fact that the organic layer was more depleted in ^{13}C than the A_h horizon. Likewise, the CO_2 from the organic layer was more depleted in ^{18}O than the CO_2 from the A_h horizon. In contrast to the δ^{13}C results, no significant relationship of δ^{18}O to temperature could be observed. However, a highly significant decrease in δ^{18}O of respiratory CO_2 from both soil layers with increasing soil moisture was found, decreasing from an average of +14‰ vs. SMOW at 25% MWHC to +4‰ at 100% MWHC.

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