The impact of soil micro-organisms on the diurnal δ18O signals of soil CO2 exchange

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Why study the $\delta^{18}O$ signal of soil CO_2 fluxes (δ_R)?

Currently, the precise response of terrestrial CO_2 sources and sinks to changes in climate remains uncertain and its understanding requires the ability to quantify the amount of CO_2 taken up during photosynthesis **separately** from the amount released by respiration. Because photosynthesis and respiration produce different ^{18}O signals, the $\delta^{18}O$ of CO_2 in the atmosphere (δ_a) is a tracer of photosynthetic and respiratory CO_2 exchange.

The net soil-atmosphere CO_2 exchange (F_R) is composed of CO_2 molecules moving from the atmosphere into the soil and back to the atmosphere (invasion) and further CO_2 molecules produced during soil respiration (Fig 1). During CO_2 hydration, an isotopic exchange occurs, causing both invasion and respiration to reset the oxygen isotope composition of soil CO_2 to that equilibrated with soil water (δ_{sw}) and modify δ_a. Recent studies have indicated that the rate of this isotopic exchange is much faster than theory predicts (f_{CA}>>1) and could result from the enzymatic activity of soil micro-organisms.

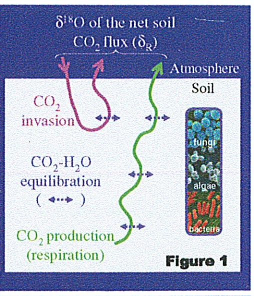


Figure 1

Field set-up

We set out to investigate the oxygen isotope signal of the net soil CO_2 flux (δ_R) using open soil chambers coupled to a tunable diode laser spectrometer deployed in a Maritime pine forest in France (Le Bray, FLUXNET site) (Fig 2).

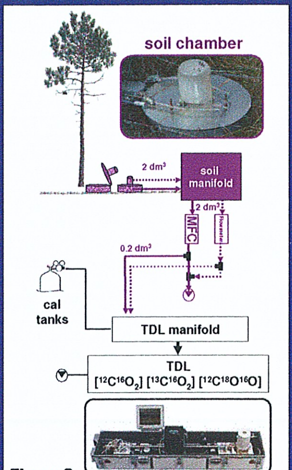


Figure 2

Results

Diurnal and synoptic variability in both the CO_2 flux rate (F_R) (Fig 3a) and the oxygen isotope signal of the net soil CO_2 flux (δ_R) (Fig 3b) were observed during our study.

The diurnal variability in δ_R was driven by changes in temperature, flux rate and the difference in isotope composition between CO_2 equilibrated with soil water and that of the atmosphere (δ_a).

The synoptic variability was characterised by a gradual depletion of soil water content (θ) punctuated by a few distinct rain events (Fig 3d).

The first rain event had a large depleting effect on δ_R because the soil water isotope signal (δ_{sw}) was reset to that of incoming rain around -5‰ VSMOW (Fig 3b).

In the dry periods between rain events δ_R become more enriched as a result of evaporation enrichment of soil water δ_{sw} (Fig 3b and 3c).

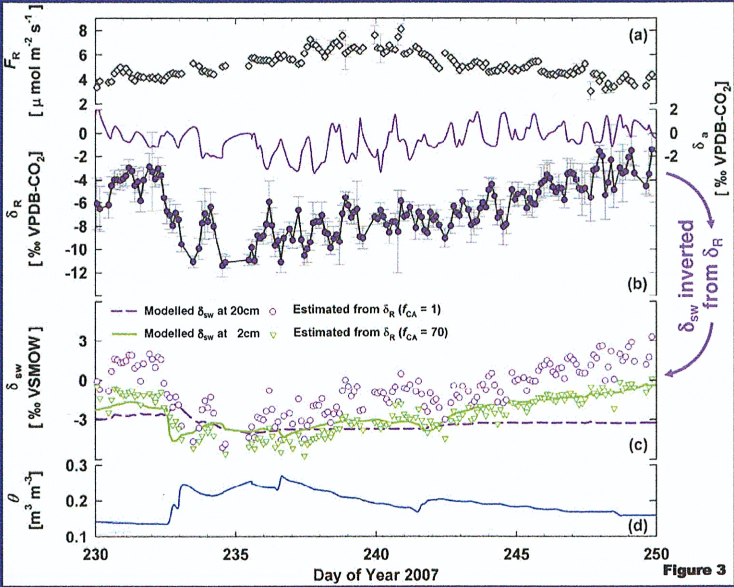


Figure 3

Do soil micro-organisms increase the rate of CO_2 hydration in soils?

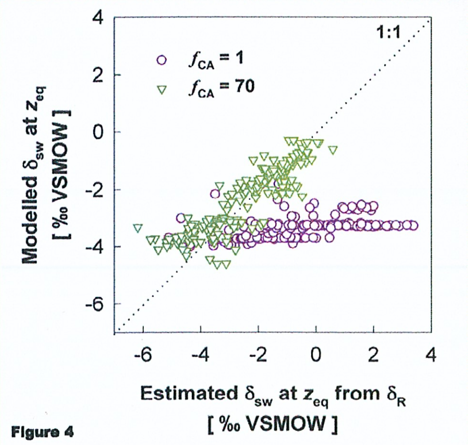


Figure 4

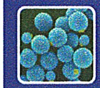
Because the δ_R signal depends on the isotopic composition of soil water (δ_{sw}) it is possible to investigate the rate of CO_2 hydration in soils.

First we inverted δ_{sw} from δ_R observations and compared these to estimates of δ_{sw} obtained from a multi-layer coupled heat, water and stable isotope transport model (Fig 3c).

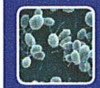
When CO_2 hydration was assumed to follow existing theory (i.e. **no** enzyme activity) we found that the modelled δ_{sw} remained fairly constant at ~-3‰ at the theoretical depth of full equilibration between CO_2-H_2O (z_{eq}) at ~20cm depth. The inverted δ_{sw} estimates displayed unnatural levels of diurnal variability that were very different from the modelled δ_{sw}.

When the rate of CO_2 hydration was made 70 times faster than the uncatalysed rate we found very good agreement between the estimates of δ_{sw} inverted from δ_R and those predicted by the model at a depth of 2cm (Fig 3c and 4).

Conclusion

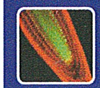


We provide evidence in this study for rates of CO_2 hydration roughly 70 times faster than those predicted by theory.



Faster CO_2 hydration can occur in the presence of carbonic anhydrase an enzyme produced in many soil dwelling micro-organsims.

This study adds to the growing evidence for CO_2 hydration rates 20-400 times faster in the soils of many different ecosystems.



This process must be accounted for if we want to use the ^{18}O of atmospheric CO_2 as a tracer for gross CO_2 fluxes.

Next steps

More experimental work is now needed to establish the mechanistic basis underpinning the observed differences in CO_2 hydration in different ecosystems.

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MARIE CURIE ACTIONS

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