Online in Situ Measurements of Soil CO2 Concentrations in Dependence of Ash Roots (Fraxinus excelsior L.)

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Root-induced temporal and spatial changes of CO_2 concentration are of high importance for biogeochemistry of soils, and thus, for their potential of long-term carbon storage. We investigated the effects of ash (*Fraxinus excelsior* L.) fine roots on CO_2 and O_2 concentrations in forest soil under constant moisture and temperature conditions in the laboratory. Using chemical optical sensors and monitoring systems by PreSens we measured CO_2 and O_2 concentrations in the rhizosphere, and 25 mm off the roots in the bulk soil. Further, fine root respiration was estimated by simultaneous measurements of O_2 consumption and CO_2 production, which reached 19 μmol CO_2 g^{-1} dw s^{-1} on average at 20 °C soil temperature. Surprisingly, our results indicated a higher CO_2 concentration in the bulk soil than in the rhizosphere.

Root respiration of plants plays a major role in biotic CO_2 production of up to 71 % of CO_2 efflux from soils (Lee et al., 2003). The portion of plant roots on total CO_2 efflux from soils shows a broad span, depending on plant species and phenology; it has a wide reaction range with respect to environmental factors. Changes of CO_2 concentration take place at a small spatial scale, but can have far-reaching consequences. Thus, the investigation of the spatial and temporal dynamics of CO_2 in the rhizosphere, a biotic and metabolic hotspot in rooted soils, is of high importance. In a laboratory study, we investigated the effects of ash fine roots on CO_2 concentration in the soil using ash saplings and natural soil from the Hainich National Park, Germany. The effects of different root sections (root tips vs. differentiated parts) on soil CO_2 concentration was investigated applying chemical optical CO_2 sensors and the pCO2 mini by PreSens, which allowed online monitoring. Diurnal patterns of CO_2 release and CO_2 gradients along the roots and towards the bulk soil could be detected. Further, we established measurements of respiration rates using microtubes mounted around intact growing roots.

Non-invasive Detection of CO2 and O2 Concentration in Soil

We planted ash saplings (*Fraxinus excelsior L.*) in 8 double split-root rhizotrones (two plants per rhizotrone), filled with homogenised silty topsoil material (16 dm^3 soil volume each). Prior to the onset of experiments the roots established in the rhizotrones under constant soil temperature (20 °C) and moisture conditions (20 % gravimetric water content) for one year. Soil temperature was measured close to the spots of gas concentration measurements by NTC thermistors (Epcos, Germany) and logged at 15 min intervals (CR1000 data logger combined with two AM416 Relay Multiplexer, Campbell Scientific Inc., USA). CO_2 and O_2 concentration were measured with chemical optical CO_2 and O_2 sensors (PreSens GmbH, Germany). The CO_2 sensitive foil of the CO_2 sensor was glued to a polymer optical fiber of 2 mm diameter with silicone rubber (A07 Elastosil RTV 1, Wacker Silicones, Germany). Calibration of the CO_2 sensors was perfomed in a water saturated gas phase at 20 °C by setting 12 calibration points from 0 to 1,000,000 ppm CO_2. An infrared CO_2 gas analyser (Li 820 CO_2 analyser, Li-Cor Inc., USA) was used to reference the established CO_2 concentrations. CO_2 and O_2 concentrations were measured simultaneously at the root tips and along fully differentiated root segments (18.5 to 50.5 cm behind the root tip). Measurements of gas concentrations started six hours after installation of the sensors (equilibration time), and were run for at least 24 hours at 5 min intervals. Root respiration rates were detected by measuring the changes of CO_2 and O_2 concentrations of five enclosed fine root segments (1.5 mL micorcentrifuge tubes) over three hours.

Changes of CO2 and O2 Content by Roots

Diurnal changes of gas concentrations could not be detected at differentiated roots (19 cm behind the root tip, Fig.1 and 2), while CO_2 concentrations at root tips showed pronounced fluctuations with higher concentrations at night (maximum [CO_2] at nighttime: 875 μmol L^{-1} vs. minimum [CO_2] at daytime: 321 μmol L^{-1}). CO_2 concentrations near the root tips (320 - 436 μmol CO_2 L^{-1}) were commonly higher than along the anatomically differentiated fine roots (111 - 130 μmol CO_2 L^{-1}; Fig. 1 and 2).

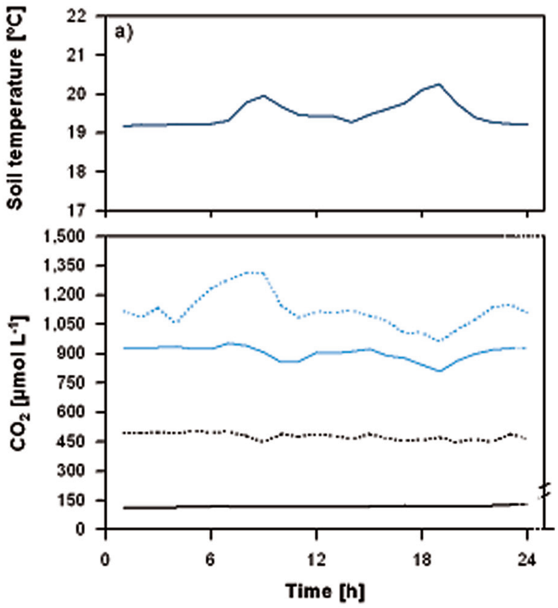

Fig. 1: Soil temperature, CO_2 (black) and O_2 (blue) concentrations of soil at ash fine root surface (solid line) and in 25 mm orthogonal distance (dotted line) in course of 1 day.

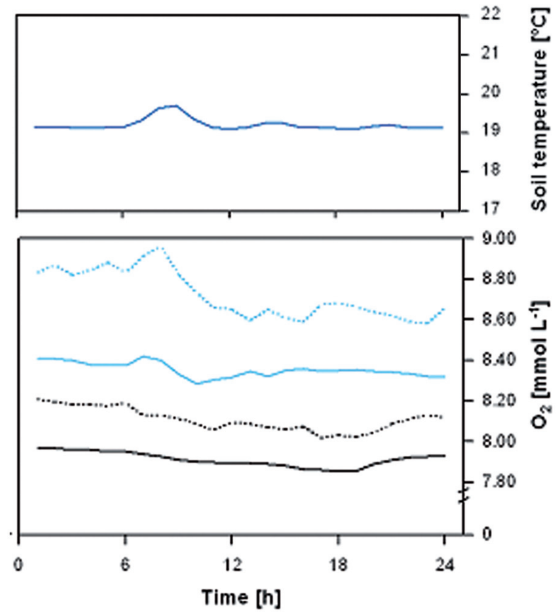

Fig. 2: Soil temperature, CO_2 and O_2 concentrations of soil at ash fine root tip (19 cm behind the root tip at the completely differentiated root segment) and in 25 mm orthogonal distance in couse of a 1 day.

Further, our measurements revealed lower CO_2 and O_2 concentrations near the root surface, at the root tip, and at older parts of the root. Effects of soil temperature were reflected in the variation of O_2 concentration, while responses in CO_2 concentration were almost absent. Due to the experimental conditions soil temperature in the rhizotrones varied only slightly from 19.1 to 19.7 °C during measurements at the root tips, and from 19.2 to 20.3 °C during measurements at differentiated roots, indicating an overall variation of merely 1.2 °C. Hence the O_2 sensors appeared to be even more sensitive to thermal changes than the CO_2 sensors. For measuring root respiration rates we simultaneously recorded O_2 decrease and CO_2 increase derived from root segments enclosed by microcentrifuge tubes (Fig. 3). We identified an increase in [CO_2] from 79 to 2,806 μmol L^{-1}, whereas [O_2] decreased from 11.01 to 10.19 mmol L^{-1}.

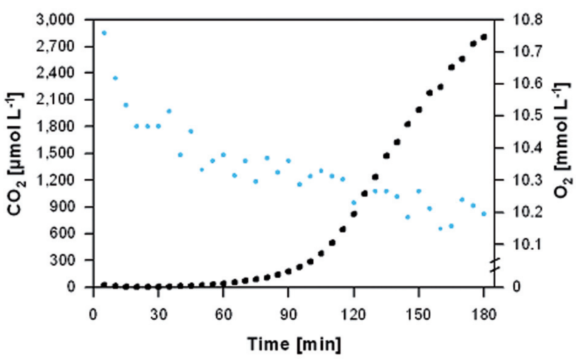

Fig. 3: Fine root respiration of ash saplings. Shown are the increase of [CO_2] (black) and the decrease of [O_2] (blue) of an intact root segment enclosed by a 1.5 mL microcentrifuge tube.

The mean calculated CO_2 production of five root segments was 19.14 $\pm$ 8,33 nmol g^{-1} dw s^{-1}. The mean O_2 consumption was 37.07 $\pm$ 8.40 nmol g^{-1} dw s^{-1}.

Conclusion

Surprisingly lower CO_2 concentrations near the root surface compared to concentrations 25 mm off the root in the bulk soil were measured in this study. This indicates a pronounced spatial heterogeneity of CO_2 in rooted soils that can be quantitatively investigated by using chemical optical CO_2 sensors. As a major methodical advantage, these CO_2 sensors do not interfere with the gas balance and gas budgets of a given system during investigation. Hence, we confirmed that disturbance-free measurements of CO_2 and O_2 concentrations in the gas phase of moist soil compartments using chemical optical CO_2 and O_2 sensors by PreSens represent a valuable system for online monitoring of carbon and oxygen fluxes in rooted soils.

References

[1] Lee M, Nakane K, Nakatsubo T, Koizumi H, 2003, Seasonal changes in the contribution of root respiration to total soil respiration in a cool-temperate deciduous forest, Plant and Soil 255, p. 311 - 318

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