Experimental soil warming in a mountain forest ecosystem

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Background

Global warming will rise forest soil temperatures and thereby accelerate enzyme kinetic driven processes like organic matter decomposition. Already fixed carbon in the humus may become vulnerable to decomposition and leave the soil as CO_2. This temperature induced increase in soil respiration could, in worst case, have the potential to shift temperate forest ecosystems from a net sink to a net source of atmospheric CO_2. The temporal and quantitative degree of the temperature induced feedback on global warming is still under debate.

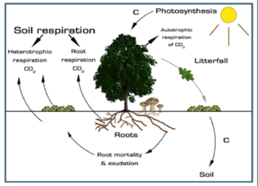

Fig. 1: Carbon cycle

Methods | Summer

We buried a heating cable into three plots and kept the soil temperature 3°C above the soil temperature of three untreated control plots. Furthermore we created three disturbed control plots where a dummy cable was buried. This enabled us to determine eventual disturbance effects by the cable installation. To separate the root respiration from the heterotrophic respiration we established six trenched plots. All tree roots were cut around the trenched plots one year before starting the measurements. Three of the trenched plots were heated (+3°C). CO_2 fluxes were measured biweekly using a transportable infrared gas analyzer. For high temporal resolution, one plot (5 treatments, 15 chambers) was measured 24 hours, fully automatically throughout the snow free period. Soil temperature and moisture from two soil depths were recorded in half hourly resolution. The automated plot was additionally equipped with ten lysimeter probes.

Fig. 3: (a) Automated plot with automatic chambers, chambers for manual measurements (orange) and the tech box (white) equipped with the infrared gas analyser, the control unit and the data loggers; (b) The heating unit. It contains of 3 transformers and a 50 kA contactor, which is operated by a specially programmed Campbell data logger; (c) Open slot during the trenching procedure.

Methods | Winter

We measured CO_2 emissions directly from the snow surface using a home made closed dynamic chamber. Additionally, we installed nine Teflon tubes with a small air collector made of a stainless steel mesh at the soil-air interface. The tubes were fixed to tree trunks, so that the other end was accessible even during thick snow cover. CO_2 fluxes were calculated from the concentration gradient (CO_2 at the soil surface; CO_2 at the snow surface) and the snow porosity folowing Massman et al., 1995. Furthermore we measured concentration gradients through the snow profile using a snow probe in 20 cm depth intervals. This allowed us a better calculation of the flux through snow packs with distinctive layering.

Fig. 5: From left to right: Snow profile with distinct layering; chamber for CO_2 flux measurements on the snow surface; Aluminum snow probe for CO_2 concentration profile measurements.

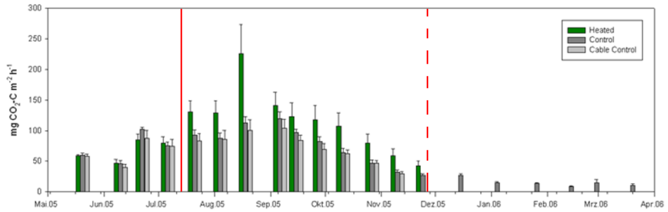

Fig. 2: Mean CO_2 fluxes from the forest soil. The red line shows the date when the heating system was switched on. The heated plots were overheated (+8°C) in late August, leading to disproportionately high CO_2 fluxes. In September, the temperature difference was 3°C again. The heating was switched off 10 days past the fist snowfall (dashed red line). The CO_2 fluxes through snow from December 2005 to March 2006 were calculated with a diffusion approach.

Results | Winter

- The soil was never frozen under the snow and the CO_2 flux through the snow ranged between 17,5 and 41,0 mg CO_2-C m^{-2} h^{-1} until the end of March.
- Flux estimates from the chamber measurements on the snow surface were 3-5 times less than flux estimates calculated with the diffusion approach.
- Distinct ice layers can impact the CO_2 flux through snowpacks (Fig. 6).

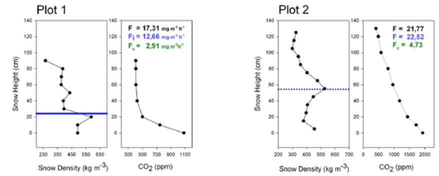

Fig 6: Snow density and CO_2 concentration of two different snow profiles. At plot 1, a distinct ice layer (blue line) acted as barrier for CO_2 diffusion. The CO_2 flux calculated from the CO_2 concentration difference between soil surface and snow surface (F) overestimated the flux compared to the flux calculated from, ice layer surface -> snow surface (Fi). At plot 2, the ice layer was less pronounced and did not act as barrier. Fc is the CO_2 flux calculated from the linear concentration increase in the chamber on the snow surface.

Results | Summer

- Soil respiration from the heated plots was approximately 30% higher than soil respiration from the control plots (Fig. 2).
- Root respiration amounted to 30 - 40% of the total soil respiration and was generally higher on warming plots.

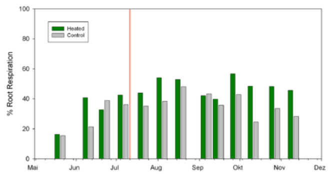

Fig. 4: Percent root respiration as calculated by subtracting the CO_2 fluxes of the heated and control plots from the fluxes of the heated- and control- trenched plots, respectively. The red line shows the start of the heating period.

Conclusions

The soil respiration strongly responded (+30%) to a soil temperature increase of 3°C throughout the first observation year. The coming years will show if this response was only an initial flush of easily decomposed organic matter or if higher temperatures will lead to a decomposition of humic substrate, thereby leading to long-term elevated CO_2 emissions from forest soils.

At our site, the winter CO_2 fluxes through snow amounted to 10-15% of the annual soil respiration. This carbon was fixed during summer and was lost to the atmosphere during winter. Therefore we strongly recommend measuring soil respiration in winter, especially if one is calculating annual soil respiration, or carbon budgets, respectively.

References

Massman W.J., Sommerfeld R.A., Zeller K., Hehn T., Hudnell L. and Rochelle S.G. 1995. CO2 flux through a Wyoming snowpack: diffusional and pressure pumping effects. Biogeochemistry of snow-covered catchments. International Association of Hydrological Sciences, Wallingford, pp. 71-79.

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