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ORIGINAL PAPER

Effect of canopy composition on soil CO_2 emission in a mixed spruce-beech forest at Solling, Central Germany

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Abstract: It was hypothesized that soil respiration can be affected by canopy composition. Hence, admixture of trees as a common forest management practice may cause significant change in the carbon cycling. This study was conducted in a mixed spruce-beech stand at Solling forest in central Germany to investigate the effect of canopy composition on soil respiration. The canopy cover was classified in four major canopy classes (pure beech, pure spruce, mixed and gap), and the area under each canopy class was identified as a sub-plot. Soil respiration in each sub-plot (*n=4*) was measured monthly from Jun 2005 to July 2006. Results show significant difference in annual soil respiration between the beech (359 $g \cdot m^{-2} \cdot a^{-1}$ C) and gap (211 $g \cdot m^{-2} \cdot a^{-1}$ C) sub-plots. The estimation of the total below-ground carbon allocation (TBCA) based on a model given by *Raich and Nadelhoffer* revealed considerably higher root CO_2 production in the beech sub-plot (231 $g \cdot m^{-2} \cdot a^{-1}$ C) compare to the gap sub-plot (51 $g \cdot m^{-2} \cdot a^{-1}$ C). The contribution of the root respiration to the total soil respiration was higher in the soil under the beech canopy (59%) compared with the soil in the gap (29%). The findings suggested that the condition under the beech canopy may cause more desirable micro-site for autotrophic respiration and consequently higher CO_2 release into the atmosphere.

Keywords: canopy class, soil respiration, gaps, total belowground carbon allocation.

Introduction

In terrestrial ecosystems, soils as the largest reservoir of carbon play a pivotal role in changing the concentration of atmospheric CO_2 (Johnson and Curtis 2001). Any change in soil properties due to different forest management methods can affect soil C pools and this can have considerable impacts on the carbon budget of the atmosphere.

Carbon dioxide is released from soil belowground through autotrophic respiration which originate from root and mycorrhizae activities and heterotrophic or microbial respiration (Brumme 1995; Buchmann, 2000).

Tree species is considered to affect soil respiration by influencing soil microclimate, the quantity and quality of above and below ground litter and the rate of root respiration (Borken and Beese 2005).

Available data showed that the total soil respiration negatively correlated with C stock in O horizons in beech and spruce stands (reviewed by Hojjati 2008). The soil respiration rates in coniferous forests are usually lower than those in broad-leaved forests located on the same soil types (Weber 1990). Comparative studies in pure and mixed beech and spruce stands by Borken and Beese (2005) showed that the total soil respiration was higher in pure beech stands compared with pure spruce stands and intermediately in mixed spruce beech stands. According to Buchmann (2000) the role of canopy to control soil respiration may be related to canopy characteristics for managing micro environmental conditions. Tewary et al. (1982) claimed that in a mixed (Oak- coniferous) forest, soil respiration rates in microhabitats beneath coniferous were lower than those beneath broad-leaved trees.

In the last centuries, the natural European beech (*Fagus sylvatica L.*) dominated forests in central Europe have been replaced to a large extent by Norway spruce (*Picea abies L.* Krast.) plantations (Rothe et al. 2002). Mixed forest types are currently recommended by foresters in order to improve the stability and biodiversity value of forest ecosystems (Hooper et al. 2005). To our knowledge, there is no information about the spatial variability of soil respiration affected by the impact of canopy composition within a mixed spruce- beech stand. The main hypothesis to be tested in this study was that in a mixed forest the heterogeneity in canopy composition may create different micro-sites with

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different soil respiration rates as the indicator of soil microbial and root activities.

Material and methods

Site description

The study was conducted in Solling Forest, in central Germany. The site is located approximately 50 km north-west of Göttingen in Lower Saxony (51°47'N and 9°37'E) at an altitude of 250–300 m. The climate at Solling can be described as sub-oceanic, with a mean annual air temperature average of 6.5°C and total annual precipitation of 1 090 mm. The soil type at the experimental site was an acid dystric cambisol (FAO) developed on triassic sandstone, covered by a loess layer. Soil texture is dominated by silty loam. Morphological humus forms are typical moder.

The experimental stand is a mixture of European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) Karst.). The canopy cover of a part of the stand was classified in four major canopy classes (pure beech, pure spruce, mixed and gap). To investigate the effect of canopy composition on soil respiration, the area under each canopy class was identified as a sub-plot.

Data collection

Since May 2005, four cylindrical PVC columns, 15 cm diameter and 25 cm tall were inserted approximately 10 cm into the organic and mineral soil under each canopy class. CO_2 concentration was measured monthly from June 2005 (one month after installing the collars) to July 2006. Measurements were carried out twice per date between 10:00 and 15:00 by placing a PVC lid over each column and using a measuring device named CO2PORT (Messwert company GmbH-Göttingen) which was a developed version of an infrared gas-analysator (Edinburgh Sensors- Gascard II). The first measurement was done immediately after the closing the column and the second one after ca. 60 minutes. Before measuring, all green herbaceous vegetation was removed from the surface area enclosed by experimental cylinders. In winter season (Dec, Jan and Feb), because of heavy snow and ice layer on the measuring points, the soil CO_2 emission could not be measured.

The temperatures were measured at 10 cm depth within soil close to each PVC column at the time of CO_2 measurement. In order to know the changes in temperature of forest floor, a digital thermometer (CornadElectronic) were installed within O_{L+F} layer under each canopy class in both plots. A Barometer (Digital Barometer-Greisinger Electronic) was used to measure air pressure close to the chambers.

Data calculation

CO_2 efflux: CO_2 fluxes were calculated with the formula suggested by Borken (1996)

$$F_{CO_2-C} = (\frac{dc}{dt} \times [\frac{Mm.vh}{Mv.Ah}] \times [\frac{Pa}{Pn} \times (1 + 0.00367Ta)]$$

where F_{CO_2-C} is the CO_2-C flux ($mg \cdot m^2 \cdot h^{-1}$), dc / dt the temporal change in CO_2 concentration within chamber ($ppm \cdot min^{-1}$), *Mm* the mass of CO_2-C mol (12.01 $g \cdot mol^{-1}$), *Vh* the volume of chamber (L), *Mv* the volume of CO_2 (22.26 $L \cdot mol^{-1}$), *Ah* the basal area of chamber (m^2), *Pn* the normal air pressure (1 013 hPa), *Pa* the actual air pressure (hPa), and *Ta* is the actual air temperature (°C)

Total Belowground Carbon Allocation (TBCA): A conceptual model (developed by Raich and Nadelhoffer, 1989) was used to quantify the fluxes of carbon. Soil respiration is the CO_2 flux from the soil and is comprised of root respiration, microbial decomposition of soil organic matter derived from dead roots, root exudates, and mycorrhizal hyphae, and microbial decomposition of aboveground litterfall:

Soil respiration = Root respiration + Root litter-C decomposition + Aboveground litter-C decomposition (1)

Raich and Nadelhoffer (1989) suggested that TBCA could be estimated from the difference between annual rates of soil respiration and aboveground litterfall.

Soil respiration=TBCA+Aboveground Litterfall-C (2)

The model assumes that the stocks of organic matter, root and litter in soil are in steady state and the amount of annual litterfall equals the amount of decomposition of aboveground litter.

Aboveground litte -C decomposition = Aboveground litterfall-C (3)

Therefore, TBCA equal to root respiration and root litter C decomposition, which is expressed in equation (4):

TBCA = Root respiration + Root litter-C decomposition (4)

In this model, annual changes in the soil and litter stores must be small relative to soil respiration and litterfall C. In current study, we used the mean annual carbon flux via foliar litterfall as the litterfall C.

Statistical analysis

The data were analysed using one-way analysis of variance (ANOVA) after checking the assumptions for parametric test. The non-parametric data were transformed to achieve normal distribution and homogeneous variances. The Tukey HSD test was used to determine significant differences at the level of $p < 0.05$. STATISTICA 7.0 was applied for statistical analyses.

Results

The average rates of soil respiration during the entire period of this investigation (from June 2005 to July 2006) ranged between 14.8–97.5 $mg \cdot m^{-2} \cdot h^{-1}$ C (Table. 1).

A significant difference in soil respiration rate was found between the beech and gap sub-plots. The beech sub-plot showed significantly ($p < 0.05$) higher respiration rate compared with the gap sub-plot (Table 1).

Table 1. Mean rates of soil respiration, annual soil respiration (S_{res}), annual C inputs via foliar litterfall (C_{lit}, Hojjati et al., 2009), root-associated CO_2 production (R_{res}) and R_{res}/S_{res} ratios in different sub-plots.

subplot	Soil respiration rate ($mg \cdot m^{-2} \cdot h^{-1}C$)	S_{res} ($g \cdot m^{-2} \cdot a^{-1}C$)	C_{lit} ($g \cdot m^{-2} \cdot a^{-1}C$)	R_{res} ($g \cdot m^{-2} \cdot a^{-1}$ C)	R_{res}/S_{res}
spruce	44.4 ab	271 ab	157	115	0.42
mixed	51.0 ab	319 ab	162	157	0.49
beech	63.5 a	395 a	164	231	0.59
gap	35.0 b	211 b	160	51	0.24

There were no significant differences in mean soil and forest floor temperatures among different subplots. Temporal trends of soil respiration followed approximately the same order as temporal changes in the mean soil temperature at 10 cm depth (Fig. 1 and 2). The lowest rates of soil respiration were observed in November and March. Soil temperature (10 cm depth) explained 46% of CO_2 released from the soil under different sub-plots (Fig. 3).

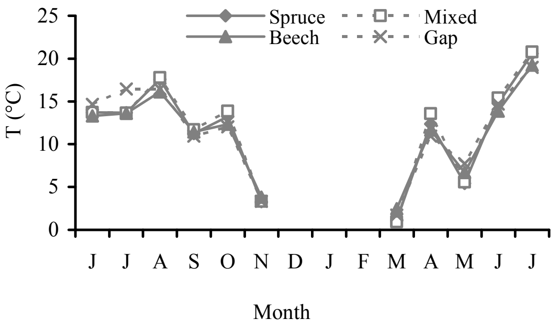

Fig. 1 Temporal variation of mean soil temperatures (°C) at 10 cm depth in different sub-plots from June 2005 to July 2006.

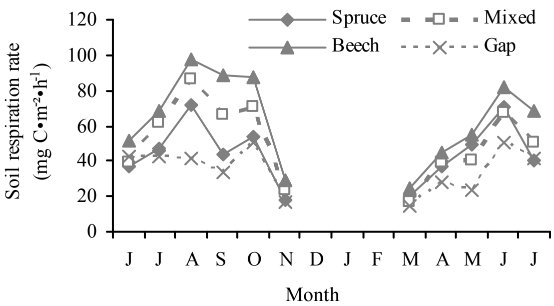

Fig. 2 Temporal variation of mean rate of soil respiration in different sub-plots from June 2005 to July 2006.

As mentioned in the material and method section, it was not possible to measure soil respirations during winter months (December, January and February). It was assumed that the soil respiration during winter was negligible. The annual soil respirations were 211–395 $g \cdot m^{-2} \cdot a^{-1}$ C (Table.1).

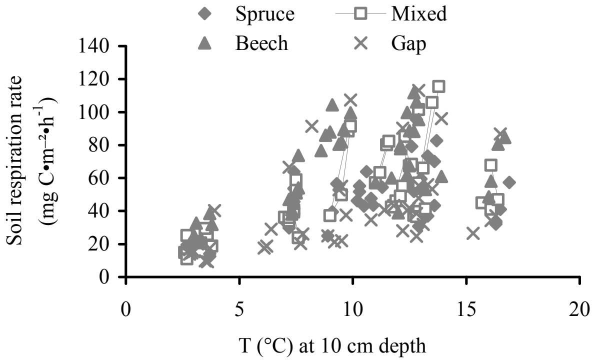

Fig. 3 Relation between the rate of soil respiration and the soil temperature at 10 cm depth.

The estimation of the root-associated CO_2 production based on a model given by Raich and Nadelhoffer (1989) revealed that TBCA or root CO_2 production were 51–231 $g \cdot m^{-2} \cdot a^{-1}$ C (Table 1). The ratios of R_{res}/S_{res} for each sub-plot indicated that the gap subplot had the relatively lowest contribution of root in total soil respiration (Table 1).

Discussion

The typical range of CO_2 efflux in this investigation was comparable with the finding of a previous study which was done in pure and mixed spruce and beech stands at the Solling forest (Borken and Beese 2005).

The correlation between soil respiration and soil temperature was in general agreement with results of earlier studies in beech and spruce stands (Epron et al. 2004). The positive relationship between CO_2 efflux and top soil temperature suggested that approximately half of the CO_2 originated from metabolic activity in the upper most soil layers.

The findings of this study revealed that the canopy composition influence annual soil respiration. The beech sub-plot showed significantly higher soil respiration, compared with the gap subplot. Brumme (1995) also expressed 40% lower soil respiration at the centre of the gap in a mature beech stand compared with the surrounding area under the canopy of beech.

CO_2 release from the forest soil originates from two different sources, decomposition of organic matter and respiration of living roots. A litter bag experiment, in the same area by Hojjati (2008), showed no significant differences in the rate of litter decomposition between the beech and gap sub-plots. Therefore, lower rate of soil respiration may be attributed to the root respiration. It was not possible to measure live root respiration in this study. Hence, root-associated CO_2 production or total belowground carbon allocation (TBCA) was used as an indicator of autotrophic soil respiration. In order to measure TBCA, it is assumed that the amount of annual litterfall equals the amount of decomposition of aboveground litter. The comparison of calculated amounts of TBCA between different sub-plots revealed that the root activity in the gap sub-plot might be lower, compared with the beech sub-plot (Table 1). The relative contribution of root respiration to total soil respiration in the gap sub-plot was 24% whereas it was 59 % in the beech sub-plot. At the same time, the biotic and abiotic parameters under the beech canopy may create more desirable condition for microbial activity and consequently higher soil respiration rate.

The relative contribution of root-associated CO_2 production to total soil respiration in the given study was within the ranges reported by other investigations (Raich and Nadelhoffer 1989; Borken and Beese 2005; Andersen et al. 2005).

The annual soil respiration in the spruce sub-plot tended to be lower compare with the beech sub-plot. This can be explained by the greater storage of carbon in the forest floor of the spruce sub-plot. C storage in organic horizons in the spruce sub-plot tended to be higher than in the beech sub-plot (Hojjati 2008). This is in accordance with findings of earlier studies in pure and mixed spruce and beech stands (Borken et al. 2002; Borken and Beese 2005; Elberling and Ladegaard-Pedersen 2005). Tewary et al. (1982) also found a significantly inverse relationship between carbon storage in the soil and soil respiration in a mixed oak-coniferous forest. In addition an external N via throughfall under the spruce canopy can suppress CO_2 formation (Berg and Matzner 1997). Hojjati et al. (2009) reported higher fluxes of inorganic nitrogen in throughfall under the canopy of spruce in the same experimental area.

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