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Influence of different tree densities on CO_2 flux from soil in Norway spruce monoculture

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Abstract: Fabiánek Tomáš, Menšík Ladislav, Kulhavý Jiří. 2015: Influence of different tree densities on CO_2 flux from soil in Norway spruce monoculture. – *Beskydy,* 8 (1): 47–53

One of the most important components of the carbon cycle in forest ecosystems is the CO_2 exchange between soil and atmosphere. Hence, forestry management has the potential to change flux and sink of the carbon dioxide in the soil. The objective of this study is to analyze and to compare soil respiration during the 2010 vegetation season in commercial Norway spruce (*Picea abies* (L.) Karst.) forest stands. Research plots are located at the Drahanská vrchovina Highlands (on the eastern edge of the Bohemian Massive), where optimal conditions for Norway spruce stands cultivation can be found in the Czech Republic (600–700 m a. s. l.). Measured soil respiration data and other soil characteristics were evaluated in young monoculture stands with different methods of forestry management. The volume of C released from the soil was measured in the range of 8.2–9.4 $t.ha^{-1}$.year and the velocity of respiration at 10 °C in the range of 2.7–3.0 $\mu mol.m^{-2}.s^{-1}$, depending on the tree density. The amount of C leached from the forest floor was found to be near 0.08 $t.ha^{-1}$ per year.

Key words: carbon dioxide, forest floor, forest management, Norway spruce, soil respiration

Introduction

Forest stands are an important part of the global biosphere and they form a final state of succession in many terrestrial ecosystems. The vitality and stability of forest stands are highly dependent on their productivity. The productive activity depends on a number of essential physiologic processes (such as assimilation activity), leading to the production of a new biomass and to the maintenance of a long standing biomass. The production activity of forest stands is determined by the amount of solar radiation absorbed, the amount of CO_2 absorbed from the atmosphere, and the availability of nutrients and water. Under natural conditions, the basic limiting factor of the productive activity is the amount of radiation absorbed (Linder 1985). Absorbed and transformed radiation is consequently utilized in the production of new biomass. This is a natural process of bio-accumulation of the carbon from the atmosphere. Thus, we can understand forests as “long-term deposit of atmospheric carbon” that are important components of the global carbon cycle (Olson 1983). The soil environment possesses a significant position in the accumulation of carbon in forest ecosystems (Valentini et al. 2000; Lee et al. 2005; IPCC 2007). Globally, soil contains around 1580 Gt C, twice the amount of carbon in the atmosphere (790–930 Gt C), and 75% of all terrestrial ecosystems (Dixon et al. 1994). Soil carbon is mostly activated from all reserves of carbon in terrestrial ecosystems. It contributes to the total annual sum of carbon released to the atmosphere - 11 to 12 times more than fossil fuel combustion; hence a small change might cause big changes in the global carbon cycle (Marland et al. 2001). Understanding the processes controlling the CO_2 flux from the soil is necessary for the accurate simulation of a future CO_2 concentration and global carbon cycle (Fahnenstock et al. 1998; Vesterdal et al. 2012). Releasing CO_2 from the soil is the second biggest flux in the carbon budget of forest ecosystems (Gower et al. 1996) and therefore it is one of the key components of the carbon cycle on a regional as well as the global scale (Raich, Schlesinger 1992). CO_2 flux from the soil represents 60–70% of the total ecosystem respiration (Davidson et al. 2006), and it is a major component of the global carbon cycle (Marland et al. 2001). Generally, soil respiration is defined as the total CO_2 flux from the surface and it is composed of root respiration (autotrophic respiration) and microbial respiration (heterotrophic respiration). Microbial respiration includes microbial decomposition of soil organic matter (SOM) rising from dead roots, roots exudate, mycorrhizal hyphae, and microbial decomposition of litter on the soil surface (leaves, needles, etc.) (Luo, Zhou 2006; Gabriel, Kellman 2014).

The presented paper evaluates and compares the CO_2 flux from the soil in allochthonous commercial stands of Norway spruce (*Picea abies* (L) Karst.) that are grown at optimal climatic conditions in the highlands (600–700 m a.s.l.). The measured soil respiration and other soil characteristics are evaluated and compared in young monoculture stands with different forestry management approaches. The aim of this study was to estimate the influence of thinning on the CO_2 flux from the forest soil surface. For example, Tang et al. (2005) reported that, as a result of the thinning, a decrease in tree density and leaf area index (LAI), an increase of the nutrients and solar irradiance availability, changes of soil temperature, the level of underground water, a higher density of roots and microbial activity can be observed. Therefore, thinning can improve forest productivity.

Material and methods

Site description: The study was based on our research carried out at the permanent field research station (49°29´ N; 16°43´E) of the Department of Forest Ecology, Faculty of Forestry and Wood Technology, Mendel University of Agriculture and Forestry in Brno. The field research station is located in the region of the Drahanská vrchovina Highlands (representing about 2.7% of the Czech Republic). It refers to a significantly forested region (668 km^2 = = over 40% of its total area) covering mainly the Culm Drahanská and Konická Highlands as well as the Moravian Karst of Devonian origin and part of principally Brno granitic eruptive rock. In the region of the field research station, acid granodiorite of the Brno massif creates a parent rock (Klimo, Kulhavý 2002). A more comprehensive description of forest stands is given in Table 1.

Norway spruce stands at the research station are the second generation (since the 19th century), following beech forest. Current forest stands were planted as 3-year old seedlings following the totally clear-cut forest (Knott 2002). The D1 forest stand was left in a state without thinning after planting. Thinning from above was applied to D4. Thinning from above removes trees from middle and upper crown classes to open canopy to favor development of most promising trees. Dominants trees are mostly removed (some dominants and intermediates trees). The thinning were applied in 2002, 2005 and 2010 (Krejza et al. 2013).

Tab. 1: Description of the research plots D1 and D4.

Plots	Species composition [%]	Age [years]	Plots area [m]	Planting/ present density of tree[†] [number.ha^{-1}]	Forest Type[†††]	Soil type[††]	A.S.L. [m]	Rainfall [mm]	Average annual temperature [°C]
D1	*Picea abies* (L.) Karst. 100	33	25 x 25	2000 /5216[††††]	5S1–*Abieto-Fagetum mesotrophicum* with *Oxalis acetosella*	Cambisols (CM)	632	638	6.5
D4	*Picea abies* (L.) Karst. 100	33	25 x 25	2000 / 1568					

[†] Knott, R., DFE, LDF, Mendelu Brno, unpublished; [††] WRB (ISSS Working Group WRB, 2014); [†††] taxonomy by FMI (Forest Management Institute, Brandýs nad Labem), [††††] trees from natural regeneration of the forest stand (Knott 2002)

Methods: The soil CO_2 flux was measured using the portable infrared gasometric analyzer (IGRA) Li8100 (LI-COR, U.S.) and chambers with diameter 20 cm during the 2010 vegetation season. Measurements were carried out in 17 permanently installed rings evenly placed in both stands over a 14-day cycle during the vegetation season of 2010 (Fig. 1). Number and location of the measurements places in the stand, was selected with a regard to area and diversity of the forest stand (Rodeghiero, Cescatti 2008). Rings were embedded in the soil 5 cm (under the forest floor layers), because of prevention CO_2 infiltration from outside to the inside measurement area. Total time of single measurement was around two hours (overall duration of one measurement cycle was five minutes on a ring, duration of CO_2 measurement was two minutes).

To compute soil respiration a method of fit a linear function was used. To estimate respiration rate at on 10 °C (R_{10}) a figure from Pavelka et al. (2007) was used. Through the use of R_{10}, it was possible compared CO_2 flux in soil environment at various temperatures. Additionally, the temperature was measured at a depth of 4 cm below the forest floor (Type E, p/n 8100-201, LI-COR, U.S.). The form of forest soil evaluation was provided of soil profiles in both experimental plots (Green et al. 1993). In order to obtain complete data on the CO_2 flux from the forest floor, water was sampled using the gravity lysimeter. The sampling devices (160 cm^2) were placed about 5 cm below the forest floor. The lysimeter was installed at plot D1 and the water was sampled in a 14-day cycle. Total carbon (TC) was analysed in the samples (in DFE laboratory, Mendelu, Brno), and subsequently the total leaching of C underneath the forest floor was calculated. Maps of soil respiration and temperature were generated with the help of the Krige interpolation function according to Pebesma (2004) using the program R (ver. 2.12.0; 2010 The R foundation for Statistical Computing). Statistical analyses were computed via the program STATISTICA 8.0 (StatSoft.Inc.) using the ANOVA method by measuring repeatedly. The statistical significance was assessed at a significance level of $p = 0.05$ (Meloun, Militký 2011).

Results

The seasonal course of CO_2 and temperature of soil is described in Fig. 2 and Fig. 3. The difference of the CO_2 flux between the stands is statistically insignificant ($F = 3.44$; $p = 0.07$). During the period investigated, 0.084 t. ha^{-1} of C of the soil profile had leached into the lysimetric water. The continuous amount of leached carbon as compared to the amount of carbon released from soil respiration during the season measured is shown in Fig. 4. The form of the forest floor was evaluated as a Leptomoder in the D4 stand and as a Mormoder in the D1 stand (Green et al. 1993). Fig. 5 shows map of distribution of annual CO2 flux from the soil surface. The sum of the months' temperatures was 66.82 °C in D1 and 64.08 °C in D4.

Over the period of seven months the forest stand D1 released a total of 30.4 t.ha^{-1} of CO_2 (8.2 t.ha^{-1} of C). The calculated rate of respiration at 10 °C (R_{10}) was 2.7 μmol.m^{-2}.s^{-1}. In the forest stand D4 34.8 t.ha^{-1} of CO_2 (9.4 t.ha^{-1} of C) had respired, R_{10} was 2.95 μmol.m^{-2}.s^{-1}. At the Fig. 6 is map of distribution of average temperature in stands.

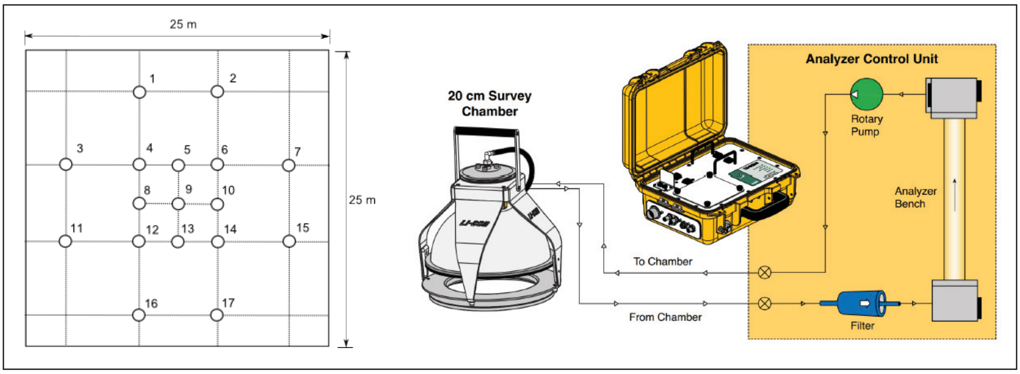

Fig. 1: Infrared gasometric analyzer (IGRA) Li8100 (LI-COR, U.S.) and scheme of permanently installed rings in research plots D1 and D4.

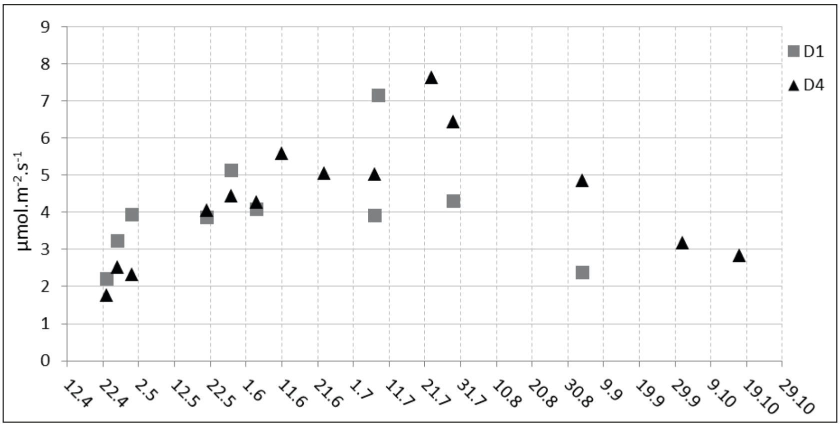

Fig. 2: The course of monthly average of soil respiration in stands D1 and D4 during season. It was measured by manual IRGA LI-COR 4800 at 17 points in each stands.

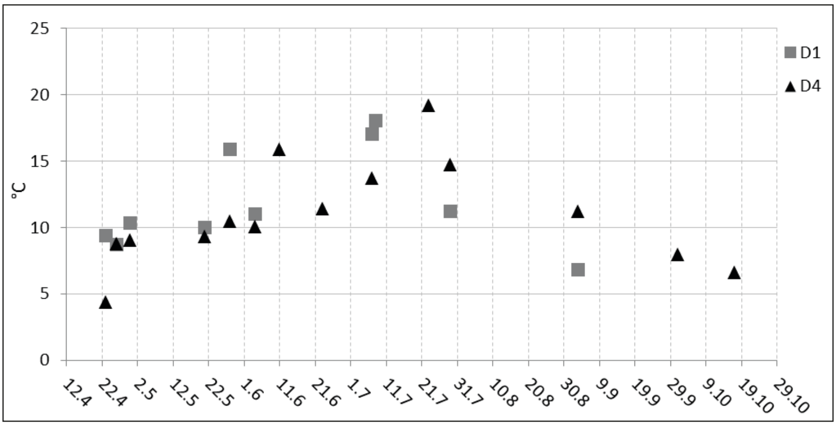

Fig. 3: The course of monthly average of soil temperature (4 cm deep) in stands D1 and D4 during season. It was measured parallel with soil respiration at 17 points in each stands.

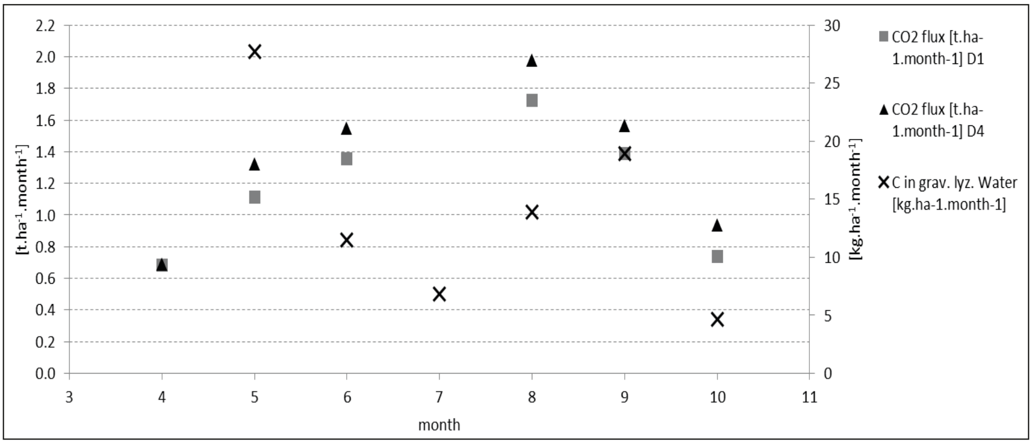

Fig. 4: Month value of C released in CO_2 flux from the soil surface, and in lysimetric water under forest floor in plots D1 and D4, during the season.

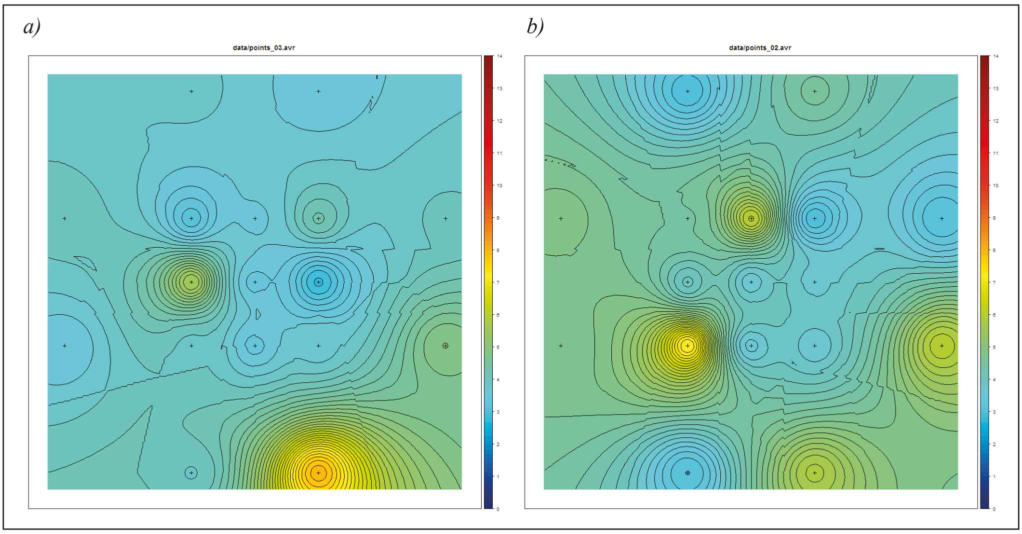

Fig. 5: The maps of soil respiration with an average value during the season in a) stand D1 and b) stand D4. Scale is in µm.m^{-1}.s^{-1}.

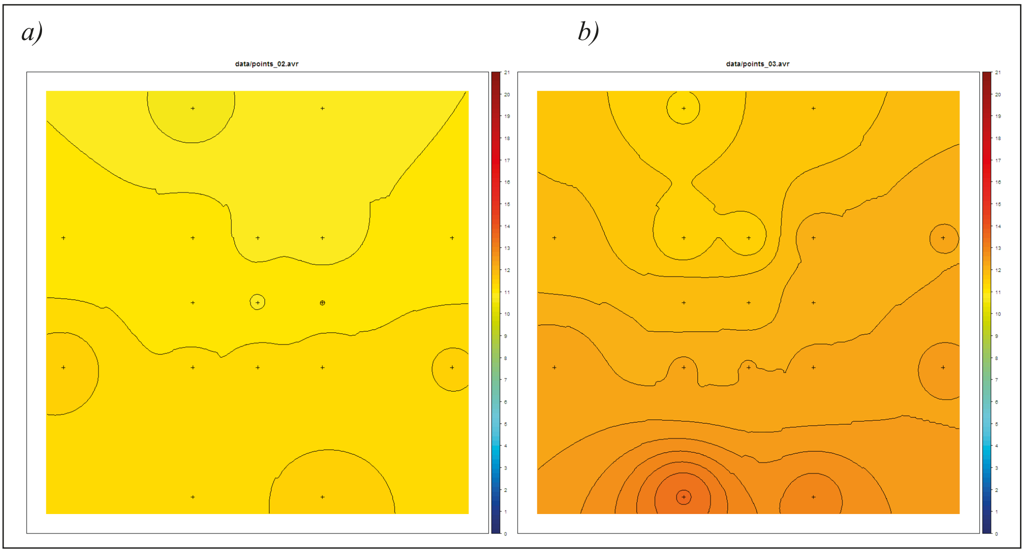

Fig. 6: The maps of soil temperature (4 cm deep) with an average value during the season in a) stand D1 and b) stand D4. Scale is in °C.

Discussion

Results of the studies considering the CO_2 flux from the soil in response to the thinning in forests stands and to a density of cultivated stands are not unequivocal (Peng et al. 2008). In the case of our measurements of CO_2 flux from the soil, we did not find a statistically significant relationship between forest stands with and without thinning management. The maps of soil respiration (Fig. 5) clearly show areas with a permanently high value of respiration. We were able to make guesses only, given the presence of high decomposition activity (decay of organic matter, etc.) and consequently on the increased production of CO_2 by soil microorganisms. Other sources of increased CO_2 might be a more densely distributed root system or a combination of these factors (Berg et al. 1982; Luo, Zhou 2006). The effect of these factors cannot be evaluated and/or proved in the methodology presented as the research of soil profile is impossible with non-destructive methods and without discontinuity measurements. However, the final differences of carbon release from the soil were similar to the data reported, for example, by Ohashi et al. (1999), obtained from CO_2 measurements in Japanese cedar (*Criptomeria japonica* D. Don) stands. His values obtained of the differences between stands with and without thinning is in the range of 0.74–0.89 kg C.m^{-2}.year^{-1}. Our value of 0.4 kg C.m^{-2}.year^{-1} is lower and this fact may be explained by the weather influence during the season and the structure of the forest floor. In our case there are periods evident with strong rainfall, which are manifested in a continuous amount of carbon leached from the forest floor (Fig. 4). Forest floor forms evaluated in stands are in accordance with the pH value (pH_{KCl} 4.0) and stock of forest floor (40 t.ha^{-1}) published by Menšík et al. (2009). In the research plot D4 with the Leptomoder form of humus we obtained a higher amount of CO_2 released from the soil to the atmosphere. This fact is primarily influenced by the microbial and animal activity (higher in Leptomoder than in Mormoder) (Green et al. 1993), and secondarily by the root respiration (Luo, Zhou 2006). The intensity of the thinning and the subsequent density of stands influence root density and respiration (Hanson et al. 2000). Unfortunately, a clear dependence could not be found and the thinning may enhance or support the growth of the rhizopshere (Ma et al. 2004; Tang et al. 2005). On the other hand Xueyong et al. (2013) attaches effect of increase soil respiration to the global climate changes and influence of the thinning is marginalized. In our case is not significant difference in soil respiration value between plots too. Bath impact of thinning on the soil respiration is often confounded by changes, which have grate influence on forest floor quality in the result (Olajuyigbe et al. 2012; Pang et al. 2013) and positive effect is not immediate.

Conclusion

Measured soil respiration data and other soil characteristics were evaluated in young monoculture stands with different methods of forestry management (without thinning, above thinning). Soil respiration in plot D1 was lower as compared to plot D4. The volume of C released from the soil was measured in the range of 8.2–9.4 t.ha^{-1}.year and the velocity of respiration at 10 °C in the range of 2.7–3.0 µmol.m^{-2}.s^{-1}, depending on the tree density. The amount of C leached from the forest floor was found to be near 0.08 t.ha^{-1} per year. The opposite results were obtained for soil temperature: in plot D1 the temperature was higher as compared to D4. These results are statistically not significant. However, according to the data obtained, we can suggest a positive influence of the thinning in our research of Norway spruce monoculture. For example it is shown in higher tree roots activity, which is reflected in higher speed of soil respiration (R_{10}) and better condition of forest floor in stand after thinning.

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