PRELIMINARY RESULTS OF SOIL RESPIRATION IN BEECH, SPRUCE AND GRASSY STANDS

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Soil respiration constitutes the second largest flux of carbon between terrestrial ecosystems and the atmosphere. This study provides the preliminary results of soil respiration (Rs) observations in three different stands, including two types of young forest stands (beech and spruce) and grassy clearings. The average values of Rs ranged from 0.92 to 15.20 µmol CO₂ m⁻² s⁻¹ in the beech stand, from 1.14 to 11.26 µmol CO₂ m⁻² s⁻¹ in the spruce stand and from 0.96 to 12.92 µmol CO₂ m⁻² s⁻¹ in the grassy stand, respectively during the whole measuring period. Maximum rates of Rs were observed on all stands at the beginning of August and minimum rates of Rs at the beginning of November. Soil CO₂ efflux exhibited a clear seasonality for all measured stands. Seasonal fluctuations of soil respiration for all stands are closely related to changes in soil temperature and soil moisture.

Keywords: experimental site Vrchslatina, soil respiration, soil temperature, soil moisture

1. Introduction

Soil respiration is a major source of CO₂ released by terrestrial ecosystems and constitutes the second largest flux of carbon between ecosystems and the atmosphere (RAICH and SCHLESINGER, 1992). Ecosystem respiration consists of both autotrophic (above and belowground plant respiration) and heterotrophic components, the latter reflecting (mostly belowground) microbial (and to a lesser degree animal) respiratory activity. Both respiration components depend on the respective substrate availability (photosynthate, litter and soil organic matter), providing a direct link between respiration and productivity (WAN and LUO, 2003). The most important abiotic influencing factors on ecosystem respiration are temperature (WOHLFAHRT et al., 2005), through its effect on enzyme kinetics, and in the case of soil respiration, also soil water availability (DAVIDSON et al., 2000; BAHN et al., 2006).

Many soil characteristics vary significantly during a year (such as soil moisture, soil temperature, microbial activity, and mineral nitrogen) and are correlated with a relatively high spatial variability (GOMORYOVA et al., 2006). Spatial heterogeneity in forest soil results from variable quality and quantity of litter input into soil variable abiotic conditions (precipitation, light, temperature) under different tree canopies at different times of year, differences in quality and quantity of stemflow and spatial differences in water and nutrient uptake by roots of trees, etc. (BRUCKNER et al., 1999, STŘELCOVÁ et al., 2006)

Although the primary mechanism for transport of CO₂ from the soil to the atmosphere is diffusion, transport may also be influenced by fluctuations in pressure, wind, temperature, and displacement by precipitation. There is a great deal of spatial and temporal variability in soil CO₂ flux due to its dependence on environmental conditions and the heterogeneity of soil. Chamber techniques are probably the most widely used means of measuring gas exchange between the soil and the atmosphere. The closed portable chambers offer the opportunity to investigate spatial variability of soil respiration and its controls. In ecosystems with high spatial variability, portable chamber systems are well suited in the search for controlling factors of soil respiration since many spatial replications ensure the full coverage of this variability (KNOHL et al., 2008).
The aim of this study is the comparison of soil respiration (Rs) in three different stands, including two types of young forest stands (beech and spruce) and grassy clearings, during the vegetation period of 2012. Apparently, the young forest stands represented very different ecosystems from the grass community in terms of carbon sequestration and cycling.

Two hypotheses have been tested:

H1: Does soil temperature and water content influence soil respiration?

H2: Are there differences in soil respiration between spruce, beech and grassland?

2. Methods

2.1. Site description

The Experimental Site Vrchslatina was established at the beginning of the 2009 growing season. A more detailed description (site, meteorological characteristics) of the whole experimental site has been published by Konôpka et al. (2013).

With regard to the content of the paper we attach a more detailed soil characterization. The site is situated in the geomorphological unit Veporské vrchy Mts., subunit Sihlianska plateau, which is composed mainly of porphyric granodiorites, biotite tonalites and granites. Cambisols were developed from this parent material. The soil properties at the research site are favourable and it is classified as Cambisol (Humic, Eutric). The textural class of the fine earth fraction is qualified as sandy loam. Though the rock fragments content is relatively high (about 30 – 35 volume percent in the whole assessed soil profile), almost all of the rock fragments are in the fraction fine gravel (0.2 – 0.6 cm) and so it does not influence the soil properties negatively. Soil reaction is only slightly acid. Values of pH measured in hydrosuspension were between 5.1 and 5.4 and values measured in CaCl$_2$ extract were between 4.3 and 4.6 (gradually decreasing towards the soil surface). The content of soil organic carbon (SOC) is high (above average for forest soils in Slovakia). In A horizon the SOC content is almost 7% and even at a depth of 50 to 100 cm it is about 1%. It has a positive effect on the soil structure and consistency. The total carbon storage in soil to a depth of 100 cm was calculated as 197 t ha$^{-1}$. The C/N ratio values also indicate good quality of soil organic matter.

The young forest stand consisting of a mosaic of pure European beech patches, pure Norway spruce patches, both naturally regenerated after shelter cut with a mean age of about 12 years, and grassy gaps dominated by Calamagrostis epigejos (L.), were selected. The total size of selected plots were approximately 0.7 ha and represented a mixture typical for naturally regenerated forests; groups of varying density with a few scattered gaps dominated by Calamagrostis epigejos (L.).

The five circular plots in beech and five in spruce patches were established in 2009. Specifically, a radius of the plots in the beech stands varied between 0.8 and 1.0 m, respectively between 0.7 and 1.0 m in the spruce stands. All trees inside the plots were labelled and basic tree characteristics were measured. Moreover, in 2010, our studies were enhanced by the inclusion of grassy plots with Calamagrostis epigejos (L.) as a dominant species. Hence, we established five square shaped plots of 3 × 3 m and subplots of 0.25 × 0.25 m for detailed measurements and sampling. The criteria as well as the reasons for the selection of individual plots are described in detail by Konôpka et al. (2013).

2.2. Soil respiration measurements

Soil respiration was measured using the LI-6400XT portable photosynthesis system (LI-COR Inc., Lincoln, Nebraska) fitted with a 6400-09 soil CO$_2$ flux chamber (Figure 1). The system volume (including gas analyzer optical bench) is 991 cm$^3$ and the measured soil area is 71.6 cm$^2$. The CO$_2$ and water vapour analyzers are attached directly to the chamber and mixing in the chamber headspace is achieved with the gas analyzer mixing fan.

![Fig. 1. Details of portable photosynthesis system Li 6400XT with a 6400-09 soil CO$_2$ flux chamber (left) and soil collar (right)](image)
For modelling soil respiration in different stands (spruce, beech and grassy) we used exponential function:

\[ \text{EFFLUX} = b_0 \exp(b_1X_1 + \ldots + b_nX_n) \]

where, \( b_0 \) – denotes the intercept of the function to which the curve approximates, \( b_1, b_n \) are regression coefficients to be estimated, and \( X_1, X_n \) are explanatory variables.

As explanatory variables, several weather parameters were selected: soil temperature (Tsoil) and soil water content (SWC).

To account for random variability between plots inside each stand, we applied nonlinear random-effects models using the package “nlme” in R (R Development Core Team, 2012).

For each type of stand, four models were tested:

- Basic models including either soil temperature or soil water content

\( m1 \) \text{EFFLUX} = b_0 \exp(b_1 \times T_{soil})

\( m2 \) \text{EFFLUX} = b_0 \exp(b_1 \times SWC)

- Advanced models including both soil temperature and water content and their interactions

\( m3 \) \text{EFFLUX} = b_0 \exp(b_1 \times T_{soil} + b_2 \times SWC + b_3 \times T_{soil} \times SWC)

\( m4 \) \text{EFFLUX} = b_0 \exp(b_1 \times T_{soil} + b_2 \times SWC)

For comparison between models and for the selection of the most probable one we used AIC (AKAIKE, 1974).

3. Results

Soil temperature and soil moisture

The seasonal course of measured soil temperature and soil moisture for the different stands is shown in figure 2 – 3. The highest soil temperature values were identified at the beginning of July and August during the measuring season on all plots. Volumetric soil water content varied between 2% and 35% in forest stand plots. The soil moisture varied between 2% and 35% in forest stand plots and between 3% and 28% in the grass plot. We saw a strong dependence on precipitation. From the beginning of August 2012 there was a more or less continuous rainless period of 44 days. This caused soil moisture to be lower than 5% of volumetric water content on all plots. The first rain (11 mm) occurred on 13th September after the drought period. This could be the cause of decreasing soil respiration, because the values of soil temperature were still stable (Figure 2 – 3). After an increase of volumetric water content in autumn, the soil respiration increased very little because of lower values of soil temperature.

Soil respiration

Soil CO₂ efflux exhibited a clear seasonality for all measured stands (Figure 2 – 3).
Beech stand

The seasonal course of Rs showed two peak curves on all beech plots (Figure 2 – left). At the end of July a mild reduction in soil CO₂ efflux was observed. This reduction was associated with a decline in soil temperature, which reached values from 12.8 to 14.2 °C during the day. The increase of soil CO₂ efflux at the beginning of August can be attributed to the ascribed recovery of soil water content after the rainfall (129 mm per 9 days) and an increase in soil temperature to 16.4 °C.

The average values of soil respiration ranged from 0.92 to 1.34 µmol m⁻² s⁻¹ in November and from 8.39 to 15.20 µmol m⁻² s⁻¹ in August 2012 (Figure 2). The maximal differences (7.16 µmol m⁻² s⁻¹) in values of soil respiration rates between the beech plots were observed during day 248 at the beginning of September.

Spruce stand

The seasonal course of Rs showed one peak curve on all the spruce plots (Figure 2 – right). During the whole season, no substantial reduction in soil CO₂ efflux was observed. The decrease of Rs values was associated mainly with a decline of soil temperature at the beginning as well as at the end of the vegetation period.
Daily average values of soil CO₂ efflux ranged from 1.78 to 2.91 µmol m⁻² s⁻¹ in April and from 8.13 to 11.26 µmol m⁻² s⁻¹ in August 2012 (Figure 2 – right). The highest differences in values of soil respiration rates between the spruce plots were observed during the 277th day at the beginning of October. The mild increase in soil CO₂ efflux during the beginning of October on plot 4 can be ascribed to the recovery of soil moisture.

Maximum rates of Rs were recorded on all spruce plots at the beginning of August, the values ranged from 8.13 µmol m⁻² s⁻¹ (ss2) to 11.26 µmol m⁻² s⁻¹ (ss4).

**Model for spruce stand**

Modelling the efflux of the soil in the spruce stand showed a similar pattern to the beech stand (Table 2). A slightly higher intercept was found for this stand, but taking the standard error into account the difference is not a significant one. On the other hand, the influence of the interaction between soil temperature and water content was found to be higher than for the beech stand (compare the parameter estimates between the both).

**Grassy stand**

The seasonal course of Rs showed a fluctuating unstable two peaked curve on all of the grassy plots (Figure 3). A significant decrease in soil respiration was observed at the end of May. This reduction was associated with a decline of soil water content, which reached values of around 15%. A further strong reduction in soil CO₂ and efflux was observed at the end of July, similarly to the beech plots.

Daily average values of soil respiration ranged from 0.96 to 1.29 µmol m⁻² s⁻¹ in November and from 8.66 to 12.72 µmol m⁻² s⁻¹ in August 2012 (Figure 3). The maximal differences (6.46 µmol m⁻² s⁻¹) in values of soil respiration rates between the grassy plots were observed during Julian day 248 at the beginning of September.

**Model for grassy stand**

Concerning the grassy stand, both the soil temperature and the interaction between the temperature and

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**Table 1.** Estimates of the final model (as selected using AIC) using nonlinear mixed-effects models applied to beech stand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (b₀)</td>
<td>0.810029</td>
<td>0.214938</td>
<td>68</td>
<td>3.76867</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>T soil</td>
<td>0.143342</td>
<td>0.017855</td>
<td>68</td>
<td>8.028094</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>T soil*SWC</td>
<td>0.317725</td>
<td>0.075159</td>
<td>68</td>
<td>4.227389</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Table 2.** Estimates of the final model (as selected using AIC) using nonlinear mixed-effects models applied to spruce stand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (b₀)</td>
<td>1.078461</td>
<td>0.258038</td>
<td>68</td>
<td>4.179471</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>T soil</td>
<td>0.10043</td>
<td>0.01144</td>
<td>68</td>
<td>-8.77882</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>T soil*SWC</td>
<td>0.556326</td>
<td>0.108636</td>
<td>68</td>
<td>5.121032</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

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Fig. 3. Seasonal course of precipitation, soil moisture at 10 cm depth, soil temperature at 10 cm depth and soil CO₂ efflux measured on five grassy (gp1-gp5) plots in 2012. Means and standard errors (bars) for soil CO₂ efflux represent measurements on three rings (n = 90) for each plot
Water content was shown to be lower than the previous types. However, the intercept was higher, which means that the efflux is much higher at the lower temperature (Figure 4).

Evaluation of the four models tested in the study showed that possibly, the most correct model from among those tested was model no. 4 for all types of stands (Table 4). This model includes the soil temperature and the interaction between the temperature and soil water content. However, in the case of the grassy stand there is a probability of 40% that model no. 3 is as good as model no. 4.

4. Discussion
The efflux of CO₂ from the soil is characterized by large seasonal fluctuations due to seasonal changes in root and microbial respiration. Although several biotic and abiotic factors influence root and microbial activity, the control exerted by temperature, and in some case moisture, is usually dominant. In the absence of water stress, variations in soil temperature account for most of the seasonal and diurnal variations in soil CO₂ efflux (Janssens et al., 2003). Seasonal fluctuations of soil respiration were confirmed during our measurements for almost all the surveyed stands.

The highest soil respiration rate was observed in the beech stand (15.20 µmol CO₂ m⁻² s⁻¹), followed by

Table 3. Estimates of the final model (as selected using AIC) using nonlinear mixed-effects models applied to grassy stand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std.Error</th>
<th>DF</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept (b₀)</td>
<td>2.021187</td>
<td>0.342306</td>
<td>65</td>
<td>5.90462</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>T soil</td>
<td>0.082723</td>
<td>0.013209</td>
<td>65</td>
<td>6.262848</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>T soil*SWC</td>
<td>0.113985</td>
<td>0.046057</td>
<td>65</td>
<td>2.474857</td>
<td>0.0159</td>
</tr>
</tbody>
</table>

Table 4. Comparison between four tested models at the spruce, beech, and grassy stands using AIC

<table>
<thead>
<tr>
<th>Model</th>
<th>Spruce</th>
<th>Beech</th>
<th>Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AIC</td>
<td>p (difAIC)</td>
<td>AIC</td>
</tr>
<tr>
<td>m 1</td>
<td>283.3627</td>
<td>0.0010</td>
<td>375.2946</td>
</tr>
<tr>
<td>m 2</td>
<td>339.2561</td>
<td>0.0000</td>
<td>425.1943</td>
</tr>
<tr>
<td>m 3</td>
<td>283.9555</td>
<td>0.0007</td>
<td>359.9409</td>
</tr>
<tr>
<td>m 4</td>
<td>269.5445</td>
<td>min</td>
<td>347.1238</td>
</tr>
</tbody>
</table>

Fig. 4. Comparison of the EFFLUX between spruce, beech and grassy stands at different soil water contents (min = 0.01 and max = 0.14)
the grassy (12.72 µmol CO$_2$ m$^{-2}$ s$^{-1}$) and spruce stands (11.26 µmol CO$_2$ m$^{-2}$ s$^{-1}$) during the vegetation period.

Cater and Ogrinc (2011) stated that the CO$_2$ flux rates ranged from minimum averages of 2.3 µmol CO$_2$ m$^{-2}$ s$^{-1}$ (winter) to maximum averages of about 7 µmol CO$_2$ m$^{-2}$ s$^{-1}$ (summer) at all the investigated locations in the Slovenian young beech forests. Epron et al. (1999) argued that soil CO$_2$ efflux varied greatly during the year, from less than 0.5 µmol CO$_2$ m$^{-2}$ s$^{-1}$ in winter, to more than 4 µmol CO$_2$ m$^{-2}$ s$^{-1}$ in summer in young beech forests. The average values of soil respiration varied from 0.92 µmol m$^{-2}$ s$^{-1}$ in November to 8.39 µmol m$^{-2}$ s$^{-1}$ in August in our young beech forest stand.

An interesting overview of maximal soil respiration values obtained in European grasslands has been published by Bahn et al. (2008). Our measured data of maximal Rs for grassy stands are comparable with those referred to in this paper.

The spruce stand showed, virtually during whole season, the lowest measured maximum value in Rs. Our measured maximal Rs values in spruce stands (11.26 µmol CO$_2$ m$^{-2}$ s$^{-1}$), however, are higher than published by Pavelka and Janouš (2001) or Subke et al. (2003) (5.15 µmol CO$_2$ m$^{-2}$ s$^{-1}$) in comparable conditions. The reason is that they presented daily averages of soil respiration, like most of the literature; we present actual average or maximal of soil respiration values.

Soil respiration exhibited pronounced spatial variations in all our studied stands. Similar results were published by Matteucci et al. (2000) who compared spatial variability of soil respiration within 3 different forest sites (beech, spruce, mixed).

The dependence of soil respiration on soil temperature has been frequently described (Lloyd and Taylor, 1994). Our study confirms this dependency. The respiration increased exponentially with the temperature increase. Therefore we applied an exponential regression function. Some authors applied linear or sinusoidal regressions between soil CO$_2$ efflux and soil temperature (Raich, Schlesinger, 1992; Ben-Asher et al., 1994; Fan et al., 1995), in most of the studies exponential function was used (Boone et al., 1998; Davidson et al., 1998; Buchmann, 2000).

We also found out that soil water content significantly influences the soil respiration rates. In many studies soil temperature alone was sufficient to explain seasonal variations of soil respiration (Burton et al., 1998; Gansert, 1994; Hanson et al., 1993; Buchmann, 2000). Several authors suggest that under certain conditions, precipitation or soil moisture significantly influence respiration (Conant et al., 1998; Buchmann et al., 1998).

5. Conclusion

This study provides the preliminary results of actual soil respiration in three different stands. The study confirms the differences in soil respiration between the surveyed stands. The testing of four different models resulted in the selection of the most suitable model for the calculation of soil respiration from soil temperature and soil water content data for all types of stands. Furthermore it was discovered that soil temperature and soil water content significantly influences soil efflux rates. Finally, it should be noted that the presented results are the first showing soil respiration measurements using soil respiration chambers in young forest stands in the territory of Slovakia.

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References


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Resumé

Cieľom príspevku je kvantifikovať a porovnať priebeh respirácie pôdy v troch rozdielnych ekosystémoch; smrekovom, bukovom a trávnom. Jednotlivé merania sa uskutočnili na piatich plochách v každom ekosystéme, ktoré sú súčasťou Výskumného objektu Vrchslatina, počas vegetačnej sezóny v roku 2012. Výsledky poukazujú na výraznú sezónnu dynamiku respirácie pôdy na všetkých sledovaných plochách. Boli testované a vybrané rovnice pre kalkuláciu pôdnej respirácie na základe teploty pôdy a obsahu vody v pôde.