Title: The Effects of Litter Production and Litter Depth on Soil Microclimate in a Central European Deciduous forest.

Concise title: Effects of Litter Production and Litter Depth on Soil Microclimate

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Aims: We examined the influence of litter quality and litter depth on soil microclimate in the detrital manipulation plots in the Síkfökút DIRT (Detrital Input and Removal Treatments) experiment.

Methods: DIRT manipulations include two litter addition (Double Litter and Double Wood), three litter removal (No Litter, No Input and No Root), and one Control treatment. Soil temperature was measured with ONSET StowAway TidbiT type data loggers and soil moisture content at 12 cm depth was determined with a FieldScout TDR 300.

Results: There were significant differences detected among plots in winter and summer soil mean temperatures as well as in the number of frost-free days. The highest annual soil temperature variation was detected in litter removal treatments, while the lowest variation was in Double Litter plots with the thickest litter layer. The root exclusion treatments had significantly greater soil moisture contents than other treatments due to loss of transpiration. The wetter and low in organic matter plots showed lower winter temperatures.

Conclusion: These differences in soil microclimate may have a highly significant, but unrecognized effect on soil carbon balance through effects on microbial processing of litter and soil C, and thus soil CO2 release and soil C sequestration.

Keywords: microclimate, soil temperature, soil moisture, detritus manipulation, DIRT, climate change
Introduction

Changes in temperature and precipitation patterns that are predicted under future scenarios of global warming will have profound effects on primary productivity, plant species diversity and composition, and ecosystem function (Wang et al., 2011; Rózsa and Novák, 2011; Williams et al., 2012; Serrano et al., 2015). All of these factors independently will feed back to alter the quality and quantity of detrital inputs to soils, further altering patterns of nutrient cycling (Biró et al., 2012; Tóth et al., 2013) and soil organic matter (SOM) content and dynamics. Indirect changes to soil temperature and moisture regimes from global climate change will also affect the processing of litter by microbes (Chapin et al., 2009; Bond-Lamberty and Thomson, 2010; Hagedorn et al., 2010; Wang et al., 2014). While both of these factors – litter production, and soil warming and/or drying - are included in most models of soil carbon balance, indirect effects of litter production and surface litter depth on soil microclimate, and thus microbial processing of litter and SOM, are less well studied. Detritus thus plays two major roles in terrestrial ecosystems: on one hand, above- and belowground litter is the source of stabilized SOM, and on the other hand, litter forms a layer on the soil surface that affects microclimate (Sayer et al., 2006).

The aim of this work was to explore effects of changing detrital inputs on soil microclimate in a Quercetum petraeae-cerris community in northeast Hungary. The Síkfőkút DIRT (Detritus Input and Removal Treatments) experiment constitutes an important part of a long-term international project that involves five experimental sites in the USA (Andrews Experimental Forest, Bousson Experimental Forest, Harvard Forest, University of Michigan Biological Station, Santa Rita Experimental Range) and one in Germany (Universität Bayreuth BITÖK). The overall objective of the DIRT project is to explore how changes in the
quality and quantity of detrital inputs affect soil physical, chemical and biological parameters (Nadelhoffer et al., 2004; Lajtha et al., 2005).

Several studies have already examined the effects of global warming on our experimental site. Longer and more severe drought periods are expected in the near future for several Central European ecosystems. The long-term meteorological data have clearly indicated that the climate of the forest has become drier and warmer over the past few decades with annual precipitation decreasing by 15-20% in many Hungarian territories (Antal et al., 1997; Galos et al., 2009). The summer climate of the Carpathian Basin has shifted towards a more Mediterranean like climate (Domonkos, 2003; Bartholy et al., 2007). The species composition and structure of the Síkfőkút forest has changed since the early 1970’s (Tóth et al., 2007): 68% of sessile oak (*Quercus petraea*) and 16% of Turkey oak (*Quercus cerris*) died. The percentage of field maple (*Acer campestre*) has increased from 0% to 28% (Kotroczó et al., 2007). This also entails several changes in detritus amount and composition (Bowden et al. 2006). Mean leaf-litter production was 4060 kg ha\(^{-1}\) y\(^{-1}\) between 1972 and 1976, and 3540 kg ha\(^{-1}\) y\(^{-1}\) between 2003 and 2010 (Kotroczó et al., 2012).

We hypothesized that detrital litter layer thickness would significantly affect annual, seasonal and daily temperature fluctuations of surface mineral soils by acting as a buffer that would also affect soil moisture levels. We also hypothesized that differences in soil moisture content among treatments would affect daily soil temperature range (DTR), with soils from plots without roots having greater soil moisture content and thus greater DTR.

### Material and methods

**Site description**
We carried out our research in the Síkfőkút Experimental Forest in northeastern Hungary. The project area (27 ha) is located in the southern part of the Bükk Mountains at altitude of 325-345 m (47°55'N; 20°26'E). The area has been protected and is part of the Bükk National Park since 1976. According to Antal et al. (1997) the mean annual temperature is 10°C and the mean annual precipitation is 553 mm. This forest is a semi-natural stand (Quercetum petraeae-cerris community) with no active management since 1976 (Jakucs, 1985). In this previously coppiced forest the Sessile oak and Turkey oak species that make up the overstory are a hundred years old. Based on the data from 2003 to 2006, litter production consists of the following tree species in decreasing order: Sessile oak (Quercus petraea), Turkey oak (Quercus cerris), Field maple (Acer campestre), and Cornelian cherry (Cornus mas). During the same period the average dry leaf-litter production was 3585 kg ha⁻¹ and the average amount of total aboveground dry detritus (including branches, twigs, fruit and buds) was 6230 kg ha⁻¹ (Tóth et al., 2007). The soils according to the WRB Soil Classification are Luvisols (Świtoniak et al., 2014) with a pHH₂O in surface soils (0-15 cm) without detrital manipulation of 5.2 and with soil organic carbon ranging between 2.96% and 4.42% depending on the detritus treatment (Tóth et al., 2013; Fekete et al., 2014).

The experimental detrital manipulation plots were established in the Síkfőkút DIRT site in November 2000. We established six treatments, each with three 7×7m replicate plots (Table 1) (Fekete et al., 2011). We applied 2 litter addition treatments Double Litter (DL) and Double Wood (DW), and 3 detritus removal treatments No Litter (NL), No Roots (NR), No Input (NI), and Control (CO) treatments. The surface solar radiation was approximately the same in all treatments, as the distribution and slope of land did not show great differences (average slope of 5 degrees) and the site faced south, so the climatic effect was same in all
plots. Moreover, the plots were established at random, thus reducing the effects of incidental
minor differences.

Soil temperature was measured with ONSET StowAway TidbiT type data loggers (Onset
Computer Corporation, USA) placed into the middle of each plot at 10 cm depth. Air
temperature was measured 0.5 meters above the ground with the same type of data loggers.
Data loggers were programmed to measure soil and air temperature every hour from
06.17.2004 to 06.16.2008. The temperature data were grouped into seasons (winter:
December, January, February; spring: March, April, May; summer: June, July, August;
autumn: September, October, November). Soil moisture content at 12 cm depth was
determined with a FieldScout TDR 300 (Spectrum Technologies Inc., USA) in all plots,
every month.

Statistical analyses

Statistical analyses were performed using Statistica 7.0. Random sampling and the
independence of samples were ensured by the experimental design. Experimental data were
statistically evaluated by one-way ANOVA (assumptions were tested by Levene’s test for
homogeneity of variances and Chi-square test for normality), linear regression and one-way
ANCOVA. When groups were significantly different, ANOVAs were followed with Tukey’s
HSD test. We analyzed the effects of air temperature on soil temperature in the treatments by
linear regression, and differences among slopes were tested using one-way ANCOVA.
Results

The effects of detritus treatments on soil temperature and soil moisture content

Detritus treatments significantly influenced soil microclimate. The annual mean temperature values did not show any significant differences between the treatments (Table 2). However, the differences were significant within the winter ($F_{(6,2191)}=70.31; p<0.01$) and the summer periods ($F_{(6,2583)}=65.2; p<0.01$) (Table 3 and 4), but there were no significant differences the transitional seasons (autumn and spring). In summer, air temperature was significantly higher than in all soil treatments, and soil temperatures in the root exclusion treatments (NR, NI) were significantly higher than in the any other soil treatments, and NL was significantly higher than in CO and the litter addition treatments. In contrast, air temperature was significantly lower than all soil treatments in winter. The temperatures in the aboveground litter exclusion treatments (NL and NI) were significantly lower than the CO, and litter addition treatments in winter. Similarly, the number of frost days, when the soil temperature was below 0°C, was significantly different among treatments (Table 2). Therefore, the annual fluctuation of soil temperature was much higher in the detritus exclusion treatments than in CO or litter addition treatments, and air temperature showed higher fluctuations seasonally than did soil temperature in the different treatments (Table 2, 3 and 4).

The relationship between air temperature and soil temperature in the six treatments was shown by regression analyses. Air temperature and soil temperatures were significantly related when analyzed within each season based on daily averages (Tables 5 and 6). Soil daily mean temperatures in the root exclusion treatments (NR, NI) were most responsive to air daily mean temperature in summer, and soil daily mean temperatures in surface litter exclusion treatments (NL, NI) were most responsive to air daily mean temperatures in winter. The correlation was stronger in summer than in winter for all treatments. The regression
analysis between air daily mean temperatures and soil daily mean temperatures exhibited significantly higher slope values in the regression equation in case of the NR and NI soil of the treatments than in the CO and litter addition plots in summer (Table 5). However, there were not significantly different slope values for the winter periods (Table 6).

Soil moisture contents were significantly higher in root exclusion treatments (NR and NI) than in the other treatments ($F_{(5,240)} = 18.21; \ p<0.001$) (Table 2). There were no other differences in soil moisture among the other treatments (Table 3 and 4). Regarding moisture content values, the quotients of the upper and lower quartiles were the lowest in root exclusion treatments, which showed that soil moisture content varied the least in these soils.

The effects of detritus on daily soil temperature range (DTR)

Hourly soil and air temperature readings were used to determine minimum and maximum daily temperatures, and the differences among minimum and maximum temperatures were used to calculate DTR. DTR of air was always significantly higher than DTR of the soils in all treatments ($F_{(6,1526)} = 812.8; \ p<0.001$). The detrital treatments significantly affected soil DTR fluctuation (Table 7). In winter, when the average daily temperature of the air is lower than daily minimum temperature of soil treatments, the soil temperatures often show a steady decline or do not change. In this case, the air DTR does not affect the temperature of the soil, especially the leaf litter-covered plots. As temperatures in winter fell to below 0°C, rapid temperature decreases were first seen in plots not covered by litter, followed by CO and DW plots; soil temperatures below freezing were not observed in DL plots. As temperatures rose above freezing, frozen soils had a 2-3 day lag due to isolating ability of the frozen upper soil layer, in winter, there were no significant differences in soil DTR among plots. In spring and
summer, soil DTR was significantly smaller in plots with a litter layer (DL, DW and CO) than in detritus removal plots (NL, NR, and NI). In autumn, DTR was significantly smaller in DL, DW and CO than in NR and NI.

Discussion

Changes in soil temperature and moisture content

Various detritus treatments and soil biological processes both directly and indirectly influence soil microclimate (Tejedor et al., 2004; Sayer 2006). Therefore, the significant differences in temperature among the soils of the treatments during the winter and summer periods are considered to be the consequences of detritus treatments. In winter (especially when there is no snow) the thickness of the detritus layer had a profound effect on soil temperature. This “insulating effect” was observed in DL treatments, as temperatures in DL soils never fell below 0°C. Soil temperature may also be influenced by soil biochemical processes (Raich and Tufekcioglu, 2000; Bernhardt et al., 2005); decomposition of organic matter and other microbial processes can release a significant amount of heat. In the colder periods exothermic decomposition processes were significantly greater in litter addition treatments and CO than in detritus removal treatments, as shown by soil respiration values (data in Fekete et al., 2014; Kotroczó et al., 2014). These higher respiration rates could both be partially due to higher temperatures in litter addition plots due to insulation effects, and could also contribute to warmer conditions. In contrast, in summer NR plots had the highest soil respiration values among the treatments and had the highest soil temperature and
moisture content as well. Because the NR treatment had no labile root inputs and no root turnover, the higher respiration rates were clearly due to microclimate effects.

NL and NI soils had lower albedo values than the lighter color surface covered by dry detritus, so they certainly absorbed more heat in summer, when solar radiation was intense. This was especially true for NI plots, whose soil was much darker due to its higher moisture content. The soil moisture values also showed large differences among the detritus treatments (Veres et al., 2013). Due to the lack of transpiration, the soils in the root exclusion treatments (NR and NI) were significantly wetter than soils in the other treatments, and they stayed moist even under severe summer drought (Fekete et al., 2012). A similar trend was found in the American DIRT sites. The soil moisture content of NR had higher with 86% than CO in Síkfőkút DIRT site, while this difference was 9.3% in Andrews DIRT site in Oregon (USA) and 17.5% in Bousson DIRT site in Pennsylvania (USA) (Brant et al., 2006). These differences between the American and Hungarian DIRT sites may be explained by climate factors. Annual precipitation at Síkfőkút is much lower than that at the US DIRT sites (Andrews: 2370 mm yr\(^{-1}\); Bousson: 1050 mm yr\(^{-1}\)), and rainfall is more seasonally distributed (Sulzman et al., 2005; Crow et al., 2009). Moreover, the annual mean temperature at Síkfőkút is higher than that at the US DIRT sites, so here's higher evaporation.

The surface litter layer also regulates the soil water content (Ogée and Brunet, 2002), on the one hand reduces the evaporation of the mineral soil, on the other hand it absorbs a certain amount of precipitation water, which thus does not penetrate into the soil. Soil moisture content may also influence soil thermal conductivity; the higher the soil moisture content, the higher its thermal conductivity (Blackburn et al., 1998; O’Donnel et al., 2009). In contrast, the heat of evaporation cools the soil surface, and this effect is greater in moister soils. The differences among the DTR in the soils of the treatments likely reflected this evaporation.
effect. The litter layer of the NR plots are similar to CO plots, but the DTR is significantly
higher in NR than in CO.

In addition, the absence of trees and shrubs in NR and NI plots leads to a lack of a shading
effect. Therefore, it was the two root exclusion treatments that showed the highest
temperature values in summer and the lowest ones in winter – in this latter case along with
NL. Many factors in addition to soil water content, such as organic matter content, also
influence soil thermal conductivity (Blackburn et al., 1998; Al-Shammary and Al-Sadoon,
2014). Soil mineral particles have much higher thermal conductivity than soil organic matter,
e.g. quartz has 14 times as high conductivity as soil organic particles (Farouki, 1986; Perry et
al., 2011). Thus soils with higher organic matter content warm more slowly than those with
lower organic matter and higher mineral matter contents – provided other parameters are the
same. Soil organic carbon was 67.3 g kg\(^{-1}\) dry soil in the upper 5 cm soil layer in DL which
was 58.6%, 46.8% and 61.1% higher than in NL, NR and NI (Fekete et al., 2014).

Clearly detrital thickness can reduce the effects of soil temperature extremes and moderate
minimum and maximum temperature values, creating a more balanced microclimatic for soil
organisms. Soil moisture may also significantly affect soil temperature. If the climate
becomes warmer and drier litter production may decrease, creating a thinner litter cover,
which may increase daily and seasonal temperature extremes. The effects of litter layer
thickness on soil processes is important to include in earth system models that aim to predict
soil carbon stocks and soil respiration.

References


Tables legends

Table 1. The applied DIRT (Detritus Input and Removal Treatments) treatments in the Síkfőkút site, Hungary.

Table 2. Soil and air properties in the Síkfőkút DIRT treatments. Different letters indicate significant difference.

Table 3. Air and soil temperature and standard error values in the Síkfőkút DIRT treatments during summer periods; (June, July, August); N per treatment = 370. Different letters indicate significant difference.

Table 4. Air and soil temperature and standard error values in the Síkfőkút DIRT treatments during winter periods (December, January, February). N per treatment = 314. Different letters indicate significant difference.

Table 5. The relationship between the air temperature and soil temperature of the different treatments in the summer periods from 2004 to 2008. Different letters indicate significant difference slope values (p<0.001). (soil temperature=a+b*air temperature; where a is a constant and b is the slope).

Table 6. The relationship between the air temperature and soil temperature of the different treatments in the winter periods from 2004 to 2008 (p<0.001). (soil temperature=a+b*air temperature; where a is a constant and b is the slope).

Table 7. Air and soil values of the daily fluctuation of the temperature in the Síkfőkút site based on the means of all treatments. (Based on 219 randomly choosed values from 17.03. 2004 to 29.02. 2008)
Table 1. Soil and air properties in the Síkfökút DIRT treatments. Different letters indicate significant difference

<table>
<thead>
<tr>
<th></th>
<th>DL</th>
<th>DW</th>
<th>CO</th>
<th>NL</th>
<th>NR</th>
<th>NI</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>m. a. t. I.</td>
<td>10.3±0.07</td>
<td>10.2±0.08</td>
<td>10.2±0.07</td>
<td>10.2±0.08</td>
<td>10.3±0.08</td>
<td>10.2±0.08</td>
<td>10.1±0.09</td>
</tr>
<tr>
<td>b. days II.</td>
<td>0</td>
<td>17</td>
<td>17</td>
<td>70</td>
<td>29</td>
<td>77</td>
<td>143</td>
</tr>
<tr>
<td>a. days III.</td>
<td>17</td>
<td>16</td>
<td>16</td>
<td>30</td>
<td>96</td>
<td>72</td>
<td>141</td>
</tr>
<tr>
<td>fluct. IV.</td>
<td>20.03</td>
<td>22.12</td>
<td>22.12</td>
<td>25.88</td>
<td>26.61</td>
<td>28.3</td>
<td>42.5</td>
</tr>
<tr>
<td>moisture V.</td>
<td>23.6a±0.61</td>
<td>25.8a±0.61</td>
<td>24.5a±0.61</td>
<td>25.3a±0.60</td>
<td>36.9b±0.50</td>
<td>34.5b±0.54</td>
<td>-</td>
</tr>
</tbody>
</table>

I. mean annual temperature from the daily mean temperature values 06.17.2004 -06.16.2008 (in °C)
II. The number of days when the daily mean temperature was below 0°C
III. The number of days when the daily mean temperature was above 20 °C
IV. Maximum fluctuation of the temperature of the examined period (in °C),
V. The average of soil moisture content between 2004-2008 (%v/v) was determined once every month in the year

Table 2. Air and soil temperature and standard error values in the Síkfökút DIRT treatments during summer periods; (June, July, August; N per treatment = 370) and winter periods (December, January, February; N per treatment = 314). Different letters indicate significant difference.
Table 3. The relationship between the soil temperature (°C) and air temperature of the different treatments in the summer and winter periods from 2004 to 2008

<table>
<thead>
<tr>
<th>treatments and air</th>
<th>daily average in all period</th>
<th>daily maximum</th>
<th>daily average in spring</th>
<th>daily average in summer</th>
<th>daily average in autumn</th>
<th>daily average in winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL</td>
<td>0.63±0.02</td>
<td>1.63</td>
<td>0.75±0.05</td>
<td>0.79±0.04</td>
<td>0.51±0.03</td>
<td>0.39±0.05</td>
</tr>
<tr>
<td>DW</td>
<td>0.74±0.03</td>
<td>2.58</td>
<td>0.71±0.05</td>
<td>0.92±0.05</td>
<td>0.66±0.04</td>
<td>0.57±0.08</td>
</tr>
<tr>
<td>CO</td>
<td>0.85±0.04</td>
<td>2.46</td>
<td>1.06±0.07</td>
<td>0.96±0.05</td>
<td>0.65±0.04</td>
<td>0.64±0.14</td>
</tr>
<tr>
<td>NL</td>
<td>1.46±0.07</td>
<td>5.04</td>
<td>2.38±0.17</td>
<td>1.54±0.06</td>
<td>0.85±0.06</td>
<td>1.01±0.12</td>
</tr>
<tr>
<td>NR</td>
<td>1.48±0.06</td>
<td>3.82</td>
<td>2.06±0.11</td>
<td>1.87±0.09</td>
<td>1.14±0.05</td>
<td>0.66±0.07</td>
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<tr>
<td>NI</td>
<td>1.87±0.07</td>
<td>6.04</td>
<td>2.96±0.18</td>
<td>1.99±0.07</td>
<td>1.16±0.06</td>
<td>1.18±0.14</td>
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<tr>
<td>Air</td>
<td>7.23±0.18</td>
<td>16.02</td>
<td>7.43±0.35</td>
<td>8.37±0.25</td>
<td>5.92±0.28</td>
<td>6.45±0.48</td>
</tr>
</tbody>
</table>

One-way ANCOVA was applied. Different letters indicate significant difference slope values (p<0.001). (soil temperature=a+b*air temperature; where a is a constant and b is the slope)

Table 4. Air and soil values of the daily fluctuation of the temperature in the Sikfőkút site based on the means of all treatments (Based on 219 randomly choosed values from 17.03. 2004 to 29.02. 2008)

Fig. 1 Temporal variation of the summer soil temperature for Double Litter, Control and No Imput treatments
Fig. 1 Temporal variation of the winter soil temperature for Double Litter, Control and No Imput treatments
Fig. 3 Summer hourly temperature profile of the soil temperature in the different treatments and the profile of air temperature between 06. 01. 2005 and 09. 30. 2005