Eurasian Journal of Soil Science

Journal homepage : http://fesss.org/eurasian_journal_of_soil_science.asp

Influence of temperature and organic matter content on soil respiration in a deciduous oak forest

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Abstract

The increasing temperature enhances soil respiration differently depend on different conditions (soil moisture, soil organic matter, the activity of soil microbes). It is an essential factor to predicting the effect of climate change on soil respiration. In a temperate deciduous forest (North-Hungary) we added or removal aboveground and belowground litter to determine total soil respiration. We investigated the relationship between total soil CO_2 efflux, soil moisture and soil temperature. Soil CO_2 efflux was measured at each plot using chamber based soil respiration measurements. We determined the temperature sensitivity of soil respiration. The effect of doubled litter was less than the effect of removal. We found that temperature was more influential in the control of soil respiration than soil moisture in litter removal treatments, particularly in the wetter root exclusion treatments (NR and NI) (R^2: 0.49-0.61). Soil moisture (R^2: 0.18-0.24) and temperature (R^2: 0.18-0.20) influenced soil respiration similarly in treatments, where soil was drier (Control, Double Litter, Double Wood). A significantly greater increase in temperature induced higher soil respiration were significantly higher (2-2.5-fold) in root exclusion treatments, where soil was wetter throughout the year, than in control and litter addition treatments. The highest bacterial and fungal count was at the DL treatment but the differences is not significant compared to the Control. The bacterial number at the No Litter, No Root, No Input treatment was significantly lower at the Control. Similar phenomenon can be observed at the fungal too, but the differences are not significant. The results of soil respiration suggest that the soil aridity can reduce soil respiration increases with the temperature increase. Soil bacterial and fungal count results show the higher organic matter content and soil surface cover litter favors the activity.

Article Info

Received : 11.07.2014
Accepted : 17.10.2014

Keywords: Added litter, Removed litter, Carbon-cycle, CO_2 efflux, DIRT

Introduction

Soil respiration in terrestrial ecosystems plays a critical role in regulating global carbon cycling. Soil contains a huge and dynamic pool of carbon (C) that is a critical regulator of the global carbon budget. Small climatically induced changes in the rate of soil respiration can have a great impact on future atmospheric CO_2 concentrations. Soil gas release is temperature sensitive; thus, global warming probably create a positive feedback, causing soils to release more greenhouse gases that will further exacerbate the problem (Johnston et al., 2004; Luo, 2007; Tóth et al. 2007; Kotroczó et al., 2012).

Soil respiration is the largest terrestrial source of CO_2 to the atmosphere and currently represents an annual flux a magnitude larger than that from anthropogenic fossil fuel combustion (Raich et al., 2002; IPCC, 2007). Soil C accumulation and turnover are important global processes: soils contain about 1.5×10^{18} g C, which is

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ISSN: 2147-4249

2-3 times bigger than the total amount of C in vegetation (Schlesinger, 1990). The C flux between soils and the atmosphere is huge, with soil respiration representing about ten times the C flux due to fossil fuel combustion (Post et al., 1990; Watson et al., 1990). Thus, any change in rates of soil C turnover will significantly affect to the global C cycle. The litter input quantity and quality are taken into account under most scenarios of global climate change. With climate change, according to the predicted increase in litter fall increase the soil CO_2 efflux and the atmospheric CO_2 concentration (Crow et al., 2009; Prévost-Bouré et al., 2010; Kotroczó et al. 2008; Kotroczó et al., 2009).

Quality and quantity of leaf litter input is considerably different in the soil of various ecosystems (Raich and Nadelhoffer, 1989; Allison and Vitousek, 2004; Kotroczó et al., 2012). Input and output processes are affected by climatic factors (such as temperature) and by soil organisms which simultaneously influence the degradation of organic matters and the abiotic dissolution of nutrients from the soil (McDowell and Likens, 1988; Qualls et al., 1991). Warming climate increases the activity of soil microorganisms and their soil enzymes (Fekete et al., 2007; Jin et al., 2010; Fekete et al., 2011a; Veres et al., 2013) which lead to increasing intensity of organic matter degradation (Kotroczó et al., 2014; Beni et al., 2014).

Degradation processes are rather influenced by increasing temperature than composition processes in the soil (Schimel et al., 1994; Kirschbaum, 1995). Increasing degradation processes lead to increasing soil respiration, which results in decreasing organic matter content of the soil and consequently, promotes the deterioration of the habitat (Kuzyakov, 2006; Millard et al., 2010; Fekete et al., 2011b). Many authors showed a positive correlation between soil respiration and temperature (Ryan et al., 1994, Bond-Lamberty and Thomson, 2010). The temperature sensitivity of soil respiration (Index of Respiration Response to Seasonal Change (IRRSC) is important; it helps to understand the effect of the ecosystem carbon dynamics to global climate change (Zheng et al., 2009).

In case of forests, carbon content of the soil is usually twice as much as the carbon content of the biomass (Somogyi, 2008). Soil carbon content is also influenced by human activities, since organic matter decomposition and impending soil erosion can be enhanced by timbering and soil disturbance. Values of soil respiration intensity provide input data for large-scale researches of carbon circulation, contribute to the revelation of interactions between the biosphere and atmosphere, and promote the drawing up of carbon balances from associations to global level. These values are also needed for making predictions and for modeling the global climatic change (Jones et al., 2003; Davidson and Janssens, 2006).

According to Göran et al. (2003), faster decomposition processes and larger carbon loss will be experienced as a consequence of 2-4°C of temperature increase, which has been predicted for the end of the century. Therefore, it is important to examine the effects of artificial changes in leaf-litter input on soil temperature as well as on dynamics of soil organic matters and consequently, on soil respiration which serves as the most important factor for determination of carbon loss.

The aim of the present research was to examine: (i) The changes in CO_2 efflux of the soil under the influence of added litter input and litter removal. (ii) The effects of litter (i.e. organic matter) removal or increasing litter input on temperature sensitivity of soil respiration. (iii) The effects of soil temperature on soil respiration.

Material and Methods

Site description

The Síkfőkút DIRT Project is a member of a long-term project (Detritus Input and Removal Treatments, DIRT) organized by the USA ILTER (International Long-Term Ecological Research). The DIRT Experiment is a long-term study of controls on soil organic matter formation; it's goal is to assess how rates and sources of plant litter inputs control the accumulation and dynamics of organic matter and nutrients in forest soils over decadal time scales. The experimental site is located in the south part of the Bükk Mountains in North Hungary (47°55'N, 20°26'E, 320-340 m above sea level). This forest belongs to the Bükk National Park, hence there is no anthropogenic influence. The site is covered by an oak forest (*Quercetum petraeae-cerris* with brown forest soils with clay illuviation (Jakucs, 1973) and the type of the soil according to the FAO Soil Classification is Cambisols. Basic meteorological and soil characteristics of the site are presented in Table 1. and Table 2. The annual precipitation amounts to 550 mm.

Table 1. Mean annual meteorological characteristics of Síkfőkút DIRT site, Hungary.

years	Mean annual			
	Soil temperature at 10 cm (°C)	Soil moisture at 10 cm (v/v%)	Air temperature (°C)	Precipitation (mm)
2002	10.3	23.4	11.3	523.3
2003	9.6	19.0	10.6	542.7
2004	9.5	27.1	10.4	678.6
2005	10.2	27.2	10.3	712.1
2006	10.1	30.5	10.8	621.3

Table 2. Mean characteristics of soil at Síkfőkút DIRT site, Hungary.

Parameters	Soil content
pH_{H2O}	5.21
C:N ('A' horizon)	20
C:N (litter)	55
Mean annual litter production (kg ha^{-1} yr^{-1})	2930

Plant litter inputs have been manipulated at the DIRT plots in the Síkfőkút Forest since 2000. Six litter treatments (three replicates per treatment, Table 3) were located randomly at the site. Plots sizes are 7×7 m (49 m^2). Litter of No Litter plots were transferred to Double Litter plots many times per year. Vegetation was continually removed from the No Roots and No Inputs plots. Mosses re-grew rapidly, and were removed semi-annually.

Table 3. Treatments methods of the DIRT (Detritus Inputs and Removal Treatments) plots (Síkfőkút, Hungary).

Treatment	Method
Control (CO)	Normal litter inputs are allowed.
No Litter (NL)	Aboveground inputs are excluded from plots.
Double Litter (DL)	Aboveground leaf inputs are doubled by adding litter removed from No Litter plots.
Double Wood (DW)	Aboveground wood inputs are doubled based on measured input rates of woody debris fall.
No Roots (NR)	Roots are excluded with impenetrable barriers extending from the soil surface to the top of the C horizon.
No Inputs (NI)	Aboveground inputs are prevented as in No Litter plots, belowground inputs are prevented as in No Roots plots.

Measurement of soil respiration and determination of index of respiration response to seasonal change value (IRRSC)

We used the standard methods of the LTER DIRT researches (Robertson et al., 1999). Soil CO_2 efflux was investigated in a previous study by Raich et al., (1990) and Grogan, (1998), who determined total annual soil CO_2 efflux at each plot using chamber based soil respiration measurements. The soda-lime technique has been used extensively for 30 yr to measure CO_2 fluxes from soil under field conditions. Measurements chambers were plastic buckets (21 cm tall and 29 cm in diam) with collars inserted in the soil preventing CO_2 leakage from chamber headspace into the atmosphere. CO_2 was absorbed with 60 g of indicator-grade soda-lime contained in 7.8 cm diameter by 5.1 cm tall cylindrical tins. Prior to use, the tins of soda-lime were oven dried at 105°C for 24 h and covered tightly. To measure CO_2 fluxes in the field, the tins were uncovered and placed on the forest floor. The measurement chambers were then placed on top of each tin. After 24 h, the tins were removed, oven dried at 105°C, and reweighted. From this difference we calculated the carbon content of CO_2:

$$C\ (mg \times m^{-2} \times h^{-1}) = ((m_B - m_A - blank) \times 1000 \times 1.69 \times 0.2729)/a/t$$

where: 'm_A' = dry weight before placement (g); 'm_B' = dry weight after placement (g); 'blank' = average of blanks measurement; 'a' = area covered by plastic bucket (0.07122 m^2); 't' = adsorption time (h). *Factors and its function in calculation* (Grogan, 1998): '1000' = change between mg and g; '1.69' = factor, weight of crystalwater in soda lime; '0.2729' = ratio of carbon content of CO_2.

The soil respiration was measured monthly and two soda lime chambers were used at every plot. We started the soil respiration measurements in 2002. The relation between soil temperature and soil respiration is $Rs = \alpha \times e^{\beta \times T}$. Where Rs is measured soil respiration rate, T is measured soil temperature at 10 cm depth, α and β are regression coefficients (β is also called temperature reaction coefficient). Exponential equation was used to analyze the relationship between soil temperature and soil respiration and to determine R^2 values. From this equation can be calculated the Q_{10} ($Q_{10} = e^{10 \times \beta}$) (Lloyd and Taylor, 1994; Boone et al., 1998; Nadelhoffer et al., 2004). We use an index of respiration response to seasonal change (IRRSC). This index is calculated in the same way as the Q_{10}, but we don't use the term Q_{10}, because we applied a field methods when we measured the soil respiration and in a forest soil, root activity, root exudation, etc. all change as seasons change, so it is not ever possible to tease out a true Q_{10} effect. Our measurements were made between 2002 and 2006.

The soil temperature was measured hourly in each 18 plots by Onset StowAway®TidbiT® temperature loggers in 10 cm soil dept.

The statistical analyses of the data were conducted using Statistica 7.0. Random sampling and the independence of sample elements were ensured by the experimental procedure established. The homogeneity of the variances was examined by F_{max}-probe. Correlation analyses and variance analyses were also applied. Temperature and soil respiration of the plots were compared by ANOVA. When groups were significantly different, ANOVA were completed with Tukey's HSD test. A value of $p<0.05$ was considered to be statistically significant. The homogeneity of slopes was tested by one-way ANCOVA (Analysis of Covariance). An "F" test for the equality of slopes of regression lines was performed.

Results and Discussion

The IRRSC varied in the Control plots from 1.1 to 2.9, in the Double Litter plots from 1.3 to 2.7, and in the No Litter plots from 1.5 to 2.7. In the removed aboveground litter input plots varied the temperature sensitivity in the highest interval. In the No Roots plots and No Inputs plots were the IRRSC values between 1.7 and 2.5. Temperature sensitivity of soil respiration differed among years. The IRRSC value in NR and NI plots was higher than in Co plots in most cases (Table 4).

Table 4. Annual Index of Respiration Response to Seasonal Change (IRRSC) values of the DIRT plots (Síkfőkút, Hungary).

IRRSC	2002	2003	2004	2005	2006	R^2	2002	2003	2004	2005	2006
DL	1.6	1.3	1.3	2.7	1.4		0.15	0.38	0.10	0.75	0.07
DW	1.4	1.3	1.6	3.0	1.7		0.12	0.38	0.38	0.84	0.15
CO	1.5	1.1	1.3	2.9	2.0		0.14	0.09	0.25	0.77	0.24
NL	1.5	1.5	2.0	2.7	2.0		0.15	0.47	0.71	0.85	0.37
NR	2.1	1.8	2.0	2.5	2.4		0.83	0.89	0.93	0.92	0.62
NI	1.7	1.8	2.2	2.5	2.3		0.49	0.79	0.93	0.91	0.55

Soil temperature varied seasonally, the highest was during summer and the lowest was during winter (Figure 1). We did not find significant differences in the annual average soil temperature among treatments ($p>0.05$). The five-year average soil temperature was CO: 9.9°C, NR: 10.1°C, NI: 9.8°C, NL: 9.7°C, DL: 10.2°C and DW: 9.8°C. We measured both the lowest monthly average (-0.37°C) and the highest (21.45°C) temperature in the No Inputs plots. The Doubled Litter input had an insulating effect. The soil temperature of the DL plots never fell under 0°C in the winter time (December, January and February); while in the summer time (June, July and August) the soil temperature increased less. The minimum soil temperature was 2.85°C and the maximum 19.20°C in the DL plots, against the removed litter inputs plots, where we measured always the highest temperature (NL: 20.39°C, NR: 20.74°C, NI: 21.45°C) (Figure 1).

The annual average temperature range was in the control plots 19°C. While the temperature range was the highest in the removed litter inputs plots (NI: 22°C, NR: 21°C, NL: 21°C). The temperature range of DW plots was same to CO plots (19°C). The temperature range of DL plots was lower with 1°C (18°C).

All treatments demonstrated a positive correlation between soil respiration and temperature, but the correlation values obtained for each treatment different (Table 5).

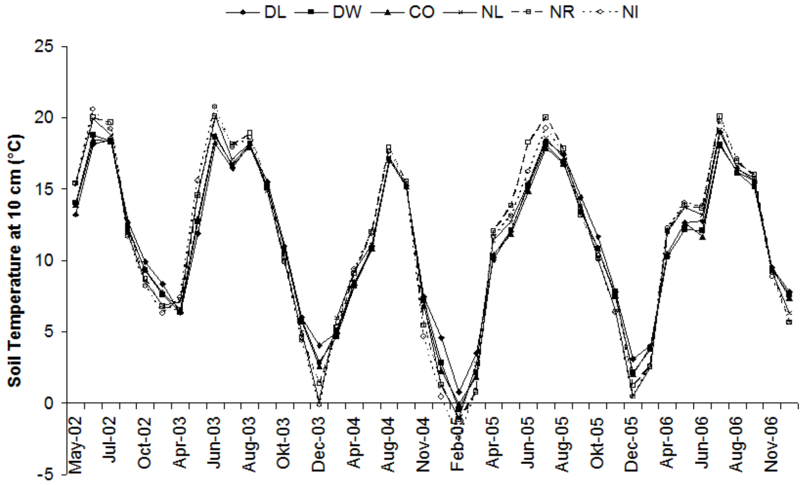

Figure 1. Soil temperature (°C) among 2002-2006.

Table 5. Total mean values and standard errors of CO_2 release and soil temperature and relationship between soil temperature and CO_2 release from 2002 to 2006.

	CO_2 release (mg CO_2 100)	Temperature (°C)	R^2	slope	p(same)	p(equal)
DL	75.93^a ± 6.50	12.05^a ± 0.84	0.20	0.057	0.67	0.795
DW	81.24^a ± 7.83	11.74^a ± 0.88	0.18	0.048	0.92	0.913
CO	78.76^a ± 7.78	11.73^a ± 0.87	0.20	0.050	-	-
NL	66.91^a ± 6.09	11.90^a ± 0.98	0.31	0.090	0.42	0.175
NR	77.52^a ± 6.71	12.28^a ± 1.02	0.61	0.119	0.55	0.006
NI	72.08^a ± 6.45	11.96^a ± 1.06	0.49	0.115	0.52	0.018

p (same) ANCOVA test results between CO and the given treatments; p (equal) significance test of the equality of slopes. Different letters indicate significant difference.

The analysis of ANCOVA showed that soil respiration strongly correlated with the temperature in the litter removal treatments, particularly NR and NI treatments, than the other treatments. A significantly greater increase in temperature induced higher carbon dioxide emissions in NR and NI treatments than the others. This is shown by the slope and p (equal) values. Temperature sensitivity of soil respiration differed among years and treatments. The index of respiration response to seasonal change value in NR and NI plots was higher than in other plots except in the wettest year 2005 (Table 4). In 2005, the highest IRRSC values were measured for all treatments, while the lowest IRRSC values were in year 2003, when soil moisture content was the lowest. The differences between the highest and lowest annual IRRSC values were the lowest (0.7 and 0.8) in NR and NI treatments, while the Control showed the highest (1.7).

The temperature sensitivity of soil respiration has been studied widely across the temperate forest ecosystems (Wang et al., 2006) and described by an exponential equation (Q_{10}). Some researchers reported that different ecosystem types, even different vegetation types within an ecosystem, also exhibited different Q_{10} values. Chen et al., (2010) found the mean Q_{10} value between 1.16 and 2.43 in sub-alpine forest ecosystem. According to Zheng et al., (2009) the average Q_{10} value of forest 2.51±0.78.

According to our results, increasing soil temperature led to increasing soil respiration in case of all treatments. This relation is more conspicuous in litter removal treatments, since the lack of litter cause higher irradiation. As a consequence of the isolation effect of leaf litter, the influence of temperature on soil respiration was lower in treatments with added litter input than in litter removal treatments. Moisture limited soil respiration much lower rate at root exclusion treatments (NR and NI), where soil were wetter throughout the year, as other treatments with drier soil. This also explains why NR and NI treatments were much closer correlation between soil respiration and temperature than the other treatments. The temperature rise in these treatments increased soil respiration greater than the others indicated by a significantly higher slope values and higher IRRSC values.

The IRRSC value in NR and NI plots was higher than in CO plots. Soil respiration responded to changes in temperature more sensitively in trenched treatments than in control (Bond-Lamberty et al., 2011). Minor differences could arise between annual IRRSC values at balanced moisture conditions, as shown in the comparison of treatments. Dependence of IRRSC values of soil moisture not only demonstrate the treatments, but in different DIRT areas receiving precipitation differences. Wang et al., (2013) measured higher Q_{10} values in a warmer (16.5 °C) and wetter (1200 mm) subtropical forest in Southern China. Sulzman et al., (2005) also measured in a cooler (8.7 °C) and much wetter (2370 mm $year^{-1}$) H.J. Andrews Experimental Forest (USA) than in Síkfőkút site. Bowden et al. (1998) also measured higher Q_{10} values in a cooler (7.1 °C) and wetter (1066 mm) Harvard Forest Long-Term Ecological Research Site (Pelini et al., 2011).

Temperature sensitivity of soil respiration varied among soils with different soil organic carbon contents (Zheng et al., 2009). In case of higher litter inputs and soil organic carbon contents could observe major soil respiration increase, if the soil moisture content is optimal for plants and decomposing organisms in the soil (Tang et al., 2006; Fekete et al., 2011a). However, these effects were not prevailed in drier periods (Fekete et al., 2012). This indicates that over the five years showed only the wettest year 2005, slightly lower IRRSC values of litter removal treatments than the other treatments. Organic carbon contents were higher in Double Litter and Control treatments than in litter removal treatments (Fekete et al., 2011a). In treatments where aboveground litter and belowground litter were removed (NR and NI) the IRRSC values fluctuated less. These plots were trenched; accordingly moisture and soil temperature was higher (contrary to other treatments) in the warm-up period. These conditions favored for microbiological processes. But this difference in temperature response between the abiotic and mineralization stages of decomposition, could lead to limitations in substrate supply at higher temperatures (Cooper et al., 2011). However Fang et al., (2001) mentioned one possible reason that it is an adaptation of microbes in the desert habitat to decrease respiration rate at high temperature to protect them from exhaustion.

Conclusion

A significantly greater increase in temperature induced higher soil respiration were significantly higher in root exclusion treatments, where soil was wetter throughout the year, than in control and litter addition treatments. These results suggest that the soil aridity can reduce soil respiration increases with the temperature increase.

Acknowledgements

We special thank Kate Lajtha and Richard D. Bowden for establishing the experiment and supervising this study. We thank Zsolt Krakomperger and Csabáné Koncz for long hours of field and laboratory work. Zsuzsa Veres was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP 4.2.4. A/2-11-1-2012-0001 'National Excellence Program'.

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