Plant Soil (2016) 398:291–300
DOI 10.1007/s11104-015-2664-5

REGULAR ARTICLE

The effects of litter production and litter depth on soil microclimate in a central european deciduous forest

István Fekete · Csaba Varga · Borbála Biró · János Attila Tóth · Gábor Várbíró · Kate Lajtha · Gergely Szabó · Zsolt Kotroczó

Received: 31 March 2015 / Accepted: 6 September 2015 / Published online: 14 September 2015

Abstract
Background and aims We examined the influence of litter quality and litter depth on soil microclimate in the detrital manipulation plots in the Síkfőkút Detrital Input and Removal Treatments (DIRT) experiment in north-eastern Hungary. We measured the soil temperatures from 06.01.2001 to 06.16.2008 and air temperature from 06.17.2004 to 06.16.2008.
Methods DIRT manipulations include two litter addition and three litter removal treatments, and one Control.
Results There were significant differences detected among plots in winter and summer soil mean temperatures ($p<0.001$) 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. Plots wetter and lower in organic matter showed lower winter temperatures.
Conclusion Climate change influences soil temperature and moisture content not only directly, but also through the change of litter production. Litter thickness can reduce the effects of soil temperature extremes and moderate minimum and maximum temperature values. 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 carbon.

Keywords Microclimate · Soil temperature · Soil moisture · Detritus manipulation · Climate change

Responsible Editor: Alfonso Escudero.

I. Fekete
Institute of Environmental Sciences, College of Nyíregyháza, H-4400 NyíregyházaSóstói u. 31./B, Hungary

C. Varga
Department of Land Management and Rural Development, College of Nyíregyháza, H-4400 NyíregyházaSóstói u. 31./B, Hungary
e-mail: kotroczo.zsolt@gmail.com

B. Biró · Z. Kotroczó (✉)
Department of Soil Science and Water Management, Corvinus University of Budapest, H-1118 BudapestVillányi út 29-43, Hungary
e-mail: kotroczo.zsolt@gmail.com

J. A. Tóth
Department of Ecology, University of Debrecen, H-4032 DebrecenEgyetem tér 1, Hungary

G. Várbíró
MTA Centre for Ecological Research, Department of Tisza River Research, H-4026 DebrecenBem tér 18./C, Hungary

K. Lajtha
Department of Crop and Soil Science, Oregon State University, Corvallis, OR 97330, USA

G. Szabó
Department of Physical Geography and Geoinformatics, University of Debrecen, Egyetem tér 1, Debrecen, Hungary

Introduction

Changes in temperature and precipitation patterns predicted under future scenarios of global warming will have profound effects on primary productivity, plant species diversity and ecosystem function (Wang et al. 2011; Rózsa and Novák 2011; Williams et al. 2012; Vicente-Serrano et al. 2015). All of these factors 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 in 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: the above- and belowground litter effect on SOM, and litter forms a layer on the soil surface that affects microclimate (Sayer 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 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) one in China (Huitong Natural Research Station of Forest Ecosystems) (Wang et al. 2013) 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. 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). Species composition and structure of the Síkfőkút forest have changed since the early 1970's (Kotroczó et al. 2007; Tóth et al. 2007), with a 68 % decline in sessile oak (*Quercus petraea*), 16 % decline in Turkey oak (*Quercus cerris*), and the share of field maple (*Acer campestre*) has increased from 0 to 28 %. This has resulted in changes in detritus amount and composition. Mean leaf-litter production has declined from 4060 kg ha^{-1} y^{-1} between 1972 and 1976–3540 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 diurnal 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 an altitude 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 (MAT) is 10 °C and the mean annual precipitation (MAP) is 553 mm. July is the hottest month with an average temperature of 20.2 °C and January is the coldest with −1.2 °C (Antal et al. 1997). 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, Turkey oak, Field maple, 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 above-ground dry detritus (including branches, twigs, fruit and buds) was 6230 kg ha^{-1} (Tóth et al. 2007). According to the FAO World Reference Base, the soils are Luvisols (Świtoniak et al. 2014) with a pH_{H2O} in surface soils (0–15 cm) without detrital manipulation of 5.2, and with a SOM of 39 g kg^{-1} dry soil (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 7×7 m replicate plots (Fekete et al. 2011). There was a Control (CO) treatment. We applied two litter addition treatments. In Double Litter (DL) plots the amount of leaf litter was doubled. In Double Wood (DW) plots the amount of wood detritus (branches, twigs and bark) was doubled, and that of litter detritus was normal. In No Litter (NL) plots the aboveground detritus, in No Roots (NR) plots the living roots, and in No Inputs (NI) plots both the aboveground detritus and living roots were totally removed (Fekete et al. 2012). The project is belong to the international DIRT sites, its data are presented on its site: http:/cropandsoil.oregonstate.edu/content/data-inventory. 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°) and the site faced south, so the climatic effect was similar 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 m 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 upper 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. When "p"≤0.05, examined values were considered to be significantly different.

Results

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

Detritus treatments significantly influenced soil microclimate. The mean annual temperature values did not show any significant differences between the treatments (Table 1). 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 2), but there were no significant differences for the transitional seasons (autumn and spring). In summer, air temperature was significantly higher than in all soil treatments. 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 1). Therefore, the annual fluctuation of soil temperature was much higher in the detritus exclusion treatments than in CO or litter addition treatments (Figs. 1 and 2), and air temperature showed higher fluctuations seasonally than did soil temperature in the different treatments (Tables 1 and 2).

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

Table 1 Soil and air properties in the Síkfőkút DIRT treatments

	DL	DW	CO	NL	NR	NI	Air
m. a. t.[a.]	10.3±0.07	10.2±0.08	10.2±0.07	10.2±0.08	10.3±0.08	10.2±0.08	10.1±0.09
b. days[b.]	0	17	17	70	29	77	143
a. days[c.]	17	16	16	30	96	72	141
fluct.[d.]	20.03	22.12	22.12	25.88	26.61	28.3	42.5
moisture[e.]	23.6a±0.61	25.8a ±0.61	24.5a ±0.61	25.3a ±0.60	36.9b ±0.50	34.5b ±0.54	-

[a] mean annual temperature from the daily mean temperature±standard error values 06.17.2004 -06.16.2008 (in °C)

[b] The number of days when the daily mean temperature was below 0 °C

[c] The number of days when the daily mean temperature was above 20 °C

[d] Maximum fluctuation of the temperature of the examined period (in °C)

[e] The average of soil moisture content±standard error values between 2004 and 2008 (%*v*/*v*) was determined once every month in the year. Tukey's HSD test at 0.05 probability level was performed in order to determine the significance of differences among treatment means

season based on daily averages (Table 3). Soil daily mean temperatures (DMT) in the root exclusion treatments (NR, NI) were most responsive to air DMT in summer (Fig. 3), and soil DMT in surface litter exclusion treatments (NL, NI) were most responsive to air DMT in winter (Fig. 4). The correlation was stronger in summer than in winter for all treatments. The regression analysis between air DMT and soil DMT 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. However, there were no significant differences in slope values for the winter periods. The homogeneity

Table 2 Air and soil temperature (°C) and moisture (*v*/*v*%) in the Síkfőkút DIRT treatments during summer periods; (June, July, August) and winter periods (December, January, February) from 06.17.2004 to 06.16.2008

	Temperature (°C)					
	Mean±SE	Minimum	Maximum	Lower Quartile	Upper Quartile	Soil moisture (*v*/*v*%)
summer						
Air	19.26d±0.17	9.96	29.83	16.99	21.38	-
DL	17.06a±0.09	11.00	20.75	16.02	18.14	21.7a±2.63
DW	16.98a±0.09	10.74	21.51	16.04	18.08	23.5a±2.55
CO	16.98a±0.09	10.90	21.51	16.04	18.13	22.5a±2.63
NL	17.53b±0.10	11.42	22.98	16.38	18.82	24.6a±2.53
NR	18.61c±0.11	12.15	25.38	17.27	20.05	35.9b±2.24
NI	18.32c±0.11	11.95	25.14	17.16	19.75	34.4b±2.14
winter						
Air	−0.02a±0.22	−12.67	8.02	−2.68	2.81	-
DL	3.57e±0.12	0.62	9.34	1.66	5.14	22.4a±1.35
DW	2.88d±0.12	−0.61	9.04	1.00	4.53	25.9ab±2.01
CO	2.91d±0.12	−0.61	8.93	1.04	4.53	24.4a±1.84
NL	1.83bc±0.13	−2.90	8.85	0.29	3.33	23.8a±2.03
NR	2.35 cd±0.12	−0.61	8.15	0.75	3.68	36.7c±0.97
NI	1.49b±0.12	−2.90	7.47	0.13	3.08	31.9bc±1.93

Tukey's HSD test at 0.05 probability level was performed in order to determine the significance of differences among treatment means. Means±standard error values. Different letters indicate significant difference

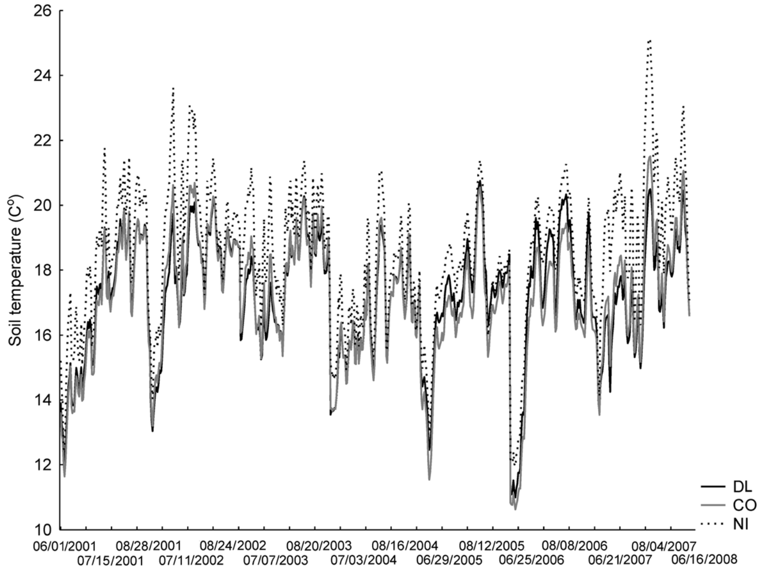

Fig. 1 Temporal variation of the summer soil temperature for Double Litter, Control and No Imput treatments

of slopes between season values showed significant different among detritus exclusion treatments. These treatments showed significantly higher values in summer than winter (Table 3).

Soil moisture contents were significantly higher in root exclusion treatments (NR and NI) than in the other treatments ($F_{(5240)}=18.21$; $p<0.001$) (Table 2). There were no other differences in soil moisture among the other treatments (Table 2). Regarding moisture content values, the coefficient of variation were the lowest in root exclusion treatments, which showed that soil moisture content varied the least in these soils.

The effects of detritus on 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

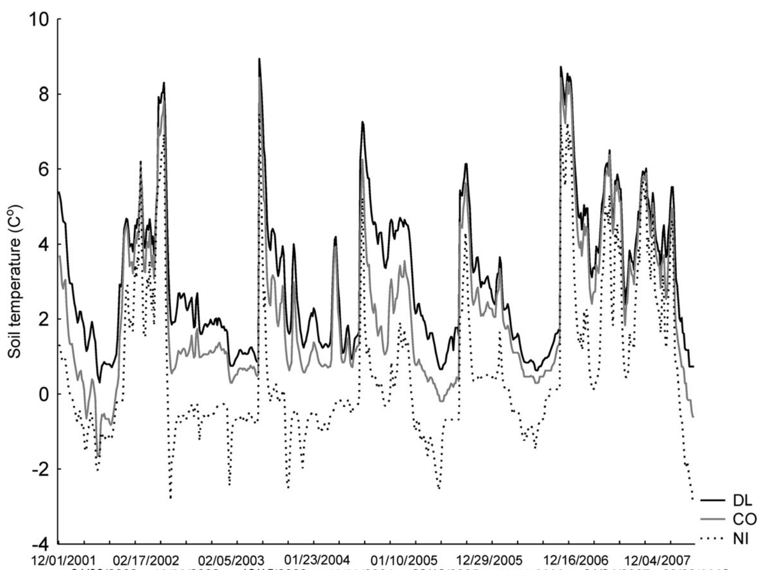

Fig. 2 Temporal variation of the winter soil temperature for Double Litter, Control and No Imput treatments

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

	summer			winter			Homogeneity of slopes between season (p) value
	Intercept (a)	Slope (b)	R^2	Intercept (a)	Slope (b)	R^2	
DL	9.52	0.39a	0.53	3.57	0.35	0.45	0.061
DW	8.67	0.43a	0.63	2.89	0.38	0.46	0.154
CO	8.70	0.43a	0.63	2.92	0.38	0.46	0.066
NL	8.16	0.49ab	0.70	1.84	0.41	0.53	0.014*
NR	7.56	0.57b	0.78	2.36	0.38	0.50	<0.001*
NI	7.95	0.54b	0.74	1.50	0.41	0.55	<0.001*

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)

was always significantly higher than DTR of the soils in all treatments ($F_{(6;1526)}=812.8$; p 0.001). The DIRT treatments significantly affected soil DTR fluctuations (Table 4). 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 (Table 4).

Discussion

Changes in soil temperature and moisture content

Various detritus treatments and soil biological processes both directly and indirectly influence soil microclimate (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

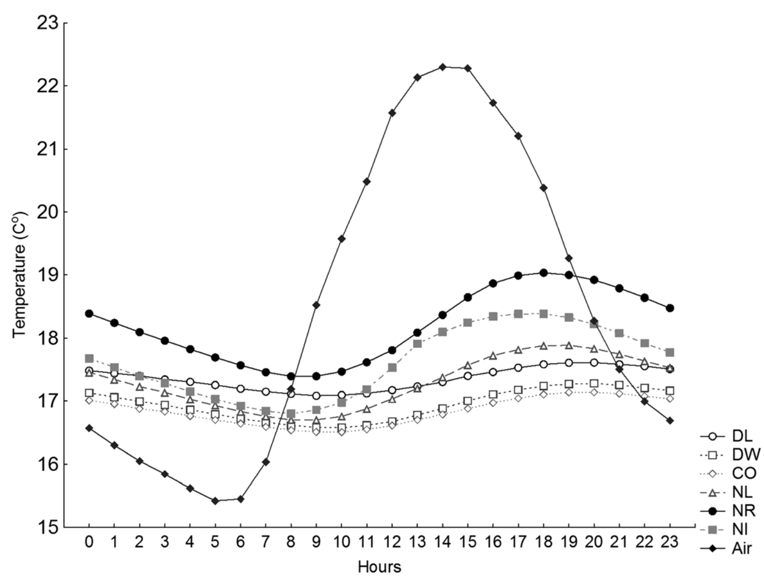

Fig. 3 Summer hourly temperature profile of the soil temperature in the different treatments and the profile of air temperature between 06. 01. 2005 and 09. 30. 2005

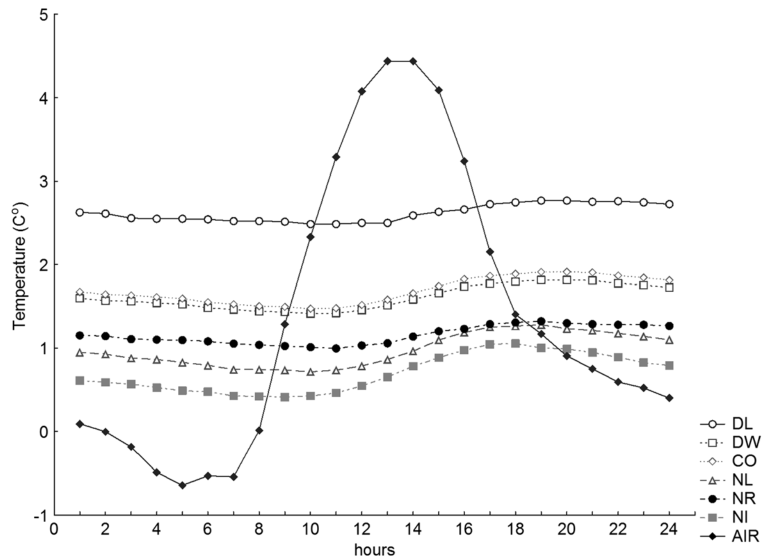

Fig. 4 Winter hourly temperature profile of the soil temperature in the different treatments and the profile of air temperature between 01. 01. 2008 and 02. 29. 2008

(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 lesser amount of heat (Khvorostyanov et al. 2008). 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 (Bonan 2008). 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, 2015). Due to the lack of transpiration, the soils in the root exclusion treatments (NR and NI) were significantly wetter than soils in the other

Table 4 Air and soil values of DTR (°C) in the Síkfőkút site based on the means of all treatments from 17. 03. 2004 to 29. 02. 2008

Treatments and air	Daily average over all season	Daily maximum	Daily average in spring	Daily average in summer	Daily average in autumn	Daily average in winter
DL	0.63a±0.02	1.63	0.75a±0.05	0.79a±0.04	0.51a±0.03	0.39a±0.05
DW	0.74a±0.03	2.58	0.71a±0.05	0.92a±0.05	0.66a±0.04	0.57a±0.08
CO	0.85a±0.04	2.46	1.06a±0.07	0.96a±0.05	0.65a±0.04	0.64a±0.14
NL	1.46b±0.07	5.04	2.38bc±0.17	1.54bc±0.06	0.85ab±0.06	1.01a±0.12
NR	1.48b±0.06	3.82	2.06b±0.11	1.87bc±0.09	1.14b±0.05	0.66a±0.07
NI	1.87c±0.07	6.04	2.96c±0.18	1.99c±0.07	1.16b±0.06	1.18a±0.14
Air	7.23d±0.18	16.02	7.43d±0.35	8.37d±0.25	5.92c±0.28	6.45b±0.48

Tukey's HSD test at 0.05 probability level was performed in order to determine the significance of differences among treatment means. Means±standard error values. Different letters indicate significant difference among the treatments

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 the moisture content of 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.

Surface detrital layers also regulate soil water content (Ogée and Brunet 2002) by reducing evaporation from mineral soil while absorbing a fraction of the precipitation. 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'Donnell 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 is 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 higher conductivity than 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 content was 51.9 g kg^{-1} dry soil in the upper 5 cm soil layer in CO. Soil carbon content was higher in DL, DW with 29.8 and 18.3 % and lower in NL, NR, NI with 18.2, 11.6, 19.5 %.

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. Increase in soil moisture content, which is in connection with litter layer thickness and with lack of living roots, has significant effect on soil temperature. Our results show that average annual dry leaf litter amount of 0.354 kg m^{-2} moderates the soil cooling off in winter by 1.1 °C and soil warming in summer with 0.6 °C. It also moderates DTR by 0.6 °C, and annual maximum temperature fluctuation by 3.8 °C. In root exclusion treatments annual maximum temperature fluctuation by 3.5 °C, DTR with 0.5 °C was higher due to lack of living roots than in treatments containing living roots. 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.

Acknowledgments This research was sponsored by the University of Debrecen and College of Nyíregyháza.

References

Al-Shammary AAG, Al-Sadoon JNA (2014) Influence of tillage depth, soil mulching systems and fertilizers on some thermal properties of silty clay soil. GJAR 2:18–32

Antal E, Berki I, Justyák J, Gy K, Tarr K, Vig P (1997) Examination of the Síkfőkút forest community heat- and water balance conditions in the deforestation and the challenges of climate change. Debrecen 83 (in Hungarian)

Bartholy J, Pongrácz R, Gelybó G (2007) Regional climate change expected in Hungary for 2071–2100. Appl Ecol Environ Res 5:1–17

Bernhardt ES, Barber JJ, Pippen JS, Taneva L, Andrews JA, Schlesinger WH (2005) Long-term effects of free air CO_2 enrichment (FACE) on soil respiration. Biogeochemistry 77: 91–116

Biró B, Kádár I, Lampis S, Gullner G, Kőmíves T (2012) Inside and outside rhizosphere parameters and dose-dependent stress alleviation at some chronic metal exposures. Acta Phytopathol Entomol Hungarica 47:373–384. doi:10.1007/s10533-005-1062-0

Blackburn E, Liangl X, Wood EF (1998) The effect of soil thermal conductivity parameterization on surface energy fluxes and temperatures. J Atmos Sci 55:1209–1224. doi:10.1175/1520-0469(1998)055<1209:TEOSTC>2.0.CO;2

Bonan GB (2008) Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science 320: 1444–1449. doi:10.1126/science.1155121

Bond-Lamberty B, Thomson A (2010) Temperature-associated increases in the global soil respiration record. Nature 464: 579–583. doi:10.1126/science.1155121

Brant JB, Myrold DD, Sulzman EW (2006) Root controls on soil microbial community structure in forest soils. Oecologia 148: 650–659. doi:10.1007/s00442-006-0402-7

Chapin FSI, McFarland J, McGuire AD, Euskirchen ES, Ruess RW, Kielland K (2009) The changing global carbon cycle: linking plant-soil carbon dynamics to global consequences. J Ecol 97:840–850

Crow SE, Lajtha K, Filley TR, Swanston CW, Bowden RD, Caldwell BA (2009) Sources of plant-derived carbon and stability of organic matter in soil: implications for global change. Glob Chang Biol 15:2003–2019. doi:10.1111/j.1365-2486.2009.01850.x

Domonkos P (2003) Recent precipitation trends in Hungary in the context of larger scale climatic change. Nat Hazards 29:255–271. doi:10.1023/A:1023690014955

Farouki OT (1986) Thermal properties of soils. Trans Tech Publications, Ltd, Clausthal-Zellerfeld, p 136

Fekete I, Zs K, Cs V, Nagy PT, Várbíró G, Bowden RD, Tóth JA, Lajtha K (2014) Alterations in forest detritus inputs influence soil carbon concentration and soil respiration in a Central-European deciduous forest. Soil Biol Biochem 74:106–114. doi:10.1016/j.soilbio.2014.03.006

Fekete I, Cs V, Zs K, Tóth JA, Várbíró G (2011) The relation between various detritus inputs and soil enzyme activities in a Central European deciduous forest. Geoderma 167–168:15–21. doi:10.1016/j.geoderma.2011.08.006

Fekete I, Zs K, Cs V, Hargitai R, Townsend K, Csányi G, Várbíró G (2012) Variability of organic matter inputs affects soil moisture and soil biological parameters in a European detritus manipulation experiment. Ecosystems 15:792–803. doi:10.1007/s10021-012-9546-y

Galos B, Goettel H, Haensler A, Preuschmann S, Matyas C, Jacob D (2009) Do forest cover changes have any feedback on temperature and precipitation extremes over Hungary? Geophys Res Abstr 11:EGU2009-7687-1

Hagedorn F, Martin M, Rixen C, Rusch S, Bebi P, Zürcher A, Siegwolf RTW, Wipf S, Escape C, Roy J, Hättenschwiler S (2010) Short-term responses of ecosystem carbon fluxes to experimental soil warming at the Swiss alpine treeline. Biogeochemistry 97:7–19. doi:10.1007/s10533-009-9297-9

Jakucs P (ed) (1985) Ecology of an oak forest in Hungary I, -Akadémiai Kiadó, Budapest, pp. 23–69

Khvorostyanov DV, Krinner G, Ciais P, Heimann M, Zimov SA (2008) Vulnerability of permafrost carbon to global warming. Part I: model description and the role of heat generated by organic matter decomposition. Tellus B 60B:250–264. doi:10.1111/j.1600-0889.2007.00333.x

Kotroczó Z, Veres Z, Fekete I, Papp M, Tóth JA (2012) Effects of climate change on litter production in a *Quercetum petraeae-cerris* forest in Hungary. Acta Silv Lign Hung 8:31–38. doi:10.2478/v10303-012-0003-6

Kotroczó Z, Veres Z, Fekete I, Krakomperger Z, Tóth JA, Lajtha K, Tóthmérész B (2014) Soil enzyme activity in response to long-term organic matter manipulation. Soil Biol Biochem 70:237–243. doi:10.1016/j.soilbio.2013.12.028

Kotroczó Z, Krakomperger Z, Papp M, Bowden RD, Tóth JA (2007) Long-term change in the composition and structure of an oak forest at Síkfőkút, North Hungary. Természetvédelmi Közlemények 13:93–100, Hungarian with English abstract

Lajtha K, Crow SE, Yano Y, Kaushal SS, Sulzman E, Sollins P, Spears JDH (2005) Detrital controls on soil solution N and dissolved organic matter in soils: a field experiment. Biogeochemistry 76:261–281. doi:10.1007/s10533-005-5071-9

Nadelhoffer K, Boone R, Bowden RD, Canary J, Kaye J, Micks P, Ricca A, McDowell W, Aitkenhead J (2004) The DIRT experiment. In: Foster DR, Aber DJ (eds) Forests in Time. Yale University Press, Michigan

O'Donnell JA, Romanovsky VE, Harden JW, McGuire AD (2009) The effect of moisture content on the thermal conductivity of moss and organic soil horizons from black spruce ecosystems in interior Alaska. Soil Sci 174:646–651. doi:10.1097/SS.0b013e3181c4a7f8

Ogée J, Brunet Y (2002) A forest floor model for heat and moisture including a litter layer. J Hydrol 255:212–233. doi:10.1016/S0022-1694(01)00515-7

Perry DA, Oren R, Hart SC (2011) Forest ecosystems. Johns Hopkins University Press, Baltimore, p 267

Raich JW, Tufekcioglu A (2000) Vegetation and soil respiration: correlations and controls. Biogeochemistry 48:71–90. doi:10.1023/A:1006112000616

Rózsa P, Novák T (2011) Mapping anthropic geomorphological sensitivity on global scale. Z Geomorphol 55:109–117. doi:10.1127/0372-8854/2011/0055S1-0041

Sayer EJ (2006) Using experimental manipulation to assess the roles of leaf litter in the functioning of forest ecosystems. Biol Rev 81:1–31. doi:10.1017/S1464793105006846

Sulzman EW, Brant JB, Bowden RD, Lajtha K (2005) Contribution of aboveground litter, belowground litter, and rhizosphere respiration to total soil CO_2 efflux in an old growth coniferous forest. Biogeochemistry 73:231–256. doi:10.1007/s10533-004-7314-6

Świtoniak M, Charzyński P, Novák TJ, Zalewska K, Bednarek R (2014) Forested hilly landscape of Bükkalja Foothill (Hungary). In: Świtoniak M, Charzyński P (eds) Soil sequences atlas. Nicholaus Copernicus University Press, Torun, pp 169–181

Tóth JA, Lajtha K, Zs K, Zs K, Caldwell B, Bowden RD, Papp M (2007) The effect of climate change on soil organic matter decomposition. Acta Silv Lign Hung 3:75–85

Tóth JA, Nagy PT, Zs K, Zs V, Zs K, Kincses S, Fekete I, Papp M, Mészáros I, Viktor O (2013) The effects of climate change on element content and soil pH (Síkfőkút DIRT Project, Northern Hungary). In: Kozak J et al (eds) The Carpathians: integrating nature and society towards sustainability, Environmental science and engineering. Springer, Berlin, Heidelberg, pp 77–88. doi:10.1007/978-3-642-12725-0_7

Veres ZS, Kotroczó Z, Magyaros K, Tóth JA, Tóthmérész B (2013) Dehydrogenase activity in a litter manipulation experiment in temperate forest soil. Acta Silv Lign Hung 9:25–33

Veres Z, Kotroczó Z, Fekete I, Tóth JA, Lajtha K, Townsend K, Tóthmérész B (2015) Soil extracellular enzyme activities are sensitive indicators of detrital inputs and carbon availability. Appl Soil Ecol 92:18–23. doi:10.1016/j.apsoil.2015.03.006

Vicente-Serrano SM, Camarero JJ, Zabalza J, Sangüesa-Barreda G, López-Moreno JI, Tague CL (2015) Evapotranspiration deficit controls net primary production and growth of silver fir: implications for circum-Mediterranean forests under forecasted warmer and drier conditions. Agric For Meteorol 206: 45–54. doi:10.1016/j.agrformet.2015.02.017

Wang F, Xu YJ, Dean TJ (2011) Projecting climate change effects on forest Net primary productivity in subtropical Louisiana, USA. Ambio 40:506–520. doi:10.1007/s13280-011-0135-7

Wang Q, He T, Wang S, Liu L (2013) Carbon input manipulation affects soil respiration and microbial community composition in a subtropical coniferous forest. Agric For Meteorol 178: 152–160. doi:10.1016/j.agrformet.2013.04.021

Wang X, Liu L, Piao S, Janssens IA, Tang J, Liu W, Chi Y, Wang J, Xu S (2014) Soil respiration under climate warming: differential response of heterotrophic and autotrophic respiration. Glob Chang Biol 20:3229–3237. doi:10.1111/gcb.12620

Williams CA, Collatz GJ, Masek J, Goward SN (2012) Carbon consequences of forest disturbance and recovery across the conterminous United States. Glob Biogeochem Cycles 26: GB1005. doi:10.1029/2010GB003947