The Effects of Detritus Input on Soil Organic Matter Content and Carbon Dioxide Emission in a Central European Deciduous Forest

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Abstract – A major objective of our research was to survey soil biological activity and organic matter content reduction in a Central European oak forest during treatments of various detritus inputs within the Síkfőkút DIRT (*Detritus Input and Removal Treatments*) Project. Beside the control, three detritus removal and two detritus duplication treatments were applied. Our examinations have proven that soil organic matter content declined relatively fast in detritus removal treatments. The reduction was especially remarkable in root detritus removal treatments, where – due to the lack of transpiration – soils were moister during the whole year than in the other treatments. The higher moisture content, despite of the reduction of detritus input, produced an intense soil respiration. This can be explained by the fact that decomposing organisms have increased the use of soil organic matter. Detritus input reduction had a significantly greater effect on soil respiration and organic matter content than detritus input duplication of the same extent. The latter did not cause any significant change compared to the control.

litter manipulation / soil respiration / DIRT Project / humus content / climate change

Kivonat – **Az avarinput hatása a talaj szerves anyag tartalmára és szén-dioxid kibocsátására egy Közép-európai lombhullató erdőben.** Kutatásaink egyik fő célkitűzése az volt, hogy a Síkfőkút DIRT (*Detritus Input and Removal Treatments*) Project keretében, felmérjük egy közép-európai tölgyerdőben a különböző avarinputot kapó kezelések talajainak biológiai aktivitását és szerves anyag tartalom csökkenését. A kontroll mellett háromféle avarelvonásos és kétféle többletavart kapó kezelést alkalmaztunk. Vizsgálataink azt bizonyították, hogy a csökkentett avarinputot kapó kezelések esetén a talaj szerves anyag tartalma viszonylag gyorsan csökken. Különösen erős csökkenést tapasztaltunk a gyökéravar elvonásos kezeléseknél, ahol a hiányzó transpiráció miatt egész évben nedvesebbek a talajok, mint a többi kezelésnél. A magasabb nedvesség tartalom hatására a szerves anyag input csökkenés ellenére is intenzív talajlégzést tapasztaltunk. Ezt azzal magyaráztuk, hogy a lebontó szervezetek a talaj szerves anyag készletét fokozottabban használják fel tápanyagként, a kieső avar mennyiség helyett. Az avarinput csökkentése szignifikánsan nagyobb hatást gyakorolt a talajlégzésre és a talaj szerves anyag tartalmára, mint az avarinput ugyanolyan mértékű növelése, mely a kontrollhoz képest nem okozott szignifikáns változást.

avarmanipuláció / talajlégzés / DIRT Project / humusztartalom / klímaváltozás

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1 INTRODUCTION

A major part of carbon dioxide getting into carbon cycle comes from respiration, weathering of rocks and volcanic activity, while industrial activities are responsible only for 5–15% of it. Forest destruction and burning, area increase and degradation of agricultural lands, melting of permafrost soils and the enhancement of soil respiration also contribute to the growing carbon dioxide emission deriving from the combustion of fossil fuels. Although the extra carbon dioxide in the atmosphere is primarily due to the combustion of fossil fuels, a considerable proportion is caused by soil organic matter content reduction through forest destruction and utilizing lands for agriculture or constructions (Wild 1988). Batjes and Sombroek (1997) estimate the organic carbon matter of soil within the upper 1 m to be 1200–1600 Gt, while Batjes (1996) thinks that there is 2376–2456 Gt carbon in the upper 2 m. According to the estimations, soil stores two and a half times more carbon as plants, and twice as much as the atmosphere (Batjes 1998). According to Buringh (1984) the present soil organic matter content is merely 75% of that before the start of agriculture. According to Raich and Schlesinger (1992) decomposing detritus (including roots) provides about 70% of total carbon output of soils which is 68 Gt/year. Soil chemical and biological processes influence global climate change by increasing the quantity of greenhouse gases. Global warming will supposedly influence the decomposition of soil organic matters, thus the global carbon cycle of the biosphere. Several researchers assume that decomposition processes are induced more strongly by temperature rise than by anabolic processes (Jenkinson et al. 1991; Schimel et al. 1994; Kirschbaum 1995), which may lead to increased atmospheric carbon dioxide content (Townsend et al. 1992; Schimel 1995; Kaye and Hart 1998; Cox et al. 2000). The enhanced soil respiration as well as the reduction in detritus production can entail the decrease in soil organic matters, thus soil degradation.

Several examinations have already revealed that a higher carbon dioxide content causes lower nitrogen concentration in plant tissues (Cotrufo et al. 1998; Norby et al. 1999, 2000). Beside nitrogen concentration decrease, the quantity of less decomposable secondary (phenols, tannins and lignin) increases (Norby et al. 2001). The qualitative parameters of detritus, such as nitrogen concentration, carbon-nitrogen ratio and lignin-nitrogen ratio, considerably influence the composition and activity of microbes (Hu et al. 2001), thus the velocity of decomposition (Swift et al., 1979; Aerts 1977). Sulzman et al. (2005) carried out researches in an old-growter Douglas-fir (*Pseudotsuga menziesii*) forest at H. J. Andrews DIRT Site (USA, Oregon) and found that the increasing detritus input with a high carbon to nitrogen ratio accelerates the decomposition of soil organic matters. So the growth of detritus production rather entails the increase of atmospheric carbon dioxide content (Norby et al. 2002) than soil carbon supply. Pendall et al. (2004) think that the high carbon to nitrogen ratio in soil increases atmospheric carbon dioxide content. Detritus decisively influences soil nutrient supply, microbial activity and humus content. The quantitative and qualitative changes in detritus production together with their effects on soil life have already been treated in several studies and research papers (Sayer et al. 2006; Pandey et al. 2007).

DIRT experiments (Detritus Input and Removal Treatments) are long-term studies of soil organic matter formation and derived from a project launched in forest and grassland ecosystems at the University of Wisconsin in 1957 (Nielson-Hole 1963). This international project’s goal is to assess how rates and sources of above- and belowground plant inputs control the accumulation and dynamics of organic matter and nutrients in forest soils over decadal time scales. The significant effects of manipulations on mineralization and respiration suggest that microbial activity was influenced by DIRT treatments (Nadelhoffer et al. 2004). Our experimental site, Síkfőkút DIRT Project, is member of the DIRT intercontinental project organized by the ILTER (International Long-Term Ecological Research) network. Síkfőkút site was established by professor P. Jakucs. Our research constitutes an important part of a long term international project that involves five more experimental sites (Nadelhoffer et al. 2004) in USA (Andrews Experimental Forest, Bousson Experimental Forest) and Germany (Universität Bayreuth, BITÖK).

A major objective of our research was to examine soil respiration and organic matter content during treatments of various detritus inputs, thus revealing the effects of changes in substrate quantity available for decomposing organisms and in soil moisture content on soils.

The extent of carbon dioxide emission is an important indicator of the intensity of organic matter decomposition and related microbial activity (Gerenyu et al. 2005). The extent of soil respiration is influenced by several factors, such as vegetation, the quantity and quality of plant residues, the quantity and activity of decomposing microorganisms, soil structure, soil pH, the quantity of available nutrients, as well as soil temperature and moisture content that are influenced by climate change to the greatest extent (Swift et al. 1979; Pántos-Derimova 1983; Rustad et al. 2000).

2 SITE DESCRIPTION

The Síkfőkút site was established in 1972 for the long-term study of forest ecosystems. The area covering 27 ha is located in the south part of the Bükk Mountains in Northeast Hungary at 325 m altitude. GPS coordinates are N 47^{o}55’ E 20^{o}28’. Annual precipitation amounts to 550 mm and annual average temperature is 10 ^{0}C. According to the FAO Soil Classification, the type of soil is cambisol. Soil pH ranges between 4.85 and 5.50 depending on the plots (Tóth et al. 2007). The forest is a semi-natural stand (*Quercetum petraeae-cerris* community) without forest management, and since 1976 is part of the Bükk National Park.

Experimental plots were established in November 2000. Following the example of American DIRT Sites, six treatments were set up in three replications. These 18 plots were arranged randomly. The treatments are: Double Litter (DL), Control (C), No Litter (NL), No Root (NR), Double Wood (DF), No Input (NI) Each plot is 7m wide and 7m long (49 m^2) (Fekete et al. 2007).

3 METHODS

Random soil samples were taken from five test holes at each plot. The test holes with a diameter of 13 mm were 15 cm deep. Sampling was carried out with Oakfield auger (Oakfield Apparatus Company, USA). Samples were homogenized and stored in a refrigerator at 4°C. Laboratory examinations were implemented within a week after sampling.

For detecting soil temperature, an ONSET, StowAway TidbiT-type data-logger (Onset Computer Corporation, USA) was placed into the middle of each plot at 10 cm depth. Data-loggers were programmed to measure soil temperature every hour. Soil tempretaure was measured continuously from 8th March 2001. Data were downloaded at set intervals generally once a year. Soil moisture content was determined after drying in oven at 105°C for 24 hours. Soil organic matter content was determined by the Tyurin method (Buzás 1988). Soil respiration was measured by examining the carbon dioxide efflux of samples according to Jenkinson and Powlson’s (1976) method.

Experimental data were statistically evaluated by *Statistica* version 7.0. We ensured randomness of sampling and the independence of each sampling element. *Kolmogorov – Smirnov* test helped determine the normal distribution of actual data. Homogenity of the variations was examined by F_{max}*-probe*. *One-way ANOVA* and *Tukey’s HSD* test were also performed.

4 RESULTS

The first sampling took place in April 2001, five months after plot establishment. At that time NR treatment revealed the highest organic matter content (3.61%); however, NI (3.26%) also surpassed the values of DL (3.19%) and C (3.08%) (*Figure 1*). The next sampling took place in December 2001. Then NR was ranked second, following DL. In 2002 the organic matter content of treatments involving detritus removal (NR, NI, NL) decreased compared to the other treatments. From 2003 till the end of examinations the samples of detritus duplicaton and control treatments revealed higher organic matter contents than the ones of detritus removal treatments (*Figure 2*). Comparing the means of 2001–2002 and those of 2003–2006, the following results were obtained: organic matter content increased by 3% in DL and DW, while decreased by 2% in C. These changes were not significant. However, detritus removal treatments revealed significant decreases (at P≤0.05): NL: 14%, NR: 17%, NI: 8%. The lowest mean value was measured in NR between 2003 and 2006.

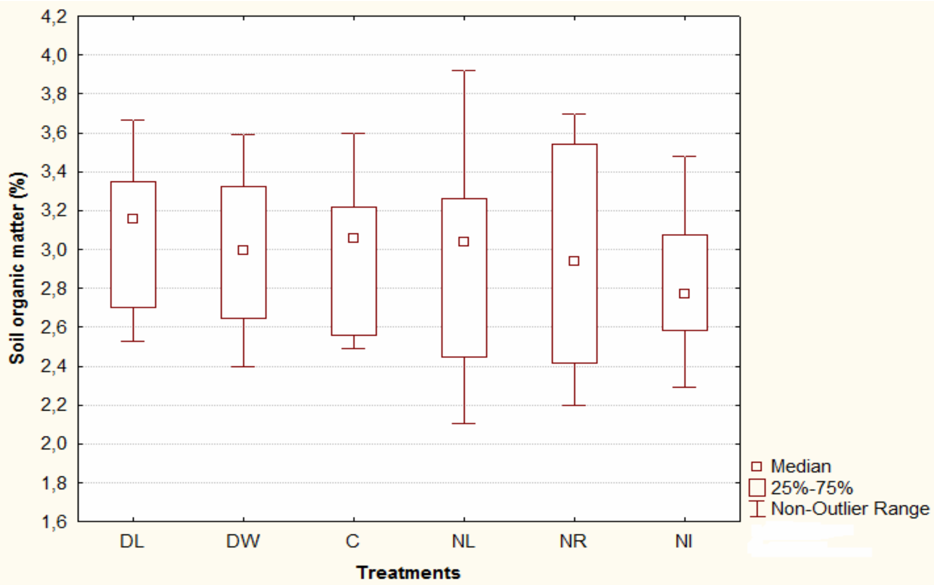

Figure 1. Mean values of soil organic matter content (n=12) in 2001 and 2002

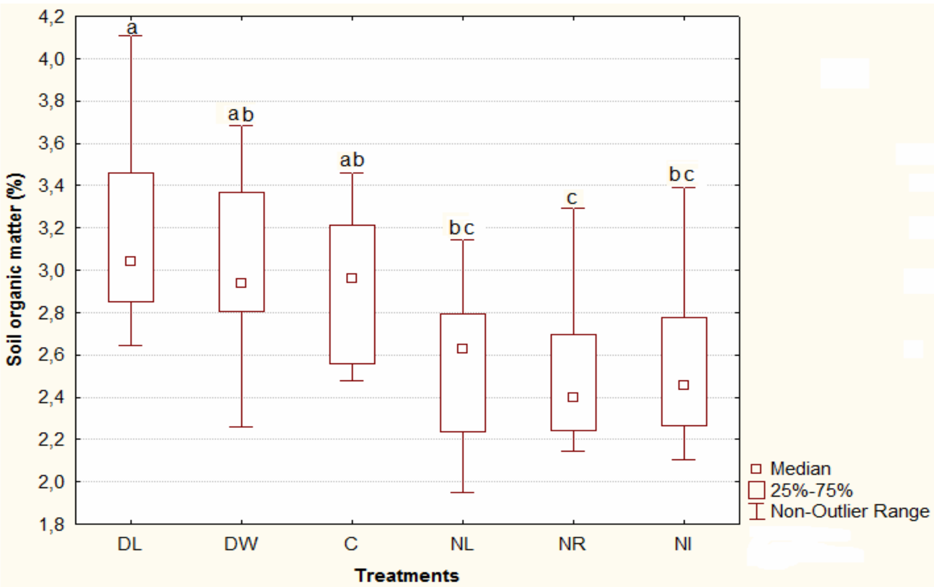

Figure 2. Effects of detritus manipulation on soil organic matter content (n=15) between 2003 and 2006. Different letters indicate significant differences according to Tukey's HSD test

Examining the organic matter content of the treatments between 2002 and 2006, ANOVA revealed significant differences between the groups ($F_{(5.36)}=6.26$; $p<0.001$). According to Tukey's HSD test, DL revealed significantly higher values than the three detritus removal treatments, as well as DW and C showed significantly higher values than NR ($p<0.05$). Regarding soil respiration, the highest mean values were measured in the detritus duplication treatments (DL, DW) and NR. These were followed by C and finally by the leaf litter removal treatments (NI, NL) (*Figure 3*). ANOVA did not reveal any significant difference between the groups ($p=0.1$) because of high variation and relatively low number of samples (N=13). However, considerable differences were observed between the treatments. Comparing the carbon dioxide emission of NL pairwise to the other treatments by t-test, all the treatments revealed significantly higher values than NL, except for NI.

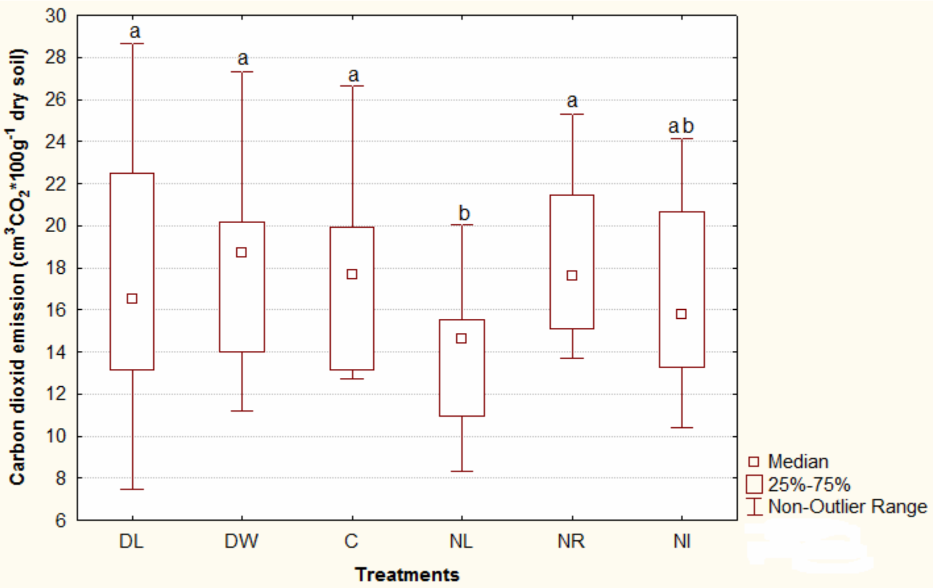

Figure 3. Mean values of carbon dioxide emission between 2004 and 2007 Double Litter (DL), Control (C), No Litter (NL), No Root (NR), Double Wood (DF), No Input (NI). Different letters indicate significant differences according to t-test

5 DISCUSSION

Carbon dioxide emission of NI surpassed that of NL, while NR exceeded both C and DW. These results – taking into consideration the extent of detritus input in the treatments – need further explanation.

Root respiration had no influence on carbon dioxide emission in NL, C, DW, DL, as the soil samples did not contain any living roots. Altough roots were removed from both NR and NI samples before the examinations, at the establishment of NR and NI plots roots had not been removed, they were let there to decompose.

Therefore, these dead roots were able to contribute to increasing soil respiration for a certain period of time. This effect could be observed in the case of certain enzymes' activities (phosphatase, phenoloxidase) and the changes in soil organic matter content (Fekete et al. 2007; Varga et al. 2008).

The higher than expected carbon dioxide emission of NR and NI can be explained primarily with the higher soil moisture content, due to the fact that plants were regularly removed, so there was no transpiration loss at all. Statistical analyses revealed that carbon dioxide emission correlates strongly with soil moisture content (Kotroczó et al. 2008).

The effects of soil moisture content and detritus input were proven by the fact that in the two sample series showing the highest soil moisture content (above 30% in all treatments) DL, C and DW samples revealed 32% carbon dioxide emission higher than NR and NI. This is because DL, C and DW plots had greater nutrient supplies, which – under appropriate circumstances, e.g. optimal moisture content for decomposing organisms – increase the intensity of soil respiration (Wan-Luo 2003; Berryman et al. 2010). Such nutrients were root exudates as well as organic compounds resulting from the decomposition of leaf litter. All these or a part of them were missing from the plots of detritus removal treatments. This fact further supports the observation that litterfall and root detritus play an important part in nutrient and carbon cycling (Sayer 2006). A further difference was that there were no plants in NR plots, detritus could only originate from the surrounding trees. The major part of leaf litter from the bushes fell to the ground outside the NR plots. According to Tóth et al. (2007), shrubs provide only 9% of the total leaf litter production at the Síkfőkút site. Thus, the quantity of aboveground detritus is lower in NR than in the other three detritus duplication treatments.

The effects of leaf litter manipulation was shown by the fact that CO_2 emission in NL was significantly lower than in treatments of aboveground detritus input (DL, C, NR, DW). CO_2 emission in aboveground input treatments was also higher than in NI; however, the difference was not significant. This can be explaned by the higher soil moisture content. In this experiment the effects of soil temperature were not relevant, as the examinations were carried out in laboratory at controlled temperature. However, in field investigations soil temperature is a crucial factor (Kotroczó et al. 2008). Comparing our results with those of the Andrews DIRT Site, we can observe the same trend sin DL, NL, C, and DW treatments (Sultzman et al. 2005). In both experiments C revealed the lowest CO_2 emission. Nevertheless, in the Andrews DIRT experiment there was a significant difference between DL, DW and C, while the difference was not significant in Síkfőkút. In 2001 NR and NI revealed higher organic matter content, which was due to the decomposing capillary roots. Living roots constantly enrich soil with their excretions (Gregory, 2006). Organic matter content was the highest in DL, C, DW since 2003 (Varga et al. 2008), although the increase was slight, however the values of NR and NI decreased by 30 and 18% between 2002 and 2006. NL also revealed a decreasing trend (22.3% between 2002 and 2006), which can be explained by the lack of leaf litter supply (Zhang et al. 2008).

This decomposition of organic matter was more intense in NR and NI, so soil CO_2 emission was higher as well. However, DL revealed the highest values regarding both CO_2 emission and organic matter content. This can be explained by the leaf litter duplication resulted in an extra amount of litter that could not be mineralized. It raised soil organic matter content. Nevertheless, during the field examination C and DW showed higher CO_2 emission than DL (Kotroczó et al. 2008). As for enzyme activity, similar tendency was observed (Fekete et al. 2011).

6 CONCLUSION

Our results have proven that additional detritus input influenced organic matter content in undisturbed soils under natural vegetation to a less extent than detritus removal for several years. The decrease in detritus input entailed the decrease in humus content relatively fast. At the Síkfőkút DIRT site detritus manipulation caused significant changes in soil organic matter content within five years. In drier conditions the increase of moisture content entailed a more intense soil respiration. If detritus input does not provide a sufficient amount of substrate for decomposing organisms, the mobile components of organic matter will be used for metabolic processes.

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