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The Effect of Climate Change on Soil Organic Matter Decomposition

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Abstract – In the last few decades the climate of Síkfőkút ILTER Forest (Hungary) became warmer and dryer. Due to the climate change the species composition of forest has been changing, and the total leaf litter production has been slightly decreasing. According to our long-term litter manipulation field experiment, which is part of ILTER Detritus Input and Removal Treatments (DIRT) Project, after a 4-5 year treating period, at the No Litter, No Root and No Input treatments the soil organic C and N content, the soil bacterial and fungal count, the soil pH, the soil enzyme activity, and soil respiration decreased. Increased soil temperature raises soil respiration exponentially, and thus if the average soil temperature increased by 2^{o}C at the dry Síkfőkút site, soil respiration would increase by 22.1%. This increase would be higher (29.9%) at a wet site, such as Harvard Forest in the USA. Increasing soil respiration can speed up global warming through a positive feedback mechanism.

oak forest, litter production, DIRT, SOM, soil respiration, soil enzymes activity

Kivonat – A klímaváltozás várható hatása az elhalt szerves anyag lebontási folyamataira. A Síkfőkúti erdő klímája az elmúlt évtizedek folyamán melegebbé és szárazabbá vált. A klímaváltozás hatására az erdő fafaj összetétele, struktúrája megváltozott, a teljes levélavar produkció csökkent. A hosszú-távú szabadföldi avarmanipulációs kísérleteink szerint, amely része az USA Detritus Input and Removal Treatment (DIRT) Projektnek, a csökkenő avarinput hatására a Nincs Avar, a Nincs Gyökér és a Nincs Input kezeléseknél, már 4-5 év múlva csökkent a talaj szerves C és N tartalma, a baktérium- és gombaszám, a pH, a talajenzimek aktivitása és a talajlégzés. Ha a globális felmelegedés következtében, a talaj évi átlaghőmérséklete 2^{o}C-al emelkedne, ez a szárazabb klímájú síkfőkúti cseres-tölgyesben kb. 22.1%-os talajlégzés növekedést eredményezne, míg a hűvösebb, nedvesebb klímájú Harvard Forest (USA) esetében ennél valamivel nagyobb 29.9%-os talajlégzés növekedés várható. A talajból történő többlet CO_2 kiáramlás pozitív visszacsatolásban tovább fokozhatja a globális felmelegedést.

tölgy erdő, avarprodukció, DIRT, SOM, talajlégzés, talajenzimek aktivitása

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1 INTRODUCTION

During the last few decades the long-term meteorological data of Síkfőkút Forest (Hungary) followed the global climate change, the forest climate became dryer and warmer (Antal et al. 1997).

Due to the climate change the tree species composition and the forest's structure have been changing dramatically. From 1972 till now the 68% of *Quercus petraea* and 15% of *Q. cerris* trees died and in the gaps new tree species (*Acer campestre*, *A. tataricum*) grew up from the shrub layer into the canopy level (Tóth et al. 2006).

The climate change also affects the soil organic matter (SOM). The SOM is a critical component of ecosystem, it provides cation exchange and water holding capacity, and it acts as a major control on soil pH. SOM also strongly promotes soil aggregation, and retains water for use by plants. Soil C accumulation and turnover are important global processes: soils contain about 1.5×10^{18} g C, which is 2-3 times bigger than the total amount of C in the vegetation (Schlesinger 1990). The C flux between soils and the atmosphere is huge, with soil respiration surpassing about 10 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 has a remarkable effect to the global C cycle. The litter input quantity and quality are taken into account under most scenarios of global climate change, but the resulting effects on SOM stability and turnover can not be predicted accurately now.

The level of SOM is influenced by litter production and added soluble organic material as input, and decomposition and leaching as output. Climate change affects on the input and output too through effects on net primary production (NPP) as well as through changes in rates of decomposition and leaching.

The litter production of Síkfőkút Forest was continuously measured from 1972 to 1976 (Tóth et al. 1985). From 2003 till now we renewed this measurement so as to get information about the effect of climate change on the litter production.

The effect of climate change on the SOM level and soil processes was studied in the framework of ILTER DIRT (International Long-Term Ecological Research, Detritus Input and Removal Treatments) project. The intercontinental ILTER network was developed by American and Hungarian scientists in 2000. The ILTER DIRT now includes five temperate forest sites including an oak forest at the Harvard Forest, MA (established 1990), a black cherry/sugar maple-dominated forest in the Bousson Experimental Forest, PA (1991), an old growth coniferous forest at the H.J. Andrews Experimental Forest, OR (1997), an oak forest at the Michigan Biological Laboratory, Pellston, MI (2004), and an oak forest in Síkfőkút Forest, Eger, Hungary (2000) (Sulzman et al. 2005). The original DIRT treatments, designed by Dr. Francis Hole at the University of Wisconsin Arboretum in 1956, consist of chronically altering plant inputs to forest soils by regularly removing surface litter from permanent plots and adding it to others (Sulzman et al. 2005). The purpose of the DIRT experiment is to assess how rates and sources of plant inputs control accumulation and dynamics of soil organic matter (SOM) and nutrients in forest soils, so this experiment is very applicable to studies of the effect of climate change on SOM and soil processes.

2 METHODS

2.1 Study site

The Síkfőkút ILTER site (47°90' N, 20°46' E, 320-340 m elevation) was established by Prof. Pál Jakucs in a mixed oak forest dominated by *Q. petraea* and *Q. cerris* in Northern part of Hungary in 1972 (Jakucs 1973, Kovács-Láng et al. 2000). Other important tree species are *Acer tataricum* and *A. campestre*. According to Antal et al. (1997) the mean annual temperature is 10°C (1978–1994), and mean annual precipitation is 553 mm year^{-1} (1973–1996).

2.2 Measuring the litter production

Litter production was measured using the methods of Tóth et al. (1985).

2.3 The plant litter manipulation experiment

Plant litter inputs have been manipulated at the DIRT plots in the Síkfőkút Forest (SIK) since 2000. Six litter input/exclusion treatments (three replicates per treatment, *Table 1*) were located randomly at the site. Plots sizes are 7×7 m. Litter from No Litter plots were transferred to Double Litter plots several times per year. New vegetation was continually removed from the No Roots and No Inputs plots. Mosses re-grew rapidly, and were removed semi-annually.

Table 1. Treatment methods of the Detritus Input and Removal (DIRT) plots

Treatment	Method
Control (C)	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 fallen woody debris.
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 and plants or lichen/moss growth were discarded.

2.4. Soil sampling

The soil samples were taken from 6 places randomly in each plot, from the top 15 cm layer, using an OAKFIELD soil sampler.

2.5 Measuring methods

Soil temperature was measured hourly in each of the 18 plots by ONSET StowAway®TidbiT® temperature loggers at the centre of the plots at 10 cm soil depth. Soil moisture was measured monthly by oven drying at 105°C and a TDR instrument in the field. The bacterial and fungal count was determined quarterly by plate methods on Beef extract and on Czapek-Dox medium. Enzyme activity of soil acid phosphatase and β-glucosidase was measured quarterly according to Caldwell et al. (1999). Soil pH(H_2O) was measured quarterly with a Cole-Parmer pH meter. Soil C and N content was measured using a VARIO EL C-H-N-O-S instrument. Soil respiration was measured monthly using the soda lime method (Raich et al. 1990, Grogan 1998). The effects of treatments were statistically evaluated with SPSS software by analysis of variance.

3 RESULTS AND DISCUSSION

3.1 Litter production

The long-term change of the litter production (*Table 2*) reflects the change of tree species composition (Tóth et al. 2006). The leaf litter production of *Q. petraea* decreased considerably and production by *Q. cerris and Acer campestre* increased. Total leaf litter production slightly decreased. The increase in the debris fraction and the smallest leaf litter production is consequence of the huge *Lymantria dispar* gradation in 2005.

Table 2. Litter production of Síkfőkút Project kg ha^{-1}

Year	*Quercus petraea*	*Quercus cerris*	*Acer campestre*	*Cornus mas*	Other shrubs	Total leaf	Brach	Crop residue	Debris	Total litter
1972	2787	786	83	203	53	3912	458	0	178	4548
1973	2731	685	86	87	34	3623	526	326	190	4666
1974	2617	827	83	200	38	3765	689	477	209	5140
1975	3074	1063	114	277	39	4567	983	156	289	5995
1976	3019	1025	182	205	19	4450	1005	228	211	5894
Average	2846	877	110	194	37	4063	732	237	215	5249
2003	2038	660	669	208	54	3629	256	987	161	5033
2004	1054	1504	631	254	72	3515	744	2104	426	6789
2005	968	1284	274	273	36	2835	471	30	4557	7893
2006	1105	1912	900	322	123	4362	360	0	481	5203
Average	1291	1340	619	264	71	3585	458	780	1406	6230

3.2 Effect of litter manipulation treatment on the soil

3.2.1 Soil temperature

The shape of soil temperature curve is similar to a sinus curve (*Figure 1*). The litter on the soil surface acts as a heat insulation layer, therefore the litter treatments influences the soil temperature (*Figure 1-3*). This effect can be seen in the soil temperature curves as an amplitude change. The amplitude sizes of different treatments are: NI>NL>NR>C>DW>DL.

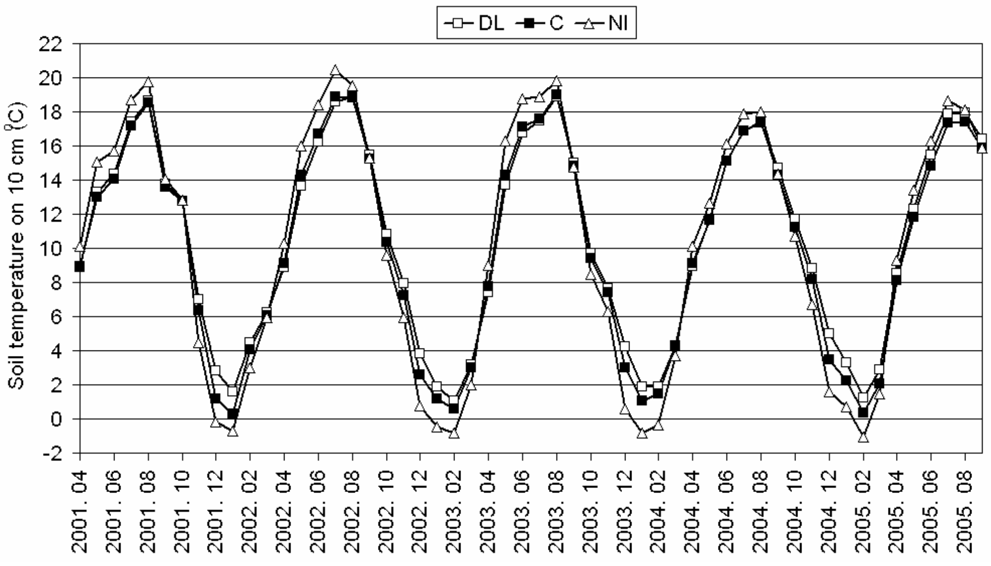

Figure 1. Effect of litter manipulation treatments (only DL, C and NI) on soil temperature in 10 cm soil depth between 2001 and 2005. (Codes explained in Table 1.)

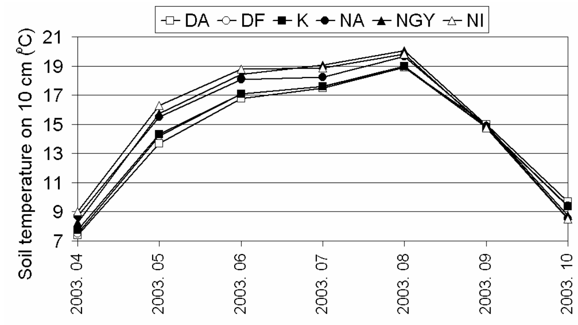

Figure 2. Effect of litter manipulation treatments on soil temperature in 10 cm soil depth over summer 2003

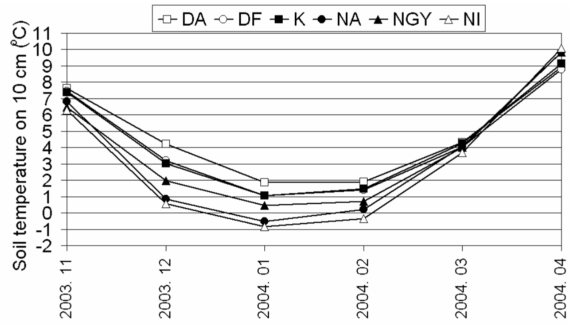

Figure 3. Effect of litter manipulation treatment on soil temperature in 10 cm soil depth over winter 2003

3.2.2 Soil moisture

The soil moisture contents both in w/w % and v/v % were similar to each other (*Figure 4, 5*). There was no significant difference between the soil moisture content at DL, NL and DW treatment compared to Control. At the same time significant differences could be seen in soil moisture contents at NR and NI treatments. In these plots high soil moisture content is a consequence of the lack of plant transpiration.

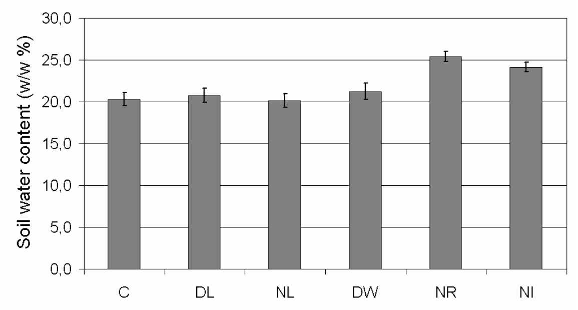

Figure 4. Soil water content % (w/w) in 0-15 cm depth (average of data between 2002 and 2005)

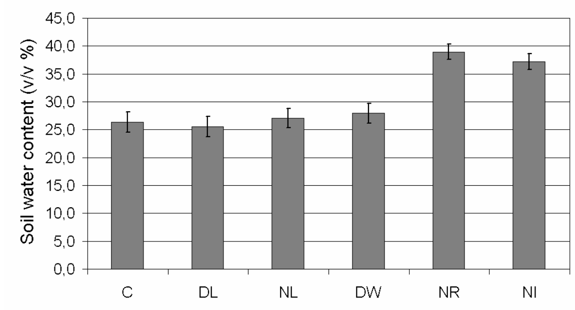

Figure 5. Soil water content % (v/v) in 0-15 cm depth. (average of the data between 2002-2005)

3.2.3 Carbon and nitrogen content of soil

In the first five years in the exclusion treatments (NL, NR, NI) C and N content of soil decreased so the long-term decrease in litter production is potentially harmful to soil fertility (*Figure 6, 7*). Surprisingly, the added litter at DL and DW treatments did not increase the C and N content of soil. An explanation of this phenomenon needs further investigation.

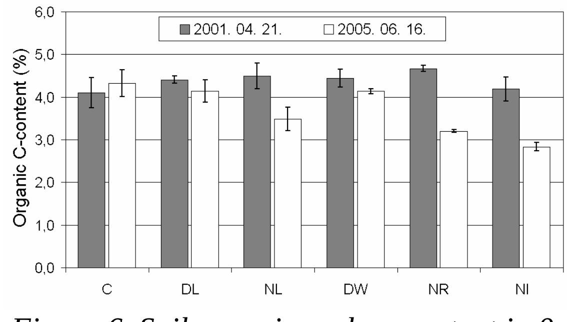

Figure 6. Soil organic carbon content in 0-15 cm soil depth.

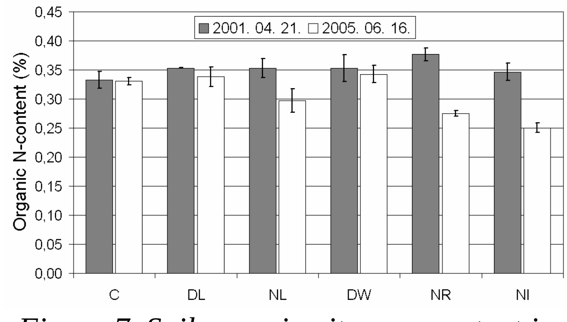

Figure 7. Soil organic nitrogen content in 0-15 cm soil depth.

3.2.4 Soil pH

The soil pH decreased in the exclusion (NL, NR, NI) treatments and increased in DL, DW treatments (*Figure 8*).

It is likely that the soil pH decrease in the NL, NR, NI treatments with decreasing litter input is due to decreases in litter cation inputs. The lower soil cation content decreases the soil buffering capacity which is unable neutralize the acidic substances resulting from litter decomposition.

In the DL and DW treatments with the increasing litter input, cation input increases too, which results in higher soil buffer capacity and pH.

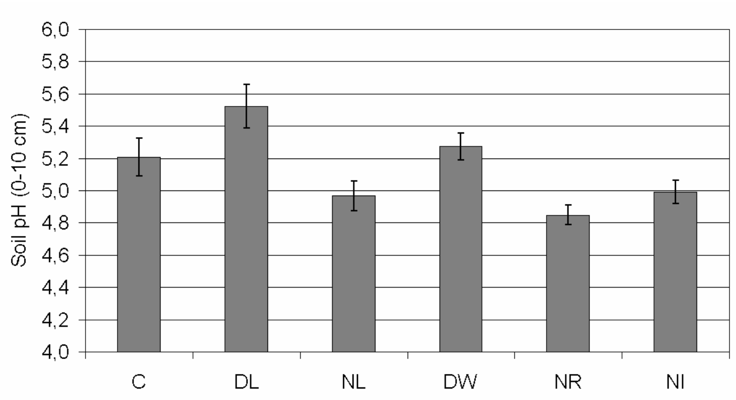

Figure 8. Soil pH (H_2O) in 0-15 cm soil depth (average of the data between 2003 and 2005)

3.2.5 Soil bacterial and fungal count

The bacterial numbers at the NL, NR, NI treatments were significantly lower than in Control plots (*Figure 9*). Similar phenomenon can be observed for the fungi too, but the differences are not significant (*Figure 10*). The highest bacterial and fungal count was observed in the DL treatment but the difference is not significant compared to the Control.

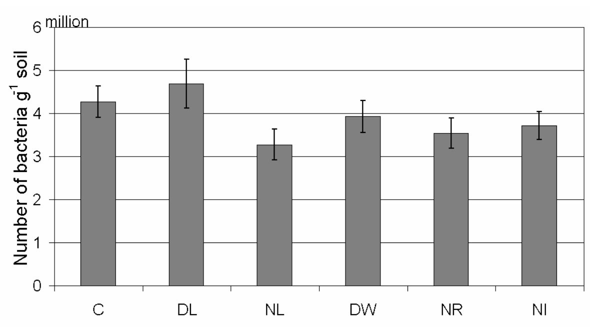

Figure 9. Bacterial count in 0-15 cm soil depth (average of the data between 2003 and 2005)

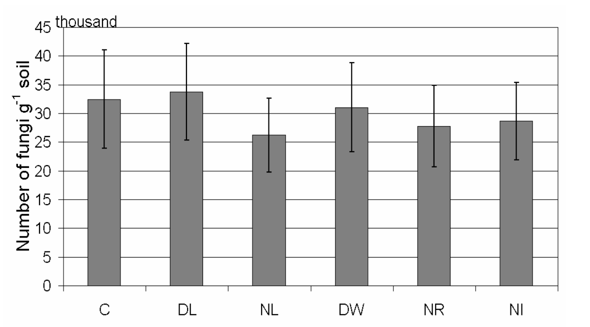

Figure 10. Fungal count in 0-15 cm soil depth (average of the data between 2003-2005)

3.2.6. Soil phosphatase and β-glucosidase activity

There were no significant differences in the soil phosphatase and β-glucosidase activity of different treatments in the first two years (*Figure 11, 12*). After this period, since 2003, the phosphatase and β-glucosidase activity of NL, NR and NI treatments has decreased, and at the same time at DL and DW treatments increased, although not significantly. There was a positive correlation between soil phosphatase and β-glucosidase activity.

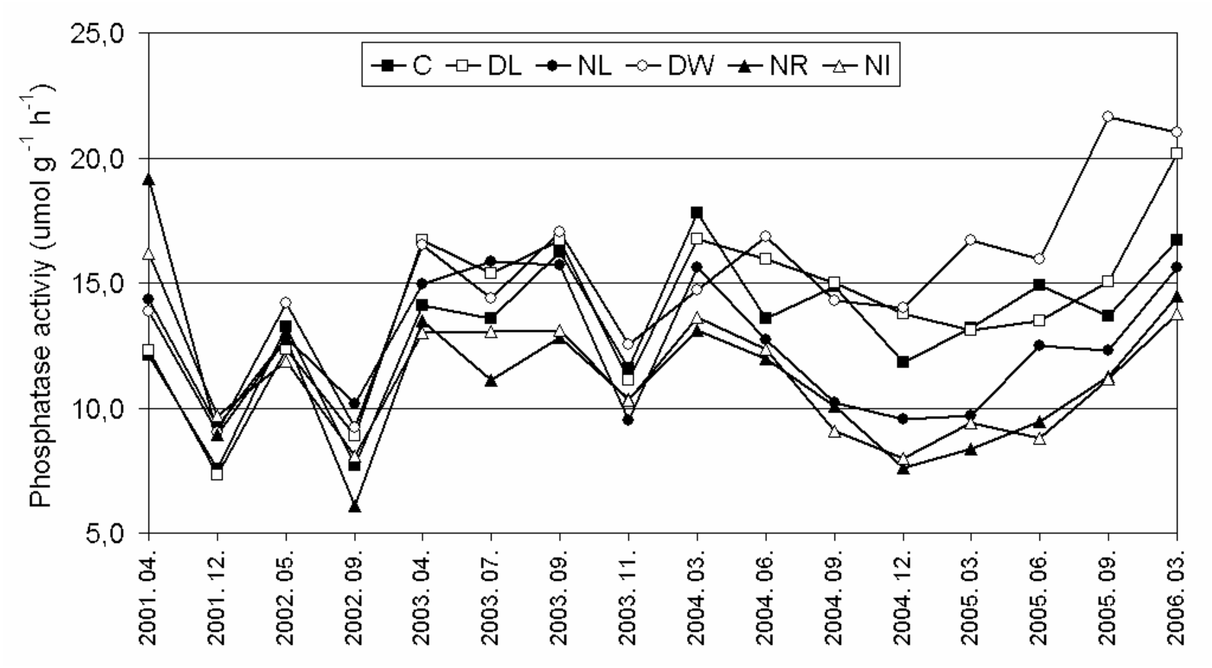

Figure 11. Changes in soil phosphatase activity

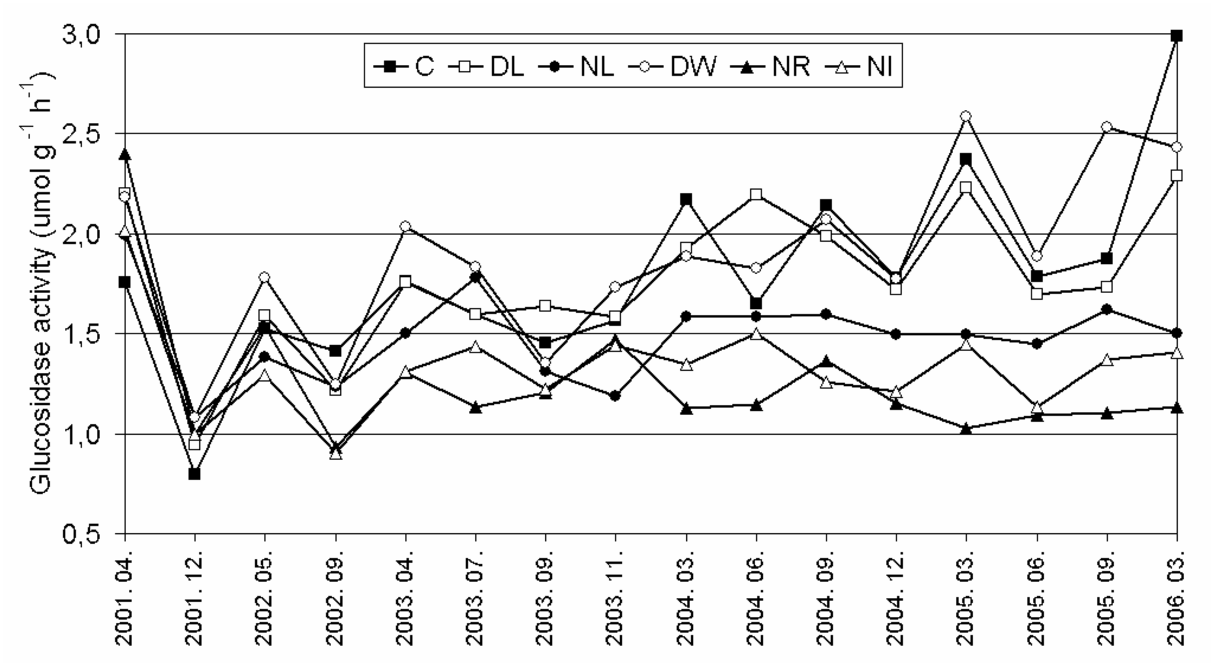

Figure 12. Changes in the soil β-glucosidase activity

3.2.7 Soil respiration

In the exclusion treatments (NL, NR, NI) soil respiration decreased significantly after 5 years, in 2005 (*Figure 13).*

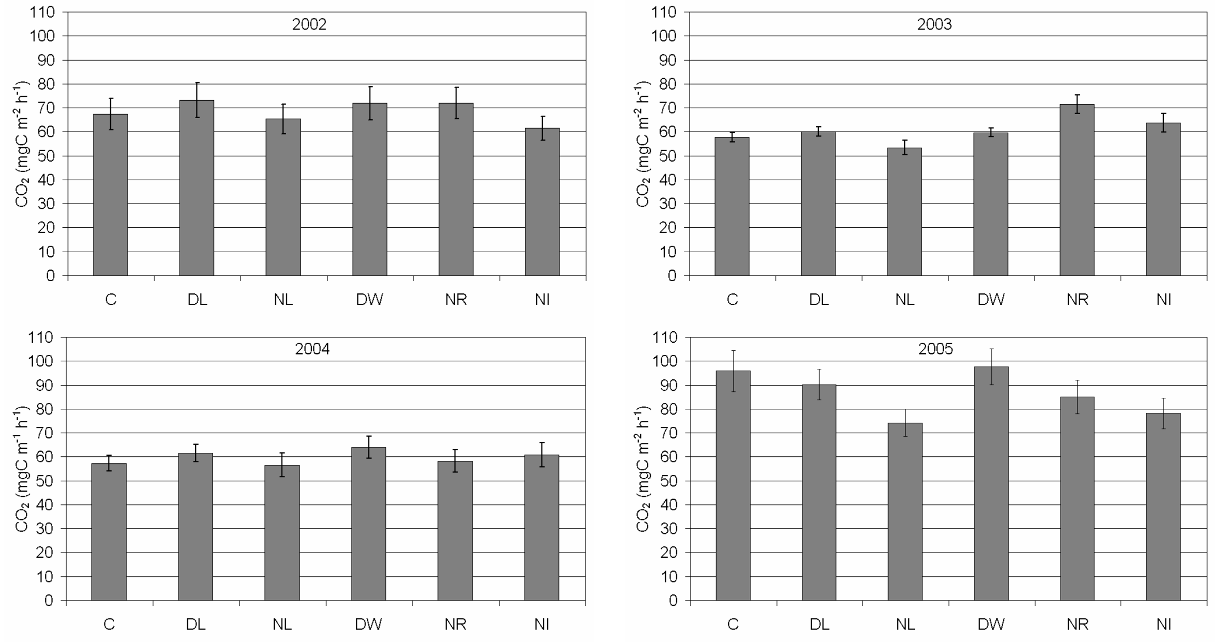

Figure 13. Effect of the litter manipulation treatment on soil respiration (yearly average)

Soil respiration was higher in every treatment in 2005. This phenomenon is possibly due to *Limantria dispar* gradation. In that year there was a large increase in *Limantria dispar* faeces deposited on the soil, which possibly increased soil respiration.

The seasonal change in soil respiration is significantly correlated with the seasonal change in soil temperature (*Figure 14*).

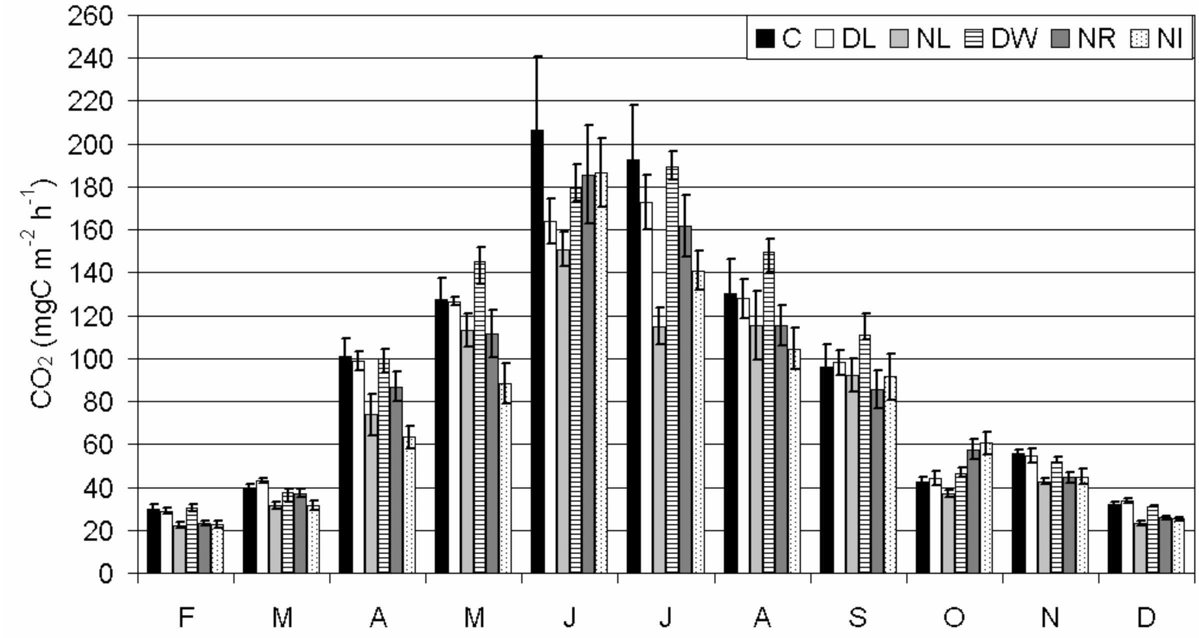

Figure 14. Seasonal changes in soil respiration in 2005

3.3 Effect of the soil temperature on the soil respiration

With increasing soil temperature, soil respiration rose exponentially (*Figure 15*). The relationship between soil temperature and soil respiration is $y = a.e^{(b.x)}$. From this equation we can calculate a Q_{10} value ($Q_{10} = e^{b.10}$). Q_{10} values calculated for the Síkfőkút Project (SIK) to those found previously in the DIRT experiment at Harvard Forest (HFR) are compared in *Table 3*. The SIK Q_{10} values are lower in every treatment compared to those seen at the HFR.

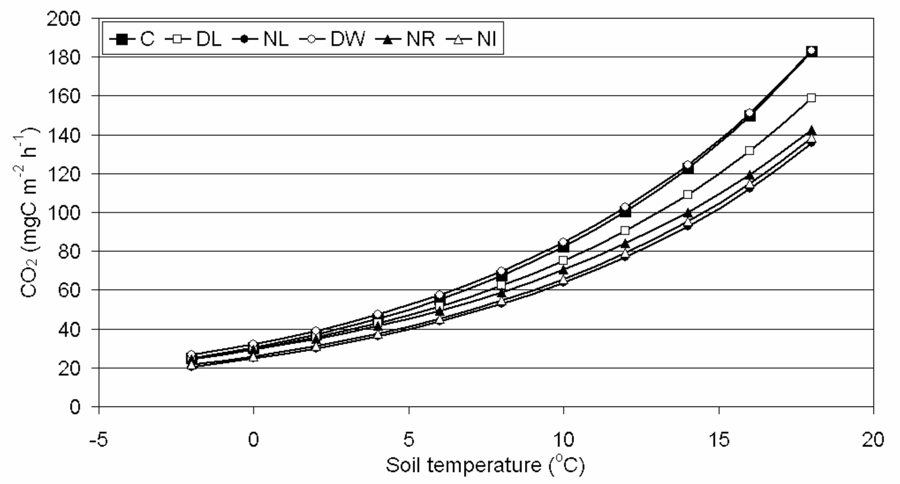

Figure 15. Effect of soil temperature on soil respiration

Table 3. The Q_{10} values of SIK and HFR for soil respiration

Treatment	Q_{10}(after 5 years treatment)	
	SIK	HFR (Micks 2002)
Control	2.7	3.7
Double Litter	2.5	3.0
No Litter	2.6	2.9
Double Wood	2.6	-
No Root	2.4	2.6
No Input	2.5	2.6

The huge 10°C soil temperature increase is not a realistic scenario, so we calculated Q_2 ($Q_2 = e^{b.2}$) instead of Q_{10}. The Q_2 shows the factor by which soil respiration will rise if the mean annual soil temperature increases 2°C. We compare Q_2 values of SIK to HFR in *Table 4.*

Table 4. The Q_2 values of SIK and HFR for soil respiration

Treatment	Q_2(after 5 years treatment)	
	SIK	HFR*
Control	1.221	1.299
Double Litter	1.206	1.246
No Litter	1.208	1.237
Double Wood	1.213	-
No Root	1.192	1.210
No Input	1.204	1.210

* Calculated date from Micks 2002

According to the *Table 4,* if the average yearly soil temperature grew by 2°C at the dry SIK site, the soil respiration would increase by 22.1% (compared to the Control). The increase would be higher (29.9%) at the wet site, at HFR (compared to the Control). Increasing soil respiration can speed up global warming through a positive feedback loop.

3.4 Effects of soil moisture on soil respiration

The effect of soil moisture on soil respiration was minor (*Figure 16*). With increases in soil moisture content, soil respiration rose slightly, but the relationship was not significant.

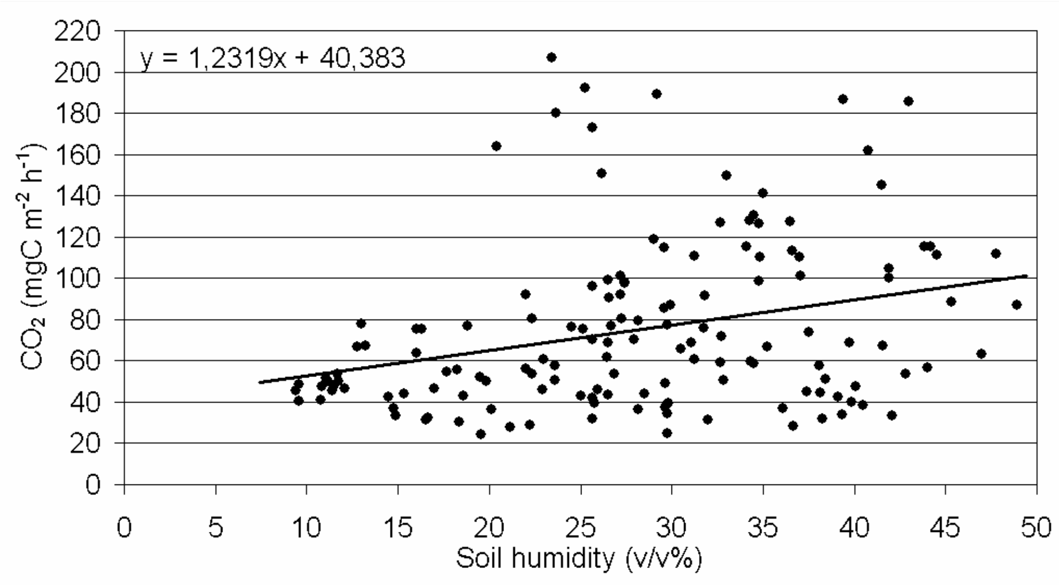

Figure 16. Effect of soil humidity on soil respiration

4 CONCLUSION

It is difficult to say, what the effect of climate change on the litter production is. During the last three decades the leaf litter production of Síkfőkút Project decreased but the total litter production increased. To substantiate the trend in litter production needs further data, so we must continue our litter production investigation in the future.

However, the decrease of leaf litter production would be harmful to the soil physical and chemical properties and the soil life. If the litter production decreased on long term, soil organic C and N content, the soil bacterial and fungal count, soil pH, soil enzyme activity, and soil respiration would decrease. At the same time the soil temperature would increase in the summer period. Increased soil temperature would raise the soil respiration exponentially which might speed up the global warming through a positive feedback mechanism.

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