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Effect of Litter Fall on Soil Nutrient Content and pH, and its Consequences in View of Climate Change (Síkfőkút DIRT Project)

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Abstract – In the DIRT (*Detritus Input and Removal Treatment*) field experiments established at the Síkfőkút Site (North Hungary) in October 2000, an experiment was initiated to study the long-term effects of litter quality and quantity on pH and nutrient content (organic carbon, N forms, PO_4^{3-}, K^+, Mg^{2+}, Ca^{2+}) of soil in a *Quercetum petraeae-cerris* forest. An eight-year litter manipulation demonstrated a close connection between the changes in pH and Mg^{2+} and Ca^{2+} concentration. The decline of litter production, the decrease of the soil pH due to lower Mg^{2+} and Ca^{2+} input lead to consequent reduction of soil buffering capacity. The acidification interferes with the decomposition process of litter and humus compounds. Our results suggest decreases in organic matter content, total N, Ca^{2+} and Mg^{2+} concentrations in the soil as a consequence of decline in forest litter production induced by climate change and a resulting degradation of the soil over a longer period.

oak forest / DIRT / Sikfokut Project / litter production / soil nutrient

Kivonat – Az avarhullás hatása a talaj tápanyagtartalmára és pH-jára, a klímaváltozás fényében. A Síkfőkúti cseres-tölgyes erdőben beállított szabadföldi avarmanipulációs kísérletünkben (Síkfőkút DIRT Project) azt a kérdést vizsgáltuk, hogy az avarprodukció összetételének megváltozása, csökkenése vagy növekedése, várhatóan milyen hatással lesz a talaj szerves szén-, teljes nitrogén-, PO_4^{3-}-, K^+-, Mg^{2+}- és Ca^{2+}-tartalmára, valamint pH-jára.

Az eddigi kutatási eredményeink azt mutatják, hogyha a klímaváltozás hatására csökkenne az erdő avarprodukciója, ez hosszabb távon a talaj szerves szén-, összes-N-, Ca^{2+}- és Mg^{2+}-tartalmának csökkenését eredményezné, ami a termőhely leromlásához vezetne. A vizsgálatainkból levonható továbbá az a következtetés is, hogy az avarprodukció hosszú távú csökkenése a talaj pH csökkenését, elsavanyodását eredményezi, mivel az avarbomlás során keletkező savas intermediereket, humuszanyagokat, a csökkenő avarinput miatt a csökkenő Ca^{2+}- és Mg^{2+}-bevitel nem képes pufferolni. Ezt alátámasztja az is, amely szerint a talaj Ca^{2+}- és Mg^{2+}-tartalma és pH-ja között pozitív szignifikáns összefüggést mutattunk ki.

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Abban az esetben, ha klímaváltozás hatására növekedne az avarprodukció, ez hosszabb távon a talaj szerves szén-, összes-N-, Ca^{2+}- és Mg^{2+}-tartalmának, továbbá a talaj pH-jának a növekedését eredményezné, ami kedvező hatással lenne a talaj termőhelyi tulajdonságaira. A Síkfőkút Projecten végzett avarprodukcióval kapcsolatos hosszú távú vizsgálataink eddigi eredményei azt mutatják, hogy az avarprodukció csökkenő tendenciájú, ami hosszabb távon kedvezőtlen hatású a talajra.

tölgyerdő / DIRT / Síkfőkút Project / avarmanipuláció / talaj elemtartalom

1 INTRODUCTION

The long-term ecological research Síkfőkút Project was started in 1972 as a part of IGBP (International Geosphere-Biosphere Program), and later it continued within the MAB (Man and Biosphere) program. The study site was designated to investigate dynamics of a temperate-zone *Quercetum petraeae-cerris* forest which is typical for Hungary (Jakucs 1973). The study area is situated 6 km northeast of the city of Eger in the foothills of the Bükk Mountains (47°55’ N and 20°46’ E) in an elevation of 320–340 m above sea level. Ensuring undisturbed research conditions the total region of forest which includes the Síkfőkút site was declared a nature reserve by the Hungarian Nature Conservation Bureau (Enactment No. 8/1976). As a consequence of lacking silvicultural management in the past decades the Síkfőkút forest is assumed to approach the state of close to natural forest. Based on the data acquired from the intensive and long-term ecological research in the past 37 years, effects of climate change (warming, drought) on forest species composition, structure and fitness are well characterized.

As a result of the climate change, species composition and other structure in the Síkfőkút *Quercetum petraeae-cerris* forest changed considerably. This was shown by the strong decline of Sessile oak (*Quercus petraea*) abundance while a progression of Turkey oak (*Quercus cerris*) and *Acer* species (Kotroczó et al. 2007). This shift in tree species composition lead to qualitative and quantitative alteration of leaf litter production and clearly affected related soil properties (Tóth et al. 2008). Considering the phenomena described above, the present study focuses on how alteration of litter production under the condition of climate change modifies physical, chemical and biological soil properties. To answer this question, the approach of DIRT (*Detritus Input and Removal Treatment*) (Neilson and Hole 1963) was applied when field experimental plots were set up for determining the effects on soil by changing amounts and quality of litter in the long-term perspective. By contributing to DIRT, the Síkfőkút Project is an associated member of the ILTER (International Long-Term Ecological Research) DIRT Project which consists of four American (Harvard Forest, Bousson Forest, Andrew Forest and Michigan Forest) and two European (University of Bayreuth and Síkfőkút) LTER sites establishing an international and intercontinental research network. We have shown similar results already in our previous litter decomposition experiments in which we found effects in the soil water dynamics, changes in bacterial end fungal flora enzyme activities (Fekete et al. 2011) and soil respiration (Kotroczó et al. 2008, Tóth et al. 2007a, 2007b, 2008). The aim of the present study demonstrates and analyzes respective effects by experiments on litter decay particularly on the chemistry of soil organic matter, nitrogen (N -NO_3^-, NH_4^+, organic N, and total N), mineral nutrients and soil pH. This paper is dedicated to the evaluation of litter decay experiments regarding nutrient dynamics and soil-pH with special regard of sampling in the framework of DIRT after eight years duration.

2 MATERIALS AND METHOD

Inside the Síkfőkút forest stand, 7×7 m permanent experimental plots were set up 2000 in accordance with the protocol used in the USA DIRT plots too (*Table 1*).

Table 1. The applied treatments in open-field experiment (Síkfőkút, Hungary).

Treatments	Description
Control (C)	Normal litter inputs. Average litter amount typical to the given forest site
No Litter (NL)	Aboveground inputs are excluded from plots. Leaf litter was totally removed by rake. This process was replayed continuously during the year.
Double Litter (DL)	Aboveground leaf inputs are doubled by adding litter removed from NO LITTER plots.
Double Wood (DW)	Aboveground wood debris inputs are doubled by adding wood to each plot. Annual wood litter amount was measured by boxes placed to the site and doubbled amount of that was applied in case of every DW plots.
No Roots (NR)	Roots are excluded by inserting impenetrable barriers in backfilled trenches to the top of the horizon C. Root resistant plastic foil was placed into the plot in the depth of 1 m hindering the roots developing outside of the plot to get into the NR plot. Trees and shrubs were eradicated when the plot was established, and plant roots decayed in time
No Inputs (NI)	Aboveground inputs are excluded from plots, the belowground inputs are provided as in NO ROOTS plots. This treatment is the combination of NR+NL treatments.

During the experiment six different treatments were applied: Control (C), No Litter (NL), No Root (NR), No Input (NI), Double Litter (DL) and Double Wood (DW) (Kotroczó et al. 2010). Every treatment was conducted in three replicates. Sample of 100 g were taken randomly on each plot from 0–5 and 5–15 cm depths using an Oakfield soil sampler (G model). Soil extracts were prepared by using two different solvents. Ammonium-lactate/-acetic acid buffer solution (0.1 M; pH=3.7) was used for extraction of soluble and easily exchangeable nutrients (Egnér et al. 1960). Calcium-chloride (0.01 M CaCl2) was used for extraction of easily soluble nutrients (Houba et al. 1990). Aliquots of 5 g air-dried, sieved and homogenized soil were extracted with 100 cm3 of the buffer solution or with 50 cm3 calcium-chloride solutions respectively during 2h shaking and filtering.

Concentrations of Ca2+ and Mg2 in the extracts were determined by means of atomic absorption spectrophotometer (AAS) (SpectrAA-20 Plus, Varian Australia Pty Ltd). Concentration of phosphorus was measured spectro-photometrically by the phospho-molibdovanadate method (VIS SP-850 Plus spectrophotometer, Metertech, Taiwan). Nitrogen species were determined spectro-photometrically by continuous flow analyzer (CFA) system (SA-2000 type Skalar photometer, Breda, The Netherlands). Soil organic matter content was determined after dry combustion (VARIO EL CNS elementary analyzer, Vario, Germany) according to Nagy (2000). Soil pH was determined in 0.01 M CaCl2 suspensions (EBRO

PHT 3140 digital pH meter with a combined glass electrode). Results were statistically analyzed by Sigma Stat software (v3.1.) using one-way variance analysis.

3 RESULTS AND DISCUSSION

3.1 Soil carbon content

The effect of removed litter on the carbon content of soil was larger than the effects of double litter input. In comparison with the Control plots (0–5cm: 5.19%; 5–15cm: 3.25%), carbon content of the soil decreased by leaf litter withdrawal in both two soil depth while Double Litter (0–5cm: 6.73%; 5–15cm: 3.12%) treatments caused increased carbon content only in the depth of 0–5 cm. In the deeper soil layers (5–15 cm) Double Litter treatment did not cause carbon accumulation during the first 8 years of study. Only the carbon content of the upper soil layer increased by the surplus litter input (*Figure 1*).

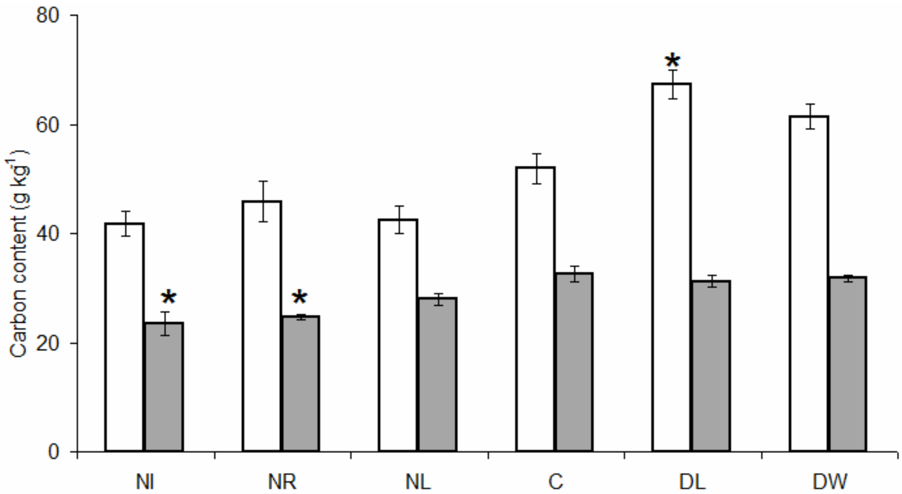

Figure 1. The effects of litter input manipulation on soil carbon content.
NI: No Input, NR: No Root, NL: No Litter, C: Control, DL: Double Litter, DW: Double Wood,
white column: 0–5 cm soil depth, grey column: 5–15 cm soil depth,
**: significantly different from Control (p < 0.05)*

These results suggest two hypotheses: 1) a decrease in litter production induced by climate change might result in declining organic matter content of soil over a longer period which can impair the soil water, temperature and nutrient storage capacity. 2) if climate change enhances litter production the resulted increase of soil organic matter content would gradually improve the former soil properties (temperature insulation, humus and cation content).

Our results (Tóth et al., 2007b; Fekete et al. 2008) indicate decreased litter production as a consequence of climate change. This supports the first hypothesis for the soil of Síkfőkút site. However, it should be added that generalization is not easy since warming climate might result in higher wood and leaf litter production as well in case of more humid ecosystems (Varga et al., 2008; Kotroczó et al. 2008; Krakomperger et al. 2008).

3.2 Nitrogen forms

In 0–5 cm depth the highest and the lowest NO_3^--N contents were measured in DL and NI plots, respectively (*Figure 2*). Other types of litter manipulation treatments, however, had no defined effects on soil's NO_3^--N content. Such lack of tendentious relationship is not surprising as nitrate is highly soluble and mobile and beside the seasonal fluctuations its momentary concentration in soil is strongly influenced by several factors such as nitrification, denitrification, uptake by plants and leaching. NH_4^+-N content in the upper 0–5 cm of soil decreased in plots where litter was excluded and increased in plots with double litter (*Figure 3*). The highest values were measured in DL plots. In the 5–15 cm soil layer only the DW treatment resulted in measurable change compared to control values (*Figure 3*). All types of litter exclusion treatments resulted in significant decrease in organic-N content in 5–15 cm depth and a non-significant decrease in the depth of 0–5 cm (*Figure 4*). In 0–5 cm depth litter addition increased the organic-N in DL plots and slightly decreased it in DW plots. Both treatments induced decrease in organic-N of 5–15 cm depth (*Figure 4*). Concerning total-N contents effects of litter manipulation treatments were only detectable in the upper 0–5 cm, while there were no differences at 5–15 cm depth (*Figure 5*).

Recently formed litter pools assimilate more NO_3^- than NH_4^+ under ambient N deposition, but may lose capacity to assimilate NO_3^- relative to NH_4^+ under potential future increases in N deposition (Micks et al. 2004). Global atmospheric composition and climate change effects on plant carbon to nitrogen ratios are thus likely to become important when predicting possible second-order impacts of the enhanced greenhouse effects (Kunz et al. 1995).

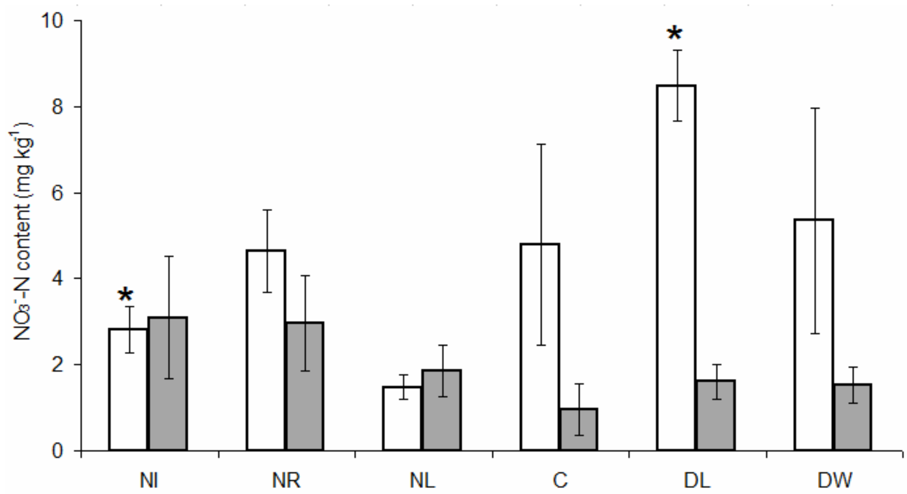

Figure 2. The effects of litter input manipulation on soil NO^{3-}-N content. Explanations are as in Fig. 1

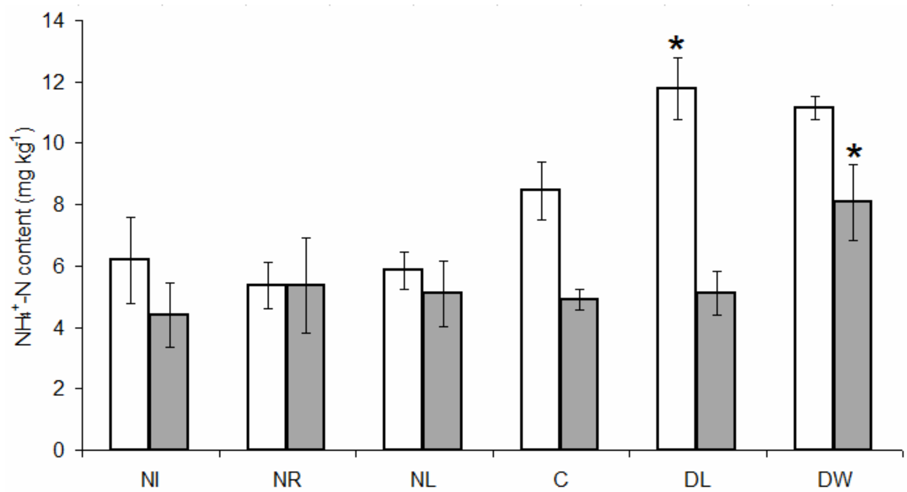

Figure 3. The effects of litter input manipulation on soil NH_4^+-N content. Explanations are as in Fig. 1

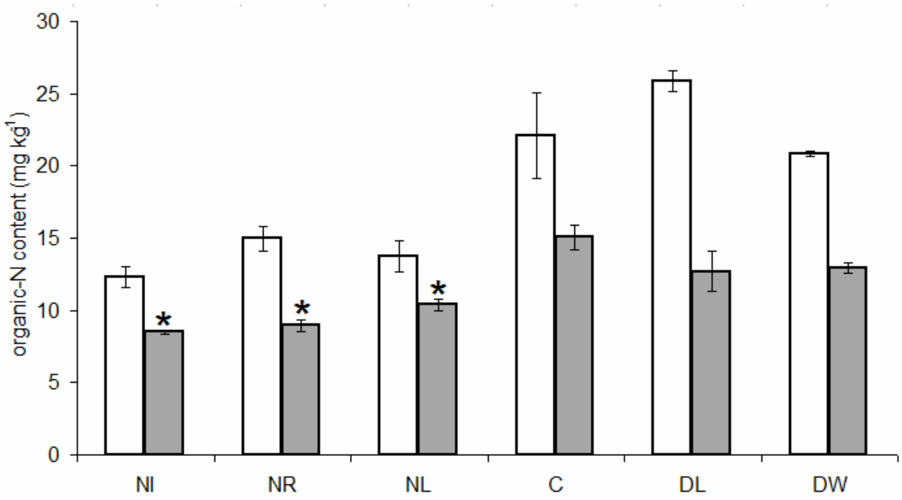

Figure 4. The effects of litter input manipulation on soil organic-N content. Explanations are as in Fig. 1

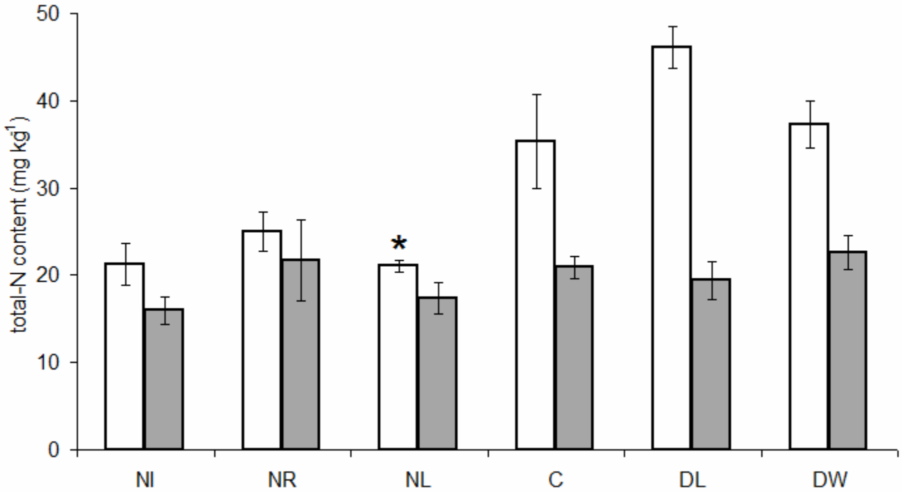

Figure 5. The effects of litter input manipulation on soil total-N content. Explanations are as in Fig. 1

3.3 Extractable phosphorus content

The upper 0–5 cm of soil contained remarkably more phosphorus than the 5–15 cm layer in plots irrespectively of the applied litter management (*Figure 6*). Surprisingly P-content in both depths increased as a result of litter exclusion while there were no significant differences in plots with doubled litter as compared to control values (*Figure 6*).

Higher P contents in plots with litter exclusion could be attributed to several factors such as: 1) in NI and NR treatments uptake of P by plants did not influence the P status of soil. 2) due to similar reasons the activity of phosphatase enzyme was also lower (Fekete et al. 2007; Fekete et al. 2008) allowing P in these plots to remain organically bound. 3) higher soil acidity in plots with litter exclusion (see later in this work) might enhance the possibility of precipitation of P in form of Fe- and Al-phosphates.

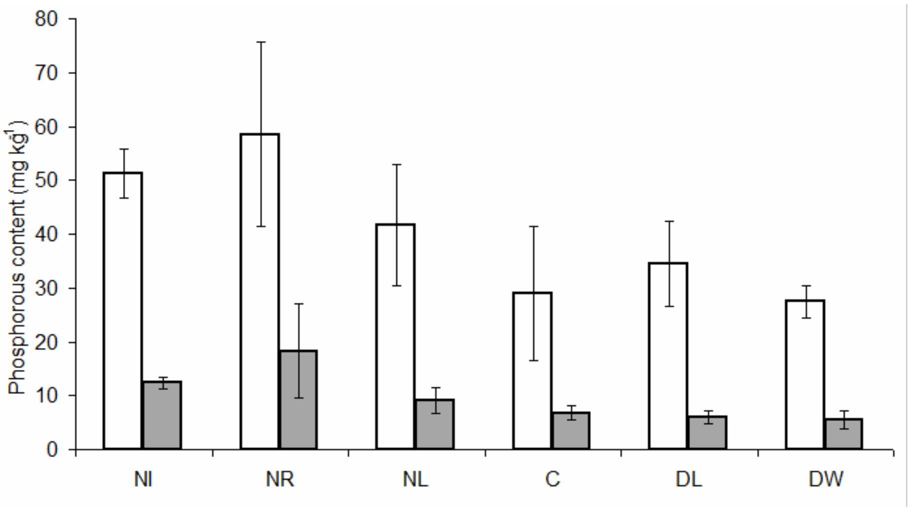

Figure 6. The effects of litter input manipulation on soil phosphorus content. Explanations are as in Fig. 1

3.4 Extractable Ca^{2+} content

Calcium content of soil declined in both depths as a result of litter exclusion. This decrease proved to be significant in NI and NL plots (*Figure 7*). Litter addition had an opposite effect since it increased the Ca^{2+}-content in the upper 0–5 cm (significantly in DL plots, *Figure 8*). In the 5–15 cm layer, however, an increase was not detectable (*Figure 7*). It can be hypothesized that potential decrease of litter production due to climate change might lower the Ca^{2+} content of soil and as a consequence reduce buffering capacity and increase the risk for acidification of the soil. In case of enhanced litter production this process might tend to enhance Ca^{2+} content and therefore improve the buffering capacity of soil.

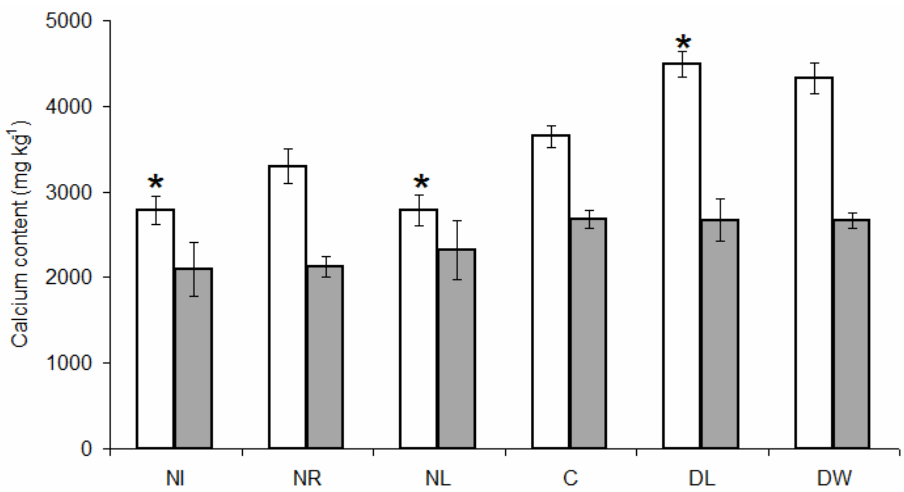

Figure 7. The effects of litter input manipulation on soil Ca^{2+} content. Explanations are as in Fig. 1

3.5 Mg^{2+} content

Magnesium content of soil decreased in both 0–5 and 5–15 cm depths due to litter exclusion treatments and differed significantly in 0–5 cm of all three treatments as compared to control (*Figure 8*). Litter addition increased Mg^{2+} content only in the 0–5 cm layer of DL treatments (*Figure 8*).

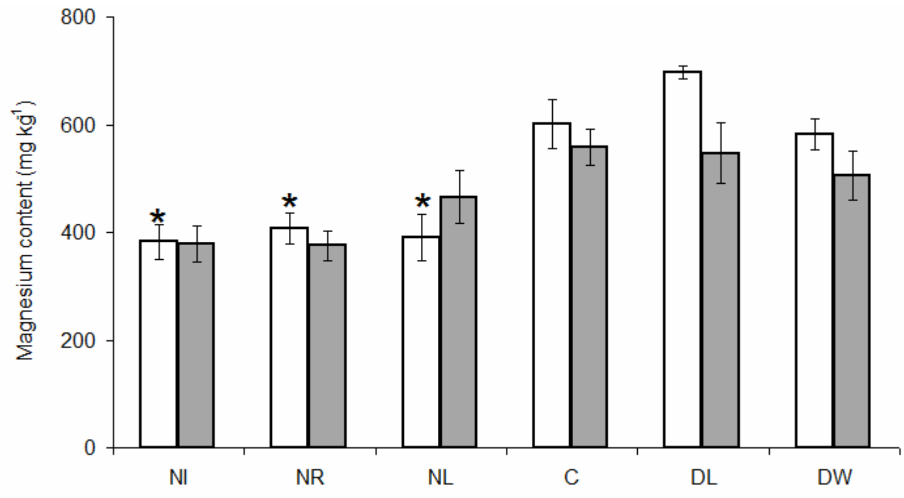

Figure 8. The effects of litter input manipulation on soil Mg^{2+} content. Explanations are as in Fig. 1

3.6 Soil pH

As a consequence of reduced litter input soil pH had decreased (*Figure 9*). This could be attributed to the depleted buffering capacity due to restricted Mg^{2+} and Ca^{2+} input which cannot compensate the acidifying effect of acidic intermediates and humus compounds. Increase of litter input resulted in higher soil pH since it also enhanced Mg^{2+} and Ca^{2+} input and improved buffering capacity (*Figure 9*). Soil pH, Mg^{2+} and Ca^{2+} concentrations in the soil changed in close positive correlation (*Figure 10 and 11*). Finzi et al. (1998) reported similar results. They found highly significant positive correlations between soil pH and extractable Ca^{2+}. In our site at 5–15 cm depth the pH is more acidic as at 0–5 cm depth. The Ca^{2+} has stronger alkaline effect as Mg^{2+}. At 0–5 cm soil depth high litter Ca^{2+} concentration coupled with a large quantity of leaf litter could increase the quantity of exchangeable Ca^{2+} on the surface (0–5 cm) (Finzi et al. 1998). These results suggest that the properties of litter in a given forest could fundamentally influence the soil pH and consequently the nutrient mobility.

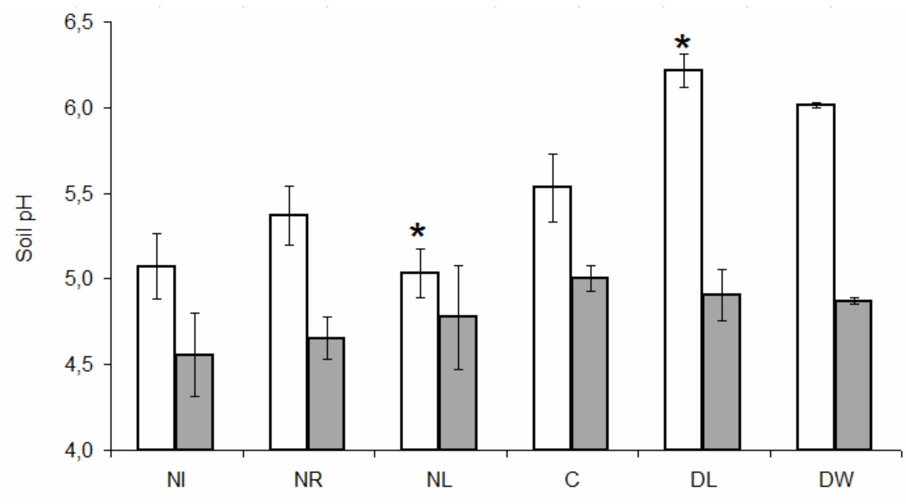

Figure 9. The effects of litter input manipulation on soil pH. Explanations are as in Fig. 1

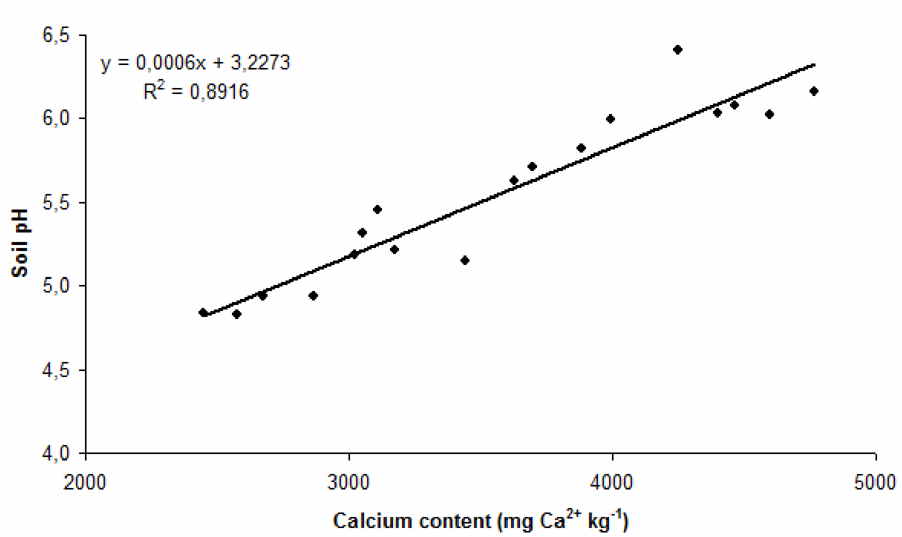

Figure 10. Results of regression analysis between soil Ca^{2+}- content and soil pH under conditions litter input manipulation (R^2=0.89)

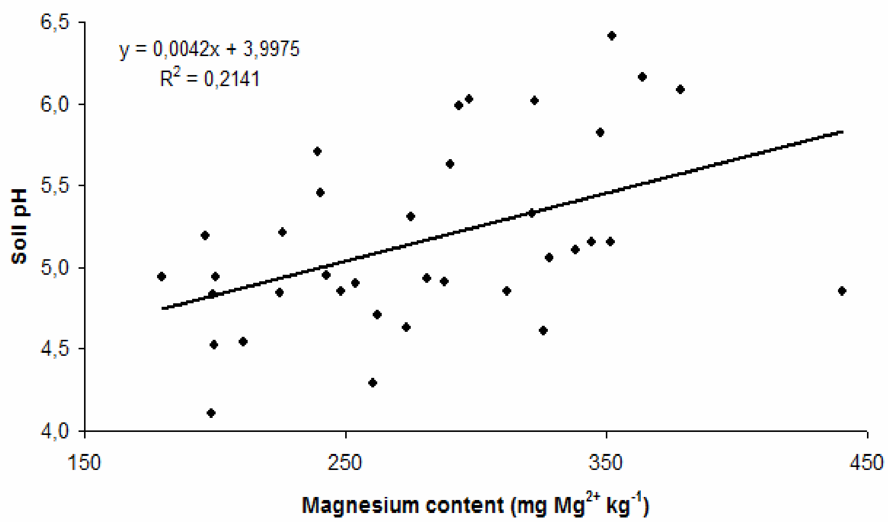

Figure 11. Results of regression analysis between soil Mg^{2+}- content and soil pH under conditions of litter input manipulation (R^2=0.21)

4 CONCLUSION

The effect of litter removal on the carbon content of soil was larger than the effects of double litter input. Carbon content of the soil decreased by leaf litter removal in both soil layers, while Double Litter treatments caused increased carbon content only in the depth of 0–5 cm. In the deeper soil layer (5–15 cm) Double Litter treatment did not cause carbon accumulation during the first 8 years of study.

We point out that organic nitrogen content of the soil decreased in both soil depths under the influence of litter withdrawal. In case of the depth of 5–15 cm, all three litter removal treatments (NI, NR, NL) caused significant decrease in N content. Double Litter treatment increased the organic N content of the upper 0–5 cm soil layer, while decreasing concentrations could be detected in the depth of 5–15 cm.

The effects of treatments on the total nitrogen content could be detected only in the upper 0–5 cm soil layer, however only the No Litter treatment was significantly different from the

Control. Considering the lower soil layer, there are no significant differences among the various treatments. In case of decreased litter production this process might tend to decrease Ca2+ content and therefore deteriorate the buffering capacity of soil and this leads to the acidification of the soil.

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