Distribution of organic carbon, microbial biomass carbon and enzymatic activity in profile of luvisols under different tree species

Silvia Labudová[1], Nora Szombathová[2], Jana Maková[3], Roman Labuda[4]

[1]Department of Microbiology, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic, E-mail: silvia.labudova@uniag.sk
[2]Department of Pedology and Geology, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic, E-mail: nora.szombathova@uniag.sk
[3]Department of Microbiology, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic, E-mail: jana.makova@uniag.sk
[4]Biopure Referenzsubstanzen GmbH, Technopark 1, 3430 Tulln, Austria, E-mail: roman.labuda@biopure.at

Abstract

Labudová, S., Szombathová, N., Maková, J., Labuda, R. 2009. Distribution of organic carbon, microbial biomass carbon and enzymatic activity in profile of luvisols under different tree species. *Folia oecol.*, 36: 108–115.

Selective influence of different deciduous and coniferous tree species (original or introduced) on chemical characteristics (pH, humus quality, total organic carbon (C_{org}), hot water extractable C (C_{hwe}), microbial biomass C (C_{mic}) and dehydrogenase activity (DHA) was studied in the Nature Reserve Arboretum Mlyňany, Slovakia. The soil profiles of nine stands represented by three deciduous trees (oak, sugar maple and cherry laurel), five coniferous (spruce, yew, white fir, Japanese cedar and Himalayan pine), and one meadow stand (taken as a reference) were included in this study. It was found that the plant cover influenced all measured parameters. The average C_{org}, C_{hwe}, C_{mic} and DHA were higher in A horizons in deciduous soils (DS) than in coniferous soils (CS). The average proportion of C_{hwe}/C_{org} in A horizon was higher in DS (about 4%) than in CS (over 3%), which was comparable with that in the meadow (3.16%). The average proportion of C_{mic}/C_{org} was found to be the highest in the meadow soil (6.13%) in comparison with DS (2.18%) and CS (1.35%). In most stands, the proportion of C_{mic}/C_{org} as well as C_{hwe}/C_{org} increased with depth, indicating a higher decrease rate in organic matter than in microbial biomass. The most favourable humus quality in A horizon in terms of HA/FA ratio was found under the trees meadow (0.92), whereas those under deciduous and coniferous were much lower and identical (0.53).

Key words

dehydrogenase activity, forest, hot water extractable carbon, meadow, microbial biomass carbon, organic carbon

Introduction

Tree species differ in their effects on soil quality and nutrient cycling. This is most often explained by differences in the quantity and quality of the overground litter produced, as well as by the rhizodeposition. These factors supplemented by the physico-chemical soil conditions have a great influence on the live and active part of the soil organic matter (SOM). Microbial biomass plays a primary role in the degradation of SOM, thus microorganisms exert feed-back effects on vegetation via mineralization and subsequently the release of mineral nutrients (Priha, 1999; Zechmeister-Boltenstern et al., 2000).

Forest soils, especially their upper horizons, are well known to possess high amounts of organic carbon. Despite this fact, their microbial activity is often energy-limited, because most of the soil C is chemically recalcitrant and/or physically inaccessible for the microbial cells. It is almost sure that the heterotrophic microorganisms gain a significant proportion of their energy from the water-soluble C pool because of its small molecular size and easy accessibility to microorganisms (Wagai and Sollins, 2002). According to many studies, water-soluble substances are more easily leached from the leaf litter of deciduous species, including birch than from coniferous species, including Scots pine and Norway spruce (Harris and Safford, 1996; Hongve, 1999).

Appart from climate, the SOM turnover is governed not only by C, but also N, polyphenols or pH of soils (Priha, 1999; Priha et al., 2001). More specifically, critical levels of C and plant nutrients that limit the enzyme activities of microbial decomposers have been found to be important in determining nutrient release from litter (Seneviratne, 2000).

Since there is lack of knowledge about the influence of introduced tree species on soil chemical and microbial properties, the objective of this study was the comparison of quantity and quality of soil organic matter, including hot water extractable carbon content, and some microbial characteristics under different coniferous and deciduous tree species in Nature Reserve Arboretum Mlyňany, Slovakia, established more than 100 years ago.

Material and methods

Study site

The study stands were located in the Nature Reserve Arboretum Mlyňany in Southwest Slovakia (E 18°21', N 48°19', altitude 165–217 m above sea level). The location is characterized by continental climate with an average annual temperature of 9.7 °C and an average annual precipitation of 566 mm (Hrubik et al., 2006). The Arboretum is situated on Neocene clay, sand and rubble sand, covered with loess, mostly without carbonates (Steinhübel, 1957; Skobla and Kovac, 1967). The main soil subtype in the studied area has been classified as Stagni Haplic Luvisols, except of the stand under Himalayan pines where the soil was classified as Haplic Luvisols (ISSS-ISRIC FAO, 1994).

The Arboretum Mlyňany was established 116 years ago with the goal to collect mainly sempervirens leafy woody plants introduced from South Europe, East Asia, North America and Korea. By the total area of 67 ha as well as by the range of the planted exotic tree taxa the Arboretum Mlyňany belongs to the biggest of its kind in central Europe.

A total of nine sites was selected in this study: one meadow site and eight forest sites: oak (*Quercus cerris,* L.), sugar maple (*Acer saccharinum,* L.), cherry laurel (*Prunus laurocerasus,* L.), spruce (*Picea abies,* L.), yew (*Taxus baccata,* L.), Himalayan pine (*Pinus wallichiana,* Jacks.), Japanese cedar (*Cryptomeria japonica,* D. Don.) and white fir (*Abies concolor,* Lindl. ed. Gord.). The studied sites differed in their ground vegetation cover. Herbs and grasses were more abundant in the deciduous stands, especially in the sugar maple stand. The meadow soil with no trees served as a reference.

Soil sampling

Trees in Arboretum have been planted in dense monoculture groups consisting of minimally five trees. The area occupied by each tree species varies between 100–250 m^2. Each pedological pit was trenched at the centre of chosen monoculture (experimental site). Thus, the determined soil properties represent the influence of the selected tree species. All experimental sites have been established on the same geological substrate and soil type. Therefore, it was appropriate to consider in this study the major differences among the soils under different tree species. The dimensions of the soil pits were: width 0.5–0.6 m, length 1.5–2.0 m, depth 1.0–1.5 m.

The soil samples were taken in spring 2005. The chemical characteristics were made in fresh and dry soil samples sieved through a 2 mm mesh. The biological soil properties (microbial biomass, enzymatic activity) were determined in soil samples incubated in plastic bags at 4 °C during 8 weeks.

Soil analyses

The content of total soil organic carbon (C_{org}) was analyzed by dichromate oxidation according to the Tyurin method (Arinuskina, 1961). The soil pH was evaluated as pH_{KCl} in a soil suspended in 1 M KCl (1:2.5). The hot water extractable carbon (C_{hwe}) was determined by method of the Körschens et al. (1990), humus fractionation by the Kononova-Belchikova method (1961). The microbial biomass carbon (C_{mic}) was determined by the fumigation-extraction method, as described by Vance et al. (1987), based on the difference between C extracted with 0.5 M K_2SO_4 from chloroform-fumigated and unfumigated soil samples. The microbial quotient (C_{mic}/C_{org}) was calculated by expressing C_{mic} as a percentage of total soil C_{org}. Dehydrogenase activity (DHA) was analyzed using TTC method according to Casida et al. (1964). Other chemical parameters characterizing soil properties in the Arboretum under oak, cherry laurel and yew were published by Szombathova et al. (2006), and those under pine and cedar by Szombathova et al. (2008).

Statistical analyses

To determine whether the differences between the averages for different tree species were significant, multifactor analysis of variance and Tukey´s test were used. Two-sample analysis and one-way analysis of variance were used to determine whether the differences between soils of three ecosystem types – deciduous (DS), coniferous (CS) and meadow (M) were significant. The statistical analyses were made in program Statgraphics Vers. 5.0 (1991).

Results and discussion

The chosen locality (Arboretum) was ideal to study how soils developing on the same substrate can be influenced by presence of different woody plant species. Alltogether, the results of our analyses demonstrated that the vegetation have clearly modified the chemical and microbiological properties of the soil.

The soil reaction (pH_{KCl}) varied from strong acid to acid at the forests sites (except of Bt and Bt/C horizons in pine soil) and it was also acid in meadow (Table 1). The average soil pH values of the A horizons was slightly lower in DS (4.13) than in CS (4.33), and higher in M (5.38) (Table 4). Contrary, studies of other authors referred to higher pH of humus horizons under deciduous trees (birch) than under coniferous (pine and spruce) (Priha and Smolander, 1996; Priha, 1999; Smolander and Kitunen, 2002). The evaluation of whole soil profiles showed that the highest pH was under the Himalayan pine (pH 7.04 in Bt/C horizon) (Table 1). We suppose that it was due to carbonates in the soil forming substrate (loess) in this part of the Arboretum. Soil forming substrate under other studied trees and meadow contained no carbonates.

The carbon content was the highest in the organic horizons (Oo) at all sites and decreased with depth. The humus layer was the thinnest under oak (0.03 m), but it had a higher concentration of C_{org} (4.89 %) (Table 1). Similar results have been reported by Priha and Smolander (1996) who also observed that the humus horizon under deciduous tree (birch) was thinner than under spruce, indicating that decomposition rates in relation to litter production were lower under spruce than under birch. Mineral A horizons in DS had higher C_{org} content than CS and M, and varied from 1.89% (cherry laurel) to 4.89% (oak), while in the coniferous stands C_{org} varied from 1.12% (cedar) to 2.91% (fir) (Table 1). The differences among the three ecosystem types (DS, CS and M) were statistically significant (Table 4). These results indicate a positive effect of broad leaf litter on C_{org} accumulation in soil.

Dissolved organic matter is a major source for leaching of many elements from forest floor. Our results showed substantial differences in C_{hwe} content among the experimental sites and among the horizons (Table 1). In general, the highest amounts of C_{hwe} were found in Oo horizons at all sites, most pronouced under pine (1,830 mg kg^{-1}) and cedar (2,020 mg kg^{-1}). The comparison between A horizons in DS, CS and M showed that the sites richer C_{hwe} were found under deciduous trees (930 mg kg^{-1}) than under CS (570 mg kg^{-1}) and M (410 mg kg^{-1}) ($P < 0.01$) (Table 4). Smolander and Kitunen (2002) also found that the concentration of water-extractable dissolved organic carbon (DOC) was higher, or at the same level in the deciduous soil (birch) than in coniferous (spruce and pine). The potentials for DOC production per unit mass of deciduous litter have been reported to be larger than those of other forest litters (Harris and Safford, 1996; Hongve, 1999). However, this may not necessarily be reflected in the soil DOC concentrations which are determined by both production

Table 1. Chemical and microbial characteristics of soil profiles at the studied sites

Horizon – depth [m]	pH_{KCl}	C_{org} [%]	HA/FA	C_{hwe} [mg kg^{-1}]	C_{mic} [mg kg^{-1}]	C_{mic}/C_{org} [%]	C_{hwe}/C_{org} [%]	DHA [µgTPF g^{-1} dry soil mass h^{-1}]
				Spruce				
Oo 0.03–0.0	3.35	4.10	nd	1,020	956.30	2.33	2.49	4.48
Ao 0.0–0.15	3.45	1.48	0.53	230	450.24	3.04	1.57	3.95
Bt 0.15–0.48	3.34	0.67	0.86	180	300.28	4.51	2.72	1.43
Btg 0.48–1.2	3.59	0.37	3.53	100	193.31	5.23	2.65	0.32
				Fir				
Oo 0.05–0.0	4.80	4.07	nd	1,400	495.11	1.22	3.44	1.13
Ao 0.0–0.10	5.80	2.91	nd	1,030	392.35	1.35	3.54	4.28
A/B 0.10–0.40	4.60	1.47	nd	530	266.57	1.81	3.61	1.53
Bt 0.40–0.75	4.30	0.32	nd	50	265.78	8.31	1.41	0.36
Btg > 0.75	4.60	0.08	nd	20	230.66	28.83	2.50	0.20

Table 1. Continued

Horizon – depth [m]	pH_{KCl}	C_{org} [%]	HA/FA	C_{hwe} [mg kg^{-1}]	C_{mic} [mg kg^{-1}]	C_{mic}/C_{org} [%]	C_{hwe}/C_{org} [%]	DHA [µgTPF g^{-1} dry soil mass h^{-1}]
				Yew				
Oo 0.02–0.0	4.00	4.05	nd	1,250	773.91	1.91	3.07	3.36
Ao 0.0–0.20	3.90	2.11	0.39	700	318.42	1.51	3.31	2.25
Bt 0.20–0.60	3.55	0.70	0.47	100	121.11	1.73	1.49	0.20
Btg 0.60–0.9	3.70	0.33	0.77	70	142.02	4.30	2.09	0.16
				Pine				
Oo 0.02–0.0	5.33	5.86	nd	1,830	101.81	0.17	3.12	5.58
Au 0.0–0.25	4.85	1.59	0.61	480	72.50	0.46	3.01	2.53
Au/Bt 0.25–0.35	5.16	0.74	0.66	170	51.29	0.69	2.28	1.13
Bt 0.35–0.60	6.96	0.28	0.94	130	106.01	3.79	4.61	0.77
Bt/C 0.60–1.0	7.04	0.17	1.06	90	30.69	1.81	5.41	0.34
				Cedar				
Oo 0.02–0.0	5.72	4.21	nd	2,020	109.92	0.26	4.80	6.49
Au 0.0–0.20	3.63	1.12	0.61	400	43.96	0.39	3.54	0.85
Btg 0.20–0.8	3.42	0.27	1.00	80	32.00	1.19	3.00	0.20
				Oak				
Oo 0.02–0.0	4.45	4.96	nd	1,310	1,039.25	2.10	2.64	11.85
Ao 0.0–0.03	4.50	4.89	0.45	1,050	1,336.40	2.73	2.14	10.96
A/Bt 0.03–0.15	3.68	2.24	0.38	770	477.13	2.13	2.92	7.43
Bt 0.15–0.50	3.49	1.03	0.48	270	312.61	3.03	2.97	3.28
Btg 0.50–0.80	3.63	0.56	1.16	190	247.52	4.42	3.36	0.23
				Sugar maple				
Oo 0.02–0.0	4.05	3.95	nd	1,430	672.64	1.70	3.62	10.58
Au 0.0–0.20	3.80	2.22	0.61	910	338.62	1.53	4.11	6.96
Bt 0.20–0.40	3.55	0.45	0.93	150	124.84	2.77	3.24	0.34
Btg 0.40–1.1	3.70	0.31	1.79	40	71.53	2.31	1.26	0.00
				Cherry laurel				
Oo 0.02–0.0	4.95	3.20	nd	980	623.86	1.95	3.06	10.02
Au 0.0–0.23	4.10	1.89	0.52	840	428.87	2.27	4.43	5.95
Bt 0.23–0.60	3.55	0.55	0.46	290	195.32	3.55	5.27	1.18
Btg 0.60–0.9	3.40	0.14	0.90	100	182.34	13.02	7.00	0.20
				Meadow				
Oo 0.05 – 0.0	5.20	3.35	nd	740	1,083.28	3.57	2.44	11.50
Au 0.0–0.25	5.38	1.31	0.92	410	803.96	6.13	3.16	6.60
Bt 0.25–0.55	4.91	0.38	2.41	260	216.93	5.79	6.92	0.98
Btg 0.55–0.80	4.03	0.26	6.28	250	227.91	8.70	9.46	0.10

C_{org}, total organic carbon; HA/FA, humic to fulvic acids ratio; C_{hwe}, hot water extractable carbon; C_{mic} microbial biomass carbon, proportion of C_{mic}/C_{org} and C_{hwe}/C_{org}; DHA, dehydrogenase activity; nd, not determined

and consumption. As to the comparison of soils from various forest types, the effects of forest vegetation on the quantity and composition of low molecular weight compounds in the soil organic matter were discussed in many studies (Jandl and Sollins, 1997; Hackl et al., 2000; Smolander and Kitunen, 2002).

High concentration of C_{hwe} in A horizons at deciduous sites resulted in a high proportion of C_{org} (about 4%) except of oak (2.14%) (Table 1). We suppose that the low proportion C_{hwe} of C_{org} in the soil under oak was not caused by the deficiency of C_{hwe}, but rather by a comparatively high C_{org} content (down to the depth of 0.50 m), which was consequently manifested in constant C_{hwe}/C_{org} proportion in the whole soil profile (Table 1). It needs be mentioned that the original growth in the Arboretum was oak-hornbeam forest, and the soil pit on this plot was trenched inside it. Of the all coniferous sites, the narrowest C_{hwe}/C_{org} at the same layer was found in soil under spruce (1.57 %), and the highest under fir and cedar (3.54%) (Table 1). Comparing the soil profiles, the highest C_{hwe}/C_{org} proportion was found in the meadow soil profile (from 2.44% in Oo to 9.46% in Btg horizon) (Table 1). Similar results were found in the proportion of microbial biomass carbon of C_{org}. Likewise, other labile fraction of organic carbon – oxidizable by $KMnO_4$ reached the highest proportion of C_{org} in soil profile on the meadow (Szombathova et al., 2005).

The quality of humus (determined as HA/FA ratio) increased with depth in each profile studied (Table 1). The most favourable humus quality in A horizon was found under M (0.92), whereas HA/FA ratios in A horizons under DS and CS were the same (0.53) (Table 4). In terms of HA/FA ratios determined for the whole soil profile, it is evident that the highest humus quality was in the meadow soil (HA/FA = 3.20) (Table 2). Interestingly, the average humus quality in the whole soil profile was higher in CS sites (0.95) than that under DS sites (0.77), which is in agreement with the report published by Lesna and Kulhavy (2003) who also found higher HA/FA ratio under coniferous Norway spruce compared to European beech. However, degrees of humification were higher under beech, and color quotient $Q_{4/6}$ showed that HA of the beech stand was more condensed and therefore of higher quality than of spruce stand.

The amount of microbial biomass carbon (C_{mic}) had a similar declining tendency with depth as it was in the case of organic carbon, but not in all experimental sites. The highest amounts of C_{mic} were in the Oo horizons within all experimental sites, but mainly in meadow and oak soils (1,083.28 and 1,039.25 mg kg^{-1}, respectively) in comparison to the other experimental sites (Table 1). The amount of C_{mic} in this layer followed the order meadow > oak > spruce > yew > sugar maple > cherry laurel > fir > cedar > pine. Similar values for the upper soil layers (up to 0.1 m) in grassland and oak soils were also reported in a study by Ananyeva et al. (2008). Despite the high C_{org} content and its water-extractable fraction in Oo horizons of two coniferous species (pine and cedar), the last were characterized by the lowest C_{mic} contents (101.81 mg kg^{-1} and 109.92 mg kg^{-1}, respectively) (Table 1). Presumably, the composition of extractable carbon compounds was not favourable for microbial utilization, although, according to Smolander and Kitunen (2002), soil microbial biomass and activities appeared to be more correlated with a total concentration of dissolved organic carbon than with its characteristics. Evaluation of C_{mic} in A horizons (Table 3) showed the highest microbial biomass C content in oak soil (1,336.60 mg kg^{-1}), despite the fact that the oak leaf litter is slower-decomposed by microorganisms due to high lignin and tannin content than eg grassland litter (Waldrop and Firestone, 2004) and/or sugar maple leaf litter (Myers et al., 2001).Our results are in accordance with the results of previous studies carried out in different types of forest ecosystems (Bauhus et al., 1998; Priha et al., 2001; Priha et al., 1999; Smolander et al., 2002), although in most of the studies mentioned, the deciduous stands were represented by birch not by oak. According to a study by Hackl et al. (2000), C_{mic} content may differ under the same tree species growing on soil types differing in their chemical characteristics (soil moisture, pH, N_t etc.).

The proportion of microbial biomass carbon of the total organic carbon is generally considered as a sensitive indicator of changes in soil organic matter quality (Anderson et al., 1989; Lavahun et al. 1996; Sparling, 1992; Stevlikova et al., 2003). By comparing the A horizons between the individual trees, the highest and the lowest values of C_{mic}/C_{org} were found under coniferous – spruce and cedar (3.04% and 0.39%, respectively) (Table 1). On contrary, other authors (Bauhus et al., 1998; Smolander et al., 2002) found higher C_{mic}/C_{org} proportion under birch (2.5%) than under spruce and pine (2.0 and 1.7%, respectively). Dyckmans et al. (2003) specified that in forest (n = 27), grassland (n = 32) and arable (n = 39) soils located in Northern Germany, the C_{mic}/C_{org}

Table 2. Chemical and microbial characteristics of soil profiles. Means of whole soil profiles at the studied sites for each type of ecosystem (coniferous forest, deciduous forest and meadow). Different superscripts indicate that the values are significantly different between the sites at $P < 0.01$

Type of ecosystem	pH_{KCl}	C_{org} [%]	HA/FA	C_{hwe} [mg kg^{-1}]	C_{mic} [mg kg^{-1}]	DHA [µgTPF g^{-1} dry soil mass h^{-1}]
Conifers	4.43[a]	1.76[a]	0.95[a]	580[a]	255.68[a]	2.03[a]
Deciduous	3.91[b]	1.97[a]	0.77[b]	630[a]	447.36[b]	5.19[b]
Meadow	4.88[a]	1.33[a]	3.20[c]	420[a]	583.02[b]	4.80[b]

C_{org}, total organic carbon; HA/FA, humic to fulvic acids ratio; C_{hwe}, hot water extractable carbon; C_{mic}, microbial biomass carbon; DHA, dehydrogenase activity proportion (FE-method) in the 0–10 cm layer varied from 0.3% to 4.3% with an average of 1.5%. Simek and Santruckova (2002) stated that C_{mic}/C_{org} proportion is higher in less fertile soils with low C_{org} content. In most sites the C_{mic}/C_{org} proportion increased with depth. This tendency was most obvious under the fir cover where C_{mic}/C_{org} in Btg horizon reached 28.8%, while under cherry laurel it was 13.02%, and under the meadow 8.7% (Table 1). Increasing tendency of C_{mic}/C_{org} ratio with depth indicates a more intensive decline of organic matter than microbial biomass with depth of soil profile (Table 1). This tendency was less evident under the meadow. We suppose that the high microbial colonization and thus lower C_{mic}/C_{org} proportions in Btg horizon under the meadow occurred due to abundant susceptible organic matter that could be transported from upper to lower soil horizons by percolating water in ilimerization process, which was the most evident under the abovementioned experimental site. In other study (Ananyeva et al., 2008), however, the C_{mic}/C_{org} values in natural ecosystems were higher in the 0–0.05 m than in 0.05–0.1 m soil layer.

The dehydrogenase activity (DHA) was 2- or 3-times higher under the deciduous tree species and the meadow than that under the coniferous trees. Significant differences in DHA were observed amongst the humus layers and also amongst the average values of DHA across entire soil profiles (Tables 2, 4). In general, the highest DHA was found in litter layers in all experimental sites except of fir (Table 1). DHA, C_{mic} as well as C_{org} showed a similar tendency within soil profile, ie all characteristics declined with depth.

We can conclude that all the parameters investigated (C_{org}, C_{hwe}, C_{mic} and DHA) showed to be influenced by both plant cover and soil depth. In general, except DHA under fir, all parameters were the highest in the organic horizons and decreased with depth. The contents of C_{org} and C_{hwe} in organic horizons were higher for coniferous soils than those measured in deciduous soils. On the other hand, biological characteristics determined in this layer (C_{mic} and DHA) were higher in DS than in CS. A horizons showed higher average C_{org}, C_{hwe}, C_{mic} and DHA in DS in comparison to CS. Also, the average proportion C_{hwe} of C_{org} in A horizons was higher in DS (about 4%) than those in CS (over 3%), or as high as in M (3.16%). On contrary, the average C_{mic}/C_{org} proportion was higher in M soil (6.13%) compared to DS (2.18%) and CS (1.35%). In most cases the proportion of C_{mic}/C_{org} as well as C_{hwe}/C_{org} tended to be higher with increasing depth. The most favourable

Table 3. Chemical and microbial characteristics of humus horizons at the studied sites. Different superscripts indicate that the values are significantly different between the sites at $P < 0.01$

Tree species	pH_{KCl}	C_{org} [%]	HA/FA	C_{hwe} [mg kg^{-1}]	C_{mic} [mg kg^{-1}]	DHA [μgTPF g^{-1} dry soil mass h^{-1}]
Spruce	3.45^{a}	1.48^{a}	0.53^{a}	230^{a}	450.24^{a}	3.95^{a}
Fir	5.80^{b}	2.91^{b}	nd	1,030^{b}	392.35^{b}	4.28^{b}
Yew	3.90^{c}	2.11^{c}	0.39^{b}	700^{c}	318.42^{c}	2.25^{c}
Pine	4.85^{d}	1.59^{d}	0.61^{c}	480^{d}	72.50^{d}	2.53^{c}
Cedar	3.63^{e}	1.12^{e}	0.61^{c}	400^{e}	43.96^{e}	0.85^{d}
Oak	4.50^{f}	4.89^{f}	0.45^{d}	1,050^{f}	1,336.60^{f}	10.96^{e}
Sugar maple	3.80^{g}	2.22^{g}	0.61^{c}	910^{g}	338.62^{g}	6.96^{f}
Cherry laurel	4.10^{h}	1.89^{h}	0.52^{a}	840^{h}	428.87^{h}	5.95^{g}
Meadow	5.38^{i}	1.31^{i}	0.92^{e}	410^{d}	803.96^{i}	6.60^{h}

Abbreviations see Table 2

Table 4. Chemical and microbial characteristics of humus horizons at the studied sites for each type of ecosystem (coniferous forest, deciduous forest and meadow) – mean values. Different superscripts indicate that the values are significantly different between the sites at $P < 0.01$

Type of ecosystem	pH_{KCl}	C_{org} [%]	HA/FA	C_{hwe} [mg kg^{-1}]	C_{mic} [mg kg^{-1}]	DHA [μgTPF g^{-1} dry soil mass h^{-1}]
Conifers	4.33^{a}	1.84^{a}	0.53^{a}	570^{a}	255.49^{a}	2.48^{a}
Deciduous	3.95^{b}	3.00^{b}	0.53^{a}	930^{b}	701.30^{b}	7.96^{b}
Meadow	5.38^{c}	1.31^{a}	0.92^{b}	410^{a}	803.96^{b}	6.60^{b}

Abbreviations see Table 2

humus quality in A horizon was found under meadow (0.92), whereas HA/FA ratios in A horizons were the most favourable under deciduous and coniferous were the same (0.53).

Acknowledgement

We are grateful to the staff of the Department of Pedology and Geology at the Slovak University of Agriculture for their help with soil sampling. This work was funded by the Scientific Grant Agency of Ministry of Education of the Slovak Republic – grant number 1/1279/04 and 1/4406/07.

References

Ananyeva, N.D., Susyan, E.A., Chernova, O.V., Wirth, S. 2008. Microbial respiration activities of soil from different climatic regions of European Russia. *Eur. J. Soil Biol.,* 44: 147–157.

Anderson, T.H., Domsch, K.H. 1989. Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biol. Biochem*., 21: 471–479.

Arinushkina, E.V. 1961. *Praktikum po chimii počvy* [Guidance for soil chemical analysis]. Moskva: Izdateľstvo Moskovskogo universiteta.

Bauhus, J., Paré, D., Côté, L. 1998. Effect of tree species, stand age and soil type on soil microbial biomass and its activity in southern boreal forest. *Soil Biol. Biochem*., 30: 1077–1089.

Casida, L.E., Klein, D.A., Santoro, T. 1964. Soil dehydrogenase activity. *Soil Sci.,* 98: 371–376.

Dyckmans, J., Chander, K., Joergensen, R. G., Priess, J., Raubuch, M., Sehy, U. 2003. Adenylates as an estimate of microbial biomass C in different soil groups. *Soil Biol. Biochem*., 35: 1485–1491.

Hackl, E., Bachmann, G., Zechmeister-Boltenstern S. 2000. Soil microbial biomass and rhizosphere effects in natural forest stands. *Phyton,* 40: 83–90.

Harris, M.M., Safford, L.O. 1996. Effect of season and four tree species on soluble carbon content in fresh and decomposing litter of temperate forests. *Soil Sci.,* 161: 130–135.

Hongve, D. 1999. Production of dissolved organic carbon in forested catchments. *J. Hydrol*., 224: 91–99.

Hrubik P., Tomasko I., Hotka P., Kuba J. 2006. Klimatické podmienky Arboréta vo vzťahu k introdukovaným drevinám [The climatic conditions of the Arboretum Mlynany SAS in relation to the introduced woods]. In Mňahončáková, E., Baruszová, N. (eds). *Sídlo, park, krajina. Zborník vedeckých prác a referátov z konferencie s medzinárodnou účasťou a 11. kolokvia katedier krajinárskej a záhradnej tvorby Nitra, 22. november 2006, časť IV.* Nitra: Slovenská poľnohospodárska univerzita, p. 148–161. (CD).

ISSS-ISRIC FAO 1994. *World Reference Base for Soil Resources, Draft*. Wageningen, Rome: 161 p.

Jandl, R., Sollins, P. 1997. Water extractable carbon in relation to below-ground carbon cycle. *Biol. Fertil. Soils,* 25: 196–201.

Körschens, M., Schulz, E., Behm, R. 1990. Heisswasserlöslicher C und N im Boden als Kriterium für das N-Nachliferungsvermögen. *Microbiology,* 145: 305–311.

Kononova, M., Belchikova, N.P. 1961. Uskorennyje metody opredelenija sostava gumusa [Short methods for determining humus quality]. *Počvovedenie*, 125–129.

Lavahun, M.F.E., Joergensen, R.G., Meyer, V. 1996. Activity and biomass of soil microorganisms at different depths. *Biol. Fertil. Soils*, 23: 38–42.

Lesna, J., Kulhavy, J. 2003. Evaluation of humus conditions under different forest stands: beech vs. spruce dominated forest stand. *Ekológia (Bratislava*), 22, Suppl., 3: 47–60.

Myers, R. T., Zak, D. R., White, D. C, Peacock, A. 2001. Landscape – level patterns of microbial community composition and substrate use in upland forest ecosystems. *Soil Sci. Soc. Amer. J.,* 65: 359–367.

Priha, O. 1999. *Microbial activities in soils under Scots pine, Norway spruce and silver birch.* PhD thesis. Helsinki: University of Helsinki. 50 p.

Priha, O., Grayston, S.J., Hiukka, R., Pennanen, T., Smolander, A. 2001. Microbial community structure and characteristics of the organic matter in soils under Pinus sylvestris, Picea abies and Betula pendula at two forest sites. *Biol. Fertil. Soils,* 33: 17–24.

Priha, O., Grayston, S.J, Pennanen, T., Smolander, A. 1999. Microbial activities related to C and N cycling and microbial community structure in the rhizospheres of Pinus sylvestris, Picea abies and Betula pendula seedlings in an organic and mineral soil. *Microb. Ecol*., 30: 187–199.

Priha, O., Smolander, A. 1996. Microbial biomass and activity in soil and litter under Pinus sylvestris, Picea abies and Betula pendula at originally similar field afforestation sites. *Biol. Fertil. Soils,* 24: 45–51.

Seneviratne, G. 2000. Litter quality and nitrogen release in tropical agriculture: a synthesis. *Biol. Fertil. Soils,* 31: 60–64.

Simek, M., Santruckova, H. 2002. Are characteristics of microbial society good indicator of soil quality? In *Biological indicators of soil quality*. Brno: MZLU, p. 32–41.

Skobla, J., Kovac, J. 1967. *Pedologický prieskum ČSSR* [Pedological survey of the ČSSR]. Vieska nad Žitavou: Roľnícke družstvo. 19 p.

Smolander, A., Kitunen, V. 2002. Soil microbial activities and characteristics of dissolved organic C and N in relation to tree species. *Soil Biol. Biochem*., 34: 651–660.

Sparling, G.P. 1992. Ratio of microbial biomass carbon to soil organic C as a sensitive indicator of changes in soil organic matter. *Austral. J. Soil Res.*, 30: 195–207.

Statgraphics, Ver. 5. 1991. Rockville, MD: STSC, Inc.

Steinhübel, G. 1957. *Arborétum Mlyňany v minulosti a dnes* [Arboretum Mlynany in the past and in present]. Bratislava: Slovenská academia vied. 145 p.

Stevlikova, T., Vjatrakova, J., Javorekova, S., Mateova, S. 2003. Effect of land management without farmyard manure application on the amount and the activity of soil microbial biomass. *Pl. Soil Envir.*, 49: 352–358.

Szombathova, N., Zaujec, A., Labudova, S., Labuda, R. 2005. Soil organic matter quality and quantity in Nature Reserve Arboretum Mlynany. In Zaujec, A., Bielek, P., Gonet, S. S. (eds). *Humic substances in Ecosystems 6.* Nitra: Slovenská poľnohospodárska univerzita, p. 181–185.

Szombathova, N., Labudova, S., Labuda, R., Konôpková, J. 2006. The influence of different vegetation on soil chemical properties in Arboretum Mlyňany. *Folia oecol.*, 33: 41–47.

Szombathova, N., Zaujec, A., Labudova, S., Labuda, R. 2008. Soil properties under different vegetation types in the Arboretum Mlyňany. *Folia oecol.*, 35: 51–59.

Vance, E.D., Brookes, P.C., Jenkinson, D.S. 1987. An extraction method for measuring soil microbial biomass. *Soil Biol. and Biochem.*, 19: 703–707.

Wagai, R., Sollins, P. 2002. Biodegradation and regeneration of water-soluble carbon in a forest soil: leaching column study. *Biol. Fertil. Soils,* 35: 18–26.

Waldrop, M. P., Firestone, M. K. 2004. Microbial community utilization of recalcitrant and simple carbon compounds: impact of oak-woodland plant communities. *Oecologia,* 138: 275–284.

Zechmeister-Boltenstern, S., Hackl, E., Bachmann, G., Donat, C. Pfeffer, M. 2000. Microbial nutrient turnover in forests with natural tree species composition. In Hasenauer, H. (ed.). *Forest ecosystem restoration: ecological and economical impacts of restoration processes in secondary coniferous forests. Proceedings of the international conference held in Vienna, Austria 10.–12. April, 2000*. Wien: Univ. of Agricultural Sciences, Inst. of Forest Growth Research, p. 296–390.

Distribúcia organického uhlíka, uhlíka mikrobiálnej biomasy a enzymatickej aktivity v profile hnedozeme pod rôznymi druhmi drevín

Súhrn

Zisťovali sme vplyv rôznych druhov listnatých a ihličnatých drevín (pôvodných aj introdukovaných) na chemické vlastnosti pôdy (pH, kvalitu humusu, celkový obsah organického uhlíka (C_{org}), v horúcej vode extrahovateľného uhlíka (C_{hwe}), uhlíka mikrobiálnej biomasy (C_{mic}) a dehydrogenázovú aktivitu pôdy (DHA) v Prírodnej rezervácii Arborétum Mlyňany. Pôdne profily deviatich stanovíšť boli reprezentované tromi druhmi listnatých drevín (dub cerový, javor cukrový a vavrínovec lekársky), piatimi druhmi ihličnanov (smrek obyčajný, tis obyčajný, kryptoméria japonská, borovica himalájska a jedľa srienistá), a jedným lúčnym porastom (kontrolný variant). Zistili sme, že rastlinný kryt ovplyvnil všetky skúmané pôdne vlastnosti. V humusových (A) horizontoch boli hodnoty C_{org}, C_{hwe}, C_{mic} a DHA vyššie pod porastmi listnatých drevín (DS) v porovnaní s ihličnatými (CS). Priemerné zastúpenie C_{hwe}/C_{org} v A horizontoch bolo väčšie v DS (okolo 4 %) ako CS (nad 3 %), čo bolo porovnateľné aj s lúčnym porastom (3,16 %). Najvyššie priemerné zastúpenie C_{mic}/C_{org} bolo zistené v pôde pod lúčnym porastom (6,13 %) v porovnaní s DS (2,18 %) a CS (1,35 %). Vo väčšine stanovíšť sa zastúpenie C_{mic}/C_{org} rovnako ako C_{hwe}/C_{org} zvyšovalo s hĺbkou, čo poukazuje na intenzívnejší pokles pôdnej organickej hmoty ako mikrobiálnej biomasy. Najvyššiu kvalitu humusu (určenú ako pomer HK/FK) v A horizontoch sme zistili pod lúčnym porastom (0,92), kým kvalita humusu pod porastom listnatých a ihličnatých drevín bola rovnaká (0,53).

Received July 14, 2009
Accepted August 31, 2009