FOLIA OECOLOGICA – vol. 42, no. 1 (2015). ISSN 1336-5266

The changes of nutrient and risk elements of top soil layers under canopy of different tree species and grassland in Arboretum Mlyňany, Slovakia

Nora Polláková[1], Vladimír Šimanský[2], Otto Ložek[3], Eva Hanáčková[4], Eva Candráková[5]

[1]Department of Soil Science and Geology, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2,
949 76 Nitra, Slovak Republic, e-mail: nora.pollakova@uniag.sk
[2]Department of Soil Science and Geology, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2,
949 76 Nitra, Slovak Republic, e-mail: vladimir.simansky@uniag.sk
[3]Department of Agrochemistry and Plant Nutrition, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2,
949 76 Nitra, Slovak Republic, e-mail: otto.lozek@uniag.sk
[4]Department of Agrochemistry and Plant Nutrition, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2,
949 76 Nitra, Slovak Republic, e-mail: eva.hanackova@uniag.sk
[5]Department of Plant Production, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra,
Slovak Republic, e-mail: eva.candrakova@uniag.sk

Abstract

Polláková, N., Šimanský, V., Ložek, O., Hanáčková, E., Candráková, E., 2015. The changes of nutrient and risk elements of top soil layers under canopy of different tree species and grassland in Arboretum Mlyňany, Slovakia. *Folia Oecologica*, 42: 29–34.

Litter represents the input-output system of nutrients in forests. Since the aim of study was to extent the knowledge of nutrient and risk elements cycling in the Arboretum Mlyňany (Slovak Republic), we investigated the contents of selected elements in the litter of tree species and grassland, and compared them with the contents of elements in the surface soil layers (0–10 cm). Results showed that the richest on N, P, K macro-elements were sod of grass, rich was litter of maple, oak and surprisingly also yew. The correlation between quantity of exchange calcium, magnesium, total nitrogen, available phosphorus, potassium, copper and iron in the surface soil layers and litters was not significant. On the contrary, statistically significant correlations were found in case of zinc and manganese in litter and their available ions in the surface soil layers (Zn: $r = 0.884$, $P < 0.001$; Mn: $r = 0.501$, $P < 0.05$). Limit values of available cadmium and zinc content were exceeded in the soil for yews, Cd for Himalayan pines and lead for spruces. Higher contents of mentioned heavy metals in soil were attributed to bioaccumulation, as well as to atmospheric deposition.

Keywords
grassland, heavy metals, litter, nutrients, soil, tree species

Introduction

Litter plays a key role in the forest life and forest soil as natural fertilizer. In forests, the amount of litter depends on the tree species composition, age, canopy and quality. At the same stand, the biomass of litter can be year to year different with even double variations (Šály, 1982). For example annual influx of elements with beech litterfall to the soil in Middle Pomerania (Poland) was: 23.2–61.0 kg ha^{-1} of nitrogen, 3.6–7.6 kg ha^{-1} of phosphorus, 8.3–26.2 kg ha^{-1} of potassium and 15.3–22.4 kg ha^{-1} of calcium (Jonczak, 2013).

During decomposition of plant material, part of the nutrient elements are liberated in inorganic dissolved form, for instance as the ions (Ca^{2+}, Mg^{2+}, K^+, NH_4^+, SO_4^{2-}, $H_2PO_4^-$). In soils of humid areas, dissolved nutrients tend to migrate down the soil profile. Under vegetation, the larger part of those nutrients is usually taken up again by plant roots and assimilated by the vegetation, and only a small fraction is lost with the drainage water. An actively growing, closed vegetation may take up several hundreds kg of nutrient elements per ha per year from the root zone, which often extends to several metres below the soil surface. Most nutrients in plants are eventually returned to the soil surface by litter fall. So the net effect of uptake by plants is that nutrients from deeper soil layers are transported to the soil surface. Part of the nutrients in the surface soils is easily available to plants (at the exchange complex or temporarily stored in microbial biomass), but part may be locked up in slowly available mineral form (especially P). This process of "nutrient pumping", which counteracts the leaching of nutrients, is especially important in mature, undisturbed forests (van Breemen and Buurman, 2003).

Up to 70–90% nutrients annually needed for forest growth are released by decomposition of organic detritus. During these processes, nutrients are preserved through their retranslocation and immobilization in order to maintain the productivity of ecosystem (Vogt et al., 1986). The contents of nutrients in soil positively correlate with litter substrate quality, showing that higher contents of soil nutrient are accompanied with good quality of litter substrate, and lower soil nutrients with poor litter quality (Ge et al., 2013).

In order to better know the cycle of nutrients and other risk elements in Arboretum Mlyňany, we investigated the contents of selected elements in litter of tree species and grassland and compared them with contents of elements in surface soil layers.

Material and methods

Study site

Arboretum Mlyňany (48º19'N and 18º21'E) is located in southern Slovakia on the north edge of the Danubian Lowland, in the valley of the Žitava river, on slightly undulated terrain, at an altitude of 165–217 m above sea level. It is situated on a late Tertiary geological formation, represented by Neogene clays, sands and rubble sands. This substratum is almost all covered by wind-deposited loess, mostly without carbonates (Cifra, 1958). Mean temperature in the area is 10.6 °C and mean annual total precipitation is 541 mm (Hrubík et al., 2011). Arboretum in Mlyňany was established in 1892. Recent inventory of the gene pool of trees and shrubs finished in 2012 showed, that the current number of taxa grown in the Arboretum is 1,933 (Hoťka et al., 2013).

Soil sampling

Elemental composition of litter and the contents of elements in soil depth 0–10 cm were investigated under canopy of tree species: natural oak-hornbeam stand (*Quercus robur,* L., *Carpinus betulus*, L.), spruce (*Picea abies,* (L.) Karsten), sugar maple (*Acer saccharinum,* L.), yew (*Taxus baccata,* L.), cherry laurel (*Prunus laurocerasus,* L.), Himalayan pine (*Pinus wallichiana,* Jacks.), Japanese cedar (*Cryptomeria japonica,* D. Don.) and grassland.

Soil and litter samples were taken in autumn 2005.

Soil and litter analyses

- Ca, Mg, Fe, Zn, Mn, Cu in dry litter was analysed by atomic absorption spectrophotometer;
- Total organic carbon content in soil and dry litter – by Tyurin method (Orlov and Grishina, 1981), total nitrogen by Kieldahl method (Fecenko, 1991);
- Soil exchange base cations (Ca^{2+}, Mg^{2+}) by extraction with ammonium acetate (Hrivňáková et al., 2011) available phosphorus and potassium in soil by method of Mehlich III (Mehlich, 1984), potentially available forms of heavy metals in soil (Cu, Zn, Cr, Pb, Cd, Ni, Fe, Mn, Co) (extraction by 2 mol dm^{-3} HNO_3) (Hrivňáková et al., 2011).

Each analysis was done in 3 repeats. Results shown in Tables 1 and 2 represent the average values (mean ± SD). Correlation analysis was used for determination the relationship between elements in the soil and litter. Statistical significance of results was assessed on minimum 95% level.

Results and discussion

Litter represents the input-output system of nutrients in forests. The rate, at which litter accumulates and decomposes, regulates the flow of energy, primary productivity and nutrient cycling in forest ecosystem.

Contents of basic macro-elements (carbon, nitrogen, phosphorus, potassium, calcium, magnesium) and microelements (iron, zinc, manganese, copper) in dry litter are shown in Table 1. The results indicate that the richest on N, P, K macro-elements was sod of grass, whereas other macro- and microelements it contained less. Rich on macro-elements was also litter of maple, oak and surprisingly also yew. Litter of Japanese cedars was characterized by a high content of calcium and that of cherry laurels had high content of magnesium. Compared to other tree species and grassland, the highest content of microelements as iron, zinc and manganese was found in the litter of yew.

Furthermore, in the litter of trees and grasses was evaluated also relative proportion of carbon and nitrogen (Table 1). Generally, C:N ratio significantly affects the rate of organic matter decomposition. The narrower the ratio is, the faster the organic matter decomposes, because contains more N available to microorganisms (Bottner et al., 2006; Gonet and Markiewicz, 2007; Gonet et al., 2008; Ondrišík, 2013) and sup-

Table 1. Content (means ± SD) of selected elements in litter of dry leaves and needles

Stand	C	N	C/N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
	(g kg^{-1})			(g kg^{-1})						(mg kg^{-1})	
1 grassland	507.00	22.59	22.44	2.58	16.49	3.52	3.10	0.32	0.04	7.04	47.34
	±13.29	±0.46		±0.07	±0.11	±0.10	±0.03	±0.00	±0.00	±0.10	±0.49
2 spruces	558.47	12.33	45.31	1.53	5.47	9.58	1.81	0.24	1.13	3.94	40.44
	±17.48	±0.30		±0.11	±0.06	±0.45	±0.01	±0.01	±0.04	±0.08	±0.32
3 oaks-hornbeams	515.10	14.18	36.33	1.66	8.58	12.00	2.94	0.27	2.34	7.30	31.68
	±9.06	±0.13		±0.08	±0.12	±0.32	±0.06	±0.00	±0.01	±0.55	±0.64
4 maples	521.80	13.23	39.43	2.90	7.75	14.41	4.22	0.21	1.12	9.92	129.65
	±20.14	±0.19		±0.14	±0.03	±0.66	±0.10	±0.00	±0.01	±0.37	±2.60
5 yews	548.45	14.44	37.98	1.53	8.20	15.65	3.07	1.40	2.05	5.35	221.86
	±11.02	±0.06		±0.07	±0.05	±0.14	±0.07	±0.01	±0.05	±0.12	±9.76
6 cherry laurels	507.83	9.95	51.05	0.99	4.51	29.71	4.40	0.70	1.57	4.07	70.06
	±7.72	±0.13		±0.02	±0.03	±2.23	±0.12	±0.01	±0.03	±0.11	±2.30
7 pines	602.36	8.54	70.54	0.93	2.22	11.59	1.54	0.62	0.08	3.82	69.66
	±5.46	±0.06		±0.02	±0.03	±0.25	±0.03	±0.01	±0.00	±0.38	±3.80
8 cedars	564.16	5.48	102.92	0.98	1.70	34.94	4.13	0.64	0.27	3.72	47.57
	±5.79	±0.15		±0.07	±0.01	±1.25	±0.11	±0.00	±0.01	±0.09	±0.87

Table 2. Content (means ± SD) of total carbon and nitrogen, available phosphorus and potassium, exchange calcium and magnesium and potentially available forms of selected elements (Fe, Mn Cu, Zn, Cd, Pb, Ni, Co, Cr) in the 0–10 cm soil layer

Stand	C_T	N_T	C_T/N_T	P	K	Ca^{2+}	Mg^{2+}	Fe	Mn	Cu	Zn	Cd	Pb	Ni	Co	Cr
	(g kg^{-1})			(mg kg^{-1})												
1 grassland	22.47	2.49	9.04	10.33	168.17	2,320	1,568	1,653	243.44	3.68	5.34	0.19	12.71	1.30	3.70	1.79
	±0.59	±0.13		±0.36	±3.61	±33.26	±14.00	±50.12	±12.29	±0.11	±0.08	±0.01	±0.15	±0.07	±0.07	±0.06
2 spruces	22.97	2.07	11.10	13.87	173.33	1,678	404	1,591	119.77	2.90	6.22	0.06	37.61	1.93	2.59	1.60
	±1.01	±0.05		±0.84	±2.08	±23.29	±2.08	±18.73	±4.04	±0.24	±0.18	±0.00	±1.25	±0.08	±0.13	±0.05
3 oaks-hornbeams	30.60	2.01	15.20	60.33	193.33	1,814	1,776	1,831	350.96	4.12	8.96	0.09	17.49	2.62	2.78	1.86
	±0.62	±0.04		±1.73	±3.06	±35.30	±18.19	±48.22	±3.61	±0.26	±0.34	±0.00	±0.30	±0.08	±0.12	±0.09
4 maples	28.70	2.99	9.60	12.00	265.17	2,106	848	1,850	245.38	7.47	9.69	0.22	11.90	4.40	2.84	1.61
	±1.23	±0.12		±0.40	±4.36	±54.34	±12.77	±57.09	±6.56	±0.17	±0.42	±0.01	±0.37	±0.16	±0.10	±0.04
5 yews	21.00	1.94	10.85	53.87	402.83	2,214	1,392	1,980	448.16	6.28	157.01	0.48	16.08	4.08	3.32	1.29
	±0.95	±0.08		±1.36	±8.08	±13.11	±11.02	±22.54	±9.17	±0.41	±7.31	±0.01	±0.37	±0.23	±0.08	±0.03
6 cherry laurels	29.70	2.09	14.23	10.00	97.87	2,000	992	1,395	510.33	5.78	8.44	0.24	13.40	5.26	5.88	1.68
	±1.37	±0.11		±0.59	±0.58	±39.89	±9.61	±35.17	±9.50	±0.44	±0.23	±0.01	±0.25	±0.16	±0.10	±0.06
7 pines	26.40	1.66	15.88	14.00	188.00	3,494	1,456	1,810	345.84	7.62	9.34	0.31	12.40	5.60	6.28	3.12
	±1.06	±0.03		±0.87	±2.08	±38.68	±10.54	±56.96	±8.54	±0.13	±0.36	±0.01	±0.14	±0.10	±0.12	±0.14
8 cedars	24.33	2.36	10.32	13.83	314.83	2,906	1,184	1,215	170.15	6.92	9.02	0.16	12.20	2.68	3.50	1.69
	±0.75	±0.12		±0.59	±5.57	±10.58	±17.09	±18.52	±8.72	±0.36	±0.21	±0.01	±0.18	±0.12	±0.11	±0.06

ports the microbial activity (Pengthamkeerati et al., 2011). Faster decomposition of organic matter means faster nutrient cycling in the environment (Sariyildiz et al., 2005). Among studied stands in Arboretum, the narrowest C : N ratio was determined in the sod of grassland (22.4 : 1), then in the litter of oak, yew, maple, spruce, cherry laurels, Himalayan pine and litter from Japanese cedars which overall had the widest C : N ratio (102.9 : 1). The reason of the wide C : N ratio was the fact that Japanese cedar does not throw down individual needles, but gradually, after drying, breaks off small twigs with needles. Therefore, under Japanese cedars the litter contained more twigs than other stands.

Moore et al. (2006) stated that C : N ratio, when there begins the release of nitrogen from litter usually refers to a certain "critical" C : N (25–30), respectively to initial concentration of N in litter 20 g kg^{-1} as threshold for net accumulation or net release of nitrogen. Similar results were reached by Vahdat et al. (2011) who moreover considered also the quality of C and N constituents of litter. They found that the critical levels of N concentration, C : N ratio, lignin and lignin:N ratio of the plant residues at which neither N mineralization nor immobilization would occur were 10.8 g kg^{-1}, 30.7, 253.5 g kg^{-1} and 17.0, respectively. In a multiple model, lignin concentration of the plant residue was the most important factor for predication the net effects of plant residue on soil mineral N dynamics. Generally, lignin physically protects most of the cellulose and hemicellulose from enzymatic hydrolysis. Also Jonczak (2009) confirmed that the different rate of poplar leaves decomposition depended on different chemical composition of the initial material, which depended on age of poplars. Lignin content correlated with the age of poplars, and its proportion decreased with the age of trees.

According to Vogt et al. (1986) about 70–90% of nutrients annually needed for forest growth are provided by decomposition of organic detritus. Therefore, we wanted to determine whether the concentration of total nitrogen, available macro-elements (P, K) and exchange cations (Ca^{2+}, Mg^{2+}) in the surface soil layer in Arboretum Mlyňany was influenced by the contents of these elements in litter. In the past, the soil in the Arboretum was enriched by nutrients released from manure which was regularly supplied to the soil. Whereas since 1965 fertilizers have not been used, it is evident that the majority of mentioned macro-nutrients (N, P, K, Ca, Mg) comes from decomposed litter. Obtained results showed that between the content of available macro-nutrients in the surface soil layer (0–10 cm) and their content in dry litter was not found any statistically significant correlation (N: $r = 0.269$, $P > 0.05$; P: $r = –0.062$, $P > 0.05$; K: r = –0.080, $P > 0.05$; Ca: $r = 0.179$, $P > 0.05$; Mg: $r = –0.046$; $P > 0.05$). The reason could be different rate of nutrients release from the studied litters. For instance, Blair (1988) found that the sequence of release five examined elements was K > Mg > Ca > P > N, whereas Liao et al. (2006) found the sequence: C > Ca > N > K > Mg > Na > P, and stated, that the above sequence of nutrients returned from leaf litter differed from the quantity sequence of these nutrients in the soils indicating that the nutrient status of the forest floor was also impacted by atmospheric deposition, throughfall, stemflow, microbial activities, runoff, erosion, leaching processes and other edaphic factors in the study area. On the base of this statement we conclude that the macro-elements content in the 0–10 cm soil layer of Arboretum Mlyňany in addition to chemical composition of litter was also influenced by other biotic and abiotic conditions, therefore the correlation between macro-elements in the litter and in 0–10 cm soil layer was not found.

Higher quality of grass litter was evident not only from their narrowest C : N ratio, but also from the narrowest ratio of total carbon (C_T) and nitrogen (N_T) in the surface soil layer (0–10 cm) as compared with soil under canopy of tree species (Tables 1–2). Obtained results showed, that differences in $C_T : N_T$ ratios in the soils between studied stands were not so marked as differences in C : N ratios between investigated litters. The same was confirmed by Šimková et al. (2014) who studied the accumulation of C_T and N_T in surface humus and mineral soil layers after the change of tree species composition in nudal beech forests.

Since, in addition to macro-elements, from the decomposed litter are released to the soil also micro-elements we examined, whether the amount of available micro-elements copper, zinc, manganese and iron in the surface soil layer in Arboretum was influenced by the contents of these elements in litter (Tables 1–2). From the results it follows, that statistically significant correlations were found between the amount of zinc, manganese in litter and their available ions in the soil (Zn: $r = 0.884$; $P < 0.001$; Mn: $r = 0.501$, $P < 0.05$), while for copper and iron such correlation was not found (Cu: $r = 0.030$; Fe: $r = 0.160$, $P > 0.05$).

Under studied canopy of tree species and grassland, in the upper soil layer (0–10 cm) was also investigated the content of available heavy metals (Table 2). It was found that the limit values according to *Decree of MA SR 531/1994/540* (1994) for cadmium (0.3 mg kg^{-1}) and zinc (40 mg kg^{-1}) have been exceeded for yews, Cd for Himalayan pines and lead (30 mg kg^{-1}) for spruces. In other stands, the limit values were not exceeded despite the fact that in the soil prevailed acidic pH when heavy metals are mostly in available forms (Kabata-Pendias and Pendias, 1984; Čurlík, 2011).

Actually, the limit values for Cd were exceeded in two stands (Table 2). Forest soils well accumulate cadmium, which in turn negatively affects the growth of trees and reduces their dry matter weight (Tomáš et al., 2007). Cadmium belongs to the most toxic heavy metals and has a high mobility in the soil-plant system (Čurlík, 2011). Zinc is an important microelement for plant physiology and its deficiency causes growth problems. On the other hand, in acidic soils Zn can manifest increased availability and even toxicity (Alloway and Ayres, 1997).

Considering available lead, Novák et al. (2010) stated that the heartwood of spruce had a high permeability, moisture contents and number of rings in sapwood, which could be subjected as geochemical archive of pollution. Also, results of our research in Arboretum confirmed that spruces considerably absorb Pb. The content of available Pb was in 0–10 cm soil layer under spruces on average up to three times higher compared with other tree species (Table 2).

Higher contents of available Cd, Zn and Pb in soil under certain trees in Arboretum Mlyňany were attributed to bioaccumulation (uptake by root system from deeper soil layers and their accumulation from decomposed litter), as well as by atmospheric deposition. It is known that crowns of trees have great filtration capacity and large surface area of their vegetation bodies (10 or more ha per 1 ha of forest area) through which they capture and eliminate considerable quantities of air pollutants (Bublinec, 2000). Thus the trees substantially contribute to air cleaning and recovery, therefore, it is necessary to protect and thoroughly take care of them.

Conclusions

The correlation between the content of macro-elements (N, P, K, Ca, Mg) in the litter and in 0–10 cm soil layer of Arboretum Mlyňany was not found, because the macro-elements content in soil is generally influenced not only by chemical composition of litter but also by other biotic and abiotic conditions.

Contrariwise, the correlations of microelements (Zn, Mn) contents in litter and their available ions in soil were statistically significant.

In the soil under yews, Himalayan pines, and spruces there were exceeded limit contents of Cd, Zn and Pb, which indicates higher bioaccumulation ability as well as filtration of atmospheric deposition by mentioned trees compared to other studied tree species.

Acknowledgement

The paper was published thanks to project No. 1/0084/13 of the Scientific Grant Agency of Ministry of Education, Science, Research and Sport of the Slovak Republic.

References

Alloway, B.J., Ayres, D.C., 1997. *Chemical principles of environmental pollution*. 2nd ed. London: Blackie Academic and Professional. 395 p.

Blair, J.M., 1988. Nutrient release from decomposing foliar litter of three species with special reference to calcium, magnesium and potassium dynamics. *Plant and Soil,* 110: 49–55.

Bottner, P., Pansu, M., Sarmiento, L., Hervé, D., Callisaya-Bautista, R., Metselaar, K., 2006. Factors controlling decomposition of soil organic matter in fallow systems of the high tropical Andes: A field simulation approach using ^{14}C- and ^{15}N-labelled plant material. *Soil Biology and Biochemistry*, 38: 2162–2177.

Bublinec, E., 2000. Minulosť, prítomnosť a budúcnosť lesných pôd Slovenska [Past, present and future of forest soils in Slovakia]. In Authors‘ Collective. *Pedofórum 2000.* Bratislava: Výskumný ústav pôdoznalectva a ochrany pôdy, p. 52–64.

Cifra, J., 1958. Stručná charakteristika pôdnych pomerov Arboréta Mlyňany [Short characteristic of soil conditions in Arboretum Mlyňany]. In Benčať, F. (ed.). *Prírodné podmienky Arboréta Mlyňany.* Bratislava: Vydavateľstvo Slovenskej akadémie vied, p. 79–96.

Čurlík, J., 2011. *Potenciálne toxické stopové prvky a ich distribúcia v pôdach Slovenska* [Potentially toxic microelements and their distribution in Slovak soils]. Bratislava: Suma print. 462 p.

Decree of Ministry of Agriculture of the Slovak Republic No. 531/1994/540.

Fecenko, J., 1991. *Návody na cvičenia z výživy rastlín a agrochémie* [Laboratory exercise manual for plant nutrition and agrochemistry]. 3rd ed. Nitra: Vysoká škola poľnohospodárska. 121 p.

Ge, X., Zeng, L., Xiao ,W., Huang, Z., Geng, X., Tan, B., 2013. Effect of litter substrate quality and soil nutrients on forest litter decomposition: A review. *Acta Ecologica Sinica*, 33: 102–108. DOI: http://dx.doi.org/10.1016/j.chnaes. 2013.01.006.

Gonet, S.S., Debska, B., Zaujec, A., Banach-Szott, M., 2008. Properties of humus of natural forest soil and arable soil. *Ekológia (Bratislava)*, 27: 351–366.

Gonet, S.S., Markiewicz, M., 2007. *Rola materi organicznej w srodovisku* [Function of organic matter in the environment]. Wroclaw, Bydgoszcz: Polske Towarystwo Substancji Humusowych. 152 p.

Hrivňáková, K., Makovníková, J., Barančíková, G., Bezák, P., Bezáková, Z., Dodok, R., Grečo, V., Chlpík, J., Kobza, J., Lištjak, M., Mališ, J., Píš, V., Schlosserová, J., Slávik, O., Styk, J., Širáň, M., 2011. *Jednotné pracovné postupy rozborov pôd* [Uniform methods of soil analyses]. Bratislava: VÚPOP, 2011. 136 p.

Hoťka, P., Barta, M., Bibeň, T., 2013. Study of the richest gene pool of trees and shrubs in Slovakia, in the Mlyňany Arboretum SAS. *Folia Oecologica*, 40: 181–187.

Hrubík, P., Hoťka, P., Fogadová, K., Kuba, J., 2011. Klimatické podmienky Arboréta Mlyňany SAV vo

Vieske nad Žitavou za obdobie 1971–2011 [Climate conditions of Arboretum Mlyňany in Vieska nad Žitavou for 1971–2011]. In Barta, M., Konôpková, J. *Dendrologické dni v Arboréte Mlyňany SAV 2011: aktuálne otázky štúdia introdukovaných drevín*. Vieska nad Žitavou: Arborétum Mlyňany SAV, 2011, p. 66–73.

Jonczak, J., 2013. Dynamics, structure and properties of plant litterfall in a 120-year old beech stand in Middle Pomerania between 2007–2010. *Soil Science Annual*, 64: 8–13. DOI: http://dx.doi.org/10.2478/ssa-2013-0002.

Jonczak, J., 2009. Litter fall decomposition in age-differentiated stands of poplar clone ´hybrid 275´. *Polish Journal of Soil Science*, 42: 159–166.

Kabata-Pendias, A., Pendias, H., 1984. *Trace elements in soils and plants*. Boca Raton, Florida: CRC Press. 302 p.

Liao, J.H., Wang, H.H., Tsai, Ch.Ch., Hseu, Z.Y., 2006. Litter production, decomposition and nutrient return of uplifted coral reef tropical forest. *Forest, Ecology and Management*, 235: 174–185.

Mehlich, A., 1984. Mehlich 3 soil test extractant a modification of Melich 2 extractant. *Soil Science and Plant Analysis*, 15: 1409-1416.

Moore, T.R., Trofymow, J.A., Prescott, C.E., Fyles, J., Titus, B.D., CIDET Working Group, 2006. Patterns of carbon, nitrogen and phosphorus dynamics in decomposing foliar litter in Canadian forests. *Ecosystems,* 9: 46–62.

Novák, M., Miková, J., Krächler, M., Kosler, J., Erbanová, L., Prechová, E., Jacková, I., Fottová, D., 2010. Radial distribution of lead and lead isotopes in stem wood of Norway spruce: a reliable archive of pollution trends in Central Europe. *Geochimica et Cosmochimica Acta*, 74: 4207–4218.

Ondrišík, P., 2013. *Dynamika anorganického dusíka v pôde a možnosti jej regulácie* [Dynamics of inorganic nitrogen in soil and possibilities of its regulation]. Nitra: Slovenská poľnohospodárska univerzita. 97 p.

Orlov, V., Grishina, I., 1981. *Praktikum po chimiji gumusa* [Guide of humus chemistry]. Moskva: Izdateľstvo Moskovskovo universiteta. 124 p.

Pengthamkeerati, P., Motavalli, P.P., Kremer, R.J., 2011. Soil microbial biomass nitrogen and β-glucosaminidase activity response to surface compaction and poultry-litter application in a claypan soil. *Applied Soil Ecology*, 51: 79–86.

Sariyildiz, T., Anderson, J.M., Kucuk, M., 2005. Effects of species and topography on soil chemistry, litter quality, and decomposition in Northeast Turkey. *Soil Biology and Biochemistry,* 37: 1695–1706.

Šály, R. 1982. *Pedológia a mikrobiológia* [Pedology and microbiology]. Zvolen: Vysoká škola lesnícka a drevárska. 383 p.

Šimková, I., Kuklová, M., Kukla, J., 2014. Accumulation of Ct and Nt in humus and mineral soil layers: the effect of change of tree species composition in nudal beech forests. *Folia Oecologica*, 41: 82–91.

Tomáš, J., Hronec, O., Tóth, T., Andrejovský, P., Adamišin, P., Lazor, P., Daňová, M., Dušecinová, A., 2007. *Poškodzovanie pôd a rastlín ľudskými činnosťami* [Damage of soils and plants by human activities]. Nitra: Slovenská poľnohospodárska univerzita. 110 p.

Vahdat, E., Nourbakhsh, F., Basiri, M., 2011. Lignin content of range plant residues controls N mineralization in soil. *European Journal of Soil Biology,* 47: 243–246. DOI: http://dx.doi.org/10.1016/j.ejsobi.2011.05.001.

van Breemen, N., Buurman, P., 2003. *Soil formation.* 2nd ed. New York: Kluwer Academic Publishers. 404 p.

Vogt, K.A., Grier, C.C., Vogt, D.J., 1986. Production, turnover and nutrient dynamics of above- and below-ground detritus of the world forests. *Advances in Ecological Research*, 15: 303–377.

Received November 26, 2014
Accepted March 30, 2015