Effects of spruce, beech and mixed commercial stand on humus conditions of forest soils

T. Fabiánek[1], L. Menšík[1], I. Tomášková[2], J. Kulhavý[1]

[1]*Institute of Forest Ecology, Faculty of Forestry and Wood Technology, Mendel University of Agriculture and Forestry in Brno, Brno, Czech Republic*
[2]*Laboratory of Plants Ecological Physiology of Systems Biology and Ecology, Academy of Sciences of the Czech Republic, Brno, Czech Republic*

ABSTRACT: A pedological survey was carried out in a spruce monoculture, beech stand, and in a mixed stand at a field research station in Rájec-Němčice of the Institute of Forest Ecology (IFE), Mendel University of Agriculture and Forestry (MUAF) in Brno in the region of the Drahanská Upland in 2004–2006. The aim of the paper was to evaluate (*i*) humus reserves and forms, (*ii*) soil reaction, (*iii*) reserves of total carbon and nitrogen for the forest floor layers and (*iv*) carbon/nitrogen ratio. Soil analyses were carried out on samples taken at the end of the growing season in a spruce, beech and mixed stand. The highest reserves of forest floor were found in the spruce stand (71.8 t/ha), which also corresponded to the exchangeable soil reaction 3.3 ± 0.4, the C/N ratio being 27.3 ± 3.0. The lowest reserves were found in the beech stand (46.7 t/ha), the soil reaction was 3.6 ± 0.5 and the C/N ratio was 26.0 ± 5.2. The mixed stand represented an intermediate value between extreme positions.

Keywords: tree species composition; soil; forest floor reserves; humus forms; pH; C/N ratio

The condition and form of humus in forest management are among key factors affecting the condition and growth of forest stands. In the course of the last century, this fact was mentioned by prominent specialists in the field of forest pedology, e.g. by Němec (1928), Mařan and Káš (1948), Pelíšek (1964), Šály (1977, 1978). The function of forest floor within the soil profile where the decomposition of plant and animal material and the subsequent release of nutrients into the soil environment occur can be considered to be fundamental. Differentiation of forest floor horizons – forest litter, mull and detritus where the particular processes of decomposition, mineralization and humification take place, is the result of humification. In the organo-mineral horizon, the decomposition of dead rhizosphere (or soil biota) and organic excrements occurs. Moreover, synthesized humus substances from surface layers penetrate there (Samec, Formánek 2007). Chemical and physical properties of forest floor layers and organo-mineral horizon show a crucial effect on the site trophic properties and on the biodiversity of forest ecosystems. Thus, through the composition of forest stands and methods of their growing we can affect the condition and properties of the soil environment and, *vice versa*, plant communities at the given site are directly dependent on the soil environment quality. In recent decades, the

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problem of allochthonous spruce (*Picea abies* [L.] Karst.) stands grown at sites outside the region of natural range has been discussed. The majority of the authors reported their effect on the soil environment as negative (Němec 1928; Pelíšek 1964; Kulhavý 1997). The humus of even-aged spruce monocultures conditions the process of acidification of the soil profile. This phenomenon was first described and termed in the 80s as "new forest decline" when Ulrich (1983) outlined possible damage to forest stands due to acidification of soils. Nevertheless, this theory has also its opponents, e.g. Šály (1978), who described acidification only as a natural process which cannot be "taken out" of the whole context of soil-forming processes and who stated that it was not possible to attribute an absolute effect to the process. Under conditions of the Krkonoše Mts., Emmer (1998) and Emmer et al. (2000) assessed borealization as a process of natural acidification of soils and impoverishment of basic cations. They found that in spruce stands pH values decreased by 0.2–0.3 and the base-exchange complex was reduced even by 10% as compared to beech stands. The problem of acidification has acquired a new dimension particularly due to the heavy air pollution load which has become evident in the Krušné hory Mts. (Erzgebirge) since the 1950s (Materna 1963; Hruška, Cienciala 2001). At that time, mass forest decline occurred in mountain regions as ecosystems with lower resistance to air pollution changed the chemistry of precipitation and atmospheric deposition (Hruška, Cienciala 2001).

Health problems of spruce monocultures occur not only due to the effects of pedological processes mentioned above but also by means of a complex of factors affecting spruce stands (fungal pathogens, insect pests, abiotic effects such as wind, dry spell, frost or the increasing general mean annual temperature in connection with the potential global change of climate). Problems of spruce monocultures affect seriously more European countries particularly with respect to the new orientation of management and use of forest ecosystems. In the Central-European region there is a large number of spruce monocultures which are not adapted to a given site (Spiecker et al. 2004). The transformation of these forests to close-to-nature forests, i.e. mixed stands, will enable to reduce the risk of the stand disintegration effectively (Klimo, Tesař 2004).

The aim of the paper was to evaluate conditions of forest floor in relation to forest stands with changed tree species composition on the Drahanská Upland. Chemical analyses (such as pH, C/N ratio) and humus forms and layers were used to obtain required information.

MATERIAL AND METHODS

Site and stand description

Pedological studies were carried out at the Rájec-Němčice field research station of the Institute of Forest Ecology, Mendel University of Agriculture and Forestry in Brno, about 3 km north of the village of Němčice (49°29'31''N and 16°43'30''E) and on research plots of MP Forests of Benešov near Boskovice, about 2.5 km north of the field research station in the central part of the Drahanská Upland. As for the type of topography, the area is included in the broken uplands of deformed border slopes of an arch megastructure. According to the topography typological classification the area is ranked among broken uplands of faulted structures and intrusive rocks of the Bohemian Highland. Acid granodiorite of the Brno massif is the parent rock of the area. The soil profile is created on slope layers of various depths with interspersed granodiorite gravel and boulders here and there. Modal oligotrophic Cambisol (Němeček et al. 2001) is the soil type of the area. The research plots are situated at an altitude of 600–660 m a.s.l. corresponding to a slightly warm climatic region (Quitte 1971), with mean annual air temperature 6.5°C and mean annual precipitation 717 mm (Hadaš 2002). The Forest Management Institute in Brandýs nad Labem classified potential

Table 1. Short description of forest stands

	Age	Stand structure (%)	Soil	Forest typology
Spruce forest stand	110	SM 100	modal oligotrophic Cambisol* Cambisols (CM)**	5S1–*Abieto-Fagetum mesotrophicum* with *Oxalis acetosella****Luzulo-Fagion*
Beech forest stand	120	BK 100		
Mixed forest stand	120	BK 55, SM 40, JD 5, MD, BO		

*soil taxonomy by Němeček et al. (2001), **WRB, ***taxonomy by FMI (Forest Management Institute, Brandýs nad Labem)

Table 2. Statistically significant differences in forest floor reserves

Layer	L			F			H		
Stand	spruce	beech	mixed	spruce	beech	mixed	spruce	beech	mixed
Spruce		**	**		**	NS		**	**
Beech	**		NS	**		NS	**		NS
Mixed	**	NS		NS	NS		**	NS	

*statistically significant differences (α < 0.05), **highly statistically significant differences (α < 0.01), NS – not significant

growth conditions as *Abieto-Fagetum mesotrophicum* with *Oxalis acetosella*.

However, we reason that the locality is situated at the upper limit of the beech forest vegetation zone. Brief characteristics of the research plots are given in Table 1.

Sampling procedure

Samplings of forest floor for the reserve determination and subsequent analyses were always carried out at the end of the growing season, in autumn, after the leaf fall (*Fagus sylvatica*) in 2004–2006. Particular samples were taken by a standard method using a metal frame of a known area (0.1 m^2). In each of the three stands, 10 samplings of particular layers (L, F, H) were carried out. Each sample was taken separately. After transfer to the laboratory, the samples were dried up at 60°C to a constant weight in an oven, weighed and mean dry weight was calculated and subsequently reserves of forest floor per ha were calculated. Samples of the organo-mineral horizon (Ah horizon) were taken in autumn 2005 and 2006 in all three stands. At five places in each of the variants, pedological ditches were dug and by means of a shovel and knife or a soil probe, Ah horizon was taken. Horizons from each replication were taken separately to a paper or plastic bag. Values of active and exchangeable soil acidity were determined by a potentiometer method (Zbíral et al. 1997) using a digital pH-meter OP-208/1 (Radelkis Budapest, Hungary). It used a KCl solution of n = 1 mol/l for assessment of exchange pH. Carbon and nitrogen were determined from samples devoid of coarse particles after fine grinding or comminution on a LECO TruSpec analyzer (MI USA) (2006) (Zbíral et al. 1997).

Statistical analyses

Statistical analyses were carried out using the Statistica Program (Stat-Soft Inc., Tulsa USA). Single-factor analysis ANOVA was used and Tukey's test was applied for the detection of differences between groups. Significance was tested on the level α = 0.05. Cluster analysis was used for the classification of forest floor reserves.

RESULTS

Forest floor reserves

Forest floor reserves (Fig. 1) were determined in the range from 46.7 to 71.8 t/ha and the forest floor depth (L, F and H horizons) fluctuated between 5 and 8 cm. The highest accumulation of forest floor occurred under the stand in a 110-year spruce monoculture. The lowest reserves occurred under the beech stand. When comparing particular layers their reserves decreased from the H layer towards the L layer of litter. The highest accumulation of humus in the H layer occurs at the spruce stand locality. The mean reserve of humus at the Rájec-Němčice field research station of the IFE MUAF in Brno (the same area as the spruce stand) in 1975 was in layers L 12.4 t/ha, F 15.8 t/ha and H 21.7 t/ha. In 1982, he reported 11, 15.8 and 22.3 t/ha in L, F and H layers, respectively and in 1990

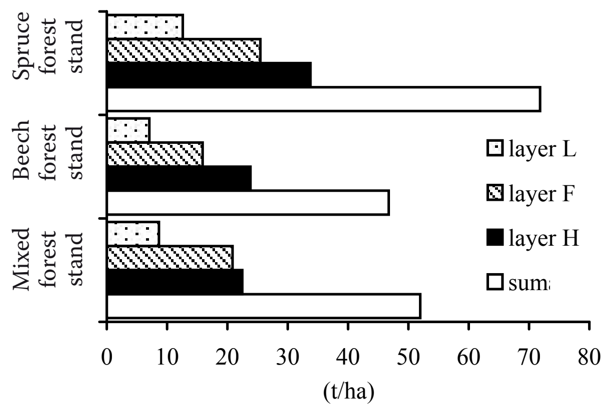

Fig. 1. Stock of forest floor

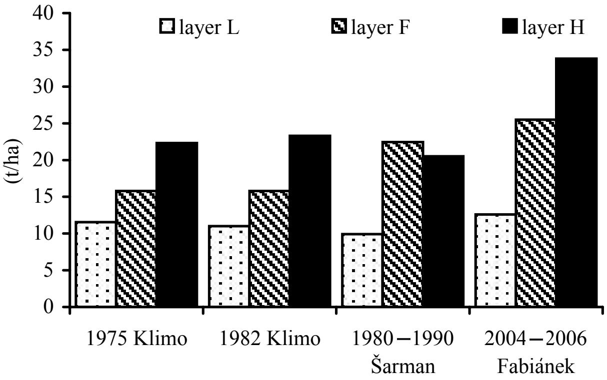

Fig. 2. Stock of forest floor in Spruce forest stand

the reserves in the particular layers were as follows: L 9.9 t/ha, F 22.5 t/ha and H 20.5 t/ha (Klimo, personal communication). Values determined in the course of research are as follows: L 12.6 t/ha, F 25.5 t/ha and H 33.8 t/ha. The humus form is the same in all stands, see moder (Němeček at al. 2001). Significant differences in the particular layers of forest floor between stands are given in Table 2.

Chemical analyses

Values of actual (in H_2O) and exchangeable pH (in nKCl) were determined. Values of exchangeable pH were always lower than those of actual pH. The exchangeable and actual reactions of soil (Figs. 3 and 4) decreased from L to H in all stands. The lowest values in forest floor (4.0 and 3.4) and in the organo-mineral horizon A_h (3.7 and 2.8) were determined at the spruce stand locality where the actual soil reaction could be specified as strongly acid or even very strongly acid.

For the spruce stand, data are available that were obtained from the previous project measurements. Already at first sight, a distinct downward tendency of the values of exchangeable pH measured in the course of 1975–1976 is evident (Fig. 5). Also in other data related to the beech stand that are available (Kulhavý 1997), it is possible to see the downward tendency of soil reaction in the course of time (Fig. 6).

The content of total nitrogen in soil in 2004–2006 ranged about 1.45% for forest floor and about 0.2% in the organo-mineral horizon A_h in all stands. As for total carbon, values range from 34.9% (beech stand) to 41.3% (spruce stand), for humus layers L, F and H from 3.3% (spruce stand) to 4.0% (beech stand) in the organo-mineral horizon A_h.

The highest reserves of carbon and nitrogen (Figs. 7 and 8) in forest floor occur in the spruce stand. The lowest C/N ratio in forest floor (Fig. 9) occurs under the 110-year spruce stand (26.0) and in the organo-mineral horizon on the beech stand area. On the contrary, the highest value was found in the beech stand (27.3) in forest floor and in the spruce stand A_h horizon (20). The C/N ratio decreases from horizon L to the organo-mineral horizon Ah.

In chemical analyses of pH, total carbon and nitrogen and C/N ratio no statistically significant differences were found.

DISCUSSION

The most important factors at the formation of forest floor are: topography, climatic and microclimatic conditions, edaphon, soil chemistry and forest stand or phytocoenosis composition (Pelíšek 1964). In this paper, particularly soil chemistry and forest stand composition are studied. As for soil characteristics, total carbon, total nitrogen, their ratio and soil reaction were selected.

The main indicator of the biomass decomposition rate is just the content of nitrogen and C/N ratio,

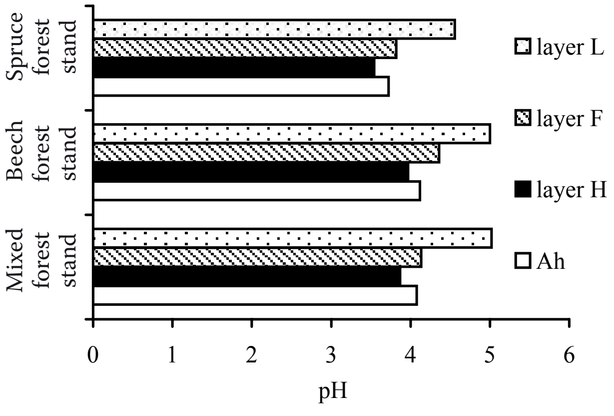

Fig. 3. Distribution of pH_{H_2O} in layers of forest floor and organomineral horizon in different forest stands

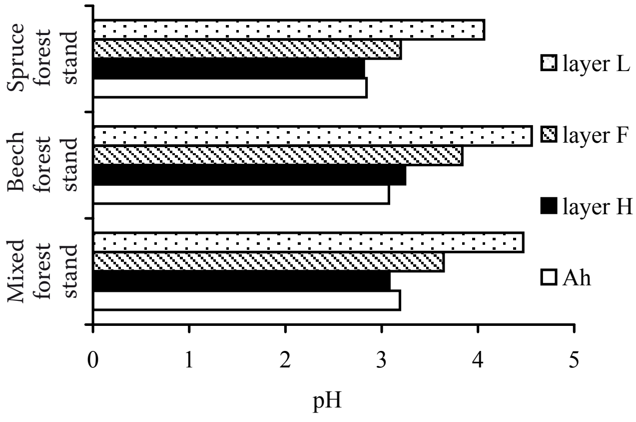

Fig. 4. Distribution of pH_{KCl} in layers of forest floor and organomineral horizon in different forest stands

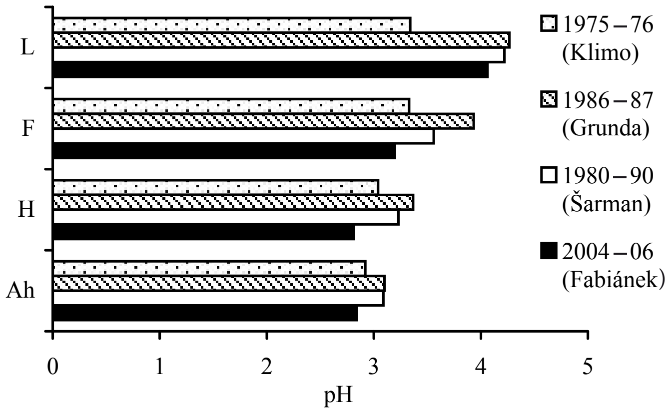

Fig. 5. pH_{KCl} in layers of forest floor and organomineral horizon of spruce forest stand found by different authors

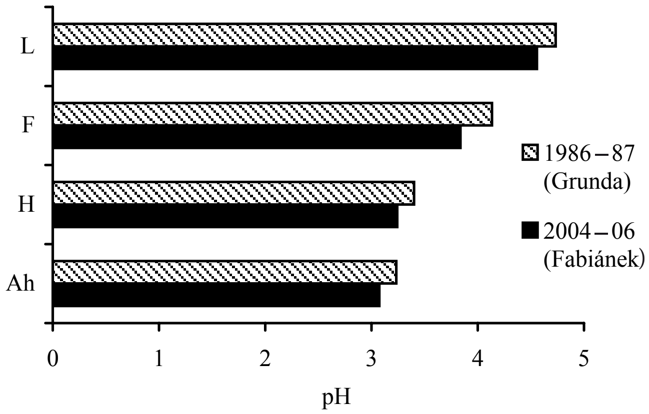

Fig. 6. pH_{KCl} in layers of forest floor and organomineral horizon of beech forest stand found by different authors

which is given by the close relationship of the C/N ratio and soil transformations of nitrogen (Cote et al. 2000). In forest soils of Europe, the C/N ratio ranges between 10 and 100 in the organic horizon, the majority of the C/N ratio values occurring within the limits 10 to 100, in mineral horizons within the limits 10 to 30. However, the evaluation of the C/N ratio is not so clear and differs between authors (Vitousek et al. 1982; Binkley, Giardina 1998; Cote et al. 2000; Prescott et al. 2000; Puhe, Ulrich 2001). Emmett et al. (1998) reported the critical value of the C/N ratio in coniferous stands about 24.

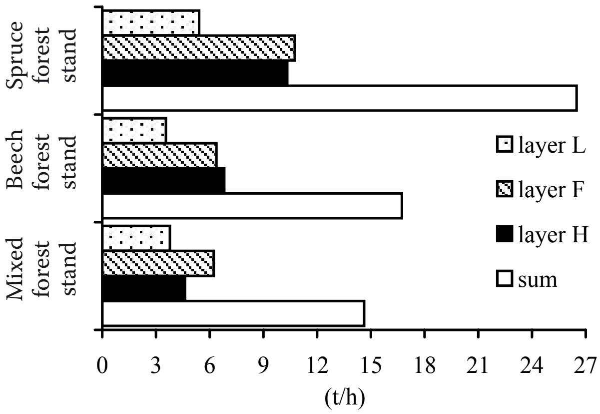

Fig. 7. Carbon stock in forest floor in different forest stands

At the ratio > 24, less than 10% nitrogen is washed out from the ecosystem. Nevertheless, at the ratio < 24, the amount of washed out nitrogen is higher than 10% of the total nitrogen in the ecosystem. Values from forest floor in the coniferous stand do not fall below the limit. The accumulation of nitrogen is highest in the H layer, which is also the deepest layer in all stands. Determined values of the C/N ratio in the beech stand are a little lower than the values that were measured in 1986–1987 in a comparable stand situated at close vicinity (Kulhavý 1997). In broadleaved stands, no limit values have been determined to generalize assessing the C/N ratio for forest stands (Hruška, Cienciala 2001). The C/N ratio has to be assessed using all analyses. Mařan and Káš (1948) reported pH values 3.7–4.5 for spruce humus. Similarly, Šály (1978) reported pH values 4.0–5.0 for coniferous litter. All stands show pH values lower than the given range, which can be another factor indicating man-conditioned acidification of the soil profile. According to the classification of buffer zones, the spruce monoculture occurs predominantly in the aluminium zone, which buffers the effects of acid inputs through the release of Al^{3+} under the presence of sesquioxides and the simultaneous origin of organic complexes. Under these conditions, a gradual decrease in the trophic potential occurs because of slow accumulation of xenobiotic substances in the

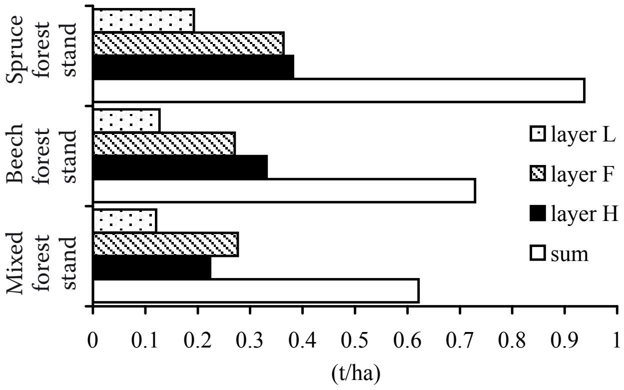

Fig. 8. Nitrogen stock in forest floor in different forest stands

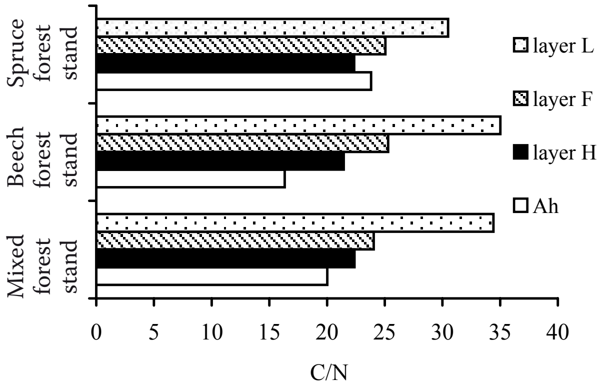

Fig. 9. C/N ratio in forest floor in different forest stands

soil. Consequently, mineral nutrients are accessible only to a limited extent and a risk of uncontrollable washing out the organic colloids increases (Ulrich 1983). In the beech stand, pH values fluctuate around the lower limit, namely 3.7–4.5 (Mařan, Káš 1948) and 5.0–6.5 (Šály 1978). Comparing the present exchangeable pH with pH values measured, there occurred a decrease by about 10% (Kulhavý 1997). As for the division of soils according to the values of soil reaction into particular buffer zones, soil under the broadleaved stand falls to the exchangeable zone. It is localized in soils where a disproportion occurs between basic cations released in weathering feldspars and H^+ inputs. Under these conditions, protons could be immobilized at exchange sites of clay minerals generally by Al^{3+} sorption (Ulrich 1983). Aluminium ions act partly as a weak acid and partly toxically, thus limiting mycorrhizae. Therefore, the compensation of acid inputs within this zone occurs particularly thanks to basic cations fixed at exchange sites of organic colloids. The values of soil reaction and the C/N ratio from soil samples of a mixed stand are within the limits of the remaining two stands. Carbon and nitrogen reserves are the lowest and their accumulation in lower layers of the forest floor does not take place.

The highest reserves and depth of forest floor were found in the 110-years old spruce monoculture of the second generation. The humus form consists of moder (according to Němeček et al. 2001) as well as in the other two stands. As compared with previous research there is an evident increase in material at present, mainly in the H layer. The impairment of soil condition probably occurred due to badly decomposable coniferous litter, which contains only a small amount of nutrients (Zlatník 1976; Van Breemen, Finzi 1998) and potentially increases acidification throughout the soil profile. In the beech stand, a smaller amount of material is accumulated. One of the factors that support the accumulation is physical conditions. Between the L and F layers of forest floor there is a layer of compacted undecomposed leaf litter which is badly permeable for air and partly also for water. In the mixed stand, the total reserve and structure of forest floor approaches stands with pure coniferous litter.

CONCLUSION

Within long-term monitoring in the course of previous projects carried out by the Institute of Forest Ecology on the Rájec nad Svitavou research plot and in its close vicinity on comparable plots, it was possible to assess soils under selected stands. In studied stands there are soils with mainly acid soil reaction and the moder humus form (according to Němeček et al. 2001). These characteristics together with reserves of carbon, nitrogen and C/N ratio in forest floor indicate actual acidification affected by human activities, not by the air pollution load but by the method of management in forest ecosystems. The effects of growing spruce monocultures are well visible in the results of soil analyses. It refers to the amount of accumulated material in layers of forest floor, which is up to three times higher than in the broadleaved stand. The values of soil reaction also indicate higher acidity in the spruce monoculture than in the beech stand. Regarding the conditions of soil under the mixed stand (55% proportion of beech), as compared with stands with pure broadleaved and pure coniferous litter, we can state that its values range within the limits of these two monocultures according to the majority of results of soil characteristics.

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Vliv smrkového, bukového a smíšeného hospodářského porostu na humusové poměry lesních půd

ABSTRAKT: Pedologický průzkum probíhal ve smrkové monokultuře, bukovém porostu a smíšeném porostu v letech 2004–2006 na výzkumném stacionáru Rájec-Němčice Ústavu ekologie lesa Mendelovy zemědělské a lesnické univerzity v Brně v oblasti Drahanské vrchoviny. Cílem práce bylo zhodnotit: (*i*) zásobu a formu nadložního humusu, (*ii*) půdní reakci, (*iii*) zásobu celkového uhlíku a dusíku pro vrstvy nadložního humusu a (*iv*) poměr uhlíku a dusíku. Půdní analýzy byly provedeny ze vzorků odebraných na konci vegetačního období ve smrkovém, bukovém a smíšeném porostu. Největší zásoba nadložního humusu byla zjištěna ve smrkovém porostu (71,8 t/ha), odpovídala i výměnná půdní reakce 3,3 ± 0,4 a poměr uhlíku a dusíku byl 27,3 ± 3,0. Nejnižší zásoba byla zjištěna u bukového porostu (46,7 t/ha), půdní reakce byla 3,6 ± 0,5 a poměr uhlíku a dusíku 26,0 ± 5,2. Smíšený porost reprezentoval svými hodnotami půdních poměrů střed mezi krajními polohami.

Klíčová slova: dřevinná skladba; půda; zásoba nadložního humusu; forma humusu; pH; poměr C/N

Corresponding author:

Ing. Tomáš Fabiánek, Mendelova zemědělská a lesnická univerzita v Brně, Lesnická a dřevařská fakulta,
Ústav ekologie lesa, Lesnická 37, 613 00 Brno, Česká republika
tel./fax: + 420 545 134 180, e-mail: tomas@usbe.cas.cz