Humus conditions and stand characteristics of artificially established young stands in the process of the transformation of spruce monocultures

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ABSTRACT: The main reason for the transformation of spruce monocultures at sites of mixed broadleaved forests is to create more natural relationships between the species structure of a stand and soil processes. The presented study compares humus conditions and basic growth characteristics of two mixed stands (spruce with beech and larch with beech) aged 25 years with a beech stand (aged 40 years) and spruce stand (aged 30 years). The purpose of the study is to evaluate (*i*) forms of forest floor, (*ii*) soil reaction, (*iii*) the content and total reserves of carbon, nitrogen and C/N ratio, (*iv*) dissolved organic carbon (DOC) in relation to stand characteristics. The highest reserve of forest floor is detected in the mixed stand of larch with beech (52.6 t/ha), the lowest reserve in a beech stand (21.0 t/ha). The soil reaction of the spruce stand and the beech stand is 4.0 (± 0.3) and 5.1 (± 0.3), respectively. The C/N ratio of the spruce stand is 23.5 (± 1.8) and that of the beech stand 18.8 ± 2.9. The DOC content decreases with layers of surface humus towards depth. Mixed stands represent by their values of soil conditions a mean between spruce and beech stands.

Keywords: tree species composition; soil; forest floor reserves and forms; pH; C/N ratio; DOC; forest stand characteristics

Problems of spruce monocultures refer seriously to more European countries, particularly with respect to the new orientation of management and using forest ecosystems. In the Central European region, there are large areas of spruce monocultures which are not adaptable to the given site. On a long-term basis, only mixed stands are economically reliable whereas in a commercial forest, spruce can be a dominant species even in the future (Spiecker et al. 2004). The main reason to transform spruce monocultures at sites of mixed broadleaved forests is to create a natural relationship between the species composition of stands and soil processes. A mixed stand can be created by the combination of natural and artificial regeneration in the course of the spruce stand transformation. The growth of a stand, stand environment and growing up to the rotation age are much more affected by the form of a mixture, in principle individual, row/belt and group (Otto 1994; Burschel, Huss 2003). In the modern conception of forest ecology and forest soil science, surface humus and humus horizons are important components

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of a forest ecosystem from the point of view of the element cycle preservation in forest ecosystems and maintaining their ecological stability. The condition and form of humus in forest management is one of key factors affecting the condition and growth of stands. In the course of the past century, this fact was mentioned by prominent specialists in the field of forest pedology, e.g. Němec (1928), Mařan and Káš (1948), Pelíšek (1964), Šály (1977, 1978). Humus represents a place of the main accumulation of carbon in the majority of terrestrial ecosystems and because it remains there unoxidated for centuries it becomes an important long-term reservoir of carbon in an ecosystem (Waring, Running 1998). Forest floor is very important for forest soils affecting a number of their properties. It is the regulator of runoff of rainfall water in watersheds, decreases the hazard of floods in piedmont and lowland regions, intercepts considerable amounts of rainfall water penetrating through crowns of stands and releases the water into underlying soil layers to increase groundwater reserves and decides on runoff, evaporation and groundwater flow (Kantor, Šach 2008). It also controls temperature conditions reducing temperature fluctuations in soils between day and night (Pelíšek 1964).

Last but not least, it serves as the source of energy for soil organisms (Sparks 2003). The aim of the paper is to evaluate humus conditions (reserves and forms of forest floor, soil reaction, the content and total reserves of carbon, nitrogen and C/N ratio, dissolved organic carbon) and basic growth characteristics of two mixed stands (spruce with beech and larch with beech) aged 25 years with a pure beech stand (aged 40 years) and pure spruce stand (aged 30 years) in the Drahanská vrchovina Upland.

MATERIAL AND METHODS

Site and stand descriptions

The study compares humus conditions and basic growth characteristics of two mixed stands established by planting at a constant spacing of 2 × 2 m (spruce with beech in the row ratio spruce1:beech1, beech proportion 30% and larch with beech in the row ratio larch1:beech2, beech proportion 40%) at the age of 25 years with a pure beech stand (40 years) established by seeding and spruce (30 years) established by planting. The study is carried out in the Rájec-Němčice field research station of the Institute of Forest Ecology, Mendel University of Agriculture and Forestry in Brno, about 3 km west of the village of Němčice (49°29'31''N and 16°43'30''E). 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 corresponding to a slightly warm climatic region (Quitte 1971). The mean annual air temperature of the area is 6.5°C and the mean annual precipitation 717 mm (Hadaš 2002). The Forest Management Institute (Brandýs nad Labem) has classified potential growth conditions as *Abieto-Fagetum mesotrophicum* with *Oxalis acetosella,* i.e. 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.

Soil sampling and analyses procedure

The diameter at breast height (dbh) and height (h) of all trees inevitable for the construction of a height diagram were determined, i.e. at the most five trees in every diameter class.

Samplings of forest floor for the reserve determination and subsequent analyses were carried out always at the end of the growing season, in autumn, after the leaf fall in 2004–2006. Particular samples were taken by a standard method using the metal frame of a known area (0.1 m^2). In each of the four stands, 10 samplings of particular layers (L, F and H) were carried out. 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 reserves of forest floor per ha were calculated from it. Samples of the organomineral horizon (Ah)

Table 1. Short characteristics of experimental forest stands

Species composition	Age	*N*/ha	Soil	Forest typology
Spruce 100	30	–	Modal oligotrophic Cambisol* Cambisols (CM)**	5S1 – *Abieto-Fagetum mesotrophicum* with *Oxalis acetosella****
Spruce 70, beech 30	25	1,630 (spruce 1,145, beech 485)		
Larch 60, beech 40	25	1,110 (larch 670, beech 440)		
Beech 100	40	2,330		

*Soil taxonomy by Němeček et al. (2001), **WRB, ***taxonomy by FMI (Forest Management Institute, Brandýs nad Labem) were taken in all three stands in autumn 2005 and 2006. On 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 from them. Horizons from each repetition 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). Fundamental nutrients, i.e. carbon and nitrogen, were determined from samples devoid of coarse particles after fine grinding or comminution on a LECO TruSpec analyzer (MI USA) (Zbíral et al. 1997). Dissolved organic carbon (DOC) of soil samples was determined by an adapted method according to Robertson et al. (1999). Then, the content of DOC was determined using Shimadzu TOC-$V_{CSH/CSN}$ analyzer (Shimadzu Corporation, Japan). Mensurational characteristics of stands were determined by standard procedures.

Processing the statistical values

Statistical analyses were carried out in the Statistics Program (Stat-Soft Inc., Tulsa, USA). Single-factor analysis ANOVA was used and for the

Table 2. Stand characteristics and statistical differences in forest floor properties

Stand characteristics	Spruce	Spruce with beech	Larch with beech	Beech
***$d_{1.3}$* (cm)/SD**				
Spruce	–	13.6/4.8	–	–
Larch	–	–	19.5/5.6	–
Beech	–	5.5/3.6	6.7/3.6	12.6/5.1
h (m)				
Spruce	–	12.3	–	–
Larch	–	–	14.9	–
Beech	–	8.5	9.3	15.5
G (m^2/ha)	–	19.9	23.7	34.0
Spruce	–	18.2	–	–
Larch	–	–	21.7	–
Beech	–	1.8	2.0	34.0
Stock of forest floor (horizons L + F + H)				
Spruce	X	NS	**	**
Spruce with beech	NS	X	**	**
Larch with beech	**	**	X	**
Beech	**	**	**	X
Stock of carbon (nitrogen) in forest floor (horizons L + F + H)				
Spruce	X	* (NS)	NS (NS)	* (NS)
Spruce with beech	* (NS)	X	* (*)	NS (NS)
Larch with beech	NS (NS)	* (*)	X	* (*)
Beech stand	* (NS)	NS (NS)	* (*)	X
pH (H_2O), (pH KCl) in forest floor (horizons L + F + H)				
Spruce	X	** (NS)	NS (NS)	** (NS)
Spruce with beech	** (NS)	X	NS (NS)	NS (NS)
Larch with beech	NS (NS)	NS (NS)	X	NS (NS)
Beech	** (**)	NS (NS)	NS (NS)	X

*Statistically significant differences ($\alpha < 0.05$), **high statistically significant differences ($\alpha < 0.01$), NS – not significant detection of differences between groups, Tukey test was applied. Significance was tested on the level of $\alpha = 0.05$. Moreover, descriptive statistics were used (mean value, standard deviation) in mensurational characteristics.

RESULTS AND DISCUSSION

Stand characteristics

The mean dbh and stand height (Table 2) of spruce and larch are rather higher than it would correspond to the site class of matures stands. The diameter range of trees in mixed variants is very broad starting with very low values with respect to the stand age of 25 years. Thus, the stands are heavily neglected from the aspect of forest management. At the same time, however, they show how beech is able to survive under a fully closed stand of larch and spruce and what are existence limits of the most disadvantaged trees. Even the variant of the beech stand shows a very broad diameter range and it is evident that trees of the largest diameter have to be removed for the formation and development of a future quality stand. It is also evident from the high value of a basal area (34 m^2/ha). Under given natural conditions, beech would be a basic species in close-to-nature stands. In a commercial forest, beech is grown even in unmixed productive stands. In spruce management, which is economically effective also in the beech forest zone, it serves particularly as a soil-improving and reinforcing species in the interest of sustainable development. In its favourable position to spruce, it can provide rather large volume of relatively valuable wood. Nevertheless, it is doubtful if it can achieve it as a row mixture. The high production potential of individually mixed larch/beech stands is known and exactly documented from the Drahanská vrchovina Upland (Klíma 1990; Hurt, Kantor 2007). Such a mixture is suitable for reinforcing belts in spruce stands.

Forest floor reserve

The forest floor reserve (Fig. 1) ranged from 22.0 to 52.6 t/ha and the depth of horizons (L, F, H) ranged from 3 to 8 cm. The forest floor stock in horizon L was determined from 4.9 to 5.3 t/ha. Statistically significant differences at the level of significance ($\alpha = 0.05$) were not found. Accumulation of humus in F horizon in an unmixed beech stand (8.4 t/ha) was statistically on the level of significance ($\alpha < 0.01$) markedly lower than in a spruce stand and mixed stands (15.0–17.2 t/ha). Accumulation of humus in H horizon in a stand of larch with beech (32.0 t/ha) was statistically markedly higher at a level of significance ($\alpha < 0.01$) than in an unmixed stand of spruce, beech and mixed stand of spruce with beech. The highest accumulation of forest floor was in the stand of larch with beech (52.6 t/ha). The lowest accumulation was found in the unmixed stand of beech (22.0 t/ha). Accumulation in the unmixed spruce stand and mixed stand of spruce with beech was 36.8 and 33.0 t/ha, respectively. The survey of statistically significant differences in the total reserve in forest floor between stands is given in Table 2. The forest floor reserve is also related to the form of humus (Emmer 1999). Humus forms were as follows: moder in the unmixed spruce stand and mixed stands, mull-moder in the unmixed beech stand (according to Němeček et al. 2001). The high accumulation of humus in H horizon in the mixed stand of larch with beech is evidently given by a fact that part of the reserve comes from a former mature spruce stand and decomposition has not occurred yet. Thus, decrease in the accumulation of humus did not take place in this horizon. Low accumulation in H horizon in

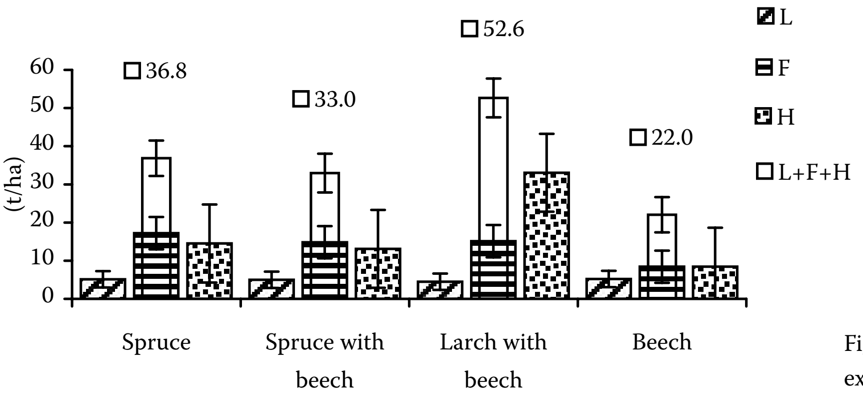

Fig. 1. Reserves of forest floor in different experimental stands

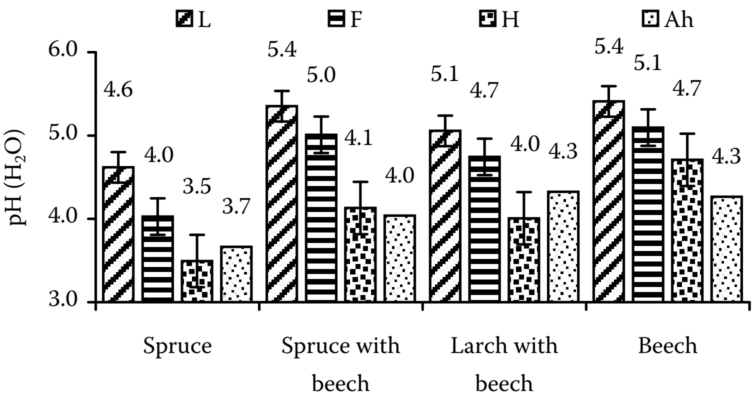

Fig. 2. Distribution of pH_{H_2O} in layers of forest floor and organomineral horizon in different experimental stands

the unmixed beech stand, which is ten to fifteen years older than other stands, indicates faster decomposition and mineralization of organic matter and better cycling of nutrients. It also corresponds to the higher content of dissolved organic carbon (DOC) and lower C/N ratio (see Figs. 6 and 7 in particular horizons of forest floor). On the basis of determined results we can conclude that the reserve of the mixed stand of spruce with beech approaches more the unmixed spruce stand than the unmixed beech stand. We can state that the proportion of beech amounting to 30% in a mixed stand shows positive soil-improving effect.

Soil reaction

Both actual (in H_2O) and exchangeable (in nKCl) pH was determined. In the surface humus, values of both actual and exchangeable pH decrease with increasing depth (Figs. 2 and 3) in all stands and the lowest values were determined in the H layer. The lowest values in forest floor in the H horizon (3.5 and 3.7) as well as in the organomineral horizon A_h (2.7 and 2.7) were determined in a pure spruce stand where the actual soil reaction could be specified as heavily acid to very heavily acid. The highest pH values in H horizon were found in a beech stand, soil reaction (in H_2O) is moderately up to heavily acid (4.7 and 4.1 forest floor, 4.1 and 3.3 A_h horizon). In L and F horizons, statistically significant differences in active and exchangeable pH occurred on the level of significance ($\alpha < 0.01$) between the unmixed spruce monoculture and mixed stands and unmixed beech monoculture. In H horizon in active pH, statistically significant differences on the level of significance ($\alpha < 0.05$) occurred between the unmixed spruce stand and mixed stand of spruce with beech, between the unmixed spruce and beech stand, mixed stand of larch with beech and unmixed beech stand. In exchangeable pH on the level of significance ($\alpha < 0.01$), statistically significant differences occurred between the unmixed beech stand and unmixed spruce stand, mixed stand of larch with beech. On the level of significance ($\alpha < 0.05$) between the unmixed beech stand and mixed stand of spruce with beech. Statistically significant differences of active and exchangeable pH in forest floor (mean values for L, F and H layers) are given in Table 2. Mařan and Káš (1948) mention pH values for beech humus within the limits 5.3–6.6 and for spruce 3.7–4.5. Similarly, Šály (1978) gives pH values for the leaf litter within the limits 5.0–6.5 and for conifers 4.0–5.0. In the event that we evaluate the mixed stand of spruce with beech and the mixed stand of larch

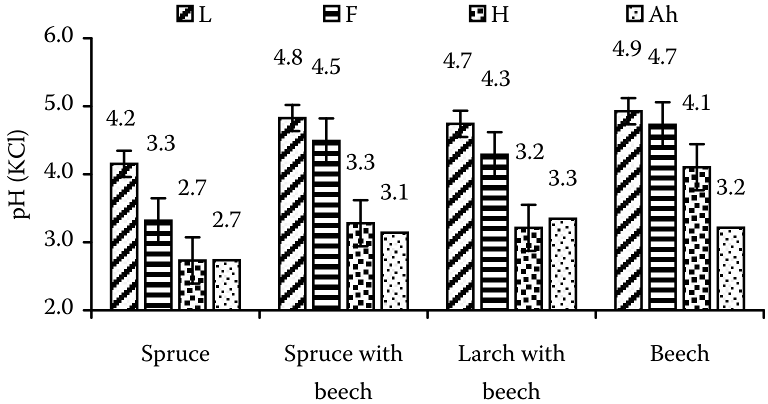

Fig. 3. Distribution of pH_{KCl} in layers of forest floor and organomineral horizon in different experimental stands

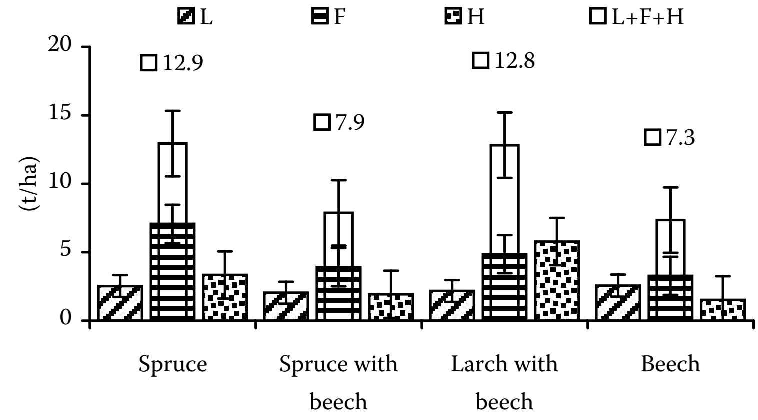

Fig. 4. Carbon reserves in forest floor in different experimental stands

with beech of various proportions we can conclude that beech in proportion from 30 to 40% positively improves pH values. It applies to larch, which rather worsens soil reaction although it occurs in a variant with beech. Exchangeable soil reaction shows a similar course as active reaction. Relatively small differences between active and exchangeable pH values show evidence of the relative sufficiency of basic cations in the uppermost layers of soil (Ulrich 1989). As for the division of soils according to values of soil reaction into particular buffer zones, soil in a spruce stand and in mixed stands is included into an exchangeable zone (aluminium zone of buffering). In the beech stand, it is possible to classify soil according to pH values to a borderline of the buffer zone of the cation exchangeable capacity where the increased input of hydrogen ions is compensated for by basic cations. Thus, compensation of the increased input of hydrogen ions occurs there through the creation of Al^{3+} ions from polymeric Al compounds (Ulrich 1989; Kulhavý 1997).

Carbon, nitrogen, C/N ratio

In 2004–2006, the content of total carbon ranged in particular stands within the limits 43.7–49.3% for L horizon, 27.5–41.1% for F horizon and 15.8–23.0% for H horizon. In the organomineral horizon A_h, the content of total carbon ranged within the limits 5.0–6.8%. In 2004–2006, the content of total nitrogen ranged within the limits 1.1–1.3% for L horizon, 1.2–1.6% for F horizon and 0.7–1.0% for H horizon. In the organomineral horizon A_h, the content of total carbon ranged within the limits 0.2–0.3%. The largest reserve of carbon (Fig. 4) in forest floor occurs in the spruce and in the larch/beech stands –12.9 t/ha and 12.8 t/ha, respectively (488 kg/ha and 532 kg/ha nitrogen, respectively, Fig. 5). Statistically significant differences were detected in carbon reserve in forest floor between mixed stands and a pure spruce and beech monoculture at the level of significance $\alpha = 0.05$; in nitrogen only between mixed stands and a pure beech stand (Table 2). The C/N ratio in forest floor in L and F horizons is similar in all four plots ranging within the limits 37–42 for L horizon and 24–25 for F horizon. The lowest C/N ratio occurs in forest floor in H horizon (Fig. 6) in a pure beech stand (19), the highest C/N ratio is in the spruce stand (24). Mixed stands show identical C/N ratio (22). The C/N ratio in the organomineral horizon A_h is lowest in the mixed spruce/beech stand and pure beech stand (17–18). On the contrary, the highest value was determined in the spruce stand (27).

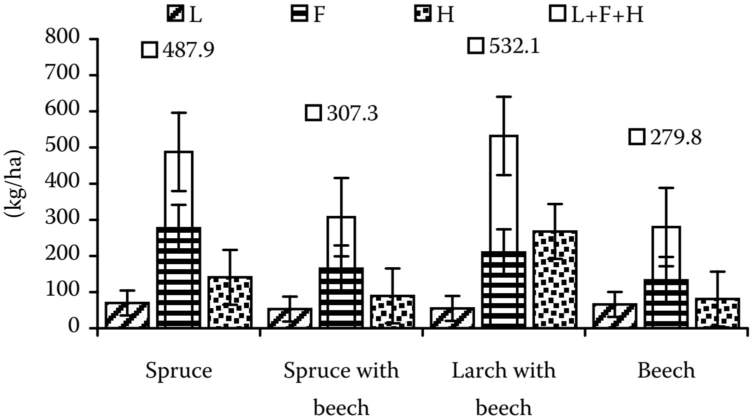

Fig. 5. Nitrogen reserves in forest floor in different experimental stands

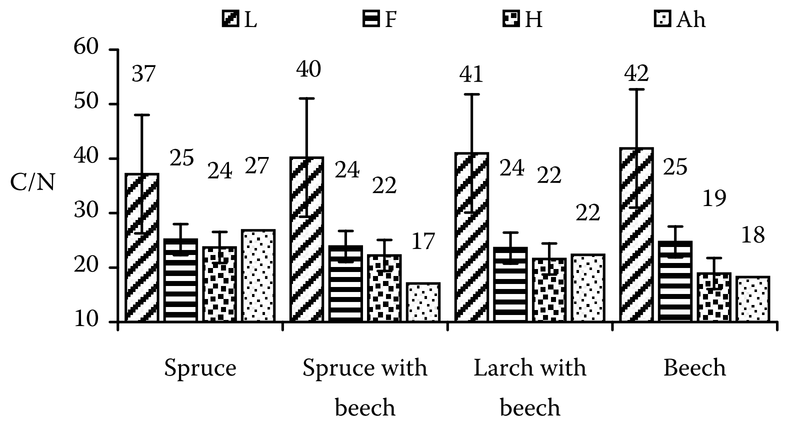

Fig. 6. C/N ratio in forest floor in different experimental stands

Statistically significant differences were not detected in the C/N ratio in forest floor and the organomineral horizon A_h between spruce and beech monocultures and mixed stands under given conditions on the level of significance α = 0.05. On the basis of results obtained, which are consistent with findings of Berger et al. (2002), we can note that in mixed stands of spruce (larch) with beech, the content of total carbon and nitrogen is lower than in the spruce stand. The main indicator of the biomass decomposition rate is just the content of nitrogen and N/C ratio, 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 10–100, in mineral horizons within the limits 10 to 30. However, the evaluation of the C/N ratio is not so clear and differs at particular authors (Vitousek et al. 1982; Binkley, Giardina 1998; Cote et al. 2000; Prescott et al. 2000; Puhe, Ulrich 2001). Emmett et al. (1998) mention the critical value of the C/N ratio in coniferous stands about 24. In broadleaved stands, no limit values have been determined yet to generalize assessing the C/N ratio for forest stands (Hruška, Cienciala 2003). Šály (1978) mentions the C/N ratio 8–20 for forest soils. The C/N ratio has to be assessed within all analyses. Humus decomposition is affected by three main factors: climate, litter quality and the abundance and character of decomposers.

Dissolved organic carbon (DOC)

When determining the content of DOC (Fig. 7) in samples of forest floor and soil horizons, a trend of gradual lowering from L horizon up to Ah in all stands was noted. Statistically significant differences were not detected in the content of DOC in forest floor and soil between spruce and beech stands and mixed stands under given conditions at the level of significance α = 0.05. It is consistent with findings presented by Michalzik et al. (2001), Magill and Aber (2000) that the highest content of DOC was noted in forest floor and then in Ah horizon. It has been proved that forest floor horizons (L, F, H) contain the highest proportion of organic substances and the proportion of organic substances markedly decreases towards depth, which conforms with literature (e.g. Šály 1977). The higher content of DOC shows evidence of the sufficiency of substrates available for soil microorganisms.

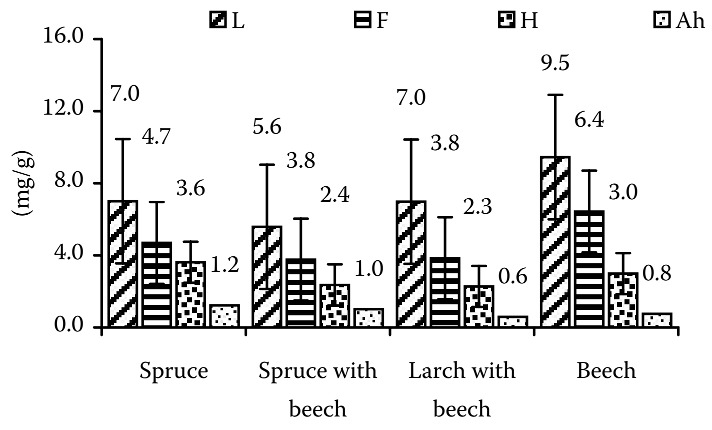

Fig. 7. The content of dissolved organic carbon (DOC) in forest floor in different experimental stands

However, it also means higher risk for soil acidification (Lesná, Kulhavý 2003).

CONCLUSIONS

The presented study compares humus conditions and basic growth characteristics of two mixed stands with unmixed beech and unmixed spruce stands. The research is carried out at a permanent field research station in the region of the Drahanská vrchovina Upland on an identical site, i.e. acid Cambisol in the fir/beech forest vegetation zone. On the basis of our research work it is possible to formulate following conclusions:

- Beech in a mixture with spruce and larch at the age of 25 years falls behind both species, nevertheless it proves sufficient vitality. In a mixture with larch it reaches a little higher mean stand height and higher mean dbh than in a mixture with spruce. An unmixed beech stand shows a very wide diameter range. For the creation of a future quality, stand trees with the largest dbh have to be removed. It is also demonstrated by the high value of basal area.
- Forest floor forms are as follow: moder in spruce stand and both mixed stands, mull-moder in beech stand.
- The statistically highest accumulation of forest floor occurs in the stand of larch with beech (52.6 t/ha) and the statistically lowest one in the unmixed beech stand (22.0 t/ha). The mixed stand of spruce with beech and the spruce stand represent a mean between the stands.
- The active soil reactions of forest floor of the spruce stand 4.0 (± 0.3), unmixed beech stand 5.1 ± 0.3 and mixed stands 4.6–4.8 (± 0.3). Statistically significant differences in active pH occur between a spruce and beech stand and between unmixed spruce and mixed spruce stand with the 30% proportion of beech. Statistically significant difference in exchangeable pH occurs between a spruce and beech stand.
- The highest reserves of carbon (nitrogen) in forest floor in the unmixed spruce stand and in the stand of larch with beech amounted to 12.9 t/ha or 12.8 t/ha of C (488 kg/ha or 532 kg/ha of N). Significant differences were found between a spruce and beech stand and mixed stands in carbon reserves and between beech stand and both mixed stands in nitrogen reserves only.
- The C/N ratio of the spruce stand was 23.5 (± 1.8), which of the beech stand 18.8 ± 2.9. C/N ratio and DOC: statistically significant differences in forest floor and soil between pure spruce and beech stand and mixed stands under given conditions were not found. The DOC content decreased with layers of surface humus towards depth.
- Mixed stands represent by their values of soil conditions a mean between spruce and beech stands.

Results obtained affirm the meaningfulness of the transformation of spruce monocultures to more stable forest by cultivation of beech.

References

BERGER T.W., NEUBAUER CH., GLATZEL G., 2002. Factors controlling soil carbon and nitrogen stores in pure stands of Norway spruce (*Picea abies*) and mixed species stands in Austria. Forest Ecology and Management, *159*: 3–14.

BINKLEY D., GIARDINA C., 1998. Why do tree species affect soil? The Warp and Woof of tree-soil interactions. Biogeochemistry, *42*: 89–106.

BURSCHEL P., HUSS J., 2003. Grundriss des Waldbaus. 3rd Ed. Stuttgart, P. Ulmer: 487.

COTE L., BROWN S., PARE D., FYLES J., BAUHUS J., 2000. Dynamics of carbon acid nitrogen mineralization in relation to stand type, stand age, and soil texture in the boreal mixed wood. Soil Biology and Biochemistry, *32*: 1079–1090.

EMMER I.M., 1999. Methodology of humus form research. Lesnictví-Forestry, *44*: 16–22.

EMMETT B.A., BOXMAN D., BREDEMEIER M., GUNDERSEN P., KJONAAS O.J., MOLDAN F., SCHLEPPI P., TIETEMA A., WRIGHT R.F., 1998. Predicting the effects of atmospheric nitrogen deposition in conifer stands. Evidence from the NITREX ecosystem scale experiments. Ecosystem, *1*: 352–360.

HADAŠ P., 2002. Temperature and precipitation condition in the high elevation spruce stands of the Drahanská vrchovina Upland. Ekológia (Bratislava), *21*, Supplement 1: 69–87.

HRUŠKA J., CIENCIALA E., 2003. Long-term acidification and nutrient degradation of forest soils – limiting factors of forestry today. Prague, Ministry of Environment CR: 165.

HURT V., KANTOR P., 2007. Production potential and ecological stability of mixed forest stands in uplands – VI. A beech/larch stand on a mesotrophic site of the Křtiny Training Forest Enterprise. Journal of Forest Science, *53*: 170–184.

KANTOR P., ŠACH F., 2008. Water balance of young Norway spruce and European beech mountain stands in growing seasons 2005, 2006. Folia Oecologica, *35*: 6–14.

KLÍMA S., 1990. Analýza výsledků probírkových zásahů na výzkumných plochách s modřínem. Lesnictví, *36*: 1001–1022.

KULHAVÝ J., 1997. Acidifikace lesních půd jako půdní proces a ekologický faktor. [Habilitační práce.] Brno, MZLU: 96.

LESNÁ J., KULHAVÝ J., 2003. Evaluation of humus conditions under different forest stands: Beech vs. spruce dominated forest stand. Ekológia (Bratislava), *22*, Supplement 3: 47–60.

MAGILL A.H., ABER J.D., 2000. Dissolved organic carbon and nitrogen relationships in forest litter as affected by

nitrogen deposition. Soil Biology and Biochemistry, *32*: 603–613.
MAŘAN B., KÁŠ K., 1948. Biologie lesa I – pedologie a mikrobiologie lesa. Praha, Melatrich: 573.
MICHALZIK B., KALBITZ K., PARK J.H., SOLINGER S., MATZNER E., 2001. Fluxes and concentrations of dissolved organic carbon and nitrogen – a synthesis for temperate forests. Biogeochemistry, *52*: 173–205.
NĚMEC A., 1928. Studie o humifikaci lesních půd. Praha, MZe RČS, 38/7: 239.
NĚMEČEK J., MACKŮ J., VOKOUN J., VAVŘÍČEK D., NOVÁK P., 2001. Taxonomický klasifikační systém půd České republiky. Praha, ČZU: 79.
OTTO H.J., 1994. Waldökologie. Stuttgart, E. Ulmer: 391.
PELÍŠEK J., 1964. Lesnické půdoznalství. Praha, SZN: 568.
PRESCOTT C.E., CHAPPELL H.N., VESTERDAL L., 2000. Nitrogen turnover in forest floors of coastal Douglas-fir at sites differing in soil nitrogen capital. Ecology, *81*: 1878–1886.
PUHE J., ULRICH B., 2001. Global climate change and human impacts on forest ecosystems. Ecological Studies, *143*: 593.
QUITTE E., 1971. Klimatické oblasti Československa. Studia Geographica 16. Brno, GgÚ ČSAV: 73.
ROBERTSON G.P., BLEDSOE C.S., COLEMAN D.C., SOLLINS P. (eds), 1999. Standard Soil Methods for Long-term Ecological Research. New York, Oxford University Press.
SPARKS D.J., 2003. Environmental Soil Chemistry. 2nd Ed. London, Academic Press: 352.
SPIECKER H., HANSEN J., KLIMO E., SKOVSGAARD J.P., STERBA H., TEUFFEL K. VON (eds), 2004. Norway Spruce Conversion: Options and Consequences. European Forest Institute Research Report 18. Leiden, Boston, Köln, S. Brill Academic Publishers: 269.
ŠÁLY R., 1977. Lesnícke pôdoznalectvo. 2. vydanie. Zvolen, VŠLD: 380.
ŠÁLY R., 1978. Pôda – základ lesnej produkcie. Bratislava, Príroda: 235.
ULRICH B., 1989. Effects of acidic precipitation on forest ecosystems in Europe. In: ADRIANO D.C., JOHNSON A.H. (eds), Acidic Precipitation. Vol. 2. Biological and Ecological Effects. New York, Springer Verlag: 189–272.
VITOUSEK P., GOSZ J.R., GRIER CH.C., MELILLO J.M., REINERS W.A., 1982. A comparative analysis of potential nitrification and nitrate mobility in forest ecosystems. Ecological Monographs, *52*: 155–177.
WARING R.H., RUNNING S.W., 1998. Forest Ecosystems: Analysis at Multiple Scales. San Diego, London, Academic Press: 370.
ZBÍRAL J., HONSA I., MALÝ S., 1997. Analýza půd III. Jednotné pracovní postupy. Brno, ÚKZÚZ: 150.

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Humusové vlastnosti a porostní charakteristiky uměle založených mladých porostů v procesu transformace smrkových monokultur

ABSTRAKT: Hlavním důvodem pro transformaci smrkových monokultur na stanovištích smíšených listnatých lesů je vytvoření přirozeného vztahu mezi dřevinným složením porostu a půdními procesy. Studie porovnává humusové poměry a základní růstové charakteristiky dvou smíšených porostů (smrk s bukem a modřín s bukem) ve věku 25 let s nesmíšeným porostem buku (40 let) a smrku (30 let). Smyslem studie bylo vyhodnotit (*i*) zásobu a formu nadložního humusu, (*ii*) půdní reakci, (*iii*) obsah a zásobu celkového uhlíku a dusíku, poměr C/N a (*iv*) rozpustný organický uhlík (DOC) v porostní charakteristiky (výčetní tloušťku, výšku, kruhovou výčetní základnu). Největší zásoba nadložního humusu byla zjištěna ve smíšeném porostu modřínu s bukem (52,6 t/ha), nejnižší zásoba v nesmíšeném bukovém porostu (21,0 t/ha). Půdní reakce nesmíšeného smrkového porostu je 4,0 (± 0,3), nesmíšeného bukového porostu 5,1 (± 0,3). Poměr C/N nesmíšeného smrkového porostu je 23,5 (± 1,8), nesmíšeného bukového porostu 18,8 (± 2,9). Obsah (DOC) se snižoval s vrstvami povrchového humusu do hloubky. Smíšené porosty reprezentovaly svými hodnotami půdních poměrů střed mezi smrkovým a bukovým porostem.

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

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