Ekológia (Bratislava) Vol. 23, No. 1, 14-23, 2004

LIMING AND FERTILIZATION EFFECTS ON RHIZOSPHERE AND SOIL PROPERTIES IN MOUNTAIN SPRUCE STAND

BOHDAN KONÔPKA, PAVEL PAVLENDA

Forest Research Institute Zvolen, T.G. Masaryka 22, 960 92 Zvolen, The Slovak Republic
e-mail: bkonopka@fris.sk

Abstract

Konôpka B., Pavlenda, P.: Liming and fertilization effects on rhizosphere and soil properties in mountain spruce stand. Ekológia (Bratislava), Vol. 23, No. 1, 14-23, 2004.

Quantity and vertical distribution of fine roots (diameter up to 0.2 cm) were studied in a 80-year-old spruce forest growing in the Low Tatras Mts in the Slovak Republic. The total biomass of fine roots in the LFH horizon and the mineral soil to a depth of 0-20 cm was from 1570 kg per ha (in the year 2002) to 2180 kg per ha (2001). Fine root density was almost 2.5 times higher in the LFH horizon than in the mineral soil at a depth of 10-20 cm. Influences of liming (Varinit) and fertilization (NPK with ratio of elements 8:14:22) on fine root biomass were analyzed as well. Fine root biomass was stimulated in the LFH horizon in the case of liming by Varinit, and in the mineral soil with a depth of 0-10 cm following NPK fertilization. Positive changes in chemical properties of soil, particularly in pH, Ca, Mg, K, and Al, were recorded two years after liming and fertilizing treatments.

Key words: *Picea abies*, fine roots, forest soil, fertilization, liming

Introduction

In the second half of the twentieth century, forest health declined in most European countries and North America. Several hypothesis have been raised to explain this phenomenon with most of them attributing on important role to air pollution (e.g. Krahl-Urban et al., 1988; Flückiger, 1989). Noxious atmospheric compounds damage forest trees either directly uptake via aboveground parts or indirectly via soil and root system.

Sulfur and nitrogen depositions have the most relevant negative consequences in forest soils (van Oene, 1994). Processes like acidification, leaching of nutrients (mostly Ca, Mg, and K) down to deeper soil horizon, and mobilization of toxic heavy metals (mainly Al) are triggered (e.g. Andersson, 1989). Further, also natural nitrogen cycling and element balances change in forest ecosystems following acid deposition. Thus, many scientists currently focus on the pollution effects on soil properties, status and functioning of tree roots, as well as on possibilities to mitigate the negative effects. Although, many studies have been conducted a lot of questions remain unanswered. Because of the spatial variation in the type of air pollution, soil and climatic conditions, as well as forest stand characteristics, the both effects and potential irrigation measures should be addressed individually for different regions.

In spite of the fact that emissions of SO_2, the dominant acidifying component in central Europe, have decreased significantly in the previous decade, the negative effects of S-deposition on forest soil are still proceeding. According to calculations of critical loads and deposition of acidity, critical loads were still exceeded in about 30% of the total forested area in Slovakia. The most acute damage occurs in Norway spruce (*Picea abies* L. Karst.) stands, especially those growing in the seventh altitudinal vegetation zone where forest soils are most sensitive (Minďáš et al., 1999). It is necessary to point out that, even if deposition would decline to levels below the critical limit, ecosystem recovery requires some delay time.

Fine roots and mycorrhyzal fungi suffer most from deteriorating environments (Persson, Majdi, 1995). Usually, fine roots are defined as roots with diameter up to 0.2 cm (e.g Böhm, 1979). This class of roots is typical short-living, characterized by large seasonal changes in standing biomass, and being extremely sensitive to a variety of stresses (Kozlowski, Pallardy, 1997). Simultaneously, fine roots are very important for trees in terms of water and nutrient absorption from soil. Understanding the effects of deposition of noxious compounds on processes in forest soils is necessary for taking efficient measures for restoring favourable soil conditions for optimal growth, development and reproduction of trees. Most probably, fine roots will respond first to improving soil properties and then, revitalization of fine roots makes up suitable conditions for recovering other parts of below- and aboveground parts of tree body.

The aim of this paper is to determine vertical distribution of fine root biomass in soil under mountain spruce stand and its inter-annual variability. Further, to analyze effect of liming and fertilization on quantity of fine roots and chemical properties in the upper soil layer.

Materials and methods

The studies were conducted in a forest stand in Studienec (forest management unit Brusno) located in the southern part of the Low Tatra Mts (the Slovak Republic) at an altitude of 1180 m a.s.l. The mean slope was 70%, eastern aspect. The stand was about 80 years old, with Norway spruce as a dominant tree species (70%). Mean diameter at breast height was approximately 30 cm, mean height 23 m, and standing stem volume about 280 m^3 per ha. The soil has been classified as a Dystric Cambisol. Parent material is a slope deposit of granodiorit. The humus has been classified as a mull-like moder. The content of coarse fragments is relatively high and increases from about 35% in the A horizon up to 85% in the deeper parts of the C horizon (below 70 cm).

In mid-June 2000, four research plots sized 6x5 m were established in the forest stand. The first plot was limed (code V) with Varinit. Varinit is a very fine milled mixture of calcium/magnesium carbonate slag and dolomitic limestone (CaO+MgO content is 48-52%, 12% of which is Mg) and was applied on the soil surface in amount of 0.66 kg per m^2. Another plot (code NPK) was fertilizer with 0.12 kg.m^{-2} of an NPK fertilizer. The ratio of N, P, and K in the NPK fertilizer was 8:14:22. The third plot received a combination of both Varinit and NPK fertilizer (V+NPK). The fourth, control plot (C) was neither fertilized not limed. The applied doses of Varinit (i.e. 6.6 t per ha) and NPK fertilizer (1.2 t per ha) correspond to upper quantities used in forestry practice.

To quantify of fine root biomass, the soil-coring method was used. Soil cores were taken with an auger having an inner diameter of 5.4 cm. In June 2000, 40 soil cores were taken from the C plot. We were able to penetrate the mineral soil only down to 20 cm because of the very high proportion of skeleton. The soil cores were separated into forest floor (LFH – organic horizon: litter, fermentation layer, and humification layer together) and for sub-samples of the mineral layer (0-10 cm and 10-20 cm). The sub-samples were carefully transferred into plastic bags and stored in a deep-freezer at –20°C before sorting. To assess inter-annual variability in fine root biomass, the soil of the C plot was sampled again in June 2001 and June 2002, following the same procedure as in 2000.

To assess effects of liming and fertilization on fine root biomass, soil cores were taken in June 2002 in the V, NPK and V+NPK plots. We sampled 15 soil cores per plot. All samples were treated in the same way as those sampled in 2000.

Living roots below 0.2 cm in diameter were hand-picked from the soil samples. Root characteristics such as color, smell, resilience, existence of root hairs, and wood structure were used to distinguish spruce roots from roots of herbs or bushes. Roots considered as living were those with higher resilience, firm and with good adhesion between the stele and cortex. Dead roots were disposed. Roots were sorted into two diameter classes (< 0.1 cm and 0.1-0.2 cm) and washed in water. The length of the roots in diameter class of 0.1-0.2 cm was measured with a precision of 0.1 cm. The length of the roots with diameter below 0.1 cm was not measured, because there were extremely ramified and fragile. The roots of both diameter classes were dried to constant weight at 70°C for 24 hours. Dry roots were weighed with a precision of 1 mg.

In June 2002, soil samples were taken to analyze chemical properties of soil in the four research plots (4 sub-samples per plot). Each sample was analyzed for pH, cation exchange properties (exchangeable Ca, Mg, K, Al), following the procedures of Bucha et al. (1998) and UN/ECE (1998).

Results

In June 2000, total fine root biomass was 1610 kg per ha in the C plot (Table 1). Most fine roots (750 kg per ha) occurred in the upper most layer 0-10 cm of the mineral soil. Fine root biomass (380 kg per ha) at a depth of 10-20 cm in the mineral soil was much smaller. Biomass of the finest root class (diameter < 0.1 cm) (940 kg per ha) prevailed over those with diameter of 0.1-0.2 cm (680 kg per ha). Total length in the larger diameter class was 870 km.ha^{-1}.

In June 2001 and 2002 fine root biomass was 2180 kg.ha^{-1} and 1570 kg.ha^{-1}, respectively (Tables 2 and 3). Also in these years, the largest part of fine root biomass was found in the mineral soil at a depth of 0-10 cm. The pattern of vertical distribution was similar in each year. The proportion of fine root biomass in the LFH horizon (mean depth 5.9 cm) was 31% (in the June 2000), 34% (June 2001), and 36% (June 2002). The biomass of fine roots in the uppermost mineral soil layer was 46%, 41%, and 38%, and in the lower mineral soil layer 23%, 25%, and 26%, in 2000, 2001 and 2002, respectively. In the LFH horizon and the mineral soil at a depth of 0-10 cm, biomass of fine roots with diameter < 0.1 cm prevailed over that of roots with a diameter between 0.1-0.2 cm. In the mineral soil at a depth of 10-20 cm, root biomass of both diameter classes was similar.

Fine root density decreased from the LFH horizon to the lowest mineral soil layer in all three years (Fig. 1). The density of fine roots in the LFH horizon was almost 2.5 times higher than in the mineral soil at a depth of 10-20 cm.

Table 1. Biomass of fine roots (average ± standard deviation) determined in June 2000

Soil layer [cm]	Diameter class of fine roots				
	< 1 mm	1-2 mm		up to 2 mm	
	weight [kg.ha^{-1}]	weight [kg.ha^{-1}]	length [km.ha^{-1}]	weight [kg.ha^{-1}]	proportion of weight [%]
LFH	315 ± 113	176 ± 70	255 ± 105	491 ± 187	31 ± 12
0-10	416 ± 245	332 ± 216	385 ± 258	748 ± 463	46 ± 22
10-20	204 ± 143	171 ± 137	233 ± 189	375 ± 281	23 ± 14
Together	935 ± 523	679 ± 407	873 ± 541	1614 ± 936	100

Table 2. Biomass of fine roots (average ± standard deviation) determined in June 2001

Soil layer [cm]	Diameter class of fine roots				
	< 1 mm	1-2 mm		up to 2 mm	
	weight [kg.ha^{-1}]	weight [kg.ha^{-1}]	length [km.ha^{-1}]	weight [kg.ha^{-1}]	proportion of weight [%]
LFH	481 ± 125	269 ± 65	391 ± 102	750 ± 191	34 ± 14
0-10	548 ± 318	343 ± 219	397 ± 258	891 ± 544	41 ± 18
10-20	254 ± 170	282 ± 206	384 ± 280	536 ± 375	25 ± 11
Together	1283 ± 641	894 ± 483	1171 ± 597	2177 ± 1132	100

Table 3. Biomass of fine roots (average ± standard deviation) determined in June 2002

Soil layer [cm]	Diameter class of fine roots				
	< 1 mm	1-2 mm		up to 2 mm	
	weight [kg.ha^{-1}]	weight [kg.ha^{-1}]	length [km.ha^{-1}]	weight [kg.ha^{-1}]	proportion of weight [%]
LFH	381 ± 122	177 ± 67	257 ± 73	558 ± 195	36 ± 13
0-10	373 ± 219	227 ± 120	263 ± 142	600 ± 332	38 ± 15
10-20	202 ± 163	206 ± 152	281 ± 195	408 ± 308	26 ± 12
Together	956 ± 554	610 ± 326	801 ± 428	1566 ± 822	100

The surface application of Varinit, NPK-fertilizer and their combination influenced chemical soil properties significantly in the LFH horizon (Figs 2-6). The large changes were recorded for soil acidity, with pH increasing from 3.6 in the control plot in the LFH horizon to 5.2 after the application of Varinit and to 5.5 after the application of Varinit and NPK-fertilizer. The application of the NPK fertilizer did not change soil acidity significantly in the LFH horizon. Also, pH of the mineral soil (depth 0-10 cm and 10-20 cm) was negligibly

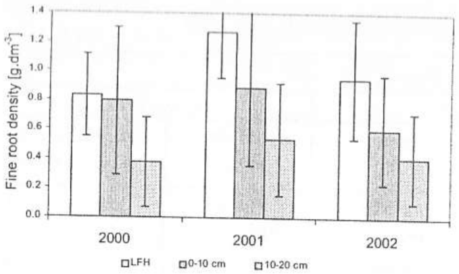

Fig. 1. Fine root density in the LFH horizon and mineral soil with depth of 0-10 and 10-20 cm in Junes 2000, 2001, and 2002. Vertical bars indicate SD (= standard deviation).

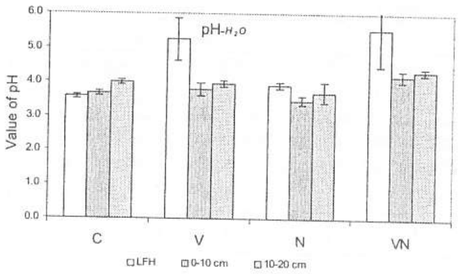

Fig. 2. Values of pH$_{\text{-H2O}}$ in in the LFH horizon and mineral soil with depth of 0-10 and 10-20 cm in June 2002 on the particular research plots (C–control, V–treated by Varinit, N–treated by NPK, VN–treated by both Varinit and NPK). Vertical bars indicate SD.

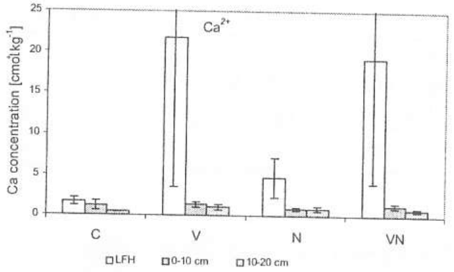

Fig. 3. Concentration of Ca in the LFH horizon and mineral soil with depth of 0-10 and 10-20 cm in June 2002 on the particular plots (C–control, V–treated by Varinit, N–treated by NPK, VN–treated by both Varinit and NPK). Vertical bars indicate SD.

effected by the treatments. Regarding to the concentrations of particular elements in the forest soil, the strongest effect was recorded for the application of the Varinit and then for the combined application of the Varinit and NPK fertilizer. Following these treatments, concentrations of exchangeable basic elements, especially Ca and Mg, increased remarkably. In addition, the concentration of mobile Al was reduced in the LFH horizon.

Surface application of Varinit influenced clearly biomass of fine roots in the LFH horizon where its quantity exceeded that of the control plot by 41% (Fig. 7). In the mineral soil having a depth of 0-10 cm, biomass of fine roots was enhanced surprisingly most in the plot treated with the NPK fertilizer (by 67%). In contrast with this tendency, the application of NPK fertilizer had a slightly negative effect on the fine root biomass in the LFH horizon. Effect of the combined application of Varinit and NPK fertilizer on fine root biomass was more stimulative in the mineral soil than in the LFH horizon.

Discussion

Standing fine root biomass at the spruce stand under investigation was between 1570 kg.ha^{-1} (2002) and 2180 kg.ha^{-1} (2001). Most authors (e.g. Ares, Peinemann, 1992; Finnér, 1991; Kodrík, 1999; Persson, 1980) reported higher quantities of fine root biomass in mature coniferous stands, usually a couple of thousands kg per ha. However, our results do not show the total biomass of fine roots (although a substantial part) in the entire soil profile, but is limited to the upper 26 cm. Also, the determined fine root biomass does not necessarily express an equilibrium, because biomass of fine roots fluctuates over the year, especially in the growing season. Konôpka, Tsukahara (2000) showed a significant increase of fine root biomass in the beginning of the growing season, when trees need to replace fine roots that died during unfavourable conditions in winter. Persson (1996) observed strong correlations between the seasonal courses of temperature and precipitation, and that of the fine root vitality (and consequently also quantity).

We observed the highest fine root density in the LFH horizon. Similar results were obtained by Konôpka and Steiner (2001) in a 60-year-old spruce-fir stand, where the density of fine roots in the LFH horizon was about 2.0, 2.5, and almost 5.0 times higher in comparison with the mineral soil at depths of 0-10, 10-20, and 20-30 cm, respectively. Hence, the density of fine roots decreased sharply with soil depth. Similarly, extremely dense concentrations of fine roots in the LFH horizon were observed in heavy soils (Persson, 1980) and in poorly drained soils (Finér, 1991). Both these authors attributed the sharply decreasing fine root biomass

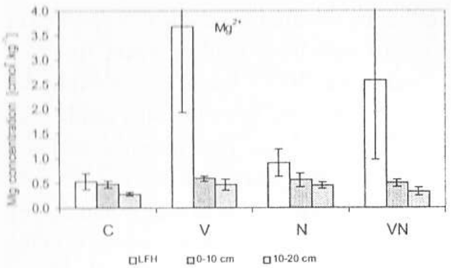

Fig. 4. Concentration of Mg in the LFH horizon and mineral soil with depth of 0-10 and 10-20 cm in June 2002 on the particular plots (C–control, V–treated by Varinit, N–treated by NPK, VN-treated by both Varinit and NPK). Vertical bars indicate SD.

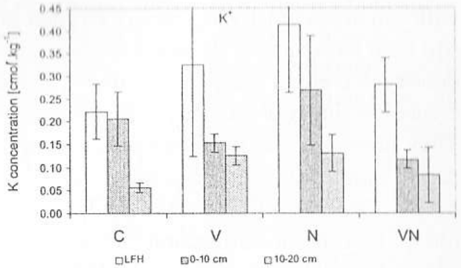

Fig. 5. Concentration of K in the LFH horizon and mineral soil with depth of 0-10 and 10-20 cm in June 2002 on the particular plots (C–control, V–treated by Varinit, N–treated by NPK, VN–treated by both Varinit and NPK). Vertical bars indicate SD.

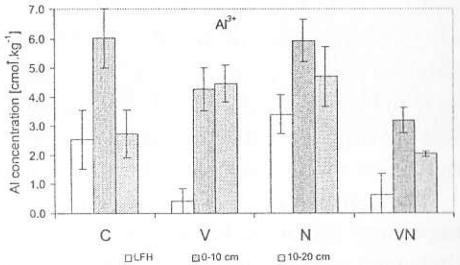

Fig. 6. Concentration of Al in the LFH horizon and mineral soil with depth of 0-10 and 10-20 cm in June 2002 on the particular plots (C–control, V–treated by Varinit, N–treated by NPK, VN–treated by both Varinit and NPK). Vertical bars indicate SD.

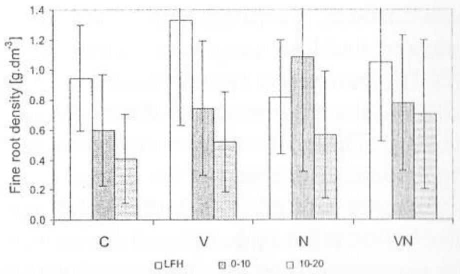

Fig. 7. Fine root density in the LFH horizon and mineral soil with depth of 0–10 and 10–20 cm in June 2002 on the particular plots (C–control, V–treated by Varinit, N–treated by NPK, VN–treated by both Varinit and NPK). Vertical bars indicate SD.

with soil depth mostly to a lack of oxygen caused either by unsuitable physical properties of soil (soil structure) or by water over-supply. In contrast with these studies where fine root density decreased sharply with depth, Konôpka, Tsukahara (2000) found rather slight decreases of fine root biomass with soil depth in a mature pine stand growing on a sandy soil. They observed a close linear relationship between density of fine root biomass and soil depth. Similarly, Ares, Peinemann (1992) stated that fine roots penetrated sandy soils very deeply. Generally, fine roots in sandy soils can reach deeper layers than in loamy and clayey ones. The vertical distribution of fine roots is governed also by nutrient concentration in the particular soil layers (Kozlowski, Pallardy, 1997). If nutrients are concentrated in the upper soil horizons, fine roots do not need to penetrate deeper layers.

After Konôpka, Tsukahara (2000), vertical distribution and total fine root biomass also depended on tree age. Vogt et al. (1987) proved that biomass of fine roots in conifers increased with stand age, until a certain stage of growth. After these authors, the stage of growth when fine root biomass reaches a maximum is often identical to the time of canopy closure. Once canopy closure has occurred, fine root biomass of conifers remains relatively constant in low-productivity stands, but decreases in high-productivity stands. Also, significant differences in total fine root biomass and in its vertical distribution are expected between particular tree species. For instance, Konôpka, Steiner (2001) found out that 60-year-old Norway spruces had 10% higher fine root biomass than silver firs of the same age and growing in similar conditions. At the same time, spruces had more shallowly distributed fine roots in comparison with the firs.

The concentration of a major part of fine root biomass in the LFH horizon or in the uppermost soil layers has at least two significant consequences. A negative consequence is that upper soil horizons suffer most intensively from stressing factors, such as acidification and climatic extremes. Deeper soil layers are usually less influenced by those stresses, but only a small fraction of fine roots grows in them. On the other hand, the shallow distribution of fine root biomass allows relatively fast access to nutritional compounds in the case of surface application of soil-improving materials. Our results proved positive chemical changes in the LFH horizon two years after application of the Varinit, NPK fertilizer and its combination. The values of pH increased remarkably, concentration of nutrients enhanced (K, Mg, and Ca), and concentrations of mobile Al decreased. Similarly, Frank, Stuanes (2003) showed that lime application increased pH and base saturation in the humus layer shortly after the treatment and then subsequently these effects moved slowly downward in the soil. These authors also stated that the type of liming material, its solubility and the applied doses determined the intensity and timing of treatment effects on the forest soil. Falkengren-Grerup (1995) proved that addition of Ca, Mg and K without raising pH was not sufficient for a good growth of plants. Thus, application of fertilizers should preferably be accompanied by pH-stabilization measures. This approach has been proved very efficient for improving vitality of Mg-deficient trees (Schaaf, 1995).

The positive chemical changes in the spruce stand also influenced fine root biomass. A stimulating effect of fertilizer containing N, K, Mg, and mainly P on biomass of fine roots was shown by Konôpka, Tsukahara (2001) in a pine stand growing on a sandy soil. Similarly, Adams, Hutchinson (1992) recorded significant stimulative effects of phosphorus on fine roots of maple. Several studies have focused on the influence of nitrogen fertilization on fine roots. Hendricks et al. (1993) summarized results from these nitrogen experiments and stated that results were ambiguous: stimulative, insignificant, and even suppressing effects on fine root quantity were also observed. In most European forest soils, nitrogen concentrations are sufficient for the physiological activity of trees. Thus, in frame of reclamation measures (fertilization), it is usually no use to add nitrogen in big amount. Nilsson, Wiklund (1995) found out that a fertilizer including all necessary macronutrients except N was efficient in restoring nutrient balances in Norway spruce stands in southern Sweden. However, at the same time, N applied alone usually accelerated tree growth in these forest ecosystems.

Positive effect on nutrient status in the upper soil horizons is only one of the effects of fertilization on forest soils and forest ecosystems. Chemical changes in the uppermost soil humus layer usually occur very rapidly but improvement of the mineral topsoil and deeper soil horizons is only very gradual (Huettl, Zoettl, 1993; Podrázský, 1996). On the other hand, liming and fertilization may cause acidification of the subsoil and may lead to higher NO_3 displacement as well as to increased leaching losses of basic cations. After Kreutzer (1995), liming as a de-acidification measure may accelerate humus decomposition and increase nitrate leaching. In addition, liming and fertilizing tended to stimulate root growth in the uppermost soil layers, increasing the risk of drought, frost and windthrow damage (Huettl, Zoettl, 1993).

Conclusions

We found that liming and fertilization positively effected chemical properties of the topsoil and tended to stimulate growth of fine roots in the Norway spruce stand. Commonly, in terms of improving forest soil conditions, materials containing mainly Ca and Mg (lime or dolomite) should be used. Nutritional deficiency in soils can be compensated through a NPK fertilizer having a lower proportion of nitrogen (about 4-5 times) than phosphorus and potassium. Ameliorating materials would be well soluble (sufficient proportion of dust particles or granulated form). In such a case, nutrients can easily reach the upper soil layers containing a major part of fine root biomass and help in tree-revitalization processes. On the other hand, the materials should also contain a certain proportion of slowly releasable particles for maintaining suitable soil properties in a long-term perspective. Liming and fertilization can improve nutritional status of declining stands, especially in the case of Mg-deficiency. However, as forest liming and fertilization may be associated with ecological risks, a careful analysis concerning the need for liming should be carried for each potential treatment area.

Translated by the authors

Acknowledgement

The authors would like to thank Mr. Miroslav Lipnický for his technical assistance in the fieldwork and Prof. Ivan A. Janssens for valuable comments on the manuscript.

References

Adams, C.M., Hutchinson, T.C., 1992: Fine-root growth and chemical composition in declining Central Ontario sugar maple stands. Can. J. For. Res., *22*, p. 1489-1503.

Ares, A., Peinemann, N., 1992: Fine-root distribution of coniferous plantations in relation to site in southern Buenos Aires, Argentina. Can. J. For. Res., *22*, p. 1575-4582.

Andersson, F., 1989: Air pollution impact on Swedish forests – Present evidence and future development. Environmental Monitorring and Assessment, *12*, p. 19-38.

Böhm, W., 1979: Methods of Studying Root System. Springer-Verlag, Berlin, 188 pp.

Bucha, T., Pajtík, J., Pavlenda, P., Maňkovská, B., Minďáš, J., 1998: Manual on methods and criteria for harmonised sampling, assessment, and analysis of the effects of air pollution on forests – ČMS Lesy (in Slovak). LVÚ Zvolen, 122 pp.

Falkengren-Grerup, U., 1995: Replacement of nutrient losses caused by acidification of a beech forest soil and its effects on transplanted field-layer species. Pland and Soil, *168-169*, p. 187-193.

Finnér, L., 1991: Root biomass on an ombrotrophic pine bog and the effects of PK and NPK fertilization. Silva Fennica, *25*, p. 1-12.

Flückiger, W., 1989: Possible causes of forest decline and research programmes in Europe. Nature and Environment Series, *43*, Council of Europe, Strasbourg, 100 pp.

Frank, J., Stuanes, A.O., 2003: Short-term effects of liming and vitality fertilization on forest soil and nutrient leaching in a Scots pine ecosystem in Norway. For. Ecol. Manage., *176*, p. 371-386.

Hendricks, J.J., Nadelhoffer, K.J., Aber, J.D., 1993: Assessing the role of fine roots in carbon cycling. Tree, *8*, p. 79-86.

Huettl, R.F., Zoetl, H.W., 1993: Liming as a mitigation tool in Germany's declining forests – reviewing results from former and recent trials. For. Ecol. Manage., *61*, p. 325-338.

Kodrík, M., 1999: Research on belowground biomass and its health conditions of the most common tree species in Slovakia (in Slovak). Habilitation thesis. Forest Ecology Institute, Zvolen, 111 pp.

Konôpka, B., Tsukahara, H., 2000: Biomass of Fine and Small Roots in Two Japanese Black Pine Stands of Different Ages. J. For. Res., *5*, p. 71-76.

Konôpka, B., Tsukahara, H., 2001: Production and vertical distribution of fine and small roots in Japanese black pine on sandy soil. J. For. Sc., *47*, p. 277-284.

Konôpka, B., Steiner, Z., 2001: Biomass of Norway spruce and silver fir rootlets in a mixed spruce-fir stand. In Minďáš, J. (eds): Perspectives of the ecological research in mountain forest ecosystems. Forest Research Institute, Zvolen, p. 90-91.

Kozlowski, T.T., Pallardy, S.G., 1997: Physiology of Woody Plants. Academic Press, San Diego, 411 pp.

Krahl-Urban, B., Papke, H.E., Schimansky, Ch., 1988: Forest Decline. Jülich Nuclear Research Center, Jülich, 137 pp.

Kreutzer, K., 1995: Effects of forest liming on soil processes. Plant and Soil, *168-169*, p. 447-470.

Minďáš, J., Pavlenda, P., Škvarenina, J., Kremler, M., Pukančíková, K., Závodský, D., 1999: Critical loads of acidity for Slovak forest ecosystems. Meteorologický časopis – Meteorological Journal, *2*, p. 15-24.

Nilsson, L.-O., Wiklund, K., 1995: Nutrient balance and P, K, Ca, Mg, S and B accumulation in a Norway spruce stand following ammonium sulphate application, fertigation, irrigation, drought and N-free-fertilisation. Plant and Soil, *168-169*, p. 437-446.

Pavlenda, P., 1996: Forest soil liming – experience and perspectives (in Slovak). Lesnícky časopis – Forestry Journal, *42*, p. 429-435.

Persson, H., 1980: Spatial distribution of fine-root growth, mortality and decomposition in a young Scots pine stand in Central Sweden. OIKOS, *34*, p. 77-87.

Persson, H., 1996: Fine-root dynamics in forest trees. In Persson, H. Batulin, I.O. (eds): Plant root systems and natural vegetation. Acta Phytogeographica Suecica, *81*, p. 17-23.

Persson, H., Majdi, H., 1995: Effects of acidic deposition on tree roots in Swedish forest stands. Water, Air and Soil Pollution, *85*, p. 1287-1292.

Podrázský, V., 1996: Liming of spruce plantations on the top locality of the Jizerské Mts. Scientia Agriculturae Bohemica, *27*, p. 271-282.

Schaaf, W., 1995: Effects of Mg(OH)$_2$-fertilization on nutrient cycling in a heavily damaged Norway spruce ecosystem (NE Bavaria/FRG). Plant and Soil, *168-169*, p. 505-511.

UN/ECE, ICP Forests, 1998: Manual on methods and criteria for harmonised sampling, assessment, monitoring and analysis of the effects of air pollution on forests. BFH Hamburg.

Van Oene, H., 1994: Modeling the impacts of sulphur and nitrogen deposition on forests. Dissertation, Swedish University of Agricultural Sciences, Uppsala, 212 pp.

Vogt, K.A., Vogt, D.J., Moore, E.E., Fatuga, B.A., Redlin, M. R., Edmonds, R.L., 1987: Conifer and angiosperm fine-root biomass in relation to stand age and site productivity in Douglas-fir forests. Journal of Ecology, *75*, p. 857-870.

Received 18. 3. 2003

Konôpka B., Pavlenda P.: **Vplyv vápnenia a hnojenia na rizosféru a pôdne vlastnosti v horskej smrečine.**

Skúmali sme kvantitu a verikálnu distribúciu jemných koreňov (hrúbky do 0,2 cm) 80 ročných smrekov rastúcich v pohorí Nízkych Tatier. Celková biomasa jemných koreňov v LFH horizonte a v minerálnej pôde s hĺbkou 0-20 cm bola od 1570 kg na ha (rok 2002) do 2180 kg na ha (2001). Hustota jemných koreňov klesala s hĺbkou pôdy, keď v LFH horizonte bola takmer 2,5 krát vačšia než v minerálnej pôde s hĺbkou 10-20 cm. Taktiež sme analyzovali vplyv vápnenia (Varinit obsahujúci hlavne Ca a Mg) a hnojenia (NPK s podielom elementov 8:14:22) na biomasu jemných koreňov. Kvantitu jemných koreňov stimulovalo v LFH horizonte použitie Varinitu a v minerálnej pôde s hĺbkou 0-10 cm hnojenie s NPK. Pozitívne zmeny sme zaznamenali pri chemických vlastnostiach pôdy, konkrétne pre hodnoty pH, Ca, Mg, K a Al dva roky po vykonaní povrchového vápnenia a hnojenia.