Source: Maaten-Theunissen M, Spiecker H, Gärtner H, Helle G, Heinrich I (Eds.) (2011): TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 9. GFZ Potsdam, Scientific Technical Report STR 11/07, Potsdam, p. 71 - 78.

Growth and Nutrition Status of Spruce (*Picea abies* (L.) KARST.) in Mountain Regions with Different Nitrogen Load Levels

M. Vejpustková [1], V. Šrámek [1] & D. Zahradník [2]

[1] *Forestry and Game Management Research Institute, Strnady 136, 252 02 Jílovitště, Czech Republic*
[2] *Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 21 Praha 6 – Suchdol, Czech Republic*
E-mail: vejpustkova@vulhm.cz

Introduction

Forests in the northern part of the Czech Republic were highly influenced by the air pollution (SO_2, NO_x) till the end of the 1980ies. By the end of the 1990ies the SO_2 emissions were reduced by nearly 90% (Fiala et al. 2002). Nevertheless the nitrogen (N) deposition remained at high level – mean total annual N-deposition exceeded 25 kg.ha^{-1} in this area (Lochman et al. 2004).
During 1999 - 2002 severe damages have been recorded within the spruce stands in the Orlické and Krušné Mountains (Czech Republic). In the Orlické Mountains mainly young spruce stands showed symptoms of damage (e.g. drying of terminal shoots, or dieback of the upper part of the crown), whereas in the Krušné Mountains widespread yellowing of spruce stands of all age classes occurred (Šach et al. 1999, Lomský & Šrámek 2004, Čermák et al. 2005). Spruce growth, however, was not affected negatively; young spruce stands showed extraordinary high height increments (Vejpustková et al. 2004). The impact of N-deposition was hypothesized.
This study aimed at the analysis of growth trends of Norway spruce (*Picea abies* (L.) KARST.) in a problematic region (Orlické Mountains, western part of Krušné Mountains) and in Žďárské Vrchy as a control locality (mean total annual N-deposition about 10 kg.ha^{-1}). At the same time as the deposition measurements, soil chemistry and nutrition amount in needles was measured to provide insight into the nutrient cycling.

Material and Methods

The Orlické and Krušné Mountains are situated in the northern part of the Bohemian Massif. The control locality Žďárské Vrchy belongs to the Czech-Moravian Highlands and it is located in the central part of the Bohemian Massif (Fig. 1). The localities were selected to represent similar site and climatic conditions (Tab. 1). Spruce stands on poor sites with a share of spruce of more than 80% were included. In the Orlické and Krušné Mountains stands exhibiting yellowing or other types of damage were preferred.

Table 1: Position and characteristics of the study sites

Region, Locality	Position		Altitude	Soil	Mean annual Temperature (°C)	Sum of annual Precipitation (mm)
	N Lat	E Long	m a.s.l.	type		
Orlické Mts., Šerlich	50°16'	16°23'	870-1010	podzol	5,4	1196
Krušné Mts., Přebuz	50°23‘	12°36‘	880-940	podzol	5,7	800
Žďárské Vrchy, Čachnov	49°43'	16°04'	680-775	cambisol	5,8	765

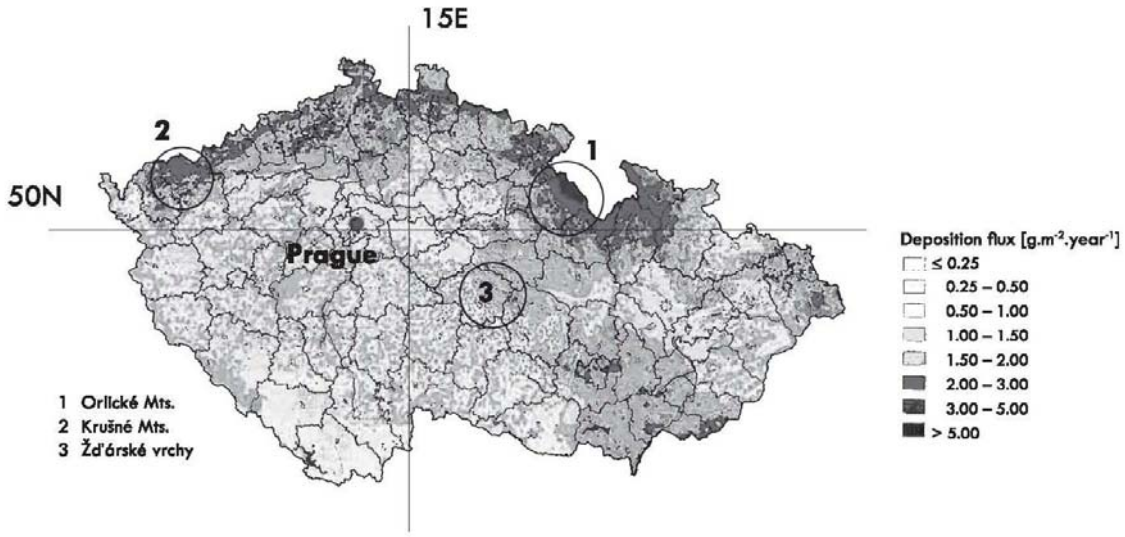

Figure 1: Map of total annual nitrogen deposition in the Czech Republic in 1999. Circles: location of the study sites.

Norway spruce growth was examined by means of detailed stem analysis of 10 sample trees of one mature spruce stand (age 120 years and more) in each region and height growth measurement of at least 400 spruce trees at the age of 10 to 50 years in each region. Sampling and growth measurements were done in the period 2002 – 2004.

For the stem analysis 10 dominant trees were cut in the mature spruce stand. First stem disc was taken in the height of 130 cm above ground (DBH), other discs then in two-meter sections. Radial increments were measured at each stem disc along 4 radii. Ring-width measurement was done using measuring table Kutschenreiter, with an accuracy of 0.01 mm. Individual ring-width series were visually cross-dated, dating was verified statistically with the COFECHA program (Holmes 1983). Verified series were used to state a height growth of the trees, derived as an average height increment in corresponding stem section, as a quotient of the section length (2 m) and the difference of tree-ring number at the beginning and the end of two-meter section.

The ring-width series of breast-height discs were standardised to eliminate the age trend with the program ARSTAN (Holmes et al. 1986). The resulting index series were aggregated by calculating mean values into the local chronology.

Height growth of the young stands was determined by measuring the annual internode lengths on an individual tree basis beginning from the tree top. For further evaluation the young stands were divided into 4 groups according to the age classes: (1) 10 – 20 years, (2) 21 – 30 years, (3) 31 – 40 years, (4) 41 – 50 years. The mean height growth curves for individual age classes were plotted.

Atmospheric deposition, soil chemistry, forest nutrition

The growth patterns in three regions investigated can be characterized by the different levels of nitrogen deposition and different quality of forest nutrition. Relationship of growth to nitrogen input was analysed in the regions of Orlické Mountains and Žďárské Vrchy, where the atmospheric deposition data were at disposal for the period 1993 - 2001.

Analysis of the soil chemistry was done in each region in the mature Norway spruce stand. Soil samples were taken in the whole profile, by genetic horizon. In the samples exchangeable amount of nutrients were stated (Al, Ca, Fe, K, Mg, Mn, Na, Zn) extracted in NH_4Cl, pseudototal element amount (Al, Ca, Fe, K, Mg, Mn, Na, Pb, S, Zn) in *Agua regia*, pH (H_2O), pH(KCl), total amount of C, N, and S, exchangeable P and dry mass stated.

Nutrition of trees was illustrated by chemical analyses of the foliage. Mixed samples of needles of individual needle year classes were melted in a mill of titanium head; then samples were

decomposed in nitrogen acid and hydrogen peroxide in microwave system MDS 2000. Amounts of P, K, Ca, Mg, Fe, Mn, B, S were stated at ICP-OES, nitrogen at CNS analyzer.

Results

Norway spruce growth

The mean ring-width chronologies of mature sample trees show high coincidence in inter-annual variation (Fig. 2). It can be supposed that the growing conditions are comparable at the study sites and tree response is similar.

After 1970 a major growth depression with minimum increment in the period 1980 – 1986 was observed in Šerlich (Orlické Mts.) and Přebuz (Krušné Mts.). Afterwards a sharp growth increase since 1987 in Šerlich and Přebuz, and since 1997 also in Čachnov (Žďárské vrchy) is indicated (Fig. 2).

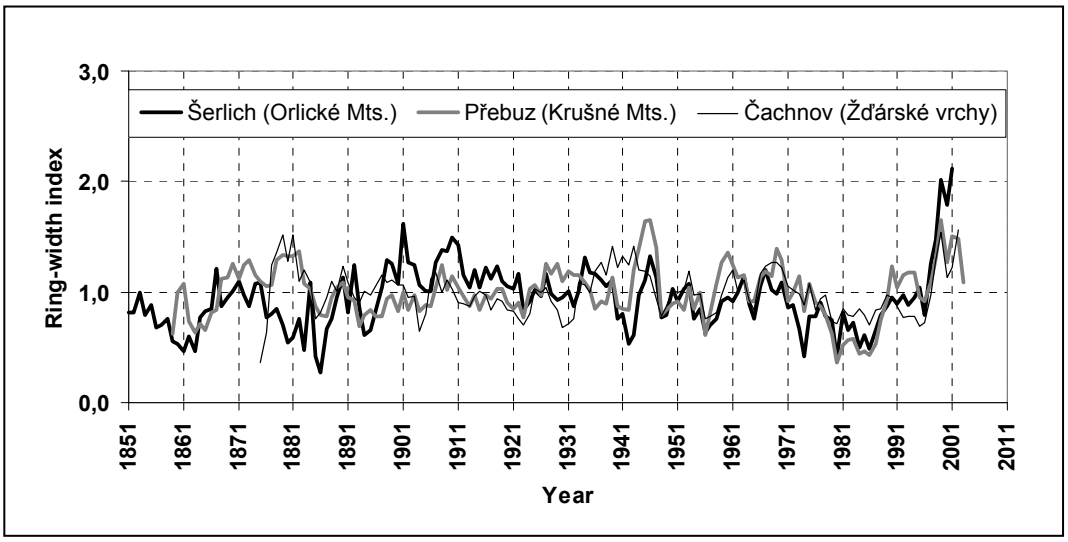

Figure 2: Ring-width chronologies of mature spruce trees.

Tree height of mature sample trees is increasing constantly; typical flattening of the height growth curve in mature age is not visible (Fig. 3). In the plots Přebuz and Čachnov the trend of height growth is almost linear over the whole lifespan of the trees.

The shift in the height curve levels was proved for the young stands (10 – 50 years of age) (Fig. 4). A significant increase of height at tree age of 15 years was found in the period 1975 – 2001. The trend was of the magnitude 1,3% per year in Žďárské vrchy, 2% per year in the Krušné Mts. and 7% per year in the Orlické Mts.

For mature spruce trees correlation analysis did not prove positive relation of growth to nitrogen inputs neither in Orlické Mts., nor in Žďárské vrchy. By contrast, for young spruce trees a significant positive correlation of annual height increment with annual wet nitrogen deposition rates was found in both regions.

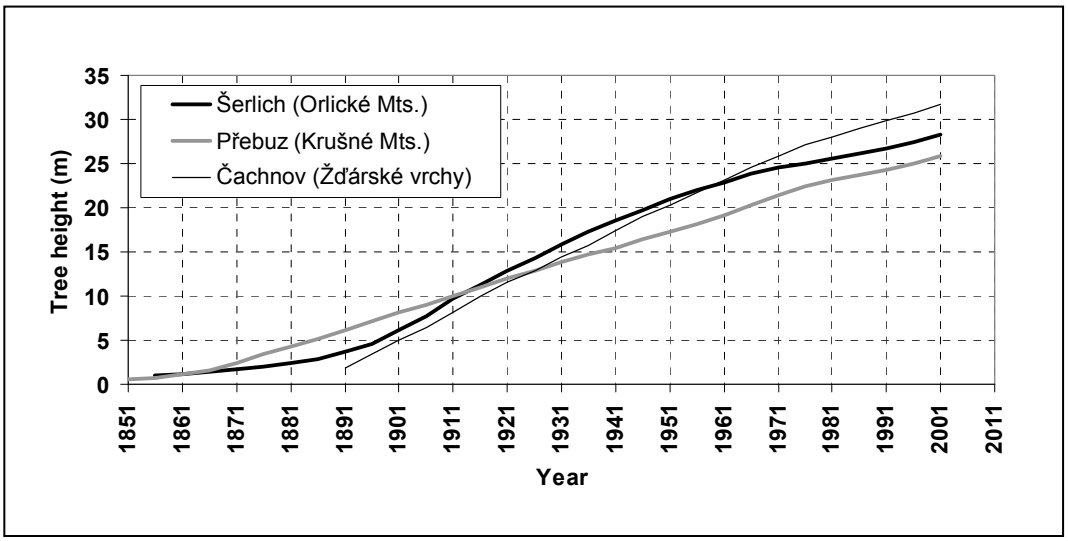

Figure 3: Height growth of mature spruce trees

Soil chemistry, nutrition amount in needles

In the localities Šerlich, Přebuz and Čachnov the soil chemistry can be classified as disturbed (Tab. 2). The values of active $pH_{(H_2O)}$ and exchangeable $pH_{(KCl)}$ confirm high acidity of the soil in all horizons (pH<4). Nitrogen amount in the soil was the highest in Šerlich, in the whole soil profile. High N concentrations even in deeper soil horizons (0,19% in 30 cm) confirm saturation of the humus and upper mineral soil layers by nitrogen, and it seems to be probable, that N is leached to deeper horizons. All studied plots exhibit significant deficit in the exchangeable calcium (<140 $mg.kg^{-1}$) and magnesium (140 $mg.kg^{-1}$) contents in the mineral soil. Most severe is this deficiency at Přebuz, where the exchangeable calcium reach only 7.8 mg.kg-1 and magnesium 2.35 mg.kg-1 in the upper mineral soil (ca. 0-30 cm). Exchangeable potassium is low (< 30 $mg.kg^{-1}$) in mineral soil at Šerlich and Přebuz.

Norway spruce nutrition, characterized as the results of the foliar analyses (Tab. 2), is most problematic at Přebuz exhibiting low or deficit content of nitrogen (< 1,3%,), phosphorus (< 1200 $mg.kg^{-1}$) and magnesium (< 700 $mg.kg^{-1}$) in mature stands and of potassium (< 3000 $mg.kg^{-1}$), calcium (< 2500 $mg.kg^{-1}$) and magnesium in young stands. Phosphorus and magnesium deficiency was identified also in the mature Norway spruce stand in Čachnov The nitrogen content in needles is good in both localities Čachnov and Šerlich. In Orlické Mts. also the supply of other nutrients is generally also good or sufficient.

Table 2: Soil and needle analysis – summary of results

	Šerlich (Orlické Mts.)	**Přebuz (Krušné Mts.)**	**Čachnov (Žďárské vrchy)**
Soil analysis (in mature stands only)	high content of N, sufficient content of P, **deficit of K, Ca, Mg,** intensive nitrification	**deficit of N, P, K, Ca, Mg**	sufficient content of N, P, K, **deficit of Ca, Mg**
Needle analysis in mature stands	good nutrition of N and P; sufficient nutrition of K, Ca, Mg	sufficient nutrition of K, Ca; **deficit of N, P, Mg**	good nutrition of N, K, Ca; **deficit of P, Mg**
Needle analysis in young stands	good or very good nutrition of N; other elements good or sufficient nutrition	good nutrition of N; **deficit of K, Ca, Mg**	*no analysis*

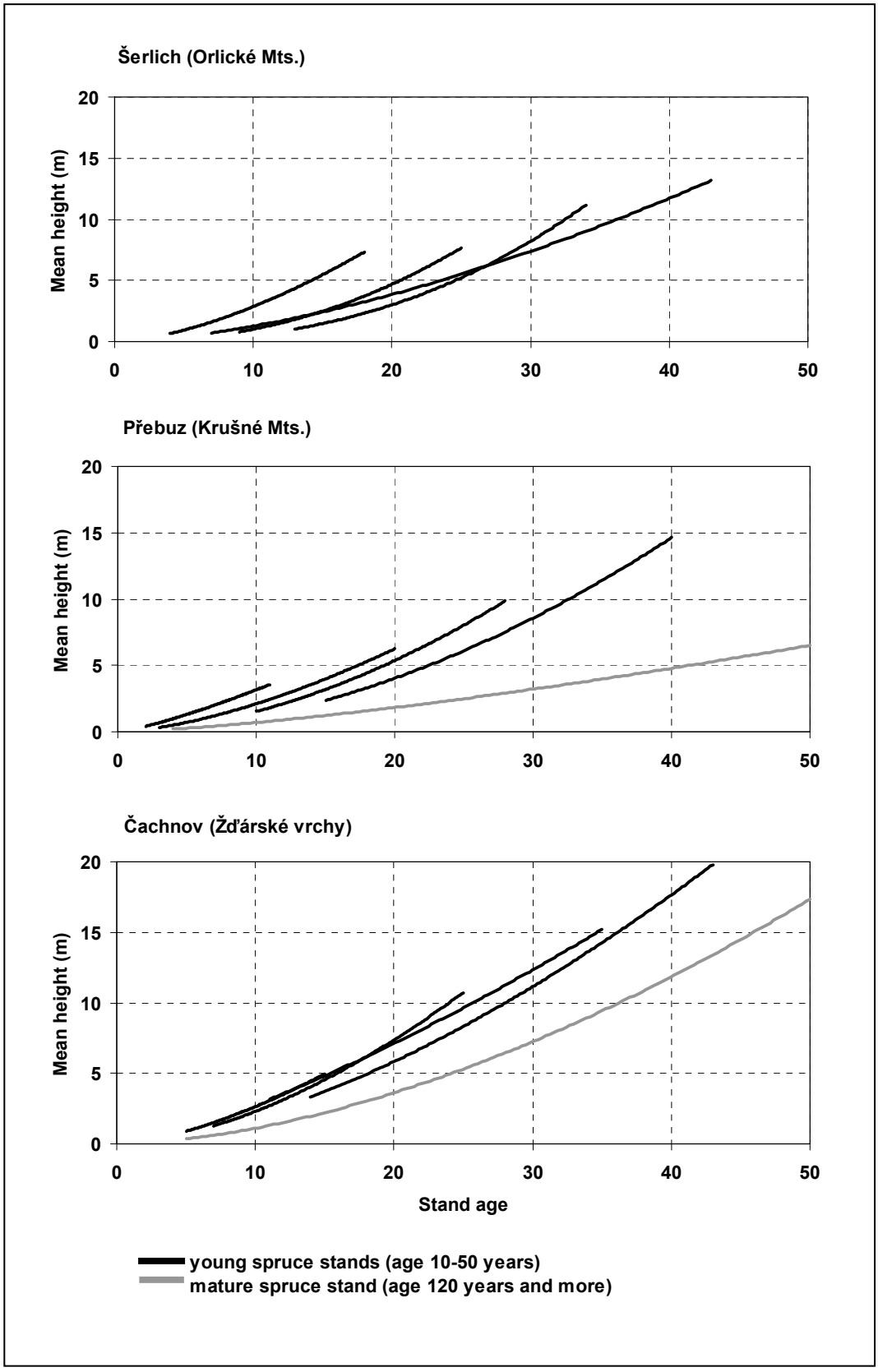

Figure 4: Height growth of young spruce stands.

Discussion

Growth depression since the mid-seventies to mid-eighties of the last century is typical for the mature spruce stands in mountain regions along the northern border of the Czech Republic (Kroupová 2002, Kroupová & Kyncl 2001, Röhle 1999, Sander et al. 1995). These authors confirm, at the same time, stand recovery at the end of eighties. Growth decrease was explained by climatic extremes in coincidence with high air pollution load at the end of the seventies and in the first half of the eighties (Kroupová 2002, Materna 1999).

Growth increase of mature spruce trees in Orlické Mts. and Krušné Mts. corresponds to lowering of the air pollution load since the end of eighties (mainly SO_2) and suitable climatic conditions. Analysis of the climatic data of the stations Deštné (Orlické Mts.), Nová Ves (Krušné Mts.) and Svratouch (Žďárské vrchy) confirms the upward trend of mean temperatures during the vegetation period. Mean vegetation period temperatures in 1992, 1994, 1999 and 2000 are among the highest in the period of measuring within the all stations. High temperatures in vegetation period were connected to low precipitation amounts in 1988 – 1994. In contrary, the vegetation seasons of 1995 – 1998 were above-average in precipitations. Growth increase in Šerlich and Přebuz after 1986 thus corresponds to warm summers; drought at the beginning of nineties did not effect the growth. Spruce in Čachnov can be sensitive to water deficit in summer period, and this may be the reason, why the sharp growth increase was observed only in 1997 – 2001 here.

Results of the soil and needle analysis confirm higher nitrogen saturation of the plot Šerlich, and, in the same time, they document serious disturbance of nutrition in the plot Přebuz. These findings do not correspond in expected way with the results of the stem analyses. Acceleration of diameter increments and also basal area and volume increments is comparable in both localities. It seems to be probable, that impact of nitrogen inputs on tree growth of the mature spruce trees is limited.

The shift in the level of the height curves of the young spruce stands in Orlicke Mts. and Krušne Mts. can be interpreted as a proof of ongoing fast changes of the growing conditions in the last 50 years. Wenk and Vogel (1996) analysed the trends of the top height of the spruce stands of different age. They proved greater steepness of the height curves with younger stands. Maximal difference among the curves of today young stands and the oldest stands was recorded at the age from 40 to 80 years; afterwards the height curves converge again. Elfving and Tegnhammar (1996), on the base of repeated measurement of pine and spruce sample trees within the national forest inventory in Sweden in 1953 – 1992, proved, that the tree height at given age significantly increases within this 40-year period, from 0.6 to 0.8% per year for these two tree species. These values are highly over-exceeded in the young stands of the localities studied in the Czech Republic.

Compared with low nitrogen amounts in needles in the mountain regions of the Czech Republic at the beginning of eighties (Materna 1986), in the nineties significant improvement of nitrogen nutrition of the young spruce stands was observed, both in Orlické (Šrámek et al. 2001) and Krušné Mts. (Lomský, Šrámek, 2004; Lomský et al. 2006). Thus it seems to be probable, that growth acceleration of the young stands in the last decade is connected not only to suitable climatic conditions in this period, but also to higher nitrogen inputs. This hypothesis is supported also by abnormal height growth rate of the youngest stands in the Orlické Mts., where, contrary to the Krušné Mts., better nutrition of nitrogen is not connected to significant deficiency of other basic elements.

Conclusions

Growth increase of mature spruce trees in Orlické Mts. and Krušné Mts. corresponds to lowering of the air pollution load since the end of eighties (mainly SO_2) and suitable climatic conditions. No relationship to N-depositions was found. Results of the soil and needle analysis confirm higher nitrogen saturation of the plot in Orlické Mts. and, in the same time, serious disturbance of nutrition in Krušné Mts. Nevertheless acceleration of volume growth is comparable in both regions.
The shift in the height curve levels of the young spruce stands can be interpreted as a proof of ongoing fast changes of the growing conditions in the last 50 years. It seems to be probable, that growth acceleration of the young stands in the last decade is connected to high nitrogen inputs. The hypothesis is supported also by abnormal height growth rate of the youngest stands in the Orlické Mts. where, contrary to the Krušné Mts., good nutrition of nitrogen is not connected to significant deficiency of other basic elements.

Acknowledgements

The study was supported by the Ministry of Agriculture of the Czech Republic, project No MZE 0002070203.

References

Čermák, M.., Martinková, M., Palovčíková, D., Jankovský, L., 2005: About phytopathological and histological aspects of Norway spruce dieback in the Orlické hory Mts. *J. For. Sci*. 51: 348 – 358.

Elfving, B., Tegnhammar, L., 1996: Trends of tree growth in Swedish forests 1953 – 1992: an analysis based on sample trees from the National Forest Inventory. *Scand. J. For. Res.* 11: 26 – 37.

Fiala, J., Bretschneider, B., Materna, J., 2002: Development of the atmospheric pollution and forest decline in the Czech part of the Ore Mts. In: Lomský, B., Materna, J., Pfanz, H. (eds.): SO2-pollution and forests decline in the Ore Mountains. Forestry and Game Management Research Institute, Jíloviště-Strnady, p. 50 – 85.

Holmes, R. L. (1983): Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* 43: 69 – 78.

Holmes, R. L., Adams, R. K., Fritts, H. C., 1986: Users Manual for Program Arstan. In: Tree-Ring Chronologies of Western North America: California, eastern Oregon and northern Great Basin. Laboratory of Tree-Ring Research, The Univerzity of Arizona, p. 50 – 65.

Kroupová, M., Kyncl, T., 2001: Orlické hory - mění se maximální hustota a podíl pozdního dřeva v letokruzích smrku? *Zprávy lesnického výzkumu* 4: 150 - 154.

Kroupová, M., 2002: Dendroecological study of spruce growth in regions under long-term air pollution load. *J For Sci.*, 48: 536 – 548.

Lochman, V., Mareš, V., Fadrhonsová, V., 2004: Development of air pollutant deposition, soil water chemistry and soil on Šerlich research plots, and water chemistry in a surface water source. *J. For.Sci*. 50: 263 – 283.

Lomský, B., Šrámek, V., 2004: Different types of damage in mountain forest stands of the Czech Republic. *J. For. Sci.* 50: 533 – 537.

Lomský, B., Šrámek, V., Maxa, M., 2006: Fertilizing measures to decrease Norway spruce yellowing. *J. For. Sci*. 52 (Special issue): 65 - 72.

Materna, J., 1986: Vliv imisí na minerální výživu lesních dřevin. Lesnictví, 32 (7): 569-580.

Materna, J., 1999: Development and causes of forest damage in the Ore Mts. *J. For. Sci*. 45: 147 – 152.

Röhle, H., 1999: Changed growth performances in Germany exemplified by spruce, and conclusions for forestry. In: Karjalainen, T., Spiecker, H., Laroussinie, O. (eds.): Causes and Consequences of Accelerating Tree Growth in Europe. EFI Proceedings No. 27, p. 217 - 227.

Sander, C., Eckstein, D., Kyncl, J., Dobrý, J., 1995: The growth of spruce (Picea abies (L.) Karst.) in the Krkonoše Mountains as indicated by ring width and wood density. *Ann Sci For* 52: 401 – 410.

Šach, F., Fottová, D., Balcar, V., Černohous, V., Kacálek, D., Nárovec, V., 1999: Mohou imise škodit v Orlických horách? *Lesnická práce* 78: 452 – 455.

Šrámek, V., Maxa, M., Šebková, V., Novotný, R., 2001: Stav výživy a imisní zátěže mladých smrkových porostů v Orlických horách na základě chemické analýzy asimilačních orgánů. Studie pro MZe. VÚLHM Jíloviště – Strnady, 30 p.

Vejpustková, M., Zahradník, D., Šrámek, V., Fadrhonsová, V., 2004: Growth trends of spruce in the Orlické hory Mts. *J For Sci* 50: 67 – 77.

Wenk, G., Vogel, M., 1996: Height growth investigations of Norway spruce (*Picea abies,* [L.] Karst.) in the eastern part of Germany during the last century. In: Spiecker, H., Mielikäinen, K., Köhl, M., Skovsgaard, J., (Eds.): Growth trends in European forests: studies from 12 countries. European Forest Institute Research Report No. 5, Springer, p. 99 – 106.