Nutrition of silver fir (*Abies alba* Mill) growing at the upper limit of its occurrence in the Šumava National Park and Protected Landscape Area

R. Novotný[1], D. Černý[2,3], V. Šrámek[1]

[1]*Forestry and Game Management Research Institute, Strnady, Jíloviště, Czech Republic*

[2]*Šumava National Park and Protected Landscape Area, Department of Forest Ecology, Vimperk, Czech Republic*

[3]*Department of Silviculture, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences in Prague, Czech Republic*

ABSTRACT: In the second half of 20th century silver fir regeneration has been observed throughout all of the Europe, including the Czech Republic. The Bohemian Forest – Šumava Mts. is one of the regions where the silver fir percentage in forest stands is supposed to be increased from the present 2% to nearly 12%. During the period 2006–2007, in the Czech part of the Bohemian Forest, samples of silver fir were taken mainly in the upper altitudinal limit of silver fir occurrence. In the present paper the results of performed analyses are compared with similar surveys conducted in the other European regions. Samples from the Bohemian Forest, in contrast to other results, differ in higher phosphorus content and lower contents of calcium and manganese. Nitrogen content is slightly higher. Our values for the other elements (magnesium, potassium, zinc, sulphur) are comparable to those reported in Poland and Slovakia. In Germany, aside from the above mentioned differences, higher magnesium content was also found within the locality sampled.

Keywords: *Abies alba*; silver fir nutrition; Šumava National Park and Protected Landscape Area; upper limit of occurrence

Silver fir (*Abies alba* Mill.) was an important species for forestry in the last centuries. Due to the transition to clear-cut forest management giving priority to Norway spruce (*Picea abies* [L.] Karst.), the ecological demands of fir were not respected, and its proportion in forest stands has decreased significantly (Uhlířová, Kapitola 2004). Over roughly 200 years, the proportion of silver fir decreased from 18% to 0.9% in the forests of the Czech Republic (Vacek et al. 2002; Uhlířová, Kapitola 2004). In the second half of the 20th century, silver fir decline connected with air pollution was observed nearly throughout Europe resulting in a further reduction of silver fir in the tree species composition (Schütt et al. 1984). After a decrease in air pollution in the 1990's, Silver fir regeneration was recorded in many regions including the Czech Republic (Herring, Eisenhauer 2001; Podlaski 2002; Schmidt, Mayer 2004). New studies have therefore focused on silver fir vitality and silvicultural measures aimed to increase its proportion in the forest regeneration were taken (Šrámek et al. 2008). Bohemian Forest is also one of the regions where the silver fir restoration is planned, from the present 2% to nearly 12% (Vacek et al. 2002).

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The natural range of silver fir is discontinuous. It grows in the mountains of Southern Europe, from the Pyrenees to the Balkans. The main centres of the range are situated in Central France, Western Germany, and the mountainous regions of Southern Europe (Meister 1999; Uhlířová, Kapitola 2004). In Central Europe, it grows up to 1,000 m a.s.l., in the Bohemian Forest up to 1,300 m a.s.l. (the highest fir was discovered at 1,338 m a.s.l. – "the fir of Skala" in Jezerní hora, personal notification), in the Alps up to 1,700 m a.s.l. Fir grows most frequently in a mixture with Norway spruce or European beech, or together with these two species.

The fir has relatively great requirements for soil conditions – it needs deep, aerated and humid soils as well as high air humidity. It roots deeper than all other conifer species, and it is also less affected by windthrows. The fir demand for oxygen content in the soil is relatively low – it can grow in deeper and wetter soils than e.g. Norway spruce. It is a typical shade-tolerant species; in the open area, it suffers from frost and bark scorch (Meister 1999; www.weisstanne.de).

Nutrient content in silver fir needles has been studied in less detail than in other commercially more important species. In the Carpathian region, some studies were performed e.g. by Maňkovská (1996); Maňkovská et al. (2004); problems of biodiversity and its changes were studied by Šamonil and Vrška (2007). In Croatia, the content of some elements in the fir needles was analyzed by Potočić et al. (2005), in Germany by Musio et al. (2004), Bäumler et al. (1995), and in France by Pinto et al. (2008).

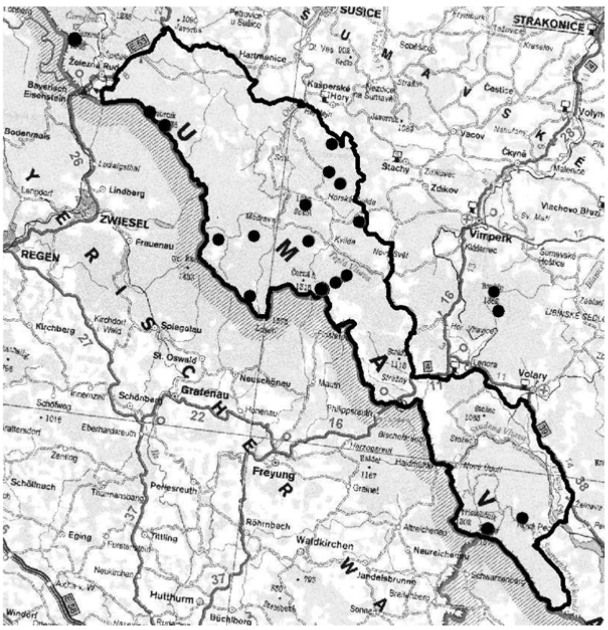

Fig. 1. Map of sampling sites

The paper presents the results of the nutrient balance and content of the stress elements in the current year needles of fir taken in 2006 and 2007 in the Bohemian Forest, in the mature stands growing predominantly above 1,100 m a.s.l.

MATERIAL AND METHODS

Samples of silver fir needles were taken in the Bohemian Forest during the winter 2006–2007. Sampling was focused on the upper limit of silver fir growth, namely from 1,110 to 1,300 m a.s.l. In the western part of the Bohemian Forest samples were taken at altitudes exceeding 1,100 m a.s.l. In the southern part, sampling was done at altitudes above 1,200 m a.s.l. Forest stands of the 7th (spruce-beech) and 8th (spruce) altitudinal vegetation zone were a criterion for sampling. For a comparison, the samples of the 6th altitudinal vegetation zone (beech-spruce) were also taken (the altitude of 800–900 m a.s.l.). A total of 81 samples were taken; 20 samples in the 6th altitudinal vegetation zone – localities Včelná, Rejštejn, Nová Pec, 36 samples in the 7th altitudinal vegetation zone – localities Zhůří, Modrava, Antýgl, Pod Plesnou, 25 samples in the 8th altitudinal vegetation zone – localities Plechý – Stifterův památník, Jezerní hora, Bučina, Weitfelerské slatě, Jelení skok. The current year needles were prepared for analyses. A map of sampling localities is shown in Fig. 1.

Samples were taken during the dormancy period (January–March) from dominant and co-dominant trees and from the 2nd or 3rd whorl. All sampled trees were fructiferous. Samples of the current year needles were analyzed in a laboratory of the Forest and Game Management Research Institute, using the ICP Forests (UN-ECE 2005) methodology and the Standard Operation Procedures. Contents of nitrogen, potassium, phosphorus, magnesium, calcium, zinc, iron, manganese and sulphur were analyzed in all samples by the OES-ICP method after nitric acid and hydrogen peroxide decomposition of the plant material in an MDS-2000 microwave system. Total nitrogen and sulphur were determined with a CNS analyzer. Chlorine was determined using argentometric titration in the plant material following decomposition with sodium carbonate. Fluoride content was analyzed by the ion-selective method after alkaline decomposition of ash. Statistical evaluation was done using the Statistica Cz software.

RESULTS AND DISCUSSION

The basic results of the chemical analyses are presented in Table 1. The median is used as a more robust parameter than the arithmetic mean.

The element content in the needles was formerly analyzed and evaluated e.g. by Maňkovská et al. (2004) or Bäumler et al. (1995). Our results from the Bohemian Forest are comparable with their results and conclusions.

Nitrogen content ranges from 9.5 to 21.5 g·kg^{-1}, the median is 13.5 g·kg^{-1}. The above-mentioned publications reported a mean value from 11.0 to 12.5 g·kg^{-1} for the localities in Germany, Poland, and Slovakia. It should be noted that the cited publications used the arithmetic mean, not the median. The mean nitrogen content in our samples was even higher – 13.9 g·kg^{-1}.

For conifers, the deficiency limit of 13 g·kg^{-1} is generally used. About one quarter of the analyzed samples fall below this level (lower quartile 12.6 g·kg^{-1}).

Phosphorus content in the samples ranges from 997 to 4,099 mg·kg^{-1}, the arithmetic mean is 2,078 mg·kg^{-1} and the median 1,952 mg·kg^{-1}. The average values in Germany, Poland, and Slovakia were significantly lower – around 1,400 mg·kg^{-1}.

Magnesium content in the samples from the Bohemian Forest ranges from 493 to 3,554 mg·kg^{-1}, the arithmetic mean is 1,971 mg·kg^{-1}, the median is 1,953 mg·kg^{-1}. In the locality in Germany (Bavarian Alps), the average value of 2,400 mg·kg^{-1} was measured. In Poland and Slovakia, the average content of magnesium in the fir needles was around 1,500 mg·kg^{-1}. The problem of magnesium in forest ecosystems was studied e.g. by Hüttl (1986) and Hüttl and Schaaf (1997). Their determined threshold for magnesium deficiency was 700–800 mg·kg^{-1}. Magnesium content below 800 mg·kg^{-1} was determined only in three of the analyzed samples. In this respect, the nutrition of the youngest needles is satisfactory. The measured mean value is higher compared to the data presented in Maňkovská et al. (2004).

Calcium content in the needles is more stable; its content increases with the age of needles. In the current year needles, the discovered values range from 810 to 10,935 mg·kg^{-1}. The median is 5,115 mg·kg^{-1}, the mean is 5,432 mg·kg^{-1}. In the study by Bäumler et al. (1995), the mean 10,900 mg·kg^{-1} in the current year needles of fir was found; in the samples from Slovakia and Poland, the values ranged from 10,400 to 15,500 mg·kg^{-1}.

The regulation of water regime is one of the most important functions of potassium, and this is also important in the resistance of individual tree species to different stresses (e.g. resistance to frost). Its content in the analyzed samples from the Bohemian Forest ranges from 3,352 to 11,067 mg·kg^{-1}. The arithmetic mean is 6,198 mg·kg^{-1}, the median is 5,862 mg·kg^{-1}. Hüttl (1986) reported a deficiency limit value of 4,000–4,500 mg·kg^{-1}. A portion of the samples had a lower potassium content compared to this value. In other sources, the mean potassium content varies from 6,453 (Slovakia) to 8,112 (Poland) mg·kg^{-1} (Maňkovská et al. 2004). In Germany, the mean value in the tested samples was 7,700 mg·kg^{-1} (Bäumler et al. 1995; Musio et al. 2004).

Table 1. Results of basic data analysis

	Valid N	Mean	Median	Minimum	Maximum	Lower quartile	Upper quartile	Range	SD
Ca (mg·kg^{-1})	81	5,431.569	5,115.211	810.824	10,935.19	3,837.053	6,861.417	5,122,780	2,263.356
Fe (mg·kg^{-1})	81	53.925	50.561	31.805	157.00	43.751	56.826	369	19.209
K (mg·kg^{-1})	81	6,197.953	5,862.083	3,352.310	11,066.98	4,827.199	7,345.797	2,605,996	1,614.310
Mg (mg·kg^{-1})	81	1,971.348	1,953.478	493.425	3,554.40	1,537.206	2,445.327	404,383	635.911
Mn (mg·kg^{-1})	81	624.807	503.981	145.070	2,198.78	354.223	732.385	193,874	440.312
P (mg·kg^{-1})	81	2,077.645	1,952.093	997.176	4,098.89	1,536.828	2,398.292	476,576	690.345
Zn (mg·kg^{-1})	81	41.027	39.503	12.037	72.52	33.288	50.179	153	12.375
N (%)	81	1.389	1.353	0.945	2.15	1.259	1.512	0	0.188
S (mg·kg^{-1})	81	1,347.654	1,323.950	1,050.000	1,795.00	1,196.630	1,445.920	38,522	196.269
Cl (mg·kg^{-1})	69	373.853	352.877	146.520	759.03	275.237	451.387	20,020	141.494
F (mg·kg^{-1})	69	1.736	1.649	0.100	6.35	1.462	1.847	1	0.857

SD – Standard deviation

As an important trace element, the zinc content was analyzed. It ranged from 12 to 73 mg·kg^{-1}, with the mean value 41 mg·kg^{-1} and the median 39.5 mg·kg^{-1}. Zinc plays an important role in the formation of chlorophyll and it takes part in many metabolic processes. Its content generally correlates with that of magnesium. The zinc content was also analyzed in the papers by Bäumler et al. (1995) and Maňkovská et al. (2004). The mean value measured in the sampled locality in Germany was 63 mg·kg^{-1}; for the localities in Poland and Slovakia it was 30 and 39 mg·kg^{-1}, respectively. The average value measured in the Bohemian Forest was comparable with the localities in Poland and Slovakia.

The sulphur values range from 1,050 to 1,795 mg·kg^{-1}. The mean is 1,348 mg·kg^{-1}, the median 1,324 mg·kg^{-1}. In the study by Maňkovská et al. (2004) the average sulphur concentrations determined in silver fir needles presented were roughly 1,350 mg.kg^{-1}, i.e. comparable with those presented here. Bäumler et al. (1995) reported the higher mean value – 1,600 mg·kg^{-1}.

The iron content ranges from 32 to 157 mg·kg^{-1}. The mean value is 53.3 mg·kg^{-1}; the median is 50 mg.kg^{-1}. In the samples from Poland, the value 92 mg.kg^{-1} was found; in the samples from Slovakia, it was 215 mg·kg^{-1} (Maňkovská et al. 2004). In the samples from Germany, the mean was 71 mg·kg^{-1} (Bäumler et al. 1995).

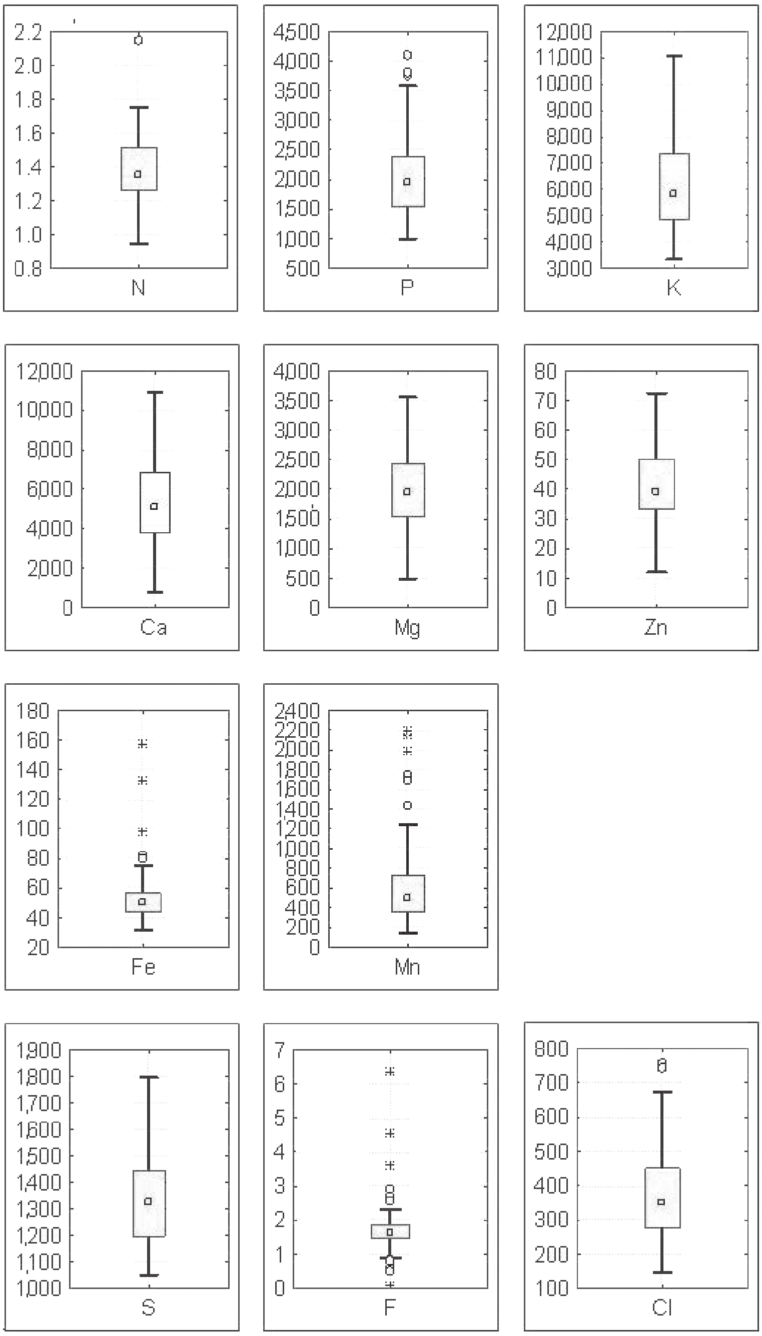

Fig. 2. Box plots of nutrient contents

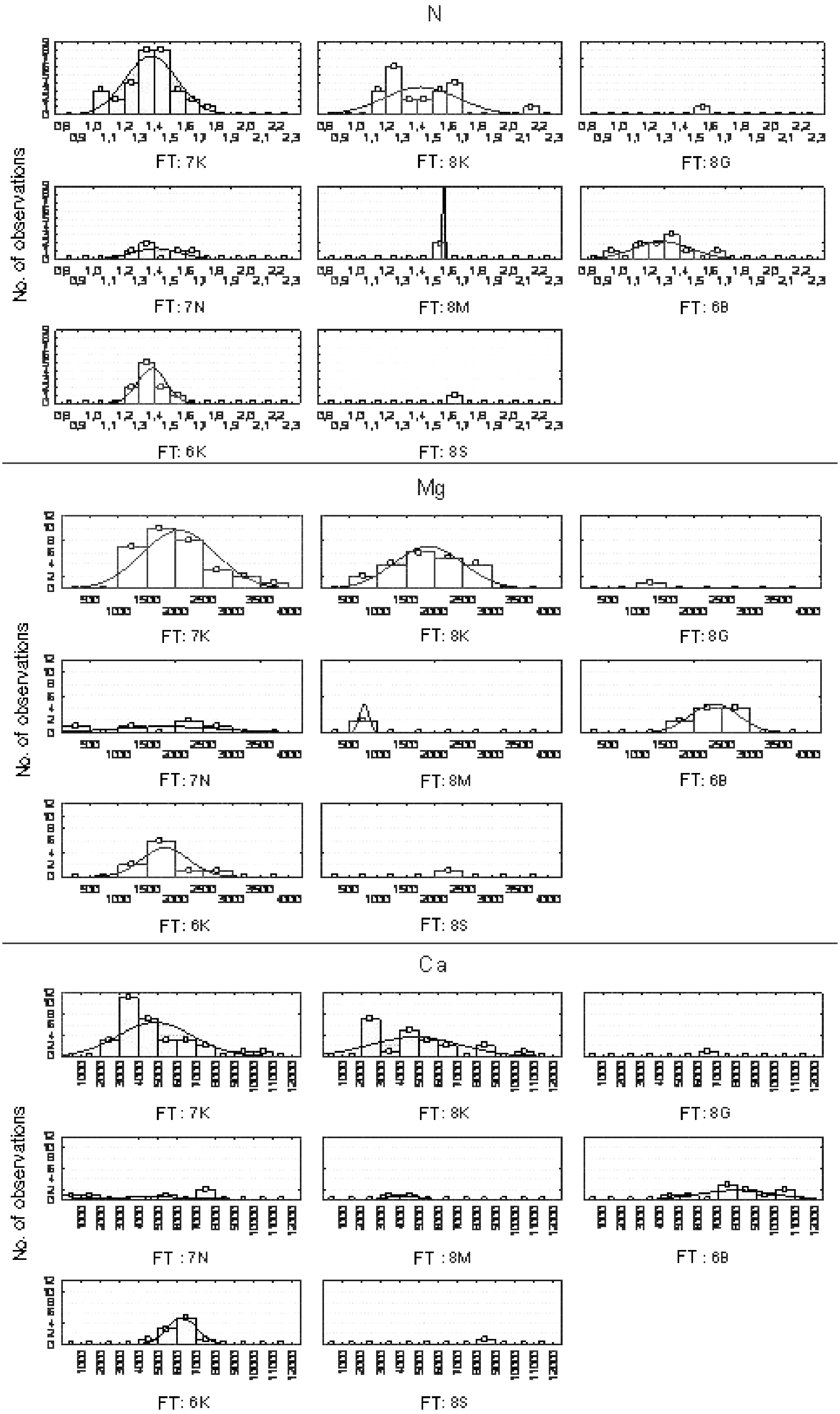

Fig. 3. Categorized histograms – nitrogen (%), magnesium (mg·kg^{-1}) and calcium (mg·kg^{-1})

Manganese content was 145–1,246 mg.kg^{-1}; the arithmetic mean was 507, the median 458 mg·kg^{-1}. Bäumler et al. (1995) reported the value 531 mg·kg^{-1} in the current year needles, Maňkovská et al. (2004) presented the mean of 1,623 mg·kg^{-1} for the samples from the localities in Poland, and the mean of 1,174 mg·kg^{-1} for the samples taken in Slovakia. The values discovered in the Bohemian Forest are significantly lower, compared to those mentioned above.

In a number of the samples (55 of 67), the content of other stress elements was also analyzed – i.e. fluorine and chlorine. The content of fluorine ranged from 0.1 to 6.4 mg·kg^{-1}, with the average 1.75 mg·kg^{-1} and median 1.63 mg·kg^{-1}.

The chlorine content ranged from 147 mg·kg^{-1} to 759 mg·kg^{-1}, with the average 374 mg·kg^{-1} and median 353 mg·kg^{-1}.

The basic nutrient contents are represented graphically in Fig. 2.

The relationship between the element content and the altitude was tested; results are presented in Table 2. Within the data set evaluated, sulphur content in silver fir needles increases significantly and calcium content decreases significantly with altitude. Along with a moderate decrease in magne-

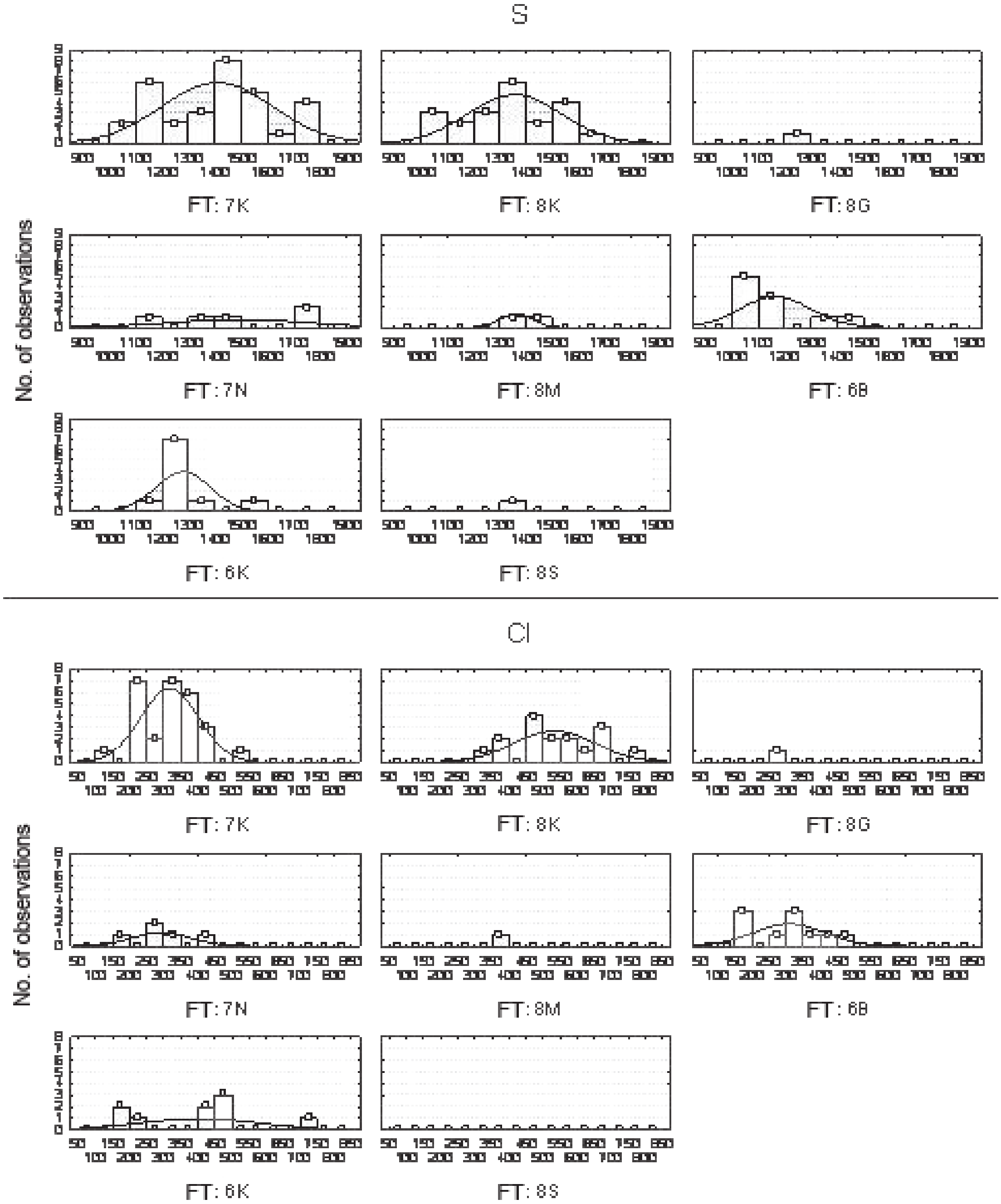

Fig. 4. Categorized histograms – sulphur and chlorine (mg·kg^{-1})

Table 2. Correlations between the altitude and nutrient content (marked correlations are significant at a level $P < 0.05$) ($N = 69$)

	Altitude
Ca	**–0.4755**
Fe	–0.0981
K	**0.3441**
Mg	–0.1687
Mn	**–0.5882**
P	0.1501
Zn	–0.0560
N	0.2049
S	**0.3648**
Cl	0.0484
F	–0.0058

sium content and an insignificant increase in nitrogen content, this may be due to higher acidification of soils at higher altitudes. However, the significant increase in potassium content with altitude does not support this hypothesis. It is possible that the grass layer could be a source of higher potassium content. In less dense forest stands of higher altitudes, the grass litter is richer in potassium (comparably similar trends see e.g. Podrázský 2007).

The fact that the samples were taken approximately at two levels of altitude must be considered. One, a smaller group, was taken at an altitude of about 800–900 m a.s.l.; the other was taken between 1,100 and 1,300 m a.s.l.

Element contents in needles were also evaluated by means of categorized histograms. The forest type group (FTG) was a criterion. Most samples were taken in the forest type groups 7K (acid soils in the 7th altitudinal vegetation zone) and 8K (acid soils in the 8th altitudinal vegetation zone). Fig. 3 and Fig. 4 show histograms for selected elements. In the higher altitudinal zone of silver fir occurrence in the Bohemian Forest, i.e. at the altitude above 1,000 (1,100) m a.s.l., no significant differences in the content of the evaluated elements were recorded in connection with the forest type group – FTG. Chloride content, higher in FTG 8K than in other FTGs, is the only exception.

When comparing all the samples, the histograms show differences in the content of sulphur between the 6th altitudinal vegetation zone on the one hand and the 7th and 8th altitudinal vegetation zone on the other. Even the Bohemian Forest, although generally considered less afflicted by air pollution, has been exposed to emissions to a certain extent; this, in spite of the fact that this load is currently in the form of deposits and not in the form of a high concentration load of harmful gases in the ambient air.

This correlation trend with respect to the forest type groups (FTG) was not recorded for other elements.

CONCLUSIONS

Silver fir, growing in the Bohemian Forest at higher elevations (1,110–1,300 m a.s.l.), shows a good nutrient supply. In spite of this, individual trees or localities can be identified in which a lower content of certain elements, mainly magnesium, under the deficiency limit has been recorded. In general, the situation based on the current year needle analysis is good.

Compared to other studies, results differ mainly in higher phosphorus content, and lower calcium and manganese contents. Nitrogen content is slightly higher. For other elements (magnesium, potassium, sulphur), the values are comparable with those from Poland and Slovakia. In the locality sampled in Germany, a higher content of magnesium (aside from the above mentioned) was also discovered. The comparison of sulphur content has to be considered carefully since, compared to the study by Bäumler et al. (1995), the air pollution situation has changed, and thus the sulphur content cannot be compared equally.

When evaluating the correlation of the element content with the altitude, the positive correlation for sulphur and potassium was significant, in addition to the negative correlation for calcium and manganese.

Comparing differences in individual forest type groups (FTG), in which the tested fir trees grow, differences in nutrient contents were discovered especially in FTG 6B. In this rich, spruce-beech forest site type in the 6th altitudinal vegetation zone, higher contents of magnesium, calcium, and zinc in needles were determined. The decline or dieback of fir in this region, when recorded, must be considered individually, keeping in mind other stress factors (biotic agents, meteorological conditions).

References

Bäumler R., Goerttler T., Zech W. (1995): Nährelement- und Schwermetallgehalte in den Nadeln von Fichten und Tannen eines Bergmimschwaldes auf Flysch (Tegernseer Alpen). Forstwiesenschaftliches Centralblatt, ***114***: 30–39.

Hering S., Eisenhauer D.R. (2001): Entwicklung des Weisstannenanbaus in Sachsen seit 1990: Wachstum und Vitalität der Weisstanne in Mittelgebirgslagen Sachsens. AFZ-Der Wald, Allgemeine Forst Zeitschrift für Waldwirtschaft und Umweltvorsorge, ***56***: 1161–1164.

Hüttl R.F. (1986): Neuartige Waldschäden und Nährelementversorgung von Fichtenbeständen in Südwestdeutschland am Beispiel Oberschwaben. Kali-Briefe, ***17***: 1–7.

Hüttl R. F., Schaaf W. (1997): Magnesium Deficiency in Forest Ecosystems. London, Kluwer Academic Publishers: 362.

Maňkovská B. (1996): Sulphur and nitrogen content of conifers and broadleaved vegetative organs in Slovakia. Ekológia, ***15***: 225–237.

Maňkovská B., Godzik B., Badea O., Shparyk Y., Moravčík P. (2004): Chemical and morphological characteristic of key tree species of the Carpathian Mountains. Environmental Pollution, ***130***: 41–54.

Meister G. (1999): Die Tanne. Baumfellblatt Nr. 14. Schutzgemeinschaft Deutscher Wald (SDW) - Bund zur Förderung der Landespflege und des Naturschutzes -Bundesverband e.V., Bonn, 4.

Musio M., Augustin N., Kahle H.P., Krall A., Kublin E., Unseld R., Wilpert K. (2004): Predicting magnesium concentration in needles of Silver fir and Norway spruce – a case study. Ecological Modelling, ***179***: 307–316.

Pinto P.E., Gégout J.C., Hervé J. C., Dhote J.F. (2008): Respective importance of ecological conditions and stand composition on *Abies alba* Mill. dominant height growth. Forest Ecology and Management, ***255***: 619–629.

Podlaski *R.* (2002): Radial growth trends of fir (*Abies alba* Mill.), beech (*Fagus sylvatica* L.) and pine (*Pinus sylvestris* L.) in the Świetokrzyski National Park (Poland). Journal of Forest Science, ***48***: 377–387.

Podrázský V. (2007): The status of forest soils in altitude transect on the site Plechý – National Park Šumava Mts. Lesnícky časopis – Forestry Journal, ***53***: 333–345. (in Czech)

Potočić N., Ćosić T., Pilaš I. (2005): The influence of climate and soil properties on calcium nutrition and vitality of silver fir (*Abies alba* Mill.). Environmental Pollution, ***137***: 596–602.

Schmidt O., Mayer F. J. (2004): Waldschutzsituation an Tanne in bayerischen Wäldern. Forst und Holz, ***59***: 593–594.

Schütt P., Koch W., Blaschke H., Lang K.J., Reigber E., Schuck H.J., Summerer H. (1984): So Stirbt der Wald: Schadbilder und Krankenheitsverlauf. München, Wien, Zürich, BLV-Verlagsgesellschaft: 95.

StatSoft Inc. (2007): Statistica 8.0. Available at www. statsoft. cz (accessed January 7, 2010)

Šamonil P., Vrška T. (2007): Trends and cyclical changes in natural fir-beech forests at the North-western edge of the Carpathians. Folia Geobotanica, ***42***: 337–361.

Šrámek V., Slodičák M., Lomský B., Balcar V., Kulhavý J., Hadaš P., Pulkrab K., Šišák L., Pěnička L., Sloup M. (2008): The Ore Mountains: Will successive recovery of forests from lethal disease be successful? Mountain Research and Development, ***28***: 216–221.

Uhlířová H., Kapitola P. (2004): Damage of Forest Species. Lesnická práce: 288. (in Czech)

UN-ECE (2005): International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests. Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests, Part IV – Sampling and Analysis of Needles and Leaves.

Vacek S., Vančura K., Zingari P.C., Jeník J., Simon J., Smejkal J. (2002): Mountain Forests of the Czech Republic. Prague, Ministry of Agriculture of the Czech Republic: 320.

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Corresponding author:

Ing. Radek Novotný, Ph.D., Výzkumný ústav lesního hospodářství a myslivosti, v.i.i., Strnady 136, 252 02 Jíloviště, Česká republika
tel.: + 420 602 291 763, fax: + 420 257 921 444, e-mail: novotny@vulhm.cz