https://doi.org/10.17221/4/2019-JFS

The changes of soil nutrient status after a 10y period in the Natural Forest Region Český les

Přemysl Fiala, Dušan Reininger, Tomáš Samek, Markéta Pospíchalová*

Central Institute for Supervising and Testing in Agriculture, Brno, Czech Republic

**Corresponding author: premysl.fiala@ukzuz.cz*

Citation: Fiala P., Reininger D., Samek T., Pospíchalová M. (2019): The changes of soil nutrient status after a 10y period in the Natural Forest Region of Český les. J. For. Sci., 65: 87–95.

Abstract: The periodical survey of forest nutrition was done in the in the Natural Forest Region (NFR) of Český les – the mountain range on a state border between the Czech Republic and the Federal Republic of Germany. The results of chemical analysis done in 2015 were compared with those provided in 2004. The trend of mineral nutrition deteriorating of forest trees has been going on, except for magnesium. The content of magnesium in spruce needles was found to be higher by 56.6 mg·kg^{-1} in the current year's needles and by 24.8 mg·kg^{-1} in the previous year´s ones. The contents of magnesium in soil determined in the extract of HNO_3 were significantly higher. The increase is 389 mg·kg^{-1}, 373 mg·kg^{-1} and 312 mg·kg^{-1} in the forest floor, respectively in organomineral and mineral horizons. However, it is not valid for the available values determined by the Mehlich method. The determination of nutrient values in the extract of HNO_3 seems to be suitable for the evaluation of changes occurred in soil and probably for the simulation of nutrition strategy of trees.

Keywords: forest nutrition survey; plant nutrition strategy; nutrition availability; mineral weathering

The acidification of forest ecosystems is a typical soil process ongoing in Central Europe forest ecosystems (Jonard et al. 2014). This process is ascribed to a complex of different diseases caused by biotic and abiotic factors. The times of strong environmental stress, caused by high industrial pollution, have been over and the depletion of soil fertility has carried on. This stress is promoted by a higher uptake of nutrients of forest ecosystems, which shows the enhancement of net ecosystem production (NEP) under elevated CO_2 concentration (Kandler, Innes 1995; Bauer et al. 1997; Peng et al. 2008; Fernández-Martínez et al. 2014; Vries de et al. 2014) and high atmospheric N deposition and is characteristic of the depletion of soil and yellowing of spruce needles. An elevated input of total N and successively elevated nitrification resulting in NO_3^- leaching as well as a probable output of previously immobilized SO_4^{2-}, are accompanied by Mg^{2+} output (Thomas, Büttner 1998; Langusch et al. 2002; Fischer et al. 2007; Guo et al. 2016). Other well-known symptoms of acidification with an inauspicious impact on the health of trees – as mobilization of potential toxic Al^{3+} and Mn^{2+} cations- have been observed in the forests of Central Europe (Göttlein et al. 1999; Augustine et al. 2005). The improving of Mg nutrition of spruce in Europe is reported by Jonard et al. (2014).

The soil status and health of forest ecosystems in sensu lato was an object of a periodical survey of forest ecosystems that was done in the Natural Forest Region (NFR) of Český les. The results of that research (in 2004 and 2015) provided the outline of the forest development in that part of Central Europe. There were 53 sites repeatedly sampled after 10 years period.

The goal of the survey is the information to forest lands owners about the chemical properties of soil and plant assimilatory tissues. The emphasis is put on acidification and soil fertility.

Supported by the Ministry of Agriculture of the Czech Republic, Project No. 44201/2014-MZE-16212.

https://doi.org/10.17221/4/2019-JFS

MATERIAL AND METHODS

Site characteristic

The Natural Forest Region (NFR) of Český les is a narrow mountain ridge meridian oriented toward the Czech – Bavaria border. In the northwest part, there is the forest of Dyleň – a partial area with the peak of Dyleň (940 m a.s.l.). The gneiss and paragneissis are prevailing rock (44.6%). The middle of NFR, called Kateřina Basin, consists of granite (12.7%) and the southern part with the highest peak of Čerchov has got gneiss as well as the parent rock (Culek et al 1996). The muscovite – biotite gneiss of the Algongy Age is prevailing parent rock (22.4%). The isles of diorite and phyllite of the same age make 2.9% and 2.1% of the timber area respectively. The mica-schist is on the 3.6% of timber land (ÚHÚL 1999).

The district cambisols, a prevailing type of soils, pass to cambisols podzols and rankers in top positions. Pseudogleys are developed in depression and gley soils in spring sites (Culek et al 1996).

The placement of repeatedly sampled sites in sense of forest vegetation zone (FVZ) is stated in Table 1.

The placement of repeatedly sampled sites in sense of edaphic categories is stated in Table 2.

There was a relatively high deposition of oxides of sulphur in 2005, even though in 1998 the program of desulphurization had been finished. The status of azote deposition keeps its level and the values of nutrition deposition decrease.

However, in comparison with the Ore Mountains range, the NFR of Český les is relatively an unpolluted area with low level of sulphur oxygen and azote oxygen deposition. The value of annual wet deposition measured at the station of Přimda decreased in case of NO_3 from 16.59 $kg \cdot ha^{-1}$ to 14.29 $kg \cdot ha^{-1}$, in case of NH_4 from 5.70 $kg \cdot ha^{-1}$ to 5.50 $kg \cdot ha^{-1}$ and in case of SO_4 from 11.25 to 5.99 $kg \cdot ha^{-1}$ during the period of 2006–2016 (http://portal.chmi.cz/files/portal/docs/uoco/isko/tab_roc/tab_roc_CZ.html).

Sampling and chemical analysis

The Central Institute for Supervising and Testing in Agriculture conducted sampling and analyses.

Samples from three soil horizons were taken up in the site of sampling. Hologranic subhorizons (F + H) were collected together in the square of 25 × 25 cm from the forest floor horizon as far as the boundary with organomineral horizon. All organic material from this area was collected except large material over 20 mm in diameter and macroscopic living material (vegetation, mosses, fungi, roots etc.) which was removed. This horizon was taken only once in the sampling site and was chosen regarding the vegetation belonging to the forest type. Mineral horizons sampling (organomineral and mineral) involves the most of root zone, important for assessing nutrient ability of soil. Upper organomineral horizon (A_h) (epipedon) was taken down to around 0.1 m and mineral horizon (B) down to 0. 4 m of soil profile. Mineral soil samples (from both organomineral and mineral horizons) were taken from 3 holes all around the sampling site to obtain higher representativeness of mineral parts of soil profiles.

Needle and leave samples were taken from insolated parts of trees, the upper thirds of young-growth stand crowns in each sampling site. Current year's and previous year's needles of spruce were taken. Prior to chemical analysis, the needles were dried without previous washing out.

Chemical analysis

Soil samples

Determinations of pH H_2O, pH $CaCl_2$ were done in air – dried soil samples according to ISO 10390:2005 which specifies the routine determination of pH using a glass electrode in a 1:5 suspension of soil in water (pH in H_2O) or in 0.01 mol/L calcium chloride solution (pH in $CaCl_2$).

Table 1. The area of forest vegetation zone (FVZ) and the number of sampling sites

FVZ*	4th (Fagus)	5th (Abies-Fagus)	6th (Picea-Fagus)	7th (Fagus-Picea)
Timber land (%)	0.3	64.0	30.8	3.7
Sampling sites	13	27	12	1

*Cited by ÚHÚL 1999; Viewegh et al. 2003

https://doi.org/10.17221/4/2019-JFS

Table 2. The area of edaphic categories (%) and the number of sampling sites

Edaphic category*	K	S	B	V	O	P	other
Timber land (%)	31	30	6	8	8	6	
Sampling sites	20	9	2	2	7	5	8

K – acidophil, S – mesotrophic, B – trophical, V – humid, O – variohumida mesotrophic, P – variohumida acidophila, other – paludosa mesotrophica, *cited by ÚHÚL 1999; Viewegh et al. 2003)

Parameters N_{tot} and C_{ox} were determined by Near Infrared Spectroscopy.

Soil mineral horizon. Determination of extractable contents of elements (P, K, Ca, Mg, Mn, Al, Fe, Zn, Cu, Pb, Cd, Cr): extraction with 2 M HNO_3 was used followed by ICP OES (optical emission spectroscopy with inductively coupled plasma) as a method of detection.

Determination of total contents of elements (P, K, Ca, Mg, Mn, Al, Fe, Zn, Cu, Pb, Cd, Cr): Mineralisation with aqua regia and determination of elements using ICP OES.

Determination of accessible elements (K, Ca, Mg, Al, Fe, S) in extract of Mehlich 3 with the ICP OES technique and spectrophotometry (P) respectively.

The exchange acidity (Al + H) is determined by titration of the soil extract in 0.1 M $BaCl_2$ by solution of 0,025 M NaOH to pH = 7.8.

Soil organic horizon. Dry ashing, uptake in HNO_3 and ICP OES detection were used for the determination of following elements: P, K, Ca, Mg, Mn, Fe, Al, Zn, Cu, Pb, Cr, Cd.

Plant material

Wet digestion with H_2SO_4, Se and H_2O_2 was used for determination of N followed by titrimetric method (Kjeldahl).

Dry ashing and uptake in HNO_3 were used for determination of B, Zn, Mn, Fe, Al, Cu, Cr, Ni, Pb, Cd, P, K, Ca, Mg, Na. The contents of the elements were measured using ICP-OES technique. Wet digestion with HNO_3 and H_2O_2 was used for S followed by ICP-OES as the technique of detection (Zbíral 1994).

Statistical analysis

Exploratory statistical analysis involves the examination of mean values, medians, coefficients of variation, maximum and minimum values. These analyses were done by the software of STATISTICA (Version 12, StatSoft). *T*-test for dependent samples was used for evaluating the time differences.

RESULTS

The changes in the soil chemistry

The assessment of the development of chemical properties consists in comparisons of soil and plant chemical characteristics obtained in 2004 and 2015 respectively. The soils are very strongly acidic. The pH_{H2O} volume ranged from 3.6 to 4.5. These values correspond partly to the buffer range of aluminium and partly to the buffer range of cation exchange capacity respectively (Ulrich 1991). The contents of nutrients in the soil horizons investigated were very low in 2015 except for N_{tot} in the forest floor (F + H) horizons. The others were on the low or insufficient level (Table 3).

The changes of soil characteristic are stated in Table 4. The pH_{H_2O} values determined in the forest floor organic horizon (F + H) were significantly lower, in 2015, on the contrary to the values in the organomineral (A_h) and mineral (B) horizons. In the B-horizon were significantly higher. In 2015, the pH_{CaCl_2} values in the organomineral (A_h) and mineral (B) horizons were significantly higher. The

Table 3. The mean values of pH, total N (%) and extractable nutrients (mg·kg^{-1}) in 2015

Horizon	pH_{H_2O}	pH_{CaCl_2}	N_{tot}	P	K	Ca	Mg
F + H	4.11	3.18	1.45	747	941	1,870	743
Ah	4.03	3.45	0.36	54	302	201	549
A	4.29	3.87	0.10	32	242	144	678

https://doi.org/10.17221/4/2019-JFS

Table 4. The changes of acidity and mean contents of elements in soil horizons (difference between 2004 and 2015)

	Forest floor organic horizon (F + H)	Organomineral horizon (A_h)	Mineral horizon (B)
pH_{CaCl2}	–0.05	**0.20**	**0.13**
pH_{H2O}	**–0.11**	0.02	**0.13**
Exchange acidity (mekv·kg^{-1})		**69.6**	**40.1**
N (%)	**–0.16**	**–0.12**	0.00
P_{MIII} (mg·kg^{-1})		–2.04	0.09
K_{MIII} (mg·kg^{-1})		**–19.1**	**–11.8**
Ca_{MIII} (mg·kg^{-1})		**–38.6**	–17.3
Mg_{MIII} (mg·kg^{-1})		–4.40	–0.66
P_{ext} (mg·kg^{-1})	**–57.1**	–33.6	–19.6
K_{ext} (mg·kg^{-1})	**214**	**–133**	**–112**
Mg_{ext} (mg·kg^{-1})	**389**	**373**	**312**
Ca_{ext} (mg·kg^{-1})	**–1,138**	**–147**	–84.2
Al_{ext} (mg·kg^{-1})	**3,733**	**1157**	**651**
Cr_{ext} (mg·kg^{-1})	**3.74**	0.10	–0.98
Cu_{ext} (mg·kg^{-1})	**–4.43**	–0.53	0.03
Fe_{ext} (mg·kg^{-1})	**2675**	**902**	–507
Mn_{ext} (mg·kg^{-1})	**–149**	42.8	76.5
Pb_{ext} (mg·kg^{-1})	**–17.5**	**–13.6**	**–4.78**
Zn_{ext} (mg·kg^{-1})	**–6.69**	1.12	–0.06

in bold – statistically significant ($P < 0.05$), MIII – available contents, ext – extractable contents

total nitrogen (N_{tot}) was significantly lower in the F + H and in the A_h horizons in 2015, and the plant available values of, K_{MIII}, Ca_{MIII}, were significantly lower in the A_h horizon. K_{MIII} was significantly smaller in A_h an B horizons.

The extractable values of phosphorus (P_{ext}) and calcium (Ca_{ext}) were lower through the whole soil profile. These shifts were significant in the forest floor horizon and in case of calcium in A_h horizon as well. The volumes extractable of potassium (K_{ext}) in the forest floor horizon were significantly higher compared to the ones in the mineral part of soil profiles (A_h, B) where they were significantly lower. The extractable contents of magnesium (Mg_{ext}) were significantly higher in all tree horizons examined (Fig. 1).

Extractable contents of aluminium (Al_{ext}) were significantly higher in all tree horizons examined and in case of iron (Fe_{ext}) in the (F + H) and A_h horizons. The manganum (Mn_{ext}) in the (F + H) horizons was significantly lower in 2015 (Table 4).

Chromium (Cr_{ext}) is rather higher in the (F + H) horizon. Lead (Pb_{ext}) was significantly lower in the (F + H) A_h and B horizons and zinc (Zn_{ext}) was significantly lower in the (F + H) horizon in 2015 (Table 4).

The solubility of chrome (Table 5) testified by the ratio of extractable and pseudototal contents in the organomineral and mineral horizons informs about the atmospheric origin of chrome (Rotter et al. 2013).

The spruce needles chemistry

The view of the development of chemical changes would be incomplete without the investigation of plant chemistry. The current and previous year´s needles of Norway spruce, the most abundant wood plant, were investigated.

According to van den Burg´s literature compilation (Mellert, Göttlein 2012), the content of N is in a lower limit of normal range. P, Ca and Mg

Table 5. The mean extractable and pseudototal contents of Cr (mg·kg^{-1})

Horizon	Cr_{extr}	Cr_{AR}	Cr_{extr} / Cr_{AR}
Ah	10.4	34.4	0.30
B	10.7	38.9	0.28

Ext – extractable contents, AR – pseudototal contents

https://doi.org/10.17221/4/2019-JFS

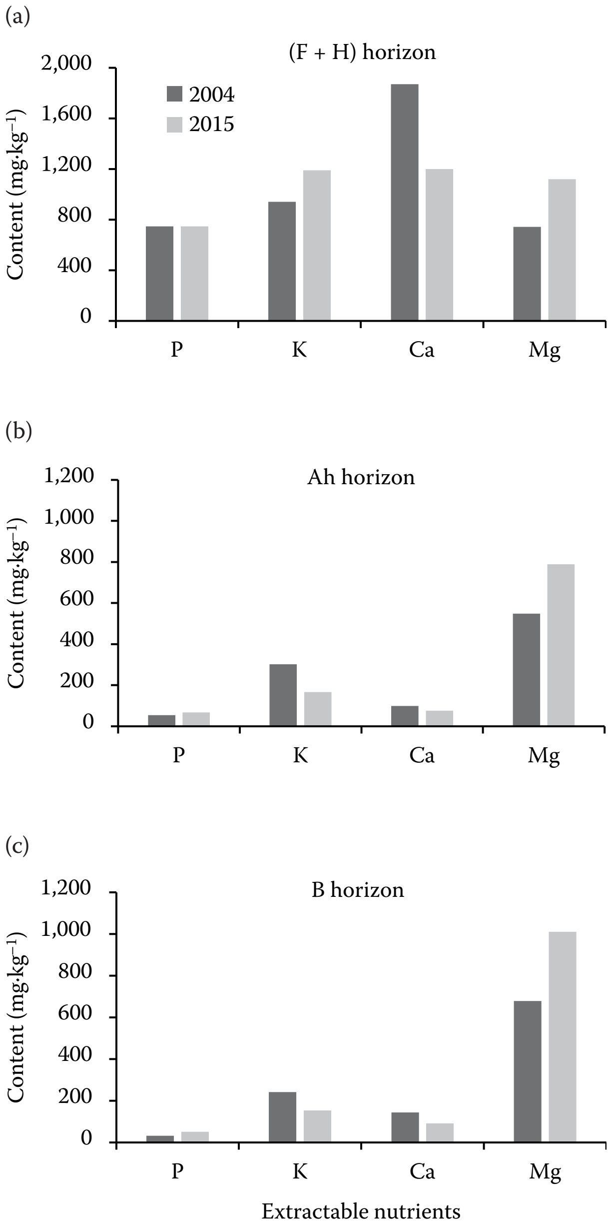

Fig. 1. The mean contents of extractable nutrients in 2004 and 2015 respectively (mg·kg−1)

correspond with the latent limit of deficiency and K with the central position of normal range (Table 6). The other elements are evaluated according to Classification Values for European Foliage Data (Fürst 2009).

The S content is close to low class but not insufficient. Fe is in low level and Zn is adequate to optimum. The B content is low in accordance to the contents detected by existing surveys (Fiala et al. 2011). The heavy metals keep the normal range of contents commonly detected in undamaged spruce forests, except for zinc with the content close to high class (Table 7).

Regarding the contents of the macronutrient, the contents of potassium decreases in the previous year´s needles significantly. The significant decrease was found in the volume of sulphur in both the stadiums of age.

Aluminium and iron decreased significantly in both the age stadiums investigated as the contents of potentially deleterious elements – cadmium, chromium, copper and lead.

The contents of boron (B) decreased significantly in both age classes and zinc (Zn) decreased in the needles of the current year.

DISCUSSION

The atmospheric chemical composition measured by the station of ČHMÚ Přimda is in accordance with the one for the areas in Central Europe (Fischer et al. 2007; Vries de et al. 2014). Therefore, we take its representative for the NFR of Český les. The important facts are: high concentration of CO_2 and N in the atmosphere and ongoing warming. The excess of NO_3^- concentrations in the soil solution is not balanced by the equivalent NO_3^-

Table 6. The mean contents of elements in the needles of Spruce of current year in 2015 and difference between the contents in 2004 – classification in according to van den Burg´s literature compilation (Mellert, Göttlein 2012).

Element	2015		The difference 2004–2015	
	mean content	classification of contents	current year needles	previous year needles
N[1)] (%)	1.47	lower of normal range	–0.04	–0.05
P[1)] (mg·kg−1)	1398	latent deficiency	53.0	–17.7
K[1)] (mg·kg−1)	6514	central of normal range	–403	**–553**
Ca[1)] (mg·kg−1)	3398	latent deficiency	63.4	531
Mg[1)] (mg·kg−1)	791	latent deficiency	56.6	24.8

in bold – statistically significant at $P < 0.005$

https://doi.org/10.17221/4/2019-JFS

Table 7. The mean content of elements in the needles of Spruce of current year in 2015 and difference between the content in 2004 – classification in according to Fürst (2009) and Fiala et al. (2011)

Element (mg·kg^{-1})	2015			The difference 2004–2015	
	mean content	classification of contents		current year needles	previous year needles
		low class	high class		
S[1)]	1096	≤ 1,100	≥ 1,800	**–126**	**–202**
B[2)]	16.2			**–2.88**	**–3.79**
Al[2)]	101			**–41.2**	**–41.2**
Fe[1)]	50	≤ 20	≥ 200	**–17.2**	**–16.3**
Cd[1)]	0.12			**–0.03**	**–0.03**
Cr[2)]	0.41			**–0.26**	**–0.48**
Cu[1)]	6.58	≤ 2	≥ 7	**–0.43**	0.21
Pb[1)]	0.44			**–0.30**	**–0.19**
Zn[1)]	31.9	≤ 20	≥ 60	**–3.94**	2.71

Cited by [1)] Fürst (2009), [2)] Fiala et al. (2011); in bold – statistically significant at $P < 0.005$

uptake (Hüttl, Schneider 1998) by a damaged tree on the stand with lessened vitality (Thomass, Bütnner 1998).Under the conditions of decreased nutrients availability, a sudden decrease in soil pH value has come due to the roots exudates activity, with the possibility of the influence of mineral dissolution rates (Harley, Gilkes 2000). The plants ability to reduce pH value of rhizosphere of 2 or more units is documented by Marschner (1995). The increase of the value of exchangeable acidity (pH_{CaCl_2}) by 0.20 units in the organomineral horizon is in accordance with a significantly higher volume of Al released from the intramineral space. It corresponds to significant increase of exchange acidity (Al + H) in both the organomineral and mineral horizons.

The available phosphorus (P_{MIII}) decreased significantly in organomineral horizons, maybe because of integration by metal (Fe and Al) ions in strong acidic soils or bound on the sorption sites, which would otherwise be occupied by Al and Fe ions (Zhang, George 2002; Lang et al. 2016). The other possibility may be a lesser supply from the forest floor horizon, where the contents of extractable P have significantly decreased. This is consistent with the conception of the recycling plant strategy at the sites poor in P, pronounced by Lang et al. (2016). Further attribute is the retranslocation from older assimilatory tissues to younger ones, which is consistent with insignificant decreasing of P content in the needles of the previous year and with significant decreasing of P extractable in the forest floor horizons documented by our investigation.

The extractable contents of phosphorus (P_{extr}) are unchangeable in mineral horizons. The level of phosphorus nutrition evaluated by the contents in needles is quite constant. This may be grace of historically gained strategy of long growing plants to cope with low stock of available phosphorus in the soil (Yang et al. 2016). There is also a possibility of substitution of the strategy of "mining" by the strategy of "scavenging", being based on symbiosis with mycorrhiza fungi (Lambers et al. 2008, Schnepf et al. 2008). The development of extractable contents of macronutrients in mineral soil (A_h and B horizons) does not fully follow the tendency described above. The content of extractable calcium kept decreasing tendencies in all the three horizons investigated, the content of extractable potassium is significantly smaller in mineral phases of soil profiles, but the content of extractable magnesium is significantly higher in all the investigated horizons.

Besides the chemical analysis of soil, the chemistry of assimilatory organs of trees was used as a monitor of a site status. There was found out an increase of the content of macronutrient P, Ca and Mg in the Norway spruce needles of the current year. This increase has not been statistically significant. However, taking into consideration a significant increase of extractable magnesium in the soil and the information on the increasing level of nutrition of European forest trees with this element (Jonard et al. 2014), we cannot overlook the similarity.

A similar tendency was observed in Europe in forests with symptoms of the so called "new type forest damage". Unexpected signs of recovery and

https://doi.org/10.17221/4/2019-JFS

improved nutrition, as indicated by higher Mg foliar contents, have been observed since late 1980s. Our study confirms those phenomena by a little increase of Mg content in both the current and previous years´ needles. Our probable explication might be a retranslocation from root cells, where Mg is often stored and released into xylem only if Mg becomes deficient (Hermans, Verbruggen 2005; White 2012). However, these phenomena of significantly Mg increase in organomineral and mineral horizons may be connected with the ability of extractant HNO_3 to release Mg from the minerals weathered under the condition of acid soils. The minerals have been becoming more soluble in acid soils and more available to plants at the same time.

The proposed trend of dissolution rate by Harley and Gilkes (2000) suggests the dependency of the dissolution of feldspars, ferromagnesian minerals and sheet silicates on pH values. From this point of view, the changes of extractable contents of Ca and Mg shown in our study reflect higher nutrients released in mineral-soil interface under ongoing more intensive weathering. The Ca has yet been released from feldspar Ca-plagioclase and has been followed by Mg released from chlorite and other minerals.

The depletion of Ca from a geological bedrock of base-poor igneous and metamorphic rocks, is reported by Huntington et al. (2000) from the area of Southeastern United States, where- due to a long-time weathering- the most Ca-bearing minerals were depleted. Raben et al. (2000) referred to significant decreasing of Ca extractable in a forest floor horizon. They also reported on the mobilization of octaedric Mg and its increase in the soil solution.

The micas are a major source of K and Mg. Greater repulsion between superposed cations of trioctatedral micas (e.g. biotite) causes easier weathering (Harley, Gilkes 2000). After the long action of Fe-ions free in acid soil, the resistance to weathering has become weaker and a part of Mg and Fe pool has been extracted from biotite by the HNO_3 extractant. This chemical agent has been able to release Mg from the chlorite or biotite under the conditions described.

The explanation of the higher contents of nutrients in the spruce needles lies in the ability of plants to increase the intensity of acquiring the nutrition from the substrate. The increase in nutrient contents in current year´s needles, observed in Central Europe (Jonard et al. 2014), has been proved in our study in the case of magnesium only.

A sufficient level of K in spruce needles is in accordance with findings of Wang et al. (2000). They declared good growth of plants examined on the gneiss. Moreover, a decreasing content in the needles of the current year and a significant decrease in the needles of the previous year may indicate a weakening supply of weathered minerals. A significant K increase in the forest floor horizon relates to a quick movement of K through the ecosystem cycle. It can be illustrated by leaching from the canopy which achieves 15 $kg \cdot ha^{-1} \cdot a^{-1}$ for a spruce and is higher than the K fluxes from litter (Langusch et al. 2003). The accumulation in a floor horizon is higher due to the decrease of Ca. The Ca enhances the release of K and Na and, in addition, it reduces their reabsorption because of effective competition (Jenny 1941).

The decrease of K in mineral parts of soil profiles and needles in the Norway spruce site may relate to more intensive uptake by roots of plants (Wang et al. 2000) facilitates, the release of K from gneiss. The K retention is completely dependent on the cation exchange capacity of the soil (Manning 2010), which is generally low in dystric cambisols. A significant increase is detected in extractable contents of Al and Fe which correspond to the increase of exchangeable acidity of soils and may relate to a lasting acidification of soil. Due to highly selective binding of Al^{3+} on exchange sites, released from silicate lattices, the Al^{3+} saturation can reach high values at low Al^{3+} concentration in soil solution (Ulrich 1991).

A significant increase of content of Cr was found only in forest floor horizons. Taking in consideration the solubility of heavy metals (Rotter et al. 2013), the mineral origin of chromium in organomineral horizons is excluded. The low ratio of extractable and pseudototal contents of Cr (0.30) corresponds to the atmospheric origin of higher contents of Cr. The increase of Cr content documented only in forest floor horizons, and significantly decreased contents in the needles of both age classes testify the atmospheric origin of Cr.

Smaller extractable contents of other heavy metals (Cu, Pb and Zn) relate to a changed composition of the atmospheric deposition after the change of industry, as is described by Jonard et al. (2014).

The last notes are given to boron. It has decreased significantly during the decade but the contents

https://doi.org/10.17221/4/2019-JFS

in the current year´s needles correspond to the content optimal from 15 to 30 mg·kg^{-1} (Legrand 2003). The B supply raised from the decomposition of litter and from the atmospheric deposition (Aphalo et al. 2002). A limiting effect of water shortage on B uptake is referred by Saarsalmi and Tamminen (2005). Due to the presence of dioctahedral mica–muscovite which is an important source of boron (Harley, Gilkes 2000), we do not regard the current decrease of boron to be crucial. We ascribe boron decreasing to a slower biochemical cycle above all, which is accompanied with lasting acidification and restricted root uptake, as well as a contemporary drier period. A more detailed study of the findings presented is not the matter of a forest nutrition survey.

CONCLUSIONS

The changes in the chemistry of a forest site, determined by a periodical survey of forest nutrition in the interval of ten years, pointed out the importance of the mineral compartment of forest ecosystems as a primary source of nutrients. There is a higher increment of wood in a condition of high concentration of CO_2 and N, accompanied by high uptake of nutrients and poverty of soils at the same time. Acquiring nutrient from minerals becomes to be an important way of providing nutrients. Under the condition of high acidity of soil environment, the minerals have become less resistant and exhausted. The survey shows that a depletion of a big amount of calcium from the easily weathered plagioclases is followed by a turn of magnesium uptake from more resistant sources – above all micas. An intensive depletion of nutrient is increased due to a nutrient competition of trees. The production of wood, as the main function of commercial forests, should be in harmony with the function of soil protection, paying full respect to the substance of plant nutrition - geochemical cycle of nutrients, including the lasting sustainability of the forest ecosystems.

References

Aphalo P.J., Schoettle A. W., Letho T. (2002): Leaf lifespan and the mobility of „non-mobile“ mineral nutrients – the case of boron in conifers. Silva Fennica, 34: 671–680.

Augustine S., Stephanowitz H., Wolff B., Schröder J., Hoffmann E. (2005): Manganese in tree rings of Norway spruce as an indicator for soil chemical changes in the past. European Journal of Forest Researches, 124: 313–318.

Bauer G., Schulze E.D., Mund M. (1997): Nutrient contents and concentrations in relation to growth of *Picea abies* and *Fagus sylvatica* along a European transect. Tree Physiology, 17: 777–786.

Culek M., Bínová L., Buchar J., Faltys V. (1996): Biogeografické členění České republiky. Enigma, Praha: 348.

Fiala P., Reininger D., Samek T., Němec P., Sušil A. (2013): Survey of Forest Nutrition within the Czech Republic 1996–2011. CISTA, Brno: 148.

Fernández-Martínez M., Vicca S., Janssens I. A., Sardans J., Luyssaert S., Campioli M., Chapin III F. S., Ciais P., Malhi Y., Obersteiner M., Papale D., Piao S. L., Rechstein M., Rodà F., Peñuelas J. (2014): Nutrient availability as the key regulator of global forest carbon balance. Nature Climate Change, 4: 471–476.

Fischer R., Mues V., Ulrich E., Becher G., Lorenz M. (2007): Monitoring of atmospheric deposition in European forests and an overview on its implication on forest condition. Applied Geochemistry, 22: 1129–1139.

Fürst A. (2009): Forest Foliar Coordinating Centre (FFCC). Available at http://www.ffcc.at/ (accessed Oct 20, 2015)

Göttlein A., Heim A., Matzner E. (1999): Mobilization of aluminium in the rhizosphere soil solution of growing tree roots in an acidic soil. Plant and Soil, 211: 41–49.

Guo W., Nazim H., Liang Z., Yang D. (2016): Magnesium deficiency in plants: an urgent problem. The Crop Journal, 4: 83–91.

Harley A.D., Gilkes R.J. (2000): Factors influencing the release of plant nutrient elements from silicate rock powders: a geochemical overview. Nutrient Cycling in Agroecosystems, 56: 11–36.

Hermans C., Verbruggen N. (2005): Physiological characterization of Mg deficiency in *Arabidopsis thaliana.* Journal of Experimental Botany, 56: 2153–2161.

Huntington T.G., Hooper R.P., Johnson C.E., Aulenbach B.T., Cappellato R., Blum A.E. (2000): Calcium depletion in a southeastern United States Forest Ecosystem. Soil Science Society of America Journal, 64: 1845–1858.

Hüttl R.F., Schneider B.U. (1998): Forest ecosystem degradation and rehabilitation. Ecological Engineering, 10: 19–31.

Jenny H. (1941): Factors of Soil Formation: A System of Quantitative Pedology. New York, Dova Publications: 281.

Jonard M., Matteucci G., Ingerslev M., Rautio P. (2014): Tree mineral nutrition is deteriorating in Europe. Global Change Biology, 21: 418–430.

Kandler O., Innes J. L. (1995): Air pollution and forest decline in Central Europe. Environmental Pollution, 90: 171–180.

https://doi.org/10.17221/4/2019-JFS

Lang F., Bauhus J., Frossard E., George E., Kaiser K., Kaupenjohann M., Krüger J., Matzner E., Polle A., Prietzel J., Rennenberg H, Wellbrock N. (2016): Phosphorus in forest ecosystems: New insights from an ecosystem nutrition perspective. Journal of Plant Nutrition and Soil Science, 179: 129–135.

Langusch J.J., Borken W., Armbruster M., Dise N.B., Matzner E. (2003): Canopy leaching of cations in Central European forest ecosystems–a regional assessment. Journal of Plant Nutrition and Soil Science, 166:168–174.

Lambers H., Raven J.A., Shaver G.R., Smith S.E. (2008): Plant nutrient-acquisition strategies change with soil age. Trends in Ecology and Evolution, 23: 95–103.

Legrand P. (2003): Carence en bore de jeunes plantations de Cèdre de l´Atlas dans le Massif Central, Revue Forestière, LV: 123–128.

Manning D.A.C. (2010): Mineral sources of potassium for plant nutrition. A review. Agronomy for Sustainable Development, 30: 281–294.

Marschner H. (1995): Mineral Nutrition of Higher Plants. London, Academic Press: 889.

Mellert K.H., Göttlein A. (2012): Comparison of new foliar nutrient thresholds derived from van den Burg´s literature compilation with established central European references. European Journal of Forest Researches, 131: 1461–1472.

Peng Z., Thomas S C., Tian D. (2008): Forest management and soil respiration: Implications for carbon sequestration. Environmental Revue, 16: 93–111.

Průša E. (1990): Přirozené lesy České republiky. Prague, SZN: 248.

Raben G., Andreae H., Meyer-Heisig M. (2000): Long-trem acid load and its consequences in forest ecosystems of Saxony (Germany). Water, Air and Soil Pollution, 122: 93–103.

Rotter P., Šrámek V., Vácha R., Borůvka L., Fadrhonsová V., Sáňka M., Drábek O., Vortelová L. (2013): Rizikové prvky v lesních půdách. Zprávy lesnického výzkumu, 58: 17–27.

Saarsalmi A., Tamminen P. (2005): Boron, phosphorus and nitrogen fertilization in Norway spruce stands suffering from Growth Disturbances. Silva Fennica, 39: 351–364.

Schnepf A., Roose T., Schweiger P. (2008): Impact of growth and uptake patterns of arbuscular mycorrhizal fungi on plant phosphorus uptake-modelling study. Plant and Soil, 312: 85–99.

Thomas F. M., Büttner G. (1998): Nutrient relations in healthy and damaged stands of mature oaks on clayey soils: two case studies in northwestern Germany. Forest Ecology and Management, 108: 301–319.

ÚHÚL (1999): Oblastní plán rozvoje lesů. Přírodní lesní oblast 11. Český les. Textová část, platnost 1999–2018. Brandýs nad Labem, pobočka Plzeň, ÚHÚL: 409. Available at: http://www.uhul.cz/images/ke_stazeni/oprl_oblasti/OPRL-LO11-Cesky_les.pdf

Ulrich B. (1991): An ecosystem approach to soil acidification. In: Ulrich B., Summer M.E. (eds): Soil acidity. Berlin, Heidelberg, New York, Springer: 28–79.

Viewegh J., Kusbach A., Mikeska M. (2003): Czech forest ecosystem classification. Journal of Forest Science, 49: 74–82.

de Vries W., Dobbertin M.H., Solberg S., van Dobben H., Schaub M. (2014): Impacts of acid deposition, ozone exposure and weather condition on forest ecosystems in Europe: an overview. Plant and Soil, 380: 1–45.

Wang J.G., Zhang F.S., Cao Y.P., Zhang X.L. (2000): Effect of plant types on release of mineral potassium from gneiss. Nutrient Cycling in Agroecosystems, 56: 37–44.

White et al. (2012): Long-distance Transport in the Xylem and Phloem. In: Marschner H. (ed.): Mineral nutrition of higher plants. London, Academic Press: 49–70.

Yang N., Zavišić A., Pena R., Polle A. (2016): Phenology, photosynthesis, and phosphorus in European beech (*Fagus sylvatica* L.) in two forest soils with contrasting P contents. Journal of Plant Nutrition and Soil Science, 179: 151–158.

Zbíral J. (1994): Analýza rostlinného materiálu. Jednotné pracovní postupy. Brno, ÚKZÚZ: 80.

Zbíral J., Honsa I., Malý S. (1997): Analýza půd III. Jednotné pracovní postupy. Brno, ÚKZÚZ: 150.

Zhang J., George E. (2002): Changes in the extrability of cations (Ca, Mg and K) in the rhizosphere soil of Norway spruce (*Picea abies*) roots. Plant and Soil, 243: 209–217.

Received for publication January 14, 2019
Accepted after corrections March 20, 2019