Acidification of Forest Soils in the Hrubý Jeseník Region

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Abstract: The Hrubý Jeseník Natural Forest Region (NFR) is a border mountain territory which belongs to the areas most heavily impacted by air pollution in the Czech Republic. This paper compares results for soil properties investigated in non-limed forest stands during the years 1994 to 2007. Differences between the 2007 and 2000/01 surveys concerning Al, Ca and Mg content and pH in particular soil horizons are depicted using kriged maps. This means of interpreting laboratory analysis results allowed us to highlight the most endangered NFR areas from an acidification standpoint. Evaluation of results for Al, Ca and Mg content, their available forms and pH values in the Hrubý Jeseník NFR in the 1994–2007 period revealed the presence of an ongoing acidification process. The southern (Praděd region) and northwestern areas (Králický Sněžník region) may be singled out as the most depleted.

Keywords: acidification; Hrubý Jeseník; kriged maps; soil properties survey; spatial distribution

The acidification of forest soils is currently a much discussed ecological problem. It is generally attributed to acid inputs in forests by rain precipitation or dry deposition which lead to an exchange between H^+ ions in the throughfall and Ca, Mg or K ions on the exchange complex (Bonneau 2005). This leads to depletion of base cations, pH decrease, the development of lower quality humus, and Al mobilization (Borůvka *et al.* 2005). Base cation depletion is a cause for concern because of the role these ions play in acid neutralization, and in the case of Ca, Mg and K, their importance as essential nutrients for tree growth and health (Fenn *et al.* 2006).

The Natural Forest Region (NFR) Hrubý Jeseník is comprised of the Králický Sněžník Mts. (Králický Sněžník, 1424 m a.s.l.), the Hrubý Jeseník Mts. (Praděd, 1491 m a.s.l.), and the most elevated section of the Rychlebské Mts. The average annual temperature is about 4°C (0.9–6.3°C) and average annual rainfall totals are about 1200 mm. From a geological standpoint, the NFR Hrubý Jeseník chiefly consists of gneisses, phyllites, schists, and amphibolites. Predominant soil types include Entic Podzols, Haplic Podzols, and Cambisols (ÚHÚL 2002).

The Hrubý Jeseník Mountains are a medium elevation mountain region in north-east part of the Czech Republic (near border with Poland) with elevation from 600 to 1400 m a.s.l. and regular fog events. Industry, traffic, heating/fuel consumption and intensive animal husbandry contributed to wet and dry atmospheric deposition of sulphur and nitrogen compounds in this area (Zapletal *et al.* 2007).

Forest stands in the NFR Hrubý Jeseník are significant in terms of wood production, water management and soil conservation. Because of the potential impact of air pollution on these functions, it is one of the most-studied forest regions in the Czech Republic as regards plant nutrition surveys and the investigation of soil properties. Surveys have already been carried out in the region on three occasions, in 1994, 2000/01 and 2007. Repeated sampling at the same stands and sampling point grids with increasingly closer points provide valuable data for evaluating changes in soil properties. The wide range of analyses performed have resulted in improved knowledge of chemical processes in the soils. The paper aims to evaluate changes in pH, extractable Al, Ca and Mg content and available Ca and Mg content for the 1994–2007 period.

MATERIALS AND METHODS

The NFR Hrubý Jeseník is situated in the north-eastern portion of the Czech Republic (Figure 1). Forest coverage is approximately 56630 ha (ÚHÚL 2002). Soil sampling was carried out in the region in 1994, 2000/01 and 2007 using the methodology currently prescribed by the Central Institute for Supervising and Testing in Agriculture (CISTA). Sampling in 1994 focused on 149 of the most elevated forest stands in the Hrubý Jeseník. In 2000/01, 151 forest stands sparsely distributed throughout the region were studied and in 2007 almost twice that number – 340 stands sparsely distributed throughout the region – were the focus of study. These numbers were adequate to ensure the survey's robustness. Forest stands were selected for sampling in such a way as to achieve uniform coverage over the region, maximizing the potential to repeat previous sample collections and ensuring sampling from stands whose health was more precarious.

One sample was taken of the forest floor (litter – OL, fragmented/fermented – OF, humus – OH together, 8–0 cm) from a defined area (25 × 25 cm) and mixed samples from mineral horizons A (0–10 cm) (1994, 2000/01, 2007) and B (11–30 cm) (2000/01, 2007). These samples were analyzed by a CISTA-accredited laboratory.

The forest floor and mineral horizon samples were analyzed using an extract with 2M HNO_3. The concentration of Ca, Mg, and Al in the extracts was determined using ICP-AES methodology. The concentration of available nutrients was determined in mineral horizons using Mehlich II soil extract in 1994, and Mehlich III soil extracts since 2000. The concentrations of Ca and Mg in the extracts was determined by means of flame atomic absorption spectrometry (FAAS). Exchangeable pH (pH_{exch}) was determined in 0.2 mol/l KCl (1994) and in 0.01 mol/l $CaCl_2$ (2000/01, 2007). Data on amelioration liming (Figure 2) was used to exclude samples from stands lying within the limed areas and stands adjacent to these areas (where high concentrations of Ca or Mg in the forest floor indicate the stands were likely a target of aerial liming).

Figure 1. Location of the Natural Forest Region (NFR) Hrubý Jeseník on the map of the Czech Republic

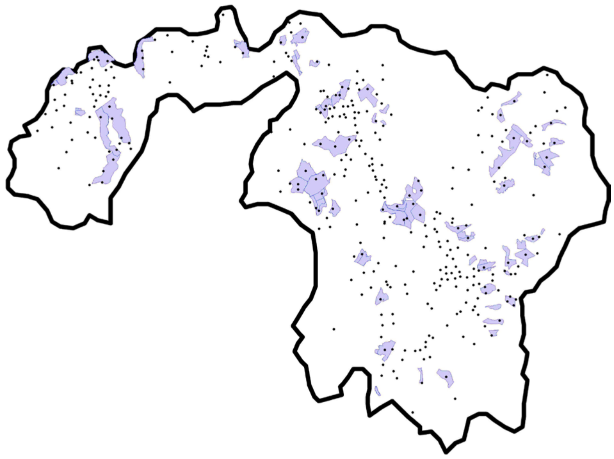


Figure 2. Liming areas (1985–1993) in the region of the Natural Forest Region (NFR) Hrubý Jeseník and sampling sites from 2007 survey

Average and median values were calculated for observed elements from each horizon for the remaining stands (1994 – 120, 2000/01 – 118, 2007 – 234) (see Table 1).

To evaluate the development and potential acidification of forest soils, a subgroup of stands was created comparing the element content determined in previous years with the element content in 2007. Only stands in which repeated sampling was done for each horizon were included in this subgroup. This leaves 97 stands for the comparison of 2000/01 versus 2007 and 100 stands to compare 1994 with 2007. A t-test for dependent samples or the Wilcoxon test was used to quantify the importance of changes in the concentrations of various elements (Table 2). Correlation coefficients were calculated for the relationship between changes in element content and pH in various horizons (Table 3). Geostatistical methods were used to create kriged

Table 1. Average values for selected soil properties (the median is given in parentheses) – all the non-limed stands

	Horizon								
	forest floor (8–0 cm)			mineral A (0–10 cm)			mineral B (11–30 cm)		
Year	1994	2000/01	2007	1994	2000/01	2007	1994	2000/01	2007
pH_{exch}	3.1 (3.0)	3.2 (3.1)	3.3 (3.3)	3.2 (3.1)	3.2 (3.1)	3.3 (3.2)	–	3.6 (3.6)	3.7 (3.7)
Al_{HNO_3} (mg/kg)	6655 (5760)	4544 (3934)	4356 (3660)	3999 (2770)	4177 (3388)	3763 (3140)	–	5334 (4010)	6562 (5550)
Ca_{HNO_3} (mg/kg)	1471 (935)	1607 (1365)	1649 (1265)	–	600 (475)	404 (237)	–	287 (184)	227 (136)
Mg_{HNO_3} (mg/kg)	1312 (678)	921 (483)	732 (401)	–	441 (201)	406 (159)	–	619 (241)	684 (336)
$Ca_{Mehlich}$ (mg/kg)	–	–	–	430 (313)	387 (297)	210 (89)	–	155 (110)	65 (29)
$Mg_{Mehlich}$ (mg/kg)	–	–	–	76 (49)	76 (70)	58 (37)	–	31 (27)	26 (14)

maps showing the spatial distribution of differences in the content of Al, Ca, Mg, and pH values for the forest floor horizon and mineral A nd B horizons. For each soil property the variogram (dependence of semivariance on the points distance) was computed, and the variogram was smoothed by mathematical model. Then the geostatistical interpolation by the method of point kriging was performed. This was done on the basis of differences between the 2000/01 and 2007 survey. Surfer 8 geostatistical software (from Golden Software, Inc.) was used for this purpose. The maps form an important supplement to the statistical evaluation and provide information about the spatial distribution of the changes observed.

RESULTS AND DISCUSSION

Exchangeable pH

The soils in the region studied may be characterized as either strongly (3–4) or very strongly (< 3) acidic (Fiala *et al.* 2007). Decreasing pH may serve as an indicator of acidification, but in this case pH is slightly increased in all horizons under both comparisons (Table 2). This may relate to Ca content, which is relatively stable in the horizons from long-term point of view. As deeper horizons are used, the change in soil acidity becomes less evident. The low value of pH and stable content of Ca amount mismatch with monitoring of acidification process. The acid soil has high resistance against the further acidification (Podrázský 1996). Tamminen and Derome (2005) found out that pH_{KCl} showed a rising trend over time in the organic layer, no trend in the 0–10 cm mineral soil layer, and a weakly declining trend in the 0–30 cm mineral soil layer.

The spatial distribution of these changes demonstrates that soil acidity is decreasing, especially in the central portion of region. By contrast, the northern and southern portions show indications of acidification on the forest floor which are most expressive in the A horizon of richer soil of hornblende schist of subsoil and continue to the B horizon, even if not as markedly (Figure 3).

Aluminium

On the basis of soil sample analyses it is possible to claim that the content of extractable Al is rather high in soils of the NFR Hrubý Jeseník, but its concentration is decreasing over the long term (a decline of 2000 mg/kg in the forest floor horizon). In B horizons, the Al concentration continues to increase (Table 2). Another important factor is the relatively high significant positive correlation between differences in pH values and Al (Table 3).

From the spatial distribution, it is apparent that Al content is increasing, especially in the central portion of the region in all three horizons (Fig-

Table 2. Comparison of average contents of selected soil properties – repeated soil survey at non-limed forest stands

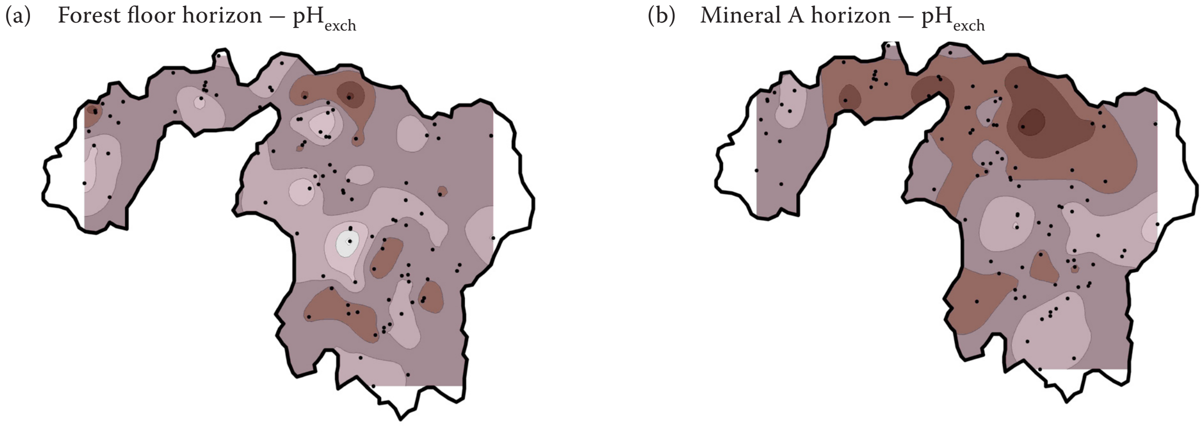
	Horizon										
	forest floor (8–0 cm)				mineral A (0–10 cm)				mineral B (11–30 cm)		
Year	1994	2000/01	2007	difference	1994	2000/01	2007	difference	2000/01	2007	difference
pH_{exch}	– 3.09	3.20 –	3.37 3.28	+ 0.17* + 0.19*	– 3.13	3.17 –	3.22 3.23	+ 0.05 + 0.10*	3.59	3.67	+ 0.08*
Al_{HNO_3} (mg/kg)	– 6305	4676 –	4109 4260	– 567 – 2045*	– 3695	4106 –	3842 3452	– 264 – 243	5455	6233	+ 778*
Ca_{HNO_3} (mg/kg)	– 1405	1598 –	1810 1372	+ 212* – 33	–	617	403	– 214*	297	217	– 80*
Mg_{HNO_3} (mg/kg)	– 1236	942 –	783 608	– 159 – 628*	–	449	500	+ 51	640	826	+ 186*
$Ca_{Mehlich}$ (mg/kg)	–	–	–	–	– 438	401 –	170 182	– 231* –256*	157.8	60.1	– 97.6*
$Mg_{Mehlich}$ (mg/kg)	–	–	–	–	– 74.1	77.7 –	47.2 61.6	– 30.5* – 12.5*	31.1	19.5	– 11.6*

*the difference is significant at P = 0.05

Table 3. Correlation coefficients of the relationships among changes in element content and pH_{exch} in various horizons (2000/01 against 2007 survey, repeated soil survey at non-limed forest stands)

	Horizon															
	forest floor (8–0 cm)				mineral A (0–10 cm)						mineral B (11–30 cm)					
	pH_{exch}	Al_{HNO_3}	Ca_{HNO_3}	Mg_{HNO_3}	pH_{exch}	Al_{HNO_3}	Ca_{HNO_3}	Mg_{HNO_3}	$Ca_{Mehlich}$	$Mg_{Mehlich}$	pH_{exch}	Al_{HNO_3}	Ca_{HNO_3}	Mg_{HNO_3}	$Ca_{Mehlich}$	$Mg_{Mehlich}$
pH_{exch}	1.00				1.00						1.00					
Al_{HNO_3}	0.35*	1.00			0.54*	1.00					0.68*	1.00				
Ca_{HNO_3}	0.22*	–0.60*	1.00		–0.11	0.01	1.00				0.17	0.20*	1.00			
Mg_{HNO_3}	0.47*	0.72*	–0.34*	1.00	0.53*	0.55*	0.09	1.00			0.35*	0.46*	0.21*	1.00		
$Ca_{Mehlich}$	–	–	–	–	–0.14	–0.09	0.89*	–0.04	1.00		–0.02	–0.06	0.73*	–0.06	1.00	
$Mg_{Mehlich}$	–	–	–	–	–0.26*	–0.04	0.66*	–0.05	0.64*	1.00	–0.15	–0.12	0.22*	–0.01	0.55*	1.00

*the correlation is significant at P = 0.05



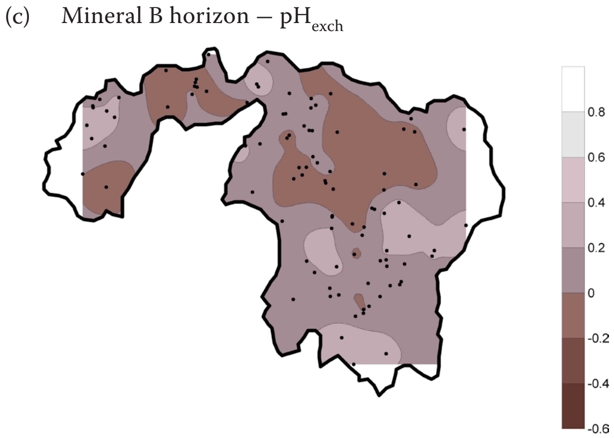
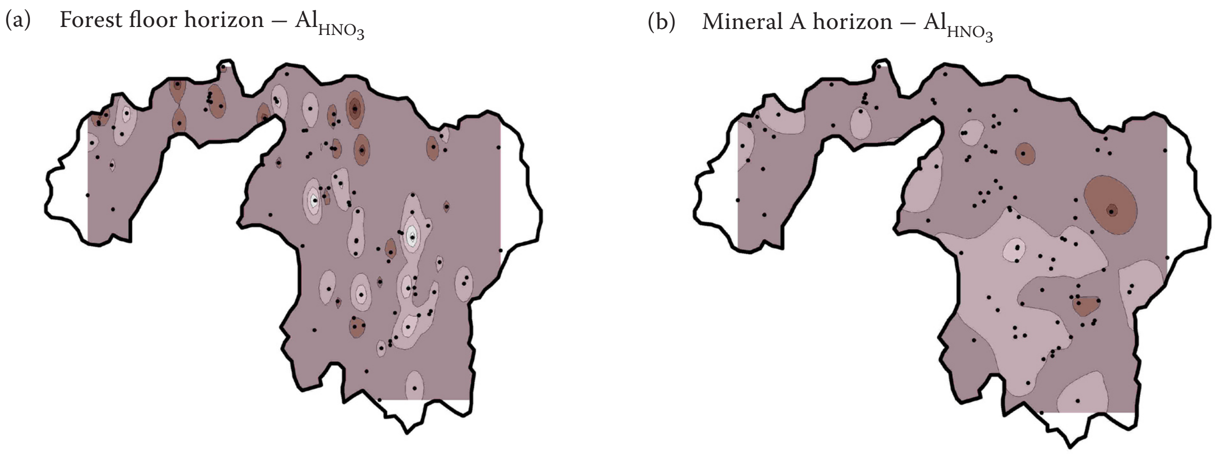


Figure 3. Kriged maps of spatial distribution of differences in exchangeable pH in soils in the Natural Forest Region (NFR) Hrubý Jeseník between 2000/01 and 2007: (a) forest floor horizon, (b) mineral A horizon, (c) mineral B horizon



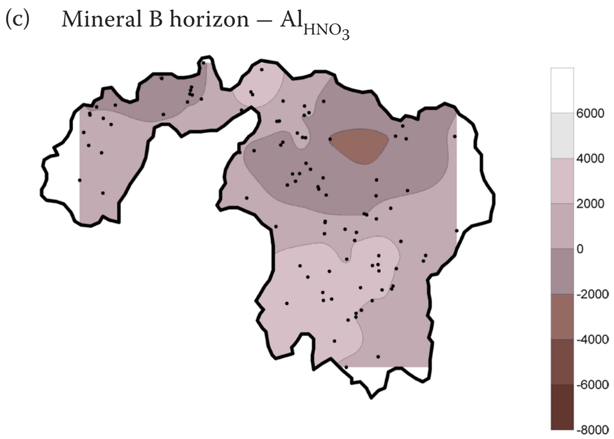


Figure 4. Kriged maps of spatial distribution of the differences in Al_{HNO_3} content (mg/kg) in soils in the Natural Forest Region (NFR) Hrubý Jeseník between 2000/01 and 2007: (a) forest floor horizon, (b) mineral A horizon, (c) mineral B horizon

ure 4). This increase is most expressive in the B horizons, where the differences reaches fairly elevated values of 2000 to 4000 mg/kg.This could be related to geological parent material in the region and the release of Al at the relatively low soil pH. The exchangeable Al, as the amount of free form of Al in the soil, is said to be generally low in soil samples with pH > 5. In contrast, at pH < 5 it strongly increases with decreasing pH (Guckland *et al.* 2009; Kochian *et al.* 2002).

Calcium

The Ca content in the forest floor horizons is very low, but the 2007 survey registers a statistically significant increase over the 2000/01 survey. The differences in extractable Ca content in forest floor possesses a significant negative correlation with the differences in extractable Mg content. By contrast, the mineral portion of the profile shows a completely different situation. The available Ca content (in the Mehlich extract) declined markedly, by more than 50%. It is apparent also in the extractable Ca (in nitric acid extract) (Table 2). In mineral horizons there is an expressive decrease from good to low Ca supply in A horizons and from low to very low supply in B horizons.

In mineral horizons, a strong positive correlation existed between differences in extractable Ca content and differences in available Ca content determined by Mehlich extraction (Table 3).

The spatial distribution showed that in the forest floor the most pronounced decrease in Ca content occurred in the southern portion of the region (the Praděd area, Figure 5a). The northern portion of the region, by contrast, showed an increasing supply of Ca. This fact may be connected to the species composition of stands due to a higher proportion of European Beech in the northern section of the region. Podrázský and Viewegh (2005) showed that differentiation of stand structure and the presence of beech impact positively on the base content.

In the mineral portion of soil profiles, the situation is evidently worse in A horizon, where the southern portion again shows more depletion. A more expressive decline is also noted close to the

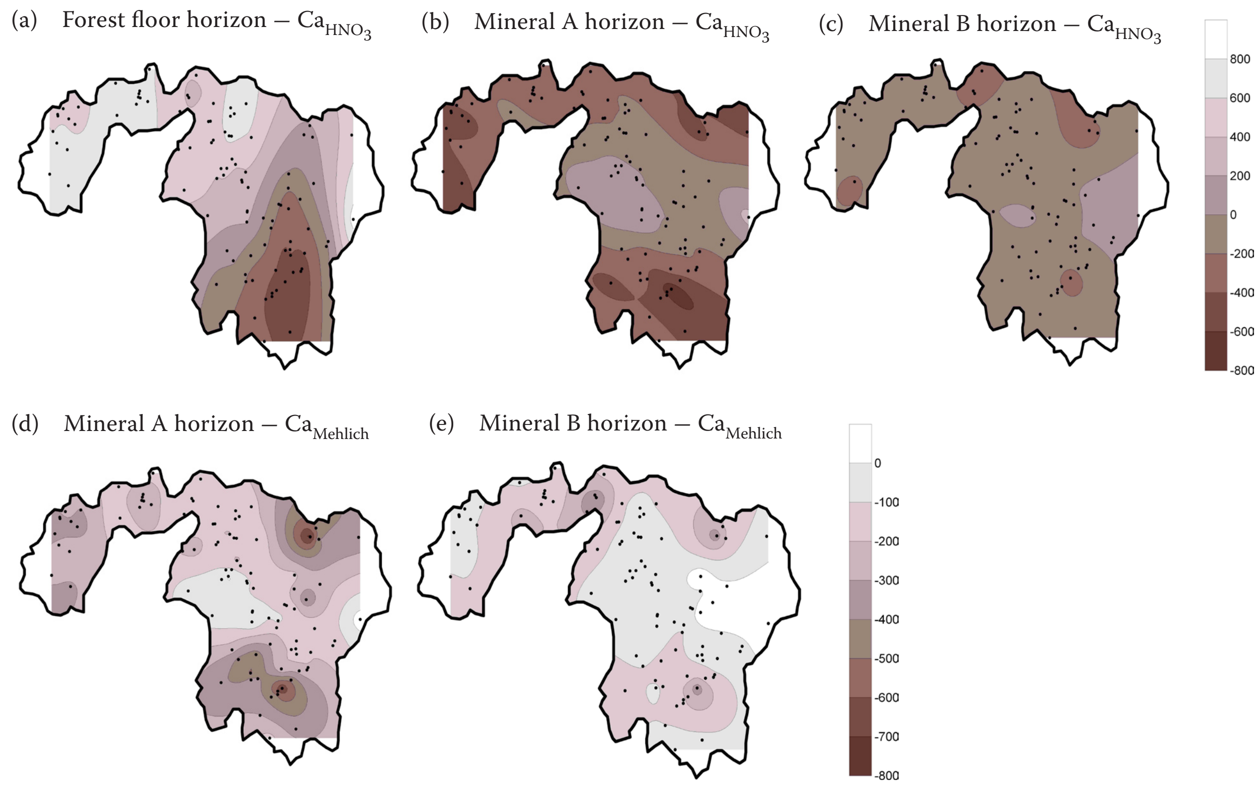


Figure 5. Kriged maps of spatial distribution of the differences in Ca content (mg/kg) in soils in the Natural Forest Region (NFR) Hrubý Jeseník between 2000/01 and 2007: (a) forest floor horizon – Ca_{HNO_3}, (b) mineral A horizon – Ca_{HNO_3}, (c) mineral B horizon – Ca_{HNO_3}, (d) mineral A horizon – $Ca_{Mehlich}$, (e) mineral B horizon – $Ca_{Mehlich}$

northeastern frontier and in the Králický Sněžník region.

The decreasing ratio of Ca to other bases with increasing depth is also consistent with the presence of weatherable minerals containing Mg, K, and Na, but not Ca, throughout the soil profile (Huntington *et al.* 2000). The shallow rooting Norway spruce can accentuate the acidification of the upper mineral soil, because the entire base cation uptake of the forest is obtained from a small part of the mineral soil. Calcium is temporarily removed from the soil, but not lost from the ecosystem, because it is retained in the tree biomass (Jandl *et al.* 2004).

Magnesium

Magnesium content in the forest floor horizons significantly decreased during the period under consideration (Table 2) from a robust supply in 1994 to a low supply in 2007. This is again an expressive decline of more than 50%. In the mineral horizons, however, no decline was noted. To the contrary, Mg content actually increased. Differences in Mg content extractable by nitric acid are significantly positively correlated with increasing values of Al and pH in all horizons. By contrast, available Mg content significantly decreased during the period under consideration in both mineral horizons, reaching low to very low values. Increase or decrease is significantly correlated to changes in available Ca content. From the spatial distribution, it is evident that an expressive decline may once again be noted in the north portion of the region in the forest floor horizons (Figure 6a). The worst situation is in the mineral A horizons, where available Mg content decreased practically throughout the entire region. As the most depleted area it is possible to mark again the southern part (Praděd region) and the northwest part (Králický Sněžník region). Increased values of available Mg content in B horizons are evidently related to geological bedrock. There is an influence of rich bedrock – a strip of hornblende schist in the middle of the NFR.

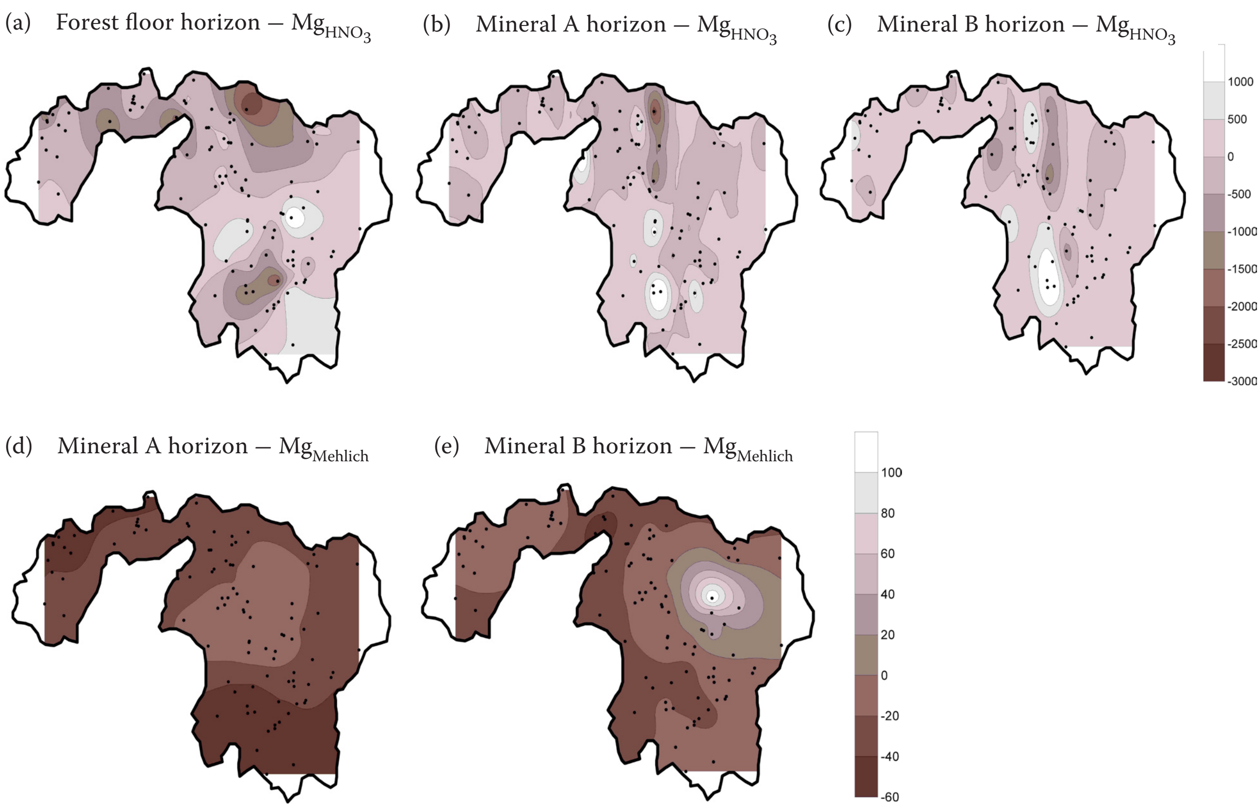


Figure 6. Kriged maps of spatial distribution of the differences in Mg content (mg/kg) in soils in the Natural Forest Region (NFR) Hrubý Jeseník between 2000/01 and 2007: (a) forest floor horizon – Mg_{HNO_3}, (b) mineral A horizon – Mg_{HNO_3}, (c) mineral B horizon – Mg_{HNO_3}, (d) mineral A horizon – $Mg_{Mehlich}$, (e) mineral B horizon – $Mg_{Mehlich}$

CONCLUSIONS

The results of evaluating the content of Al, Ca, and Mg, their available forms, and pH_{exch} values in the NFR Hrubý Jeseník for the period 1994–2007 show evidence of an ongoing acidification process in some parts of the region. Although a slight decline in soil acidity was noted, soil pH is still strongly to very strongly acidic.

The Al content is still rather high and down to the soil profile, is rising. The content of available Ca and Mg forms decreased dramatically during the period under consideration and it reached low or very low supplies from a plant nutrition standpoint. However, the extractable content of these elements showed different trends. While Ca content is stable in the forest floor horizons, Mg content has markedly decreased. The situation is completely different in the mineral horizons, where Ca content is continuously decreasing, while Mg content is rising.

The spatial distribution visualization of focused soil properties development in the NFR Hrubý Jeseník has permitted the localization of areas where an acidification process is in progress. These results may be used to form a valuable basis for appropriate ameliorative measures to be taken to halt this unfavourable process.

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