Prediction of medium- and long-term changes in soil reaction in a beech forest based on observations in the beech stemflow zone

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Abstract

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The active soil reaction in a mature beech forest subjected to alkaline dust deposition reflected parallel influence of both alkaline and acid deposition. As a result, the active soil reaction within the stemflow zone at the depth of 5–10 cm decreased from 7.4 and 6.5 to 5.9 and 4.7, respectively. Outside the stemflow zone, the soil pH values were reduced from 7.9 to 6.6. This phenomenon occurred due to the long-range acid air pollution transport. Stechiometric calculations showed that the amount of acid deposition was amplified through the stemflow effect in beech trees that in their turn partly offset the alkaline deposition. Thus, the active reaction of the topsoil subjected to stemflow moved from moderately alkaline to moderately acid range during the period 1990–2006, while a similar shift from moderately alkaline towards neutral values occurred outside the stemflow zone. The pH decrease was correlated with a more than 90% reduction in alkaline dust emissions from magnesite works. In the stemflow zone, the active soil reaction at the depth of 5–10 cm is supposed to remain in the related intervals up to about 2030. Outside the stemflow zone, the active soil reaction at the same depth should persist in the neutral range until 2015. Subsequently, the active soil reaction will move towards the moderately acid range even outside the stemflow zone. Standard forest management will probably cause the active soil reaction to converge to the original soil pH value of 5 in the course of approximately 200 years.

Keywords

forest soils, beech forests, stemflow, alkaline deposition, acid deposition, soil reaction prognosis

Introduction

Acidification or alkalization of soils occurs through H^+ transfer processes across vegetation cover, soil solutions and soil minerals (Bremen et al., 1983). Important determining factors are: composition and development of vegetation, soil-forming parent material, woody species composition, air pollution and variability of soil properties. On one hand, the Slovak Republic has an unfavorable position, being heavy influenced with long-range air pollution transport. Prevailing western and northwestern winds displace airborne pollutants towards the Central Europe. Therefore, inputs of sulphates, nitrates and other acid components into forest ecosystems remain high, despite a considerable drop in domestic emissions (Pichler and Bublinec, 2006).

Along with the acidification of forest soils, however, their alkalization took place across certain localities, such as the Muráň Valley, as well. It features a high concentration of magnesite industry whose products play an important role in exports of the Slovak Republic. The production is based on the magnesite deposits in the Carboniferous rocks. Currently, two major plants in Jelšava and Lubeník are functioning within the area of interest, but their recent impact on the surrounding environment has been limited due to the introduction of efficient separation facilities. In the past, mainly between 1970 and 1990, that situation was different due to the continuous release of polydisperse emissions containing solid particles of magnesium and calcium oxide, making several thousand metric tons a year. This fact has resulted in a considerable degradation of the adjacent areas, where the Mg content in soils exceeded 2,000 mg kg^{-1} (Bobro et. al., 2000; Hančuľák and Bobro, 2004). According to these authors, soils of some monitoring plots have already begun to lose their Mg surpluses due to improved situation in airborne pollutant load, ie in places where the Mg input does not exceed the natural Mg losses of 23–34 kg ha^{-1} $year^{-1}$ any longer. The alkaline reaction in the local soils has been caused by presence of low soluble minerals such as periclase, magnesite, calcite and amorphous MgO. The magnesium losses thus occur mainly owing to the secondary minerals such as hydromagnesite, nesquehonite, brucite and others that are able to migrate as a part of the soil solution (Bobro et al., 2000).

The main adverse effect of the strongly increased alkalinity consists in the nutrients immobilisation, because the optimum reaction varies between pH 5.0–6.5. Among the elements whose intake by plants is affected, phosphorus, potassium, nitrogen and trace elements rank comparatively high (Bublinec, 1971).

In this context, it is important to note that conclusions on the impact of natural or anthropogenic depositions are often made based on their isolated effects. In reality, however, combined effects of various depositions are rather a rule than an exception, and they depend on their concentrations and variable exposure times. Thus, the result may be additive, synergic or even antagonistic (Anonymus). Neither assessments nor predictions of airborne pollution impact on soils should therefore be made without a proper attention paid to their mutual interactions. The interaction processes in respect to their transport mechanisms, deposition, chemical reactions, kinetics and spatial heterogeneity of the environmental patterns manifest a high variability both in space and time. To identify the trends means to investigate processes on appropriate time scales and choose suitable validation procedures.

In our study, we leaned on the amplification of airborne pollutants input through stemflow. Stemflow is typical of various beech species due to the specific habitat of the genus *Fagus* (Gersper, 1970; Gersper and Holowaychuk 1970), as different from other species such as oak (Tužinský and Soroková, 2002). Jochheim and Schäfer (1988) established that the stemflow zone received eight times more water enriched by particles and dissolved chemical compounds in comparison with areas only exposed to throughfall. Such processes led to formation of spots in which soil was significantly acidified due to higher amount of acid deposition from coal-fired power plant and remote pollution sources (Šály and Pichler, 1993). Their existence influenced the spatial variability of soil microbiological activity (Gömoryová, 2004a, 2004b). The stemflow-impacted zone was also used by Werner (1988) to study the processes of heavy metals accumulation in forest soils. In a broader sense, it has been the application of geobiocenotic fields concept as defined by Zinke (1962) and Karpachevsky (1977). It relies on the fact that trees, as the main edificators in forest ecosystems, modify the effects of environmental factors in a predominantly circular or radial pattern.

Our approach aimed at the description, interpretation and prediction of soil reaction changes under the influence of past alkaline deposition and continuing acid deposition in the Muráň Valley. The study goals consisted in establishing how the soil pH changes under the European beech trees (*Fagus sylvatica* L.) in the area of interest are likely to be influenced by the stem flow under the current load by airborne pollutants.

Material and methods

We based our investigations on several assumptions:

- The increase in hydrogen protons in the buffer intervals of carbonates (pH 6.2–8.6), silicates (pH 5.0–6.2) and sorbents (pH 4.2–5.0) as defined by Ulrich (1983) can be considered approximately as a linear process.
- An n-fold increase in the acid deposition causes an n-fold acceleration of a soil acidification (Sparks, 2003).

Site description

The soil sampling was carried along a transect in hills of the Revúcka Vrchovina Mts, on the northern slope of Tri Peniažky (583 m asl), 2.5 km SSW of the Jelšava Magnesite Plant, at an elevation of 490 m asl. (Fig. 1). The area is built by black and grey schists and white crystalline limestones from the carboniferous period. The yearly precipitation amount reaches 800 mm. In 1990 when the first sampling was performed, the 95-year-old beech stand had 0.8 stocking and 90% canopy closure. It belongs to the Fagetum pauper forest association with scarce herb layer of *Hedera helix*. The original soil type was Dystric Cambisol whose reaction was around pH 5.0, but it increased to 7.5–8.0 by 1990 due to magnesite pollution. In spite of the alkaline airborne pollution load, the beech forest did not show signs of physiological damage.

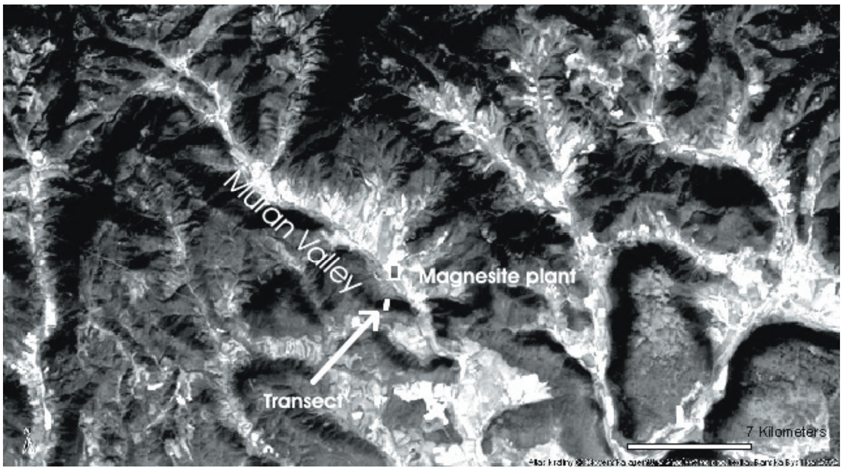

Fig. 1. Tri Peniažky beech transect and Jelšava Magnesite Plant in the Muráň Valley

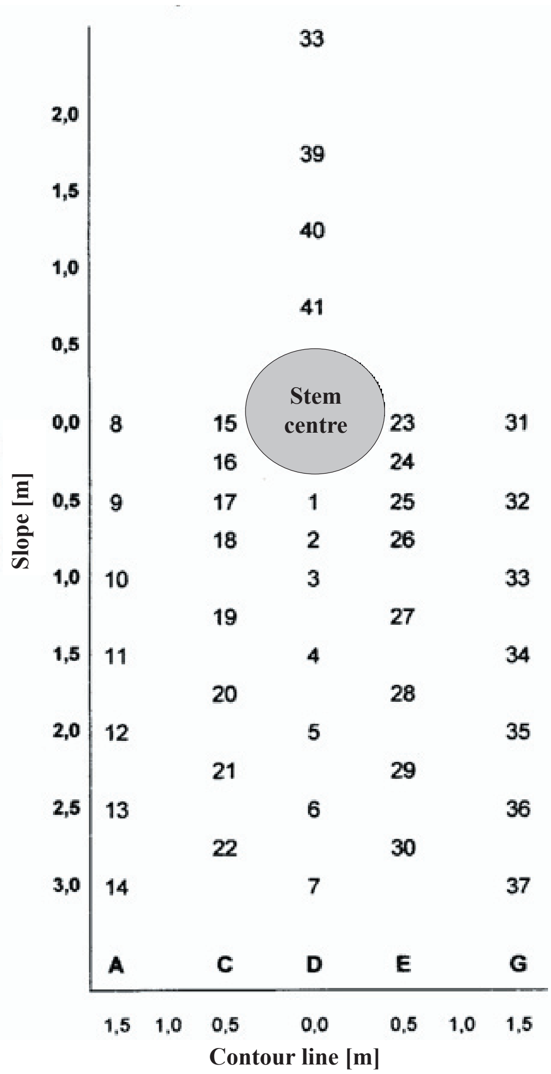

Fig. 2. Soil sampling scheme at Tri Peniažky beech transect

Soil samples

The soil sampling was carried out under five beech trees from the main canopy, ie tree classes 1 and 2 according to Kraft (1884), in October 1990 and 2006. Samples weighing 250 g were taken from the depth of 5–10 cm, according to the sampling scheme given in Fig. 2. The active soil reaction in samples was measured in the laboratory, using a glass ion-sensitive electrode referenced with a standard calomel electrode and a meter (Schofield and Taylor, 1955).

Data analysis

Spatial interpolation among the discrete pH values was performed to identify the stemflow zone defined as a circular or elliptical continuous area with comparatively low pH around the stem. Subsequently, the area-wise ratio between the stem flow zone and the rest of the scheme was calculated. The ratio was used as a percentile dividing the set of measured soil pH values into two classes – affected by either stemflow or throughfall. The pH values were then recast as hydrogen protons concentrations, according to the relation pH = $-\log[H^+]$ and $C_{(H+)} = 10^{(-pH)}$. Regression and correlation analysis was applied to the hydrogen protons activities. Extrapolated trends in both active and exchange reactions were projected, using regression lines. To assess the prediction, the $C_{(H+)}$ increase in soil subjected to stemflow from 1990 to 2006 was compared with the corresponding values in soil exposed to the througfall only. We then established whether the result would fell into the same order of magnitude as the stemflow/throughfall ratio, ie 6–12, as given by Tužinský (2004) and Johnson and Lehmann (2006).

Results and discussion

Interpolated contours of the active soil reaction at the 5–10 cm depth under the beech trees based on values measured in 1990 are given in Fig. 3. Similar contours based on samples taken from the same depth in 2006 are graphed in Fig. 4. A simple ocular inspection of the graphs shows a considerably increased soil reaction span in 2006 when compared to 1990. Also the spatial variability of soil reaction increased by 2006 due to heterogeneity of throughfall, as indicated by an increased number of circular patterns of pH contours. The comparatively lower spatial variability in soil reaction as recorded in 1990 apparently occurred due to distinctive processes connected with acid and alkaline deposition. The deposition of alkaline dust on the soil surface is spatially more uniform. During the winter season, it settles on the snow cover surface that releases it during the snowmelt. At the same time, acid airborne pollutants are much less captured by the snow particles. Their maximum input occurs in the spring when they are dissolved in the raindrops that must penetrate the foliated tree canopies that cause a considerable spatial variability of throughfall (Krečmer and Fojt, 1981). It is the liquid precipitation that has the highest capacity to capture and dissolve the sulfate emissions (Pichler and Bublinec, 2006). Finally, only these take part in the stemflow process. The observed increase in the active soil reaction across the entire soil surface developed owing to the highly active MgO and better soluble CaO, along with the products of their reaction with the air and soil CO_2, or with the air and soil moisture, ie $MgCO_3$, $Mg(OH)_2$ (Novák 1981) and $Ca(OH)_2$.

In spite of the full area soil pH increase, the process of the planar differentiation had already begun by 1990, because the initial stage of stemflow zone formation could be detected at that time (Fig. 3). Data in Table 1 show the 10th and 90th percentiles for the measured soil pH values. All the data bellow the 10th percentiles fall into the zone subjected to stemflow that had an average planar area of 0.16 m^2, as seen from Table 2. From these tables, a 10th percentile decrease and a stemflow zone planar increase are evident.

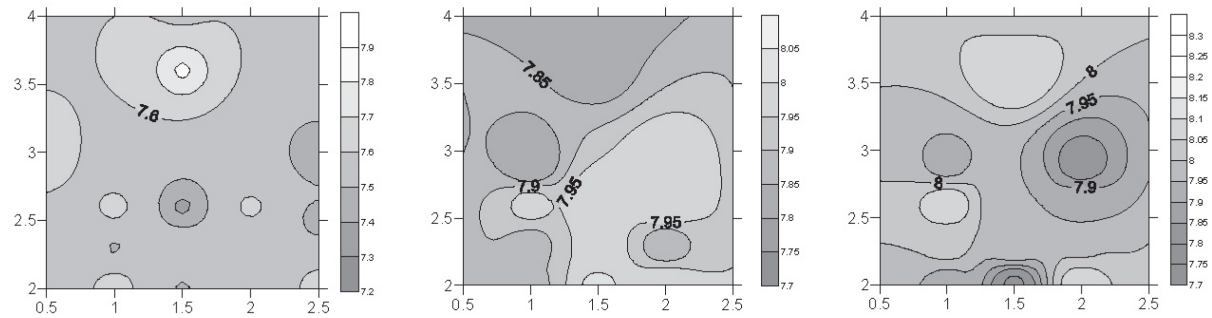

Fig. 3. Active soil reaction contours at Tri Peniažky beech transect, measured in 1990
Beech stem centres have co-ordinates [1.5, 1.5].

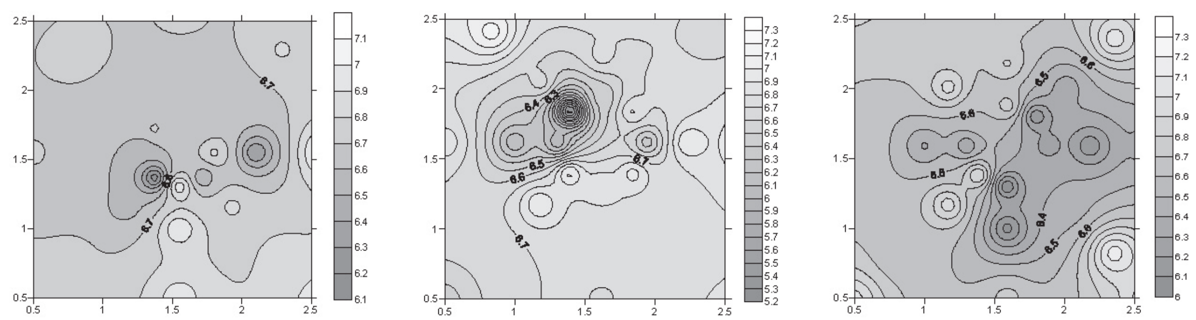

Fig. 4. Active soil reaction contours at Tri Peniažky beech transect, measured in 2006
Beech stem centres have co-ordinates [1.5, 1.5].

Table 1. Basic statistical characteristics of the active soil reaction values, measured at the Tri Peniažky beech transect

Year	Valid N	Mean	Minimum	Maximum	10^{th} percentile	90^{th} percentile	Std. dev.
1990	227	7.80	7.22	7.84	7.50	8.01	0.23
2000	127	6.72	5.25	7.30	6.34	7.06	0.30

Table 2. Planar areas of zones impacted by stemflow and throughfall at the Tri Peniažky beech transect

Zones	Planar Area [m^2]	
	1990	2006
Stemflow zone	0.16	0.28
Througfall-affected zone	3.84	3.72
Total area	4.00	4.00

That resulted from an antagonistic effect of the acid deposition containing H_2SO_4 and HNO_3 along with H_2CO_3 on one side, and the aforementioned alkaline dust on the other side. If the S and N deposition within the area of interest, amounting to 2.0 g m^{-2} $year^{-1}$ S and 1.5 g m^{-2} $year^{-1}$ N (Závodský, 2002a, b), is considered, it corresponds stoichiometrically to approximately 2.8 g m^{-2} $year^{-1}$ Mg that enters chemical reactions with both elements. According to the measurements from the margins of the area of interest, the total deposition of Mg in 1998 varied around 2.1 g m^{-2} $year^{-1}$ (Hančuľák and Bobro, 2004). The literature gives 3.0 g m^{-2} $year^{-1}$ of Mg as a natural loss from soils (Hronec, 1996; Indrikson and Zalitis, 2004). From this point of view, secondary minerals originating in an airborne-pollution-loaded environment such as hydromagnesite, nesquehonite, brucite and others play an important role, while they are able to migrate at least partially with the soil solution (Bobro et al., 2000), similar to easy-soluble $Mg(NO_3)_2$ that forms deposition during reactions with $(NO_3)^-$. In this rough approximation, we did not consider the natural loss of magnesium from soil due to retention in the tree biomass as sulphur too was retained in that pool. Moreover, we assumed that the nutrients intake occurred from the original mineral part of the soil.

Further development of active soil reaction at 5–10 cm between 1990 and 2006 showed that the magnesium loss from the soil under investigation prevailed over the alkaline dust deposition. During the 15 study years, the active reaction dropped from 7.4 to 5.9 within the stemflow zone. In the throughfall zone, such drop was much less pronounced, from 7.9 down to 6.6 (Fig. 5). Based on Fig. 5, we can conclude that the active soil reaction in the stemflow zone decreased from the moderately alkaline interval into moderately acid interval. In the throughfall zone, the soil reaction changed from the moderately alkaline interval into neutral. The reaction is supposed to remain in these intervals till 2030 and 2015 respectively.

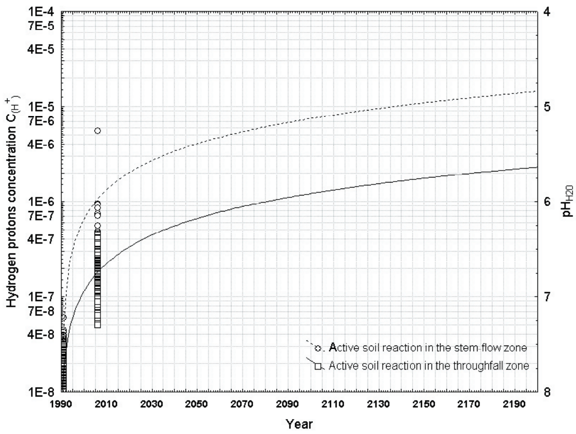

Fig. 5. Regression lines of the active soil reaction in the stemflow and throughfall zones at the Tri Peniažky beech transect

These predictions are consistent with the generally observed six- to twelve-times-higher rainwater input into the stemflow zone compared to the throughfall, which means that such an increase in water percolation linked with the corresponding immission load speeds up proportionally the soil acidification processes in the stemflow zone compared to the throughfall-impacted zone. Indeed, according to Fig. 5, the soil pH values in the throughfall zone will decrease to levels measured in the stemflow zone in 2006 by 2080 so that the process will take six times longer than in the stemflow zone. That is also in compliance with the assumption of increased acidification resulting from higher acid airborne pollution load according to Sparks (2003).

Conclusions

The measurement and evaluation of both active and exchangeable soil reaction under a mature beech forest growing within an area under alkaline dust deposition from the Magnesite Works, Inc., Jelšava, showed an antagonistic influence of the alkaline pollution and acid deposition from both local and remote sources. The resulting pattern was co-determined by the stemflow water percolation through the topsoil.

Thus in 1990, the soil pH values measured in H_2O unexpectedly did not indicated any increase compared to the values measured in samples taken outside the stemflow zone. Instead, there was found an overall increase in the actual reaction to 7.5–8.0 over the whole area, irrespective of the sampling point position.

Stoichiometric calculations showed that the amount of acid deposition amplified by the stemflow effect of beech trees has mitigated the alkaline deposition. By 2006, such trends in the relevant forest stand prevailed in general. In the stemflow zone, the active soil reaction at the depth of 5–10 cm decreased from 7.4 and 6.5 to 5.9 and 4.7, respectively. Outside the stemflow zone, the pH reduction was less dramatic, from 7.9 to 6.6. So, during the period 1990–2006, the active reaction of the topsoil subjected to stemflow moved from moderately alkaline to moderately acid while a similar shift from moderately alkaline range towards neutral values occurred outside the stemflow zone. The pH decrease was correlated with a more than 90% reduction in alkaline dust emissions from the magnesite plant.

The active soil reaction at the 5–10 cm depth in the stemflow zone is supposed to remain in the respective intervals until 2030. Outside the stemflow zone, the active soil reaction at the 5–10 cm depth will probably persist in the neutral range until 2015. Subsequently, the active soil reaction will move towards the moderately acid range even outside the stemflow zone. Under the standard forest management, the active soil reaction is to converge to the original approximate soil pH 5 in the course of approximately 200 years.

Acknowledgements

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References

Anonymus. *Reduction of SO_2 and Particulate Emissions – Synthesis report*. Szentendre (Hungary): The Regional Environmental Center for Central and Eastern Europe. 52 p.

Bublinec, E. 1994. *Koncentrácia, akumulácia a kolobeh prvkov v bukovom a smrekovom ekosystéme* [Concentration, accumulation and cycling of elements in beech and spruce ecosystems]. Acta dendrobiologica. Bratislava: Veda. 132 p.

Bublinec, E. 1971. *Intoxikácia pôdy v okolí závodov na spracovanie magnezitu, jej meliorácia a vplyv na výživu rastlín* [Soil intoxication in the surroundings of magnesite plants, its amelioration and influence on plants nutrition]. Biologické práce, 17 (5). Bratislava: Slovenská akadémia vied. 88 p.

Bobro, M., Hančuľák, J., Dorčáková, H., Bálintová, M. 2000. Monitorovanie imisnej záťaže pôd v Muránskej doline [Monitoring of imission load in soils in the Muránska valley]. *Acta Montanistica Slovaca*, 5: 33–35.

Breemen, N. van, Mulder, J., Driscoll, C. T. 1983. Acidification and alkalization of soils. *Pl. and Soil*, 75: 283–308.

Gersper, P. L., 1970. Effect of American Beech Trees on the radioactivity of soils. *Soil Sci. Soc. Amer. Proc.*, 34: 318–323.

Gersper, P. L., Holowaychuk, N. 1970. Effect of stemflow water on a Miami soil under a Beech Tree. Morphological and physical properties. *Soil Sci. Soc. Am. Proc.*, 34: 779–786.

Gömöryová, E. 2004a. Small-scale variation of microbial activities in a forest soil under a beech (Fagus sylvatica L.) stand. *Polish J. Ecol*. 52: 311–321.

Gömöryová, E. 2004b. Priestorová variabilita niektorých mikrobiálnych charakteristík v bukovom poraste. In Rohošková, E. (ed). *Pedodiverzita. Zborník referátov z konferencie Pedologické dny 2004*. Roztoky u Křivoklátu: Česká pedologická společnost, p. 34–35.

Johnson, M. S., Lehmann, J. 2006. Double funneling of trees: Stemflow and root-induced preferential flow. *Ecosci.*, 13: 324–333.

Hančuľák, J., Bobro, M. 2004. Vplyv magnezitového priemyslu na imisnú záťaž oblasti Jelšavy tuhými imisami [Impact of magnesite industry on the solid immission load in the Jelšava area]. *Acta Montanistica Slov.*, 9: 401–405.

Hronec, O. 1996. *Exhaláty, pôda, vegetácia* [Air pollution, soil, vegetation]. Prešov: TOP Bratislava: Slovenská poľnohospodárska a potravinárska komora. 325 p.

Indriksons, A., Zalitis, P. 2004. Cycle of Water and Biogenous Elements in the Forest Ecosystems in Latvia. In Andersson, F., Birot, Y., Päivinen, R. (eds). *Towards the Sustainable Use of Europe's Forests – Forest Ecosystem and Landscape Research: Scientific Challenges and Opportunities*. EFI Proceedings, 49, p. 171–180.

Jochheim, H., Schäfer, H. 1988. „Die Baumfuss–Methode“ dargestellt anhand einer Untersuchung der Immissionsbelastung von Nordwest-Jugoslawischen Buchenwälder. *Z. Pfl.-Ernähr. Bodenkunde*, 151: 81–85.

Karpačevskij, L. O. 1977. *Pestrota pochvennogo pokrova v lesnom biogeocenoze*. Moskva: Izdateľstvo Moskovskogo Universiteta. 312 p.

Kazda, M, Glatzel, G. 1984: Schwermetallanreichungen und Schwermetallverfügbarkeit im Einsickerungsbereich von Stammablaufwasser in Buchenwäldern (Fagus sylvatica L.) des Wienerwaldes. *Z. Pfl.-Ernähr. Bodenkund.*, 147: 743–752.

Kraft, G., 1884. *Beiträge zur Lehre von den Durchforstungen, Schlagstellungen und Lichtungshieben*. Hannover: Klindworth's. 147 p.

Krečmer, V, Fojt, V. 1981. Kritické poznámky k metodologii měření kapalných podkorunových srážek [Critical remarks on throughfall measurement methodology]. *Vodohosp. Čas*., 29: 148–164.

Schofield, R. K., Taylor A. W. 1955. The measurement of soil pH. *Soil. Sci. Soc. Am. Proc.,* 17: 164–167.

Sparks, D. L., 2003. *Environmental Soil Chemistry*. London: Academic Press. 352 p.

Šály, R., Pichler, V. 1993. Súčasné zmeny pôdnej reakcie v bučinách [Current changes in soil reaction in beech forests]. *Acta fac. For. Zvolen*, 35: 51–69.

Tužinský, L. 2004. *Vodný režim lesných pôd* [Forest soils water regime]. Zvolen: Technical University Press. 102 p.

Tužinský, L., Soroková, M. 2001. Hydropedologické cykly v luvizemi pod dubovým porastom [Hydropedological cycles in a luvisol under oak forest]. *Acta fac. For. Zvolen*, 43: 355–368.

Ulrich, B. 1983. Soil acidity and its relations to acid deposition. In Ulrich, B., Pankrath, P. (eds). *Effects of accumulation of air pollutants in forest ecosystems*. Dordrecht: D. Reidel Publishing Co., p. 127–143.

Werner, W. 1988. Stickstoff-u. Phosphor-Mineralisation im Versickerungsbereich des Stammablaufwassers von Buchen. *Flora*, 181: 339–352.

Závodský, D. 2002a. Depozícia síry emitovanej z domácich a zahraničných zdrojov. [Sulphur deposition from domestic and foreign sources]. In *Atlas krajiny Slovenskej republiky*. Bratislava: Ministerstvo životného prostredia SR. 334 p.

Závodský, D. 2002b. Depozícia dusíka emitovaného z domácich zdrojov a zahraničných zdrojov [Nitrogen deposition from domestic and foreign sources]. In *Atlas krajiny Slovenskej republiky*. Bratislava: Ministerstvo životného prostredia SR. 334 p.

Zinke, P. J. 1962. The pattern of influence of individual trees on soil properties. *Ecology*, 43: 130–133.

Stredno- a dlhodobá predpoveď pôdnej reakcie v bučine na základe pozorovaní zóny stoku po kmeni buka

Súhrn

Meraním a vyhodnotením aktívnej a výmennej pôdnej reakcie v bukovom poraste v okrajovej časti oblasti zasiahnutej alkalickým prašným spadom zo Slovenských magnezitových závodov, a. s., Jelšava, bol preukázaný vzájomne protismerný účinok alkalického prašného spadu na jednej strane, a kyslých imisií z diaľkového prenosu v kombinácii s intenzívnou perkoláciou vody v pôde zóny stoku po kmeni bukov. V zóne stoku po kmeni buka, kde sa účinky oboch depozícií prejavili v podobe zosilnenej účinkom jedincov buka ako edifikátorov geobiocenotických polí, t. j. pôsobením stoku po kmeni, dosiahla už v roku 1990 výmenná reakcia pôdy v hĺbke 5 cm hodnoty pH 6,2–6,6 z mierne kyslého intervalu, hoci aktuálna aj výmenná reakcia pôdy celoplošne vzrástla až na úroveň pH_{H_2O} 7,56–8,00 a pH_{KCl} 7,0–7,2.

Ďalší vývoj aktívnej reakcie pôdy v hĺbke 5–10 cm v období rokov 1990 a 2006 preukázal odbúranie antropogénnej alkalinity pôdy. Počas 15-tich rokov poklesla aktívna pôdna reakcia v hĺbke 5–10 cm v zóne stoku po kmeni zo 7,4 na úroveň 5,9. V medzikmeňovom priestore bol pokles aktívnej reakcie v tejto hĺbke menej prenikavý, z hladiny 7,9 na 6,6. V medzikmeňovom priestore nastal pokles aktívnej reakcie zo 7,7 na 6,8. Aktívna reakcia pôdy vystavenej pôsobeniu stoku po kmeni bukov tak poklesla za obdobie od roku 1990 do roku 2006 z mierne alkalického pásma do mierne kyslého pásma, v medzikmeňovom priestore z mierne alkalického pásma do neutrálneho pásma.

Predpokladaná doba ďalšieho zotrvania aktívnej pôdnej reakcie v uvedených pásmach bude v zóne stoku po kmeni v hĺbke 5–10 cm do r. 2030. V medzikmeňovom priestore zotrvá aktívna pôdna reakcia podľa použitého modelu v neutrálnom pásme v hĺbke 5–10 cm iba do roku 2015. Následne sa aktívna reakcia pôdy v medzikmeňovom priestore posunie do mierne kyslého pásma. Viac ráz opakované vyťaženie a opätovná obnova porastu povedú k postupnej konvergencii aktívnej reakcie pôdy v zóne stoku a v medzikmeňovom priestore na pôvodnú úroveň pH_{H_2O} 5.

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