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TEMPORAL AND SPATIAL TRENDS AND SPECIFIC AIRBORNE POLLUTANT QUANTITIES IN BEECH STANDS MODIFIED BY REGENERATION CUTS

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Abstract

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This work investigates the input of H^+ ions as a constituent of acid deposition in a series of beech stands with modified densities. The research was conducted in the Kremnické vrchy Mts during 1994–2008. The highest average amounts of H^+ ions at 14.4 mmol $H^+.day^{-1}m^{-2}$ were recorded on a plot subjected to heavy silvicultural intervention, while the lowest average amounts were observed on the original intact plot with 12.4 mmol $H^+.day^{-1}m^{-2}$. The variation coefficient values did not exceed 30%, and this indicates rather uniform ecological conditions in the study plots. The tests herein confirmed a significant influence of silvicultural intervention on the amount of H^+ ions entering the stand.

Key words: air pollution, proton H^+, cutting phases, forest beech

Introduction

Proton load in the atmosphere indicates the presence of acid components, primarily sulphates and nitrates, which negatively influence atmospheric quality to a great extent. The value of this variable is very important since nitrogen oxides (NO_x) are precursors of tropospheric ozone creation. Therefore, appropriate data on the proton load can determine the amount of air pollution, and enable assessment of potential ozone production in any given region. Past assessment of human air pollution production has mainly been based on the input of acid substances such as SO_2, NO_x, which created soil acidification and caused large-area damage to forest stands. Therefore, efforts to reduce the main pollutants in the Western Carpathian Mts were instituted in 1990, and these resulted in 20% reduction in SO_2 and particulate matter and 50% less NO_x (Spišáková et al., 2003). Despite these positive changes in the balance of emitted and airborne substances, their acidification effects on forest soils still remain (Hruška et al., 2001; Walna, Kurzyca, 2007). This is a consequence of elements accumulated over several previous decades throughout Central Europe (Alewell et al., 2000; Elvingson, Ågren, 2004; Hadaš, 2009). At the turn of the century, this positive trend began reversing, again showing a moderate increase in certain indicators, with sulphur dioxide rising from126.95t in 2000 to 131.18 t in 2001 (Klinda, Lieskovská, 2008). Polluting agents today differ from prior ones, so that current pollution now consists of flying particulate matter (PM_{10}), nitrogen oxides (NO_x) and ozone (Váňa, Smrčková, 2000; SHMÚ, 2006).

Our research priority was to describe the condition of beech stands modified by regeneration cuts in greater detail. This was considered in the context of their potential damage through elevated concentrations of specific pollutants, and the appropriate method of passive samplers was instituted for this purpose. The aim of this contribution is to analyze and summarize the temporal and special trends in proton load input in the Kremnické vrchy Mts region between 1994 and 2008. Our results highlight the differences between the proton load values measured before and after silvicultural intervention.

Material and methods

This study assessed the quantitative differences in airborne pollutants in forest stands growing under almost identical conditions but differing in the stocking density. The research locality is situated in the SE part of the Kremnické vrchy Mts of the Západné Karpaty Mts (φ = 48°38´ N, λ = 19°04´ E) at 470–510 m a.s.l. A series of shelterwood cuts was applied in degrees corresponding to the commonly managed forest stands. The first modification of the stocking density was made in February 1989 (Greguš, 1987). This intervention resulted in the creation of the following stand series: a small-area clearing, a plot with heavy intervention and a plot with medium intervention, while a plot with light intervention and an intact original stand supplied the control. After these interventions, the dominant woody plant on all plots was beech. This beech species covered 94.7% of the forest floor in the original stands which were 80–90 years old at the time of the first intervention. The short distance between the individual plots measured approximately.100–110 m, and they were situated on a W-oriented slope of 30 to 36% inclination. The stand density following this intervention was reported by Barna (2000). The second intervention was then applied in spring 2004, in accordance with forest management rules (Barna, 2004). The stand densities after each intervention are summarized in Table 1, and further detail concerning the research plots is contained in Dubová, Bublinec (2006) and Schieber (2007).

The concentration of protons (H^+) was determined by passive samplers, as designed by Obr (1989). The sampling equipment is composed of nylon and consists of three parts: a cylinder covered with two layers of filter paper, a vessel attached to the bottom of the cylinder and a shelter. This entire apparatus is adfixed to a vertical

T a b l e 1. Stocking density of modified beech stands on model research plots in the Kremnické vrchy Mts (Central Europe).

Phase of management process	Original stand	Small clear-cut area	Heavy intervention	Medium intervention	Light intervention
1989 after the first intervention	0.9	0.0	0.3	0.5	0.7
2004 after the second intervention	1.0	Pole stand	0.0*	0.3	0.5

* The clear cut on this plot in the second intervention series concerned only the original parent stand shelter, the plot maintained coverage with natural regeneration in the pole stage (thicket).

holder. The absorption solvent of exactly 20 ml of a 2 M solution of potassium carbonate with admixed glycerol was pipetted into the vessel. Due to capillary elevation, this solution fully penetrated the filter paper. The collectors were installed on each plot in pairs to ensure control, and for insurance against damage to one sampler. This exposure was run at 10–12 weekly intervals dependent on seasonality. This equipment perfectly monitored the captured gases (SO_2, NO_x, HF), liquids (HNO_3, H_2SO_4) and solid particles (NH_4HSO_4) on the filter paper surface throughout the entire year. The proton load indicates the presence of acid substances in the atmosphere, and these neutralize the alkalinity of the potassium carbonate solvent in the field. The non-neutralised residuum represents the difference between exposed and non-exposed absorption solution by titration with hydrochloric acid on the Tashiro indicator (Kellerová et al., 1997; Kellerová, 1999). Results of this summation method, in parallel with various localities, compares the regional differences, including the degree of air pollution and stand-stocking density. The passive sampler method forms a supplementary tool for specification of continuous dry deposition of gases and particles on the paper surface. It is also beneficial in wet deposition since the proton load can be influenced by wet deposition where precipitation created in the atmosphere from horizontal air flow is captured on the surface. This most frequently occurs in mists containing high concentrations of air pollutants .

Statistical tests including those of measurement and position characteristics were performed by Statistica v 7, and the distribution normality was assessed by the Shapiro-Wilkov W test. Significance of differences in the inter-locality basic data sets was evaluated by the Student t-test for independent variables (Janík, Schieber, 2010).

Results and discussion

The shelter wood-cut series was carried out in 1989. By 1994, the plots on which the parent stand stocking was modified into small-sized clearing and plots subjected to heavy, medium and light intervention were covered with a regenerated understorey layer in the stages of pole stand and later young growth. Meanwhile, the original plot without intervention maintained its original character without understorey throughout the entire study period.

Between 1994 and 1998 the proton (H^+) load input was highest on the small-sized clearing at 22%, while the original beech stand without intervention recorded the lowest load of 17% (Fig. 1). This created a linear trend decreasing from the small-area clearing to the original intact stand (Fig. 2).

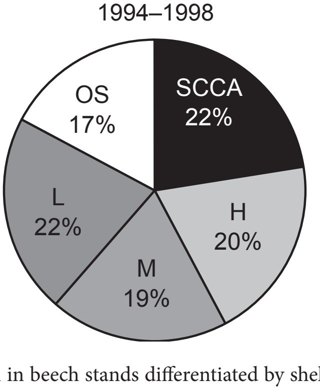

Fig. 1. Percentage of airborne deposition in beech stands differentiated by shelterwood cuts, and in the original intact stand during 1994–1998.
Notes: OS – original stand, SCCA – small clear-cut area, H – heavy intervention, M – medium intervention, L – light intervention.

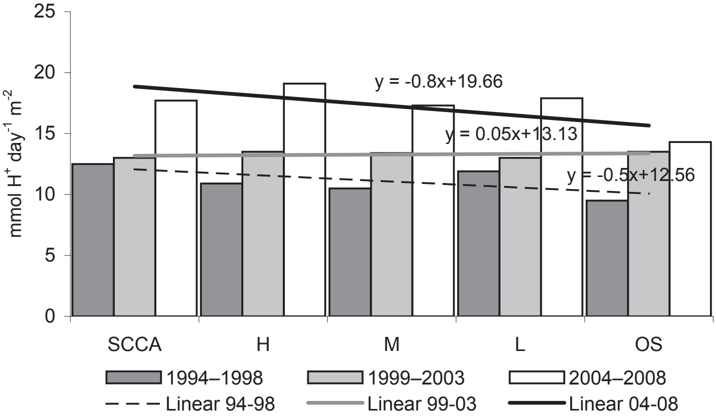

Fig. 2. Amount of H^+ ions in mmol H^+ $day^{-1} m^{-2}$ in sub-mountainous beech stands in the Kremnické vrchy Mts during 1994–2008, and linear trends after the first and the second shelterwood cut series.

The stands with modified density were regenerated step by step with differences between the plots becoming smaller due to the dynamically changing crown canopy. The input values in the following years from 1999 to 2003 were equilibrated so that the amount deposited on each plot averaged 20% (Fig. 2). Although the pole stand and young growth which initiated stand formation had commenced their roles in filtering airborne pollutants, this occurred to a lesser extent than in the original stand.

The second cut series applied in 2004 changed the stocking density in the model stands obtained in 1989 from the original parent stand by applying heavy, medium and light cut. This altered stocking density also induced changes in the crown structure and canopy (Table 1).

All trees remaining on the plot treated with heavy cut in the first series were removed. The growth conditions and microclimate on this plot exhibited characteristics of a "small area clearing". The understorey, which had regenerated naturally14 years after the first cut series, was in the pole-stand phase. Since the understorey had attained neither the appropriate crown height nor adequate diameter by that time, its filtering capacity was ineffective. Between 2004 and 2008, the proton input on this plot, at 19.4 mmol H^+ $day^{-1} m^{-2}$, was higher than on the other plots. The pollutant amounts deposited on this plot were similar to those following the first shelterwood cut on the "small-area clearing" plot. In contrast, deposition of only 14.3 mmol H^+ $day^{-1} m^{-2}$ was recorded on the completely closed stand, thus registering an overall 17% during this same period. Removal of certain trees from the parent stand on the plot formerly treated by medium cut resulted in this plot's stocking density reduction to 0.3. This value corresponds to that on the heavy intervention plot. Meanwhile, the stocking density on the formerly lightly treated plot decreased to 0.5, corresponding exactly with that on the medium cut plot. The understorey formed in these stands was scarcer and thinner, because the dense crown canopy prevented the heavy growth observed on the "small area clearing"plot, and also on the plot subjected to heavy intervention in the first modification phase.

T a b l e 2. Basic statistical characteristics of proton load (H^+) on model plots in sub-mountainous beech forests in mmol H^+ day^{-1} m^{-2}: model situation for central Europe in the Západné Karpaty Mts.

Phase of management process	Original stand	Small clear-cut area	Heavy intervention	Medium intervention	Ligh intervention
Sample size	15	15	15	15	15
Mean	12.4	14.4	14.4	13.7	14.3
Variance	14.4	11.5	15.9	17.1	11.0
Standard deviation	±3.7	±3.4	±3.9	±4.1	±3.3
Standard error	0.9	0.9	1.0	1.1	0.9
Coefficient of variation (%)	29.8	23.6	27.1	29.9	23.1
Minimum	7.1	8.9	8.7	8.5	9.3
Maximum	21.3	21.9	21.5	22.5	20.8
Confidence -95.0%	12.5	12.2	11.4	12.4	10.3
Confidence +95.0%	16.3	16.6	22.5	20.8	14.5

The proton load values on the research plots between 1994 and 2008 varied from 9.39 to 30.75%, reflecting equilibrium in conditions among all the partial plots. The lowest values of variation coefficient were recorded on the plot treated with medium silvicultural intervention, and modified in 2004 by light cut to 0.5 stocking density. The highest variability was recorded for the original intact plot which had 0.9 stocking. while values for the remaining statistical characteristics are listed in Table 2.

Since our null hypothesis was that "the differences between the proton load amounts before and after cutting intervention were random", the next step was to examine the differences on the individual model plots. These test results revealed that the differences on these plots were far beyond the 99% significance level, so we rejected the null hypothesis and accepted the alternative. A similar result was manifested in the confidence intervals

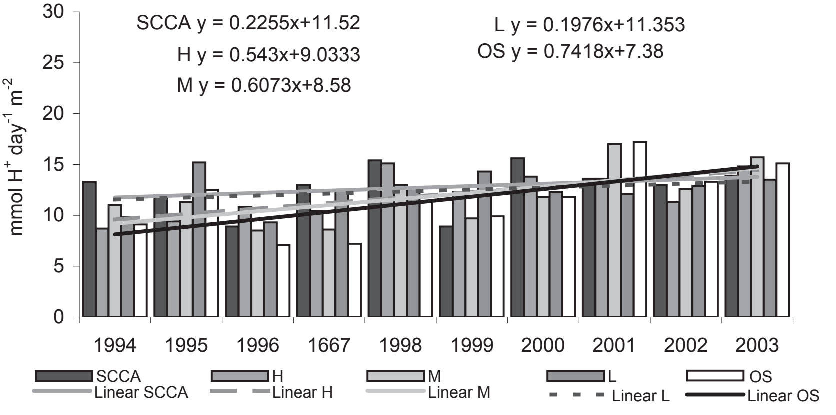

Fig. 3. Trend of input of H^+ ions on individual research plots in the Kremnické vrchy Mts before 2003.

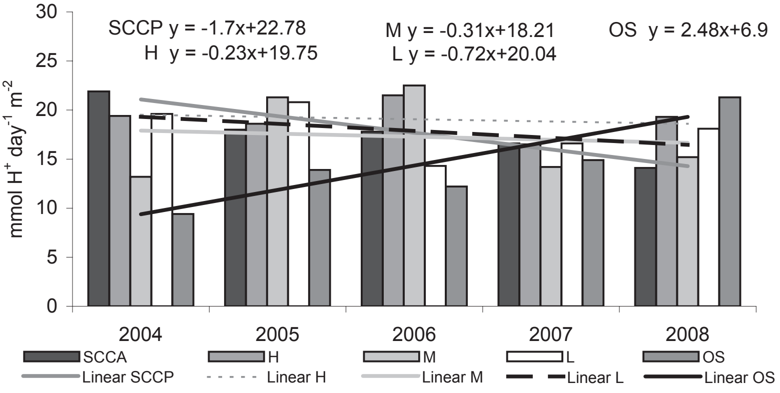

Fig. 4. Trend of input of H^+ ions on individual research plots in the Kremnické vrchy Mts after the second cut in 2004.

(Table 2), while no difference was confirmed on the original intact plot. Significant differences were confirmed only between the original plot and the plot subjected to heavy intervention, and also the original plot and the plot with medium intervention. It therefore follows that reduction of stocking density unequivocally affects the amount of proton load entering the stand. The validity of this statement increased with the increasing reduction in the individual plots, while inter-plot differences appear less significant.

Upon evaluation of inter-annual differences, it was clear that the trend in proton load (H^+) increased annually on all examined plots between 1994 and 2003 (Fig. 3).

An increasing trend between 2004 and 2008 following the second cut series was observed only on the original plot, while other plots recorded decreases (Fig. 4).

This course is associated with the amounts of nitrogen oxides (NO_x) alone, and it does not follow the pattern of sulphite oxidant decrease (Fig. 5). A retail park is under develop-

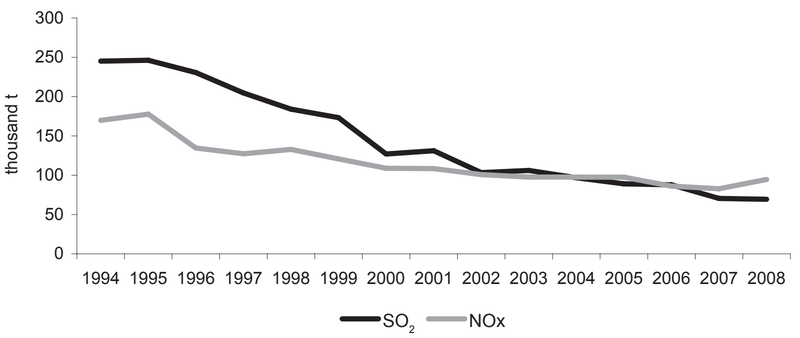

Fig. 5. Developmental trends in NO_x and SO_2 emissions in Slovakia during 1994–2008 (SHMÚ, 2009).

ment and construction in close proximity to the research plots, and automobile traffic is increasing rapidly in this area.

Conclusion

Statistical evaluation of the data from this15-year-span research shows that stocking density plays an important role in the penetration of pollutants in forest stands. This was most evident in the intact original beech stand which had the highest stocking density of 0.9–1.0 and the lowest pollutant imput values of 19% after the first intervention and 17% after the second. Our hypothesis concerning the important filtering function of tree crowns and crown canopy in the deposition of polluting substances in forest stands was validated. This held true in both the first and second cut series. Removal of a certain numbers of trees resulted in increased penetration of polluting substances into the individual stands. Following natural regeneration and artificial planting, stand conditions changed dynamically, and the amounts of pollutants entering individual plots became similar to those for the original stand. It can be concluded that the results of our 15-year study have confirmed that the method of shelterwood cutting commonly used in forest management is the ecologically optimal natural protection against the input of polluting substances in forest stands and their deposition in forest soil.

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