Statistical evaluation of air pollution in a model situation of beech stands in the Western Carpathians Mts

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Abstract

Kellerová, D., Janík, R. 2011. Statistical evaluation of air pollution in a model situation of beech stands in the Western Carpathians Mts. *Folia oecol.*, 38: 162–168.

Quantity of specific airborne pollutants (H^+ and O_3) was monitored at regular intervals over vegetation periods on a series of plots with modified stocking density. The statistical testing of the obtained values resulted in finding a significant difference (99% level) in proton H^+ input between the original intact parent stand and the plot treated with heavy cut; and, after the second intervention, the original stand and the plot treated with medium cut. The lowest mean values of (H^+) were recorded on the plot with the original parent stand (1999–2006: 13 mmol H^+ day^{-1} m^{-2}). It is evident that the stands play a role of a filter significantly influencing the input of pollutants deposed inside forest ecosystems. The maximum values, especially in year 2005, reflect the effect of the second cutting intervention realised in year 2004. The differences in O_3 concentration among the particular modified plots were not found as significant as in proton load H^+. The differences in amount of proton load and amount of ground level ozone among the plots were found significant for all plots at the level of 99%. It follows that the input of emissions into forest stands depends on chemical composition of the polluted substances.

Key words

air pollution, cutting phases, European beech, ground level ozone, proton H^+

Introduction

The anthropic activities together with natural processes cause important changes, climatic included, to forest ecosystems in Central Europe. At the centre of interest are broadleaved woody plants (Greguš and Kellerová, 2002), representing about 49.7% of forest cover in Slovakia. In terms of wood production is the leading species beech *Fagus sylvatica* L., with the highest portion making 31.2% of woody plants in Slovak forests. Beech, together with spruce and fir, belongs to distinctly sensitive species. The direct effect of airborne pollutants on forests stands seems to show a general decreasing trend; on the other hand, the acidification of forest soils is still persisting – due to elements accumulated for long (Hruška et al., 2001; Walna and Kurzyca, 2006). Therefore, protection of forest ecological stability is of primary importance – by choosing and applying appropriate silvicultural and regeneration methods. The aim of our research was to find out whether and how can close-to-nature regeneration methods influence the input of polluting substances in the forest environment.

Our research aim was to quantify differences in specific emissions (ground level ozone and H^+ proton load), entering model beech ecosystems with modified stocking density. Our basic assumption was that there would be distinct differences in amounts of specific substances in the individual years of experiment between the years before and the years after the silvicultural intervention.

Material and methods

Study site

We studied specific airborne pollutants entering beech ecosystems, namely the quantitative differences in amounts of these substances among the stands growing in similar conditions but at different regeneration phases. The stocking density was modelled in such a way as to correspond to the values common in forest management practice. The original stand composition at the site was: beech (76%), fir (15%), oak (4%), and hornbeam (5%). The first felling intervention realised in February 1989 (Greguš, 1987), resulted in the following plot series: obtained by applying heavy cut, obtained by medium cut, obtained by light cut, and the intact original parent stand. In the original stand is dominant beech – covering 94.7% of the area. The stand age at the time of the first intervention was 80–90 years. The plots are situated on a west-facing slope with an inclination of 30% to 36%, very close one to other (at a distance about 100–110 m). More details concerning the plots can be found in Dubová and Bublinec (2006); Schieber (2007). The stand density in the following years was improved by Barna (2000), the second intervention adjusting the stand density was made in spring 2004 (Barna, 2008). The plot, in 1989 treated with heavy cut, was delivered of all the remaining trees in felling maturity, the density on medium intervention and light intervention plots has been reduced. The changes in stocking density associated with the two interventions as well as the development after the interventions are illustrated in Table 1.

The research plots are situated in SE part of the Kremnické vrchy Mts (φ = 48°38' N, λ = 19°04' E) at 470–510 m a.s.l. The site climate is moderate warm and moderate wet. The long term mean annual temperature is 8.2 °C, in the growing season 14.9 °C. The mean annual rainfall makes from 510 mm to 1,040 mm, in the growing season from 160 to 530 mm (Kellerová and Dubová, 2002; Janík, 2006).

As for the airborne pollutants, the research plots are neither under the direct impact of polluting substances nor extremely stressed by the transboundary transport. In the near Zvolenská basin, however, are situated three stationary energy production units, and a dense network of car and railway transport, which may cause pollution stress to the research plots when weather conditions allow to. The research on air quality was conducted on a regional scale, focussing on the ground layer in forests at an appropriate distance from the pollution source. However, the topical issue concerning regional pollution today becomes ozone – displaying in mountain and submountain areas even higher values than in urban agglomerations Tschiedel, 2001; Fleischer et al., 2005. In years 1992–1996, the area of the Western Carpathians, and so also Central Slovakia, belonged to the most stressed ones in Europe, with the critical value exceeded sometimes as much as two (Bytnerowicz et al., 2004, Kremler, 2002).

Methods

For the study of input of polluting substances in forest ecosystems is suitable the method of proton load (H^+) designed by Obr (1989), for the ground ozone (O_3) is commonly used the sorption-accumulation method (Werner, 1991).

These methods, working with passive samplers, supply the pattern of the total deposition with dry and to some extent also wet deposition. The dry deposition is running continually, meaning such phenomena as deposition of gaseous and solid particles on the plant surface.

Proton load, indicating presence of acid substances in atmosphere: gaseous SO_2, $NO_{x,}$ liquid HNO_3, H_2SO_4 and solid $NH_4HSO_{4,}$ neutralises alkalinity of potassium carbonate solution exposed in field. The non-neutralised residuum is determined as the difference between the non-exposed and exposed absorption solution by titration with HCl on the Tashiro indicator (Kellerová, 1999). Nitrogen oxides belong to the important ozone precursors. An increase in nitrogen oxides may cause excessive ozone formation. Proton load, as an indicator of acid substances in atmosphere can provide information about their tendencies in the region.

The Werner´s method for ozone determination uses selective reaction of indigo applied on filtering paper with the atmospheric ozone. After a seven-day exposition in the field, the sampled material is examined in the laboratory, with using spectrophotometry (Kellerová, 2002).

The quantity of specific pollutants was determined at regular intervals within the growing seasons.

Selected statistic characteristics were processed and tested with using the package Statistica v 7. The normality of distribution of the basic set was tested with the Shapiro-Wilk W-test. Significance of differences

Table 1. Stocking density in beech stands in the Kremnické vrchy Mts, modified by cutting

Phase of management process	Original parent stand	Heavy intervention	Medium intervention	Light intervention
1989 after the first intervention	0.9	0.3	0.5	0.7
2004 after the second intervention	1.0	0.0*	0.3	0.5

*The plot from which all the trees of the parent stand shelter were removed during the second intervention did not result clear as it had just been covered with a 15-year-old stand at small pole stage.

concerning the basic sets between the localities was evaluated with the Student t-test for independent variables.

Results and discussion

In year 1999, ten years after the first cutting intervention modelling the required phases of forest management process. From the viewpoint of the original parent stand, the plots obtained after heavy cut, medium cut and light cut were grown with a natural understorey at small pole stage. The original parent stand, kept intact since the beginning of the research, displayed its authentically character without understorey. The model situation was analysed statistically as relations between the stand modification and amount of specific air pollution: protons H^+ and ground level ozone, entering the stand.

Variability of proton load values in years 1999–2006 on all the modified plots ranged from 33.2% on the plot treated with medium cut (stocking density 0.5 and 0.3 after the first and the second intervention, respectively) to 54.9% on the original intact plot (stocking density 0.9 and 1.0, respectively). Smaller differences in variability of the results were recorded before the cutting in year 2004 (Table 2).

The values of standard deviation were relatively low: from 4.7 on the plot treated with heavy cut resulting in 0.3 stocking density after the first intervention, to 7.2 on the plot treated with medium cut resulting in density values 0.5 and 0.3, after the first and the second intervention, respectively.

Table 2. Descriptive statistics of proton H^+ and ground level ozone on model research plots in the Kremnické vrchy Mts before and after cutting in 2004 year

Plot	Original parent stand	Heavy intervention	Medium intervention	Light intervention
Statistics	Proton H^+ before cutting in 2004			
Mean	39.68	55.57	14.38	11.19
Minimum	20.00	10.00	5.10	4.20
Maximum	84.00	114.00	22.90	19.00
Std. dev.	15.77	25.75	5.51	6.12
Std. error	2.98	6.88	1.47	2.17
Coeff. of variation.	39.70	46.40	38.20	54.90
	Proton H^+ after cutting in 2004			
Mean	29.56	42.79	14.35	21.63
Minimum	8.00	12.00	4.20	13.00
Maximum	88.00	80.00	22.30	30.00
Std. Dev.	20.24	18.44	4.76	6.49
Std. error	3.89	4.92	1.27	2.29
Coeff. of variation.	51.10	42.90	33.30	40.10
	Ground level ozone before cutting in 2004			
Mean	40.96	48.46	14.62	21.88
Minimum	12.00	10.00	4.80	11.40
Maximum	86.00	96.00	23.40	33.90
Std. dev.	19.39	24.46	5.56	7.26
Std. error	3.73	6.78	1.54	2.57
Coeff. of variation.	47.30	50.50	38.50	33.20
	Ground level ozone before cutting in 2004			
Mean	36.00	46.71	12.69	17.05
Minimum	8.00	10.00	4.70	8.50
Maximum	85.00	90.00	21.30	25.20
Std. dev.	16.83	21.81	5.11	6.34
Std. error	3.24	5.83	1.37	2.24
Coeff. of variation.	46.70	46.70	40.20	36.80

Std. dev., Standard deviation; Std. error, Standard error; Coeff., Coefficient.

As for the values of proton load quantity, the lowest were measured on the plot treated with heavy cut: 4.2 mmol H$^+$ day^{-1} m^{-2} in year 2000. Also on the other partial plots were the lowest values obtained in spring 2000.

Maximum values of 33.9 mmol H$^+$ day^{-1} m^{-2} in year 2005 were obtained on the plot subjected to medium cut, resulting in stocking density values 0.5 and 0.3, after the first and the second intervention, respectively. Very similar situation with an amount of 30.0 mmol H$^+$ day^{-1} m^{-2} was in the same year on the plot treated with heavy cut. The results of the experiment show influence of the second intervention realised in year 2004. The values of the other statistic characteristics are summarised in Table (2).

The lowest average values among all the plots were recorded on the intact plot covered with the original parent stand (1999–2006: 13 mmol H$^+$ day^{-1} m^{-2}) – showing the evident filtering role of beech forest stand significantly influencing the amount of pollutants deposed inside the forest ecosystem.

The inter-annual differences as well as differences among the modified plots were tested by pair tests for differences between two independent sampling sets. The results show that the differences at higher significance level concerning years were observed primarily after the second cutting performed in 2004 with the aim to reduce the stocking density on the plots formerly treated with heavy, medium and light cut. A high measure of differentiation was obtained especially by comparing year 2006 with the other years.

As for the differences among the plots, at the 99% probability level were identified as significant only the differences between the original parent stand and the plot heavy cut in the first intervention and between the original stand and plot medium cut after the second intervention.

We can see that removal of trees from the stand, that means changing stocking density, has an undeniable impact on amount of atmospheric protons entering the forest stand and then the forest soil. This statement is more true more is reduced the stocking density on the plot. The significance of differences among the plots decreased with the time – in absence of tree felling and in presence of natural regeneration processes. That means that the dynamically and naturally regenerated processes started to serve their filtering role concerning the polluting substances entering the forest ecosystems, Fig. 1.

The general drop in anthropogenic emissions was supposed to draw also a drop in O_3 concentration; no unequivocal trend, however, in the area of the Western Carpathians has been observed. The measure of variability in this indicator is about 50%. The lowest value, 39.7%, was recorded on the original plot with a stocking density of 0.9, later 1.0. The highest variation coefficient values were recorded on the plot subjected to heavy or final cut of the parent stand: 51.1%, Table 1. Comparing the values before and after the cutting in year 2004, we can see relatively balanced patterns reflecting low impact of management intervention on the ozone amount. Also in this case, the variability values were lower on the original plot than on the other research plots.

The lowest value of standard deviation making 16.8 was obtained on plot medium intervention, the highest one, making 25.8, on the original intact plot.

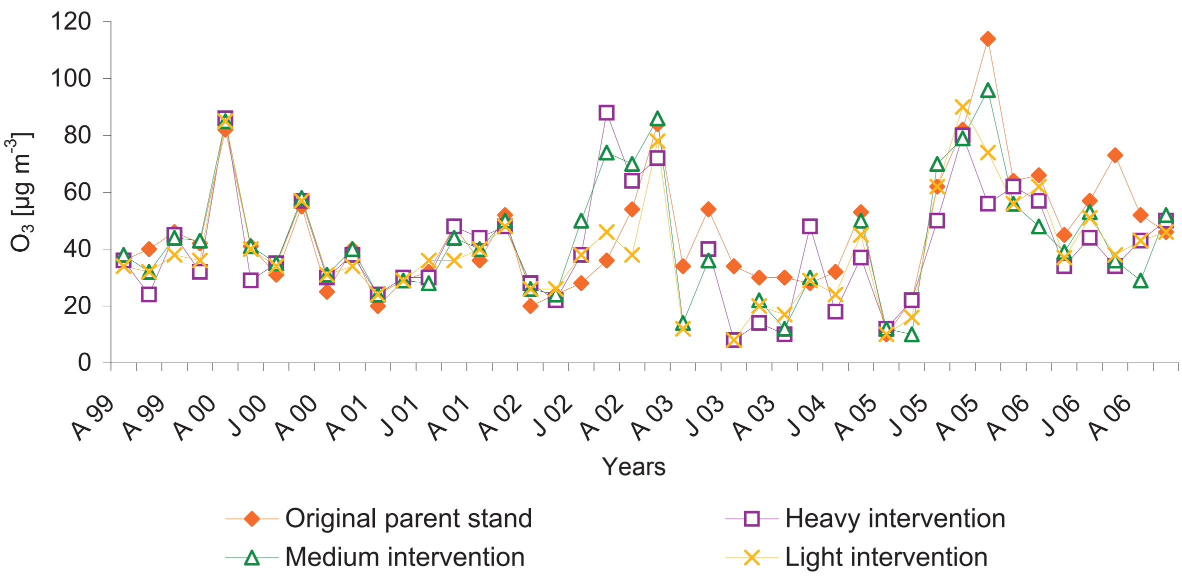

Fig. 1. Mean three-monthly values of proton load in mmol H$^+$ day^{-1} m^{-2} in growing seasons (S, spring; S, summer; A, autumn).

The other studied statistic characteristics are summarised in Table (2).

Low values ranging from 8.0 to 12 μg m^{-3} were measured on all partial plots, except the intact original stand (plot with a stocking density of 0.9 and 1.0 in years 1989 and 2004, respectively) on which the lowest value of this variable was about 20.0 μg m^{-3}. Very low values were observed especially in year 2005 that means the year following the second intervention. The absolute maximum, making 114.0 μg m^{-3}, was obtained in the original stand in autumn 2005. The maxima on the other experimental plots both before and after the intervention ranged between 88.0–96.0 μg m^{-3} (Fig. 2).

The differences in proton load as well as in ground level ozone were found significant among all the plots at the level of 99%. Statistical evaluation of the specific components (O_3, H^+**)** resulted in finding that in case of these ozone substances, the reduction of stand stocking density did not influence their amount entering the forest stand to such extent as the input of protons. Certain part of atmospheric protons H^+ is intercepted by the tree crowns, the others enter the soil. As for ozone, the formation and concentration of this substance is affected by several additional factors: physical, chemical, biological and certainly some other, not recognised yet. Therefore, also the results of this experiment are to deal within a broader context, acting in synergy and representing only an isolated fragment of the state of art in ecosystems waiting for additional monitoring and study.

Conclusions

Quantitative differences in specific emissions (protons H^+ and ground level ozone) entering the modified beech stands were primarily dependent on their chemical composition – as show the statistic characteristics with differences relevant at 99% significance level.

The proton load quantity was clearly affected by removing trees from the stand, which means by stocking density reduction. This was evident, with 99% probability, namely after the first intervention for the original stand and the plot treated with heavy cut and after the second intervention between the original stand and the plot subjected to medium cut.

The stands 10–15 years after the intervention were continually and dynamically regenerated. The tree crowns and stand canopy were already serving the filtering function for substances entering the forest stands and soil from the contaminated atmosphere. This fact was backed-up also with very similar variability values.

As for the time trends, evident inter-annual differences at a higher significance level occurred especially after the second cutting intervention realised in year 2004.

The statistic evaluation resulted in finding that the modified stand density did not show as obvious influence in case of ground level ozone as in case of proton load.

The studied specific atmospheric elements exhibited different effects – depending not only on the chemical nature of the substance and on the state of ecosystem but also on a range of other factors acting in synergy.

Acknowledgement

This work was supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences (Projects no.

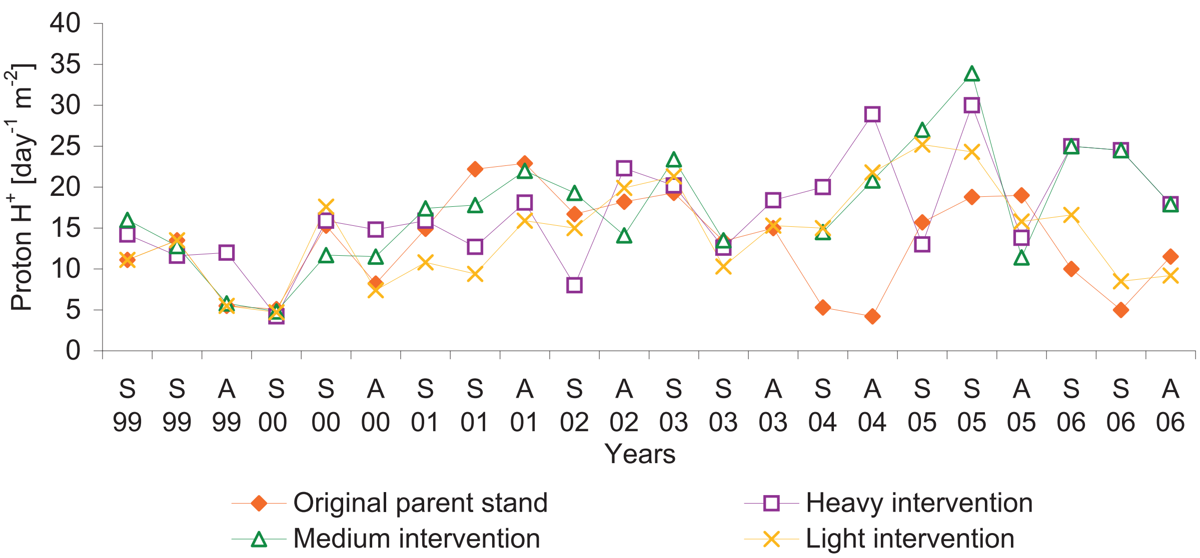

Fig. 2. Mean monthly ozone concentration values (μg m^{-3}) in growing seasons April–September.

2/0034/10, 2/0055/10, 2/0068/10). We also acknowledge D. Kúdelová for preparing the English text.

References

Barna, M. 2000. Impact of shelterwood cutting on twig growth in predominant beech trees (Fagus sylvatica L.). *Ekológia (Bratislava),* 19: 314–353.

Barna, M. 2008. The effects of cutting regimes on natural regeneration in submountain beech forests: species diversity and abundance. *J. Forest Sci.,* 54: 533–544.

Bytnerowicz, A., Godzik, B., Grodzinska, K., Frączek, W., Musselman, R., Manning, W., Badea, O., Popescu, F., Fleischer, P. 2004. Ambient ozone in forest of Central Eastern European mountains. *Envir. Poll.*, 130: 5–16.

Dubová, M., Bublinec, E. 2006. Evaluation of sulphur and nitrate-nitrogen deposition to forest ecosystems. *Ekológia (Bratislava)*, 25: 366–376.

Fleischer, P., Godzik, B., Bičárová, S., Bytnerowicz, A. 2005. Effects of air pollution and climate change of forests of Tatra Mountains, Central Europe. In *Plant responses to air pollution and global change*. Tokyo: Springer-Verlag Tokyo, p. 111–121.

Greguš, C. 1987. *Vybrané lesné ekosystémy v SSR, ich produktivita, stabilita, ochrana a podrobné metodické postupy zakladania TVP* [Selected forest ecosystems SR, their productivity, stability, protection and particular methodic approach basic RMP]. Zvolen: Ústav ekológie lesa Slovenskej akadémie vied, Lesoprojekt. 104 p.

Greguš, C., Kellerová, D. 2002. *Hodnotenie dlhodobého rozvoja lesného hospodárstva do roku 2000 na Slovensku* [Evaluation of the long term development of forest management in Slovakia up to year 2000]. Zvolen: Ústav ekológie lesa Slovenskej akadémie vied, Lesoprojekt. 81 p.

Hruška, J., Cienciala, E., Moravčík, P., Navrátil, T., Hofmeister, J. 2001. Dlouhodobá acidifikace a nutriční degradace lesních půd [Long-term acidification and nutritional depletion of forest soils]. *Lesn. Práce*, 80 (12): 24–32.

Janík, R. 2006. Characteristic of air temperature in beech ecosystem. *Silva balc.,* 7: 69–75.

Kellerová, D. 1999. Integral method of proton load determination in forest ecosystems. *Ekológia (Bratislava),* 18: 106–112.

Kellerová, D., Dubová, M. 2002. The hydrogen ion deposition and proton load of the Kremnické vrchy Mts. *Ekológia (Bratislava),* 21: 423–430.

Kellerová, D. 2002. Surface ozone at the beech ecological experimental station. Kremnické vrchy Mts. *Ekológia (Bratislava),* 21: 26–32.

Kremler, M. 2002. Daily and annual course of surface ozone concentrations at Slovak monitoring station. *Meteorol. Čas.,* 7: 29–36.

Obr, F. 1989. *Technológia prípravy pôdy pre zabezpečenie prirodzenej obnovy v lesoch pod vplyvom imisií* [Methods of soil treatment securing the natural regeneration of forests influenced by pollutants]. Final report. Zvolen: Lesnícky výskumný ústav. 29 p.

Schieber, B., 2007. Change of flowering phenology of six herbal species in a beech forest (Central Slovakia): a decade analysis. *Pol. J. Ecol*. 55: 233–244.

Tchiedel, J., Wienhaus, O., Ruhle, G., Kellmann, E. 2001. Ochrana rastlín voči škodlivým účinkom ozónu na príklade tabaku (BEL-W3), buka, smreka a brezy [Plant protection against damaging ozone effect, documented on examples of tobacco (BEL-W3), beech, spruce and birch]. In *Stav a perspektívy ekologického výskumu horských lesných ekosystémov. Zborník referátov a posterov z medzinárodnej vedeckej konferencie: proceedings of papers and posters from international scientific conference, Poľana, 22.–25. 10. 2001* Zvolen: Lesnícky výskumný ústav, 2001. 1 electronic optical disc (CD-ROM).

Walna, B., Kurzyca, I. 2007. Evaluation of bulk deposition in protected woodland area in Western Poland. *Envir. Monit. Assess*, 131: 13–26.

Werner, H. 1991. Methodische Details für das Ozonmonitoring mit Indigopapieren. In Weissberger, K., Biebl, P., Brandtner, B., Puxbaum, H. *II Workshop zum Thema Integrale Messmethoden. Workshopbericht der Unterarbeitsgruppe Integrale Messmethoden im Rahmen von ARGE ALP und ARGE Alpen-Adria* [II workshop on the integrale measurement methods. Report of the working group Integral measurement methods in frame of ARGE ALP und ARGE Alpen-Adria]. Salzburg: Salzburger Landesregierung. 110 p.

Štatistické hodnotenie kvality znečisteného ovzdušia v modelových podmienkach podhorských bučín Západných Karpát

Súhrn

Kvantita špecifických imisných látok (H^+ a O_3) sa zisťovala v pravidelných časových intervaloch na plochách s modifikovaným zakmenením počas vegetačných období a štatisticky sa vyhodnotila.

Pri testovaní plôch sa s 99 %-nou istotou potvrdili významné diferencie v inpute protónov H^+ medzi pôvodným porastom a plochou s intenzívnym zásahom, resp. po druhom ťažbovom zásahu s plochou so stredne intenzívnym zásahom.

Najnižšie priemerné hodnoty (H^+) zo všetkých plôch boli zaznamenané na pôvodnej materskej ploche bez zásahu (1999–2006: 13 mmol H^+ deň$^{-1}$ m^{-2}). To ukazuje, že porast pôsobí ako filter a významne ovplyvňuje množstvo deponovaných znečisťujúcich látok do vnútra lesného ekosystému. Z maximálnych hodnôt dosiahnutých najmä v roku 2005 vidieť vplyv druhého ťažbového zásahu realizovaného v roku 2004.

Významnosť rozdielov koncentrácii O_3 medzi jednotlivými modifikovanými plochami a rokmi nebola potvrdená na takej vysokej úrovni ako to bolo pri protónoch H^+.

V prípade významnosti rozdielov medzi množstvom protónovej záťaže a množstvom prízemného ozónu sa táto potvrdila medzi všetkými skúmanými plochami navzájom na hladine významnosti 99 %. Z čoho vyplýva, že významným faktorom pri vstupe imisií do porastu je ich chemické zloženie.

Received April 12, 2011
Accepted May 5, 2011