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# Atmospheric deposition and critical loads in a climax oak forest in the Štiavnické vrchy Mts

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**Abstract**

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Air pollutants have been for decades subjected to scientific research – due to their worldwide impact on the people's health and natural environment. We sampled vertical precipitation in an oak forest ecosystem at the locality Skalie in the Štiavnické vrchy Mts. The obtained samples partially represent the atmospheric deposition – the process of accumulation of air pollutants on the ground surface. These samples were evaluated from the viewpoint of acid rain. In accordance with the assumption, there have been found apparent differences in annual concentrations of chemical components and elements between the rain water having passed through tree crowns (throughfall) or forest edges and the open area. The sulphates ranged from 3.8 in the open area to 18.2 mg $l^{-1}$ in the forest gap. In case of nitrogen, the values of atmospheric deposition ranged from 13.8 kg $ha^{-1}$ $yr^{-1}$ in the forest gap to 23 kg $ha^{-1}$ $yr^{-1}$ under the oak crowns, in case of sulphur we obtained 7.7 in the open area and 23.8 kg $ha^{-1}$ $yr^{-1}$ in the forest gap. Comparing the calculated deposition loads with the critical loads, we did not observe exceeding of limits.

**Key words**

oak forest ecosystem, acid precipitation, atmospheric deposition, critical loads, the Štiavnické vrchy Mts

## Introduction

Forest ecosystems still belong to the most endangered parts of the natural environment. One of the main threats is input of air pollutants. Determining sources of air pollution are: power engineering, including energetic equipments of industrial plants and local heating, industrial technologies, especially metallurgy, chemistry, production of building materials and quickly developing road transport. Unfavourable effects of air pollution across the major part of Slovakia are multiplied by its remarkably broken topography. A number of big industrial plants are situated in deep valleys and hollow basins with restricted conditions for dispersal of pollutants in the atmosphere. In closer surroundings of these pollutant sources, ultimate ecological and environmental damage is observed permanently. Apart from this, the whole central Europe is still an area with strong regional air pollution and acid precipitation resulting mainly from transboundary transport of air pollutants (Posch et al., 2005).

From the above-said it is apparent that the damage can not only be done to forests in neighbourhood of industrial or residential areas but also to forests relatively remote from these pollution sources. This was also the case of our research plot influenced by a relatively remote source – the aluminium plant in Žiar nad Hronom. The amounts of substances emitted from the plant do not represent a significant share in total balance of air pollution and in consecutive damage to forest ecosystems in Slovakia. On the other hand, the quality and aggressiveness of these pollutants cause considerable weakening, or even destruction, of forest ecosystems in the area of the pollutants´ impact. At last, in our case we can speak about a peculiar aluminium air pollution mode. Our point of interest is acidifying

air pollution. For a long time, thousands tons of $SO_2$ were leaving the aluminium plant, and their spreading area was rather large – due to a 204 m high chimney (Kellerová, 2005).

The impact of air pollution on forest ecosystems can be manifested in different forms. Subsequent processes running in soils are often key important in studying the problem. They can manifest themselves through degradation of soil organisms' microbial activity (eg Gömöryová and Střelcová, 2006). Therefore, we need to evaluate all these processes and to recognise the "buffering capability"of forest ecosystems in relation to these substances (Kunca et al., 2006).

Acid rain and the connected processes of deposition of miscellaneous components on the ground surface maintain a topical problem, because the global climate change and greenhouse effect are increasing in popularity. Research on contaminant input from air and precipitation quality in different types of forest ecosystems in Slovakia can be dated since long. However, we have to underline that this research has almost always been focused on uplands or mountain areas where this process is quantitatively more pronounced (eg Minďáš and Kunca, 1997; Kellerová, 2006). There were also performed some similar measurements in oak forests, to certain extent (eg Tužinský, 2004), but we have no information on any performed in the Štiavnické vrchy Mts. With this paper we would like to contribute to the knowledge database of atmospheric deposition and acid rain in Slovakia but also to information on the oak throughfall. This is also important for hypothesising about a potential climate change in forest ecosystems.

The objective of our work was to determine the annual values of precipitation quantity and quality in the studied oak ecosystem (*Quercus petraea* (Matt.) Liebl.) and to compare them with the values from the adjacent open area. Based on these measurements, we quantify atmospheric deposition fluxes and confront them with the calculated values of critical deposition loads. In general, we evaluate impact of precipitation, mainly from view of its quality, on total hydrochemical balance of oak forest ecosystems.

## Material and methods

At three sampling spots at the permanent research plot (PRP) – open (control) area, forest gap and under crown space – all the types of vertical precipitation, partially also horizontal precipitation intercepted in trees crowns, were collected in three polyethylene rain gauges (with a capture area of 475 $cm^2$) and evaluated as bulk deposition. The samples were taken regularly at 10 to 14 day intervals, and always when necessary. The chemical analyses were primarily focused on acidifying (also potentially for soil) chemical substances as sulphates, nitrates and ammonium. In terms of basic biochemical balance, we also determined principal base cations, electric conductivity and pH values in the samples. The value of electric conductivity (EC) expresses the bulk concentration of all chemical substances (mineralization) in water solution.

The bulk annual deposition is the sum of deposed amounts of components determined in precipitation ($NH_4^+$, $NO_3^-$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$) over a year. It is given in kg $ha^{-1}$ $yr^{-1}$. Deposition of each compound was calculated as the product of the compound's concentration in mg $l^{-1}$ detected in the precipitation sample and the precipitation quantity fallen on a unit area in mm, and afterwards summarised for the observed period (year) (Fea, 1996). All the average values were calculated as weighted means.

The samples were processed in the laboratory of the Technical University in Zvolen, Faculty of Forestry, Department of Natural Environment. The description of methods used in the laboratory analyses can be found in Mihálik et al. (1993).

The PRP Skalie is situated in territory of the School Forests in Kysihýbeľ near Banská Štiavnica. The PRP was established towards the end of 2004, with the purpose of monitoring fluxes and atmospheric precipitation quality in a natural forest ecosystem with prevailing sessile oak. The stand is two-storied and classified as a protective forest, aged from 180 to 190 years, with a stand density of 0.7. The PRP is localised at an altitude of 680 m asl, on a SW oriented slope. The soil type is cambisol. The species composition of the forest is following: sessile oak 80%, European beech 10%, hornbeam 5% and allochtonous Norway spruce 5%.

## Results and discussion

Maximum precipitation totals were found, in accordance with expectations, in the open area where the annual total was 597 mm. Minimum values, which represented only 65% of the open area values, were found in the forest gap. Here the long crowns of several trees bordering the gap have probably a significant influence on interception and evaporation. The annual throughfall total was found 472 mm. Comparing the data obtained for the throughfall with the corresponding values found in the open area, significant differences in concentrations of chemical compounds and elements in throughfall and edge-effect-influenced precipitation in the examined oak forest ecosystem are apparent (Table 1). It is especially evident in case of electric conductivity. The values of this parameter, increasing from the open area via the forest gap to the under-crown space, confirm a high enrichment of precipitation. There was also found similar growing trend for the other compounds with exception of sulphates.

Table 1. pH values, electric conductivity (EC in µS $cm^{-1}$) and average concentrations of chosen chemical substances in mg $l^{-1}$ in precipitation on permanent research plot Skalie

| | pH | EC | $NH_4^+$ | $NO_3^-$ | $SO_4^{2-}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^+$ | K+ |
|---|---|---|---|---|---|---|---|---|---|
| Open area | 6.1 | 23.4 | 3.3 | 1.0 | 3.8 | 0.7 | 0.2 | 0.6 | 1.5 |
| Forest gap | 5.9 | 37.5 | 4.2 | 1.0 | 18.2 | 1.1 | 0.3 | 0.7 | 7.5 |
| Throughfall | 5.9 | 46.1 | 5.8 | 1.6 | 11.9 | 2.2 | 0.5 | 0.9 | 9.4 |

In general, the critical range of precipitation acidity has been established as $H^+$ concentrations exceeding 0.3 mg $l^{-1}$ or pH values less or equal to 3.5; to which correspond sulphates concentrations above 14 mg $l^{-1}$ (Škvarenina, 1997). The comparison of the threshold values with our values listed in Table 1 shows that the pH values are significantly below the critical limit and they are relatively low also in Slovak conditions with slightly acid chemical reaction. However, sulphates surprisingly exceeded the limit in the space of forest gap where some specific processes like small turbulences of the air masses and larger contacting area of longer tree crowns can play a role.

In connection with these parameters, we give a list of the total input of these substances from atmosphere. In Table 2 are evident certain differences in particular chemical components dependent on localisation of the sampling spot. Typical are the values from the forest gap where the well-known "edge effect" of tree crowns is apparent. The total input of nitrogen (anion and cation form) ranges between 13.8 kg $ha^{-1}$ $yr^{-1}$ in the forest gap and 23 kg $ha^{-1}$ $yr^{-1}$ under the oak crowns. For sulphur, this interval is from 7.7 to 23.8 kg $ha^{-1}$ $yr^{-1}$ but inversely ordered – from the open area to the forest gap.

For comparison we also present the results of Kunca (2005) who has determined the model values of atmospheric deposition with acidifying potential in the territory of the Štiavnické vrchy Mts for three altitudinal levels (Table 3). The biggest differences between the modelled and measured values can be observed for nitrogen, especially for its ammonium form. It seems that a hypothesised slowly growing trend of this precipitation component in Slovakia has turned to reality. On the other hand, the nitrate deposition is quite low, which is probably caused by a long distance of the plot from the main transport communications.

Comparison of our deposition values with the critical loads gives us information about possible negative impact of atmospheric components entering the forest ecosystem. Kunca (2005) sets for the oak forest ecosystems in the Štiavnické vrchy Mts critical values of sulphur deposition loads ranging from 0.2 to 16.4 keq $ha^{-1}$ $yr^{-1}$ with the average value of 2 keq $ha^{-1}$ $yr^{-1}$. After conversion of our deposition results according to the specific natural conditions of the examined oak forest, when the highest input of sulphur was found in the forest gap (23.8 kg S $ha^{-1}$ $yr^{-1}$ = 1.5 keq S $ha^{-1}$ $yr^{-1}$), it is obvious that at the PRP Skalie the critical limits for acidifying sulphur have not been exceeded.

The same we can conclude about the critical loads of nitrogen in the Štiavnické vrchy Mts where they range from 0.7 to 33 keq $ha^{-1}$ $yr^{-1}$ with the average value of 3.1 keq $ha^{-1}$ $yr^{-1}$. The highest input of both forms of nitrogen is in the under-crown space (23 kg N $ha^{-1}$

Table 2. Values of atmospheric deposition in kg $ha^{-1}$ $yr^{-1}$ for oak forest ecosystem and open area on permanent research plot Skalie

| | $S\text{-}SO_4^{2-}$ | $N\text{-}NO_3^-$ | $N\text{-}NH_4^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^+$ | $K^+$ |
|---|---|---|---|---|---|---|---|
| Open area | 7.7 | 1.3 | 15.1 | 4.2 | 1.1 | 3.7 | 9.1 |
| Forest gap | 23.8 | 0.9 | 12.9 | 4.5 | 1.3 | 2.9 | 29.4 |
| Throughfall | 18.7 | 1.7 | 21.3 | 10.5 | 2.5 | 4.2 | 44.1 |

Table 3. Model values of acidifying components from atmospheric deposition for three altitudinal levels in open area and oak forest ecosystem in territory of the Štiavnické vrchy Mts in kg $ha^{-1}$ $yr^{-1}$ (Kunca, 2005)

| Altitude | $S\text{-}SO_4^{2-}$ | | $N\text{-}NO_3^-$ | | $N\text{-}NH_4^+$ | |
|---|---|---|---|---|---|---|
| | Open area | Oak stand | Open area | Oak stand | Open area | Oak stand |
| 300 m | 8.5 | 14.4 | 3.7 | 4.4 | 7.2 | 8.6 |
| 550 m | 11.7 | 19.9 | 4.3 | 5.2 | 8.5 | 10.2 |
| 1000 m | 13.7 | 23.2 | 5.1 | 6.1 | 10.0 | 11.9 |

$yr^{-1}$ = 1.6 keq S $ha^{-1}$ $yr^{-1}$). Comparing the values we can see that the critical limits have not been exceeded either in this case.

Compared to the critical acid loads in the Slovak forest ecosystems, especially oak, (Minďáš et al., 1999) it is apparent that the 95 percentile critical limit for sulphur – 22.5 keq $ha^{-1}$ $yr^{-1}$ has not been exceeded.

## Conclusions

From viewpoint of water balance in the studied oak forest ecosystem, the lowest values were determined in the forest gap, and they only represented 65% of the amount found in open area (597 mm). Significant change in concentrations of chemical compounds and elements in the rain water having passed through crowns or through forest edges in the oak forest ecosystem is apparent from our further results and comparisons with the open area. Mainly from viewpoint of quality, we have revealed some notable facts which can significantly influence the total hydro-chemical balance of oak forests. In spite of certain abatement of air pollution in Slovakia, the share of some xenobiotic substances in precipitation is kept rather high – concentration of sulphates in the forest gap is higher than the limit of 14 mg $l^{-1}$. The total input of nitrogen ranges from 13.8 kg $ha^{-1}$ $yr^{-1}$ in the forest gap to 23 kg $ha^{-1}$ $yr^{-1}$ in the throughfall. The interval of atmospheric deposition of sulphur is from 7.7 to 23.8 kg $ha^{-1}$ $yr^{-1}$ with the minimum values occurring in the open area to the maximum ones in the forest gap. The values of acid load measured on the research plot Skalie have not exceeded the critical limits.

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# Atmosférická depozícia a kritické záťaže klimaxovej dubiny v Štiavnických vrchoch

## Súhrn

Z pohľadu vodnej bilancie dubového lesného ekosystému sme najnižšie hodnoty, ktoré predstavovali len 65 % z hodnôt voľnej plochy (597 mm), zistili v porastovej medzere. Z našich ďalších výsledkov a porovnaní s voľnou plochou je zrejmá výrazná zmena koncentrácií chemických zložiek a elementov po prechode korunami alebo ich okrajom v dubovom lesnom ekosystéme. V týchto prírodných podmienkach je význam atmosférických zrážok, ich kvality a kvantity, zrejmý. Hlavne z pohľadu ich kvality sme zistili niektoré zaujímavé fakty, ktoré môžu výrazne ovplyvniť celkovú hydrochemickú bilanciu dubových lesných ekosystémov – podiel niektorých xenobiotických látok v zrážkach je stále, aj po určitom celoslovenskom znížení hlavne emisií síry, pomerne vysoký (koncentrácia síranov v porastovej medzere je väčšia ako limitných 14 mg $l^{-1}$). Celkový vstup dusíka (obidve formy) sa pohybuje zhruba od 13,8 kg $ha^{-1}$ $rok^{-1}$ v porastovej medzere po 23 kg $ha^{-1}$ $rok^{-1}$ pod korunou duba. V prípade síry je to od 7,7 po 23,8 kg $ha^{-1}$ $rok^{-1}$ od voľnej plochy po porastovú medzeru. V prípade výskumnej plochy Skalie však nedochádza k prekračovaniu kritických záťaží acidity pre síru a ani dusík.

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