Impact of regeneration cutting on sulphate concentration and amount in throughfall water in conditions of submontane beech forests in the Western Carpathians Mts

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Abstract

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This work summarises the values of amount and concentration of SO_4^{2-}, measured in precipitation totals on open plot and in throughfall in submontane beech forests in the Kremnické vrchy Mts, Western Carpathians Mts over a 4-year research period. The measurements were carried out in beech forest stands with stocking density modified (reduced) to various degrees in years 1989 and 2004 by regeneration cutting. The maximum concentration of SO_4^{2-} was recorded on the former clear cut: 33.34 mg l^{-1} in year 2002. The lowest value of 6.57 mg l^{-1} was obtained in year 2005 on the partial plot subjected to intensive intervention leading to the stocking density of 0.3. Higher sulphate concentration values was recorded in the autumn and winter, the lower ones in the spring and summer. No inter-annual differences in S-SO_4^{2-} content and concentration have been confirmed.

Key words

submontane beech forest, sulphate concentration, throughfall, the Western Carpathians Mts

Introduction

The cutting-edge environmental issues today are: 1. global warming, 2. ozone layer depletion coupled with greenhouse effect, 3. air pollution followed by soil acidification. They all share a common feature and primary cause: negative impact of human activities.

Research on sulphate concentration in precipitation water and in throughfall is very important, as these factors belong to the main ones involved in the process of soil acidification. Sulphur, nitrogen and solid particles cover the major part of acidification in the forest soil development.

Since the 60s to 80s of the last century, sulphur and sulphur compounds have become of a major concern worldwide – due to the rapid economic development, coal mining and rising demands from industry and consumers. The result has been a steep increase in the emitted pollutants, primarily SO_2 and nitrogen oxides. Lindberg and Lovett (1992) declare that the sulphur in form of SO_2 represents up to 60% of the total sulphur. Sulphur in atmospheric precipitation enters the soil (Stachurski and Zimka, 2000), from which it displaces basic ions and causes acidification. Acidification is a long term and cumulative process (Hruška et al., 2001) exhibiting dynamic development. The alarming degradation of life environment, especially forest soils, unveiled urgent needs to set deposition limits for forest ecosystems – as valid tools for governments in designing mitigation strategies for sulphur and nitrogen emissions in Europe and in the North America (Matzner and Meiwes, 1994).

Reduction of industry, reduction of coal mining in Poland and in the former DDR and conversion of industry across the whole "East Block" in 1990s were responded by decrease in sulphur and nitrogen emissions (Zapletal, 2006; Prechtel et al., 2001).). Evaluated with using selected indicators for sustainable development, the territory of the Slovak Republic is medium sensitive to sulphur deposition. The critical value for the SR is 10–30 kg ha^{-1} $year^{-1}$. The actual S deposition, however, is beyond these limits in about ¼ of Slovak forest soils. The total reduction in basic pollutants across the SR territory in years 1989-99 was 57.9%, representing almost 6% yearly, on average. In year 2006 was recorded an on average 50% drop in sulphur deposition (3.8–6.4 kg ha^{-1} y^{-1}) compared to year 2001.

In the neighbouring Czech Republic, the substances emitted over the period 1990–2000 dropped: SO_2 by 86% and ammonium by 53%. The decreasing trend in SO_2 emissions in W Europe (Netherlands, Germany, Sweden) since 1980 has also been recorded by Fricke and Beilke (1992) and by Prechtel et al. (2001).

Nevertheless, the danger of acidification is a still persisting ecological problem of extraordinary importance Alewel et al. (2000); mainly due to its character is long-term and due to the fact that sulphur penetrates the soil vertically and accumulates in deeper soil layers.

The aim of this work was to quantify the sulphur amount in atmospheric deposition and to support/reject the hypothesis about influence of silvicultural interventions on sulphur amount in the water fallen through tree crowns (throughfall).

Material and methods

Study area

The research plots (RP) are situated in the Kremnické vrchy Mts (48°38' N and 19°04' E), at 450–510 m a.s.l., on a slope with an inclination of 17–20°. The stand age is 80–110 years, the absolutely dominant woody species is beech, the average stand height is 28 m (Barna, 2004). The site climate is moderately warm, moderately hilly District B5 with a mean annual temperature $t_{1951–1980}$ 6.8 °C and the mean annual precipitation over the same period 778 mm (Schieber, 2006). The mean precipitation total in the growing season is 395 mm (Dubová and Bublinec, 2006). The length of growing season is 115–165 days.

As for the type, the plots have been classified into the 3-rd forest vegetation tier (fvt), fertile order B, transient order from fertile to nitrophilous (B/C), group of forest types Fagetum pauper inferiora.

As for coeno-taxonomy, the central association is Dentario bulbiferae-Fagetum, frequent is also Carici pilosae-Fagetum.

In year 1989, the stands were subjected to a series of parallel cuts differing in intensity, with the primary aim to reduce the stand stocking density. There was obtained a series of partial plots (PP) with different reduced density. In year 2004 was applied the second series of cuts, aimed at further density reduction and at creation of new ecological conditions. In such a way, there have been modelled conditions for better understanding and use of abilities of commercial stands in submontane beech forests.

Throughfall

Precipitation water as well as throughfall water was collected in plastic collectors with a defined catchment surface placed by 10 on each plot. A collector consisted of a funnel with a filter fixed on a collection container. To limit evaporation, the container was placed in a larger vessel. The water was sampled regularly, at monthly intervals and after each noticeable precipitation event.

Chemical analyses

The amount of SO_4^{2-} was determined by titration with lead nitrate in dithizon and converted by calculation to the sulphate sulphur.

Statistic methods

Statistical calculations of parameters of measure and position as well as the tests were made with using the package Statistica v 7. The normality of distribution of the data set was tested with the Shapiro-Wilk's W test. The significance of inter-annual differences was evaluated with the Student's t test. The results were also verified with the statistical package Statgraphics. Simple regression was used for assessment of the influence of precipitation totals on sulphate concentration in atmospheric precipitation and in soil solutions for the individual soil horizons.

Results and discussion

Sulphur amount and concentration on partial plot H

In year 1989 was this plot treated with a clear cut removing the entire forest cover. At the time, SO_4^{2-} concentration on this plot was the highest among the partial plots. Later, however, the plot was grown with a 12–14 year-old young stand, reaching, towards the end of the study period a mean height of 12 m, which could influence the measured values. The mean values of sulphate concentration were 17.2 mg l^{-1}. The precipitation total and throughfall amount displayed a comparatively high variability, making 61.9%. The general trend in SO_4^{2-} concentration was found decreasing (Table 1). The annual dynamics in over 2002–2004 exhibited maximum values in summer: 43.1 mg l^{-1}. The lowest values were measured in autumn: 6.9 mg l^{-1}. Since the intervention in 2004, where this partial plot was left without intervention (no parent stand to remove), maximum values of SO_4^{2-} concentration occurred in the autumn

(17.13–22.06 mg l^{-1}), minimum in the spring – 7.03 mg l^{-1}. As for the precipitation total (Table 2), higher values were measured after the intervention in 2004, with 1,003.4–1,381.7 mm (2002–2004) precipitation fallen on this plot. The sulphate sulphur deposition in year 2002 was 67.1 kg – exceeding the critical value for Slovakia set by Kalúz (2004) as 30 kg ha^{-1} y^{-1} by more than two times. Such a contradiction with the just discussed distinct drop in emitted sulphur oxides may be assigned to the nature of these substances as well as to good dispersing conditions (a 204 m high chimney) concerning the important pollution sources: the aluminium plant in Žiar nad Hronom and the fossil-fuel power station in Nováky.

Table 1. Descriptive statistics of SO_4^{2-} concentrations in the Kremnické vrchy Mts (Western Carpathians Mts) in years 2002–2006

Plot/stocking	H (0.0/0.0)	I (0.3/0.0)	S (0.5/0.3)	M (0.7/0.5)	K (0.9/1.0)
Valid	4	4	4	4	4
Mean	17.3	13.9	13.6	15.6	14.5
Minimum	11.6	6.6	9.2	9.2	11.7
Maximum	33.3	26.2	21.8	24.4	20.5
Std. deviation	10.7	8.5	5.6	6.5	4.0
Std.error	5.4	4.3	2.8	3.3	2.0
Coeff. of variation	61.9	61.2	41.2	41.7	27.7

Stocking before/after cutting in year 2004.

Table 2. The concentrations of SO_4^{2-} in the Kremnické vrchy Mts (Western Carpathians Mts) in years 2002–2006

Plot/stocking	H (0.0/0.0)	I (0.3/0.0)	S (0.5/0.3)	M (0.7/0.5)	K(0.9/1.0)
			[mg l^{-1}]		
Winter	28.90	37.10	44.40	53.50	24.90
Spring	38.23	35.08	18.75	22.60	24.72
Summer	43.10	30.82	35.81	30.30	34.22
Autumn	17.87	20.31	12.71	18.47	11.55
Vegetation period	38.02	28.42	31.86	29.57	32.14
Year 2002	33.34	26.23	21.76	21.38	20.46
Winter	–	–	–	–	–
Spring	12.96	11.71	12.75	20.04	15.52
Summer	16.20	12.20	10.01	10.68	14.69
Autumn	6.90	8.05	9.28	11.36	6.24
Vegetation period	17.16	13.31	13.01	13.93	17.98
Year 2003	11.90	11.11	11.42	16.17	12.58
Winter	10.48	–	–	–	7.60
Spring	14.10	–	–	–	14.60
Summer	10.81	11.45	6.92	9.19	10.07
Autumn	17.13	12.00	19.20	9.29	21.17
Vegetation period	12.18	6.51	8.43	9.24	12.48
Year 2005	12.33	6.57	9.19	9.21	11.71
Winter	–	–	–	–	–
Spring	7.03	8.25	19.17	11.48	9.62
Summer	19.09	20.47	15.01	11.47	20.75
Autumn	22.06	20.83	15.98	15.38	19.71
Vegetation period	12.36	12.25	11.96	11.04	12.39
Year 2006	11.57	11.78	11.84	12.42	13.38

The critical value of 14 mg l^{-1} for SO_4^{2-} (Kunca, 2007) concentration was exceeded only once, in year 2002.

The testing did not confirm significant inter-annual differences in SO_4^{2-} concentration in the throughfall water. The results of regression analysis unveiled the strong dependence of SO_4^{2-} concentration and S-SO_4^{2-} amount on the precipitation total, with the correlation coefficient having a value of 0.85.

Sulphur amount and concentration on partial plots I, S, M ,K

The values of all the studied parameters were very similar on all the partial plots. The average SO_4^{2-} concentration ranged from 13.5 mg l^{-1} on plot S with stocking density 0.5 and 0.3 in year 1989 and 2004, respectively, to 15.5 mg l^{-1} on plot M so with the corresponding stocking density values 0.7 and 0.3. The difference compared to the former clear cut was up to 4 mg l^{-1}. The lowest variability was recorded on the control plot without intervention – 27.7%, which reflects comparatively stable and even conditions on this plot. Somewhat higher values – 41.2% were obtained on the PPs S and M. The partial plot subjected in 2004 to final shelterwood cut exhibited almost the same values as the former clear cut plot.

In the amount of deposed sulphur, the „richest“ was year 2006 on all the plots, with 67.5 kg S-SO_4^{2-} on PP I and just above 45 kg on the other plots. These rather high values were also associated with high precipitation totals on the individual plots (from 1,717.3 mm on PP I to 1,035.1 mm on the control intact plot (Table 3).

The highest sulphur amounts on the individual plots were recorded in the autumn or winter. Lower values were obtained in the spring or summer – in dependence on the precipitation total over the concerned period. Occurrence of the highest sulphate sulphur amounts in atmospheric precipitation as well as in soil water show very similar patterns in the autumn and (Dubová and Bublinec, 2006). Pichler et al. (2006) report maximum S-SO_4^{2-} values of precipitation in mixed forests occurring in winter months. Keiser and Guggenberger (2005) carrying research on 90-year-old beech forests

Table 3. Air precipitation and throughfall in the Kremnické vrchy (Western Carpathians Mts) in years 2002–2006

Plot/stocking	H (0.0/0.0)	I (0.3/0.0)	S (0.5/0.3)	M (0.7/0.5)	K (0.9/1.0)
			[mm]		
Winter	50.0	42.0	38.0	40.0	29.6
Spring	132.5	128.4	124.8	113.5	110.7
Summer	468.9	494.4	346.9	287.4	305.3
Autumn	323.4	651.6	92.7	450.9	538.8
Vegetation period	609.3	636.4	473.3	392.1	414.0
Year 2002	974.8	1,316.4	1,102.4	891.8	984.4
Winter	–	–	–	–	–
Spring	400.0	423.2	383.1	338.5	307.6
Summer	133.6	128.5	103.8	92.3	73.9
Autumn	199.3	190.5	169.9	167.2	166.7
Vegetation period	275.6	254.9	205.2	187.0	163.9
Year 2003	732.9	742.2	656.8	598.0	548.2
Winter	26.4	28.5	–	–	170.2
Spring	284.8	217.3	–	–	241.7
Summer	598.0	261.0	467.1	454.0	454.4
Autumn	94.2	63.5	105.8	98.7	79.0
Vegetation period	950.2	529.4	539.9	520.2	751.0
Year 2005	1,003.4	570.3	572.9	552.7	945.3
Winter	–	–	–	–	–
Spring	926.5	1,228.2	677.3	711.4	663.8
Summer	190.2	265.5	186.0	164.1	144.5
Autumn	265.0	223.6	293.4	278.5	226.8
Vegetation period	1,050.0	1,387.3	846.0	804.4	757.6
Year 2006	1,381.7	1,717.3	1,156.7	1,154.0	1,035.1

in NE Bavaria recorded in autumn months occurrence of up to 53% of the total organic sulphur.

The statistical tests and regression analysis have confirmed a high influence of the precipitation total on concentration and amount of S-SO_4^{2-} on the particular PPs.

For comparison: Piirainen et al. (2004) recorded in spruce forests in N Finland an average sulphur deposition of 1.5 kg ha^{-1} after a clear cut, compared to 4.6 kg ha^{-1} before the cutting. The critical value for forest stands reported by Ǻgren (1992) is 3–8 kg ha^{-1} y^{-1}. Novák et al. (2007) measured 56 kg ha^{-1} y^{-1} in spruce stands in the Ore Mountains in N Bohemia at 490 m a.s.l. in 1994. This is in accordance with observations that the sulphur amount in coniferous stands is higher than in beech or generally broadleaved stands. For spruce forests in Slovenia reports Šimončič (1996) even 33 kg ha^{-1} of sulphur. Dubová and Bublinec (2006) measured in spruce stands in the Poľana Mts 65.4 kg ha^{-1} y^{-1}. The S-SO_4^{2-} amounts recorded in the atmospheric deposition in the ridge part of the Low Tatras Mts by Bublinec and Dubová (1995) were 44.5 kg ha^{-1} in the stand and 32.7 kg on the open plot.

Conclusions

Concentration and amount of SO_4^{2-} in the throughfall sampled from submontane beech forest stands is mostly dependent on the total atmospheric precipitation, on distance from the pollution source and, to a smaller extent, on intensity of the applied silvicultural treatments. We can derive the following conclusions: The highest S-SO_4^{2-} values were recorded on the former clear cut plot or on the plot subjected to intensive cut. The course of SO_4^{2-} concentration displays a general decreasing trend, depending exclusively on the precipitation amount. It follows that controlled cutting intensity can serve as a tool for controlling the sulphur deposition.

As for the annual dynamics of SO_4^{2-} concentration and amount of S-SO_4^{2-}, higher values were obtained in the autumn or winter, lower in the summer. In spite of the declared reduction of emitted sulphur oxides, there were a number of cases where the values of SO_4 concentrations were beyond the critical limits. The cause may be multiple, such as: distance from the emission source (Žiar nad Hronom, Nováky), prevailing wind direction, species composition, silvicultural methods.

Considering the sulphur amount in atmospheric precipitation and amount of sulphur deposed in soil on the particular partial plots, the studied forest stands in the Kremnické vrchy Mts, that means also the Western Carpathians Mts, can be ranked as lower-stressed with sulphur pollution not only in frame of Slovakia but also within the whole Central Europe.

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Vplyv ťažbovo-obnovného zásahu na koncentráciu a obsah síranov v podkorunových zrážkach v podmienkach podhorských bučín Západných Karpát

Súhrn

V práci vyhodnocujeme 4-ročnú periódu merania koncentrácií a množstva SO_4^{2-}, v zrážkovom úhrne na voľnej ploche a v podkorunových zrážkach podhorských bučín Kremnických vrchov patriacich do Západných Karpát. Merania sme uskutočnili v bukových porastoch, kde bol v roku 1989 a 2004 uskutočnený ťažbovo-obnovný zásah za účelom redukcie zakmenenia. Maximálna hodnota koncentrácie SO_4^{2-} bola zaznamenaná na ploche bývalého holorubu s 33,34 mg l^{-1} v roku 2002. Najnižšie hodnoty boli namerané v roku 2005 na čiastkovej ploche s intenzívnym zásahom a zakmenením 0,3 s hodnotou 6,57 mg l^{-1}. Vyššie hodnoty koncentrácií síranovej síry boli zaznamenané v jesenných resp. zimných mesiacoch, nižšie v jarných resp. letných mesiacoch. Medziročné rozdiely v obsahu S-SO_4^{2-} a koncentrácii SO_4^{2-} neboli potvrdené.

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