

Ionic deposition and chemistry of soil solutions in a forested study area in the Chojnów Forest District in the years 2004–2007

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Abstract: The study was carried out in the years 2004–2007 in a permanent observation plot established in a pine tree stand growing in a mixed fresh coniferous forest habitat of the Chojnów Forest District. Analyses pertained to the deposition of mineral compounds delivered to soil with bulk precipitation in the open field and throughfall and to chemical compositions of soil solution at a depth of 25 cm and 50 cm. pH, electrical conductivity and concentrations of Ca, Mg, Cl, NO₃, SO₄, Na, K, Fe, Mn, NH₄, PO₄, Zn, Cd, Cu, and Pb were analysed in precipitation and in soil solution samples.

Total load of ions under the canopy of pine trees ranged between 47 and 61 kg·ha⁻¹·year⁻¹. Acidifying ions (N + S + Cl) contributed in 51% to the total ionic load (in mol_e·ha⁻¹·year⁻¹) while base ions (Ca + Mg + Na + K) in only 36%. Respective percentage contribution in bulk precipitation was 69% and 19%.

No relationship was found between the chemical composition of soil solutions (at both depths) and the chemical composition of precipitation waters. Analysed soil solutions were acidic (average pH at the depth of 25 cm and 50 cm was 4.3 and 4.4, respectively) and the molar ratio of the sum of base cations (Ca, Mg, and K) to Al in the majority of examined samples from the upper soil layer, was much lower than 1. This is the evidence of low buffering capacities of analysed soil in relation to acidifying loads and indicates a potential threat for the pine stand stability.

Key words: bulk precipitation, deposit, flux, load, soil solutions, soil water, throughfall, throughfall precipitation

INTRODUCTION

Atmospheric precipitation is an important pathflow of ions to the environment. Precipitation in forested areas is modified in tree crowns and reach the substratum in the form of throughfall. Numerous studies confirm that forests act as air filters due to their roughness and retention of air pollutants by tree crowns. This phenomenon refers to atmospheric aerosols: airborne dispersed liquid and solid particles of natural (i.e. molecules of pulverised soils and weathering rocks) and anthro-

pogenic (metal compounds, aromatic hydrocarbon, etc.) origin. Horizontal deposition is the higher the higher and more developed is the flora growing in the site (ZIMKA and STACHURSKI, 1996; MALEK, 2002; BŁAŚ and SOBIK, 2004).

Deposition of sulphates, nitrates and chlorides reacting with solid phase of the soil induces leaching of cations and soil acidification. Rainfall components that reach the soil influence soil solutions chemistry and soils themselves and affect numerous soil processes (HANSEN *et al.*, 1994; AVILA *et al.*, 1995; BREDEMEIER *et al.*, 1995; HALLGREN LARSSON *et al.*, 1995; ŁABĘTOWICZ, 1995; BEIER *et al.*, 1998; KREUTZER *et al.*, 1998; OSTROWSKA *et al.*, 1998). As soil solutions are the main carrier of ions migrating downwards through the soil profile, surface and ground waters may be contaminated by airborne elements (LASKOWSKI *et al.*, 1995).

The aim of this paper was to estimate changes of stand throughfall deposition in pine forest floor in relation to deposition in the open field and to identify the effect of these depositions on the chemistry of soil solutions in forest stand.

STUDY SITE AND METHODS

Permanent observation plot located in the Chojnów Forest District was described in KOWALSKA and JANEK (2009). Single-storey pine stand covers gleyic arenosol derived from glacio-fluvial deposits. The soil reaction in the humus layer (fresh moor type) is strongly acidic – pH in the CaCl_2 extract is 3. The acidification decreases down the soil profile – pH at the depth of 40–80 cm is 4.2–4.4.

The study plot was established in 2003 and regular surveys started in January 2004. Studies were carried out in agreement with the standards of European forest environmental monitoring which is realised in the Forest Research Institute (Manual..., [http](#):). Water amount and chemical composition of bulk precipitation, throughfall and soil solutions were analysed bi-weekly from January 2004 to the middle of 2005 and at monthly intervals later on. In the beginning, stemflow was also analysed but due to the character of tree stand (dominated by pine trees) resulting in the minor contribution of this type of precipitation to ionic deposition, the analyses were terminated in the middle of the year 2005.

The load of mineral compounds was calculated based on the amount and chemical composition of bulk precipitation and throughfall. The methods of analysing both types of precipitation were described in KOWALSKA and JANEK (2009).

Soil solutions were sampled with the quartz-teflon suction lysimeters PRE-NART[®] by applying the vacuum of ca. 72 kPa. The lysimeters were evenly spaced along the diagonal of the study plot at depths of 25 cm and 50 cm. Samples were collected twice a month to the middle of the year 2005, then once a month with a break during frosts when there was a risk of damage of glass elements of the sampling system by freezing water.

Samples were transported to the laboratory immediately after collection where, on the sampling day, their volume was measured by weighing, electrical conductivity by the conductometric method, and pH by the potentiometric method. Remaining part of the sample was filtered through membrane filters with pore size of 0.45 μm and then divided into two sub-samples: one preserved with the addition of nitric acid (0.5 part of acid per 100 parts of water). Concentrations of Ca, Mg, Na, K, Fe, Mn, Al, Zn, Cd, Cu, and Pb were determined by the atomic emission spectrometry method (ICP-OES). The second sub-sample was used to determine the concentration of chlorides, nitrate-nitrogen, sulphates, phosphates, and ammonium-nitrogen by the ion chromatography method. Chromatographic analyses were performed within 1–2 days after sampling, or samples were stored in a temperature below -20°C for maximum 1 month. One month sample storage without freezing was allowed before the metals determination.

Results of analyses were checked by ionic balance, by comparing measured and calculated conductivity, and by calculating sodium to chloride ratios (except for soil solutions samples). Unsatisfactory test results were a basis for re-analysis of the samples. If repeated analysis did not bring any changes, the results were accepted.

Statistical calculations were made with the STATISTICA software.

RESULTS

DEPOSITION OF IONS

Bulk deposition in the open field in the years 2004–2007 averaged $2564 \text{ mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ 46% out of which were deposited in winter months (X–III). Calcium deposition was the largest ($290 \text{ mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$) among the alkaline metal ions followed by sodium, magnesium, and potassium (90, 67, and $48 \text{ mol}_c \cdot \text{ha}^{-1}$, respectively; Tab. 1). Mean annual load of mineral nitrogen in precipitation reached $979 \text{ mol}_c \cdot \text{ha}^{-1}$. Ammonium-nitrogen constituted 67% of that amount. The load of sulphate-sulphur and chlorides was substantially smaller: 608 and $184 \text{ mol}_c \cdot \text{ha}^{-1}$, respectively.

Stand throughfall deposition recorded in the study plot differed greatly from that in bulk precipitation (Tab. 1). During four years of the study it varied between 2411 and $3377 \text{ mol}_c \cdot \text{ha}^{-1}$. Respective annual loads ranged between 47 and $61 \text{ kg} \cdot \text{ha}^{-1}$. The average sum of ions under canopies was $2717 \text{ mol}_c \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ out of which $1600 \text{ mol}_c \cdot \text{ha}^{-1}$ fell in winter months. Annual stand throughfall deposition was larger than bulk deposition by only 5%. In the summer half-year the deposition under canopies amounted to 82% of the deposition in bulk precipitation whereas in the winter half-year – 132%.

Table 1. The load of ions in summer, winter, and the whole year in bulk precipitation (BP) and throughfall (TF) (in mol_c·ha⁻¹) based on averaged four-year data (2004–2007)

Component	BP			TF		
	IV–IX	X–III	I–XII	IV–IX	X–III	I–XII
Load	1387	1177	2564	1131	1585	2717
H	3	62	65	87	153	240
Ca	171	119	290	194	208	402
Mg	41	26	67	101	91	192
Na	35	55	90	41	69	110
K	31	17	48	160	109	269
Al	3	14	17	14	23	37
Cl	75	109	184	83	163	246
N-NO ₃	168	151	319	118	189	307
N-NH ₄	446	214	660	83	161	244
S-SO ₄	308	300	608	228	372	600
Fe	2	14	16	2	3	5
P-PO ₄	32	3	35	5	26	31
Mn	1.3	1.4	2.7	11	14	25
Cd	0.04	0.03	0.07	0.01	0.02	0.03
Cu	1.0	1.3	2.3	0.8	0.6	1.4
Pb	0.1	0.4	1.5	0.1	0.1	0.2
Zn	68	91	159	4.7	4.5	9.2

The throughfall deposition of alkaline ions was substantially higher than in bulk deposition. Mean annual loads followed the sequence Ca > K > Mg > Na with respective loads of 401, 269, 193, and 110 mol_c·ha⁻¹·year⁻¹. Sulphate-sulphur dominated among acidifying ions (600 mol_c·ha⁻¹); slightly smaller was the load of nitrogen (551 mol_c·ha⁻¹) composed in 56% of nitrate-nitrogen. Throughfall delivered annually 246 mol_c·ha⁻¹ of chloride ions.

SOIL SOLUTIONS

Soil solutions, unavailable in frost periods, were not collected during periods of small atmospheric precipitation and in the periods of intensive transpiration (summer drought) either. Hence, the number of samples throughout the year was often limited and interpretation was based on a small number of data.

Mean annual pH of soil solutions was 4.3 at the depth of 25 cm, and 4.4 at the depth of 50 cm (Tab. 2). The increase of pH with depth was accompanied by lower concentration of aluminium ions and higher ratio of the sum of base cations to aluminium ions.

Table 2. Chemistry of soil solutions at the depth of 25 cm and 50 cm (*EC* – electrical conductivity in $\mu\text{S}\cdot\text{cm}^{-1}$, mineral compounds in $\text{mg}\cdot\text{dm}^{-3}$)

Parameter	25 cm					50 cm				
	2004	2005	2006	2007	2004–2007	2004	2005	2006	2007	2004–2007
<i>EC</i>	66±13	67±3	72±7	64±8	68±9	78±12	77±10	65±5	59±1	71±11
pH	4.3	4.3	4.3	4.2	4.3	4.4	4.4	4.4	4.4	4.4
H	0.049±0.004	0.051±0.003	0.052±0.005	0.058±0.004	0.052±0.005	0.039±0.003	0.042±0.001	0.037±0.002	0.042±0.007	0.040±0.004
Ca	2.65±0.31	2.10±0.45	2.08±0.56	1.85±0.45	2.20±0.54	2.72±0.52	2.41±0.48	1.82±0.22	1.81±0.21	2.22±0.55
Mg	0.72±0.09	0.59±0.15	0.72±0.16	0.59±0.13	0.66±0.15	0.83±0.18	0.84±0.28	0.64±0.08	0.64±0.07	0.75±0.22
Al	3.64±0.33	3.50±0.46	4.00±1.14	3.90±0.72	3.76±0.77	3.32±0.59	3.35±0.43	3.07±0.28	2.83±0.15	3.20±0.45
Cl ⁻	3.81±1.66	4.25±1.34	3.50±1.88	3.12±1.00	3.69±1.60	5.16±1.84	5.72±2.50	3.52±1.30	3.14±0.79	4.58±2.16
N-NO ₃ ⁻	0.01±0.01	0.03±0.05	0.04±0.03	0.07±0.00	0.03±0.04	0.02±0.04	0.08±0.05	0.07±0.05	0.10±0.04	0.07±0.05
S-SO ₄ ²⁻	3.91±0.42	3.79±0.74	4.32±0.87	4.38±0.78	4.09±0.76	5.09±0.64	5.73±1.76	4.72±0.43	4.90±0.15	5.21±1.18
Na	1.54±0.18	1.68±0.27	1.38±0.49	1.63±0.37	1.54±0.37	2.09±0.28	1.93±0.23	1.33±0.30	1.61±0.14	1.75±0.40
K	1.49±0.45	1.40±0.27	0.58±0.28	0.30±0.09	0.97±0.59	1.23±0.15	1.12±0.38	0.72±0.13	0.57±0.17	0.94±0.37
Fe	0.45±0.07	0.38±0.02	0.52±0.39	0.34±0.07	0.43±0.22	0.17±0.03	0.13±0.03	0.11±0.03	0.06±0.03	0.12±0.05
N-NH ₄ ⁺	0.04±0.03	0.05±0.03	0.07±0.02	0.08±0.02	0.06±0.03	0.05±0.01	0.04±0.02	0.08±0.11	0.08±0.05	0.06±0.07
P-PO ₄ ³⁻	0.004±0.007	0.024±0.058	0.000±0.000	0.000±0.000	0.007±0.030	0.003±0.008	0.009±0.020	0.000±0.000	0.001±0.003	0.004±0.013
Mn	0.177±0.053	0.162±0.047	0.171±0.039	0.142±0.029	0.165±0.046	0.209±0.081	0.175±0.040	0.132±0.035	0.112±0.023	0.160±0.060
Cd	0.001±0.000	0.001±0.000	0.001±0.001	0.001±0.000	0.001±0.000	0.001±0.000	0.001±0.000	0.001±0.001	0.001±0.000	0.001±0.000
Cu	0.031±0.016	0.020±0.003	0.013±0.004	0.011±0.003	0.019±0.012	0.026±0.011	0.016±0.002	0.011±0.004	0.008±0.002	0.015±0.009
Pb	0.002±0.001	0.005±0.002	0.002±0.001	0.008±0.000	0.004±0.003	0.001±0.001	0.003±0.002	0.001±0.001	0.008±0.000	0.003±0.003
Zn	0.077±0.024	0.082±0.011	0.061±0.016	0.048±0.022	0.068±0.023	0.094±0.032	0.100±0.024	0.056±0.024	0.052±0.027	0.079±0.034

Mean conductivity at both depths was similar and amounted to ca. $70 \mu\text{S}\cdot\text{cm}^{-1}$. Monthly mean electrical conductivity varied from 40 to $88 \mu\text{S}\cdot\text{cm}^{-1}$ in upper soil layer, and from 50 to $96 \mu\text{S}\cdot\text{cm}^{-1}$ in the lower one. The concentration of examined ions at both depths followed the sequence $\text{S-SO}_4 > \text{Cl} > \text{Al} > \text{Ca} > \text{Na} > \text{K} > \text{Mg}$. In most cases the concentration of nitrate-nitrogen, ammonium-nitrogen, orthophosphates, cadmium and lead were below the detection limits of applied analytical methods. Hence, these values are not discussed in the paper.

DISCUSSION

DEPOSITION OF IONS

The load of protons in throughfall was substantially larger than in bulk precipitation which confirms results of other studies (JANEK, 2002; MORRIS *et al.*, 2003). HOULE *et al.* (1999) found, however, that throughfall deposition of protons on a full-year basis in deciduous stand was significantly lower than in wet deposition, and in coniferous stand not significantly different from that in wet deposition in the open field. In the vegetation season coniferous as well as deciduous canopies neutralised acid deposition and retained 36% and 66%, respectively, of the incoming H^+ .

Total annual load of ions under canopies (in $\text{mol}_e\cdot\text{ha}^{-1}$) calculated as a mean of four-year data exceeded by ca. 5% the load in bulk precipitation though this was not the rule in all study years. The load of ions in spruce stand in the Augustów forest was twice as much as the load in bulk precipitation, while the load under the pine canopy was higher by only ca. 20% (JANEK, 2002). The mean annual load in both types of precipitation in Chojnów was dominated by acidifying ions (sulphates, mineral form of nitrogen and chlorides) similarly as in studies conducted in the Borecka forest (OSTROWSKA *et al.*, 1994). The share of acidifying ions in total load in the open field expressed in $\text{mol}_e\cdot\text{ha}^{-1}$ amounted to 67%, whereas base cations (calcium, magnesium, potassium, and sodium) contributed in only 20%. These values in throughfall reached respectively 51% and 36%. Enrichment in alkaline ions during the passage of throughfall through canopies partially balanced the input of acidifying loads.

In summer months the load of acidifying ions in bulk precipitation, in contrast to throughfall, was larger than in winter months (Fig. 1a, b). During the vegetation season in non-forested areas, the load of ammonium ions increased substantially. Their origin may be attributed to the agricultural activity. Under canopy the foregoing load was much smaller than in the winter season mainly as a result of retaining by tree crowns. During winter the throughfall deposition of sulphur, chlorides and nitrogen exceeded the bulk deposition. Long-term studies (MOFFAT *et al.*, 2002) started in Norway in the middle of the 1980's showed the decrease of acidity and

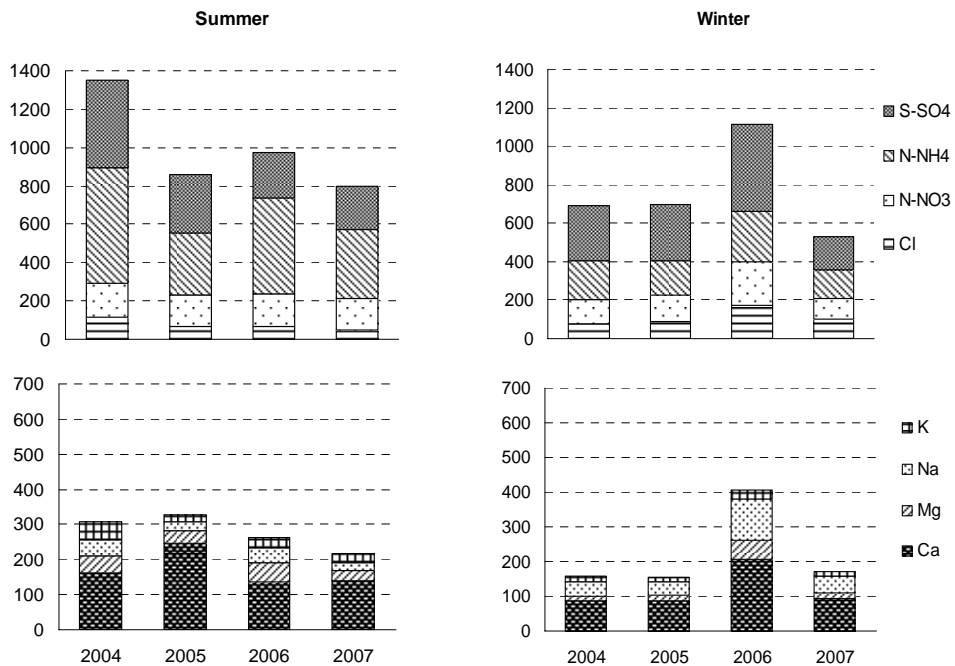


Fig. 1a. The load in mol_c·ha⁻¹ of acidifying (above) and base (below) ions in summer months IV–IX (on the left) and winter months X–III (on the right) in bulk precipitation in the years 2004–2007

of the mean flux input of some of analysed ions in throughfall and open field precipitation with the increase of acid neutralising capacity. A decrease of sulphur and mineral nitrogen deposition with the increase of nitrate-nitrogen deposition was recorded in the Netherlands (BOXMAN *et al.*, 2008). A four-year study period in Chojnów proved to be too short to observe temporal trends of loads despite noticeable differences among particular years of study.

SOIL SOLUTIONS

Dynamic changes in the chemistry of soil solution are related to complex biogeochemical processes regulating elements transfer between solid and liquid phase, e.g. ion exchange, weathering of minerals, mineralisation. The rate and direction of changes are modified by stand and climate conditions, land use and management at present and in the past, soil treatments, condition and age of tree stands (GAWLIŃSKI and OSTROWSKA, 1993; KRÁM *et al.*, 1997; SCHAAF *et al.*, 1997; NIELSEN *et al.*, 1999, NIHLGÅRD and ALAUZIS, 2002). The reduction of acidifying deposition since the close of the last century across Europe caused noticeable changes in soil chemistry reflected in the composition and properties of soil solutions.

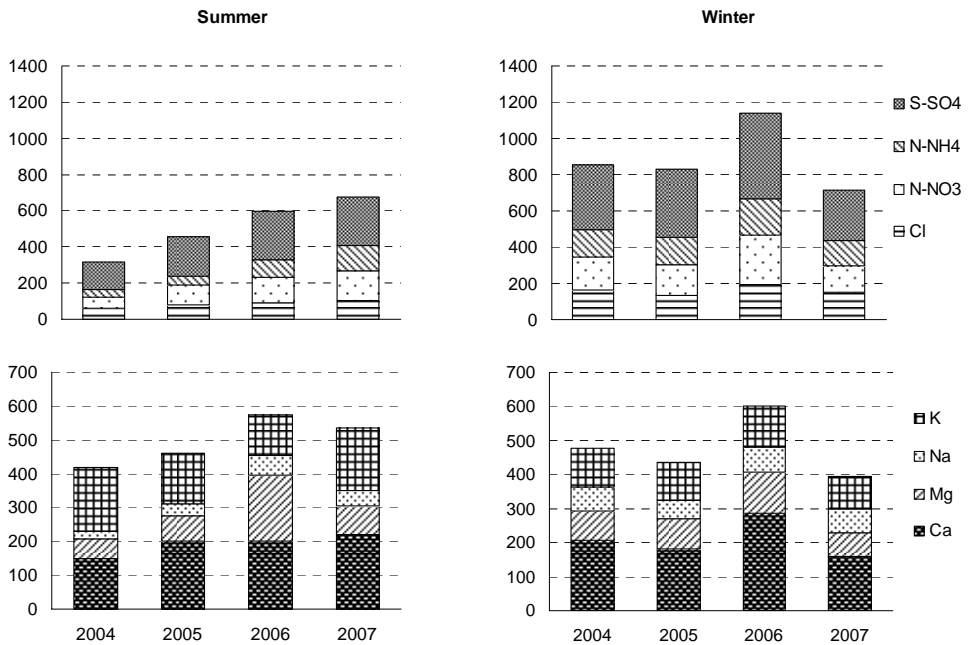


Fig. 1b. The load in mol_c·ha⁻¹ of acidifying (above) and base (below) ions in summer months IV–IX (on the left) and winter months X–III (on the right) in throughfall in the years 2004–2007

Long-term monitoring study in Norway (MOFFAT *et al.*, 2002) demonstrated that the character of soil solutions is significantly affected by the chemistry of precipitation reaching the soil surface. This effect is especially distinct in upper soil layers where any changes, both long-term and seasonal, exhibit most intensively. In spite of decreasing input of acidifying ions soil acidification is still in progress. In the Netherlands, in pine stand, the acidification of soil solutions in upper mineral soil increases though leaching of nutrients decreased with the decreasing emission of sulphur and nitrogen. The process of acidification will be hampered when the concentration of base cations increases, which may last for many decades (BOXMAN *et al.*, 2008). Moreover, sulphur accumulated in the soil as a result of previous emission in the regions receiving large acidifying loads in the past, may undergo a gradual mobilization (OULEHLE *et al.*, 2006; DE VRIES *et al.*, 2007) combined with the release of protons to soil solutions, that would enhance excessive leaching of base cations.

Soil solutions in Chojnów are dominated by sulphate and aluminium ions. Linear correlation ($R = 0.87$) revealed close relationship between sulphur content in the soil solution at the depth of 25 cm and *S* deposition under the canopy, that suggests airborne origin of sulphur in the liquid phase of the upper soil layers. Further analysis of correlation indicated that the remaining chemical compounds in soil

solutions, except for chloride concentrations ($R = 0.70$) seemed to depend neither significantly nor directly on throughfall deposition.

According to the data of the European Intensive Monitoring, below throughfall inputs of $10 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{y}^{-1}$, the leaching of nitrogen is negligible. Another factor limiting the leaching of nitrogen is a high (over 30) C/N ratio in organic soil layers (DE VRIES *et al.*, 2007). In Chojnów the sum of mineral nitrogen only in 2006 approached $10 \text{ kg}\cdot\text{ha}^{-1}$ being lower in other years and the C/N ratio in humic soil layer ranged between 25 and 35. As no significant amounts of nitrates were found in soil solutions one may conclude that the ecosystem did not reach the maximum of its N retention capacity.

The soil solutions from Chojnów were acidic. Below pH 4.5 or below 25% of base saturation of the soil sorption complex (as it was the case in Chojnów) acidic deposition is mainly neutralised in the soil by Al release (DE VRIES *et al.*, 2003). It may be the reason for high Al concentration in soil solutions in Chojnów. Free aluminium ions have strong phytotoxic properties which are, however, moderated at increasing concentrations of base cations. It is assumed that at molar ratio of Ca/Al or $(\text{Ca} + \text{Mg} + \text{K})/\text{Al}$ less than 1 poses a risk of damage to plant roots and negatively affects plant growth depending on species-specific plant sensitivity.

Mean annual molar ratio of $(\text{Ca} + \text{Mg} + \text{K})/\text{Al}$ in the years 2004 and 2005 oscillated around 1 (Fig. 2). In the next years the ratio decreased and was lower in the upper than in the lower soil layers. The decline of $(\text{Ca} + \text{Mg} + \text{K})/\text{Al}$ ratio should be mainly attributed to decreasing concentrations of Ca and K since Mg concentrations changed little at both soil depths (Fig. 3). Conclusions on the ecological risk resulting from exceeding the critical ratio of base cations to aluminium seem premature according to Swiss studies (WALDNER *et al.*, 2007). However, a potential threat for the plants should be taken into consideration.

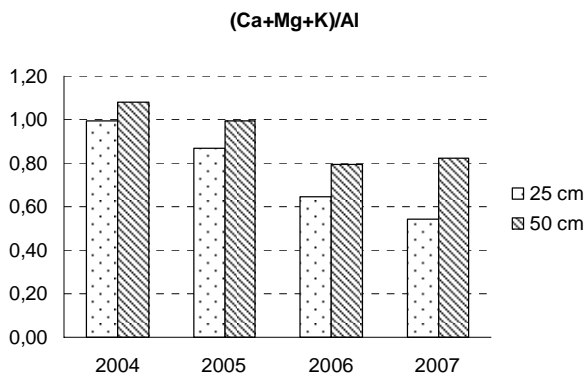


Fig. 2. Molar ratio of base cations to aluminium ion in soil solutions from the depths of 25 and 50 cm

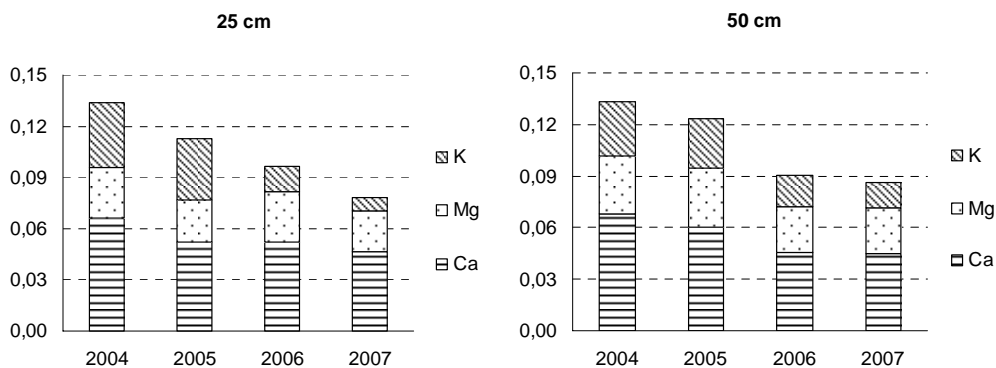


Fig. 3. Comparison of the concentrations ($\text{mmol}\cdot\text{dm}^{-3}$) of base cations in soil solutions from the depths of 25 and 50 cm

CONCLUSION

Chemistry of waters in Chojnów was studied in the period of significant reduction of sulphur emissions that started already in the 1990's. After only four years of research it is difficult to ascertain whether the ecosystem is still under deepening chemical stress caused by previous and current emissions or is recovering the equilibrium.

Total load of ions in bulk precipitation in the years 2004–2007 was $2587 \text{ mol}_c\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$ on average. The load of ions under pine canopies was by ca. 5% larger and averaged $2717 \text{ mol}_c\cdot\text{ha}^{-1}\cdot\text{year}^{-1}$. The share of acidifying ions (N + S + Cl) in the total load of ions, expressed in $\text{mol}_c\cdot\text{ha}^{-1}$, considerably exceeded the share of base ions (Ca + Mg + Na + K), both in bulk precipitation and in through-fall.

The effect of atmospheric deposition on the chemistry of soil solutions is expressed only in the concentrations of sulphates and chlorides. Analysed solutions were acidic. Mean annual pH was below 4.5, and the molar ratio of the base cations (sum of Ca, Mg, and K) to Al was in most samples far less than 1. Along with other soil properties it is an evidence for low buffering capacity of studied soil with respect to acidifying load and indicates a potential risk for the tree stand stability.

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STRESZCZENIE

Kształtowanie się depozytu jonów oraz chemizmu wód glebowych w środowisku leśnym na stałej powierzchni obserwacyjnej w Nadleśnictwie Chojnów w latach 2004–2007

Słowa kluczowe: *depozyt, ładunek, opady atmosferyczne, opady na otwartej przestrzeni, opady podkoronowe, roztwory glebowe, wody glebowe*

Badania prowadzono w latach 2004–2007 na stałej powierzchni obserwacyjnej, założonej w drzewostanie sosnowym na siedlisku bór mieszany świeży w Nadleśnictwie Chojnów. Badania dotyczyły wielkości ładunku składników mineralnych docierających do podłoża wraz z opadami atmosferycznymi na otwartej przestrzeni oraz pod okapem drzewostanu, a także składu chemicznego roztworów glebowych na głębokości 25 i 50 cm. W próbkach opadów oraz wód glebowych oznaczano pH i przewodność elektryczną właściwą oraz wykonywano analizy zawartości jonów: Ca, Mg, Cl, NO₃, SO₄, Na, K, Fe, Mn, NH₄, PO₄, Zn, Cd, Cu i Pb.

Sumaryczny ładunek jonów pod okapem drzewostanu sosnowego kształtował się w zakresie od 47 do 61 kg·ha⁻¹ rocznie. Udział jonów zakwaszających (N + S + Cl) w ładunku sumarycznym jonów pod okapem, wyrażonym w mol_c·ha⁻¹, wyniósł 51%, natomiast udział jonów alkalicznych (Ca + Mg + Na + K) osiągnął zaledwie 36%. Wartości te w opadzie na otwartej przestrzeni wyniosły odpowiednio 69 i 19%.

Nie stwierdzono silnego związku składu chemicznego roztworów glebowych (z obu głębokości) z właściwościami chemicznymi wód opadowych. Odczyn badanych roztworów glebowych był kwaśny (średnie pH na głębokości 25 i 50 cm wyniosło odpowiednio 4,3 i 4,4), a stosunek molowy sumy kationów zasadowych (Ca, Mg i K) do kationu Al w większości badanych prób z górnego poziomu glebowego był daleko mniejszy od granicznej wartości 1. Świadczy to o niewielkich zdolnościach buforowych gleb w stosunku do ładunku zakwaszającego, a także wskazuje na potencjalne zagrożenie stabilności drzewostanu.

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