

Atmospheric deposition of nitrogen and sulphur in relation to critical loads of nitrogen and acidity in the Czech Republic

M. ZAPLETAL

Centre for Environment and Land Assessment – Ekotoxa Opava, Opava, Czech Republic

ABSTRACT: Estimates of dry and wet deposition of sulphur and nitrogen were compared with critical loads of sulphur and nitrogen in the Czech Republic on 1 × 1 km grid. Deposition was estimated from monitored and modelled concentrations in the atmosphere and in precipitation where the most important acidifying compounds are sulphur dioxide, nitrogen oxides and ammonia, and their reaction products. Wet deposition was derived from concentration values for SO_4^{2-} , NO_3^- and NH_4^+ in precipitation and from precipitation amounts. Dry deposition was derived from concentrations of gaseous components and aerosol in the air, and from their deposition velocities. A simple mass balance model was used to calculate critical loads of sulphur and nitrogen. The annual average value of total (potential) acid decreased from 4,147 to 2,185 mol H^+ /ha/year between 1991 and 2000. A reduction in total sulphur and nitrogen (total potential acid) deposition by about 60% would protect 98% of the area of sensitive forests.

Keywords: acidity; atmospheric deposition; critical loads; nitrogen oxides; sulphur oxides

High concentrations of air pollutants have been observed in the Czech Republic for a long time. These pollutants cause and accelerate acidification of forest soils. Spatial distribution of damaged forest ecosystems exhibits too a serious causal relation between high values of air pollutant concentrations and the forest ecosystems. Sulphur dioxide, nitrogen oxides, ammonia and their reaction products are very important acidifying components in the Czech Republic. To evaluate the potential influence of a wide variety of acidifying components on the forest ecosystems it is necessary to know the locality where the actual atmospheric deposition of acidifying components exceeds the critical load. Critical load is a quantitative estimate of the exposure to one or more pollutants below which no significant harmful effects on specified sensitive elements of the environment occur according to our present knowledge (NILSSON, GRENNFELT 1988). The working plan for the implementation of the UN ECE Convention on Long-Range Transboundary Air Pollution (LRTAP)

includes the production of maps of deposition, critical loads and exceedances as a basis for developing potential abatement strategies for sulphur and nitrogen. In this respect, accurate estimates of actual deposition onto vegetation, soil and water surfaces became an important topic in the Czech Programme on Acidification (ZAPLETAL 1995, 1996, 1998a,b, 2002; SKOŘEPOVÁ et al. 1997, 2001, 2003).

MATERIAL AND METHODS

Acid atmospheric deposition

The following acidifying components were considered in this study: sulphur dioxide (SO_2), nitrogen oxides (NO , NO_2), nitric acid (HNO_3), ammonia (NH_3), sulphates (SO_4^{2-}), nitrates (NO_3^-) and ammonium (NH_4^+) in aerosol, air and precipitation, respectively. One mole of SO_2 can form two equivalents of acid, one mole of NO_x or NH_3 can form one equivalent of acid (ERISMAN et al. 1989). The maximum

Supported by the Ministry of Environment of the Czech Republic, Project VaV/740/1/02.

amount of acidifying components removed from the atmosphere by deposition, hereafter referred to as total potential acid deposition, is estimated by:

$$\text{Total potential acid} = 2 \text{SO}_x + \text{NO}_y + \text{NH}_x \quad (1)$$

where: SO_x – the total of oxidized sulphur compounds (gaseous SO_2 , SO_4^{2-} particulates in air and precipitation),

NO_y – the total deposition of oxidized nitrogen compounds (NO , NO_2 , HNO_3 , NO_3^- in air and precipitation),

NH_x – the total deposition of reduced nitrogen compounds (NH_3 and NH_4^+ in air and precipitation).

Wet deposition

For this study, the database of the Air Quality Information System of the Czech Republic was used (ČHMÚ 1992, 1995, 1999, 2000, 2001a). The concentrations of SO_4^{2-} , NO_3^- and NH_4^+ in precipitation collected by monitoring stations were available. Precipitation at these stations was collected by the bulk method (samplers are exposed continuously and samples are therefore enriched with dry deposition) and by the wet-only method (an automatic collection of precipitation excluding the contribution of dry deposition). Correction factors were applied to correct the dry deposition in precipitation collected by the bulk method (ZAPLETAL 2002).

The total potential acid wet deposition of nitrogen and sulphur compounds estimated in this study is:

$$\begin{aligned} \text{Total potential acid (wet deposition)} &= \\ &= 2 \text{SO}_4^{2-} + \text{NO}_3^- + \text{NH}_4^+ \end{aligned} \quad (2)$$

Annual average wet deposition of SO_4^{2-} , NO_3^- and NH_4^+ for each 1×1 km grid in the territory of the Czech Republic in 1991, 1994 and 2000 was computed as the product of annual average concentrations of SO_4^{2-} , NO_3^- and NH_4^+ in precipitation and of annual precipitation amounts.

Dry deposition

Dry deposition fluxes were estimated from measured concentrations of gases and aerosol particles in air multiplied by the corresponding deposition velocities:

$$F = V_d(z) C(z) \quad (3)$$

where: F – the deposition flux of the component per unit area (e.g. m^2 , ha),

V_d – the deposition velocity of the component,

$C(z)$ – the concentration of the component at a height z above the ground.

The concentrations of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and dust aerosol are routinely monitored and evaluated in the Czech Republic. For this study the databases of the Air Quality Information System of the Czech Republic (ČHMÚ 1992, 1995, 1999, 2000, 2001a) were used. Annual average concentrations of NO_x and SO_2 computed from daily measurements were interpolated using Kriging technique on a 1×1 km resolution grid. Annual average concentrations of NH_3 , HNO_3 , sulphate aerosol (SO_4^{2-}), nitrate aerosol (NO_3^-) and ammonium aerosol (NH_4^+) in the territory of the Czech Republic for the years 1991, 1994 and 2000 were taken from the EMEP-LRTAP model (TUOVINEN et al. 1994; BARRETT et al. 1995; VESTRENG, KLEIN 2002) at 150×150 km or 50×50 km resolution.

Deposition velocity for gases was calculated using the resistance analogy (ZAPLETAL 1998b, 2002) from meteorological and land use data. Deposition velocity for particles was obtained by parametrization of friction velocity for low vegetation according to WESELY et al. (1985) and for forests according to ERISMAN (1992).

Because monitoring stations for concentration monitoring $C(z)$ of gaseous components and aerosol in the atmosphere are not distributed evenly over the territory of the Czech Republic, the concentration data had to be interpolated to 1×1 km grids covering the total territory. Annual average value of dry deposition D was calculated from annual average concentration $C(z)$, annual average deposition velocity V and time t in a 1×1 km grid resolution.

Critical loads of nitrogen and sulphur

Methodology of critical loads of nitrogen and sulphur is based on the mass balance of hydrogen ions in forest soils providing steady state mass balance, which cause acidification and which occurred acidification neutralize (POSCH et al. 1995). The simple mass balance method summarized in CCE Status Report 1995 (POSCH et al. 1995) was used to calculate sulphur and nitrogen critical loads for forest soils in the territory of the Czech Republic. The values of weathering rates were derived from the soil type (SKOŘEPOVÁ et al. 1997). Soil types and soil texture characteristics were taken over from maps at a 1:500,000 scale (SKOŘEPOVÁ et al. 1997). The data on the basic cation deposition were provided by the CCE from the European background database (SKOŘEPOVÁ et al. 1997).

Table 1. Annual averages of precipitation amount, wet depositions of sulphur and nitrogen compounds (SO_4^{2-} , NO_3^- and NH_4^+) and total potential acid in the Czech Republic in 1991, 1994 and 2000 (mol H^+ /ha/year)

Year	Annual average of precipitation amount (mm)	Wet deposition (mol H^+ /ha/year)			Total potential acid (mol H^+ /ha/year)
		SO_4^{2-}	NO_3^-	NH_4^+	
1991	617	548	290	410	1,248
1994	688	506	317	406	1,229
2000	695	374	280	384	1,038

Table 2. Annual averages of dry deposition fluxes of sulphur and nitrogen compounds and total potential acid in the Czech Republic in 1991, 1994 and 2000 (mol H^+ /ha/year)

Year	Dry deposition (mol H^+ /ha/year)							Total potential acid (mol H^+ /ha/year)
	SO_2	SO_4^{2-}	NO_x	HNO_3	NO_3^-	NH_3	NH_4^+	
1991	1,675	88	407	86	162	424	57	2,899
1994	790	88	407	86	162	424	57	2,014
2000	281	53	236	83	50	389	55	1,147

RESULTS AND DISCUSSION

Wet deposition

The annual average total wet deposition of sulphur and nitrogen compounds (SO_4^{2-} , NO_3^- and NH_4^+) was estimated in the Czech Republic for 1991 at 1,248 mol H^+ /ha/year, for 1994 at 1,229 mol H^+ /ha/year and for 2000 at 1,038 mol H^+ /ha/year. The annual average precipitation amount and annual average wet deposition of sulphur and nitrogen compounds (SO_4^{2-} , NO_3^- and NH_4^+) and total potential acid in 1994 and in 1998 in the Czech Republic are presented in Table 1.

The annual average wet deposition of SO_4^{2-} , NO_3^- and NH_4^+ did not change very much between 1991 and 2000. The resultant wet atmospheric deposition values are affected by annual average concentrations of components in precipitation

and annual precipitation amounts. Significance of annual precipitation amounts is evident mainly in mountain areas where the highest levels reach up to 1,800 mm.

Dry deposition

The annual average total dry deposition of sulphur and nitrogen compounds (SO_2 , SO_4^{2-} , NO_x , HNO_3 , NO_3^- , NH_3 and NH_4^+) was estimated in the Czech Republic in 1991 at 2,899 mol H^+ /ha/year, in 1994 at 2,014 mol H^+ /ha/year and in 2000 at 1,147 mol H^+ /ha/year. The annual average dry deposition fluxes of sulphur and nitrogen compounds and total potential acid in the Czech Republic in 1991, 1994 and 2000 are presented in Table 2.

In the period 1991 to 2000 a remarkable decrease in the annual average of gaseous SO_2 deposition can be observed.

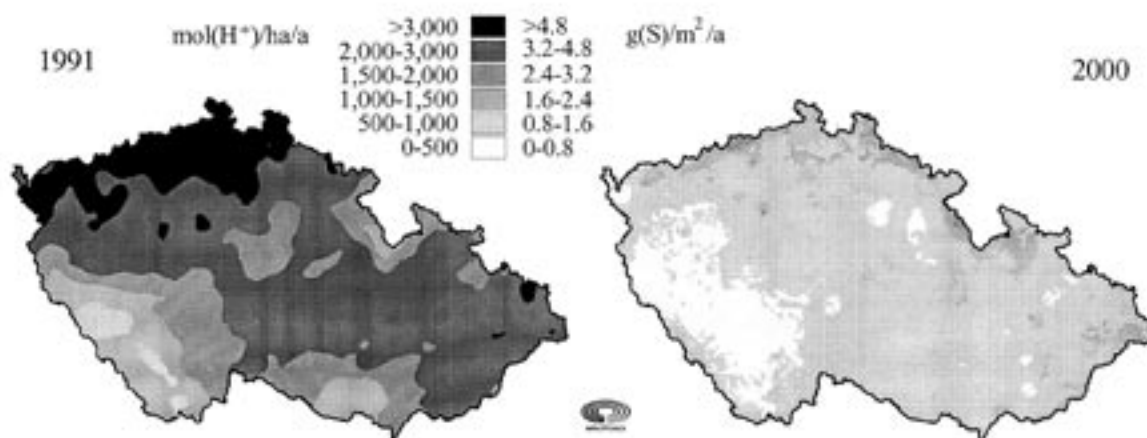


Fig. 1. Total deposition of SO_x in the Czech Republic on a 1×1 km grid in 1991 and 2000 in mol (H^+)/ha/year (g (S)/ m^2 /year)

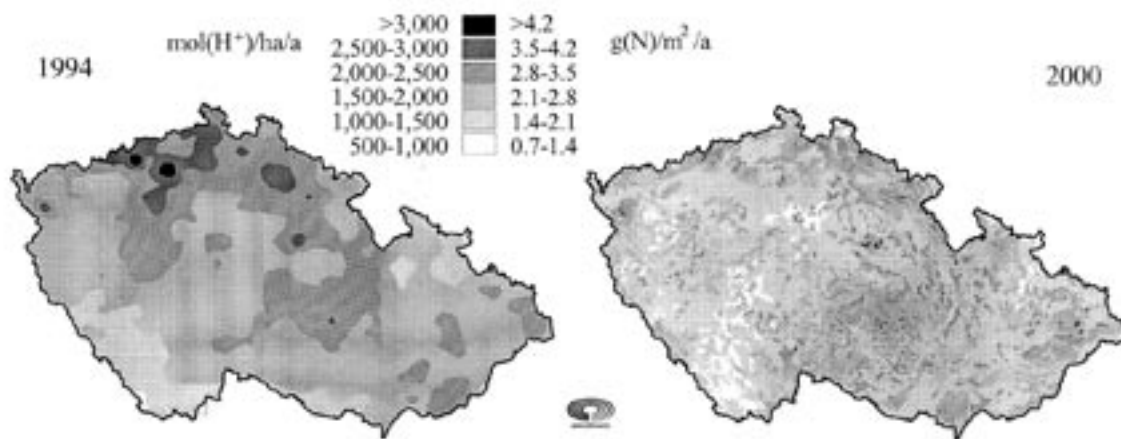


Fig. 2. Total deposition of nitrogen ($\text{NO}_y + \text{NH}_x$) in the Czech Republic on a 1×1 km grid in 1994 and 2000 in mol (H^+)/ha/year (g (N)/m²/year)

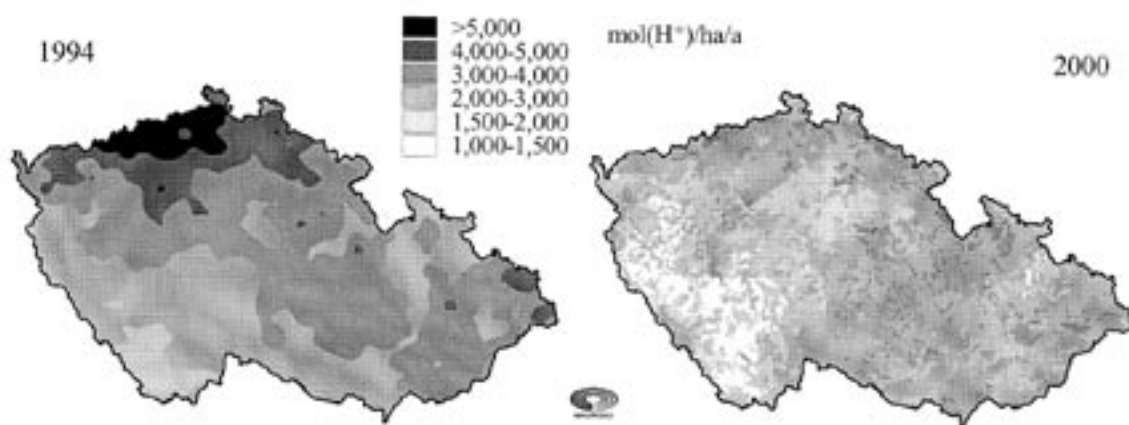


Fig. 3. Total deposition of potential acid in the Czech Republic on a 1×1 km grid in 1994 and 2000 in mol (H^+)/ha/year

Total deposition

The annual average total deposition of sulphur and nitrogen compounds in the territory of the Czech Republic was computed as the sum of the annual averages of wet deposition and dry deposition. Spatial distribution of total deposition of SO_x on a 1×1 km grid in 1991 and 2000 is shown in Fig. 1. Total deposition of SO_x is influenced by the emissions from large industrial sources in the north-west and north-east part of the Czech Republic and Prague region. A decrease in total deposition of SO_x in 1991 to 2000 was caused by the abatement of SO_2 emissions in the Czech Republic

and in the countries of Central and Western Europe (VESTRENG, KLEIN 2002). A tendency of a decrease in total deposition of SO_x is especially apparent in the most loaded regions of the north-west and north-east part of the Czech Republic and Prague region. A trend of a decrease in gaseous deposition of SO_2 is much more obvious than that of wet deposition of SO_4^{2-} .

Spatial distribution of total deposition of nitrogen ($\text{NO}_y + \text{NH}_x$) on a 1×1 km grid in 1994 and 2000 is shown in Fig. 2. Total deposition of NO_y is influenced by the emissions from agglomeration areas of high combustion (industry, traffic and heating/fuel consumption) and, to lesser extent, by emissions from

Table 3. Dry, wet, total deposition of SO_x , NO_y and NH_x and the total potential acid deposition (TPAD) in 1991, 1994 and 2000 (mol H^+ /ha/year)

Year	SO_x			NO_y			NH_x			TPAD
	dry	wet	total	dry	wet	total	dry	wet	total	
1991	1,763	548	2,311	655	290	945	481	410	891	4,147
1994	878	506	1,384	655	317	972	481	406	887	3,243
2000	334	374	708	369	280	649	444	384	828	2,185

Table 4. The level of emissions of sulphur dioxide, nitrogen oxides and ammonia in kt/year in 1990 and 2000, emission limits in kt/year for the year 2010 and percentage limitation of emissions in 2000 and 2010 compared to 1990

Component	Level of emissions			Emission limits	
	1990	2000		2010	
	kt/year	kt/year	%(1990)	kt/year	%(1990)
SO ₂	1,876	265	-86	283	-85
NO _x	742	397	-46	286	-61
NH ₃	156	74.5	-52	101	-35

car traffic on important roads. Total deposition of NH_x is especially influenced by NH₃ emissions in agricultural areas with intensive animal production (north and east part of the Czech Republic).

Spatial distribution of total deposition of potential acid on a 1 × 1 km grid in 1994 and 2000 is shown in Fig. 3. The annual average deposition of total (potential) acid was estimated to be 2,185 mol H⁺/ha/year in 2000. The annual average of total hydrogen ion deposition calculated by the Czech Hydrometeorological Institute was estimated to be 546 mol H⁺/ha/year in 2000 (ČHMÚ 2001b). The difference between the deposition of total (potential) acid and

total hydrogen ion deposition results from different methods of deposition calculation:

1. The method of calculation of total hydrogen ion deposition did not include all acidifying components removed from the atmosphere by deposition (e.g. SO₄²⁻, NO₃⁻, NH₄⁺ particulates in air and NH₃).
2. The wet hydrogen ion deposition was computed on the basis of pH values measured in precipitation.

The dry, wet, total deposition of SO_x, NO_y and NH_x and the total potential acid deposition in 1991, 1994 and 2000 are presented in Table 3. In the pe-

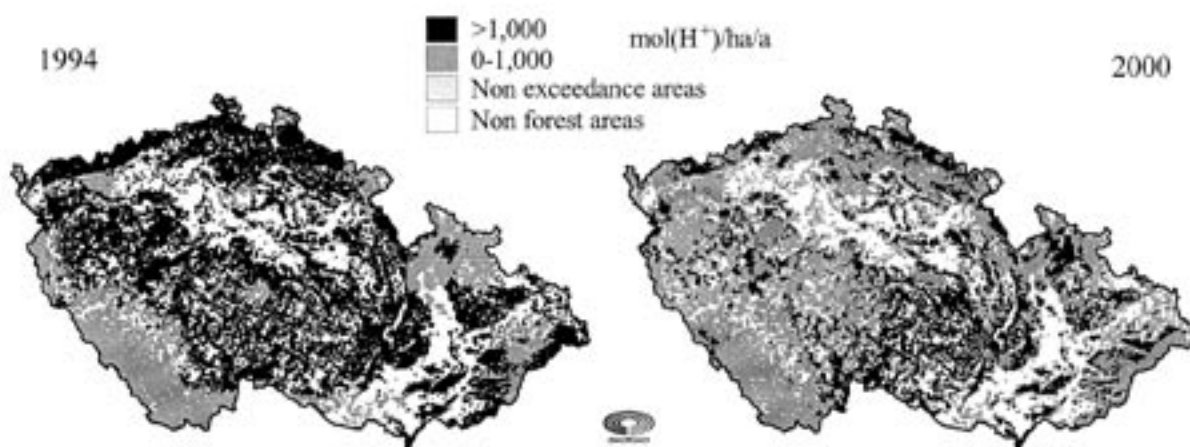


Fig. 4. Exceedances of critical loads of nutrient nitrogen in the Czech Republic on a 1 × 1 km grid in 1994 and 2000 in mol (H⁺)/ha/year

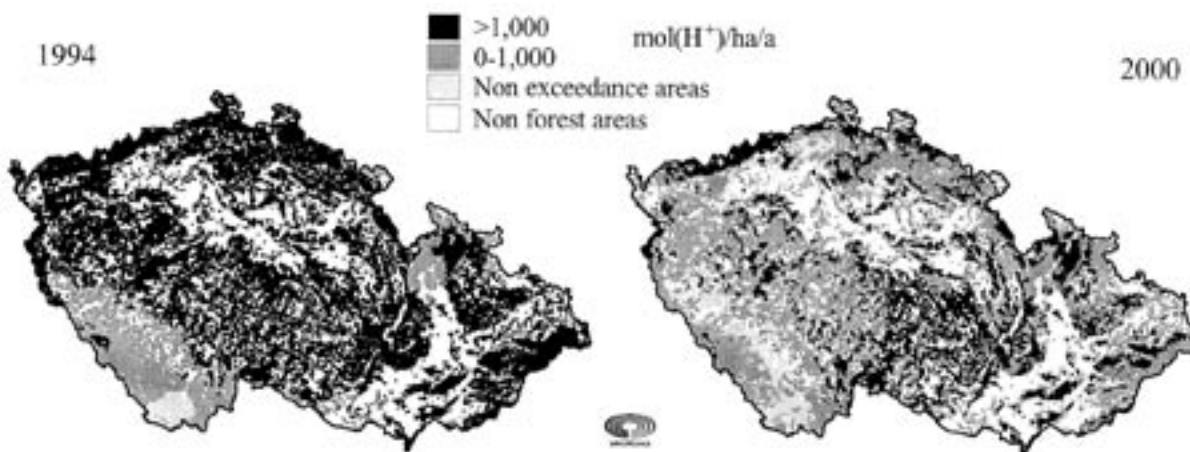


Fig. 5. Exceedances of critical loads of acidity in the Czech Republic on a 1 × 1 km grid in 1994 and 2000 in mol (H⁺)/ha/year

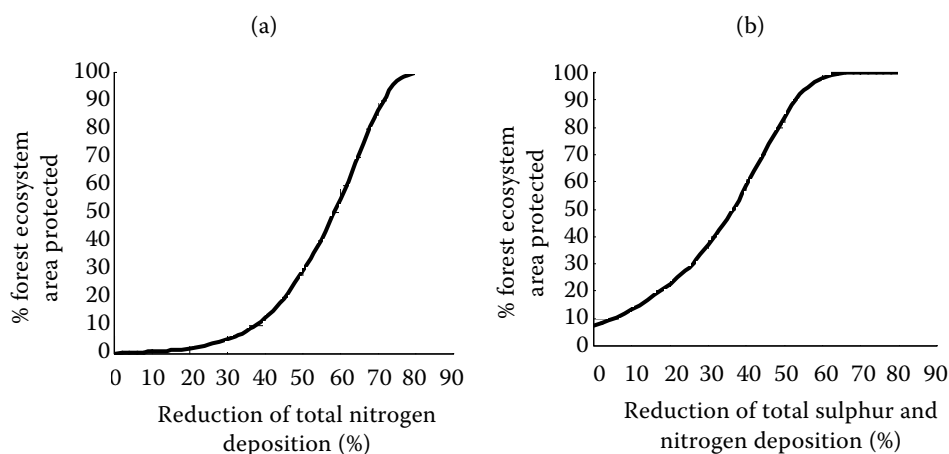


Fig. 6. Predicted improvement of forest condition with changes in atmospheric deposition of total nitrogen ($\text{NO}_y + \text{NH}_x$): (a) and atmospheric deposition of sulphur and nitrogen, (b) in the Czech Republic

riod 1991 to 2000 a remarkable decrease in the annual average of dry SO_x deposition can be observed. Annual average wet deposition of SO_4^{2-} , NO_3^- and NH_4^+ did not change very much between 1991 and 2000. The resultant wet atmospheric deposition values are affected by annual average concentrations of components in precipitation and annual precipitation amounts. Significance of annual precipitation amounts is evident mainly in mountain areas where the highest levels reach up to 1,800 mm.

In Table 4 the values of national emission limits in 2010 (VESTRENG, KLEIN 2002) are compared with the level of emissions of SO_2 , NO_x and NH_3 in the Czech Republic in 1990 and 2000 and percentage limitation of emissions in 2000 and 2010 is compared with 1990. The table documents a reduction of sulphur dioxide and ammonia below the level of emission limits for the year 2010. The emission limit for nitrogen oxides has meanwhile been exceeded.

A decrease in total deposition of SO_x from 1991 to 2000 (Table 3) was caused by the abatement of SO_2 emissions in the Czech Republic (Table 4) and, to a lesser extent, in the countries of Central and Western Europe.

Exceedances of critical loads of nutrient nitrogen and acidity

Total deposition of nitrogen ($\text{NO}_y + \text{NH}_x$) was compared with critical loads of nutrient nitrogen and exceedances were evaluated. Fig. 4 documents the exceedances of critical loads of nutrient nitrogen in 1994 and 2000.

In 1994, critical loads of nutrient nitrogen were exceeded on 100% of the total forested area while in 2000 it was on 99%.

Total potential acid deposition was compared with critical loads of acidity and exceedances were evaluated. Fig. 5 documents the exceedances of critical loads of acidity in 1994 and 2000.

In 1994, critical loads of acidity were exceeded on 98% of the total forested area while in 2000 it was on 93%. The decrease corresponds to the trends of dry deposition of sulphur dioxide.

Information on the spatial distribution of atmospheric deposition rates and critical loads can be used to estimate the impact of potential changes in atmospheric deposition rates. We estimate that a 60% reduction in total nitrogen deposition ($\text{NO}_y + \text{NH}_x$) compared to 2000 would protect 55% of the forested area in the territory of the Czech Republic (Fig. 6a). We estimate that a 60% reduction in combined sulphur and nitrogen deposition compared to 2000 would protect 98% of the forested area in the territory of the Czech Republic (Fig. 6b).

CONCLUSIONS

It was estimated that the annual average deposition of SO_x in the Czech Republic decreased from 2,311 to 708 mol H^+ /ha/year between 1991 and 2000. The annual average NO_y deposition was estimated to be 945 and 649 mol H^+ /ha/year in 1991 and 2000, respectively. The annual average NH_x deposition was estimated to be 891 mol H^+ /ha/year and 828 mol H^+ /ha/year in 1991 and 2000, respectively. The annual average deposition of total (potential) acid decreased from 4,147 to 2,185 mol H^+ /ha/year between 1991 and 2000.

Sulphur compounds (SO_x) contributed by about 56% in 1991 and 32% in 2000 to total potential acid deposition in the Czech Republic. The change in contributions of sulphur compounds (SO_x) to the total potential acid deposition in the Czech Republic in the period between 1991 and 2000 reflects approximately the change in emissions of SO_2 (Table 2). A decrease in emissions of SO_2 from large industrial sources in the north-west and north-east part of the Czech Republic and Prague region between 1991 and 2000 is the main reason for a decrease in total

deposition of SO_x (Fig. 1) and total potential acid deposition (Fig. 3) in these regions at this time.

Oxidized nitrogen species (NO_y) contributed by about 23% in 1991 and 30% in 2000, and reduced nitrogen species (NH_x) contributed by about 21% in 1991 and by 38% in 2000 to the total potential acid deposition in the Czech Republic. Wet deposition contributed by 30% in 1991 and by 48% in 2000 to the total potential acid deposition in the Czech Republic.

The annual average exceedance of critical loads for nitrogen decreased from 1,213 to 858 mol H^+ /ha/year and the annual average exceedance of critical loads for acidity decreased from 1,731 to 733 mol H^+ /ha/year in the Czech Republic between 1994 and 2000. In comparison with the exceedances of critical loads for nitrogen and acidity observed in 1994, the absolute values of exceedances have generally decreased throughout the Czech Republic, and the regional number of exceedances has changed significantly. While the highest exceedances were located in the northwest part of the country in 1991 (Krušné hory Mts.), in 2000 these were located in central parts of the Czech Republic. A reduction in current total deposition of nitrogen ($\text{NO}_y + \text{NH}_x$) by about 60% compared to 2000 would protect 55% of sensitive forests. A reduction in current total sulphur and nitrogen deposition by about 60% compared to 2000 would protect 98% of sensitive forests.

References

- BARRETT K., SELAND Q., FOSS A., MYLONA S., SANDNES H., STYVE H., TARRASSÓN L., 1995. European Transboundary Acidifying Air Pollution: Ten years calculated fields and budgets to the end of the first Sulphur protocol, EMEP/MSW, Report 1/95. Oslo, Norwegian Meteorological Institute: 71.
- ČHMÚ, 1992. Souhrnný roční tabelární přehled koncentrací znečišťujících látek ze staničních sítí České republiky 1991. Praha, Český hydrometeorologický ústav: 160.
- ČHMÚ, 1995. Znečištění ovzduší na území České republiky a chemické složení srážek. Souhrnný roční tabelární přehled 1994. Praha, Český hydrometeorologický ústav: 386.
- ČHMÚ, 1999. Znečištění ovzduší a atmosférická depozice v datech, Česká republika 1998. Praha, Český hydrometeorologický ústav: 299.
- ČHMÚ, 2000. Znečištění ovzduší a atmosférická depozice v datech, Česká republika 1999. Praha, Český hydrometeorologický ústav: 329.
- ČHMÚ, 2001a. Znečištění ovzduší a atmosférická depozice v datech, Česká republika 2000. Praha, Český hydrometeorologický ústav: 345.
- ČHMÚ, 2001b. Znečištění ovzduší na území České republiky v roce 2000. Praha, Český hydrometeorologický ústav: 169–170.
- ERISMAN J.W., LEEUW F.A.A.M.DE, AALST R.M. VAN, 1989. Deposition of the most acidifying components in the Netherlands during the period 1980–1986. *Atmospheric Environment*, 23: 1051–1062.
- ERISMAN J.W., 1992. Atmospheric deposition of acidifying compounds in the Netherlands. [Ph.D. Thesis.] Utrecht, Utrecht University: 155.
- NILSSON J., GRENNFELT P., 1988. Critical loads for sulphur and nitrogen. Report from a workshop held at Skokloster, Sweden, 19–24 March 1988, Miljörapport 1988, 15. Copenhagen, Nordic Council of Ministers: 120.
- POSCH M., DE SMET P.A.M., HETTELINGH J.P., DOWNING R.J. (eds.), 1995. Calculation and Mapping of Critical Thresholds in Europe. Stat. Rep. 1995, Coordination Centre for Effects, Rep. No. 259101004. Bilthoven, RIVM: 198.
- SKOŘEPOVÁ I., ROUŠAROVÁ Š., PAČES T., ZAPLETAL M., 1997. National Focal Centre Reports: Czech Republic. In: POSCH M., HETTELINGH J.P., DE SMET P.A.M., DOWNING R.J. (eds.), Calculation and Mapping of Critical Thresholds in Europe – Status Report 1997. RIVM Report No. 259101007. Coordination Centre for Effects, Bilthoven, RIVM: 66–70.
- SKOŘEPOVÁ I., ROUŠAROVÁ Š., BENEŠ S., WITHERS R., PAŘÍZEK I., PAČES T., ZAPLETAL M., KOPECKÝ M., 2001. National Focal Centre Reports: Czech Republic. In: POSCH M., DE SMET P.A.M., HETTELINGH J.P., DOWNING R.J. (eds.), Modelling and mapping of critical thresholds in Europe. Status Report 2001, Coordination Centre for Effects, RIVM Report No. 259101010. Bilthoven, RIVM: 125–128.
- SKOŘEPOVÁ I., ROUŠAROVÁ Š., WITHERS R., SKOŘEPA J., FIALA J., LIVOROVÁ H., POKORNÝ P., ZAPLETAL M., 2003. National Focal Centre Reports: Czech Republic. In: POSCH M., HETTELINGH J.P., SLOOTWEG J., DOWNING R.J. (eds.), Modelling and Mapping of Critical Thresholds in Europe. CCE Status Report 2003, ICP M & M Coordination Center for Effects, RIVM Report No. 259101013. Bilthoven, RIVM: 62–67.
- TUOVINEN J.P., BARRETT K., STYVE H., 1994. Transboundary acidifying pollution in Europe: Calculated fields and budgets 1985–1993. EMEP/MSW, Report 1/94, Oslo, Norwegian Meteorological Institute: 115.
- VESTRENG V., KLEIN H., 2002. Emission data reported to UNECE/EMEP: Quality assurance and trend analysis & Presentation of WebDab. EMEP/MSW, Status Report 1/2002. Oslo, Norwegian Meteorological Institute: 101.
- WESELY M.L., COOK D.R., HART R.L., 1985. Measurements and parametrization of particulate sulphur dry deposition over grass. *Journal of Geophysical Research*, 90: 2131–2143.

- ZAPLETAL M., 1995. Gas deposition of sulphur dioxide on the territory of the Czech Republic in 1991. *Studies in Environmental Science*, 64: 459–462.
- ZAPLETAL M., 1996. Gas deposition of nitrogen oxides on the territory of the Czech Republic in 1994. In: SUTTON M.A., DOLLARD G.J., FOWLER D. (eds.), *Atmospheric Ammonia: Emission, Deposition and Environmental Impacts*. Poster Proceedings. Poster papers from the International Conference on Atmospheric Ammonia. Culham, Oxford 2–4 October 1995. Midlothian, Institute of Terrestrial Ecology: 104–108.
- ZAPLETAL M., 1998a. Atmospheric deposition of nitrogen compounds in the Czech Republic. In: HOEK K.W., ERISMAN J.W., SMEULDERS S., WISNIEWSKI J.R., WISNIEWSKI J. (eds.), *Proceedings of the First International Nitrogen Conference 1998*, 23–27 March 1998, Noordwijkerhout, The Netherlands. Oxford, Elsevier Science: 305–311.
- ZAPLETAL M., 1998b. Atmospheric deposition of nitrogen compounds in the Czech Republic. *Environmental Pollution*, 29: 305–311.
- ZAPLETAL M., 2002. Atmospheric deposition of nitrogen and sulphur compounds in the Czech Republic. In: GALLOWAY J., COWLING E., ERISMAN J.W., WISNIEWSKI J., JORDAN C. (eds.), *Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection*. Contributed Papers from the 2nd International Nitrogen Conference, 14–18 October 2001, Potomac, Maryland, USA. Lisie, Abingdon, Exton, Tokyo, A.A. Balkema Publishers: 294–303.

Received for publication October 10, 2004

Accepted after corrections May 19, 2005

Atmosférická depozice dusíku a síry ve vztahu ke kritickým zátěžím dusíku a acidity v České republice

M. ZAPLETAL

Centrum pro životní prostředí a hodnocení krajiny – Ekotoxa Opava, Opava, Česká republika

ABSTRAKT: Odhady suché a mokré depozice síry a dusíku byly porovnány s kritickými zátěžemi síry a dusíku na území České republiky v síti 1 × 1 km. Depozice byla odhadnuta z monitorovaných a modelovaných koncentrací acidifikačních látek v ovzduší a ve srážkách (oxid siřičitý, oxidy dusíku, amoniak a jejich reakční produkty). Mokrú depozice byla odvozena z naměřených koncentrací SO_4^{2-} , NO_3^- a NH_4^+ ve srážkách a ze srážkových úhrnů. Suchá depozice byla odvozena z koncentrací plynných látek a aerosolů v ovzduší a jejich depozičních rychlostí. Pro výpočet kritických zátěží síry a dusíku byl použit model založený na hmotnostní bilanci prvků. Průměrná roční hodnota celkové potenciální kyselé depozice klesla mezi roky 1991 a 2000 ze 4 147 mol H^+ /ha/rok na 2 185 mol H^+ /ha/rok. Snížení hodnot celkové depozice síry a dusíku (potenciální kyselá depozice) o 60 % vzhledem k roku 2000 by chránilo 98 % území citlivých lesů.

Klíčová slova: acidita; atmosférická depozice; kritické zátěže; oxidy dusíku; oxidy síry

Oxid siřičitý, oxidy dusíku, amoniak a jejich reakční produkty jsou významnými acidifikačními látkami v lesních ekosystémech České republiky. Pro posouzení širokého okruhu potenciálních vlivů acidifikačních látek na lesní ekosystémy potřebujeme vědět, kde aktuální atmosférická depozice těchto látek překračuje kritickou zátěž. Kritická zátěž je nejvyšší dávka znečišťující látky, která ještě nezpůsobí chemické změny, které by měly dlouhodobé škodlivé účinky na nejcitlivější ekosystémy. Cílem práce je hodnocení vývoje at-

mosférické depozice síry a dusíku v letech 1991 až 2000 ve vztahu ke kritickým zátěžím dusíku a acidity lesních půd na území České republiky v síti 1 × 1 km. Celková potenciální kyselá depozice = $2\text{SO}_x + \text{NO}_y + \text{NH}_x$, kde SO_x je celková (mokrú a suchú) depozice sloučenin síry (SO_2 a SO_4^{2-}), NO_y je celková depozice oxidovaných sloučenin dusíku (NO , NO_2 , HNO_3 a NO_3^-) a NH_x je celková depozice redukováných sloučenin dusíku (NH_3 a NH_4^+). Předpokládá se, že jeden mol SO_2 může v konečné formě vytvořit dva vodíkové ionty H^+ , zatímco jeden mol NO_x nebo

NH₃ jeden vodíkový iont H⁺. Depozice byla odhadnuta z monitorovaných a modelovaných koncentrací acidifikačních látek v ovzduší a ve srážkách. Data o koncentracích acidifikačních látek ve srážkách a v ovzduší byla získána z databáze Informačního systému kvality ovzduší (ČHMÚ) a z EMEP-LRTAP modelu. Mokrú depozice byla odvozena z naměřených koncentrací SO₄²⁻, NO₃⁻ a NH₄⁺ ve srážkách a ze srážkových úhrnů. Suchá depozice byla odvozena z koncentrací plyných látek a aerosolů v ovzduší a jejich depozičních rychlostí. Pro odhad depozičních rychlostí z meteorologických dat, charakteristik povrchů a vegetačních pokryvů v síti 1 × 1 km byl použit několikanásobný rezistenční model. Depoziční rychlosti aerosolových částic v síti 1 × 1 km byly odvozeny z parametrizace třecí rychlosti pro nízkou vegetaci a pro lesy. Metodika hodnocení kritických zátěží síry a dusíku je založena na hmotové bilanci vodíkových iontů v lesních půdách za předpokladu ustáleného stavu chemických prvků, které způsobují okyselování a které vzniklé okyselení neutralizují. Hodnoty kritických zátěží síry a dusíku pro lesní ekosystémy na území České republiky byly vyhodnoceny na základě jednoduchých hmotových bilanci vodíkových iontů.

Mezi roky 1991 a 2000 klesla v České republice průměrná roční hodnota mokré depozice (SO₄²⁻, NO₃⁻ a NH₄⁺) z 1 248 mol H⁺/ha/rok na 1 038 mol H⁺/ha/rok. Ve stejném období klesla průměrná roční hodnota suché depozice (SO₂, NO_x, HNO₃, NH₃ a aerosol) z 2 899 mol H⁺/ha/rok na 1 147 mol H⁺/ha/rok.

Pokles průměrné roční hodnoty celkové depozice SO_x mezi roky 1991 a 2000 z hodnoty 2 311 mol H⁺/ha/rok na 708 mol H⁺/ha/rok byl způsoben omezením emisí SO₂ v České republice a ve střední a západní Evropě. Tendence poklesu celkové depozice SO_x je zvláště patrná v nejzatíženějších oblastech, tj. v severozápadních Čechách, v Praze a na Ostravsku. Pokles průměrné roční hodnoty celkové depozice NO_y mezi roky 1994 a 2000 z 945 mol H⁺/ha/rok na 649 mol H⁺/ha/rok, který se projevil zejména ve střední, severní a severozápadní části

České republiky, byl způsoben omezením emisí NO_x z velkých průmyslových zdrojů v České republice. Pokles průměrné roční hodnoty celkové depozice NH_x mezi roky 1991 a 2000 z 891 mol H⁺/ha/rok na 828 mol H⁺/ha/rok byl ovlivněn zejména omezením emisí NH₃ v oblastech s intenzivní zemědělskou činností (severní a východní část České republiky). Pokles průměrné roční hodnoty celkové potenciální kyselé depozice mezi roky 1991 a 2000 z 4 147 mol H⁺/ha/rok na 2 185 mol H⁺/ha/rok byl ovlivněn především poklesem emisí SO₂.

V České republice byly mezi roky 1990 a 2000 sníženy emise SO₂ o 86 %, emise NO_x o 46 % a emise NH₃ o 52 %. Emise oxidu siřičitého a amoniaku byly v roce 2000 sníženy pod úroveň emisních stropů pro rok 2010. Emisní strop pro oxidy dusíku byl v roce 2000 překročen.

Celková depozice dusíku (NO_y + NH_x) překračovala kritické zátěže nutričního dusíku v roce 1994 na celé ploše lesních ekosystémů, v roce 2000 na 99 % plochy lesních ekosystémů. Průměrná hodnota překročení kritických zátěží nutričního dusíku celkovou depozicí dusíku na území lesních ekosystémů České republiky v síti 1 × 1 km byla v roce 1994 odhadnuta na 1 213 mol H⁺/ha/rok (17 kg N/ha/rok) a v roce 2000 na 858 mol H⁺/ha/rok (12 kg N/ha/rok). Celková potenciální kyselá depozice překračovala kritické zátěže síry a dusíku (acidity) v roce 1994 na 98 % plochy lesních ekosystémů, v roce 2000 na 93 % plochy lesních ekosystémů. Průměrná hodnota překročení kritické zátěže síry a dusíku (acidity) celkovou potenciální kyselou depozicí na území lesních ekosystémů České republiky v síti 1 × 1 km byla v roce 1994 odhadnuta na 1 731 mol H⁺/ha/rok a v roce 2000 na 733 mol H⁺/ha/rok.

Největší překročení kritických zátěží dusíku a acidity bylo v roce 1991 lokalizováno v severozápadní části České republiky, zatímco v roce 2000 ve střední části České republiky. Snížení hodnot celkové depozice dusíku (NO_y + NH_x) o 60 % k roku 2000 by chránilo 55 % území lesů. Snížení hodnot celkové depozice síry a dusíku (potenciální kyselá depozice) o 60 % k roku 2000 by chránilo 98 % území lesů.

Corresponding author:

Doc. Ing. MILOŠ ZAPLETAL, Dr., Centrum pro životní prostředí a hodnocení krajiny – Ekotoxa Opava,
Horní náměstí 2, 746 01 Opava, Česká republika
tel.: + 420 553 696 132, fax: + 420 553 628 512, e-mail: milos.zapletal@ekotoxa.cz
