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Deposition monitoring at 5 sites in The Netherlands in 2005

An overview of 10 years of measurements

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Preface

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Abstract

During one year, throughfall was measured in five Level II forest sites in the Netherlands as part of the Pan-European monitoring programme for the Intensive Monitoring of Forest Ecosystems. The data for the monitoring year 2005 are reported and a canopy exchange model was applied to estimate the atmospheric deposition to these sites. Next to information for 2005, also an overview of the results for the period 1995-2005 is given. For this overview a link is made between the monitoring results and changes in emissions, resulting from different national and international policy efforts.

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Summary

The Pan-European Programme for the Intensive Monitoring of Forest Ecosystems is the so-called Level II Programme of the International Co-operative Programme on Assessments and Monitoring of Air Pollution Effects on Forests (ICP Forests of UN/ECE). It provides the framework in which analysis of the effects of atmospheric loads and its temporal variation is investigated. The current monitoring programme of ICP Forest at the Level II plots in the Netherlands includes deposition measurements at five sites. Throughfall is measured by the Energy Research Centre of the Netherlands at Dwingelo, Hardenberg, Speuld, Zeist and Leende. Bulk deposition is measured close to the Hardenberg and Leende site. For the other three sites, bulk deposition data are obtained from the National Air Quality Monitoring Network by the National Institute of Public Health and the Environment.

This report describes the measurements performed in 2005 and the results of the quality checks performed on the data. The total nitrogen deposition in 2005 varied between 1430 and 2560 $mol.ha^{-1}.y^{-1}$. Lowest nitrogen deposition is measured at Zeist, the other sites showing more or less the same input. Potential acid deposition is highest at Speuld and amounts to 3750 $mol.ha^{-1}.y^{-1}$. The other sites show inputs of about 3000 $mol.ha^{-1}.y^{-1}$, except Zeist receiving about 2300 $mol.ha^{-1}.y^{-1}$.

In general the sites show a further (although small) decrease in deposition, after a small increase in 2003. The only exception being the deposition of reduced nitrogen at Hardenberg and Zeist, which shows a very varying pattern. However, overall there is a decreasing trend for all components when considering the whole period of 1995-2005. Comparison of the trend of the emission of Dutch sources and the total deposition shows a difference between these two trends in time, possibly caused by the influence of foreign sources, uncertainties in the reported emissions and/or changing chemistry.

1. Introduction

The Pan-European Programme for the Intensive Monitoring of Forest Ecosystems is the so-called Level II Programme of the International Co-operative Programme on Assessments and Monitoring of Air Pollution Effects on Forests (ICP Forests of UN/ECE). It provides the framework in which analysis of the effects of atmospheric loads and its temporal variation is investigated. The current monitoring programme of ICP Forest at the so-called 'Intensive Monitoring' (Level II) plots in the Netherlands includes the yearly assessment of the forest condition, foliar composition and the soil solution since 1992 at 14 sites (12 before 1995) and the five-yearly assessment of a large number of more slowly changing parameters. The chemical composition of the groundwater has been measured three-monthly at the initial 12 sites during all years. In 1990 a national survey of the chemical composition of needles, litter, soil and soil solution was also conducted for 150 stands (De Vries and Leeters, 1996), which has been repeated in 1995 for 200 stands, including the 14 intensive monitoring plots.

EC-LNV co-ordinates the Dutch contribution to ICP Forest. ECN performed throughfall measurements at 5 Level II plots in the Netherlands between January 2005 and December 2005, using the method recommended by Draaijers et al., (1996). The research was financed by the EC through EC-LNV and by the Ministry of Housing, Physical Planning and the Environment (VROM).

This report gives an overview of the results for the 5 plots in 2005. The results for 2003 and 2004 are described in Bleeker et al. (2004a,b). This report first gives a description of the sites and the measurement methods. The results of the measurements are described in Chapter 3. In Chapter 4 an overview of 10 years of measurements 1995-2005 is given. The observed trends in deposition are linked to changes in emissions, in order to investigate the success of national and international policy efforts on reducing the emissions of acidifying and eutrophying compounds. The report ends with short conclusions.

2. Experimental

The current monitoring programme of ICP Forest at the Level II plots in the Netherlands includes the yearly assessment of the forest condition, foliar composition and the soil solution since 1992 at 14 sites. At these sites, throughfall gutters were installed in 1995 and for one year data were collected (Erisman *et al*., 1997). In October 1997 the measurements were continued at four of the 14 sites. Since March 2003 throughfall measurements were also started at a fifth site. The sites, stand characteristics, the coordinates and the dominant tree species are given in Table 2.1. Figure 2.1 shows the location of the sites in a map of the Netherlands. The plots are located in the main forested areas in the country: in Overijssel (2), the Utrechtse Heuvelrug (4), the Veluwe (3), Drenthe (1) and Brabant (5).

Table 2.1 *Sites, stand characteristics and their co-ordinates*

No.	Plot	Locatie	Lon	Lat	Species	Distance to forest edge (m)	Tree height (m)	Crown coverage (%)	Bulk deposition site
1	2085	Dwingelo	06° 26' 45"	52° 50' 20"	Scots pine	>100	>20	>75	928 Witteveen
2	106	Hardenberg-DG	06° 33' 00"	52° 32' 42"	Douglas fir	>100	>20	50-75	Rheezerveen
3	2084	Speuld-DG	05° 44' 17"	52° 16' 03"	Douglas fir	>100	30-35	>75	732 Speulder Veld
4	1040	Zeist-EI	05° 13' 50"	52° 06' 32"	Oak	20-40	20-25	50-75	628 Bilthoven
5	175	Leende	05° 31' 04"	51° 19' 19"	Scots pine	20-40	20-25	50-75	Leende

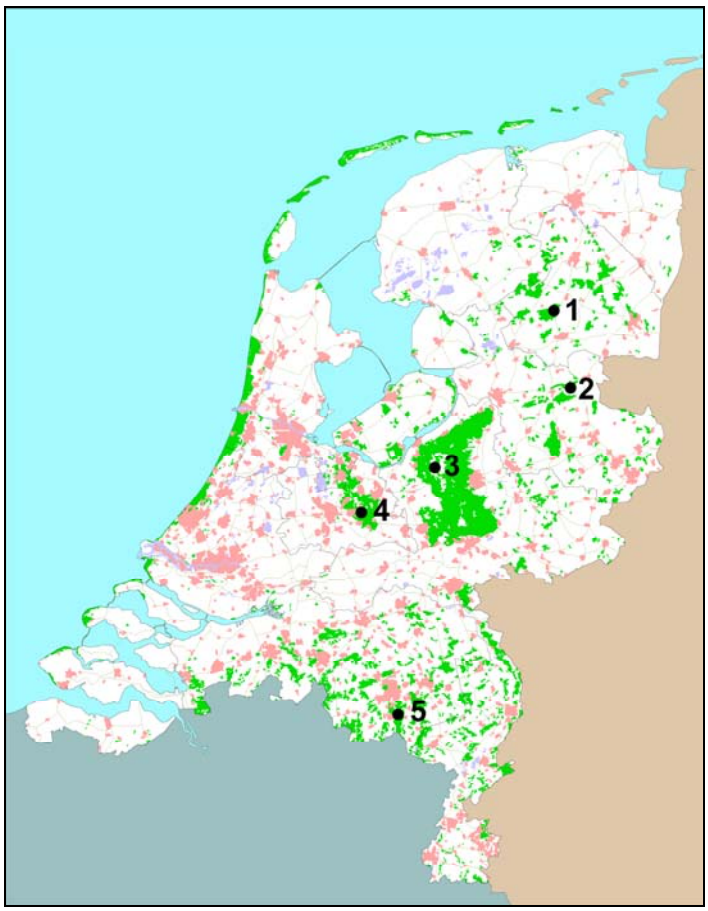


Figure 2.1 *Location of the throughfall monitoring sites*

2.1 Sampling and analysis

The sampling was performed according to the descriptions in the Submanual on deposition on ICP Forests Level 2 plots (ICP Forest Expert Panel on Deposition, 1994, updated 06/1999) and data was handled according to the *Basic documents for the implementation of the intensive monitoring programme of forest ecosystems in Europe* (EC, VI/3908/95-EN). An extensive description of the methods is given in Part VI of the ICP-Forests Manual (ICP, 2004). Bulk deposition (open field) measurements were only performed at the plots Hardenberg (106) and Leende (175). For all other locations, bulk precipitation was obtained from wet-only measurements performed by RIVM at the sites indicated in Table 2.1. The data from the Air Quality Monitoring Network were kindly being made available by RIVM (RIVM, 1999; 2000). Open field precipitation is measured as two-weekly averages, which were combined in the lab to obtain monthly samples.

At each plot, 10 gutters are used. These gutters are placed in two parallel lines of 5 gutters, each at distances of 1-2 m. The gutters are 5 m long and have a collecting area of about 400 cm^2. They are placed with an angle of 15^o, with a maximum height of about 1.5 m above the surface. Sample bottles are placed below the surface. Sample bottles were collected two-weekly and the gutters were rinsed with demi-water. After sampling the samples were kept in the dark at a temperature of 4 ^oC. Five individual samples per sampling period were pooled into one sample, resulting in two pooled samples per sampling period. The two-weekly pooled samples were then combined in the lab to obtain monthly samples.

In the lab, the monthly sample was split; one half was acidified with HNO_3 to pH 1 for analyses of metals. These were determined by atomic absorption spectroscopy (ICP-AES). Ions determined were: K, Ca, Mg, Na, Al, Mn and Fe. The other sample was used to determine conductivity, pH (potentiometric), Cl, NO_3, SO_4 by ionic chromatography, N_{total} by Kjeldahl analysis and NH_4 by Flow Injection Analysis, FIA/conductivity. Before delivering the data, data checks were performed, as described in de Vries *et al.*, (1999) and outlined in the next paragraph.

2.2 Quality checks

Several criteria were met to safeguard the quality and to estimate the uncertainty. First of all the measurement set-up, conservation and handling of samples was done according to the recommendations in Draaijers *et al.*, (1996) and the ICP-Forests Manual (ICP-Forests, 2004). Gutters were used instead of open samplers. The number of gutters was 10. Secondly, sample analysis was performed according to and with methods certified by STERLAB. Finally, samples were collected and stored in light-tight bottles at low temperatures. $CHCl_3$ was added as a preservative to prevent biological conversion. Additional quality checks can be done after sampling and are described in Erisman *et al*. (2001).

3. Results

In this chapter, the results of the monitoring of throughfall and bulk precipitation at the five sites are given. First, the results of the quality checks are discussed after which the results of the year 2005 are given.

3.1 Quality checks

The quality checks were done as previously reported by Erisman *et al.* (2001). About 10% of the data show discrepancies from the acceptable ranges in ionic balances, conductivity and/or Na-Cl ratio. Errors could be identified based on the interpretation of the three criteria and in few cases they were corrected for. Examples of errors that were encountered were dilution factor not taken into account and missing values. Samples were reanalysed or, if no explanation could be found, only one of the duplo samples was taken into account. The corrected data are shown in Figure 3.1 to Figure 3.3. These figures show the comparison of the cations versus the anions (Figure 3.1), the measured versus the calculated conductivity (Figure 3.2) and the Na-Cl ratio versus the deviation of the ionic balance (Figure 3.3).

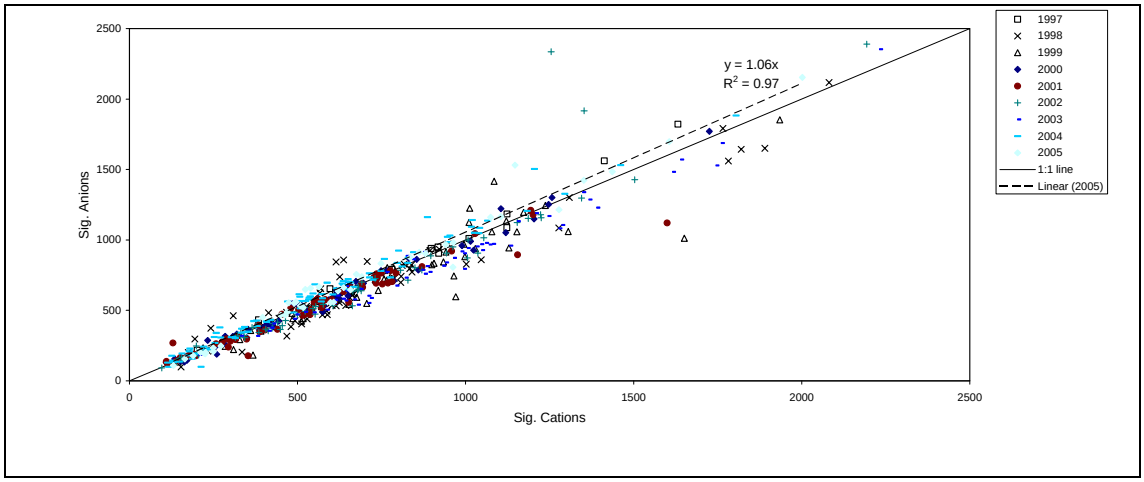


Figure 3.1 *Cations versus the anions for monthly samples for the period 1997-2005 (meq.m^{-3})*

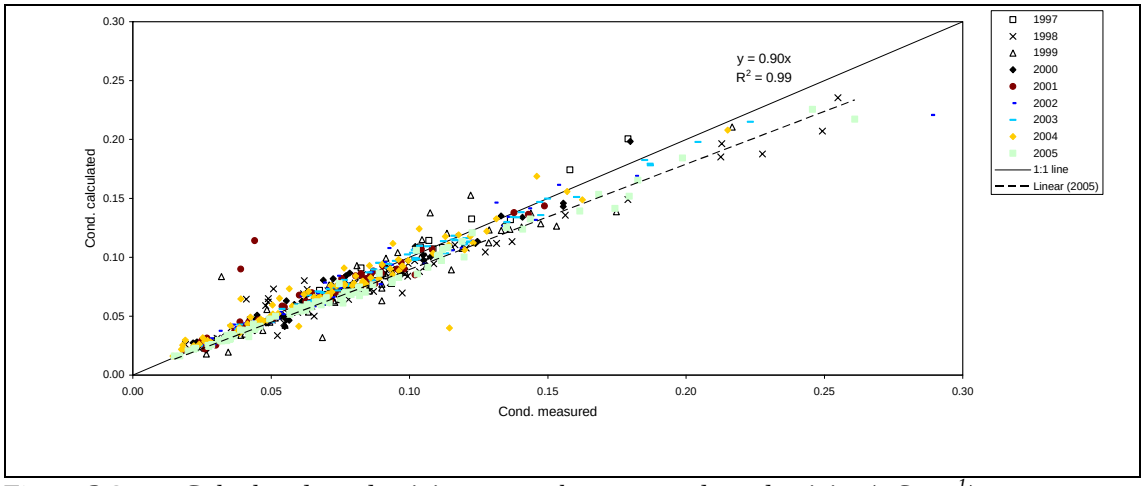


Figure 3.2 *Calculated conductivity versus the measured conductivity (mS.cm^{-1})*

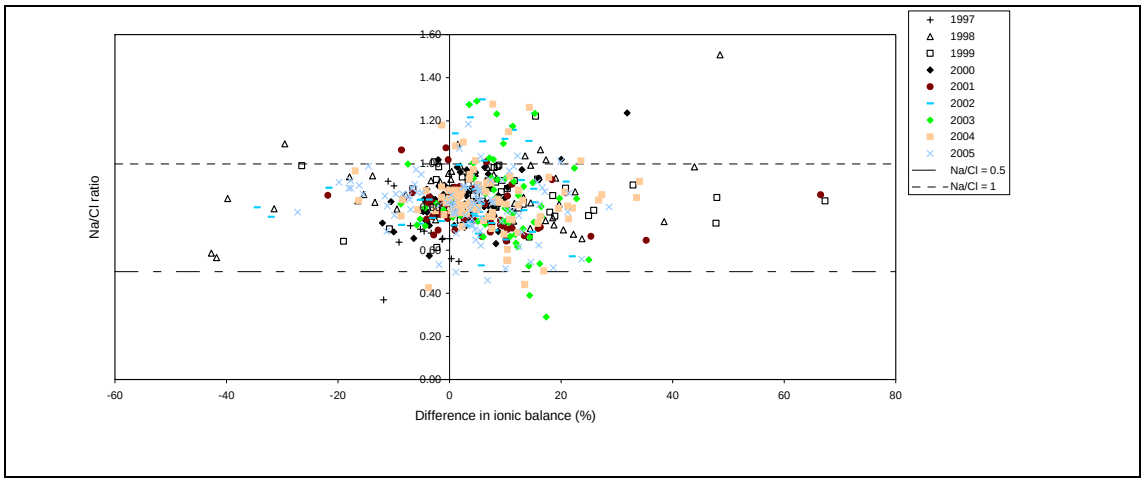


Figure 3.3 *Molar Na-Cl concentration ratio versus the deviation of the ion balance (%)*

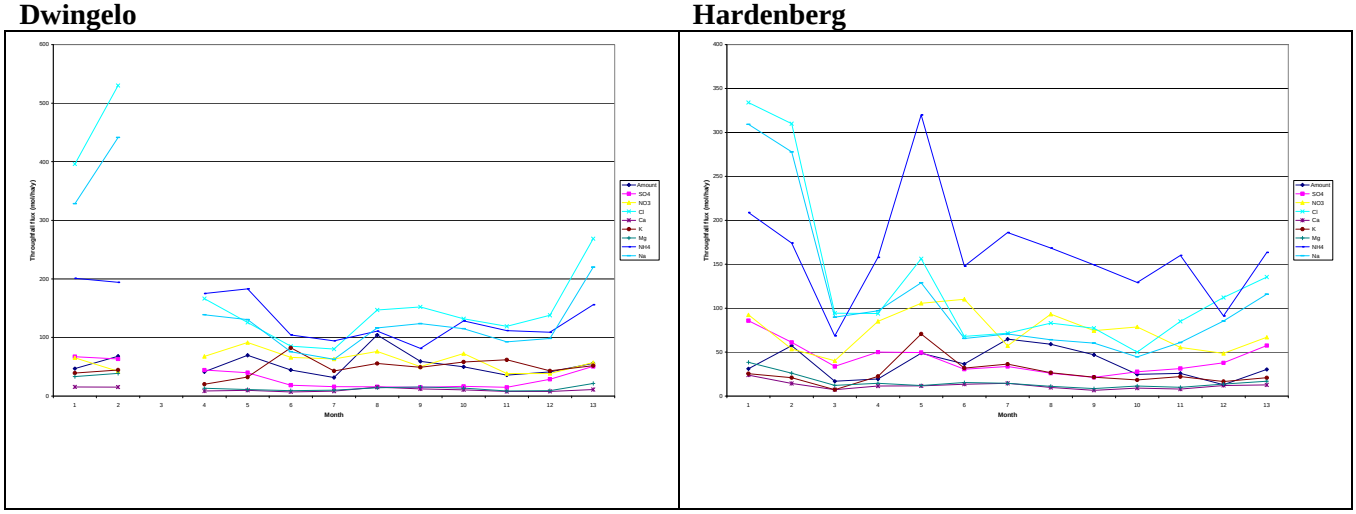
As can be seen from the figures, most of the data fall within the acceptable ranges (Erisman *et al*., 2001). However, several data are rejected when using the FIMCI software to evaluate the data using the above described data checks, especially related to the conductivity test. It is suspected that the FIMCI software uses more stringent criteria for rejecting data then listed in de Vries *et al*. (1999). Organic compounds might also cause the data to be outside the limits.

Annual fluxes were calculated by averaging the concentrations for those periods, which fulfilled either the ion-balance or conductivity criteria, or both. These concentrations were multiplied by the total amount of throughfall or precipitation over the whole year, including also the rejected periods.

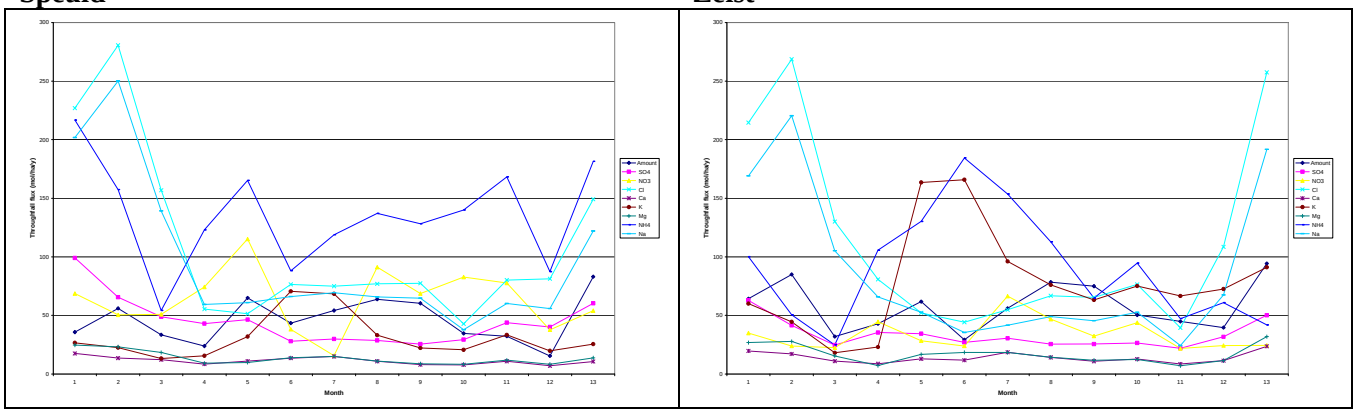
3.2 Temporal variations in throughfall fluxes

The temporal variation as monthly averages in throughfall fluxes of K^+, Ca^{2+}, Mg^{2+}, Na^+, NH_4^+, Cl^-, NO_3^- and SO_4^{2-} is plotted in Figure 3.4 for the five sites. Generally, the throughfall fluxes display the same pattern for all components, except for sodium and chloride. The temporal variation is primarily determined by the amount of precipitation for each month, while for chloride and sodium the occurrence of storm events largely determines the variation. Fluxes are low when the amount of precipitation is low. All sites show distinct peaks during the autumn and winter period for sodium and chloride. July was very dry, resulting in very low fluxes for that month.

Dwingelo **Hardenberg**



Speuld **Zeist**



Leende

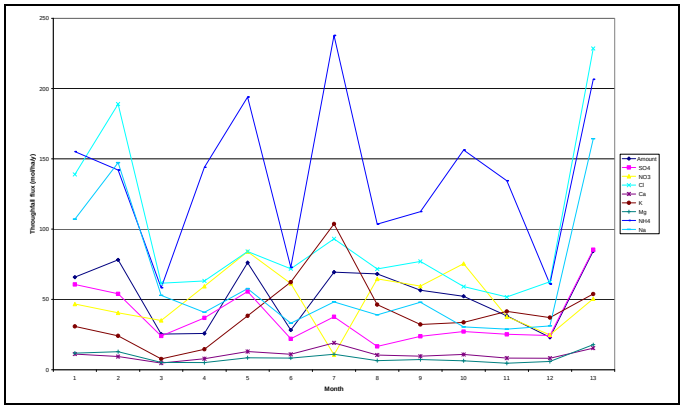


Figure 3.4 *Temporal variations in throughfall fluxes (mol.ha^{-1}.y^{-1}) and amount of throughfall (mm) in 2005*

3.3 Annual average throughfall fluxes in 2005

The fluxes of throughfall and open field precipitation were calculated by multiplying the concentration with the amount of water and make the necessary conversions to express the flux in mol.ha^{-1}.y^{-1}. Table 3.1 gives the fluxes for the year 2005. Annual average fluxes were calculated as the sum of monthly fluxes. The open field bulk measurements were corrected for the dry deposition contribution to the bulk precipitation. For this correction average factors (ratio between wet-only deposition and bulk precipitation fluxes) were taken from Van Leeuwen

et al. (1995). The total nitrogen flux is calculated as the sum of nitrate and ammonium fluxes, whereas the potential acid flux is estimated according to:

$$Potential\ acid = NH_4^+ + NO_3^- + 2\ SO_4^{2-} \quad [9]$$

Table 3.1 *Annual throughfall fluxes measured at the five sites and open field (of) precipitation measured at Hardenberg and Leende in 2005 in mol.ha^{-1}.y^{-1}*

site:	NH_4	Na	Mg	K	Ca	Cl	NO_3	SO_4	Tot N	Pot. Acid
Dwingelo	1692	2011	206	587	133	2420	755	408	2447	3264
Hardenberg	2124	1470	204	341	154	1670	961	546	3085	4177
Speuld	1766	1253	176	403	146	1431	825	589	2591	3768
Zeist	1171	1121	219	1016	181	1459	438	437	1610	2485
Leende	1778	829	111	526	139	1252	650	493	2428	3414
of-Hardenberg	346	233	34	36	25	277	342	88	688	864
of-Leende	708	218	33	70	38	251	412	152	1120	1424

Throughfall fluxes of total nitrogen are lowest at Zeist, a plot relatively far away from livestock breeding areas. The northern sites and Speuld show approximately the same nitrogen loading of appr. 35 kg N.ha^{-1}, with highest values at Hardenberg of appr. 43 kg N.ha^{-1}. The potential acid fluxes are highest in Hardenberg (4180 mol.ha^{-1}.y^{-1}) and lowest in Zeist (2490 mol.ha^{-1}.y^{-1}).

4. Deposition estimates

Deposition estimates can be made by using a canopy exchange model. Such a model is described in the Erisman *et al*. (2001). The sections below describe the results of the model followed by a description of deposition trends at the different plots.

4.1 Dry, wet and total deposition estimates

Dry deposition fluxes in 2005 calculated with this model, together with the wet deposition data measured by RIVM (RIVM, 1999) and the total deposition, are given in Table 4.1. Dry deposition is generally an order of magnitude higher than wet deposition and determines about 70% of the total deposition flux for NH_4, SO_4 and NO_3. The total nitrogen deposition varies between 1430 and 2560 mol.ha^{-1}.y^{-1}, with the lowest nitrogen deposition at Zeist and the other sites showing more or less the same input. Potential acid deposition is highest at Speuld and amounts to 3750 mol.ha^{-1}.y^{-1}. The other sites show inputs of about 3000 mol.ha^{-1}.y^{-1}, except Zeist receiving about 2300 mol.ha^{-1}.y^{-1}.

Table 4.1 *Deposition estimates per plot in 2005 in mol.ha^{-1}.y^{-1}.*

Location	Dry deposition			Wet deposition			Total deposition			Total Nitrogen	Potential Acid
	NH_4	SO_4	NO_3	NH_4	SO_4	NO_3	NH_4	SO_4	NO_3		
Dwingelo	810	260	460	520	140	290	1330	410	750	2080	2900
Hardenberg	830	460	620	350	90	340	1180	550	960	2140	3240
Speuld	1180	430	540	550	160	290	1730	590	830	2560	3740
Zeist	410	220	100	580	210	340	990	440	440	1430	2310
Leende	910	340	240	710	150	410	1620	490	650	2270	3250

4.2 Trends in deposition

Throughfall and open field precipitation has been measured at the four sites in 1995-1996, 1998, 1999, 2000, 2002-2005. From these data, the temporal variation can be determined. Figure 4.1 to Figure 4.4 show the temporal variation in deposition estimates for four of the sites as derived from throughfall measurements and bulk deposition data after application of the canopy exchange model. For Leende, only a few years of measurements are available, therefore no real temporal variation can be given here yet. Overall the other four sites show a further (although small) decrease in deposition, after a small increase in 2003. The only exception being the deposition of reduced nitrogen at Hardenberg and Zeist, which shows a very varying pattern for these two sites. However, overall there is a decreasing trend for all components when considering the whole period of 1995-2005.

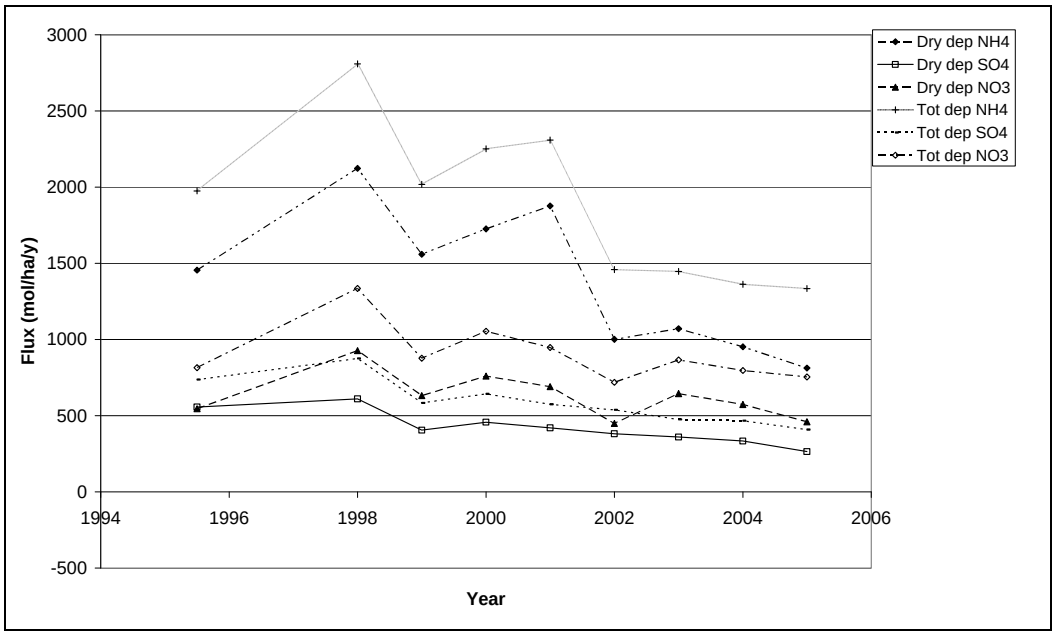


Figure 4.1 *Temporal variation in deposition measured at Dwingelo*

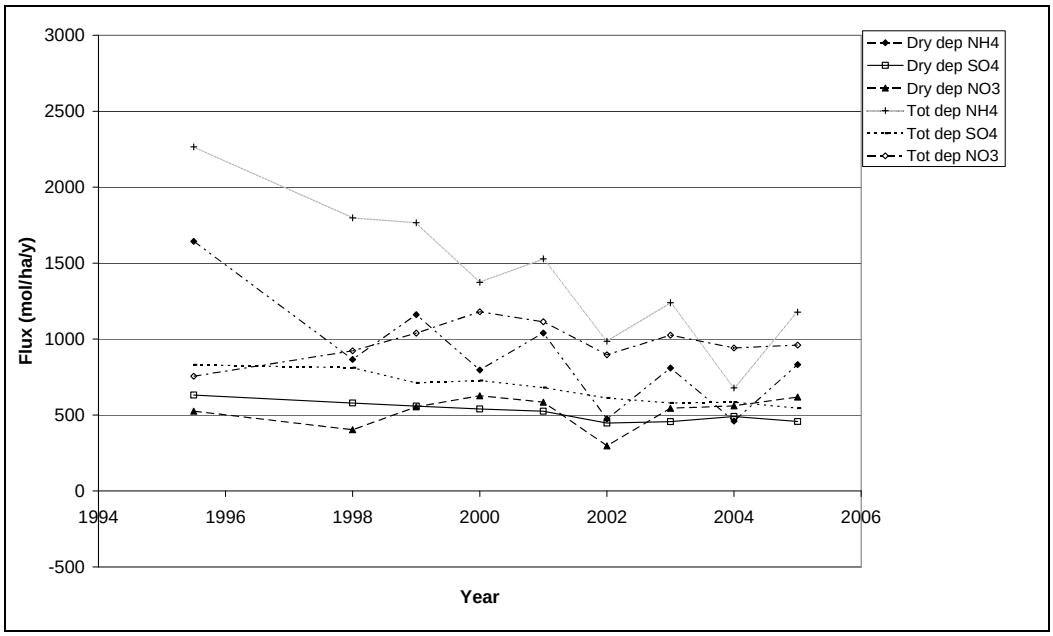


Figure 4.2 *Temporal variation in deposition measured at Hardenberg*

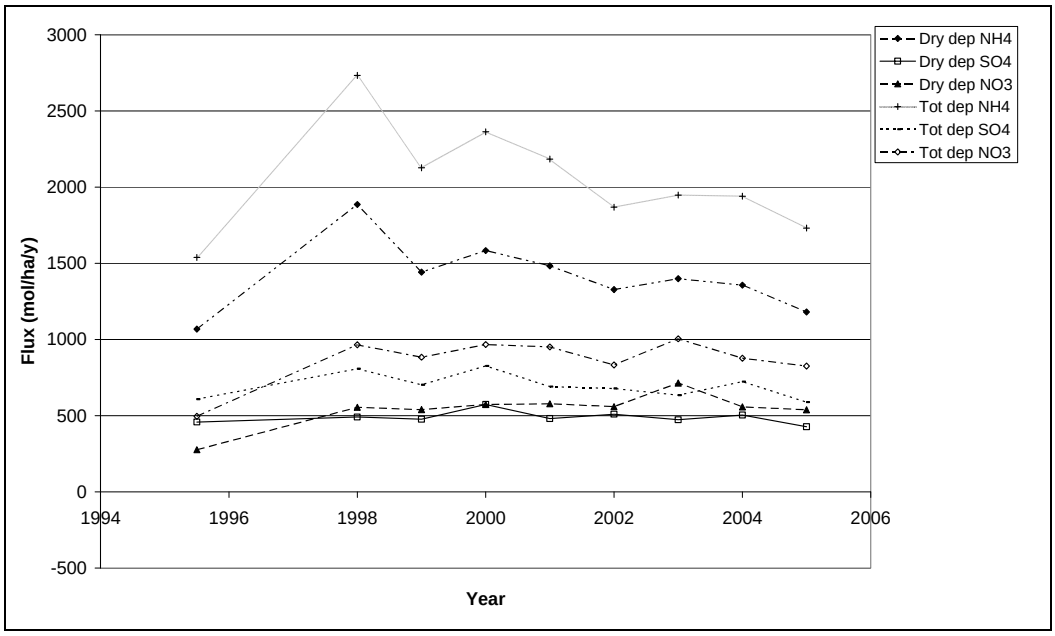


Figure 4.3 *Temporal variation in deposition measured at Speuld*

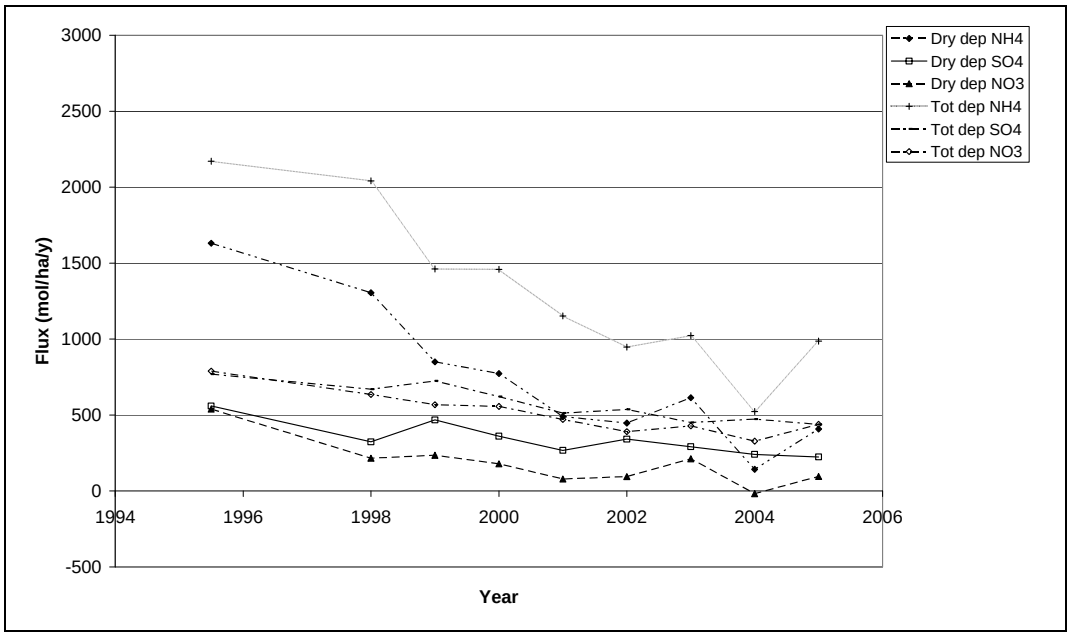


Figure 4.4 *Temporal variation in deposition measured at Zeist*

5. Evaluation of emission trends

Based on the information presented in the previous chapter, a comparison was made between the measured depositions and the Dutch reported emissions. This is done to investigate the effectiveness of Dutch policy on emission reductions. On forehand it must be noted that this investigation may be hampered by the fact that the Dutch depositions are not only originating from Dutch sources, but for about 60% by sources located in other European countries.

Figure 5.1 shows the trend in reported emissions for the period 1990-2005 for respectively SO_2, NO_x and NH_3 (Emission Registration, 2007). These trends show a gradual decrease over the years for all three components. Figure 5.2 shows the trend of the average deposition for the period 1995-2005. Two years of data seem to be missing; in fact it is 1.5 years, since no measurements were done between mid 2006 and end 2007. The 2005 values represent the period from mid 2005 to mid 2006. The variation over the 5 measuring locations is shown in the figure by means of the error bars. Looking at the width of the different error bars, it is clear that NH_x shows the largest variation in deposition over the different measuring locations. NO_y shows the smallest difference for these measuring locations, showing that only a small gradient over the different sites exists.

For NH_x decrease of the deposition after 1998 is very distinct, both in the average values and in the minimum and maximum values. Since NH_x largely originates from Dutch sources, a more direct link between Dutch policy on emission reduction and these depositions can be made. For NO_y and SO_x a similar pattern as for NH_x occurs, although this is less pronounced than for NH_x. A direct link with the Dutch emission reductions is more difficult, since about 60-75% of the deposition originates from foreign emissions.

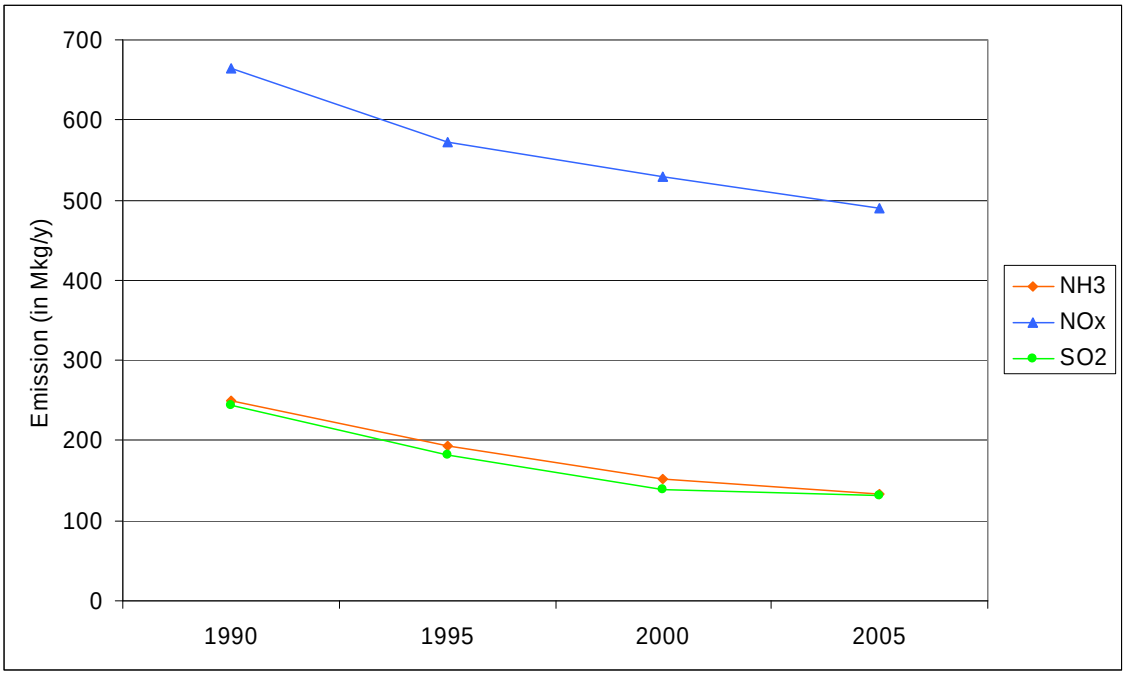


Figure 5.1 *Reported emissions for SO_2, NO_x and NH_3 for the period 1990-2005*

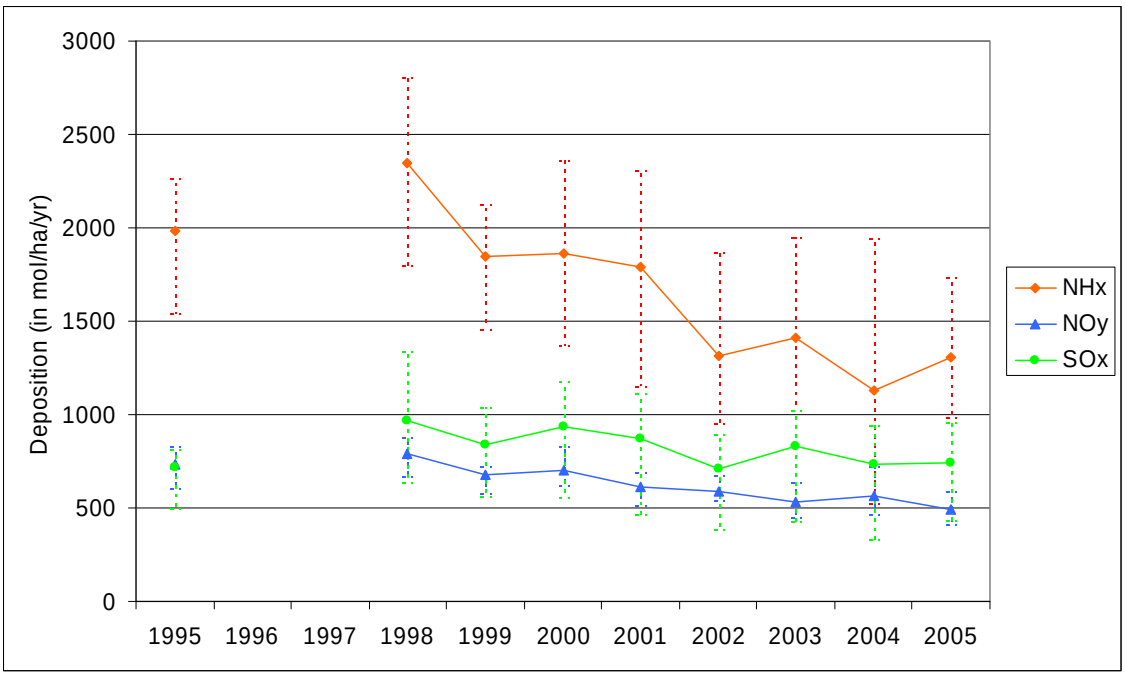


Figure 5.2 *Trend in average deposition of NH_x, NO_y and SO_x for the period 1995-2005. Error bars represent the deposition variation over the different locations*

The comparison between Dutch reported emission data and measured depositions is shown in Figure 5.3. The presented values are relative to the 1995 values. In general the overall trends shown in Figure 5.1 and Figure 5.2 are also visible here. From Figure 5.3 it becomes more clear that there is a difference in the trends. While the emissions decrease from 1995 to 2005, the deposition first increases and then decreases in the last five years. This difference in trends can be caused by e.g.:

- influence of foreign sources (different 'speed' of emissions reductions)
- reported emissions not representing the actual emissions
- shift in chemistry, causing non-linear behaviour

A more extensive comparison is needed, including large scale deposition modelling, to further investigate the different trends for emissions and depositions. However, in general it can be stated that the deposition of NO_y and NH_x is in line with the emission trend. For SO_x the trends are not similar: a continuous decrease in emissions is not reflected in the depositions - deposition values in 2005 are about the same as in 1995.

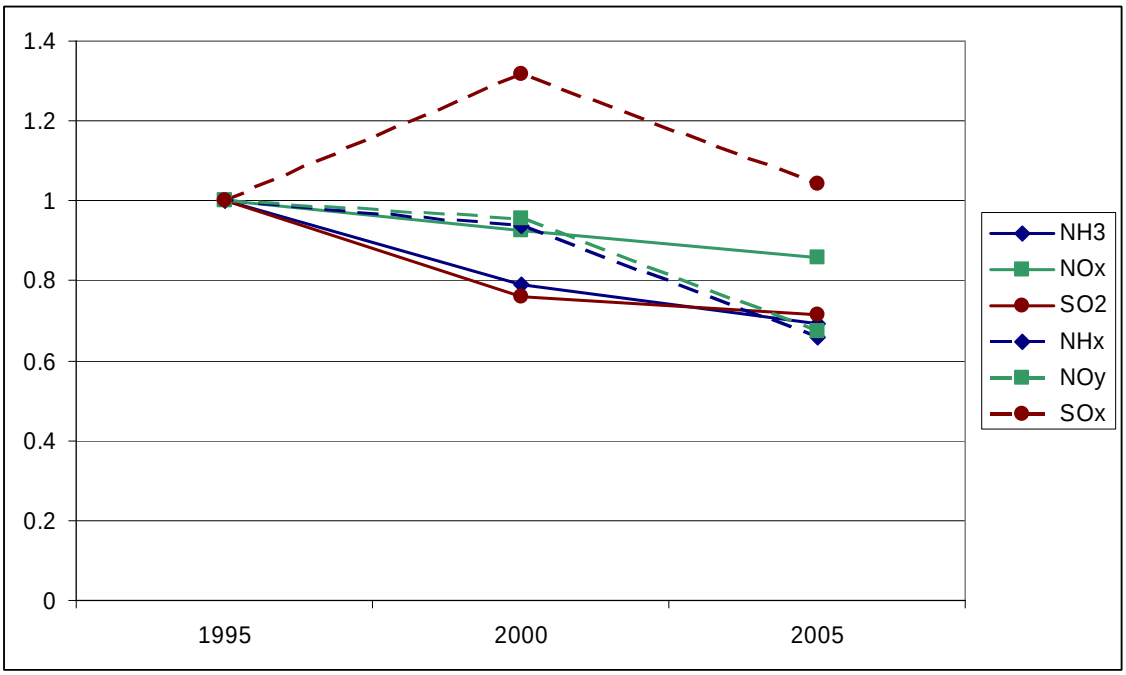


Figure 5.3 *Trends in emissions (NH_3, NO_x and SO_2) and deposition (NH_x, NO_y and SO_x) for the period 1995-2005 (relative to 1995 values)*

6. Conclusions

During one year (between January and December 2005), throughfall measurements were performed at 5 ICP Level-II plots in the Netherlands. The measurements were performed with 10 gutters per plot, sample bottles were stored in light protected bottles at low temperatures, all to assure high quality results. Most of the fluxes could be used to estimate atmospheric deposition after the application of several quality checks. For the estimation of atmospheric deposition, a canopy exchange model was applied and dry and wet deposition fluxes were calculated.

Throughfall fluxes of total nitrogen are lowest at Zeist, a plot relatively far away from livestock breeding areas. The northern sites and Speuld show approximately the same nitrogen loading of appr. 35 kg $N.ha^{-1}$, with highest values at Hardenberg of appr. 43 kg $N.ha^{-1}$. The potential acid fluxes are highest in Hardenberg (4180 $mol.ha^{-1}.y^{-1}$) and lowest in Zeist (2490 $mol.ha^{-1}.y^{-1}$).

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In general the sites show a further (although small) decrease in deposition, after a small increase in 2003. The only exception being the deposition of reduced nitrogen at Hardenberg and Zeist, which shows a very varying pattern. However, overall there is a decreasing trend for all components when considering the whole period of 1995-2005.

Comparison of the trend of the emission of Dutch sources and the total deposition shows a difference between these two trends in time, possibly caused by the influence of foreign sources, uncertainties in the reported emissions and/or changing chemistry. Further evaluations are needed to quantify the different influences on the overall trends.

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