CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION
INTERNATIONAL CO-OPERATIVE PROGRAMME ON ASSESSMENT AND MONITORING
OF AIR POLLUTION EFFECTS ON FORESTS
and
EUROPEAN UNION SCHEME
ON THE PROTECTION OF FORESTS AGAINST ATMOSPHERIC POLLUTION

United Nations Economic Commission for Europe	European Commission

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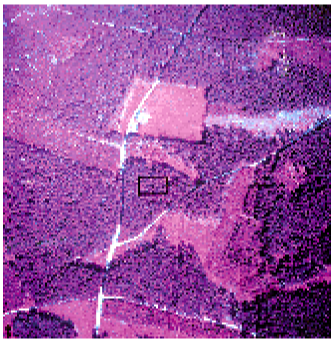
Intensive Monitoring of Forest Ecosystems in Europe

Technical Report 2000



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FIMCI Forest Intensive Monitoring Coordinating Institute

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FIMCI
Forest Intensive Monitoring
Coordinating Institute

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Abstract

EC - UN/ECE, 2000; De Vries, W., G.J. Reinds, M.S. van Kerkvoorde, C.M.A. Hendriks, E.E.J.M. Leeters, C.P. Gross, J.C.H. Voogd, E.M. Vel. *Intensive Monitoring of Forest Ecosystems in Europe, 2000 Technical Report.* EC, UN/ECE 2000, Brussels, Geneva, 191 pp.

Apart from an overview of the implementation of the Intensive Monitoring Programme of forest ecosystems in Europe and the various methodological aspects involved in data evaluation, this Technical Report gives information on results obtained in surveys on crown condition, soil condition, foliar condition, atmospheric deposition and soil solution chemistry. It also includes examples from results related to remote sensing. The major aim of this year's report was to gain insight in element concentrations in view of critical chemical values and in relationships between results from the various surveys and environmental factors, in comparison to previously obtained results. Examples of aerial photography show that this technique can successfully be used to gain information on the representativity of stand characteristics, such as crown condition, stand height and stand structure, within the plot in comparison to the area surrounding the plot including time series of those characteristics. Major conclusions for the different surveys are:

- Both bulk and total deposition of N appeared to be higher than S deposition at nearly all the plots in 1997 and the average calculated total N deposition was approximately twice the S deposition. Atmospheric deposition was significantly influenced by the geographic region and to a lesser extent by rainfall, altitude and tree species.
- Stand age alone explained 5-36% of the variation in crown condition, depending on tree species. Apart from stand age, 15-30% of the variation in defoliation could be explained by the variation in precipitation, temperature, N and S deposition and foliar chemistry.
- At approximately 30% of the stands, the nutrient status of the foliage can be judged as insufficient and unbalanced for at least one nutrient. Atmospheric deposition, meteorological parameters, soil chemistry, and site characteristics all contributed to the explanation of foliar nutrient concentrations. The percentage variation accounted for generally decreased going from N> Mg> S> Ca> K> P. The foliar N and S concentrations of the coniferous species, especially pine, were significantly related to the N and S deposition.
- Nitrogen pools in the organic layer of forest soils varied mostly between 100 and 250 $kg.ha^{-1}.yr^{-1}$. Considering the net N input by deposition, a time interval of 10 years might give a significant difference in N pools for approximately 25% of the plots. Approximately 30-50% of the variation in element pools in the organic layer was mostly explained for by various stand and site characteristics, precipitation, temperature and pH.
- Concentrations of NO_3 and ratios of Al to Ca+Mg+K, above levels that are indicative for adverse effects, occurred in the subsoil at some 10 – 40% of all plots, respectively. Those plots were mainly located in a transect from Finland to Spain. The variation in concentrations of major ions in the soil solution could to a large extent be explained by differences in atmospheric deposition and to a lesser extent by variations in precipitation and soil chemistry.

Keywords: Intensive monitoring, data management, forest, crown condition, increment, meteorological stress, atmospheric deposition, soil solution chemistry

Contents

Preface

The Pan-European Programme for Intensive and Continuous Monitoring of Forest Ecosystems has been implemented to gain a better understanding of the effects of air pollution and other stress factors on forests. At present 864 permanent observation plots for Intensive Monitoring of forest ecosystems have been selected (513 in the European Union and 351 in several non-EU countries).

The Pan-European Programme is based on both, the European Scheme on the Protection of Forests against Atmospheric Pollution (Council Regulation (EEC) No 3528/86) and the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) under the Convention of Long-Range Transboundary Air Pollution (UN/ECE). The Intensive Monitoring Programme aims at the assessment of crown condition, increment and the chemical composition of foliage and soil on all plots over a period of at least 15 to 20 years. Additional measurements on selected plots include atmospheric deposition, meteorological parameters, soil solution chemistry and ground vegetation. In all these surveys, a number of mandatory and optional parameters has been defined. Data are submitted to the Forest Intensive Monitoring Co-ordinating Institute (FIMCI), being a contractor of the European Commission (EC) that has been set up to validate, store, distribute and evaluate the data at European level. Within FIMCI, Alterra Green World Research (formerly SC-DLO) and Oranjewoud International work together. Apart from the data management, FIMCI also acts as an information centre for National Focal Centres (NFC's), including both EU-Member States and the other participating countries of ICP-Forests.

By the end of 1996 the results of the four core surveys on the Intensive Monitoring plots (crown condition, soil, foliage, forest growth) and of atmospheric deposition with data from 1995 (or earlier) were for the first time submitted to FIMCI. In 1997 these data and the data accompanying reports were validated and the first evaluations were presented in the second Technical Report of 1998. By the end of 1997, the NFC's submitted data for the second time, including first information on soil solution and meteorology. These data were validated in 1998 and presented in the third Technical Report. That report includes the results of the annual surveys (crown condition, deposition, meteo and soil solution) for 1996 and a further evaluation of the forest growth data of 1995 and 1996. This years report includes results from all surveys, except forest growth and ground vegetation. The results are related to the year 1997 in case of foliage, atmospheric deposition, meteorology and soil solution. For crown condition and soil, it refers to average data until 1997. The report also includes information on Remote Sensing results at a limited number of plots.

The target groups of this report are the active participants of the Intensive Monitoring Programme (National Focal Centres, National Involved Research Institutes, Scientific Advisory Group, the Expert Panel Members, the Standing Forestry Committee of the European Union and ICP Forests) and the Scientific Community. The preparation of this report was possible thanks to the submission of data and information by the NFC's to FIMCI and the active participation and co-operation of the members and deputy members of the Scientific Advisory Group. We also thank Dr. M. Bierkens for his statistical support.

Extended Summary

The monitoring programme

The Pan-European Intensive Monitoring Programme of Forest Ecosystems was started in 1994. The general aim of the Intensive Monitoring Programme is to contribute to a better understanding of the impact of air pollution and other factors on forest ecosystems. At present, the programme covers 864 plots in 30 participating countries (513 plots in the EU and 351 plots in non-EU countries). Due to its non-systematic character the intensive monitoring data set is not representative for Europe in the statistical sense, but it does give information on stress and effects on a European-wide scale.

Some surveys are carried out on all plots (crown condition, soil chemistry, foliage and forest growth). At part of those plots, assessments of atmospheric deposition (494 plots), meteorology (188 plots), soil solution chemistry (252 plots), ground vegetation (637 plots) and remote sensing (approximately 150 plots) are carried out. In total 784 Intensive Monitoring plots have been installed. For most of the plots (around 85%) information on the methods applied has been received, validated and stored. The results presented in this report include validated and stored data: (i) up to 1997 with respect to crown condition (754 plots) and soil (604 plots), (ii) for the latest assessment with respect to foliar composition (701plots) and (iii) for the year 1997 with respect to atmospheric deposition (465 plots) and soil solution (192 plots).

Objectives

The major aim of this year's report is to gain more insight in the relationship between crown condition, chemical soil composition and foliar chemistry and environmental factors, such as stand/site characteristics, meteorological conditions and atmospheric input. With respect to soil, special emphasis is given to the changes in nutrient concentrations and nutrient pools required to get a significant difference between two soil surveys in different years. The time period that is needed to get such a difference is also investigated in view of differences in soil pools, atmospheric deposition and soil characteristics affecting element retention. Furthermore, the use of Remote Sensing in the forest monitoring programme is illustrated. Finally, an update on atmospheric deposition and soil solution chemistry is presented in view of the previous Technical Report, because of the large increase in plots between 1996 and 1997.

Accuracy and comparability of the data

The accuracy of the plot-averaged data depends on the number of observations or samples in view of the homogenity of the plot. The calculated numbers that are required to derive an accurate plot-mean value and the actual numbers used compare well for most of the surveys. In case of soil solution, however, the actual number of samplers was comparatively small.

The comparability of data at European level is influenced by the data assessment methods. With respect to crown condition, changes in assessment dates of more than one month hardly occurred. Largest changes took place between 1995 and 1996. With respect to the soil and foliar survey, reference methods were generally used for the extraction and analyses of the elements. An exception is the use of the HF method for the assessment of total element concentrations in soil. This deviating non-reference method is used for the analyses on a relatively large number of plots. Regarding the deposition and soil solution surveys, comparable methods were used at most of the plots. For monitoring of throughfall data, use was mostly made of funnels. For monitoring of the soil solution, use was made of suction cups (sometimes combined with zero tension lysimetry) at the majority the plots. Furthermore, the majority of used lysimeters is made of materials that are considered appropriate, such that the sample solution is not influenced by the sampler itself.

Results from ring tests for the chemical analyses of the soil, foliage and atmospheric deposition (bulk precipitation and throughfall) generally indicated no large comparability problems for the concentrations of major ions, except for total concentrations of base cations in the soil and sulphur in foliage.

Data quality assurance

Data consistency checks were carried out on all the data submitted in the various surveys. This includes checks on the validity of codes and the plausibility of results of parameters or parameter combinations. Special attention was given to the quality assurance and quality control (QA/QC) of the chemical composition of bulk deposition, throughfall, stemflow and soil solution. This included a check on:

- The balance between the sum of cations and the sum of anions. As with previous year, results for the balance between cations and anions showed large differences varying from a strong anion excess to a large cation excess. Approximately 50% of the measurements in bulk deposition, throughfall, stemflow and soil solution appeared to fulfil the requirement that the percentage difference is less than 20%. This result is worse than for 1996, specifically for soil solution samples, where the percentage of measurements in an acceptable range of ±20% was nearly 90% in 1996.
- The difference between measured and calculated electric conductivity. Those results were better than the difference between the sum of cations and anions. An allowable discrepancy between measured and calculated conductivity of 20% was fulfilled by approximately 62% of the measurements for bulk deposition, 69% for throughfall, 70% for stemflow and 79% for the soil solution.
- The ratio between Na and Cl concentrations. On average the Na/Cl ratio in bulk deposition, throughfall, stemflow and soil solution resembled those in seawater (0.858 $eq.eq^{-1}$). Unlike the results in 1996, very high Na/Cl ratios were hardly found, indicating that Na contamination due to Na release from the bottle in which solution samples are kept in the field, does not occur frequently.

As with previous year, the results of the various QA/QC procedures on the chemical composition of deposition and soil solution samples pose questions to the accuracy and comparability of the data.

Remote sensing

Along with the establishment of intensive monitoring plots in the forest, several countries took aerial photographs of their plots. The major aim was in all cases to document the situation of the site at the beginning of the observation period. Aerial data supplements terrestrial data and therefore provides a more comprehensive picture of the ecosystem. In this report, examples are given that show that aerial photography can successfully be used to gain information on:

- The representativity of site characteristics of the forest ecosystem within the plot with respect to the area surrounding the plot.
- Tree or stand parameters, such as crown condition, stand height and stand structure, both within the Level 2 plot and in the vicinity of the Level 2 plot.
- Time series of forest ecosystem condition, such as crown condition and canopy closure.
- Relationships between stand structure and ground vegetation by linking the results of aerial photographs with terrestrial data.

Atmospheric deposition

Estimates of atmospheric deposition are based on throughfall and bulk deposition at the plots. The evaluation of annual atmospheric deposition data was related to 402 Intensive Monitoring plots for which annual bulk deposition fluxes could be calculated based on measurements in 1997. This is a strong increase compared to 1996, mainly due to the inclusion of more than 80 plots in Germany. For throughfall, the number of plots equalled 267. An assessment of relationships between the atmospheric inputs and environmental factors was related to the plots where throughfall data are available. Major conclusions are given below.

Ranges and geographic variation of atmospheric inputs in view of critical loads
A comparison of the atmospheric deposition in 1996 and 1997 at the same plots showed a slight decrease in both the S and N input. Both bulk and total deposition of N appeared to be higher than S deposition at most of the plots in 1997. N inputs were higher than S deposition at nearly all plots in Western Europe (UK, Belgium, Netherlands, Luxembourg, France), but it was also the case at many plots in Central Europe (Poland, Czech Republic, Austria, Hungary). The average calculated total N deposition was approximately twice as large as S, whereas in 1996 it was calculated to be 50% larger than S.

Approximately 55% of the considered plots received a calculated total N input above 1000 $mol_c.ha^{-1}.yr^{-1}$. At this deposition level, the species diversity of the ground vegetation may decrease due to the disappearance of species typical for N limited habitats. Below this deposition level, tree growth may, however, be hampered due to limited N availability. The total input of acidity was comparable in 1996 and 1997 and ranged mostly between 200-4000 $mol_c.ha^{-1}.yr^{-1}$. Considering a variation of critical acid loads of approximately 1500-3500 $mol_c.ha^{-1}.yr^{-1}$, elevated Al/(Ca+Mg+K) ratios are likely at part of the plots. Results of the soil solution survey showed that this is indeed the case.

Relationships between atmospheric deposition and environmental factors
As with the previous year, results of a multiple regression analysis showed that the geographic region has a dominant influence on the deposition data. The atmospheric deposition of all ions was significantly higher going from the Northern Boreal regions to Western Europe. The deposition SO_4, NO_3 and Ca was significantly higher in the Central/Eastern part of Europe, but NH_4 was slightly higher in Western Europe. There was a highly significant positive correlation between atmospheric deposition and rainfall for all elements, except for NO_3. Altitude was negatively correlated with the deposition of all compounds, except for NO_3 and Ca.

Relationships between crown condition and environmental factors

Crown condition, in terms of defoliation and discoloration, is assessed at all Intensive Monitoring plots. In this years report, the average defoliation (using all data up to 1997) of pine, spruce, oak and beech was related to major environmental (stress) factors at 262 different Intensive Monitoring plots. Apart from stand and site characteristics, the environmental factors included nutrient status (foliar composition), atmospheric deposition and meteorological parameters. The latter data were partly derived from interpolation.

Results showed that 20-50% of the variation in defoliation can be explained by the variation in stand age, soil type, precipitation, temperature, N and S deposition and foliar chemistry, depending on tree species. This is larger than the variation that could be explained on Level 1 plots, using modelled deposition data and excluding foliar composition. In that study, methodological differences among countries accounted for >30% of the variation in defoliation. Inclusion of this so-called country effect might be relevant in future regression analysis when the number of plots does allow this. Defoliation significantly increased with stand age, due to a natural ageing effect found in many studies. The defoliation of spruce and oak appeared to be larger in sandy soils compared to clayey soils. The effect of precipitation and of N and S deposition varied. Higher deposition and precipitation data were sometimes related to an increased defoliation, whereas sometimes the reverse was true. Foliar concentrations were generally not significantly related to defoliation. When it occurred, however, a lower nutrient availability was related to a higher defoliation. An in-depth interpretation is still hampered by a lack of information on stand history, pests and diseases at most of the plots and by the relatively small data set used for the regression analysis. Such an interpretation can be expected after some 3-5 years.

Foliar composition

The evaluation of the foliar composition was related to 674 plots of pine, spruce, oak and beech at which the most recent foliar analyses was carried out (nearly all in 1996 and 1997). An assessment of relationships of the foliar nutrient concentrations with environmental factors took place at some 200 plots due to the limited availability of deposition data (approximately 50 plots for pine, 100 for spruce, and 20-30 for oak and beech. Major conclusions are given below.

Ranges in foliar concentrations and foliar rations in view of critical values
As expected, nutrient concentrations in the foliage of oak and beech are 1.5 to 2 times higher than in the foliage of pine and spruce, except for P. In the majority of the stands (mostly more than 80%), the nutrient status of the foliage can be judged as sufficient and balanced for each nutrient separately. Nevertheless, at approximately 30% of the plots the nutrient status was low (possibly insufficient and unbalanced for at least one nutrient). For most nutrients, beech has the highest percentage stands with an insufficient and unbalanced nutrient status. This is specifically true for the Mg for which the percentage of stands with a sufficient and balanced status is 68% only.

Relationships between foliar concentrations and environmental factors
Atmospheric deposition, meteorological parameters, soil chemistry, and site characteristics all contributed to the explanation of foliar nutrient concentrations. The percentage variation accounted for and the impact of various predictor variables varied considerably per nutrient and tree species. Relative high percentages explained variation were found for N with the exception of beech (51-79%) and for Mg with the exception of spruce (46-74%). Low percentages variation accounted for were found for P (20%-34%), K (26%-40%) and Ca (16-47%). The N and S deposition were significantly related to the foliar N and S concentrations for the coniferous species, especially pine. With the exception of Mg, no effect could be demonstrated of the deposition of basic cations on the foliar basic cation concentration. Acid deposition however,

showed a significant negative correlation with the foliar basic cation concentration. The foliar P concentration varied in different climatic regions, expressed by impacts of temperature, precipitation and altitude. Temperature showed to be the most dominant and sometimes even the only significant parameter for all species except beech. In general the foliar concentration of the basic cations was positively correlated to the concentration of the cation concerned in the organic and/or mineral layer. The influence of site and stand characteristics (soil type, altitude and stand age) was different depending on the tree species.

Element pools in the soil

Element pools in the soil were calculated at 604 plots, using available soil data up to 1997. The assessment of time periods needed to get significant differences and/or relationships with environmental factors was related to the availability of deposition data and varied mostly between 100-200 plots, depending upon the element considered. Major conclusions are given below.

Required pool changes and time periods to derive significant differences
Changes that are required in element pools to detect significant differences depend on the pool size, the standard deviation in the pool size (bulk density and element concentration) and on the number of samples that were taken. At most plots, substantial changes in carbon, nitrogen and base cation pools are needed before a significant difference can be detected. Smallest changes are required in the organic layer, followed by the mineral topsoil. A second soil survey might therefore concentrate on those layers. Time periods that are needed to assess a significant difference have been calculated with respect to N in the organic layer and base cations in the mineral layer, since those pools are liable to changes caused by nitrogen or acid deposition. Results showed that a time interval of 10 years, which is generally considered for a repetition of the soil survey, might give a significant difference in N and exchangeable base cation pools for approximately 25% and 10% of the plots, respectively.

Relationships between element pools and environmental factors
The variation in element pools in the organic layer was mostly explained for approximately 30-50% by various stand and site characteristics, precipitation, temperature and pH. In most cases, the meteorological factors explained the major part of the variation in element pools in the organic layer. Pools are larger in more acid, wetter and colder locations, related to an inhibited mineralisation under those circumstances. Soil type was the most important explaining variable in the mineral layer, followed by precipitation and temperature. The pH only had a significant effect on the pool of exchangeable base cations.

Soil solution chemistry

Data for the soil solution chemistry in 1997 were stored for a total of 192 plots in twelve countries concentrated in Western and Northern Europe. The evaluation focused on the range in concentrations of major ions in soil solution (SO_4, NO_3, NH_4 H, Al, Ca, Mg, K) in view of critical levels and impacts of N and S deposition and soil chemistry. Major conclusions are given below.

Range in element concentrations in view of critical levels
As with the previous year concentrations of SO_4, NO_3, total N, Al and Ca were mostly lower than 2000 $mmol_c.m^{-3}$. A striking difference is the much lower concentration of NH_4 in the organic layer. A comparison of element concentrations at similar plots showed that NO_3 concentrations were generally lower, whereas Al concentrations were higher compared to 1996. For example, the

concentrations of NO_3 in soil solution exceeded the official ground water quality criterion of 800 $mmol_c.m^{-3}$ in the subsoil at 9% of the plots, compared to 24% in 1996. Those plots are mainly situated in Central Europe. An Al concentration of 200 $mmol_c.m^{-3}$, that is sometimes considered indicative for negative impacts on tree roots, was exceeded in the subsoil at 57% compared to 34% in 1996. The Al/(Ca+Mg+K) ratios exceeded a critical ratio of 1.0 in approximately 30-39% of the plots, depending on the layer considered, compared to 9-21% in 1996. As with 1996, both the NH_4/K ratio and NH_4/Mg ratio hardly ever exceeded a critical value of 5.0 in the mineral soil.

Relationships between soil solution chemistry and environmental factors

The concentration of potentially toxic Al in the subsoil was strongly related to the concentration of SO_4 and NO_3 in acid soils (soils with a base saturation below 25% or a pH below 4.5). Unlike previous year, this relationship was not found in the topsoil. Above those base saturation and pH levels, there was no relationship. In this situation there was a strong relationship between Ca and strong acid anions, indicating that the acidity is neutralised by the release of base cations at high base saturation. As with previous year, the variation in concentrations of major ions in the soil solution could to a large extent be explained by differences in atmospheric deposition, but the variation that could be explained was less. Furthermore, meteorological conditions (specifically precipitation) had a significant impact on all ions, except N compounds and the pH. Another result was that base saturation is significantly related to base cation concentrations and pH, while the C/N ratio is not significantly related to N compounds.

1 Introduction

In order to gain a better understanding of the effects of air pollution and other stress factors on forest ecosystems, a Pan-European Programme for Intensive and Continuous Monitoring of Forest Ecosystems has been implemented. This chapter first presents information on the background and current status of the Intensive Monitoring Programme (Section 1.1). It then highlights the focus of this year's Technical Report in view of the overall objectives of the programme (Section 1.2) and it ends with a description of the content of the Technical Report (Section 1.3). The target groups of this report are the active participants of the Intensive Monitoring Programme (National Focal Centres, National Involved Research Institutes, Scientific Advisory Group, the Expert Panel Members, the Standing Forestry Committee of the European Union and ICP Forests) and the Scientific Community.

1.1 Background and aim of the Intensive Monitoring Programme

Background of the programme

The Pan-European Programme is based on both the European Scheme on the Protection of Forests against Atmospheric Pollution (Council Regulation (EEC) No 3528/86) and the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) under the Convention of Long-Range Transboundary Air Pollution (UN/ECE). Based on the agreed selection criteria, laid down in Commission Regulation (EC) N^o 1091/94, the EU Member States started to select and install their plots in 1994. After acceptance of the relevant parts of the ICP Forests Manual (Task Force meetings in Lillehammer and Prague, 1994 and 1995), also the non-EU countries started with the selection and installation process. In January 1995 and January 1996 progress reports on the selection and installation of the Intensive Monitoring plots were prepared (e.g. EC, 1996; 'orange brochure'). Since then several countries have reviewed their selection and in some cases amendments have been made.

The Intensive Monitoring Programme includes the assessment of crown condition, forest growth (increment) and the chemical composition of foliage and soil on all plots. Additional measurements on a limited number (at least 10%) of the plots include atmospheric deposition, meteorological parameters, soil solution chemistry and ground vegetation. In the expert panels on deposition and meteorology, the possible inclusion of ambient air quality (O_3, SO_x, NO_x and NH_x) and of phenology has been discussed. Within each of these surveys, a number of mandatory and optional parameters have been defined. The temporal resolution of the surveys is scheduled as follows:

- crown condition (at least once a year)
- chemical composition of the concentrations of needles and leaves (at least every 2 years)
- soil chemistry (every 10 years)
- increment / forest growth (every 5 years)
- atmospheric deposition (continuous)
- soil solution chemistry (continuous)
- meteorology (continuous)
- ground vegetation (every 5 years)
- remote sensing/aerial photography (once)

Aims of the Programme

The major objective of the 'Pan-European Programme for the Intensive Monitoring of Forest Ecosystems' is to gain a better insight in the impacts of air pollution (specifically the elevated deposition levels of SO_x, NO_x and NH_x) and other stress factors on forest ecosystems. Scientific evaluations should thus focus on the relationships between the parameters describing the forest condition (such as defoliation, growth and nutrition) and the influencing parameters (such as site and stand characteristics, soil, meteorology and deposition). An overview of the most relevant relationships to be derived with the data in the Intensive Monitoring database is given in Fig. 1.1.

1.2 Aim of the report

Aims and contents of previous reports

The Technical Reports on the 'Pan-European Programme for the Intensive Monitoring of Forest Ecosystems' in Europe differ each year in contents in view of the increased data availability in time. The first report, presented in 1997 only included a description of the contents of the database and of the data assessment methods for the core surveys and a data evaluation strategy. The second Technical Report presented in 1998 focused strongly on a description of data assessments (data coverage, data comparability, data reliability) and on preliminary results of key parameters in the four core surveys (crown condition, soil, foliar composition and forest growth) and atmospheric deposition. This report included preliminary correlative studies between key parameters and major stand and site characteristics, but did not contain in-depth evaluations, since the data in most surveys did not yet allow such evaluations.

More in-depth evaluations were included in the third Technical Report, which focused on atmospheric deposition, meteorology and soil solution chemistry. Methods and results specifically aimed at insight in: (i) the relationship between atmospheric deposition and stand/site characteristics and meteorological conditions and (ii) the simultaneous impact of atmospheric deposition, meteorological conditions and soil chemistry on the soil solution chemistry.

Aim of this report

The focus of this year's report is on crown condition, soil condition and foliar condition, specifically focusing on relationships with stand and site characteristics and environmental factors such as meteorology and atmospheric deposition. With respect to soil, emphasis is also given to the required changes in nutrient pools to detect significant differences and the expected time periods before such differences can be detected. Information on atmospheric deposition and its relationship with soil solution has also been included, but this is more an update of the results of the previous year, because of the strong increase in plots for those surveys. The relationship between environmental factors and forest ecosystem condition that has been investigated in this year's report is further illustrated in Fig. 1.1.

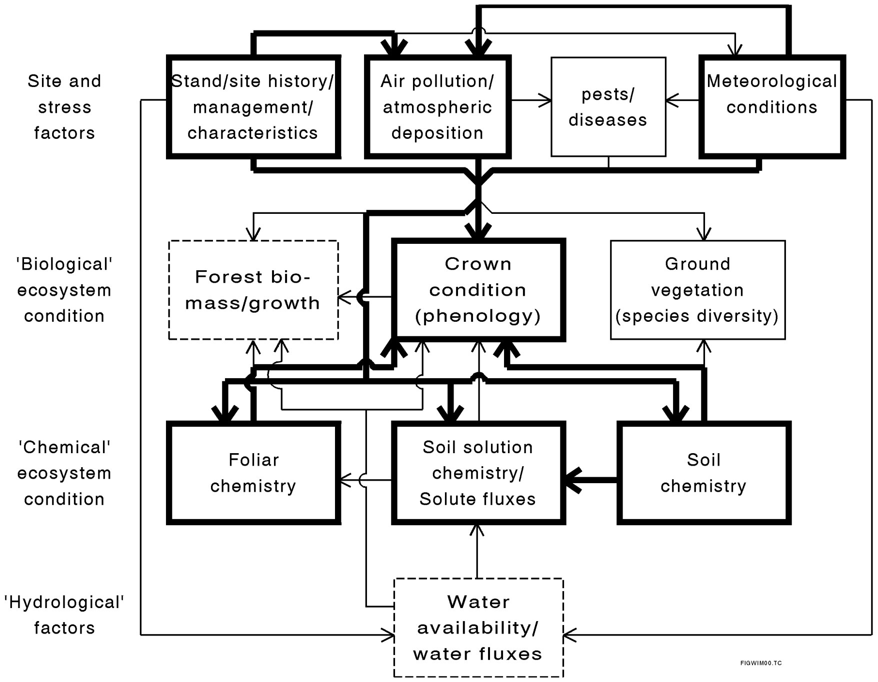


Figure 1.1 *Flow diagram illustrating the relationships between site and stress factors and the forest ecosystem condition. Boxes and arrows in bold are specifically investigated in this year's report. Attention is further given to boxes with dotted lines.*

Selection and presentation of key parameters

An overview of key parameters in the various surveys is given in Table 1.1. The key parameters considered in this year's report are given in bold. More information on the background of these key parameters is given in Klap et al. (1997) and in De Vries et al. (1998).

1.3 Contents of the report

Chapter 2 provides information on the current implementation (plot selection and data submission) of the Intensive Monitoring Programme. General methodological aspects, such a the reliability/comparability and the statistical evaluation of data are described in Chapter 3. Chapter 4 presents examples of the use of Remote Sensing, in documenting plot information and providing insight in the representativity of the plot. The Chapters 5 to 9 present the methodological approaches and the results of evaluations related to key parameters in the surveys on atmospheric deposition (Chapter 5), crown condition (Chapter 6), foliar condition (Chapter 7), soil condition (Chapter 8) and soil solution chemistry (Chapter 9). The methodological approach refers to methods for data assessment, data quality assurance (if applicable) and data evaluation. Chapter 10 contains the discussion and several conclusions related to the results presented in Chapter 5 to 9.

Table 1.1 Key parameters describing the available 'ecological and chemical' forest condition and stress. Values in bold are included in this year's report.

Type of parameter		Key parameter
Ecological condition	**- crown condition**	**Defoliation**, discoloration
	- growth	Diameter, tree height, Stand Density Index[1)], Site structure Index[1)]
	- ground vegetation	Ground vegetation index
Chemical condition	**- foliar composition**	**N, P, S, Ca, Mg, K, N/P, N/Ca, N/Mg, N/K,** Fe, Mn, Cu, Zn
	- soil composition	
	• carbon	**C**
	• nutrients:	**N, P[2)], S[2)], Ca[2)], Mg[2)], K[2)],** C/N, N/P
	• acidity:	**pH, base saturation[3)]**
	• toxic elements:	Pb, Cd, Cu, Zn
	- soil solution chemistry	**SO_4, NO_3, NH_4, Ca, Mg, K, Al, pH, DOC**
Stress	- stand and site characteristics	Tree species, tree age, climatic region, altitude, soil type
	- biotic stress	Easily assessable damage types
	- air pollution	O_3, SO_2, NO_x and NH_3 concentrations in air
	- atmospheric deposition	**SO_4, NO_3, NH_4, Ca, Mg, K, pH in bulk deposition, throughfall and stemflow**
	- meteorology	Precipitation, temperature, evapotranspiration[1)]

[1)] Those parameters are derived from basic data.
[2)] Limited to the organic layer only.
[3)] Limited to the mineral layer only.

Results of the survey on atmospheric deposition focus on an update of (i) ranges in bulk deposition, throughfall and calculated total atmospheric deposition, accounting for canopy interaction fluxes, (ii) ratios of major ions in atmospheric deposition and (iii) relationships between throughfall or calculated total atmospheric deposition and stand/site characteristics (Chapter 5). Results of the crown condition survey are limited to the assessment of relationships between the average defoliation of monitoring plots until 1997 and environmental factors (stand and site characteristics, meteorology, atmospheric deposition and foliar chemistry) influencing the crown condition (Chapter 6). Results of the foliar survey are presented in terms of (i) ranges in nutrient concentrations and nutrient ratios in view of critical values and (ii) relationships between foliar concentrations and environmental factors, including atmospheric deposition (Chapter 7). Results of the soil survey focus on (i) pools of carbon and nutrients (N, P, S, K, Ca, Mg) in the organic and mineral layer, (ii) the changes that are needed to assess significant differences for those pools, (iii) the expected time periods before such differences can be detected and (iv) the relationships between those pools and environmental factors, including meteorology and atmospheric deposition (Chapter 8). Data on element concentrations in the soil solution are evaluated in view of (i) possible exceedance of critical levels, (ii) correlations between the acid-base chemistry of the soil solution and the sulphate and nitrogen concentrations and (iii) the overall combined influence of several environmental factors on the soil solution chemistry (Chapter 9).

2 The Intensive Monitoring Programme: plot selection and data submission

The Intensive Monitoring Programme is carried out on sites that were selected in such a way that it includes the major tree species-soil type combinations in a country. Due to its non-systematic character, the intensive monitoring data set is not representative for Europe in the statistical sense, but it does give information on stress and effects on a European-wide scale. In this chapter an overview of plots in the various surveys (Section 2.1) and of the data that have been stored until 1997 (Section 2.2) are presented.

2.1 Plots in the various surveys

The Intensive Monitoring Programme now includes 864 plots from 30 participating countries. Some countries that participate in the ICP Forests programme, have indicated their participation in the Intensive Monitoring programme, but have not yet sent the general plot information. For some other European countries, it is not yet sure whether and when they intend to join the Intensive Monitoring Programme. With the possible inclusion of these countries the total number of plots could rise to approximately 900.

Table 2.1 shows the number of plots selected and installed and the number of plots on which the different surveys (crown condition, soil, foliage, increment and deposition, soil solution, meteorology and ground vegetation) are (planned to be) executed. Four surveys have to be conducted on all plots (crown condition, soil, foliage and increment). According to the information received, atmospheric deposition is carried out at 494 plots. Surveys with respect to meteorology and soil solution are carried out at 188 and 252 plots respectively. Based on information submitted by the countries (which is not yet complete), it can be concluded that ground vegetation surveys will be carried out at 637 plots, whereas the application of aerial photography is foreseen at more than 150 plots (Table 2.1). Actually, many countries still have to send information whether remote sensing techniques are applied at part of the plots. Several countries also plan to carry out additional surveys on the plots, such as phytopathology, litterfall, study of lichens and/or mosses, mycorrhiza and/or fungi and other in-depth studies to soil water regimes, gas exchange and intensive air quality measurements. The number of plots that have presently been installed equals 784 of the 864 plots.

An overview of the surveys carried out at the different plots is given in Fig. 2.1. This map is based on information submitted until February 2000. The map indicates that the (relative) number of plots at which the continuous surveys on deposition and soil solution are carried out varies strongly between countries. It also shows that ground vegetation is recorded at most of the plots. Only a few countries have indicated that they do not assess ground vegetation data (yet). For the location of plots with meteorological data, the reader is referred to the Technical Report 1999.

Table 2.1 Overview of the number of selected plots for the main surveys

Countries	Total	Crown	Soil	Foliar	Increm.	Atm. Dep.	Meteo	Soil sol.	Gr. Veget.	Rem. Sens.
EU countries										
Austria	20	20	20	20	20	20	2	2	20	20
Belgium Flanders	12	12	12	12	12	6	2	6	12	-
Belgium Wallonia	8	8	8	8	8	2	1	2	8	-
Denmark	16	16	16	16	15	10	3	10	15	5
Germany	89	89	89	89	89	86	66	78	80	49
Greece	4	4	4	4	3	4	4	2	4	-
Spain	53	53	53	53	53	11	11	6	53	-
France	100	100	100	100	100	25	25	15	99	14
Ireland	15	15	15	15	15	3	8	3	9	15
Italy	26	26	26	26	26	15	12	2	26	20
Luxembourg	2	2	2	2	2	1	2	-	2	-
Netherlands	14	14	14	14	14	4	-	14	14	-
Portugal	9	9	9	9	9	1	1	1	9	-
Portugal Azores	4	4	4	4	4	1	1	1	-	-
Finland	31	31	31	31	31	16	13	16	31	?
Sweden	100	100	100	100	100	46	-	46	-	12
United Kingdom	10	10	10	10	10	10	2	7	10	-
Total EU	513	513	513	513	511	261	153	211	392	135
non-EU countries										
Bulgaria	3[1]	3	3	3	3	3	3	3	3	?
Belarus	81[1]	81	81	81	81	-	-	-	-	-
Switzerland	16	16	16	16	16	13	16	7	16	16
Czech Republic	10	10	10	10	10	2	1	1	10	-
Estonia	7	7	7	7	7	5	0	2	7	?
Croatia	7	7	7	7	7	2	3	3	4	?
Hungary	14	14	14	14	14	14	7	-	14	-
Lithuania	9	9	9	9	9	-	-	-	9	9
Latvia	2	2	2	2	2	2	2	2	2	-
Norway	19	19	19	19	19	19	-	19	19	-
Poland	148	148	148	148	148	148	-	-	148	?
Romania	13	13	13	8	13	4	-	4	13	?
Russia	12	12	12	12	12	12	-	-	-	?
Slovenia	3[1]	3	3	3	3	2	3	-	-	?
Slovak Republic	7	7	7	7	7	7	-	-	-	2
Total non-EU	351	351	351	344	349	233	35	41	245	17
Total	864	864	864	857	860	494	188	252	637	162

[1] In these countries plots have not yet been installed.

2.2 Submitted data and information until 1997

Table 2.2 gives an overview of the number of installed plots, and the number of plots for which data, DAR-Q and both data and DAR-Q's are stored. This table shows that the number of plots for which data were stored and DAR-Q information is available is only slightly lower than the number of installed plots for all the surveys, except ground vegetation. The main reasons for this difference are:

- some countries have not submitted data for some of the surveys
- some countries submitted data that have still not been stored because the data are not yet complete or problems persist with respect to their quality
- at some of the installed plots, monitoring has started only very recently. Consequently, no data or DAR-Q information is available yet

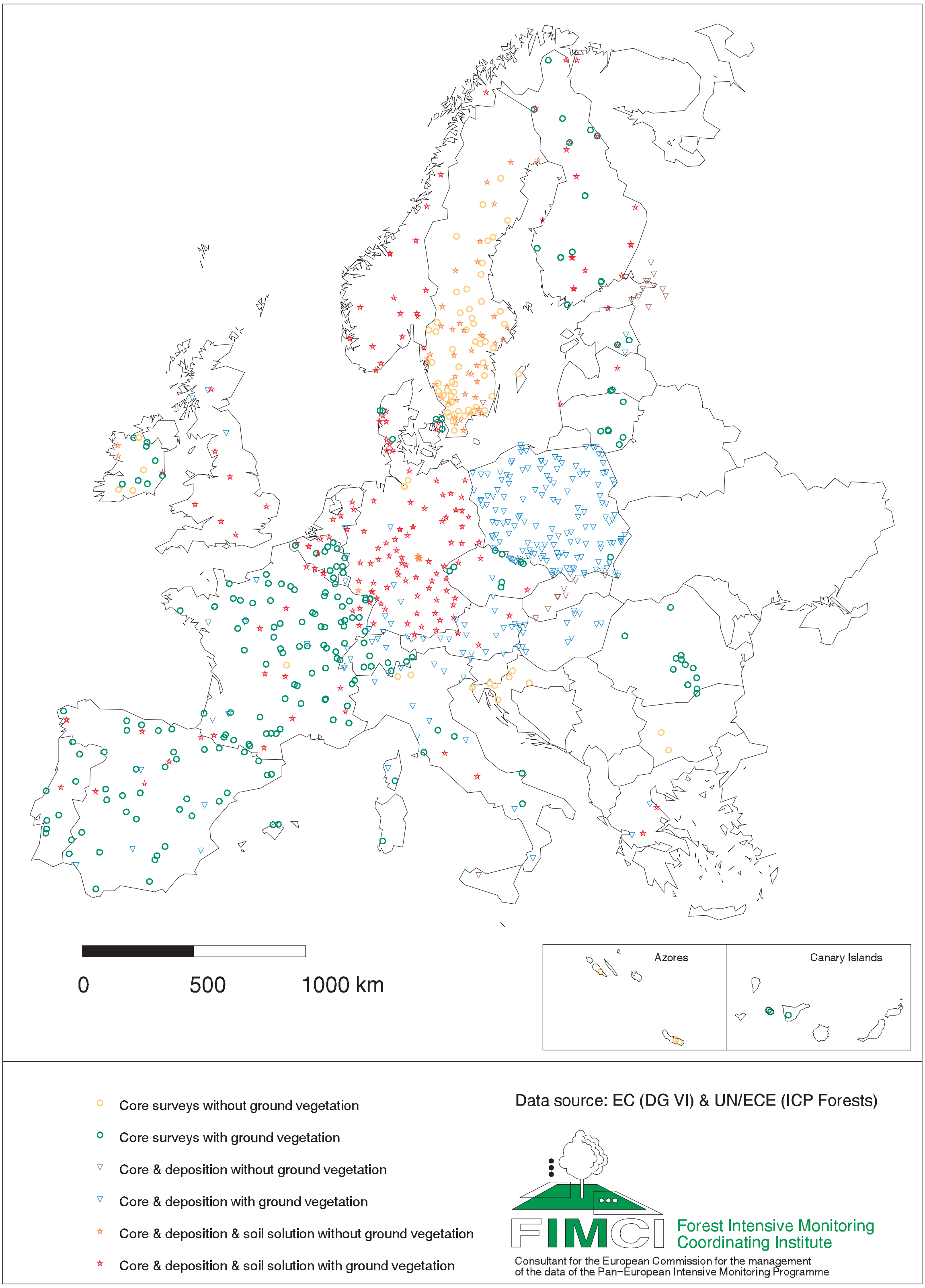


Figure 2.1 Geographical distribution of surveys conducted at the Intensive Monitoring plots (based on information received until May 2000).

Compared to last years' report, the number of plots with data for 1997 has increased for most surveys. Furthermore table 2.2 shows that for the vast majority of the plots with stored data, also the DARQ information is available.

Table 2.2 Overview of the number of plots for which data and/or information was submitted for the eight surveys until the year 1997[1]

Survey	Selected plots[2]		Data stored		DAR-Q information stored		Data and DAR-Q information stored	
	EU	non-EU	EU	non-EU	EU	non-EU	EU	non-EU
Crown condition	513	351	506	248	496	240	495	230
Soil condition	513	351	435	169	445	216	433	169
Foliar condition	513	344	498	229	443	241	440	225
Increment	511	349	465	61	457	89	432	39
Deposition	261	233	285	203	246	191	233	169
Meteorology	153	35	133	5	143	4	132	4
Soil solution	211	41	184	17	125	17	115	17
Ground vegetation	392	245	62	0	124	9	21	9

[1] For soil, foliage and increment, also data from earlier years have been used.

[2] The number of plots for which plot characteristics were received was 762 (see Section 2.1)

3 General methodological aspects

3.1 Data quality checks and data presentation

Data quality checks

Procedures, carried out by FIMCI to check the quality of data and information, include: (i) registration and documentation, (ii) inventory and validation checks, (iii) feedback inventory phase and (iv) digital storage of data and information. Information on these main steps has been given in the 'Strategy plan for the validation and evaluation of data' (De Vries et al., 1996) and in the second Technical Report (UN/ECE, EC; De Vries et al., 1998). Apart from checks on the consistency and validity of file names and file structures, the data integrity checks form the core of this data validation procedure. This includes checks on the validity of codes and the plausibility of results of parameters or parameter combinations. More specific information on checks on the consistency of deposition data and soil solution chemistry is given in the Sections 5.2.3 and 9.2.3.

Data presentation

Crown condition data were presented as averages over the whole monitoring period (mainly 1994-1997). The soil data that are measured in 10 years intervals, were limited to the most recent survey in the period 1990-1997. The number of data sets before 1994 is very limited. Similarly, data on the foliar surveys were related to the most recent survey, being nearly all in 1996 and 1997. The year 1997 was used for all continuous monitoring data (deposition, meteorology and soil solution). In presenting those data the temporal aggregation was set at one year.

For the soil solution chemistry parameters, a distinction was made between the organic layer and two mineral layers, namely a depth-weighted average up till 40 cm (biologically active topsoil where most roots occur that is most influenced by atmospheric deposition) and a depth-weighted average up between 40 cm and 80 cm, which is generally the lower boundary of the root zone.

3.2 Assessment of data reliability

General approach

Within the Intensive Monitoring Programme a variety of data assessment methods is applied with respect to sampling layout and set-up (including sampling numbers), measuring equipment in the field and methods for digestion (soil and foliar survey) and analysis. As a result, differences in accuracy and comparability of the stored data exist. These aspects may influence the results of an evaluation and can be considered, e.g. by (i) a certain selection of the evaluation data set or (ii) giving higher weights to those data that are considered to be more reliable.

The accuracy and comparability of applied methods (as described in the DAR-Q's) has been focussed upon (i) the number of observations or samples that were taken (and possibly pooled in certain surveys) in a forest stand to get a value for that stand (accuracy) and (ii) the digestion and analyses methods that were used to measure the chemistry of foliage, soil and deposition (comparability). More specific information on the data assessment methods is given in the chapters on the respective surveys. Those chapters also contain information on the results of ringtests. Here we only discuss the interpretation of the number of observations or samples at plot level in view of data reliability, which is a relevant aspect for all surveys. More information on this topic has been given in last year's report (De Vries et al., 1999).

Sampling numbers at plot level

The number of observations (or samples) that are needed to obtain a representative value of a certain parameter for a forest stand, depends mainly upon the spatial variability in the parameter concerned (relative standard deviation) and the required reliability (accepted margin of error) of the average value for a stand. Assuming a normal distribution, the required number of samples can be calculated as (Hammond and McCullagh, 1978):

$$n = t_\alpha^2 \cdot S^2 / D^2 \qquad (3.1)$$

where:

n = number of observations

t_α = tabled Student t factor for a given uncertainty α; for $\alpha = 0.05$, $t_\alpha = 1.96$

S = standard deviation within the plot, relative to the mean value (%)

D = margin of error within the plot, relative to the mean value (%)

Depending on the required reliability, D, and the relative standard deviation in a given parameter, the required number of observations varies as given in Table 3.1 (see Eq. 3.1 with $t_\alpha = 2$). For data with a strongly skewed distribution within a plot (e.g. crown condition data), a transformation may first be needed to get a normal distribution and calculate the required number of observations.

Table 3.1 The required number of samples or observations at plot level for a given parameter as a function of the spatial variability of that parameter (relative standard deviation, S) and the required reliability (acceptable relative margin of error, D)

Relative margin of error	Required number of samples				
	S=20%	S=30%	S=40%	S=50%	S=60%
D=5%	64	144	256	400	576
D=10%	16	36	64	100	144
D=15%	7	16	28	44	64
D=20%	4	9	16	25	36
D=25%	3	6	10	16	23

Table 3.1 shows that the number of samples/observations that is required to obtain an average value with a reliability within 5% is generally very high (generally >100), especially when the spatial variability is large. Such numbers are often considered impracticable. Accepting a margin of error of 20%, Table 3.1 indicates that a number of 4-36 samples is needed depending on the S-value. Using a number of 20-25 samples leads to a reliability of the average value within 10-25%, when the relative standard deviation varies between 20 and 60%, a range that is often encountered for parameters in natural environments. The actual numbers used are presented in the relevant chapters. In the evaluation of data in multiple regression analyses, the square root of the number of samples has been included as a weighting factor, to account for the reliability of the data (see Section 3.3.2 for further details).

3.3 Statistical data evaluation

3.3.1 General approach

The statistical evaluation of the data was focused on the key parameters in the surveys on atmospheric deposition, crown condition, foliar composition, soil and soil solution chemistry. To test hypotheses about the impact of the various environmental factors, statistical techniques were used to investigate the relationship between:

- Atmospheric deposition versus stand and site characteristics and precipitation.
- Crown condition versus stand and site characteristics, temperature, atmospheric deposition, foliar chemistry and soil chemistry.
- Foliar composition versus stand and site characteristics, temperature, atmospheric deposition and soil chemistry.
- Soil chemistry versus stand and site characteristics, temperature and atmospheric deposition.
- Soil solution chemistry versus stand and site characteristics, precipitation, atmospheric deposition and soil chemistry

Site characteristics included as predictor variables were soil type, geographic or ‘climatic’ region and altitude. Stand characteristics included tree species and stand age, being in some cases a surrogate for stand height. More literature-based information on the predictor variables used is given in Section 5.2.4, 6.2.4, 7.2.4, 8.2.4 and 9.2.4, respectively. Fig. 3.1 gives an overview of the expected relationships.

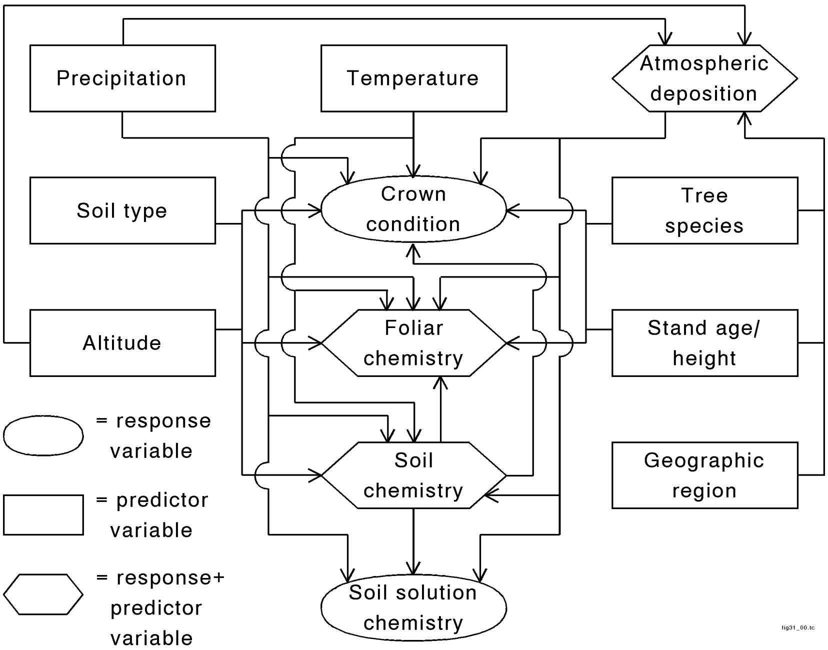


Figure 3.1 Expected relationships between environmental factors (predictor variables) and forest ecosystem condition (response variables).

Insight in the possible relationships between forest ecosystem responses and environmental factors can be obtained by applying ordination techniques. We have only applied this technique to the foliar chemistry data and its predictor variables (stand and site characteristics, meteorological parameters, deposition and soil chemistry). Further insight can be obtained by multiple regression techniques, relating the expectation value of a certain response variable to predictor variables in a quantified way. A general problem in statistical correlative research is the unavailability of data on relevant predictor variables and the possibility of confounding between the effects of correlated parameters (e.g. precipitation and atmospheric deposition). Consequently, it is only worthwhile to carry out such an analysis based on a hypothesis with respect to the possible impact and interactions of predictor variables, while interpreting the results with care in view of confounding effects. Both ordination and regression methods are described in more detail below.

3.3.2 Ordination techniques

Ordination is the collective term for multivariate techniques arranging sites on the basis of observed similarity in a variety of measured attributes (both response and predictor variables). It is also referred to as multidimensional scaling, component analysis, factor analysis and latent structure analysis (Ter Braak, 1995). It can be used as an exploratory technique to analyse dose-response (cause-effect) relationships. Application of multivariate techniques is particularly relevant when relating multiple responses, such as the chemistry of atmospheric deposition the foliage or soil (solution), to multiple causes such as the stand and site factors influencing inputs and fates of pollutants. An overview of the various techniques, depending on the type of ordination and the assumed responses between the y- and x-variables is given in Table 3.2.

Table 3.2 Multivariate techniques used in dependence of the type of ordination and the assumed responses between the y- and x-variables

Ordinate technique (Gradient analysis)	Assumed linear response	Assumed optimal response
Indirect	Principal Component Analyses (PCA)	Correspondence Analysis (CA)
Direct	Redundancy Analyses (RA) Project to Latent Structure Analyses (PLS)[1]	Canonical Correspondence Analysis (CCA)

[1] Also denoted as Partial Least Squares Modelling

In this report, principal component analysis (PCA) was used to determine meaningful patterns among the variables considered. The PCA diagram summarises the mutual correlations among response variables and, when measured, their correlation with predictor variables. In the PCA diagram, highly correlated variables lie close together, while uncorrelated variables lie far apart. Predictor variables can be superimposed on this plot, i.e. they are simply regressed on the sites after the construction of the diagram. Continuous predictor variables are represented by arrows, nominal ones by points. When a predictor variable points to a certain response variable their correlation is positive, when they point away from this variable, their correlation is negative. When their direction is perpendicular on the direction of the response variable they are uncorrelated. Further details of this method were provided in last years report (De Vries et al., 1999).

3.3.3 Multiple regression techniques

Regression analysis focuses on a particular response variable and how this is related to (environmental) predictor variables. The term response variable stems from the idea that it responds to the environmental variables in a causal way, but causality cannot be inferred from regression analysis. The x-variables can either be selected from the ordination, being an exploratory method to gain insight in possible cause-effect relationships, or from hypothetically adopted cause-effect relationships based on literature information. Regression analysis is specifically suitable to: (i) assess the relative contribution of environmental variables to the response variable and (ii) predict the response variable at sites where the environmental predictor variables are available.

Supposed relationships were of the form:

$$\log y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \cdots\cdots + \alpha_n x_n \qquad (3.2)$$

where log y is the expectation value of the response variable (atmospheric deposition, soil solution chemistry), x_1 to x_n are predictor variables (stand and site characteristics, meteorological parameters etc.) and α_1 to α_n are the regression coefficients.

The regression analysis was applied by using a so-called Select procedure. This procedure combines predictor variables that were qualitative (indicator variables), such as tree species and/or soil type with quantitative variables. This approach combines forward selection, starting with a model including one predictor variable, and backward elimination, starting with a model including all predictor variables. The 'best' model was based on a combination of the percentage of variance accounted for ($R^2_{adj.}$), that should be high and the number of predictor variables, that should be low. Even though some site variables were intercorrelated, specifically (climatic) region and soil type, both were included since both do have a specific impact on most of the key parameters. In order to meet the requirement of regression analyses that the response variable is normally distributed with a constant variance at fixed values of the predictor values, the considered responses were log-transformed. This also causes interaction to be less significant. Normality was checked by a scatter plot of the residuals against the fitted values.

Tree species, soil type and geographic region were included as qualitative variables. Based on the grouping described in the Technical Report of 1998 (De Vries et al., 1998) 6 major groups of tree species were used (pine, spruce, other coniferous, oak, beech and other broadleaves) and 3 main groups for soil type (Podzols and Arenosols, being acidic sandy soils, Cambisols and Luvisols being slightly acidic sandy soils and clayey soils and remaining non-calcareous soils). Only in case of carbon or nutrient pools in the mineral soil, a distinction was made in 9 soil groups (see De Vries et al., 1998). The limitation of tree species and soil types to those groups only was based on the expected differences in major influences, considering the limited number of data. With respect to atmospheric deposition, a distinction was made in Northern Europe (divided in Boreal and Boreal Temperate), Western Europe (Atlantic climate), Central Europe (Continental and Sub-Continental) and Southern Europe (Mediterranean climate). Altitude and stand age, which are given in intervals of 50 m and 20 yr, respectively, were included as quantitative variables by using the average value of each considered class (e.g. 325 m in the altitude class 300-350 m and 30 yr. in the age class 20-40 yr.).

Even though it may be relevant to include interactions between tree species and the other stand and site characteristics (since the effect of those characteristics on atmospheric deposition and soil solution chemistry may differ for various tree species), this was not done to limit the degrees of freedom used by the predictor variables. As a rule of thumb, the number of observations should exceed 4 times the degrees of freedom (Oude Voshaar, 1994).

Table 3.3 gives an overview of the predictor variables with their maximum degrees of freedom.

Table 3.3 Overview of predictor variables and interaction included in the various regression models with their maximum degrees of freedom.

Predictor variable	Degrees of freedom				
	Crown condition	Soil chemistry	Foliar chemistry	Deposition	Soil solution chemistry
Tree species	-	3	-	3	3
Soil type	3	3	3	-	3
(Deposition) region	-	-	-	5	-
Altitude	1	1	1	1	-
Age	1	-	1	-	-
Atmospheric deposition	1	1	1	-	1
Precipitation	1	1	1	1	1
Temperature	1	1	1	-	-
Soil characteristics	1	-	1	-	1-2
	9	10	9	10	9-10

The influence of each characteristic on a given key parameter was thus assessed while accounting for the impact of the other relevant stand and site characteristics. The approach implies that a stratification is made with respect to tree species and climate region characteristics.

4 Remote sensing

4.1 Introduction

Several countries took aerial photographs of their Intensive Monitoring plots at the time of the establishment. The major aim was to document the situation of the site at the beginning of the observation period. The Expert Panel of the European Commission in charge (*Working Group on Remote Sensing Applications for Forest Health Assessment)* defined guidelines for the application of aerial photographs on intensive monitoring plots in an EU- Manual on Remote Sensing Applications on Forest Health Assessment (EC, 2000). These recommendations are based on the experiences gathered during the last twenty years with aerial inventories for forest damage assessment.

Aerial photography is a good non-destructive way to supplement terrestrial data and provide a more comprehensive view of the ecosystem. There are a number of factors that make remote sensing, and especially aerial photography, a suitable medium for monitoring forest ecosystems:

- Aerial photographs accurately document the condition of important parts of an ecosystem at any given time. They can easily be evaluated at a later date.
- Remote sensing produces a view of forest ecosystems that is not visible from the ground. The parts of the crown which have the greatest significance for the assessment of vitality - the top and the upper outside parts of the crown - are generally more visible on aerial photographs. So discoloration, which as a rule first starts to appear on the upper surfaces of needles and leaves, is better recognised from the bird's eye view than from below.
- Whereas the terrestrial survey of the Intensive Monitoring Programme is based on plots, remote sensing also provides important information on the area surrounding the plot, thus giving information on the representativity of the plot.
- The application of special film material allows the exploitation of information in the near infrared wavelengths. When Colour Infrared (CIR) film is used, both the visible and the near infrared bands of the spectrum can be captured and reproduced on the photograph. This is particularly important for the interpretation of tree species, natural age classes and forest damage, since morphological changes in cell structure strongly influence the reflection of near infrared light.
- Photogrammetric mapping and accurate measurement of tree or stand parameters is possible. These results can then easily be linked with other data.
- Aerial photographs allow temporal changes to be observed when photo flights are repeated. This will also show whether the representativity of the plot has changed over time.

Aerial photography cannot be used for chemical measurements but can give additional information on effect parameters. As aerial photograph evaluations are not a mandatory action to be carried out on Intensive Monitoring plots, no common results including all countries can be presented. The results obtained until now in some countries are, however, of relevance for a long-term monitoring approach. Some of them will be presented in this chapter as examples to illustrate the possibilities. This chapter will concentrate on the additional value to terrestrial observations.

4.2 Methodological aspects

The major objective of the Working Group on Remote Sensing Applications for Forest Health Assessment is to harmonise the methods for the application of aerial photographs within the European Intensive Monitoring program. The EU- Manual on Remote Sensing Applications on Forest Health Assessment (EC, 2000) was therefore amended by a chapter with recommendations on appropriate techniques for data assessment (photo flight) and data evaluation (e.g. photo-interpretation, photogrammetric measurements). All reported assessments on Intensive Monitoring plots using aerial photographs were carried out according to the manual.

4.2.1 Locations

Fig. 4.1 shows the locations from which it is known that aerial photographs were taken (locations in Finland, Sweden, Denmark, Ireland, France, Germany, Austria, Italy, Lithuania and the Slovak Republic). A differentiation is further made between basic evaluations and advanced evaluations of the photographs (see also Section 4.2.3). No aerial photographs were taken in Belgium, both Walonia and Flemish Region, the Netherlands and Hungary. For most plots no information is available yet whether remote sensing was carried out (Fig. 4.1).

4.2.2 Data assessment methods

All aerial photo's are made in accordance with the manual on Remote Sensing Applications on Forest Health Status Assessment (EC, 2000). The knowledge of the precise location of the forest plots is an obvious prerequisite to the use of CIR aerial photography. In many cases it turns out that the co-ordinates are not exactly known. Differences of 100 or 200 meters are often encountered if the permanent test sites or stands are not defined by natural lines which can be clearly recognised in the aerial photograph (paths, stand boundaries). This information may be sufficient to plan the flight, but it is not sufficient for the exact location of the boundaries of the plot.

If the flight has already been carried out but the exact co-ordinates of the plot are not exactly known, the location of the plot in the photographs can be determined by a field check with appropriate photographic enlargements. Another possibility is to use crown maps elaborated in the stand, showing characteristic distributions of trees. In the latter case, there are substantial limitations in coppice stands.

The precision of the geodetic referencing is important for the comparability of measured co-ordinates on the ground and in the photographs. Based on experiences in Italy for Level 2 plots, control points taken from maps achieve an average accuracy of 1 to 2 meters for the location. This allows in most cases the identification of single trees by their terrestrial co-ordinate. However, control points measured by geodetic techniques or high precision GPS measurements in the field are preferable. They allow an orientation accuracy of 10 – 20 centimetres, which may be relevant in relation to ground vegetation monitoring.

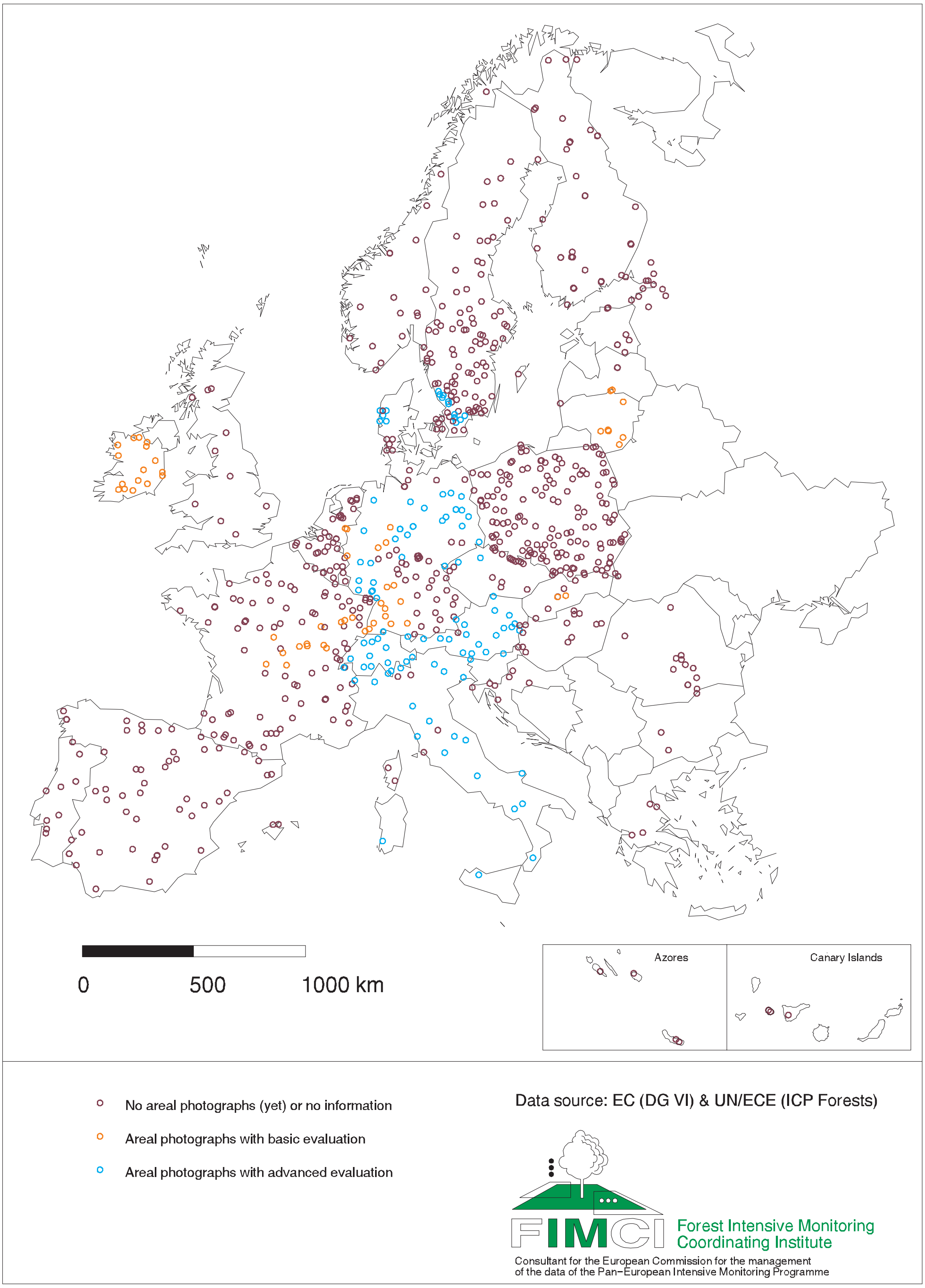


Figure 4.1 Geographical distribution of the Intensive Monitoring plots with Remote Sensing data.

The experiences within the Intensive Monitoring Programme showed that the exact localisation of the plots is often very time consuming, mainly due to the lack of exact ground co-ordinates. The improvement made with GPS high quality measurements allows the exact measurement of the plot corners and additional ground control points. In a similar way and in combination with the surveys the exact location of trees can be determined. Once the aerial photographs have been absolutely orientated all information derived from them is geo-referenced and can be linked to any other geo-referenced information system. The EU-Remote Sensing Manual lists the appropriate methods for the absolute orientation of aerial photographs.

4.2.3 Data evaluation methods

Levels of ambition with respect to the evaluation of aerial photography

Five optional levels of ambition have been identified for the possible application of aerial photography. These options are summarised in Table 4.1. In general, two different approaches exist to evaluate aerial photographs: visual interpretation and photogrammetry. Visual interpretation refers to the basic evaluation (options 2 and 3), whereas photogrammetry refers to the advanced evaluation (options 4 and 5). The various options with respect to the interpretation of aerial photography are discussed in more detail below.

Table 4.1 Options for including aerial photography as part of the Level 2 Programme

Option	Application	Repetition
1	CIR aerial photographs taken for documentation purposes only. No interpretation or photogrammetric measurements.	At least once, at the beginning of the survey.
2	As for Option 1, but photographs are also interpreted to assess the representativity of each plot in relation to the surrounding forest. No other interpretation or photogrammetric measurements. Simple photogrammetric instruments are sufficient.	Repetition will vary depending on forest management intensity and rate of change (e.g. 3 - 10 year cycle).
3	As for Option 2, but including various assessments of individual trees using appropriate interpretation keys (e.g. species, age class, crown condition, social class and special phenomena). No photogrammetric measurements are carried out. Simple photogrammetric instruments are sufficient.	At the start of the survey and then at a suitable cycle.
4	As for Option 3, but including a number of photogrammetric measurements such as obtaining the x, y, z co-ordinates of every tree, tree height, and the production of crown polygons. High precision photogrammetric instruments are required.	As above.
5	As for Option 4, but including detailed photogrammetric analysis such as digital terrain models and digital canopy models. High precision photogrammetric instruments are required.	As above.

Documentation (option 1)

Aerial photographs can document the condition of the Intensive Monitoring plots at a particular point in time. This is the most basic option for using CIR aerial photography as part of the Level 2 Programme. In this option aerial photographs are taken of the plot and the surrounding forest area for documentation purposes only. No assessments or measurements are carried out on the photographs. The photographs will be available for possible future reference and assessments.

Basic photo-interpretation to assess the representativity of Intensive Monitoring plots (option 2)

In option 2 the photographs are used to assess how representative each plot is in each stand and the surrounding forest in terms of species and species composition, natural age class, crown closure, management practices and forest health condition.

Advanced photo-interpretation to assess single tree information on Intensive Monitoring plots (option 3)
The main purpose of this option is to derive single tree information by visual interpretation of aerial photographs. The observation of the upper tree crown on aerial photographs provides additional information to the terrestrial surveys. The interpretation results can also be used as a control for the verification of terrestrial assessments and for documentation purposes. In this option individual trees in the plots or sub plots should be evaluated by visual interpretation using common standards on the photographs. A simple crown map will help to verify the interpretation.

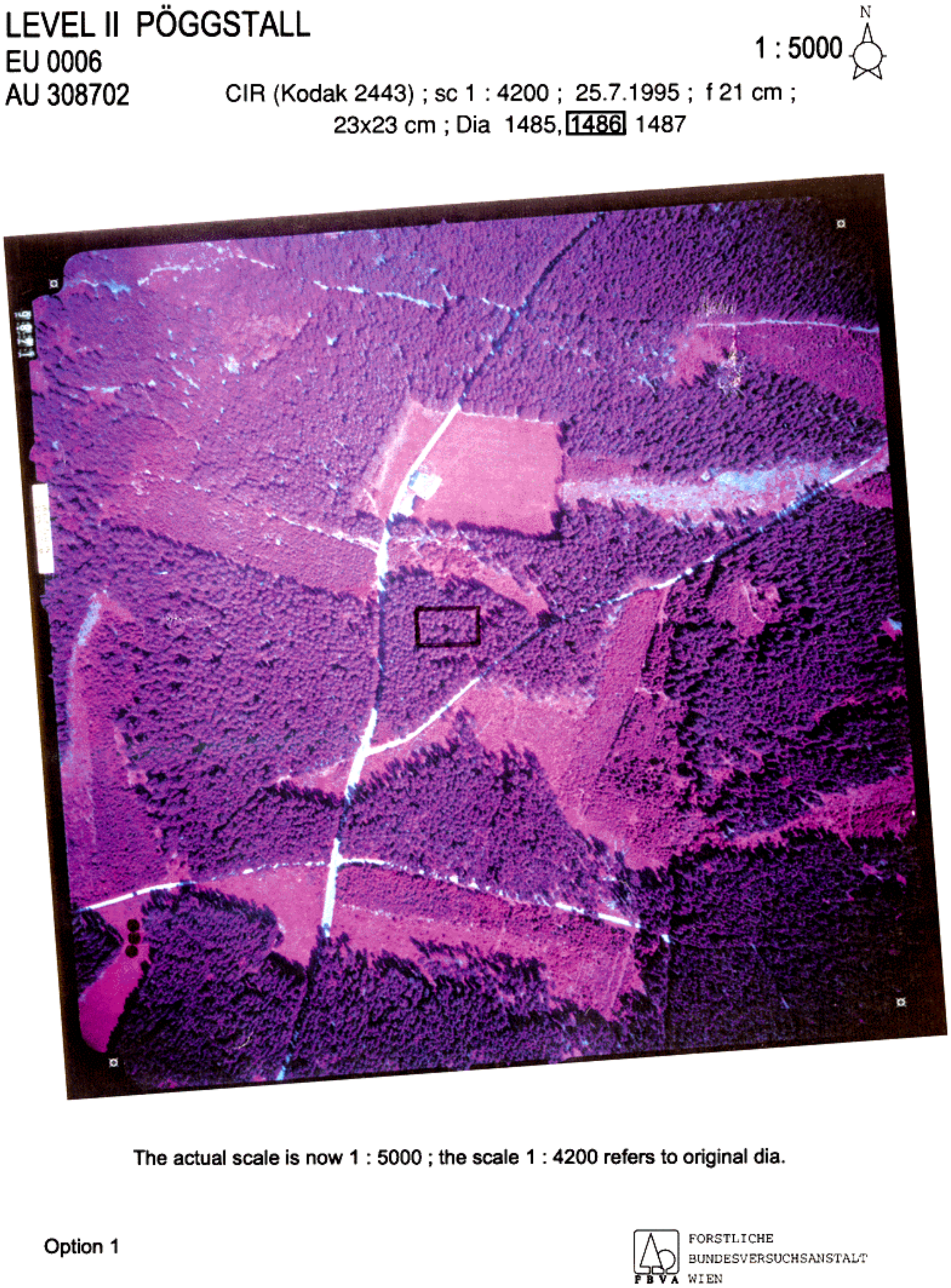
Advanced photogrammetric measurements (option 4)
Option 4 introduces advanced photogrammetric techniques. The geodetic x, y, z co-ordinates of every single tree should be determined. This will guarantee the identification of each tree in all subsequent inventories. In addition, the delineation of forest stands (Option 2) should then be improved by photogrammetric means. All maps or spatial information derived from the photographs will then be compatible with maps and information from other sources. Supplementary to the single tree interpretation outlined in Option 3, several photogrammetric measurements of tree crowns can be carried out.

Highly advanced photogrammetric measurements (option 5)
Option 5 requires the most advanced photogrammetric equipment and specific know how. For specific investigations and complex modelling of forest ecosystems the results of advanced photogrammetric analysis of the plot and the surrounding forest will be useful. This form of analysis will also provide high quality information for other investigations like digital canopy models or single tree crown models.

4.2.4 Data comparability and data reliability

All reported assessments and evaluations were carried out according to the manual. The aerial photographs from different locations should thus be comparable. Furthermore the results of the photography based surveys can be checked or repeated at any time. Although there is no agreement yet on an official quality assurance method for data derived from aerial photographs by photo interpretation or photogrammetric measurements, the following methods are used:

- Repeated interpretations by the same interpreter at periodic intervals (control of interpretation constancy);
- Comparisons of various interpreters, interpretation of the parameter (control of interpretation convergence);
- Combination of the above mentioned two procedures;
- "Classic" comparison of terrestrial assessment and the evaluation of aerial photography, bearing in mind the difference inherent in these two kinds of valuation;
- Random follow-up interpretations carried out by independent interpreters;
- Plausibility checks using evaluation programmes compiled from the acquired data.



LEVEL II PÖGGSTALL
EU 0006
AU 308702

1 : 5000

CIR (Kodak 2443) ; sc 1 : 4200 ; 25.7.1995 ; f 21 cm ;
23x23 cm ; Dia 1485, 1486 1487

The actual scale is now 1 : 5000 ; the scale 1 : 4200 refers to original dia.

Option 1

FORSTLICHE
BUNDESVERSUCHSANSTALT
WIEN

Figure 4.2 Documentation sheet of the Level 2 plot Pöggstall in Austria (plot 6).

4.3 Results and discussion

The examples presented in this chapter focus on results that supplement terrestrial surveys. The first results are related to documentation and a basic evaluation focusing on the representativity of a plot (Section 4.3.1) and an advanced evaluation focusing on the structure of a stand (Section 4.3.2). The other examples are results from aerial photograph evaluations that go beyond the manual options. It includes an example of the assessment of forest condition in the vicinity of a level 2 plot, which is an aspect related to representativity (Section 4.3.3) and two examples of the change in forest crown condition and canopy closure in time (Section 4.3.4). Finally, an example is given of the use of remote sensing in data evaluation by combining aerial photography with ground vegetation data (Section 4.3.5). In this chapter, no results have yet been presented of a comparison between aerial photographs and ground assessments of forest crown condition.

4.3.1 Documentation and representativity

By taking aerial photographs according to the EU-Manual recommendations, the condition on the Level 2 plot is fixed for a given date and information of high density is stored on film material. Together with the indicated location of the plot and the most important flight parameters, the pictures are ready for evaluations at any time. Fig. 4.2 demonstrates how the documentation of permanent monitoring plots is realised, using the example of an Intensive Monitoring plot in Austria.

The representativity of the plot for the surrounding forest area has been assessed in aerial photographs for approximately 50 Intensive Monitoring plots. The two main approaches used were stand wise interpretation of key parameters, such as species composition, crown closure, etc (option 2), and interpretation of single trees in a dense sampling grid (option 3). The latter option was mainly used to compare the forest damage situation in the plot with the situation around the plot. In Fig. 4.3, an example is given for the Intensive Monitoring plot Pöggstall in Austria, introduced above. The map visualises the degree of comparability for four observed parameters, i.e. natural age class, crown closure, tree species and forest health condition, between the plot and forest stands in the vicinity of the plot.

4.3.2 Stand structure

The stand structure of Intensive Monitoring plots presently is mainly characterised by values for the stem diameter distribution measured in the field. According to the results presented in the previous Technical Report, most of the observed stands have a uniform structure (De Vries et al., 1999). However, on a specific plot, more detailed descriptions of stand structure might be important for understanding the dynamic of forest ecosystems and is helpful in the interpretation of throughfall measurements. The basic data, used to describe or calculate the tree crown or canopy of an Intensive Monitoring plot can be derived from photogrammetric measurements taken in a given grid (e.g. of 1 x 1 meter) without further treatments. This visualisation gives an impression of the basic data set.

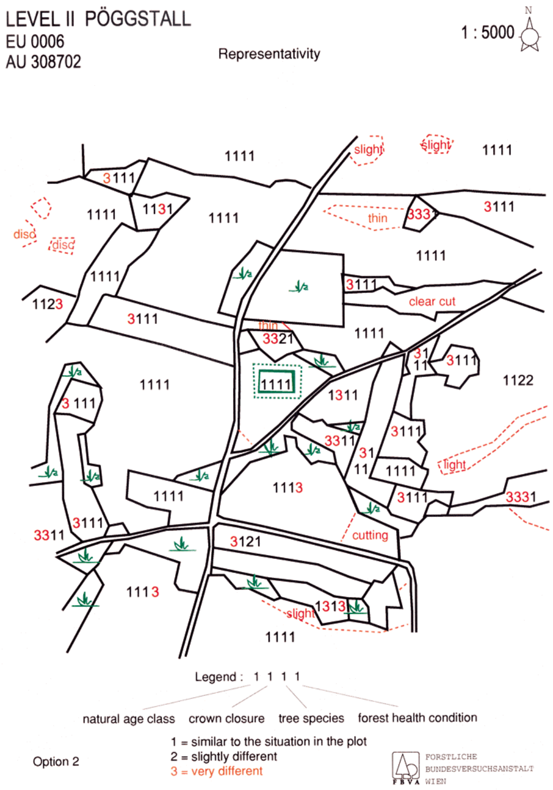


Figure 4.3 *Map indicating the representativity of Intensive Monitoring plot Pöggstall in Austria (compare Fig. 4.2)*

A more advanced approach to calculate the tree crown or canopy is based on crown polygon and tree top measurements of single trees, using digital canopy models. In this approach, specific algorithms are used to calculate the tree crown for each single tree species. Together with information on the tree species and the number of the trees, the situation on the plot can then be visualised. An example of this approach is given in Fig. 4.4, which shows crowns of pine (in blue) and of spruce (in green) for an Intensive Monitoring plot in Austria. The numbering of the trees corresponds to the terrestrial numbering.

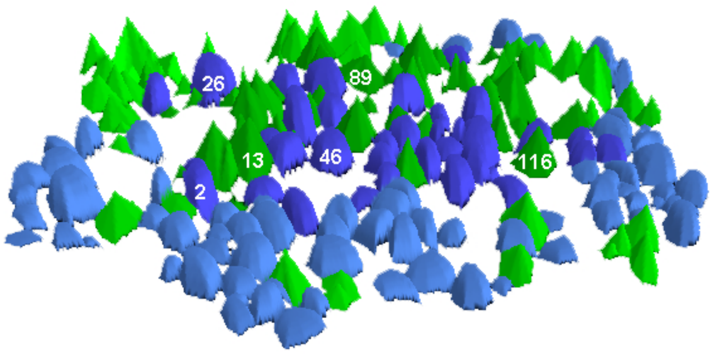


Figure 4.4 *Digital canopy model of Intensive Monitoring plot 5 in Austria. Blue crowns are pines, green crowns are spruces*

A Krige-Interpolation can be used to interpolate the crown surface data from the photogrammetric measurements. This is a common geostatistical approach to interpolate spatial correlated data. Before the interpolation, the spatial autocorrelation of the data is investigated by means of (semi) variograms (see Journal and Huijbregts, 1978). The analysis of the (semi) variograms gives an idea about the similarity of spatially distributed parameters. The variogram function, which is a mathematical description of the similarity (correlation) in dependence of the distance of the plots, is used as a weight within the spatial Krige-Interpolation.

A more detailed digital reconstruction of the stand structure can be derived by combining terrestrial measured data, such as diameter at breast height (DBH) and tree height with quantitative information on the canopy layer of a stand based on photogrammetric measurements. Such digital visualisations have been carried out in Germany, for example an Intensive Monitoring plot in the northern part of the Black Forest in southern Germany (plot 809). Apart from these spatial data sets, indexes for roughness of the crown structure can be calculated using the measured canopy data. Wolff et al. (1999), for example, calculated the standard deviation of crown length using geostatistical methods for all test sites. This index is correlated with the degree of biodiversity and is helpful to estimate the rainfall interception rates for the observation area.

4.3.3 Assessment of forest condition in the vicinity of Intensive Monitoring plots

Aerial photographs also allow the assessment of the condition of forests, surrounding the Intensive Monitoring plots. An example is a Forest Condition Survey in the vicinity of German Intensive Monitoring plots, that was carried out using absolutely orientated CIR-aerial photographs (scale 1:5000) at a 50 m x 50 m survey grid. The surveyed area was about 25 ha, which means that about 120 grid points per plot were assessed. To describe the crown condition per plot a so-called damage index was calculated on the basis of the crown condition assessment of four single trees - always next to each grid point (Wolff et al., 1999). The spatial distribution of the damage index was calculated by Krige-Interpolation. Fig. 4.5 shows the spatial distribution of the damage index in the vicinity of the German Intensive Monitoring plot "Cunnersdorf".

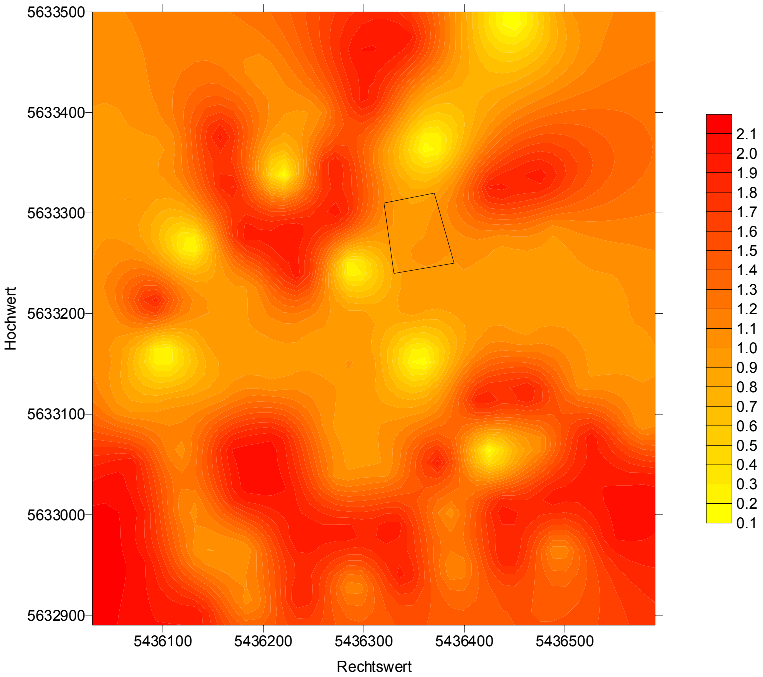


Figure 4.5 Forest condition situation on the Intensive Monitoring plot "Cunnersdorf" (plot 1403) in Germany and of the surrounding forest area

4.3.4 Time series of forest condition development

Time series of aerial photography are most suitable for the monitoring of forest condition development. Pictures taken on different dates that are evaluated by the same expert using standardised guidelines and by comparing identical trees leads to highly reliable results. From some Intensive Monitoring plots in Nordrhein Westphalia (Germany) aerial photographs do exist since the mid-eighties. This allowed a pilot project on the development of these sites during the last 15 years. One example is given in Fig. 4.6, showing the change in forest crown condition in a beech stand between 1988 and 1997. It shows that the overall crown condition of the plot decreased during that period, with individual differences.

Another example of a time series derived by aerial photographs is presented in Fig. 4.7. The figure shows the development of the canopy layer in the beech stand in Nordrhein Westphalia introduced above. The picture shows that big gaps in the canopy (e.g. on the left hand of the graphic) are covered with tree crowns in 9 years. This result is typical for beech in which gaps in the canopy are getting closed by neighbouring trees in a short time period.

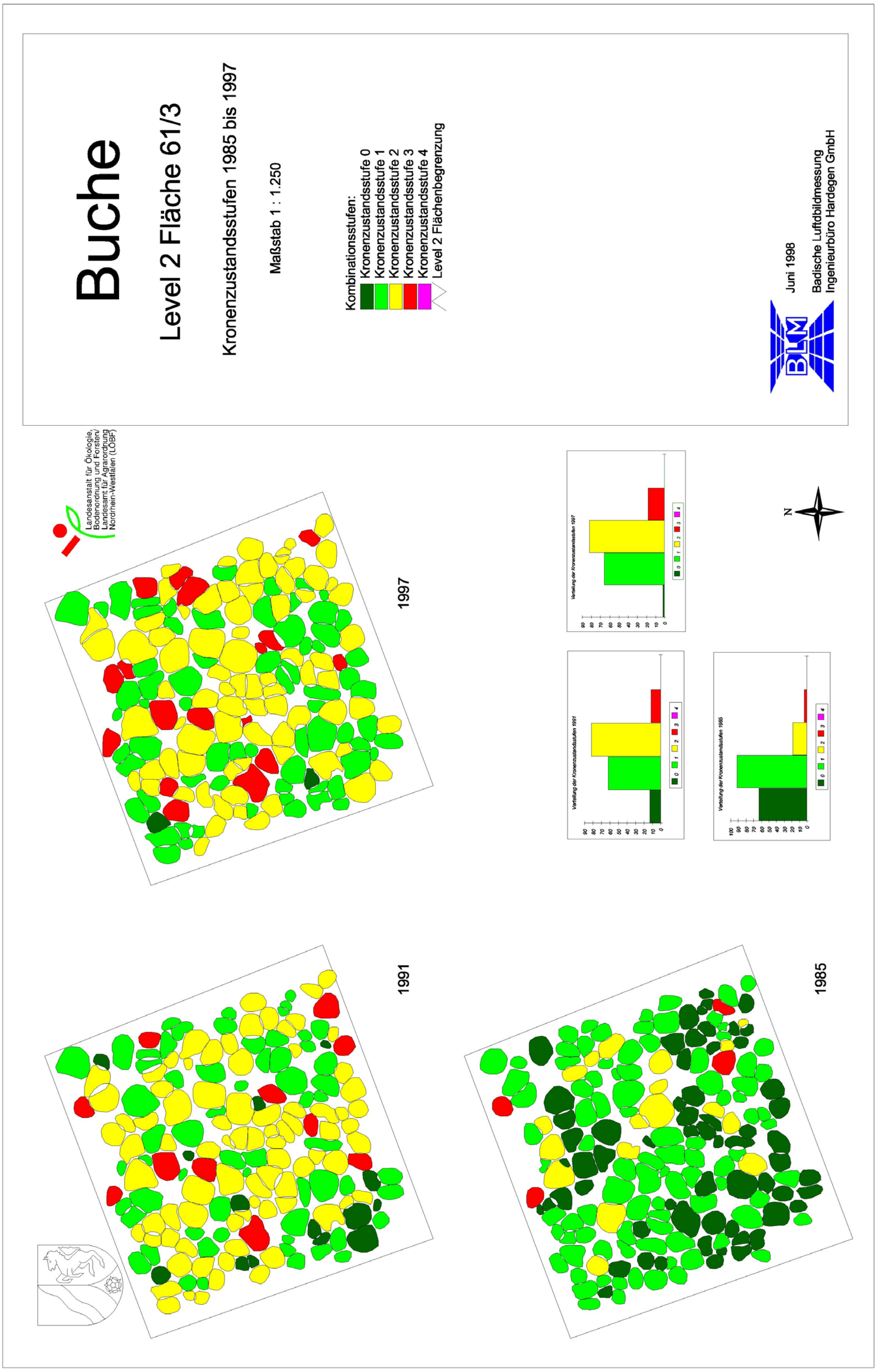


Figure 4.6 *Forest crown condition development of an Intensive Monitoring Beech plot (61/3) in Nordrhein Westphalia*

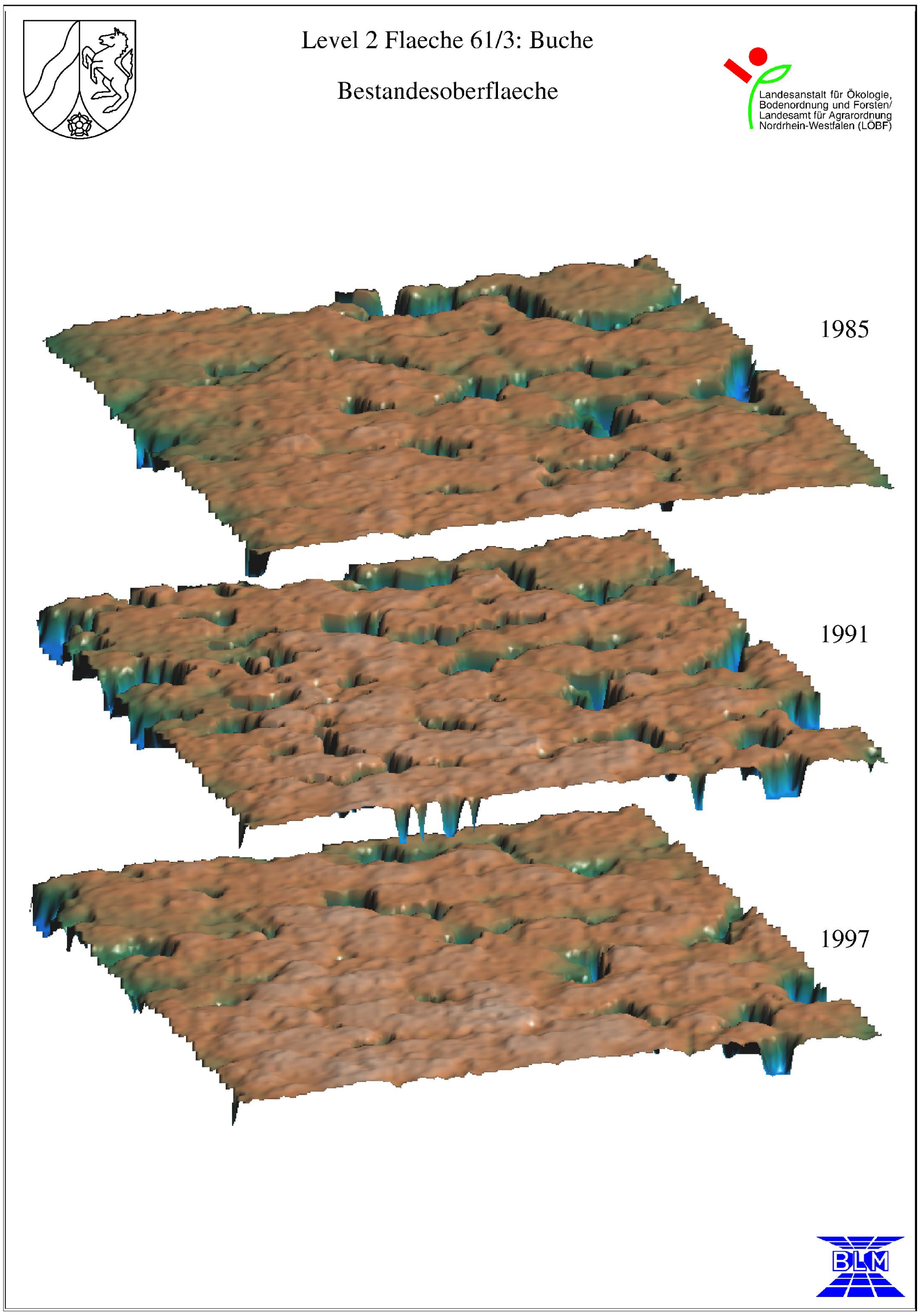


Figure 4.7 Changes in the canopy closure of the Intensive Monitoring Beech plot (61/3) in Nordrhein Westphalia between 1988 and 1997.

4.3.5 Combining information from aerial photographs with ground vegetation data

The occurrence of Wood Small-red *Calamagrostis epigejos* has strongly increased in Scots pine forests of the North-eastern German lowlands during the last decade. This grass species with shoot-lengths up to two meters is regarded to be a strong impediment for tree regeneration (Bolte, 1998). Canopy thinning, followed by increased below-canopy irradiance, is recognised as an important factor for the expansion of *Calamagrostis epigejos*. The effect of canopy thinning and related below-canopy light climate on the distribution of the grass was therefore studied in an irregular thinned 45-years-old Scots pine forest of the northeastern German lowlands (Bolte, 1998; Wolff et al., 1999). In the Scots pine stand a transect of 16 adjacent plots (10m x 10m) was installed and marked. The crown gaps of the tree stand were mapped using aerial colour infrared photographs (CIR) supported by a terrestrial mapping of *Calamagrostis epigejos*.

The results of the mapping of canopy gaps and *Calamagrostis epigejos* are presented in Figure 4.8. The figure shows that *Calamagrostis epigejos* dominates in areas with larger gap complexes, but aerial photograph analysis also showed that the grass also occurred in total canopy covered areas of the Scots pine stand.

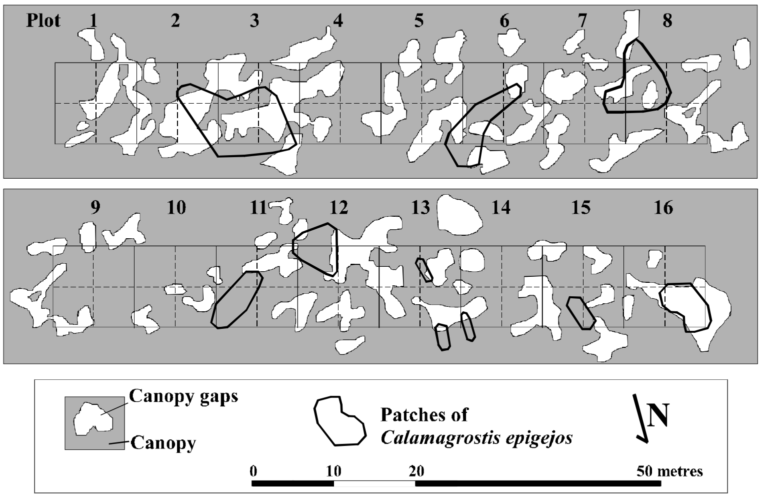


Figure 4.8 *The occurrence of Calamagrostis epigejos in relation to canopy closure in a transect in a Scots pine forests in North-eastern Germany.*

4.4 Conclusions

Aerial data supplement terrestrial data and therefore provide a more comprehensive view of the ecosystem. The examples given show that aerial photography can successfully be used to gain information on:

- The representativity of site characteristics of the forest ecosystem within the plot in comparison to the area surrounding the plot.
- Tree or stand parameters such as crown condition, stand height and stand structure, both within the Intensive Monitoring plot and in the vicinity of the Intensive Monitoring plot.
- Time series of forest ecosystem condition, such as crown condition and canopy closure.
- Relationships between stand structure and ground vegetation by linking the results of aerial photographs with terrestrial data.

Whenever possible, use of aerial photography is thus advocated at Intensive Monitoring plots. The approach is specifically useful when aerial photographs are repeated after a certain period of time, thus allowing a multi-temporal analysis. This also shows whether the representativity of the plot has changed over time. Repetition rates will vary depending on the intensity of management practice and the rate of change of the forest. A repetition rate of between 3 to 10 years is recommended in most cases.

5 Atmospheric deposition

5.1 Introduction

Information on atmospheric deposition of nitrogen and sulphur compounds and of base cations is of key importance to understand the biogeochemical cycle in forest ecosystems. Elevated atmospheric deposition fluxes influence the soil solution chemistry (see Chapter 9) and through that the nutritional status of forests (see Chapter 7).

Atmospheric deposition can be distinguished in wet deposition or wash-out, where the particles and gases are extracted from the atmosphere by rain or snow and are deposited with the precipitation, and dry deposition where particles and gases deposit directly. An indication of the wet deposition on forests can be derived from bulk deposition data nearby the forests, which also includes a fraction of dry deposition. Multiplying the air concentrations by a so-called dry deposition velocity gives the dry deposition. The total deposition (total atmospheric load) on a forest ecosystem, being the sum of wet, fog and dry deposition, can be compared with a critical load. Air concentration data are, however, hardly available at the Intensive Monitoring plots. Therefore, an indication of the total (wet and dry) deposition on forest canopies was derived from the sum of throughfall and stem flow (which equals the input to the soil system) corrected for canopy interaction, such as canopy uptake (in case of NH_4) and canopy leaching (in case of base cations). The assumptions related to this approach have been described in the previous Technical Report (De Vries et al., 1999).

The mentioned previous report gave an extensive description and evaluation of the deposition data from 1996. This chapter only presents an update of that information, using the results of 1997. The main reason is the large increase in plots with deposition data, specifically in Germany. Apart from various methodological aspects, described in Section 5.2, this chapter focuses on results related to:

- the magnitude of atmospheric inputs in view of critical loads (Section 5.3.1)
- the relative contribution of N and SO_4 compounds in the potential acid input and the contribution of base cations in neutralising the acid input from the atmosphere (Section 5.3.2)
- the influence of site and stand characteristics on the atmospheric input, specifically total deposition (Section 5.3.3)

Results on annual inputs are presented in $mol_c.ha^{-1}.yr^{-1}$. These results can be recalculated to $kg.ha^{-1}.yr^{-1}$ by a multiplication factor of 0.016 for SO_4-S and 0.014 for N.

5.2 Methodological aspects

5.2.1 Locations

The total number of plots at which deposition measurements took place until 1997 is 488 (see Table 2.2). In 1997 this number equalled 465 in a total of 23 countries. New countries compared to 1996 are Denmark, Germany, Switzerland, Spain and Italy. Bulk deposition was measured at 443 plots (Table 5.1). With the exception of Poland, with a total number of 148 bulk deposition plots, throughfall was measured at all plots where bulk deposition was measured (317 plots). At a total of 22 plots throughfall was measured, whereas bulk deposition was not included. Stemflow was only measured at 51 plots in 12 different countries (Table 5.1). The geographic variation of the plots where (i) bulk deposition, (ii) bulk deposition and throughfall and (iii) bulk deposition, throughfall and stemflow was measured in 1997 is given in (Fig. 5.1). It shows that most deposition plots are concentrated in Central Europe.

The number of plots used in the data evaluation is limited to those where the number of measurements was sufficient to compute annual deposition fluxes. At these plots, measurements are available for at least 75% of the year. Those numbers equalled 414 for bulk deposition, 267 for throughfall and 38 for stemflow. At 255 plots annual fluxes for both bulk deposition and throughfall could be derived, thus allowing the calculation of total deposition.

Table 5.1 Number of plots at which deposition, throughfall and stemflow was measured in 1997 in the various participating countries.

Country	Number of plots1)					
	Bulk deposition		Throughfall		Stemflow	
Finland	24	(17)	24	(17)	-	-
Sweden	45	(42)	45	(42)	-	-
Norway	17	(17)	17	(17)	-	-
Denmark 2)	3	(3)	15	(10)	6	(5)
U.K.	10	(10)	10	(10)	-	-
Ireland	3	(3)	3	(3)	3	(3)
Netherlands	1	-	4	-	-	-
Belgium	8	(8)	8	(8)	3	(3)
Luxembourg	1	(1)	1	(1)	1	(1)
Germany	83	(79)	84	(80)	12	(12)
France	25	(25)	25	(25)	4	(4)
Estonia	5	(4)	5	(4)	-	-
Poland	148	(147)	-	-	-	-
Czech Republic	2	(1)	3	(1)	-	-
Hungary 2)	8	(7)	13	(11)	9	(7)
Austria	20	(20)	20	(20)	1	(1)
Switzerland	5	(5)	5	(5)	-	-
Croatia	1	(1)	1	(1)	-	-
Slovak Republic	4	(4)	4	(4)	2	(2)
Spain	11	(1)	11	(1)	-	-
Portugal	2	(2)	2	(2)	1	-
Italy	13	(1)	13	(1)	8	(1)
Greece	4	(4)	4	(4)	1	(1)
Total	443	(414)	317	(267)	51	(38)

1) Numbers in brackets refer to the plots for which annual deposition fluxes could be calculated.

2) For Hungary and Denmark the limited number of bulk samplers represent the bulk deposition at all deposition plots (13 and 15 plots respectively) since plots are located at short distances to each other

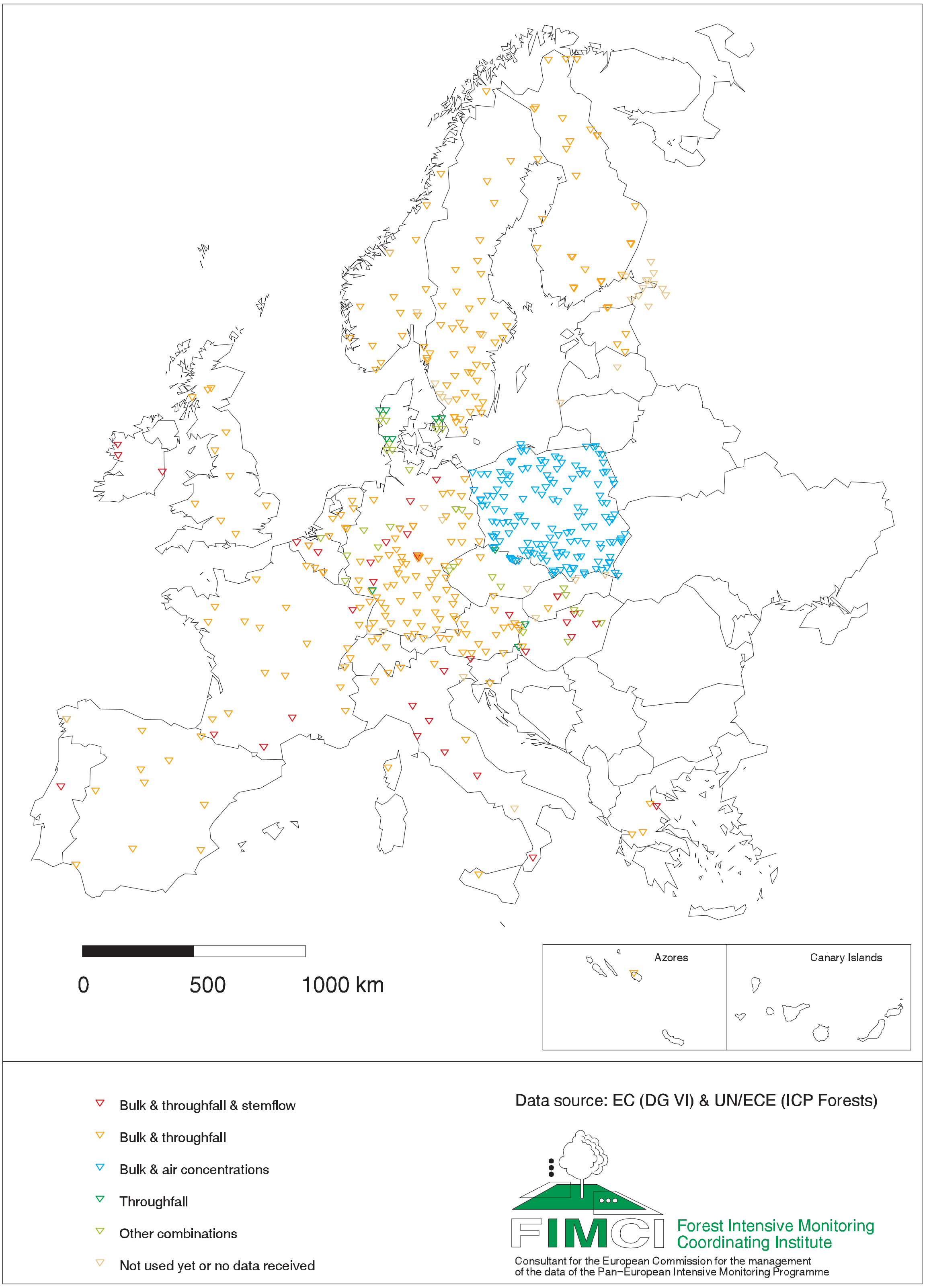


Figure 5.1 Geographic variation of locations with atmospheric deposition data in 1997.

5.2.2 Data assessment methods

Data assessment information for deposition monitoring until 1997 has been stored for 436 plots in 22 countries. This implies an increase of 41 plots compared to 1996. Updated information has been received for 24 plots of three countries. These updates generally concern small changes in the sampling layout (e.g. an extension of the number of throughfall collectors) or analysis techniques. The presentation of applied data assessment methods given below concerns only 390 plots for which both data and DAR-Q information is available. Two countries with a considerable number of plots submitted no DAR-Q so far.

Sampling devices/sampling frequencies

For monitoring of throughfall data use was mostly made of funnels (85%), whereas three different types of gutters were used at 13% of the plots. No information was available for 6 plots (2%). Funnels had diameters ranging from 10 to 21 cm. Most of the plots have funnels with a diameter between 20 and 21 cm (41%), followed by diameter < 12 cm (31%) and diameters between 14 and 18 cm (28%).

The sampling frequencies for throughfall measurements were mostly weekly or fortnightly. Only on 8% of the plots, for which sampling frequencies were reported, frequencies of 4-weekly periods were indicated. Sampling frequencies for stemflow were weekly at 68% of the plots. The other 32% have a 2-weekly sampling frequency.

Number of samples

To ensure that the determined atmospheric deposition data are representative for the monitoring plot, a good sampling set-up is essential. A sufficiently large number of samplers should be used to get a representative average value, considering the spatial variation in throughfall. Generally recommended minimal requirements mentioned in literature are the installation of at least 10 randomly placed funnels with a diameter of 20 cm (Lövblad, 1994). For measuring throughfall the use of gutters is sometimes preferred above funnels (Draaijers et al., 1998), because they integrate the input over a larger canopy, thus yielding more representative estimates of the throughfall flux (e.g. Beier and Rasmussen, 1989).

The comparison between these recommendations in literature and actually used number and type of throughfall samplers in the Intensive Monitoring, showed that in general the numbers of samplers were sufficiently large (Fig. 5.2). On the plots where funnels are used (85% of all deposition plots) the number of throughfall samplers used mostly ranged from 10-15 (61%). More than 15 samplers were used on 32% of the plots where funnels are applied. On 7% of these plots less than 10 samplers are placed. The minimum number of samplers per plot was reported to be 4. According to the literature this would not be enough.

Representative sampling of stemflow is difficult, due to large variations between trees. It requires sampling of a large number of trees. A number of minimal 5-10 trees is mentioned in the literature (Lövblad, 1994). However, this number seems to be a rather conservative estimate (Draaijers et al., 1998). The number of 5 trees was not reached on 81% of the plots. However, a sampling system in which multiple trees are connected to one collection tank, may have been reported as one sampler in the DAR-Q's. The number of sample trees may thus be underestimated to some extent.

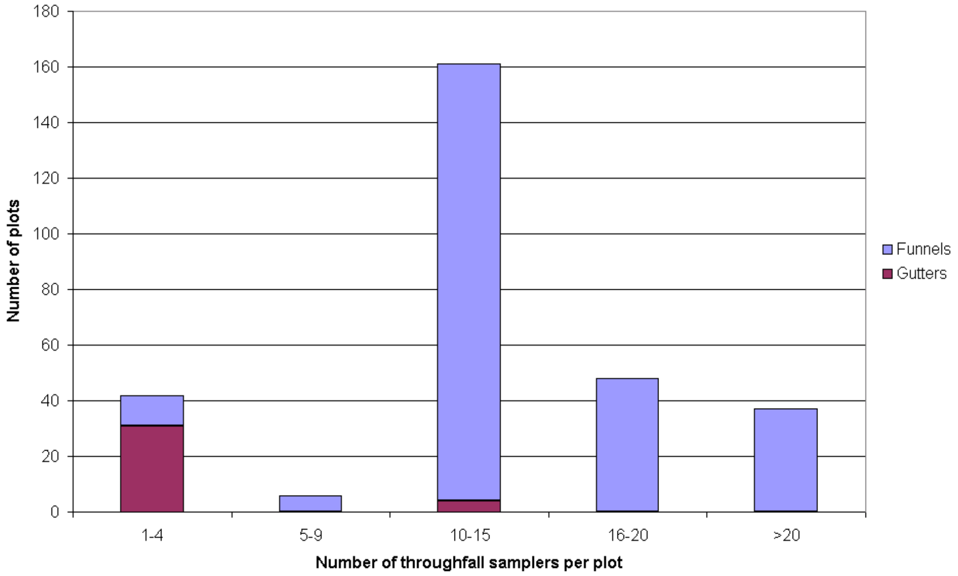


Figure 5.2 Number of samplers used to measure throughfall in 1997.

In most cases bulk deposition was measured on one sampling site in the open field in the vicinity of the Intensive Monitoring plot. For 82.8% of all open field stations the reported distance was not longer than 1 kilometre, 13.5% being within 100 m, 45.7% between 100 and 500 m and 23.6% between 500 and 1000 m. For the other 17.8% the distance increased to 4300 meter. The number of bulk deposition samplers per site ranged between 2 and 6 on the majority of the plots (96%) on which bulk is measured. For 36% of the plots no information on bulk deposition samplers has been received, indicating that no bulk samples are taken on these plots.

Data comparability

As discussed before, ringtests are essential when reliability and comparability of data are regarded. Insight in the quality of analysis by the various laboratories could be obtained from such a ringtest carried out in 1996 (Lövblad, 1997). A total of 133 laboratories from different countries participated in this exercise, of which 18 laboratories are also participating in the Intensive Monitoring programme. The performance of these 18 laboratories was compared to the whole group of 133 laboratories participating in the intercomparison exercise. The 18 laboratories in general had good results (5.9% outliers). In general no comparability problems for the deposition values existed. More information on the results is given in De Vries et al. (1998). Joint field campaigns are also carried out with respect to deposition monitoring, comparing impacts of different sampler spacing and sampler numbers in the Speulder forest in the Netherlands.

5.2.3 Data quality assurance

Procedures for quality assurance and quality control (QA/QC) included a check on all individual measurements with respect to:

- the balance between cations and anions
- the difference between measured and calculated electric conductivity
- the ratio between Na and Cl concentrations

In principle, those procedures should already be carried out with the FIMCI check programme by the laboratories producing the data, followed by a control by the NFC, when preparing the data submission. Nevertheless, the checks made by FIMCI during the data validation showed that such a check was not always carried out by the individual laboratories and the NFC's. As with the previous year, the balance between cations and anions, for example, showed that some countries might have submitted concentration data for sulphate, nitrate and ammonium in mg $SO_4.l^{-1}$, mg $NO_3.l^{-1}$ and $NH_4.l^{-1}$ instead of mg SO_4-$S.l^{-1}$, mg NO_3-$N.l^{-1}$ and NH_4-$N.l^{-1}$. The various procedures and results are described in detail in Annex 3.

A summary of the results, focusing on a comparison between the checks on the cation-anion balance and the conductivity in 1996 and 1997 is given in Table 5.2.

Table 5.2 Percentage of measurements in an acceptable[1)] range with respect to the difference in cation-anion balance and calculated versus measured conductivity.

Type of measurement	Cation-anion balance (%)		Conductivity (%)	
	1996	1997	1996	1997
Bulk deposition	49	51	54	62
Throughfall	58	49	63	69
Stemflow	60	48	74	70

[1)] For both the cation-anion balance and the conductivity, the acceptable range was set at ±20%

The results show a decrease in data quality in 1997 compared to 1996 when considering the cation-anion balance check. Only 50% of the data was in an acceptable range. Results for the conductivity check slightly improved in 1997 compared to 1996, with 60-70% of the measurements in acceptable range. A strict comparison of both years cannot be made, since the number of samples on which the checks were carried out mostly increased by a factor of two.

Since sea spray is the most important source of Na and Cl at most of the plots (especially near the coast), the Na/Cl ratio should resemble that of sea water (approximately 0.86 $mol_c.mol_c$). On an annual basis, a range of 0.5-1.0 is common. A comparison of the Na/Cl ratios in 1996 and 1997 is shown in Fig. 5.3.

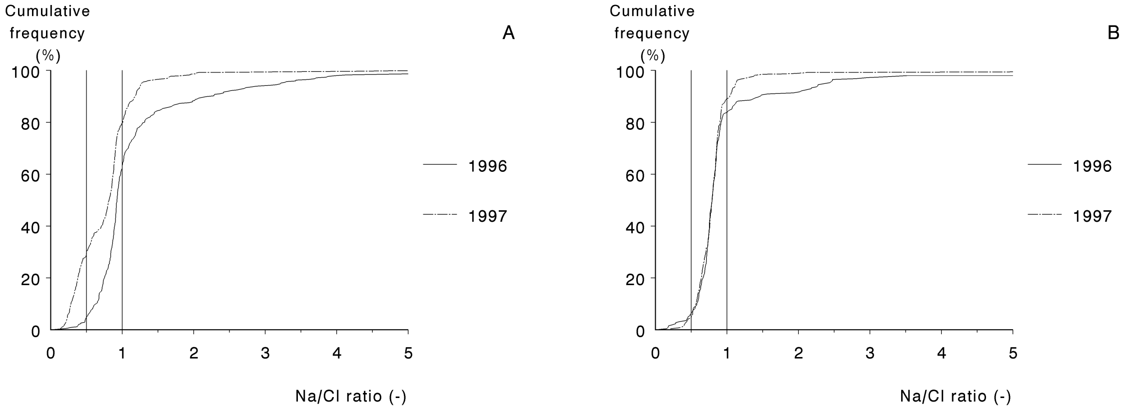


Figure 5.3 Cumulative frequency distributions of the Na/Cl ratios in 1996 and 1997 based on annual average concentrations in bulk deposition (A) and throughfall (B).

Results show that in 1997 the Na/Cl ratio was within this range at approximately 50% of the plots for bulk deposition and 84% for throughfall (Fig. 5.3). In 1996 this number was 58% and 77%, respectively. High values were, however, observed less frequently in 1997 indicating that Na contamination might be limited this year. Again, a strict comparison can not be made considering the increase in plots in 1997 compared to 1996.

5.2.4 Data evaluation methods

Calculation of annual fluxes of bulk deposition, throughfall and stemflow

Annual deposition fluxes of the major ions were calculated by multiplying the biweekly or monthly precipitation amounts (in mm) by the ion concentrations ($meq.m^{-3}$) and summing up to one year. Calculations were only made if measurements were available for at least 75 % of the year; otherwise the data were not used. In case of missing data, the total flux and average concentration for the entire year were computed by assuming that the deposition in the period without data was equal to the average deposition in the rest of the year.

Stemflow was only measured at a limited number of plots (Section 5.2.1). At plots where such information was missing, the annual stemflow was estimated from the annual throughfall according to Ivens (1990), as described in the previous Technical Report (De Vries et al., 1999).

Calculation of annual total deposition from bulk deposition, throughfall data and stemflow

Total deposition was derived by correcting the input by both throughfall and stemflow for exchange processes occurring at the forest canopy. This was done by adapting a canopy budget model, developed by Ulrich (1983) and extended by Bredemeier (1988), Van der Maas et al. (1991) and Draaijers et al. (1994), according to:

$$BC_{td} = \frac{Na_{tf} + Na_{sf}}{Na_{bd}} \cdot BC_{bd} \tag{5.1}$$

$$SO_{4,td} = SO_{4,tf} + SO_{4,sf} \tag{5.2}$$

$$NO_{3,td} = NO_{3,tf} + NO_{3,sf} \tag{5.3}$$

$$NH_{4,td} = NH_{4,tf} + NH_{4,sf} + NH_{4,ce} \tag{5.4}$$

$$H_{td} = H_{tf} + H_{sf} + H_{ce} \tag{5.5}$$

with:

$$BC_{ce} = BC_{tf} + BC_{sf} - BC_{td} \tag{5.6}$$

$$NH_{4,ce} = \left(\frac{NH_{4,tfbd}}{NH_{4,tfbd} + H_{tfbd} \cdot f_H} \right) \cdot BC_{ce} \tag{5.7}$$

where

$$NH_{4,tfbd} = (NH_{4,tf} + NH_{4,bd})/2 \quad (5.8)$$

$$H_{tfbd} = (H_{tf} + H_{bd})/2 \quad (5.9)$$

and

$$H_{ce} = BC_{ce} - NH_{4,ce} \quad (5.10)$$

where:
BC = base cations (Ca+Mg+K)
tf = throughfall ($mol_c.ha^{-1}.yr^{-1}$)
sf = stemflow ($mol_c.ha^{-1}.yr^{-1}$)
td = total deposition ($mol_c.ha^{-1}.yr^{-1}$)
bd = bulk deposition ($mol_c.ha^{-1}.yr^{-1}$)
ce = canopy exchange ($mol_c.ha^{-1}.yr^{-1}$)
f_H = an efficiency factor of H in comparison to NH_4

More information on the assumptions and weaknesses of this approach were presented in the previous Technical Report (De Vries et al., 1999).

An independent estimate of the total deposition of oxidised and reduced nitrogen was obtained by using empirical results of the Integrated Forest Study (IFS) reported by Johnson and Lindberg (1992) for spruce and spruce-fir forests, according to:

$$N_{td} = 1.69 \cdot (N_{tf} + N_{sf}) + 91.9 \quad (5.11)$$

In calculating the canopy uptake of N (NH_4) for spruce/fir forests we took the minimum of Eq. (5.7) and Eq. (5.11) with an absolute minimum and maximum of 100 and 800 $mol_c.ha^{-1}.yr^{-1}$, respectively. For all other forests, Eq. (5.7) was used to calculate the NH_4 canopy uptake with an absolute minimum and maximum of 100 and 400 $mol_c.ha^{-1}.yr^{-1}$, respectively. More information about the approach was given in De Vries et al. (1999).

Assessments of relationships between atmospheric deposition and stand / site characteristics

An overview of the expected relationships between stand and site characteristics and atmospheric deposition has been given in Section 3.3.1 (see also Fig. 3.1). Apart from region (differences in air pollution levels) and altitude, the throughfall (total deposition) flux is largely influenced by the tree species (e.g. Draaijers et al., 1992), tree height (e.g. Stevens, 1987) and canopy coverage (e.g. Draaijers et al., 1992) which all affect the surface roughness and canopy exchange. Canopy coverage is in turn related to indices for stand density and stand structure. When using throughfall data, soil type may also influence the results of base cations, as it affects the internal cycle in the ecosystem of these elements. The influence of stand and site characteristics on the selected key parameters for atmospheric deposition was tested by means of multiple regression approaches (Section 3.3.3). Since the available information on stand height, stand density index and stand structure index was very limited at the plots where atmospheric deposition was measured, those variables were not included in the analyses. The regression models were thus of the following general type:

$$\begin{aligned}\log(\text{key parameter}) = {} & f_1\,(\text{geographic region}) + f_2\,(\text{altitude}) + f_3\,(\text{tree species})\\ & f_4\,(\text{stand age}) + f_5\,(\text{precipitation})\end{aligned} \tag{5.12}$$

The logarithmic transformation was performed because most deposition data had a skewed log-normal distribution. The key parameters used were the measured throughfall fluxes of SO_4, NO_3 and NH_4 and the calculated total deposition fluxes of Ca, Mg and K. With respect to SO_4, NO_3 and NH_4, throughfall was assumed to be representative for total deposition. The reason for not using the calculated total deposition of NH_4 is because of the uncertainties associated with calculating NH_4 uptake. The canopy uptake of SO_4 and NO_3 is likely to be small.

5.3 Results and discussion

5.3.1 Ranges and geographic variation in bulk deposition, throughfall and total deposition

A summary of the results of annual deposition fluxes of major ions in 1996, as presented in the previous Technical Report (De Vries et al., 1999), and in 1997 is presented in Table 5.3. Results show a significant higher deposition of N compounds and a significant lower input of SO_4 in 1997 compared to 1996. Changes in the Ca fluxes, being the major cation neutralising the acid input, were comparatively small.

Table 5.3 Ranges in the annual SO_4, N and Ca fluxes ($mol_c.ha^{-1}.yr^{-1}$) by bulk deposition, throughfall and total deposition in 1996 and 1997.

	Year	No of plots	SO_4 flux			N flux			Ca flux		
			5%	50%	95%	5%	50%	95%	5%	50%	95%
Bulk deposition	1996	270	108	496	1355	99	434	1127	29	334	1352
	1997	402	111	422	1220	134	733	1615	42	284	1415
Throughfall	1996	165	97	547	2806	57	561	3058	41	313	1402
	1997	267	114	478	1628	55	719	2072	62	379	1049
Total deposition	1996	165	111	595	3104	74	902	3316	35	202	968
	1997	267	126	533	1779	117	1111	2827	52	298	968

The difference between 1996 and 1997 is influenced by the increase in the number of plots in 1997 compared to 1996. The differences in fluxes between the two years may also have been influenced by different meteorological circumstances. Strict comparison requires the same number of plots in both years. Results of such a comparison are presented in Table 5.4. This table shows a slight decrease in the deposition of both SO_4 and N, whereas Ca input stays relatively constant. This demonstrates convincingly that the increased number of plots, specifically in Germany, leads to a different ratio between the N and SO_4 input compared to 1996.

Table 5.4 Ranges in the annual SO_4, N and Ca fluxes ($mol_c.ha^{-1}.yr^{-1}$) by bulk deposition, throughfall and total deposition in 1996 and 1997.

	Year	No of plots	SO_4 flux			N flux			Ca flux		
			5%	50%	95%	5%	50%	95%	5%	50%	95%
Bulk deposition	1996	335	124	459	1251	115	514	1247	39	281	1219
	1997	335	144	431	1229	142	730	1658	42	285	1705
Throughfall	1996	224	127	595	2215	71	824	2367	50	388	1058
	1997	224	144	490	1609	64	764	2297	64	404	1041
Total deposition	1996	224	150	685	2619	132	1293	3150	42	253	835
	1997	224	155	548	1789	124	1186	2885	53	311	936

More specific information on the bulk deposition, throughfall and total deposition in 1997 is given below.

Bulk deposition

Bulk deposition of SO_4 varied mostly between 100 and 1200 $mol_c.ha^{-1}.yr^{-1}$ and for N between 100 and 1600 $mol_c.ha^{-1}.yr^{-1}$ (approximately 90% of the values). The bulk deposition of acidity, being the sum of both compounds, minus the input of base cations corrected for chloride (Ca+Mg+K+Na–Cl), ranged from less than 0 (the input of base cations is higher than the deposition of SO_4 and N) to more than 2000 $mol_c.ha^{-1}.yr^{-1}$ (Fig. 5.4A). Ca, that neutralises the potential acid input, varied mostly between 50 and 1400 $mol_c.ha^{-1}.yr^{-1}$ (Fig. 5.4B).

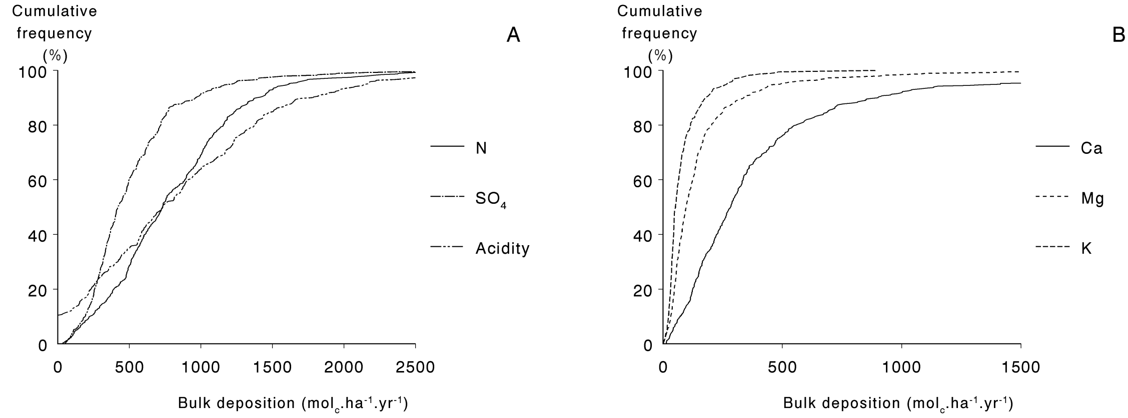


Figure 5.4 Cumulative frequency distributions of the bulk deposition of SO_4, N and acidity (A) and of base cations (B) at 402 Intensive Monitoring plots.

The influence of geographic region on the annual average bulk deposition fluxes is illustrated in Table 5.5.

Table 5.5 Annual average bulk deposition fluxes of major elements as a function of geographic region

Region	N[1]	Bulk deposition flux ($mol_c.ha^{-1}.yr^{-1}$)						
		SO_4	NO_3	NH_4	Ca	Mg	K	Na
North/Boreal	44	173	108	91	62	81	33	337
North/Boreal temperate	25	295	251	220	215	215	41	287
West/Atlantic	53	458	285	431	200	188	53	715
Central/East	240	636	394	589	685	152	99	199
South/Mediterranean	39	460	297	413	487	194	110	400

[1] N = number of plots; total = 402. One plot is located in the Azores with no information on climatic region.

As with the results in 1996, the data show that the deposition of all compounds is lowest in Northern Europe. There is a clear gradient in the deposition of SO_4 and N compounds and of Ca, going from Northern Scandinavia (Boreal) to Southern Scandinavia (Boreal Temperate) to Western, Central and Eastern Europe. The deposition of Ca and K is highest in Central/Eastern Europe and in the Mediterranean area, whereas Na is most important in countries located near the sea (Western Europe and the Mediterranean area).

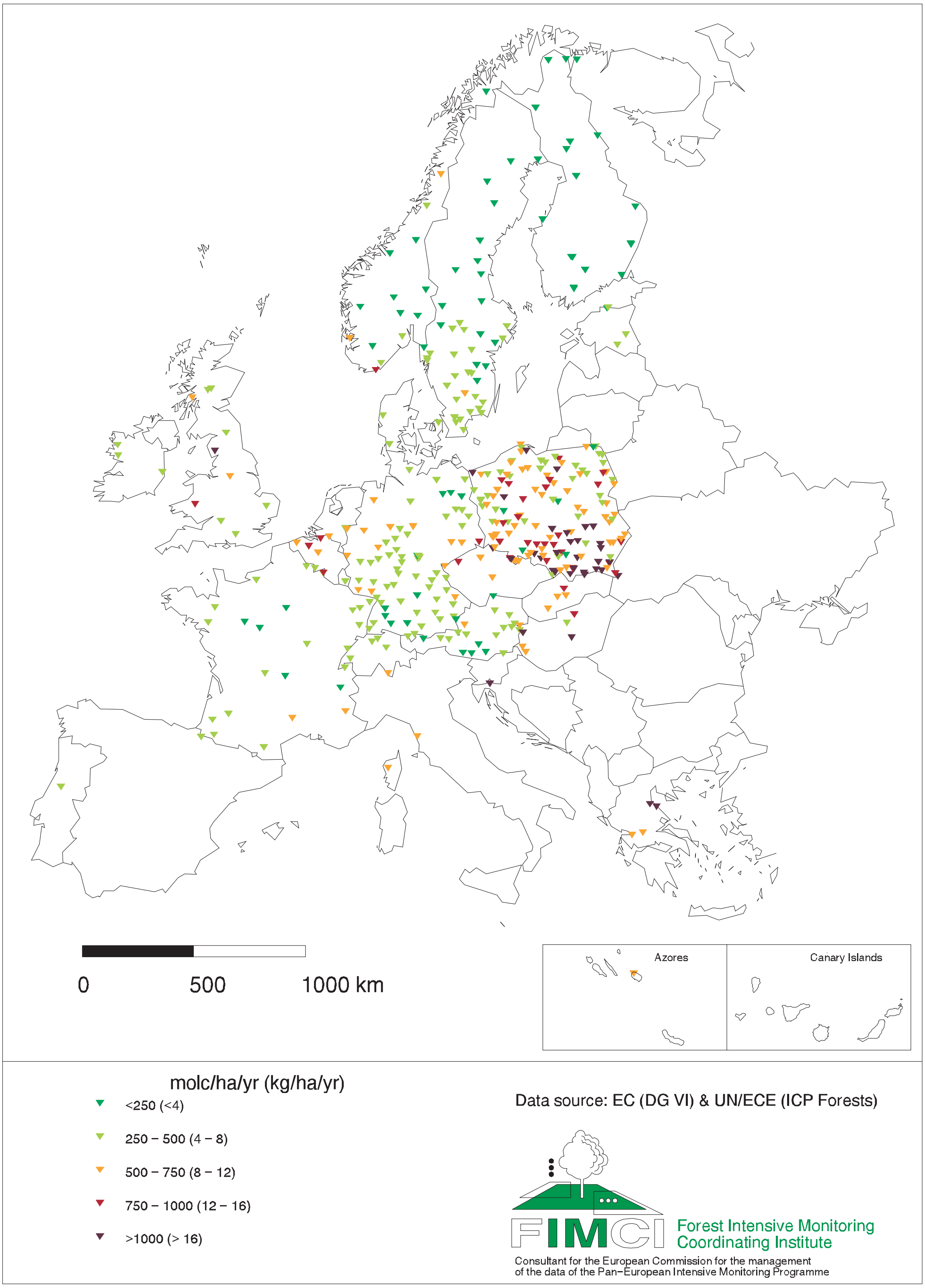
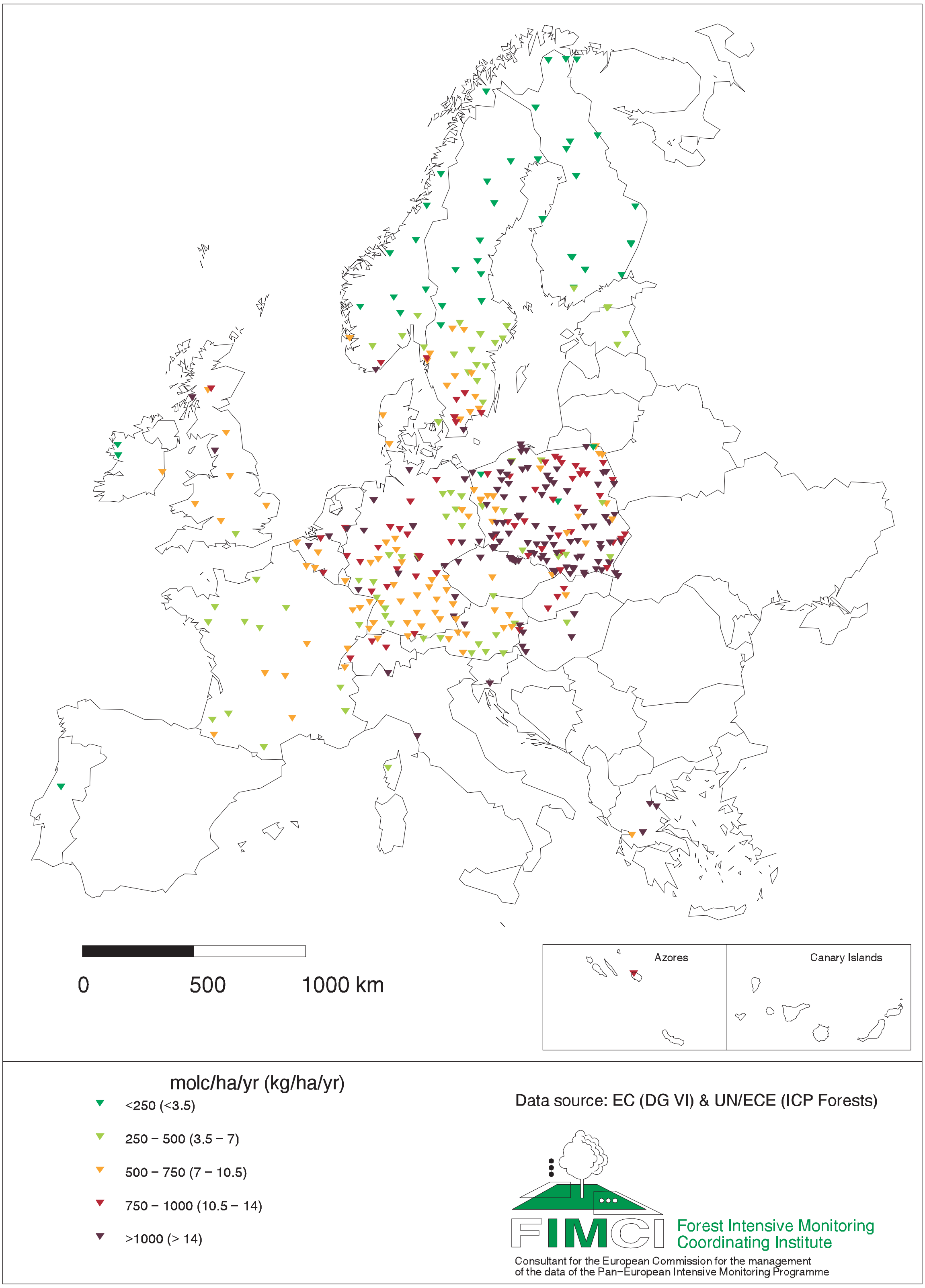


Figure 5.5 Bulk deposition of SO_4 at Intensive Monitoring plots in 1997



Data source: EC (DG VI) & UN/ECE (ICP Forests)

Figure 5.6 Bulk deposition of N at Intensive Monitoring plots in 1997

The influence of geographic region is also illustrated on maps of the bulk deposition of SO_4 (Fig. 5.5) and N (Fig. 5.6) at the Intensive monitoring plots. As with the maps shown in the previous Technical Report (De Vries et al., 1999), the figures show low deposition values (<250 – 500 $mol_c.ha^{-1}.yr^{-1}$) of both SO_4 and N at plots in Northern Europe, with the exception of some plots in the southernmost part of Norway and Sweden.

Unlike the results for 1996, bulk N deposition appeared to be higher than bulk SO_4 deposition at nearly all the plots. In 1996, bulk deposition of N was mainly higher than SO_4 deposition at plots in Western Europe (UK, Belgium, Netherlands, Luxembourg, France), whereas the reverse was generally observed at plots in Central Europe (Poland, Czech Republic, Austria, Hungary).

Throughfall

Throughfall fluxes of N and SO_4 were only slightly higher than for bulk deposition. Approximately 90% of the values varied between 100 and 1600 $mol_c.ha^{-1}.yr^{-1}$ for SO_4 and between 50 and 2000 $mol_c.ha^{-1}.yr^{-1}$ for N (Fig. 5.7A). Throughfall fluxes for base cations were quite comparable to bulk deposition, with the exception of K, which was much higher (Fig. 5.7B).

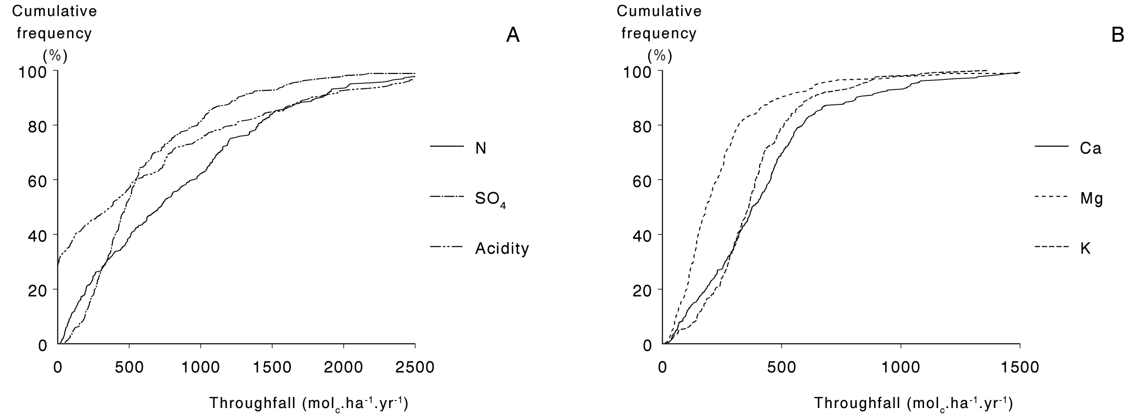


Figure 5.7 Cumulative frequency distributions of the throughfall of SO_4, N and acidity (A) and of base cations (B) at 267 Intensive Monitoring plots.

As with bulk deposition, the throughfall fluxes for SO_4 and NO_3 were highest in Central/Eastern Europe, but NH_4 deposition was slightly higher in Western Europe (Table 5.6).

Table 5.6 Annual average throughfall fluxes of major elements as a function of geographic region

Region	N[1)]	Throughfall flux ($mol_c.ha^{-1}.yr^{-1}$)						
		SO_4	NO_3	NH_4	Ca	Mg	K	Na
North/Boreal	44	212	76	52	107	132	193	488
North/Boreal temperate	25	357	154	102	292	254	279	419
West/Atlantic	60	770	366	613	431	395	469	1209
Central/East	98	850	691	603	550	204	412	264
South/Mediterranean	39	508	363	411	596	263	471	404

[1)] N = number of plots; total = 267. One plot is located in the Azores with no information on climatic region.

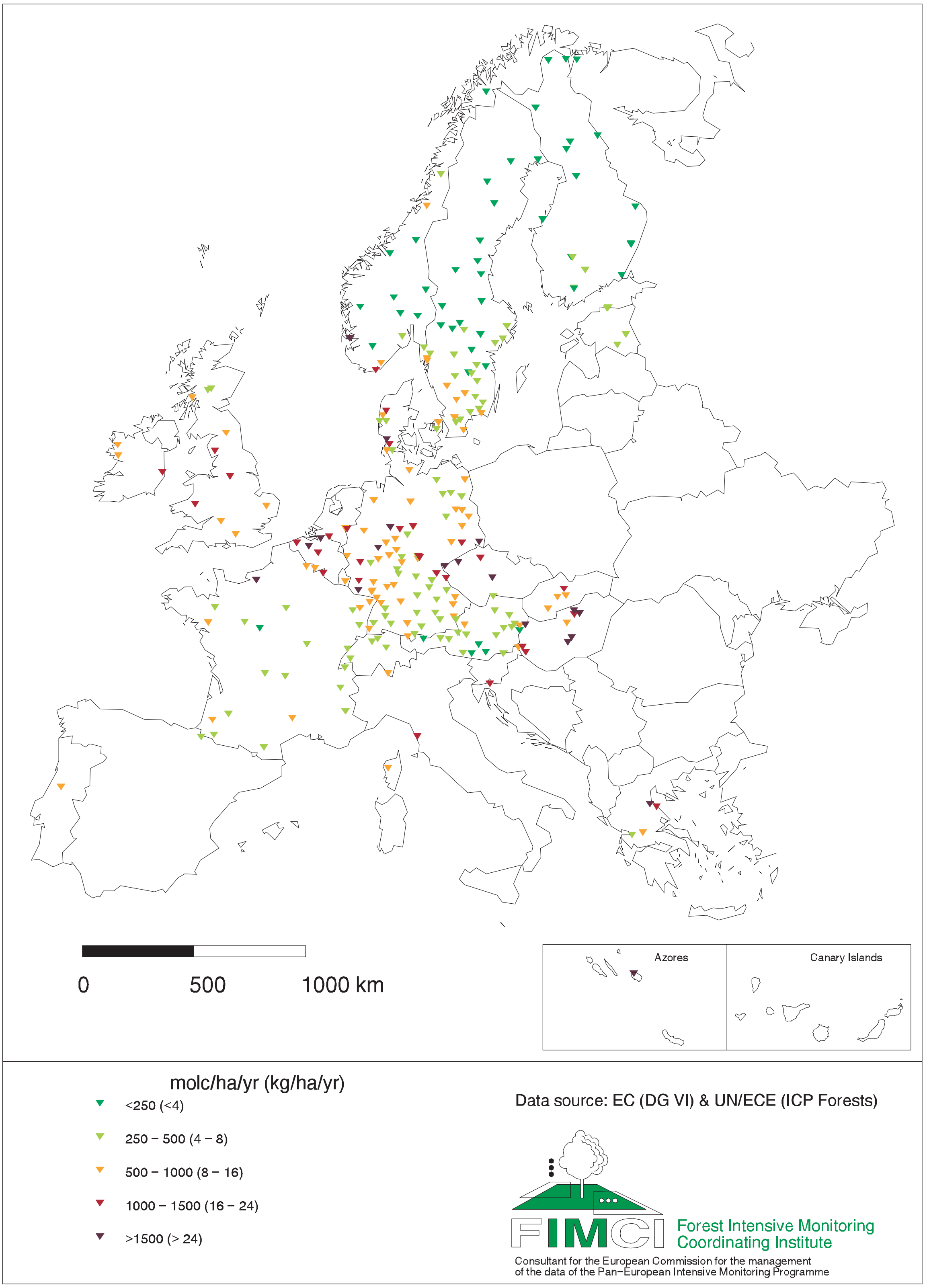


Figure 5.8 Throughfall of SO_4 at Intensive Monitoring plots in 1997

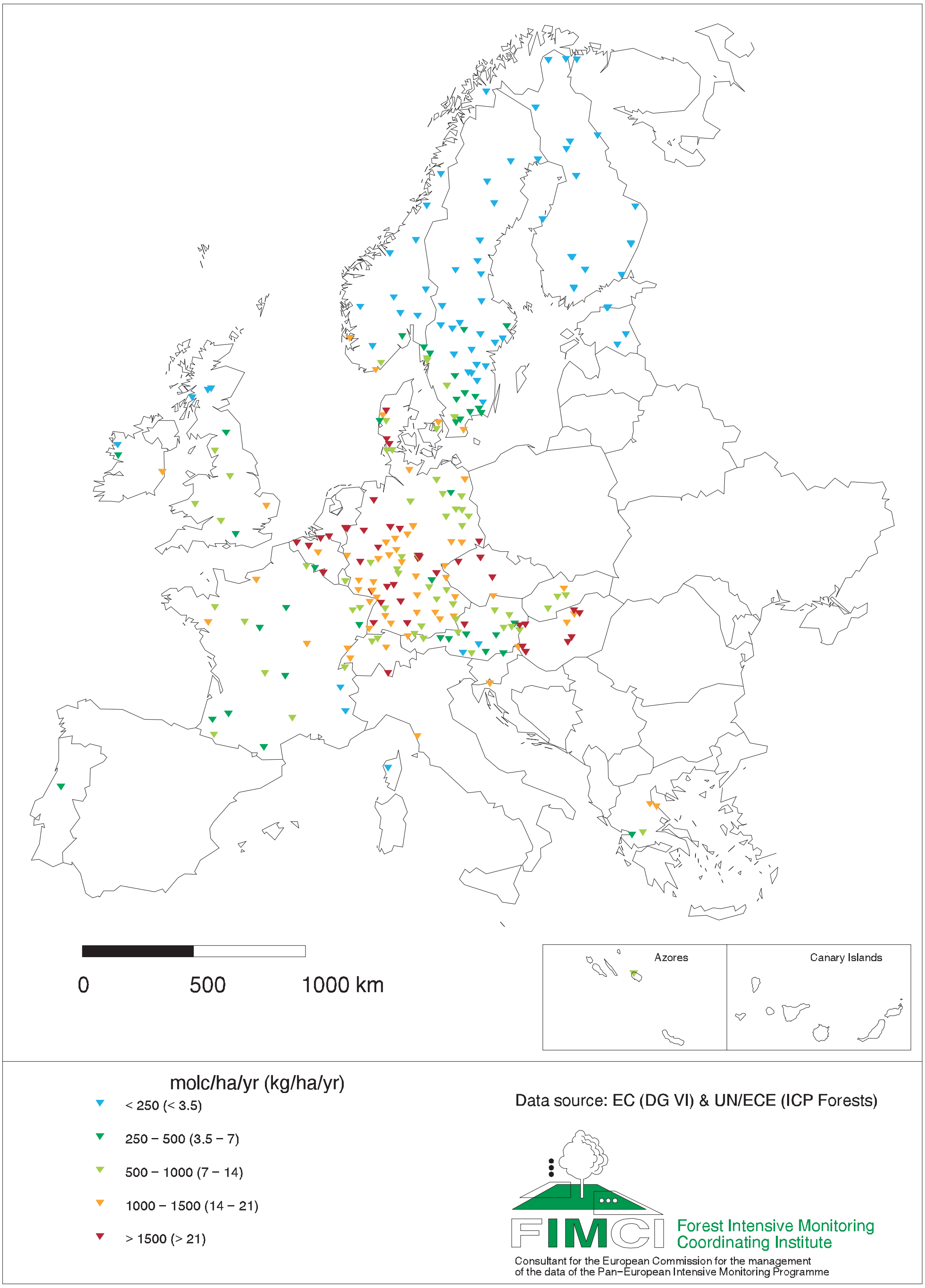


Figure 5.9 Throughfall of N at Intensive Monitoring plots in 1997

This differs from 1996, in which NH_4 deposition was significantly higher at the plots in Western Europe (De Vries et al., 1999). Going from 1996 to 1997, however, the number of plots in Western Europe stayed the same (60 plots), whereas it increased from 26 to 98 plots in Central/Eastern Europe, due to the inclusion of Germany. It is clear that N deposition in this country is relatively high, specifically when compared to SO_4 deposition. This result illustrates that conclusions about the influence of a region has to be considered with care, due to the uneven representation of plots in the various regions. The geographic variation of throughfall fluxes of SO_4 and N compounds is further illustrated in Fig. 5.8 and Fig. 5.9, respectively.

Results show high inputs of both SO_4 and N at plots in the Netherlands, Belgium and Luxembourg but also in the Czech Republic, Slovak Republic and Hungary. This illustrates that high deposition of SO_4 is generally associated with an increased N deposition (see also Section 5.3.2). In Central Europe the acidic input is largely set off by the input of base cations.

Total deposition

Ranges in total deposition of SO_4 and NO_3 are comparable to those in throughfall, since the input of both compounds by stemflow is only 10% of the input by throughfall. The total SO_4 deposition mostly ranged between 100-2000 $mol_c.ha^{-1}.yr^{-1}$, whereas the total N deposition varied between 100-3000 $mol_c.ha^{-1}.yr^{-1}$ at most of the plots (Fig. 5.10A). Due to canopy uptake of NH_4, the calculated total deposition of NH_4 and N was much higher than in throughfall. Median values for N input increased from 719 $mol_c.ha^{-1}.yr^{-1}$ for throughfall to 1111 $mol_c.ha^{-1}.yr^{-1}$ for total deposition (from approximately 10-15.5 $kg.ha^{-1}.yr^{-1}$) (Fig. 5.10A). The total input of acidity ranged mostly between 200-4000 $mol_c.ha^{-1}.yr^{-1}$.

For the base cations, the ranges in total deposition values were more comparable to bulk deposition than to throughfall (mostly between 100 and 2000 $mol_c.ha^{-1}.yr^{-1}$ for the sum of Ca, Mg and K) indicating the less significant contribution of dry deposition compared to SO_4 and N compounds (Fig. 5.10B).

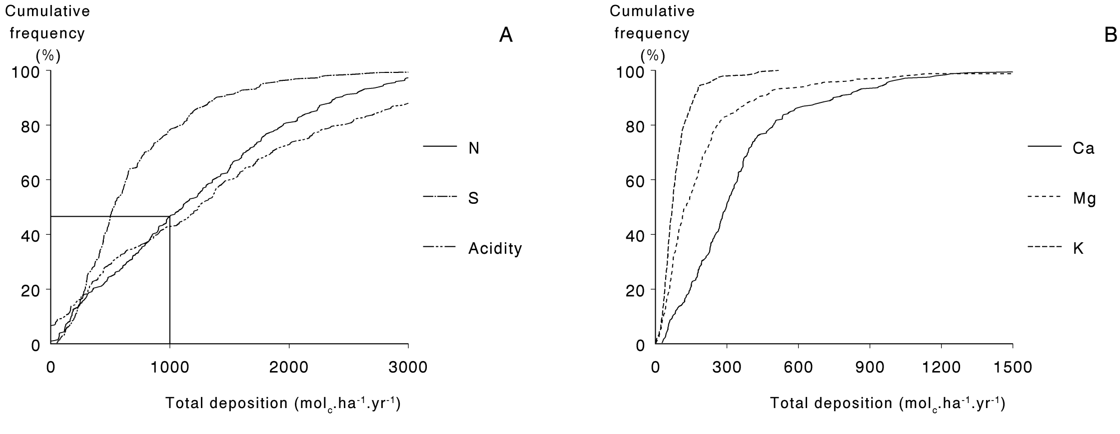


Figure 5.10 Cumulative frequency distributions of the total deposition of SO_4, N and acidity (A) and of base cations (B) at 244-266 Intensive Monitoring plots, depending on the element.

Approximately 55% of the considered plots get an external N input above 1000 $mol_c.ha^{-1}.yr^{-1}$ (Fig. 5.10A), being a critical load related to a decrease in species diversity of the ground vegetation of forests (approximately 15-20 $kg.ha^{-1}.yr^{-1}$; Bobbink et al., 1996). A similar percentage was found in 1996. Present loads above 1500-3000 $mol_c.ha^{-1}.yr^{-1}$ may have adverse impacts on tree health, such as nutrient unbalances and increased shoot-root ratios causing drought stress. This depends amongst others, on the relative contribution of NH_4 and NO_3 deposition, the nitrification rate and buffer rate of the soil and the tree species (De Vries, 1993; Bobbink et al., 1996). On the other hand, one has to be aware that N loads below e.g. 1000 $mol_c.ha^{-1}.yr^{-1}$ may hamper tree growth due to N limitation.

Critical acid loads, related to an increased ratio of Al to the base cations Ca, Mg and K vary mostly between 1500 and 3500 $mol_c.ha^{-1}.yr^{-1}$, depending mainly on the buffer rate of the soil and the sensitivity of the tree species to elevated Al/(Ca+Mg+K) ratios (De Vries, 1996). A specific comparison of present loads and critical loads is needed to get insight in the possible exceedance of critical acid loads since total atmospheric deposition on most of the plots varied between this range. Data on the present Al/(Ca+Mg+K) ratios in soil solution at part of those plots do, however, indicate that the acid input causes exceedances of the critical Al/(Ca+Mg+K) ratio in 30-39% of the cases, depending on the layer considered (Section 9.3.1).

The impact of geographic location on total deposition fluxes is comparable to bulk deposition, despite the much lower number of plots in Central/Eastern Europe (Compare Table 5.6 and 5.7). Major differences between bulk and total deposition occur for NH_4, which is approximately twice as high in total deposition than in bulk deposition. Total deposition data may, however, been biased by the calculation procedure.

Table 5.7 Annual average total deposition fluxes of major elements as a function of geographic region

Region	N[1)]	Total deposition flux ($mol_c.ha^{-1}.yr^{-1}$)						
		SO_4	NO_3	NH_4	Ca	Mg	K	Na
North/Boreal	37-44	233	84	156	97	129	51	537
North/Boreal temperate	25	399	172	250	300	298	69	464
West/Atlantic	52-60	912	431	1104	367	332	96	1458
Central and East	92-98	941	757	1001	454	138	95	298
South/Mediterranean	38-39	562	394	805	464	198	109	451

[1)] N = number of plots; total = 244-266, depending on the element. One plot is located in the Azores with no information on climatic region.

5.3.2 Ion ratios in bulk deposition, throughfall and total deposition

Sulphur versus nitrogen compounds

As with the results from the previous year, a significant correlation was found between the input of N and SO_4 at the various Intensive Monitoring plots (Fig. 5.11). The percentage variance accounted for in linear regression relationships equalled 62% for bulk deposition (52% in 1996), 62% for throughfall (51% in 1996), 48% for stemflow (69% in 1996) and 55% in total deposition (63% in 1996). The regression relationships appeared to be comparable to 1996. In that year, however, the average N input in bulk deposition and throughfall equalled the SO_4 deposition, whereas the mean values now equal 1.61 for bulk deposition and 1.31 for throughfall (indicating N uptake). The N to SO_4 ratios ranged from approximately 0.5 to 2.5 (Table 5.8). Assuming that the calculated N uptake rates are reasonable, the average N to SO_4 ratio in total deposition is nearly 2.0. This result is only slightly influenced by the different number of plots for total deposition (251) compared to throughfall (266).

Table 5.8 Ranges in the N to SO_4 ratio in bulk deposition, throughfall and total deposition at the Intensive Monitoring plots.

Statistic	N/SO_4 ratio		
	Bulk deposition (N = 401)	Throughfall (N = 266)	Total deposition (N = 251)
mean	1.61	1.34	1.86
5%	0.73	0.32	0.57
50%	1.63	1.21	1.70
95%	2.35	2.60	3.88

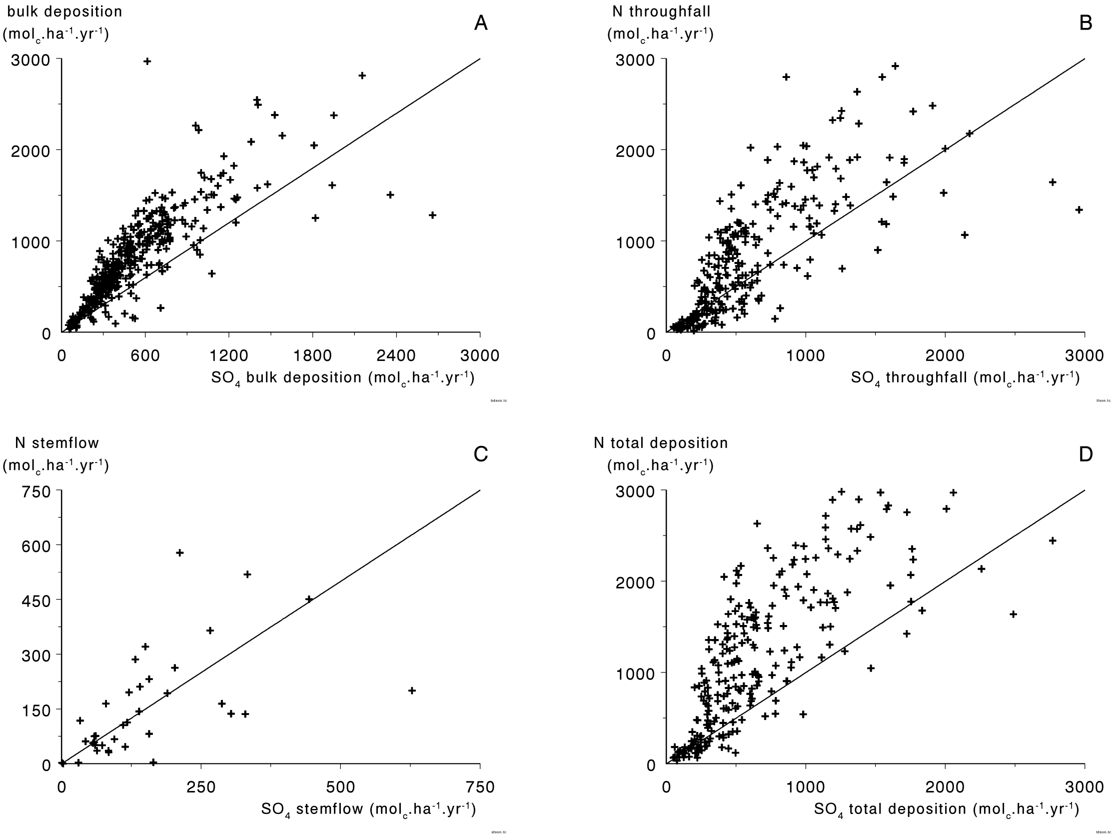


Figure 5.11 Relationships between the annual fluxes of N and SO_4 in bulk deposition plots (A; 401 plots), throughfall (B; 266 plots), stemflow (C; 38 plots) and total deposition (D; 251 plots). The solid line represents the 1:1 line.

The higher N deposition than SO_4 deposition at most of the plots is a striking result. In the eighties, SO_4 emissions were generally considered the most important cause of acid deposition. However, since then SO_4 emissions and thereby SO_4 deposition have strongly decreased over large parts of Europe whereas NO_x emissions decreased more slightly and NH_3 emissions mostly stayed constant. This causes N to be a dominating factor in the acidic input in large parts of Europe. The relationship between N and SO_4 deposition points toward co-emission from SO_x (mainly industry), NO_x (mainly traffic) and NH_x (mainly agriculture) in industrialised areas. Furthermore, the correlation between the input of NH_4 and SO_4 (not shown) may be influenced by co-precipitation of both ions (e.g. Van Breemen et al., 1982).

The relative contribution of NH_4 and NO_3 in N deposition varies largely over the plots (Table 5.9) but in general there is a weak but significant correlation between both N compounds (Fig. 5.12).

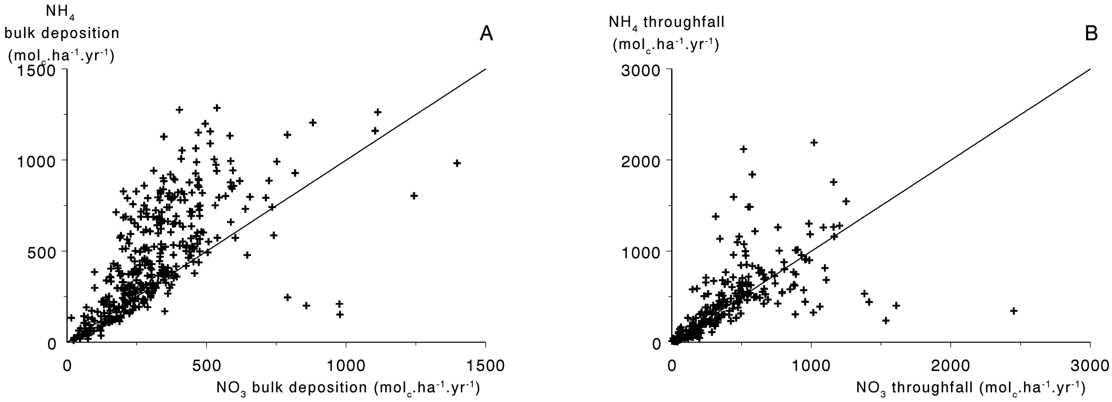


Figure 5.12 Relationships between the annual fluxes of NH_4 and NO_3 in bulk deposition (A; 401 plots) and throughfall (B; 266 plots). The solid line represents the 1:1 line.

Unlike the previous year, the NH_4/NO_3 ratios were higher in bulk deposition than in throughfall. In 1996, the average NH_4/NO_3 ratio in bulk deposition was approximately 1.0, whereas the present ratio is 1.5 (Table 5.9). The lower ratio in throughfall (1.14) indicates the preferential uptake of NH_4. The NH_4 to NO_3 ratio in total deposition is likely to be even higher than for bulk deposition, but this ratio has not been given considering the uncertainties in the assumption that all N is taken up as NH_4. The percentage of variance accounted for in the relationships between NH_4 and NO_3 equalled 32% for bulk deposition (was 27% in 1996) and 35% for throughfall (was 37% in 1996).

Table 5.9 Ranges in the NH_4 to NO_3 ratio in bulk deposition, throughfall and stemflow at the Intensive Monitoring plots.

Statistic	NH_4/NO_3 ratio		
	Bulk deposition (N = 401)	Throughfall (N = 266)	Stemflow (N = 37)
mean	1.51	1.14	1.40
5%	0.65	0.36	0.28
50%	1.36	0.99	1.08
95%	2.74	2.56	4.09

Base cations versus acidic compounds

Whether the input of SO_4 and N compounds from the atmosphere causes acidification is strongly influenced by the deposition of accompanying base cations. The relationship between Cl corrected base cation deposition (Ca + Mg + K + Na – Cl) and the sum of N and SO_4 deposition at the Intensive Monitoring plots is low, especially for total deposition (Fig. 5.13). The input of base cations counteracting the SO_4 and N input is relatively higher in bulk deposition (Fig. 5.13A) than in the total deposition (Fig. 5.13B). This is due to the larger input of dry deposition of SO_4 and N compounds compared to base cations.

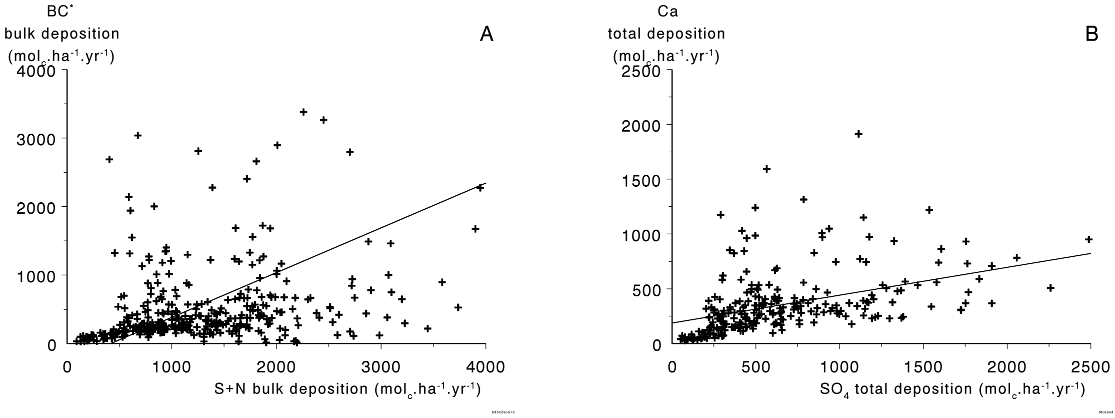


Figure 5.13 Relationships between the annual fluxes of chloride corrected base cations (BC^*) and SO_4+N in bulk deposition (A; 402 plots) and total deposition (B; 245 plots). The solid line represents a regression line.

A more significant relationship was observed between the deposition of Ca and SO_4 in total deposition. The percentage variance accounted for in linear regression relationships was 41% for bulk deposition (40% for the results in 1996) but only 20% for total deposition (57% in 1996). The latter result is, however, influenced by the calculation procedure and may not adequately present total deposition data. The correlation may partly be due to associated emissions of SO_2 and Ca from smelters and refineries, whereas recent investigations also indicate co-precipitation of Ca and SO_4. In general, highest correlations were found in Central Europe. In Mediterranean countries, the sources of base cations generally differ strongly (e.g. Saharan dust) from those of sulphur (e.g. SO_4 emissions).

An overview of the ranges in the ratios between base cation inputs and SO_4 and N inputs (Table 5.10) further illustrates that the impact of base cations on the potential acid input can be very large at certain plots. It sometimes can lead to a negative acid input, since the base cation deposition is larger than the sum of SO_4 and N deposition.

Table 5.10 Ranges in BC^* (chloride corrected base cation) to SO_4+N ratios and Ca/SO_4 ratios in bulk deposition and total deposition at the Intensive Monitoring plots.

Statistic	BC^* to SO_4+N ratio		Ca/SO_4 ratio	
	Bulk deposition (N = 393)	Total deposition (N = 245)	Bulk deposition (N = 402)	Total deposition (N = 253)
mean	0.47	0.42	0.85	0.64
5%	0.06	0.08	0.24	0.20
50%	0.29	0.24	0.58	0.48
95%	1.48	1.19	2.60	1.71

5.3.3 Relationships between atmospheric deposition and environmental factors

Results of a multiple regression analysis of the deposition data on the various environmental factors is shown in Table 5.11. The regression analysis included both qualitative variables (geographic region and tree species) and quantitative variables (altitude and precipitation) as described in Section 5.2.4. The results for the geographic region are related to Western Europe (Atlantic region), while the effect of the tree species is related to pine forests.

Table 5.11 Overview of the predictor variables explaining the deposition of SO_4, NO_3, NH_4, N, Ca, Mg, K and BC (sum of Ca, Mg and K).

Predictor variables	SO_4	NO_3	NH_4	N	Ca	Mg	K	BC
Region								
West Atlantic$^{1)}$								
North/Boreal	--	--	--	--	--	--	--	--
North/Boreal temperate	--	--	--	--				
Central/East	++	++	++	++	+	-		
South/Mediterranean					+		+	+
Precipitation	++		++		+	++	++	++
Site/stand								
Altitude	--		--			--	--	--
Stand age	--				--	-	-	--
Tree species$^{1)}$	+				--		+	++
N$^{2)}$	252	252	251	251	195	195	190	190
R^2_{adj} (%)$^{3)}$	55	62	70	68	58	36	28	47

++ significant at the p 0.01 level and t>3 and positive correlated with response variable

\+ significant at the p 0.05 level and t>2 and positive correlated with response variable

-- significant at the p 0.01 level and t>3 and negative correlated with response variable

\- significant at the p 0.05 level and t>2 and negative correlated with response variable

1) Reference is pine forest in the Atlantic region. A + for tree species indicates that deposition is higher for spruce forests and/or deciduous forests.

2) N = number of plots.

3) R^2_{adj} = percentage variance accounted for.

The variation in deposition explained by the included environmental factors is mostly above 50% for SO_4 and N compounds and for Ca (55-70%). The explanation is significantly higher than in 1996, especially for SO_4 and N compounds (in that year, the values for R^2_{adj} ranged from 35-42% for those compounds; De Vries et al., 1999). Comparable to the results from 1996, the region explains most of the variation. As with the Tables 5.5-5.7 presented before, the regression results indicate that atmospheric deposition of all ions is significantly lower in the Boreal regions compared to Western Europe (the Atlantic region), with the exception of Ca, Mg and K deposition in southern Sweden and southernmost Norway (Boreal temperate). This holds also for Central/Eastern Europe (Subatlantic/Continental region) and Southern Europe (the Mediterranean region). Another clear result is that SO_4, NO_3 and Ca deposition is significantly higher in the Central/Eastern and in the West Atlantic part of Europe compared to the rest of Europe.

The strong positive correlation of all deposition variables with precipitation, except for NO_3 and N, indicates the increase in wet deposition with an increase in rainfall. The results furthermore indicate that altitude is significantly negatively correlated with atmospheric deposition, except for NO_3 and Ca. Impacts of tree species on the element deposition is mostly low in this dataset, since geographic region overwhelms the variation. The influence of trees on deposition can also be an artefact due to the correlation between tree species and region. The significant negative relationship between age and atmospheric deposition of sulphur and base cations is unlike the expectations, considering that tree height is positively correlated with stand age. It might be due to an increased defoliation of older trees. Again, however, there is also a possibility of confounding. In general it is both the region and precipitation that explains most of the variation. A separate analyses, in which only annual deposition data were used for which the difference between the sum of cations and anions was within 20%, gave similar results. The number of plots reduced to approximately 50% (129 plots for SO_4 and N compounds and 108 plots for base cations) and the value of R^2_{adj} was within 3%. Only for Mg the value of R^2_{adj} increased from 36% to 49%.

5.4 Conclusions

Atmospheric deposition data for 1997 at the Intensive Monitoring plots have been evaluated in view of (i) the order of magnitude of atmospheric inputs in view of critical loads, (ii) the relative contribution of N and SO_4 compounds and of base cations in the atmospheric input and (iii) relationships between atmospheric deposition and environmental factors. A similar evaluation was done in 1996. Major conclusions related to differences between both years are given below.

Ranges and geographic variation of atmospheric inputs in view of critical loads

A comparison of the inputs at the same plots shows a slight decrease in both the SO_4 and N input. Both bulk and total deposition of N appeared to be higher at nearly all the plots in 1997. This is unlike the results for 1996, where N inputs were mostly higher than SO_4 deposition at plots in Western Europe (UK, Belgium, Netherlands, Luxembourg, France), whereas the reverse was generally observed at plots in Central Europe (Poland, Czech Republic, Austria, Hungary).

Approximately 55% of the considered plots received a N input above 1000 $mol_c.ha^{-1}.yr^{-1}$, being a deposition level at which the species diversity of the ground vegetation may decrease. Below this deposition level tree growth may, however, be hampered. The total input of acidity was comparable in 1996 and 1997 and ranged mostly between 200-4000 $mol_c.ha^{-1}.yr^{-1}$. Considering a variation of critical acid loads of approximately 1500-3500 $mol_c.ha^{-1}.yr^{-1}$, elevated Al/(Ca+Mg+K) ratios are likely at part of the plots (see also Section 9.3.1).

The relative contribution of N and SO_4 compounds and of base cations in the atmospheric input

On average, the N input in bulk deposition and throughfall was approximately 1.5 times the SO_4 deposition. The average N to SO_4 ratio in the calculated total deposition was nearly 2.0, compared to 1.5 in 1996. As with previous year, the relative contribution of NH_4 and NO_3 in N deposition varied largely over the plots, but NH_4 was the dominating N compound at most of the plots. A clear relationship was observed between the (Cl corrected) base cation deposition and the sum of N and SO_4 deposition at the Intensive Monitoring plots, indicating that a larger buffering takes place in the atmosphere at increased emissions of SO_4 and N compounds. This is most likely due to associated emissions of SO_2 and Ca from smelters and refineries (coal burning) and possibly co-deposition of Ca and SO_4.

Relationships between atmospheric deposition and environmental factors.

As with the previous year, results of a multiple regression analysis showed that the geographic region has a dominant influence on the deposition data. The atmospheric deposition of all ions increased significantly going from the Northern Boreal regions to Western Europe. The deposition SO_4, NO_3 and Ca was significantly higher in the Central/Eastern part of Europe, but NH_4 was slightly higher in Western Europe. There was a highly significant positive correlation of atmospheric deposition and rainfall for all elements except for NO_3. The deposition of all compounds was significantly lower at higher altitudes with the exception of NO_3 and Ca. Using data of 1996, NO_3 deposition was also negatively correlated with altitude, illustrating that the different impacts of environmental factors on different ions should be interpreted with care.

6 Crown condition

6.1 Introduction

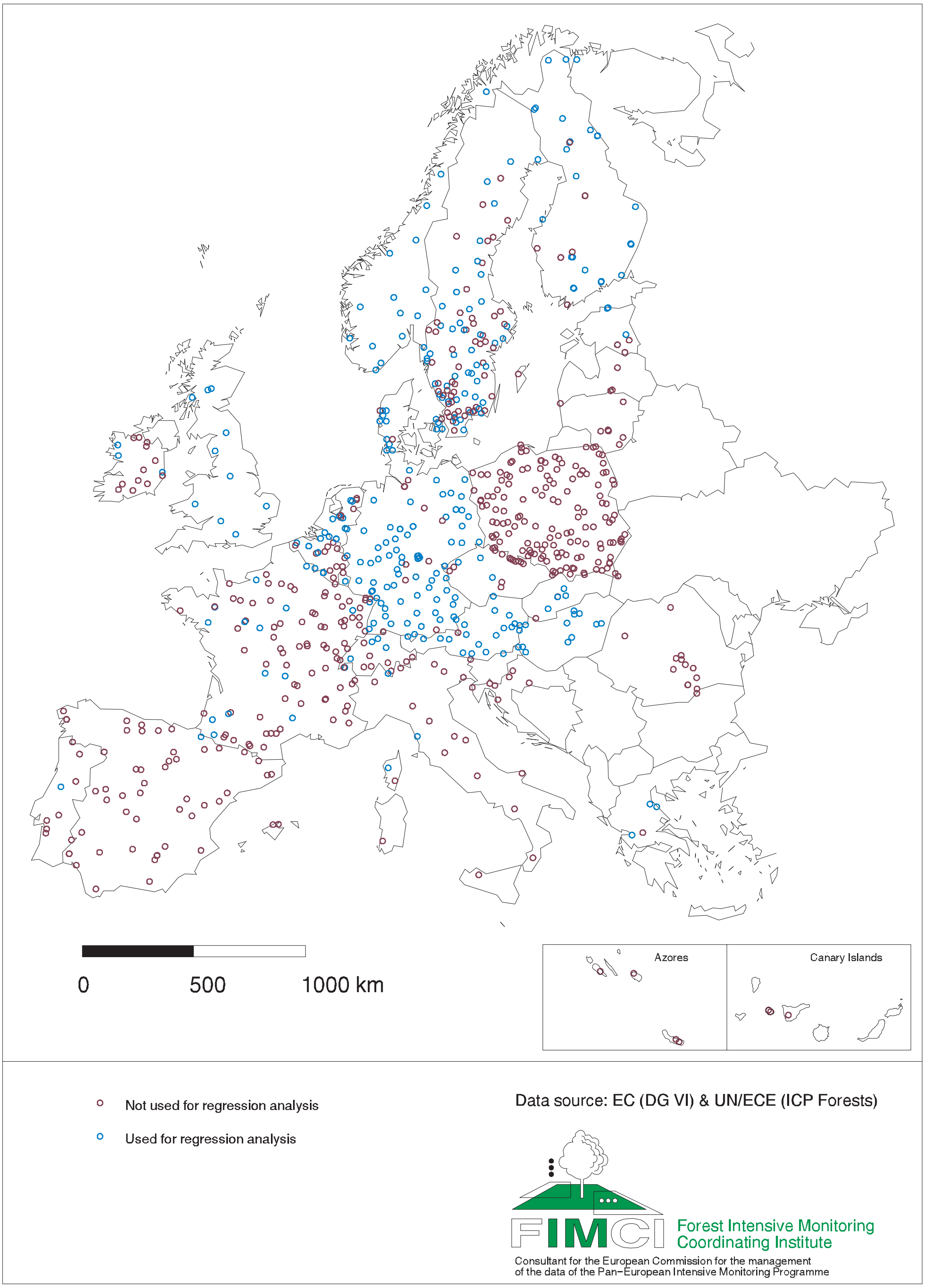
Crown condition, in terms of defoliation and discoloration, is assessed at all monitoring plots. Both defoliation and discoloration are considered as key parameters. This type of information has also been assessed at the systematic 16 x 16 km^2 grid in Europe since 1987. At the Intensive Monitoring plots, there are also a large number of additional parameters that may be assessed, but until now, only 8 countries submitted such optional data.

With respect to crown condition, it is important to ultimately concentrate the evaluation on changes over the years. The reason for this is that the absolute crown condition data can be influenced by differences in data assessment methods between the countries (e.g. Klap et al., 1997; 2000). At present, however, the number of assessment years is too low to allow such an evaluation. Therefore, the average defoliation of the different Intensive Monitoring plots, using all data up to 1997, was related to stand and site characteristics and major environmental (stress) factors. The approach was limited to four major tree species, i.e. pine, spruce, oak and beech. The advantage of this approach is that the average value gives a better indication of the geographic variation in defoliation than an actual value. The disadvantage is that the number of years that were used to calculate an average value differed between plots. In most cases, it referred to an average between 1995 and 1997. Environmental factors included nutrient availability in terms of foliar composition, atmospheric deposition and meteorological parameters. The latter data were partly derived from interpolation. An in-depth interpretation is still hampered by lack of information on stand history and a lack of other stress factors, such as pests and diseases and air quality, at most of the plots. The evaluation is limited to defoliation, which is the most important crown condition parameter.

6.2 Methodological aspects

6.2.1 Locations

The number of plots at which crown condition has been assessed increased from approximately 25 in the period 1990-1993 to 303 in 1994, 430 in 1995, 697 in 1996 and 714 in 1997. The total number of plots at which defoliation of the fout tree species at least once has been assessed up to 1997 equals 754. Fig. 6.1 shows the geographical distribution of all those plots. The map also shows the plots that were used in a multiple regression analysis, relating the average crown condition to environmental stress factors (262 plots). The geographical distribution of the "regression" plots is highly comparable to the geographical distribution of the plots where atmospheric deposition has been measured (see Fig. 5.1), since atmospheric deposition is generally the limiting environmental variable in the regression analysis (see also Section 6.2.4).



Data source: EC (DG VI) & UN/ECE (ICP Forests)

Figure 6.1 Geographical distribution of the Intensive Monitoring plots with crown condition assessments up to 1997.

6.2.2 Data assessment methods

DAR-Q information was available for 725 of the 754 plots with crown condition data up to 1997. On 64 plots (four countries) the DAR-Q information has been updated in 1997. This concerns 14 new plots on which crown condition is assessed for the first time and 50 plots with a change in methodology. The main changes are in the number of assessed trees, which are adjusted according to the Manual. The Manual states that in principle all trees in the (sub) plots are to be assessed.

The number of plots on which Kraft class 1, 2 and 3 are assessed has decreased somewhat (to 79%) in favour of the number of plots on which also subdominant trees (Kraft class 4) are assessed. This number has increased to 15% of the plots. With the changes in DAR-Q information also the information on the type of reference tree used, has slightly changed. For the 1997 assessments 73% local reference trees were used (75% in 1996) and 27% absolute reference trees (25% in 1996).

Easy identifiable causes of damage are assessed and recorded together with the crown condition assessments at most of the plots, but submitted information is very limited up to now. Especially biotic causes of damage (insects, fungi etc.) can be responsible for a large part of deterioration of crown condition and especially for large fluctuations in defoliation or discoloration. An aspect of the methodology that has not gained attention in the Technical Report yet is the direction of assessment of the trees. In many cases (e.g. mountainous locations or dense stands) the terrain conditions will force an assessment from a fixed direction. Biases can occur if trees are assessed from different directions at different years, because the condition of the crown may appear different according to the assessment position. This information is available in the information base.

6.2.3 Data comparability and data reliability

In this report we focus on data comparability in view of differences in assessment periods and assessed trees in the period 1994-1997. This is the period in which the number of assessed plots increased considerably (see Section 6.2.1).

Differences in the assessment periods

Periods of assessment are dependent on tree species and climate and on specific weather conditions in the assessment year. Time of the annual reassessment should, however, be similar each year. For broadleaves, where the assessment period is of considerable importance for defoliation and discoloration assessment, approximately 90% of the assessments were taken in July and August in the period 1994-1997 with the exception of 1996 in which only 77% of the assessments took place in this period. The assessment periods ranged from end of June to the middle of October (Table 6.1). For conifers, the assessment ranged from February to December but most assessments (65-85% depending upon the year) occurred in July and August (Table 6.1). Again, in 1996 the percentage of plots that were assessed outside this period was largest. Autumnal assessments (September or later) occurred relatively often for conifers. The autumnal assessments of broadleaves mostly refer to evergreen species, although a few assessments of deciduous species were even carried out in the beginning of October.

Table 6.1 Assessment periods used for the determination of defoliation between 1994 and 1997.

Assessment period	Number of plots							
	Conifers				Broadleaves			
	1994	1995	1996	1997	1994	1995	1996	1997
January	0	0	0	0	0	0	0	0
February	0	0	2	1	0	0	0	0
March	1	1	1	4	0	0	0	0
April	6	11	8	8	0	0	0	0
May	4	3	3	0	0	1	1	1
June	0	5	1	1	0	3	2	6
July	31	63	141	172	22	52	70	73
August	152	116	178	197	56	93	101	120
September	22	27	66	99	8	8	29	28
October	0	17	60	4	0	0	18	0
November	1	12	12	0	0	0	1	0
December	0	18	3	1	0	0	0	0
Total	217	273	475	487	86	157	222	228

Information about the changes in assessment dates between the years can only be made for plots where defoliation was assessed in both years (201 between 1994-1995, 429 between 1995-1996 and 680 between 1996-1997). Results (Fig. 6.2) show that differences of less than one month occur at ca. 80% of the observations for both conifers and broadleaves in the period 1994-1995 and 1996-1997. The changes were largest between 1995 and 1996 in which about 14% of the all plots were assessed more than 30 days later, whereas 12% were assessed more than 30 days earlier. The largest changes were found for coniferous plots. In many cases these large changes are due to adjustments in the prescribed periods in Manuals and Regulations. As such they imply an improvement in the data assessments. However, these changes may influence the comparability between 1995 and 1996 crown condition assessments. It is likely that large variations in the assessment date affect the results. For now, all results have been included in the evaluation.

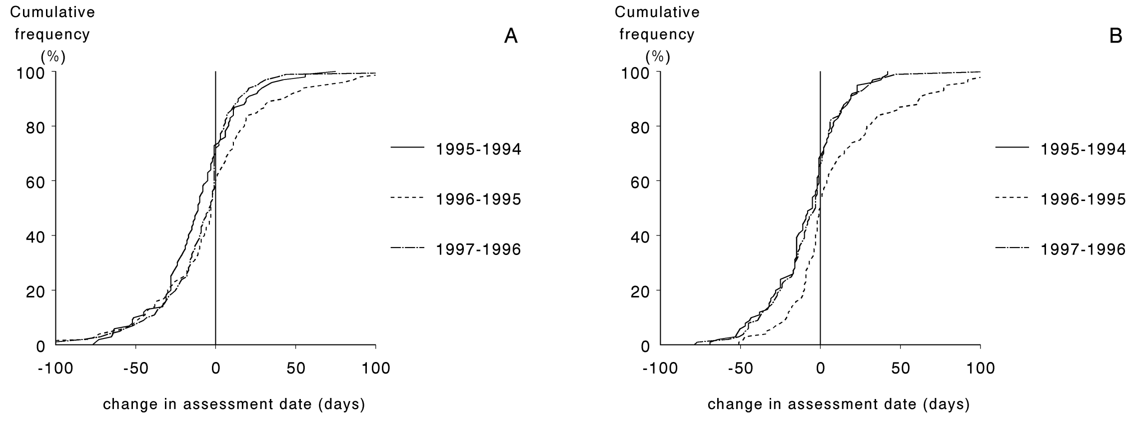


Figure 6.2 Differences in assessment periods for determination of defoliation between 1994 and 1997 for conifers (A) and broadleaves (B)

Difference in the number of assessment trees

The range in the number of selected assessment trees in the period 1994-1997 is given in Table 6.2. This number gives insight in the accuracy of the estimated average defoliation at the plot. When only a few assessment trees are selected, it may cause bias as these trees may not represent the health status of the whole plot or forest ecosystem adequately, nor is the future situation (time series) sufficiently guaranteed (Eichhorn, pers. comm.).

The percentage of plots with less than 20 assessment trees (given as minimum in the Manual for the assessment year 1996) increased from approximately 10% in 1994 to approximately 20% in 1996 and 1997 (Table 6.2). Inversely, the percentage of plots where over 40 trees were selected (indicated as 'preferred' in the Manual) increased from approximately 30% in 1994 to approximately 40% in 1996 and 1997. In 1995 this number was 46%, with only 2% of the Intensive Monitoring plots with less than 20 assessment trees (Table 6.2). Amendments in the EU Regulations and the ICP Forests Manual state that in principle all trees in the plot (or sub-plot) are to be assessed. These Amendments did not apply to the assessments up to 1996. As a result many countries still measured a fixed number of (selected) assessment trees in these years.

Table 6.2 Number of assessment trees used for the determination of defoliation between 1994 and 1997

Assessment trees	Number of plots			
	1994	1995	1996	1997
≤20	28	7	156	156
21-30	32	92	111	119
31-40	98	135	150	155
41-50	15	40	73	71
51-60	5	32	36	34
61-100	16	52	81	84
101-150	24	45	53	60
> 150	9	27	37	35
Total	227	430	697	714

Information about the changes in number of assessment trees between the years is given in Fig. 6.3. Results show that between 1994-1995 the same number of trees was used at more than 80% of the plots. In the period 1995-1997 this number equalled approximately 70%, with an additional proportion of more than 10% with an increase or decrease of less than 10 trees. The number of stands with a considerable increase or decrease in number of assessed trees was very small.

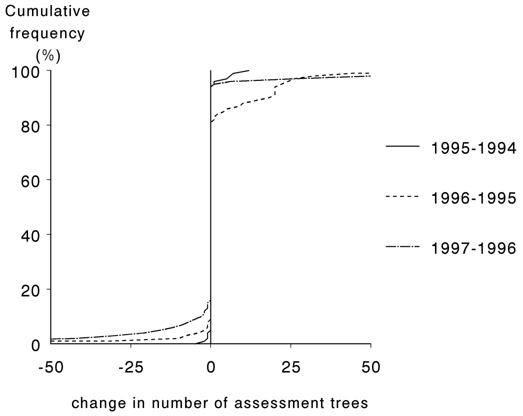


Figure 6.3 Differences in the number of assessed trees per plot used for the determination of defoliation between 1994 and 1997.

The number of trees that is required will depend on the within-plot variability (standard deviation) in crown condition (Section 3.2). Information on this variability can be assessed for each plot since data are available at the tree level. Results for 1995 (UN/ECE, EC; De Vries et al., 1998) showed a median value of 45% for the relative standard deviation. Assuming that the results for this year are representative, it implies that on average, 20 sample trees is a minimum for a reliable plot-mean value of the defoliation, accepting a margin of error of 20% (see Table 3.1). In general the variability in defoliation increases with age. A large increase in relative standard deviation implies that several hundreds of trees are needed for a reliable assessment (see also Table 3.1). For that reason it is relevant to assess crown condition for all trees in the plot as indicated in the amended EU regulation.

6.2.4 Data evaluation methods

The influence of the various environmental variables on the crown condition of four major tree species (pine, spruce, oak and beech; see also the grouping described in the Technical Report of 1998) was investigated by a multiple regression analysis. The various predictor variables used are: stand and site characteristics, meteorological parameters, the external input from the atmosphere and element concentrations in foliage. Those predictor variables were selected based on their availability and their expected influence on the crown condition (assessed by means of defoliation) of the trees. The predictor variables can be divided in natural and anthropogenic stress factors. For both groups hypotheses can be described that explain a decrease in crown condition.

Natural stress factors

The hypothesis of natural stress focuses on the adverse effects of unfavourable weather conditions, especially drought, and on pest infestations or fungi attacks as a major cause for damage (De Vries et al., 2000). Information on the presence and impact of pests and fungi is not submitted within the Intensive Monitoring Programme and could thus not be included in the regression. The influence of these biotic stress factors is generally expected to be larger on trees that are already affected by some other kind of stress factor and are thus more sensitive for insects or fungi. The outbreak of pests can also have a direct relation with specific weather conditions. Raitio and Kilponen (1999) mention the exceptionally high numbers of *Hymenoptera* and butterfly larvae obviously to be a result of a warm summer.

In the 1999 Technical Report (De Vries et al., 1999) the influence of meteorological stress factors is introduced and discussed within the scope of the Intensive Monitoring Programme. Very low and very high temperatures relative to ‘normal’ conditions at the site can cause stress and are in that way expected to have influence on the crown condition. High temperatures mainly affect transpiration rates and activity of enzymes. Such effects were found by Šrámek (1998). Low temperatures can cause damage in cases of severe or incessant winter frost through freezing or dehydration of needles and buds by which they can be damaged or die off. The effects described above imply that the influence of temperature is not unequivocal. At low temperatures, an increase in temperature may improve forest condition (e.g. an increased growth, related to a better crown condition), whereas the reverse may be true at high temperatures. In general, effects/risks are higher when the deviation from the optimal range is larger for a given species-site combination.

The impact of precipitation in terms of drought or excessive rainfall on crown condition is generally considered to be of importance. In a number of studies a significant relation is found between drought and crown condition. Solberg (1999a, b) expressed drought by means of both temperature and precipitation. The results of his study clearly supported the hypothesis that summer droughts increased senescent yellowing and needle losses during the following autumn. Klap et al. (2000) concluded that drought stress is an important predictor variable for the four major tree species in Europe. As with temperature, the impact of precipitation is not unequivocal. At low precipitation, an increase in precipitation may improve forest condition (e.g. an increased growth and crown condition related to a better water supply), whereas the reverse may be true at high precipitation due to water excess.

Antropogenic stress factors

The hypothesis of antropogenic stress strongly focuses on the relation between the emission of sulphur and nitrogen and its negative effect on the crown condition. These emissions are expected to have direct impact because of elevated concentrations of SO_2, NO_x and NH_3 in the air as well as an indirect soil mediated impact of S and N deposition. Emissions of air pollutants such as SO_2, NO_x and O_3 can affect the trees directly if concentrations reach levels toxic to the plants (Strand, 1997). Several effects can be distinguished: i) negative impact on the leaf cuticle/stomata causing physiological drought, (ii) carbon allocation shifts leading to a weakened root system and (iii) accelerated foliar leaching affecting the nutrient status (De Vries et al., 2000).

The hypothesis on the effect of N and S deposition on the crown condition focuses on the acidifying effect of both N and S compounds as well as on the eutrophication effect of nitrogen. The atmospheric deposition of sulphur and nitrogen compounds may lead to enhanced leaching of base cations, lowered pH (which influences mineralisation processes) and increased concentration of toxic aluminium in the soil, which in turn might effect the vitality of forest trees (Solberg and Tørseth, 1997). A negative impact is likely to occur in acidic soils, where toxic Al will be released in response to acid deposition, whereas the opposite may occur in base rich soils, where base cations will be released (see also Section 9.3). An increased nitrogen input may further lead to an improved N availability in nutrient poor forest ecosystems, thus increasing forest growth (Spiecker et al., 1996) and possibly also crown condition. High N inputs may, however, lead to the development of nutrient unbalances, i.e. the ratio between N and Ca, Mg and K will increase and eventually become unfavourable for tree growth and forest health (Strand, 1997). Furthermore, drought problems might occur since N input stimulates the growth of the canopy, but leaves the root system almost unaffected. The sensitivity of trees for natural stress factors such as frost and attacks of fungi might increase (De Vries et al., 2000). The impact of nitrogen and sulphur on forest is thus not unequivocal as it depends on the local circumstances (soil type, tree species) and the magnitude of the input. In other correlative studies (e.g. Klap et al., 2000 and Solberg and Tørseth, 1997) the impact of acid deposition was indeed not always unambiguous.

Regression analysis

Supposed regression relationships were of the form:

$$\mathrm{logit\,defoliation} = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \cdots\cdots + \alpha_n x_n \tag{6.1}$$

where logit defoliation is the expectation value of the response variable, x_1 to x_n are predictor variables and α_1 to α_n are the regression coefficients. The regression analysis was applied by using a so-called Select procedure (see Section 3.3.3). The various predictor variables used are summarised in Table 6.3. Logarithmic transformations were executed on all predictor variables, except for tree age and temperature.

The natural stress factors included are precipitation and temperature. It is expected that those parameters may have either a positive or a negative effect on crown condition, depending upon the range of the parameters, for reasons described before. The anthropogenic stress factors included are S and N in throughfall. High values of these parameters are expected to correlate with high defoliation. Air concentrations are not systematically assessed yet in the Intensive Monitoring Programme and therefore they have not been included in the regression analysis. Furthermore, the major nutrients in foliage are included, which do give information on the nutrient availability. The foliar composition can be considered both an effect parameter and a stress parameter. Higher concentrations of S and N together with lower concentrations of Mg, K, Ca and P are expected to be correlated to higher defoliation. Finally, soil acidity was included as a predictor variable.

Next to the above mentioned stress factors, a number of stand and site characteristics are included in the regression analysis. These characteristics are proofed to be of considerable importance for explaining the crown condition in relation to stress factors. Their impact is twofold. At first there might be an interaction with the stress factors. An example is the interaction between soil and deposition as given by Solberg and Tørseth (1997). Besides the interaction with stress factors, stand and site characteristics are expected to have a direct relation with the crown condition. Especially the relation between an increasing tree age and an increasing defoliation is found in a number of studies (Klap et al., 2000; Raitio and Kilponen, 1999; Solberg, 1999a).

Table 6.3 Overview of the predictor variables explaining crown condition (defoliation).

Type of variable	Predictor variable
Stand characteristics	Soil type, Age, Altitude
Meteorological parameters	Precipitation, Temperature
Throughfall fluxes	N, S
Foliar concentrations	N, P, S, Ca, Mg, K
Soil acidity	pH-$CaCl_2$

Results are limited to four major tree species, being pine, spruce, oak and beech, which predominate in Northern and Central Europe. The total number of plots with information on the defoliation of those tree species up to 1997 equalled 754, i.e. 315 for pine, 252 for spruce, 159 for oak and 135 for beech. The regression analyses were, however, only performed on plots where all information, mentioned in table 6.3, was available, except temperature data that were missing at most of the plots. The total number of plots used in the regression analyses was 222, i.e. 59 for pine, 99 for spruce, 33 for oak and 35 for beech. Temperature data were derived from interpolation of 30-year averaged data, which gives an impression of the average meteorological circumstances (After Leemans and Cramer, 1991). Actually, the derivation from the average situation is likely to be most important, but this information was not available at most plots. For precipitation, use was made of the results of bulk deposition monitoring for the period in which crown condition was assessed (if available for the whole period). Throughfall data were also averages for the period of crown condition assessment, when available. All annual data refer to calendar years (January - December).

6.3 Results and discussion

6.3.1 Ranges in defoliation and environmental factors affecting defoliation

In the regression analysis the average values over the number of assessed years of both the defoliation and the predictor variables per plot are used. In table 6.4 the ranges of these average values in defoliation and environmental factors are given. This is done to get insight in the range of predictor and response variables used in the regression analyses.

Table 6.4 Ranges (minimum-maximum) in defoliation and environmental factors affecting defoliation.

Variable	Pine	Spruce	Oak	Beech
Defoliation (%)	0 - 51	0 - 49	2 - 44	3 - 41
Stand characteristics				
Age (yr)	10 - 130	10 - 130	30 - 130	30 - 130
Altitude (m)	25 - 1075	25 - 1525	25 - 725	25 - 1525
Meteorology				
Precipitation (mm.yr^{-1})	298 - 1577	381 - 2045	580 - 1731	581 - 3001
Temperature (°C)	-1 - 15	-3 - 10	7 - 16	-1 - 16
Throughfall				
N deposition (mol$_c$.ha^{-1}.yr^{-1})	26 - 4490	19 - 3169	161 - 4056	511 - 2051
S deposition (mol$_c$.ha^{-1}.yr^{-1})	51 - 3183	67 - 2742	354 - 6347	360 - 1781
Foliage				
N concentration (g.kg^{-1})	10 - 24	9.4 - 18	12 - 39	19 - 32
P concentration (g.kg^{-1})	0.59 - 2.3	0.90 - 2.6	0.80 - 2.4	0.74 - 2.1
S concentration (g.kg^{-1})	0.78 - 1.7	0.59 - 1.6	0.77 - 3.3	1.2 - 2.1
K concentration (g.kg^{-1})	1.4 - 8.6	2.5 - 11	4.8 - 13	4.4 - 9.9
Ca concentration (g.kg^{-1})	1.0 - 5.9	1.2 - 10	2.6 - 15	2.0 - 14.1
Mg concentration (g.kg^{-1})	0.46 - 2.0	0.46 - 2.1	1.0 - 4.7	0.56 - 2.8

Table 6.4 shows that both the response and predictor variables covers a very large range, likely to cover the common variations within Europe. There are also clear differences between tree species. The highest amount of precipitation for instance is for pine only 56% of the highest amount for beech. And the range of N deposition for beech is much narrower (385 – 2217 mol$_c$.ha^{-1}.yr^{-1}) as it is for pine (26 – 4490 mol$_c$.ha^{-1}.yr^{-1}) and oak (161 – 4051 mol$_c$.ha^{-1}.yr^{-1}). This is likely to be due to the distribution of these tree species over Europe.

In addition figure 6.4 gives the frequency distribution of the average defoliation up to 1997 for all the plots (754) and the plots that are considered in the regression analyses (222). The figure shows that the ranges in defoliation at the regression plots for the pine and beech is comparable to those at all plots. For pine and oak, there are clear differences, the regression plots having less defoliation. Defoliation mostly ranged between 0 and 40%. The slope of the average defoliation for pine and spruce is steeper than for oak and beech indicating a higher average defoliation for the latter tree species.

6.3.2 Relationships between defoliation and environmental factors

Table 6.5 gives in summary the results of the regression analysis. The defoliation of the tree species could be explained for 30 – 50% by the predictor variables included. Apart from the well known effect of stand age, an additional 15-30% of the variation could be related to variation in meteorological variables, atmospheric deposition and foliar chemistry.

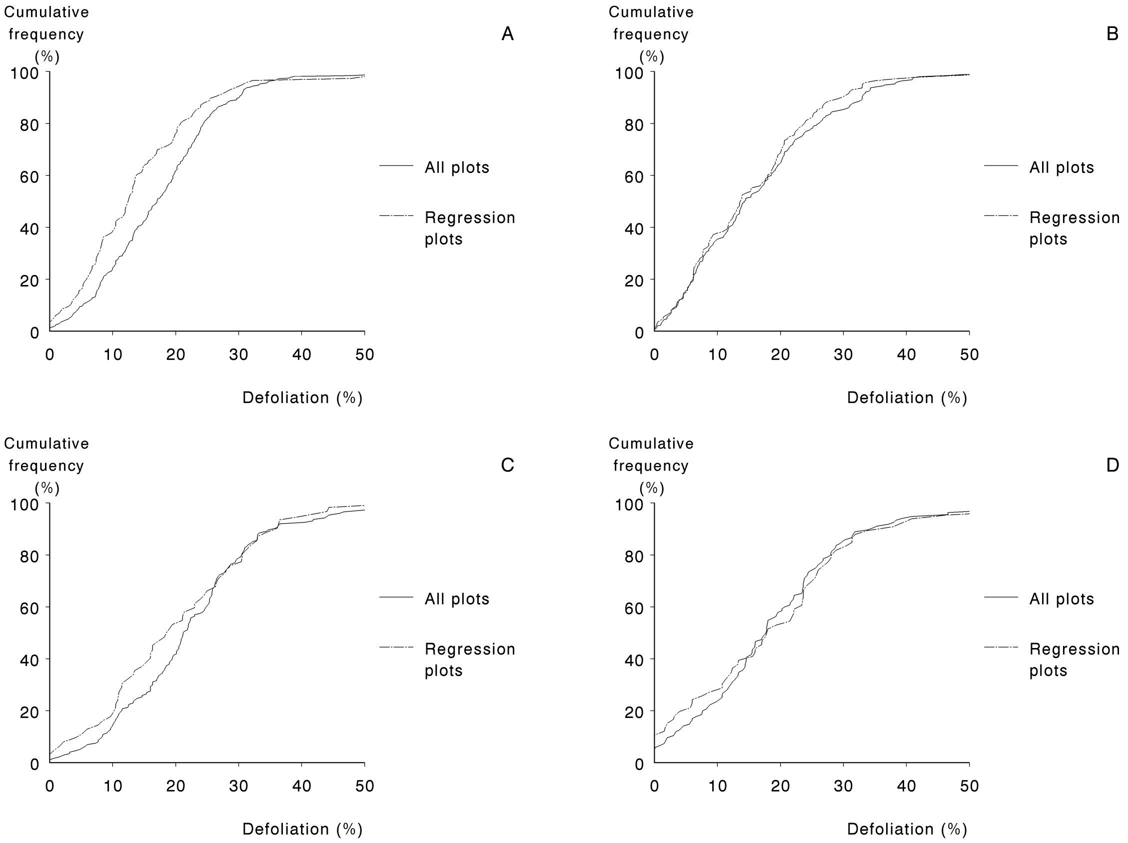


Figure 6.4 *Average defoliation of pine (A), spruce (B), oak (C) and beech (D) in all the crown condition plots (754) and in the plots were regression analyses was carried out (262).*

Most of the results of the regression analysis, as presented in Table 6.4, are in line with the hypotheses with respect to the impact of environmental factors on crown condition. The major results are given in the order: stand and site characteristics, natural stress factors and antropogenic stress factors.

Stand and site characteristics

As with previous studies, an increasing stand age was correlated with higher defoliation for all tree species. This effect is found in a number of other studies as a major explanation for variations in crown condition (See Seidling, 2000 for an overview of those studies). The relationship with stand age was highest for beech, explaining 36% of the variation in defoliation, lowest for pine (5%) and intermediate for spruce and oak (9% and 13%, respectively). As trees get older their defoliation generally increases regardless of other conditions due to a natural ageing effect. Soil type was significantly related to the defoliation of spruce. Defoliation was lower going from sandy soils to loamy/clayey soils. This effect can be explained by the increased water storage capacity and possibly also nutrient availability and acid buffering capacity of the latter soils. Altitude had no significant relation with defoliation. Actually, the impact of altitude might be confounded with temperature.

Table 6.5 Overview of the predictor variables explaining defoliation of 4 tree species of the Intensive Monitoring Plots with the number of plots (n) and the percentage variance accounted for ($R^2_{adj.}$).

Variable	Pine	Spruce	Oak	Beech
Stand characteristics				
Soil type		-1)		
Age (yr)	+	++	+	++
Altitude (m)				
Meteo				
Precipitation ($mm.yr^{-1}$)	+	--		
Temperature (°C)			-	--
Deposition				
N deposition ($mol_c.ha^{-1}.yr^{-1}$)		-	++	+
S deposition ($mol_c.ha^{-1}.yr^{-1}$)		++		
Foliage				
N concentration ($g.kg^{-1}$)	+			
P concentration ($g.kg^{-1}$)				
S concentration ($g.kg^{-1}$)				
K concentration ($g.kg^{-1}$)				
Ca concentration ($g.kg^{-1}$)		--	++	
Mg concentration ($g.kg^{-1}$)				
N	59	95	33	35
$R^2_{adj.}$	21	35	44	48

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable
1) A – implies that defoliation decreases going from sandy soils to loamy/clayey soils, whereas a + implies the opposite

Natural stress factors

As stated in the hypothesis, an increase in precipitation can both have a negative effect on defoliation, due to excessive rainfall, and a positive effect by reducing drought impacts. The local circumstances (soil, tree species etc) are expected to be of large influence on the impact of precipitation on the crown condition. This effect can be seen in the regression study. Higher precipitation was related to a significant lower defoliation for spruce, whereas the opposite was true for pine. The significance of the results for pine is, however, small and may be due to confounding with e.g. atmospheric deposition. The analysis indicates that spruce might, however, suffer from drought. This is also in line with the expectations as spruce is a species for humid locations. An increase in temperature was related to lower defoliation of deciduous trees.

Antropogenic stress factors

N and S deposition is mostly related to a higher defoliation. Increased SO_4 deposition has an adverse effect on the crown condition of spruce (increased defoliation). Higher N deposition is related to a higher defoliation of oak and beech, but the opposite is true for spruce. The possibility of both a positive and negative effect of increased N and S deposition was already mentioned in the hypotheses. In general, spruce forests are located on acid soils thus causing a release of Al in response to elevated S inputs. The positive impact of N deposition on spruce can also be explained by the fact that many spruce stands occur in Northern Europe where the N availability is low and a (relative) shortage of nitrogen does sometimes occur. Additional N input may thus cause an increased growth and decrease in defoliation. The negative correlation of N deposition with the defoliation of oak might indicate that N excess occurs at high N inputs. On the other hand, no impact of N deposition on the foliar N concentration of the deciduous trees was found (Section 7.3, Table 7.11), thus questioning the causality of this correlation.

The relations between foliar concentrations and defoliation were in general not significant. This seems not so strange, since the results of the foliar survey indicate that nutrient stress, due to a low availability occurs at a relative low number of plots (Section 7.3). A separate analysis in which qualitative variables were used for the foliar condition did, however, neither show a significant difference between the classes sufficient/insufficient and balanced/unbalanced with respect to the nutrient status (See also Section 7.2.4 for these classes). The concentrations of P, S, K and Mg were not related to defoliation. Only for Ca, a highly significant relationship was found with the defoliation of spruce and oak. For spruce, however, defoliation was significantly less at higher Ca concentrations, whereas the opposite was found for oak. The possible negative effect of a decrease in nutrient availability on crown condition was mentioned in the hypothesis. The result observed for spruce coincides with that of Cape et al. (1990), who found that low Mg concentrations and high N/Mg ratios were related to a poor crown condition (e.g. high degree of defoliation) for Norway spruce. The impact of nutrient ratios was not included in our study, because of the problem of confounding predictors. The negative effect of elevated Ca concentrations on the crown condition of oak can, however, not be explained.

6.4 Conclusions

The small data set, which is used for the regression analysis, especially for beech and oak, complicates drawing conclusions from the results obtained from the regression analyses. A confounding effect between certain predictor variables is hard to tackle and might occur sooner in a small data set. The effect of soil type on defoliation might for instance not always be distinguished because most plots of a certain species occur on one soil type. With an increase of the amount of data this effect will become smaller. Nevertheless, the following general conclusions can be drawn:

- Highly significant positive relations are found between defoliation and stand age in line with other studies. Stand age alone explained 5-36% of the variation in crown condition, depending on tree species.
- Apart from stand age, 15-30% of the variation in defoliation could be explained by the variation in precipitation, temperature, N and S deposition and foliar chemistry. This is much larger than the variation that could be explained at Level 1 plots using modelled deposition data, while excluding foliar composition (Klap et al., 2000). In that study, methodological differences among countries accounted for >30% of the variation in defoliation. Inclusion of this so-called country effect might be relevant in future regression analysis when the number of plots does allow this.
- Higher N and S deposition were related to a higher defoliation except for Spruce for which lower defoliation is related to higher N deposition. The effect of precipitation also varied. It sometimes caused higher defoliation, whereas sometimes the reverse is true. The negative effect may be due to excessive rainfall or release of toxic aluminium in response to acid deposition. Inversely, the positive effect may be due to lower drought stress or increased N availability in nutrient poor forests. This conclusion is in line with results from other correlative studies on the impact of acid deposition.
- Relationships between foliar concentrations and defoliation are generally not significant.

A more in-depth discussion about the validity of the presented results is given in Chapter 10. In general, one should be aware that a significant relationship does not necessarily mean a causal relationship.

7 Foliar condition

7.1 Introduction

Background

The chemical composition of the foliage of forest trees is an important indicator for the functioning of these trees, especially with respect to their nutrition. The foliage provides the photosynthetic capacity of the trees and a disturbance of the chemical composition of these organs may affect the health status (crown condition) and the growth of the trees. The concentration of elements (nutrients) and element ratios in foliage provides insight in the nutritional status of the tree in terms of deficiency or excess, either in an absolute sense or relative to the concentration of other elements. An optimum range of concentrations can be distinguished for all elements and ratios. With this respect, it should also be noted that the deposition of elements, which is generally considered as a risk, could be beneficial in production forests in which deficiency of this element occurs.

Since the first appearance of the symptoms of large-scale forest damage, disturbances in the tree nutrition in response to exposure to air pollutants and atmospheric deposition were considered one of the explanations for the visible symptoms of defoliation and discoloration. Based on a literature review, Roberts et al. (1989), for example concluded that spruce decline in Central Europe mainly results from foliar Mg deficiency. This deficiency was considered to be caused by a combination of (i) an increased Mg demand, due to an increased tree growth in response to elevated N inputs and (ii) a decreased Mg uptake, due to root damage caused by Al mobilisation in response to elevated acid inputs.

Foliar disturbances can also be considered as an autonomous effect of air pollution and atmospheric deposition on forest nutrition. Those effects interact with effects related to the chemical and physical status and the fertility of the site. Previous studies on single stands and previous regional studies showed that the following effects could be expected from atmospheric deposition of S and N compounds:

- enhanced N concentrations related to N deposition, causing enhanced growth (the fertilising effect of N deposition), increased sensitivity to drought, frost and diseases and elevated N leaching.
- decreased ratios of base cations to nitrogen caused by excess N uptake and/or enhanced growth, leading to an induced deficiency of base cations.
- an absolute deficiency of base cations caused by leaching of these elements from the soil and from the leaves and reduction in the uptake related to a smaller root system or uptake interactions with nitrogen or aluminium.

Apart from a description of the various methodological approaches that have been applied (Section 7.2), this chapter focuses on results with respect to:

- The range in the concentrations and ratios of major nutrients (N, P, S, Ca, Mg and K) in the foliage of the most representative tree species in Europe (pine, spruce, oak and beech) in view of critical levels (Section 7.3.1).

- The relationship between the foliar concentrations of major nutrients in the considered tree species as a function of stand age, meteorological parameters and nutrient availability in terms of chemical soil composition, and atmospheric deposition (Section 7.3.1).

7.2 Methodological aspects

7.2.1 Locations

Fig. 7.1 shows the geographical distribution of all the plots covered with pine, spruce, oak and beech (674) at which foliar analyses were carried out up to 1997. The map also shows the plots that were used in a multiple regression analysis, relating foliar concentrations to environmental stress factors (222). The geographical distribution of the "regression" plots is highly comparable to the geographical distribution of the plots where atmospheric deposition has been measured (see Fig. 5.1), since atmospheric deposition is generally the limiting environmental variable in the regression analyses (see also Section 7.2.4).

7.2.2 Data assessment methods

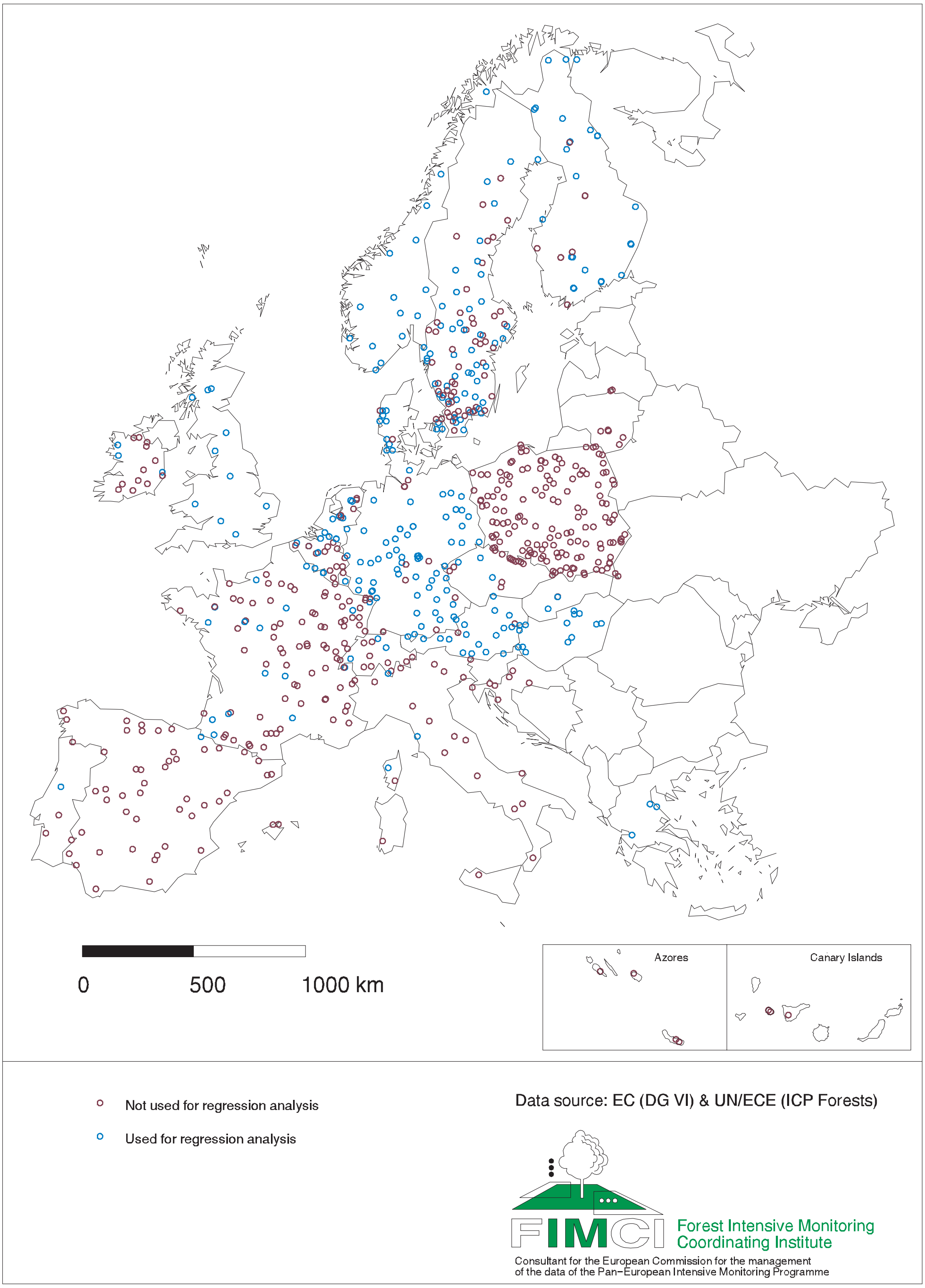
DAR Questionnaire information for the foliage inventory was stored for 25 countries. The method information applied to 683 Intensive Monitoring plots. The considerable increase compared to the previous (1995) survey on foliage (information on 517 plots) can largely be attributed to the submission of the Polish DAR-Q's for 148 plots. The information of data assessment methods presented below is based on 639 DAR-Q's.

Site selection and sampling devices/ preparation

In general, the sample trees were carefully selected to ensure a good representativity. A review of the selection criteria shows that for 91.1% of the plots trees were selected, using representative age, tree species, defoliation and sanitary status as criteria. The actual sample collection was done by climbing, use of pruning devices or shooting. Table 7.1 gives the number of plots on which these methods are used. The sample preparation consisted for all countries of grinding and drying. The drying temperatures varied from approximately 10 °C to 110 °C.

Table 7.1 Number of plots per sample collection method

Sample collection method	number of plots
Long pruning device	68
Long pruning device and climbing	101
Long pruning device and shooting	44
Climbing	269
Climbing and shooting	19
Shooting	130
No information	8
Total	639



Data source: EC (DG VI) & UN/ECE (ICP Forests)

FIMCI Forest Intensive Monitoring Coordinating Institute

Consultant for the European Commission for the management
of the data of the Pan–European Intensive Monitoring Programme

Figure 7.1 Spatial distribution of the plots at which foliar analyses were carried out up to 1997.

Digestion methods

The number of different methods (combinations of digestion and analysis methods) ranged between 18 and 26 per analysed key parameter. After lumping of extraction techniques (Fig. 7.2), it becomes clear that nitrogen was determined mostly by using Kjeldahl or elementar analysers (oxygen ashing). Applied digestion/extraction methods for P, K, Mg, Ca, Zn, Mn and Fe all were divided in a similar way. Extraction in microwave was applied most often (43-46%), followed by wet ashing (around 40%). Furthermore pressure bombs, dry ashing and pellet were applied. Sulphur was most often determined using wet ashing techniques (34%) and microwave extraction (33%). Oxygen ashing was used for 19% of the plots. Methods which appeared to give deviating results were wet ashing for N and P, dry ashing for Ca, Mg, K and S and oxygen ashing for S.

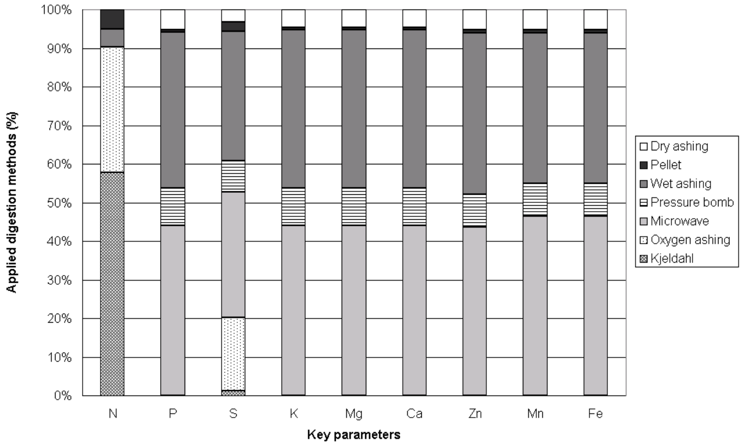


Figure 7.2 Applied digestion methods for foliage key parameters (in % of total number of foliar survey plots of which information was received).

7.2.3 Data reliability

Sampling numbers

The number of sample trees and the number of samples per tree are of influence on the representativity of the monitoring data. Results on the number of sampled trees are summarised in Fig. 7.3.

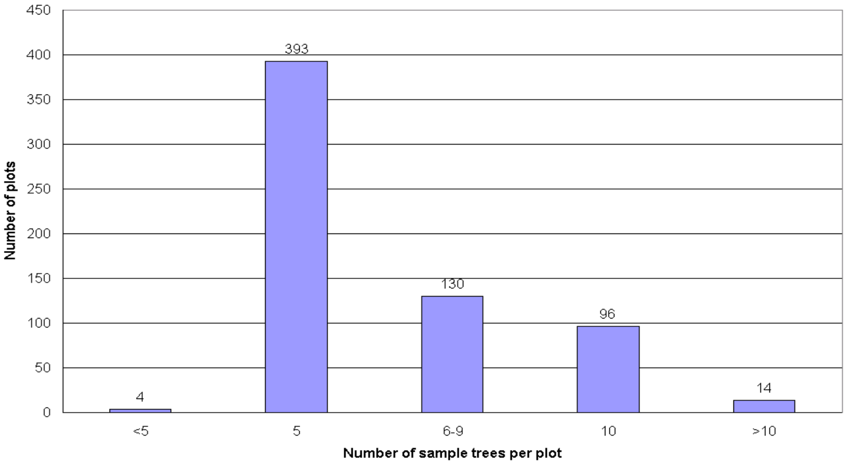


Figure 7.3 Number of sample trees used for the determination of foliar chemistry

On almost all plots the minimum number of 5 sample trees (as prescribed in the guidelines and manuals) were sampled. For 61% of the plots 5 trees were sampled, 6-9 trees were sampled on 20% of the plots, 10 trees on 15% of the plots, whereas 15-16 sampled trees were reported for 2% of the included plots. For 2 foliage plots no information on number of sample trees was submitted. On most plots with coniferous trees, samples were taken of both the current year and the second year needles. Results presented in this report, however, are limited to foliar concentrations in current year needles only.

Intercalibration tests

In the Technical Report of 1998 results were presented of the second Needle/leaf Interlaboratory Test of 95/96. The conclusions from that intercalibration test on foliar key parameters were that results were very good to good for N, P, Ca, K, Mg and Mn and acceptable for Fe, Zn and Cu (see De Vries et al., 1998; Stefan et al., 1997). It was furthermore concluded that the results for S are more problematic, especially for the lower values. Here, we present the results of the third Needle/leaf Interlaboratory Test of 97/98. In total 35 of the 43 laboratories reported in the DAR-Q's on foliar analysis (also those of which no data were used in this years analysis) participated in this test. In total 50 European laboratories participated. The results of the 3rd interlaboratory test (on all participating laboratories) showed that the comparability of the results for sulphur and copper were better compared to the 2nd test in 95/96. On the other hand the comparability of the results for phosphorus, calcium, magnesium, potassium and manganese got worse. The results of the test are summarised in figure 7.4.

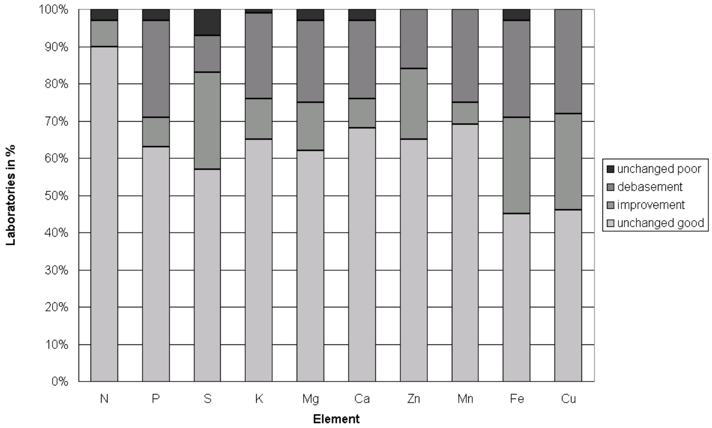


Figure 7.4 Results of the 3rd Interlaboratory test compared to the results of the 2nd test. (as presented on the 5th Expert Panel meeting 5/6 October 1998 in Vienna)

Of all foliar digestion methods the pressure digestion combustion of foliar gave in most cases more homogeneous results than the classic wet digestion and the microwave systems or dry ashing methods. As can be seen in figure 7.2 for the majority of the digestions, wet digestion and microwave are used.

7.2.4 Data evaluation methods

Data presentation in view of criteria for foliar composition

Criteria for nutrient concentrations in foliage are mostly based on the fact that, within a certain range of foliar concentrations, positive relationships exist between the nutrient concentration and the growth and outer appearance of plants (i.e. the occurrence of visual symptoms of deficiency).

Many compilers of lists of nutritional ranges of forest tree species have used different names for critical concentrations and ranges. Van den Burg (1985) used the following ranges of foliar mineral nutrient concentrations, going from low to high concentrations:

- Deficiency range: foliar concentration, associated with the occurrence of visual symptoms of deficiency often indicating considerable growth reduction.
- Low range or “insufficiency” range: foliar concentrations that are higher than the threshold value of visual deficiency, but associated with poor or insufficient growth.
- Normal, adequate or sufficient range: foliar concentrations that are associated with, what in practice is considered to be, an acceptable level of growth for forest stands.
- Optimum range: range where increased foliar concentrations do not lead to better growth.
- High range: foliar concentrations that are exceptionally high (compared to the lower end of the optimum range) but that are not associated with considerable growth depression.
- Toxicity range: foliar concentrations of mineral nutrients that are so high that growth is depressed, sometimes associated with visual symptoms of toxicity.

In practice, foliar concentrations hardly ever occur in the toxicity range and even not in the high range, except for nitrogen. Data by Van den Burg (1988) suggest that concentrations above 20-25 $g.kg^{-1}$ are high for spruce and pine respectively, whereas concentrations above 30 $g.kg^{-1}$ are in the toxicity range. Note, however, that these ranges are specifically related to growth. Much lower values (approximately 18-20 $g.kg^{-1}$) have been reported as critical values related to the increased sensitivity to frost damage (e.g. Aronsson, 1980) and to fungal diseases such as *Sphaeropsis sapinea* and *Brunchorstia pinea* (e.g. Roelofs et al., 1985). This is generally the optimal range for the growth of these coniferous tree species.

With respect to foliar condition, use was made of only three ranges, based on criteria which are reported in the report of the Forest Foliar Coordinating Centre for major nutrients and nutrient ratios (Stefan et al., 1997). The ranges reported for the major nutrients (N, P, Ca, Mg, K, S) and nutrient ratios in foliage of major tree species clusters are given in Table 7.2 and 7.3.

Table 7.2 Criteria used for the judgement of the foliar nutrients concentrations in four tree species clusters (source: FFCC Report, Stefan et al., 1997)

Tree species	Class/	Nutrient concentration ($g.kg^{-1}$)					
cluster	criteria1)	N	P	K	Ca	Mg	S
Spruce	1	*<12*	*<1.0*	*<3.5*	*<1.5*	*<0.6*	*<1.1*
	2	12-17	1.0-2.0	3.5-9.0	1.5-6.0	0.6-1.5	1.1-1.8
	3	>17	>2.0	>9.0	>6.0	>1.5	>1.8
Pine	1	*<12*	*<1.0*	*<3.5*	*<1.5*	*<0.6*	*<1.1*
	2	12-17	1.0-2.0	3.5-10	1.5-4.0	0.6-1.5	1.1-1.8
	3	>17	>2.0	>10	>4.0	>1.5	>1.8
Oak	1	*<15*	*<1.0*	*<5.0*	*<3.0*	*<1.0*	-
	2	15-25	1.0-1.8	5.0-10	3.0-8.0	1.0-2.5	-
	3	>25	>1.8	>10	>8.0	>2.5	-
Beech	1	*<15*	*<1.0*	*<5.0*	*<4.0*	*<1.0*	*<1.3*
	2	15-25	1.0-1.7	5.0-10	4.0-8.0	1.0-1.5	1.3-2.0
	3	>25	>1.7	>10	>8.0	>1.5	>2.0

1) 1 = low, 2 = normal or adequate, 3 = optimal to high. Low values (in italic) were used as an indication of an insufficient nutrient availability

Table 7.3 Criteria used for the judgement of foliar nutrient ratios (Source: FFCC report, Stefan et al., 1997)

Tree species	Class/criteria [1)]	Nutrient ratio (g.g^{-1})			
		N/P	N/K	N/Ca	N/Mg
Spruce	1	<6.0	<1.3	<2.0	<8.0
	2	6-17.0	1.3-4.9	2.0-11.3	8.0-28.3
	3	*>17.0*	*>4.9*	*>11.3*	*>28.3*
Pine	1	<6.0	<1.2	<2.0	<8.0
	2	6-17.0	1.2-4.9	2.0-11.3	8.0-28.3
	3	*>17.0*	*>4.9*	*>11.3*	*>28.3*
Oak	1	<8.3	<1.5	<1.9	<6.0
	2	8.3-25.0	1.5-5.0	1.9-8.3	6.0-25.0
	3	*>25.0*	*>5.0*	*>8.3*	*>25.0*
Beech	1	<10.6	<1.8	<2.3	<12.0
	2	10.6-25.0	1.8-5.0	2.3-6.3	12.0-25.0
	3	*>25.0*	*>5.0*	*>6.3*	*>25.0*

[1)] 1 = low, 2 = normal or adequate, 3 = optimal to high. High values (in italic) were used as an indication of an unbalanced nutrient status

In the literature, more ranges (up to six) have been defined for the foliar composition, ranging for very high (up to a toxicity level) to very low (up to a visible deficiency level) from the viewpoint of forest growth. Considering those ranges the limits in both tables are typical for the boundaries from low to normal and from normal to optimal (high).

The information in Table 7.2 and 7.3 was used to present the percentage of plots where either the nutrient availability was insufficient (nutrient concentrations in class 1, low) or the nutrient status was unbalanced (nutrient ratios in class 3, high) or both. Those estimates were made for each major tree species while distinguishing:

- P concentrations versus N/P ratios
- Ca concentrations versus N/Ca ratios
- Mg concentrations versus N/Mg ratios
- K concentrations versus N/K ratios

Results are given in a quadrant according to Table 7.4.

Table 7.4 Allocation of results to different classes with respect to nutrient availability and nutrient balance.

	Insufficient nutrient availability	Sufficient nutrient availability
Unbalanced nutrient status	ratio high concentration low	ratio high concentration average/high
balanced nutrient status	ratio low/average concentration low	ratio low/average concentration average/high

Hypotheses about the impacts of environmental factors on nutrient concentrations in foliage

Both tree age and altitude may affect the nutrient concentrations in foliage. An age effect was observed by Hendriks et al. (1997) in a correlative study for 200 forested stands in the Netherlands. Positive and negative relationships were found. For altitude a positive relationship with defoliation was demonstrated by Klap et al. (1997). It is unknown whether this also effects the foliar nutrient concentration.

Meteorological variables, such as precipitation and temperature, may also affect the foliar concentrations. Hendriks et al. (1997) could not demonstrate an effect of precipitation on foliar nutrient concentrations and found only a small positive temperature effect for the foliar N-concentration. This study was, however, limited to the Netherlands, with a much lower variation in precipitation and temperature than for Europe. For precipitation two kinds of effects can be expected. At first a positive effect may be expected on water limited sites. Through precipitation nutrients solve in the soil solution and can be taken up by the roots by which the foliar nutrient concentration will rise. Large amounts of precipitation, however, will dilute the nutrient concentration in the soil solution by which foliar nutrient uptake may decrease. A same sort of effect may be expected for temperature. A positive temperature effect can be expected in areas where low temperatures have a limiting effect on root activity and metabolic processes. A negative effect may be expected in cases of high temperatures, which hampers transpiration and metabolic processes and through that foliar nutrient concentrations (see also the hypotheses with respect to crown condition in Section 5.2.4). Actually, the values for precipitation and temperature could best be expressed as a deviation from an optimal range.

Elevated nutrient deposition is expected to lead to higher foliar nutrient concentrations. For some deposition components a stronger effect is expected because of direct leaf uptake of the nutrient (i.e. N and to a lesser extent S), while other components are mainly taken up by the root system. Finally, a positive relationship between the nutrient concentrations in the organic and mineral layer and the foliar nutrient concentrations is expected. Soil acidity (pH-$CaCl_2$) is expected to have a negative effect on the foliar nutrient concentration, due to decreased nutrient availability at a lower pH and possibly root damage by dissolved Al. A comparable effect is expected for the base saturation. Foliar cation concentrations are expected to be highest when the base saturation is also high.

Assessment of relationships between nutrient concentration in foliage and environmental factors

The regression relationships derived are based on the assumption that the actual chemical composition of the foliage is a result of a series of relationships within the forest ecosystem, and between the forest ecosystem and its environment. These relationships, reflecting the pathways of the various nutrients, can be worked out in the following functions.

$$C_{foliar} = f\,(\text{species, age, availability}) \qquad (7.1)$$

Where C_{foliar} is the concentration of a certain element and the ‘availability’ is the availability of the considered element, which is assumed to be influenced by:

$$\text{Availability} = f\,(\text{chemical soil composition, meteorological parameters, deposition}) \qquad (7.2)$$

The influence of the various environmental variables on the foliar composition of four major tree species was investigated by a multiple regression analyses. Supposed relationships were of the form:

$$\log \text{foliar X concentration} = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \cdots\cdots + \alpha_n x_n \qquad (7.3)$$

where log foliar X concentration is the expectation value of the response variable (foliar chemistry), x_1 to x_n are predictor variables (stand and site characteristics, meteorological parameters etc.) and α_1 to α_n are the regression coefficients. The regression analysis was applied by using a so-called Select procedure (see Section 3.3.3) of the statistical computer language GENSTAT.

The various predictor variables used (element concentrations in organic layers and mineral layers, meteorological characteristics and the external input from the atmosphere) in explaining the foliar composition are summarised in Table 7.5. The chemical composition of the soil (including the organic layer) included the element concentration in the organic layer and mineral topsoil (0-20 cm), the base saturation or C/N ratio, depending on the considered element. Meteorological conditions include temperature and precipitation, whereas 'deposition' included the deposition of the considered element and the deposition of acidity, when it interacts with the considered element. In order to assure normal distributions, logarithmic transformations were executed on all predictor variables, except for tree age and temperature. Furthermore, a logit transformation was applied to the base saturation.

Table 7.5 Major environmental variables affecting foliar concentrations

Variable	N	P	S	Ca, Mg, K
Stand characteristics				
Tree age	X	X	X	X
Altitude	X	X	X	X
Meteorology				
Temperature	X	X	X	X
Precipitation	X	X	X	X
Deposition				
N	X			
P 1)				
S			X	
Ca, Mg, K				X
Acidity4)				X
Soil Chemistry				
pH-$CaCl_2$	X	X	X	
X organic layer	X	X	2)	X
X mineral layer	X		2)	
C/N ratio organic layer	X			
C/N ratio mineral layer	X			
Base saturation mineral layer				X3)

1) Data on P deposition are hardly available

2) Data on S concentrations in the organic and mineral layer are hardly available

3) The sum of exchangeable Ca, Mg, K (and Na) was used as a surrogate for separate exchangeable concentrations, that were not available

4) Acidity stands for the sum of S and N deposition

Results are limited to four major tree species, being pine, spruce, oak and beech. The total number of plots that were used to describe ranges in nutrient concentrations and nutrient ratios for those tree species equalled 674 for N, K, Ca and Mg, 673 for P and 670 for S. The analyses were performed on plots where all information, mentioned in table 7.5, was available, except temperature data that were mostly missing at the plots. Temperature data were derived from interpolation of 30-year averaged data, which gives an impression of the average meteorological circumstances. For precipitation, use was made of the results of bulk deposition monitoring for the period in which crown condition was assessed (if available for the whole period).

7.3 Results and discussion

7.3.1 Ranges in nutrient concentrations and nutrient ratios in view of critical levels

Ranges in nutrient concentrations

Results of the ranges in the concentrations of major nutrients in pine, spruce, oak and beech are presented in Table 7.6. As expected, the foliar concentrations of all major nutrients were about 1.5-2.0 times as large in the broadleaves (oak and beech) as in the conifers (pine and spruce), except for P. Foliar P concentrations hardly differed between conifers and broadleaves. Nutrient concentrations generally decreased going from N > K ≈ Ca > Mg > P ≈ S. More insight in the distribution of the element concentrations in the various tree species is given in Fig. 7.5.

Table 7.6 Ranges in nutrient concentrations as a function of tree species. The lower limit is the 5%, whereas the upper limit is the 95%.

	No of Plots1)	N	P	S	K	Ca	Mg
Pine	245	9.9-19	0.90-1.8	0.78-1.6	2.3-7	1.6-5.1	0.70-1.9
Spruce	200	11-17	0.98-2.1	0.69-1.5	3.0-8	2.1-8	0.68-1.6
Oak	126	13-31	0.73-2.0	1.0-2.2	5.0-12	3.8-12	0.99-2.8
Beech	103	19-29	0.88-1.7	1.2-2.2	4.5-10	3.4-14	0.61-2.8

1) The number of plots refers to the N, K, Ca and Mg concentrations. For P and S, the total number of plots was 1 and 4 less, respectively.

As with the results presented in a previous Technical Report (De Vries et al., 1998), low foliar concentrations of P, K, Ca and Mg were only observed at 4-11% of all the plots (was 3-12% in the previous round). A relatively large number of plots with low foliar concentrations was, however, observed for beech (11-29% depending on the element). High concentrations of N were mainly observed in oak (44%) and beech (42%). It equalled 53% and 56%, in the previous survey (De Vries et al., 1998). Low N concentrations were observed in 17% of the plots with pine and spruce and on less than 10% of the oak stands, whereas it did not occur for beech plots (Fig. 7.5A). The striking low S concentrations in conifers found for the previous survey (mainly 1994-1995) was again observed in the last survey (mainly 1996-1997). The percentage of plots with a low S concentration was 45% for pine (was 57%) and 78% for spruce (was 84%). This may reflect the decreased S deposition on those tree species (see Section 7.3.3).

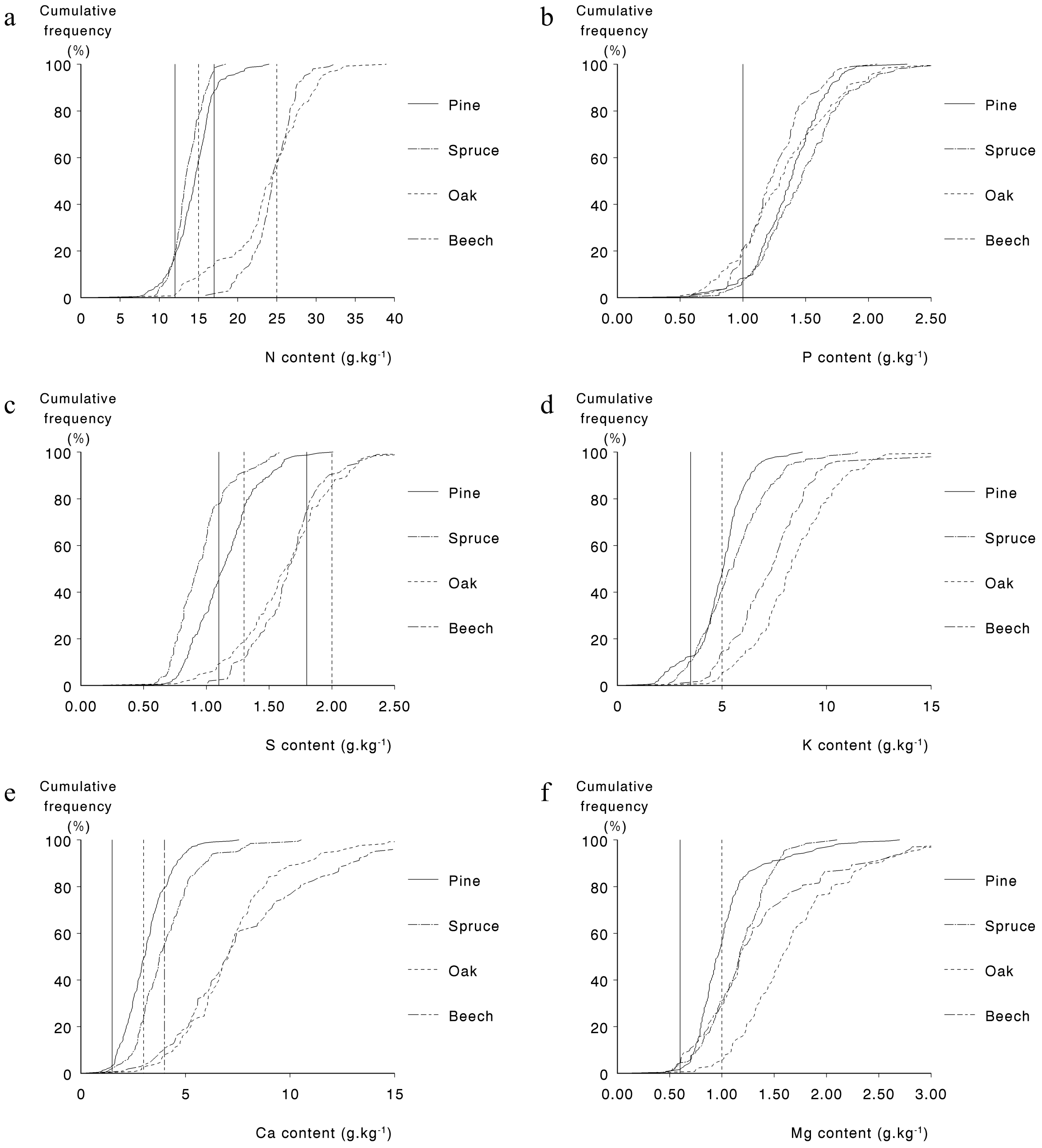


Figure 7.5 *Cumulative frequency distributions of the foliar concentration of N (a), P (b), S (c), K (d), Ca (e) and Mg (f) for the four major tree species clusters. The solid and dashed vertical lines for P, K, Ca and Mg indicate the distinction between an insufficient, sufficient and high nutrient availability for coniferous and deciduous trees, respectively. For Ca the distinction differs for oak and beech (see Graph e). For N and S the distinction between a sufficient and excessive supply is also indicated with the vertical lines.*

Ranges in nutrient ratios

Ranges in nutrient ratios of the four major tree species are shown in Table 7.7.

Table 7.7 Ranges in nutrient ratios as a function of tree species. The lower limit is the 5%, whereas the upper limit is the 95%.

	No of Plots1)	N/P	N/K	N/Ca	N/Mg	N/S
Pine	245	8.0-16	1.7-5.7	2.7-9.2	5.4-25	9.3-18
Spruce	200	6.1-14	1.4-4.6	1.9-7.2	7.7-22	9.6-19
Oak	126	12-30	2.0-4.3	1.7-7.3	6.6-25	11-18
Beech	103	14-29	2.3-5.2	1.6-7.7	8.4-41	11-19

1) The number of plots refers to the N, K, Ca and Mg concentrations. For P and S, the total number of plots was 1 and 4 less, respectively.

More insight in the distribution of the element ratios in the various tree species in view of available criteria is given in Fig. 7.6.

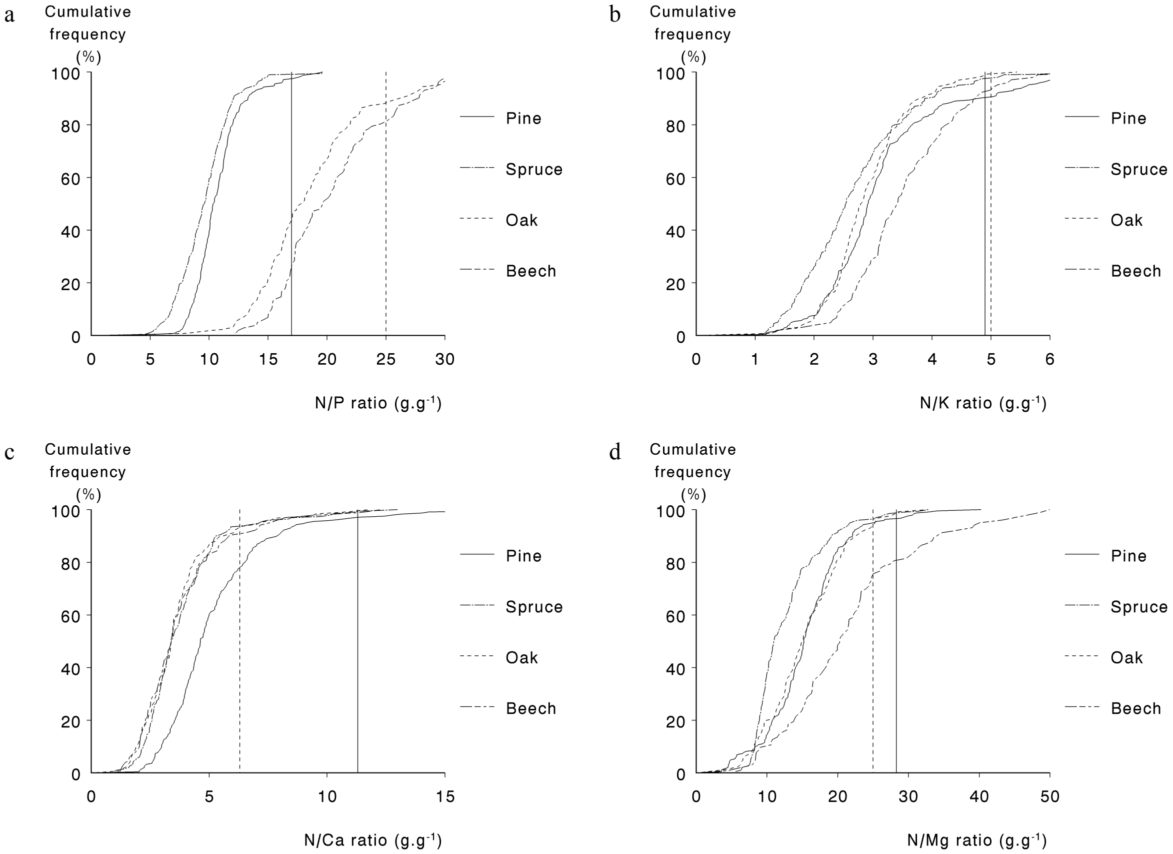


Fig. 7.6 Cumulative frequency distributions of the foliar ratios of N/P (a), N/K (b), N/Ca (c) and N/Mg (d) for the four major tree species clusters. The solid and dashed vertical lines indicate the distinction between a balanced and unbalanced nutrient status for coniferous and deciduous trees, respectively.

The range in the foliar N/P ratio was much wider for the deciduous species than for the coniferous species. This is mainly due to a higher maximum, which is more than two times as high as for the coniferous species (Table 7.7). For none of the other foliar nutrient ratios, such a large difference between the coniferous and deciduous tree species was found. The higher maximum for the deciduous species resulted in a relative high percentage of stands that have an unbalanced N/P ratio (Fig. 7.6a). For the deciduous species this percentage was 10%-20% (was 6-12% in the previous survey), while for the coniferous species it was only a few percent. The median of the foliar N/P ratio was about 1.7 to 1.9 times lower for the conifers than for the broadleaves (Fig. 7.6a).

The differences in the range of the N/K ratio were small for all tree species. Remarkable is that the highest maximum N/K ratios occurred in pine (Table 7.7.). As a consequence, pine had the highest percentage of stands with an unbalanced N/K ratio, viz. 10% (Fig. 7.6b). This was 6% in the previous survey (De Vries et al., 1998)

Ranges and distribution of the N/Ca ratios were quite similar for all species, except for pine (Table 7.7 and Fig. 7.6c). Highest N/Ca ratios were found for this tree species. Nevertheless, the percentage of stands with an unbalanced (high) N/Ca ratio was higher for oak and beech because of a different criterium (Fig. 7.6c).

With the exception of beech, the ranges in N/Mg ratio were quite similar for all species. The range for beech had a higher maximum than the other species (Table 7.7), while the minimum value was comparable for all species. However the median of beech was up to two times higher than the median for the other species (Fig. 7.6c). The percentage plots having an unbalanced N/Mg ratio, was 29% for beech. For the other species less than 5% exceeded this limit.

Evaluation of the results in view of critical levels

In the previous sections the foliar nutrient concentrations and ratios were presented separately. A more detailed picture of the tree nutrient status can be obtained by combining both concentrations and ratios, which are related to the nutrient supply and the nutrient balance, respectively. When combining these classes, four combination classes arise with respect to a sufficient and an insufficient nutrient supply and a balanced and an unbalanced nutrient status as presented in Table 7.8.

Table 7.8 Percentage of plots in four different classes with respect to nutrient availability and nutrient balance as a function of tree species.

Tree		P		K		Ca		Mg		All	
		Insuff.	Suff.	Insuff.	Suff.	Insuff.	Suff.	Insuff.	Suff.	Insuff.	Suff.
Pine	Unbal.	0.8	2.0	9.4	0.4	1.6	1.6	1.2	2.4	13.1	4.1
	Bal.	7.3	89.8	2.9	87.3	1.6	95.1	0.0	96.3	9.8	73.1
Spruce	Unbal.	1.0	0.0	2.5	0.0	1.0	0.0	1.5	0.0	6.0	0.0
	Bal.	5.5	93.5	7.5	90.0	0.5	98.5	2.5	96.0	15.5	78.5
Oak	Unbal.	6.3	5.6	0.8	0.0	2.4	4.8	3.2	3.2	11.9	11.1
	Bal.	14.3	73.8	4.0	95.2	0.0	92.9	1.6	92.1	15.1	61.9
Beech	Unbal.	14.7	4.9	7.8	0.0	2.9	0.0	22.3	2.9	37.9	5.8
	Bal.	2.9	77.5	5.8	86.4	7.8	89.3	6.8	68.0	11.7	44.7
All	Unbal.	4.0	2.5	5.5	0.1	1.8	1.5	4.9	1.9	14.5	4.5
	Bal.	7.4	86.0	4.9	89.5	1.9	94.8	2.1	91.1	12.8	68.2

The major part of the plots has a sufficient nutrient supply and a balanced nutrient status (Table 7.8) in line with the results presented before. Nevertheless, the nutrient status can be considered insufficient of unbalanced for at least one of the elements at approximately 30% of the plots. One should be aware that insufficient might be an overstatement, since the concentrations are considered to be low. The nutrient supply and nutrient balance of the coniferous species is somewhat better than for the deciduous species. This holds especially for P and Mg. A relative high percentage of the beech-plots had an insufficient supply of P and Mg and an unbalanced N/P and N/Mg ratio. Oak also had a relative high percentage of plots with an insufficient P supply. For spruce it is remarkable that when the nutrient supply is sufficient, the nutrient status is always balanced.

Flückiger and Braun (1998) suggest that the N nutrition is sufficient in cases where the N/P ratio is balanced, even when the N nutrition is classified as insufficient (table 7.3). Applying this to our study, it would not have large consequences because the number of plots having an insufficient N status is low (less than 20% in coniferous stands and less than 10% in deciduous stands; Fig. 7.5a). In situations where cations are readily available, nitrogen deposition will stimulate growth without symptoms of damage, but when supplies of cations are limited, additional nitrogen will exacerbate the shortages (Schulze and Freer-Smith, 1991). Hence, in cases of low cations supply, the nitrogen/cation ratio is very important. Roberts et al. (1989) states that foliar Mg deficiency primarily results from low Mg availability in acid soils. The foliar Mg concentration was linearly correlated with exchangeable and soil solution Mg, which was also demonstrated by Hendriks et al. (1997). The results of this European study also are in line with these findings.

7.3.2 Relationship between foliar concentrations and environmental factors

Ranges in environmental factors

Regression relationships were established for a limited number of plots where all relevant predictor variables, as defined in Table 7.5, were available. An overview of the total number of plots used in the regression analysis is given in Table 7.9. The reduction in the number of plots for which regression analyses could be performed compared to the total number of plots for which data on foliar concentrations are available, see Table 7.6, was mainly due to the unavailability of deposition data. A further reduction was mainly due to unavailability of element concentrations in the organic layer. In performing the regression analysis, use was made of results from acceptable digestion methods only (Section 7.2.2). Furthermore, data were not used when information on the pre-treatment was not available.

Table 7.9 Number of plots used in the regression analysis as a function of tree species and element concentration.

Tree species	Number of plots					
	N	P	S[1)]	K	Ca	Mg
Pine	49	39	48	38	42	43
Spruce	91	59	95	89	88	93
Oak	28	23	22	24	17	24
Beech	35	26	30	23	23	23

[1)] The relatively large number of plots for S is due to the fact that the S concentration in the organic layer is not included in the regression analysis

When researching the relationships between foliar nutrient concentrations and determining parameters not only the absolute values of these parameters are important, but also the width of the range of the parameters. Only in cases of sufficient variation in the range of the parameters, relationships can be found. This means that in cases a parameter has effect on the foliar nutrient concentration but the range of the parameter is small (i.e. the value for all plots is high or low), it will become difficult to demonstrate an effect through statistical analysis. The range in foliar concentrations and predictor variables is shown in table 7.10. It should be realised that the relationships can not be applied outside the range of those predictor variables or environmental factors.

Table 7.10 Ranges in response variables (foliar concentrations) and predictor variables (environmental factors) as a function of tree species, used in the regression analyses. Here, the lower limit is the minimum, whereas the upper limit is the maximum.

Variable	Pine	Spruce	Oak	Beech
Foliar concentrations				
N concentration (%)	10.1 - 24.0	9.4 - 18.5	11.8 - 39.0	18.9 - 32.4
P concentration (%)	0.59 - 2.31	0.90 - 2.58	0.80 - 2.36	0.74 - 2.07
S concentration (%)	0.78 - 1.68	0.59 - 1.57	0.77 - 3.33	1.19 - 2.12
Ca concentration (%)	1.01 - 5.92	1.16 - 10.39	2.57 - 14.61	1.98 - 14.05
Mg concentration (%)	0.46 - 1.97	0.46 - 2.10	0.78 - 4.73	0.52 - 2.82
K concentration (%)	1.37 - 8.60	2.47 - 11.35	4.80 - 12.90	4.42 - 9.94
Stand characteristics				
Age (yr)	10 - 130	10 - 130	30 - 130	30 - 130
Altitude (m)	25 - 1075	25 - 1525	25 - 725	25 - 1525
Meteo				
Precipitation (mm.yr^{-1})	411 - 1828	411 - 1828	512 - 1887	517 - 1678
Temperature (°C)	-1 - 15	-3 - 10	7 - 16	-1 - 16
Deposition				
N deposition (mol$_c$.ha^{-1}.yr^{-1})	26 - 4490	17 - 3210	195 - 4056	462 - 2038
SO_4 deposition (mol$_c$.ha^{-1}.yr^{-1})	51 - 4117	57 - 4181	245 - 8143	307 - 2959
Ca deposition (mol$_c$.ha^{-1}.yr^{-1})	27 - 817	28 - 996	131 - 2299	100 - 1445
Mg deposition (mol$_c$.ha^{-1}.yr^{-1})	14 - 1537	0 - 1698	38 - 1035	35 - 537
K deposition (mol$_c$.ha^{-1}.yr^{-1})	4 - 299	4 - 410	26 - 365	21 - 205
Humus layer				
N concentration (g.kg^{-1})	2 - 19	2 - 27	2 - 20	7 - 24
P concentration (g.kg^{-1})	0.39 - 1.08	0.21 - 1.17	0.08 - 1.42	0.17 - 1.22
S concentration (g.kg^{-1})	0.74 - 2.69	0.91 - 2.60	0.60 - 2.86	0.43 - 1.99
K concentration (g.kg^{-1})	0.39 - 6.68	0.44 - 6.67	0.52 - 5.44	0.52 - 6.54
Ca concentration (g.kg^{-1})	1.20 - 7.48	0.17 - 9.63	0.99 - 9.78	1.59 - 28.70
Mg concentration (g.kg^{-1})	0.21 - 8.26	0.20 - 7.18	0.44 - 7.99	0.44 - 12.68
C/N ratio (-)	18.2 - 77.1	12.2 - 47.2	13.8 - 36.2	14.2 - 45.1
Mineral layer				
N concentration (g.kg^{-1})	0.2 - 6.1	0.4 - 18.9	0.3 - 8.6	0.9 - 13.7
C/N ratio (-)	15.0 - 45.0	12.7 - 53.3	11.3 - 42.5	12.4 - 30.0
Base saturation (%)	4.3 - 88.0	2.5 - 98.0	3.0 - 89.0	4.5 - 76.0
pH-$CaCl_2$ (-)	2.92 - 6.55	2.81 - 7.30	2.90 - 7.30	2.80 - 6.09

The variation in foliar concentrations in the plots used for regression analyses was similar to those for all plots. This implies that the range is representative for Europe, since all plots are evenly distributed over Europe (Fig. 7.1). The variation also seems large enough to find relationships with environmental factors. The same is true for precipitation and mean annual temperature that both show a variation that is large enough to demonstrate possible effects. Similarly, the range for the deposition components and soil chemical data seems large enough for possible effects on the foliar nutrient concentration. In general, the range seems to cover the expected range in the whole of Europe quite adequately.

In the following sections the relationships between foliar element concentrations and its influencing factors are given. Results are presented using both log-transformed and original data on the foliar concentrations. This was done since the original foliar chemistry already had a near-normal distribution. In most cases, the variation that could be explained was similar, but sometimes either the original or the log-transformed data gave better results.

Relationships derived for nitrogen

Results of the regression relationships derived for N are given in Table 7.11.

Table 7.11 Overview of the predictor variables explaining foliar nitrogen concentrations of 4 tree species of the Intensive Monitoring Plots with the number of plots (N) and the percentage variance accounted for ($R^2_{adj.}$).

Predictor variables	Scots pine (Pinus sylvestris)		Norway spruce (Picea abies)		Pedunculate oak (Quercus robur)		Beech (Fagus sylvatica)	
	log	normal	log	normal	log	normal	log	normal
Deposition								
N	++	++	++	++				
Meteorology								
Temperature	--				--	--	+	
Precipitation		+					++	++
Soil Chemistry								
N organic layer								
C/N ratio organic layer		--	--	--				
N mineral layer		--					+	
C/N ratio mineral layer								-
pH mineral soil								
Site characteristics								
Soil type	-	-			+	+		
Altitude			++	++				
Stand characteristics								
Stand age			--	--				
N	49	49	91	91	28	28	35	35
$R^2_{adj.}$	74	79	59	58	56	51	32	28

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable

The variation in N concentration could to a relatively large extent be explained by several of the included predictor variables. The percentages variation accounted for ranged from 28-32% for beech to 74-79% for Scots pine. Nitrogen deposition turned out to be the most important variable for pine and spruce. This is further illustrated in Figure 7.7. N deposition alone already explained 60% of the variation in pine and 32% in spruce. Unlike the coniferous species, no relationship was found between nitrogen deposition and foliar N concentration for the deciduous species.

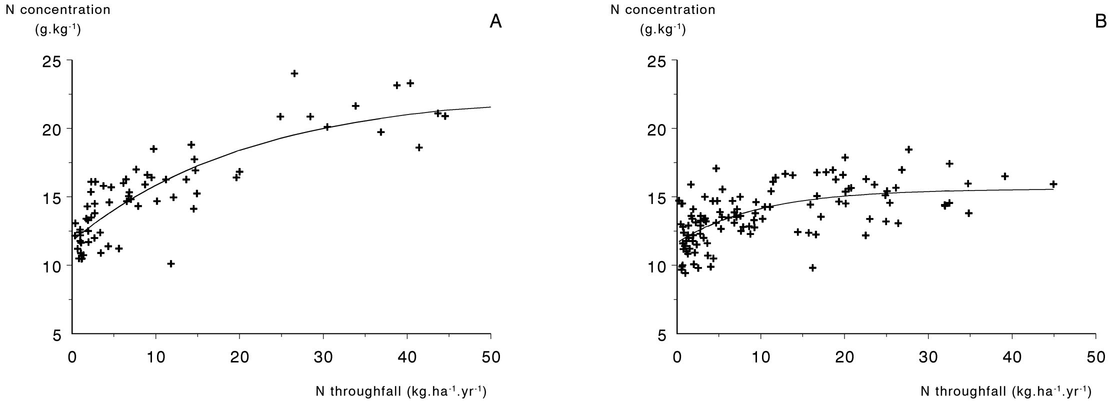


Figure 7.7 Relationships between N concentrations in pine (A) and spruce (B) and N in throughfall.

Precipitation was positively correlated to the foliar N concentration of pine and beech, whereas temperature was negatively related to the foliar concentration of pine and oak. No or only weak relationships were found with nitrogen concentrations or C/N ratios in the organic and mineral layer, with the exception of Norway spruce. Apart from Norway spruce, stand age was not related to the foliar nitrogen concentration. Table 7.11 shows that none of the predictor parameters had a significant contribution to the foliar nitrogen concentration of all the researched tree species. Also the combinations of relevant variables were different for all the tree species, indicating that tree species react specifically to the key parameters.

Relationships derived for phosphorous

Results of the regression relationships derived for P are given in Table 7.12.

Table 7.12 Overview of the predictor variables explaining foliar phosphorous concentrations of 4 tree species of the Intensive Monitoring Plots with the number of plots (N) and the percentage variance accounted for ($R^2_{adj.}$).

Predictor variables	Scots pine (Pinus sylvestris)		Norway spruce (Picea abies)		Pedunculate oak (Quercus robur)		Beech (Fagus sylvatica)	
	log	normal	log	normal	log	normal	log	normal
Deposition								
Acid deposition								
Meteorology								
Temperature	--	--	--	--	--	--		
Precipitation	+	++						++
Soil Chemistry								
P organic layer								
pH mineral soil			-	-				
Site characteristics								
Soil type								
Altitude	--	--	++	++				
Stand characteristics								
Stand age								
N	39	39	59	59	23	23	26	26
$R^2_{adj.}$	33	34	27	25	29	23	0	20

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable

For the foliar phosphorus concentration only weak relationships could be demonstrated with the available set of parameters. The percentage variance accounted for did not exceed 35% (Table 7.12). Temperature showed to be an important factor for the foliar phosphorus concentration, which may refer to mineralisation and root activity. It is striking that the phosphorus concentration of the organic layer and the soil acidity do not show up as relevant factors. Only for Norway spruce a weak relationship was found with the soil acidity. An effect of stand age on the foliar phosphorus concentration could not be demonstrated. For beech, part of the variation could only be explained by the variation in precipitation using the original data. Using log-transformed data, there was no relationship with any predictor variable.

Relationships derived for sulphur

Results of the regression relationships derived for S are given in Table 7.13.

Table 7.13 Overview of the predictor variables explaining foliar sulphur concentrations of 4 tree species of the Intensive Monitoring Plots with the number of plots (N) and the percentage variance accounted for ($R^2_{adj.}$).

Predictor variables	Scots pine (Pinus sylvestris)		Norway spruce (Picea abies)		Pedunculate oak (Quercus robur)		Beech (Fagus sylvatica)	
	log	normal	log	normal	log	normal	log	normal
Deposition								
SO_4^{2-}	++	++	++	++		++		+
Meteorology								
Temperature								
Precipitation								+
Soil Chemistry								
pH mineral soil								
Site characteristics								
Soil type						-		
Altitude	--		++	++		+		
Stand characteristics								
Stand age			--	--				
N	48	48	95	95	22	22	30	30
$R^2_{adj.}$	58	40	31	33	0	37	0	16

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable

Relationships between the foliar S concentration and environmental factors differed considerably depending on tree species and the use of either original or log-transformed data. Using the original data, reasonable relationships showed up for pine, spruce and oak and a poor relationship for beech (Table 7.13). Deposition of SO_4^{2-} showed to be the dominant and most significant factor for pine and spruce as illustrated in Fig. 7.8. Deposition alone already explained 45% of the variation in pine and 27% for spruce when using log-transformed data. The influence of SO_4^{2-} deposition could only convincingly be demonstrated for the coniferous tree species. This might be due to the higher deposition range for these species. The deciduous species do not have plots with a SO_4^{2-} deposition as low as the coniferous species do. Using log-transformed data, no variation at all could be explained for the deciduous species. With respect to the poor results regarding S, especially for the deciduous tree species, one has to be aware that the comparability of foliar S concentrations is low (see Section 7.2.3).

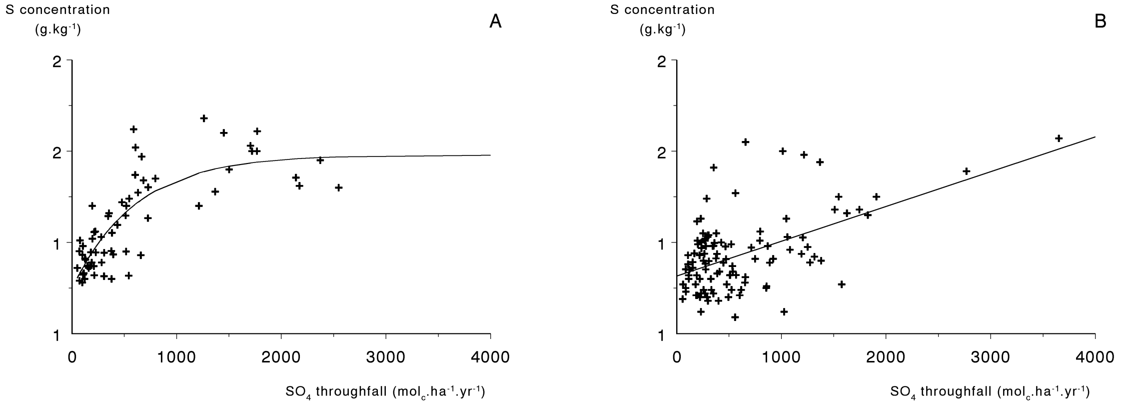


Figure 7.8 Relationships between S concentrations in pine (A) and spruce (B) and S in throughfall.

Relationships derived for K

Results of the regression relationships derived for K are given in Table 7.14.

Table 7.14 Overview of the predictor variables explaining foliar potassium concentrations of 4 tree species of the Intensive Monitoring Plots with the number of plots (N) and the percentage variance accounted for ($R^2_{adj.}$).

Predictor variables	Scots pine (Pinus sylvestris)		Norway spruce (Picea abies)		Pedunculate oak (Quercus robur)		Beech (Fagus sylvatica)	
	log	normal	log	normal	log	normal	log	normal
Deposition								
K^+						+		
Acid deposition	++	++						
Meteorology								
Temperature			--	--				++
Precipitation			+	++			-	
Soil Chemistry								
K organic layer			++	+				
Base saturation min. layer								
Site characteristics								
Soil type	++	++			+	+	+	
Altitude								
Stand characteristics								
Stand age								+
N	38	38	89	89	24$^{1)}$	24$^{1)}$	23	23
$R^2_{adj.}$	32	40	29	25	26	33	37	35

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable
$^{1)}$ All plots

From other studies (Hendriks et al., 1997) it is known that it is hard to explain the foliar potassium concentration of tree species because of the high solvability and uptake velocity of this element. In this light, the percentages variation accounted for are relatively high (25%-40%; Table 7.14). For all tree species different variables were found to be relevant. Explaining variables are found for all the different kind of factors: deposition, meteorology, soil chemistry, site and stand characteristics. Unlike the other elements, the use of either original or log-transformed hardly affected the results.

Relationships derived for Ca

Results of the regression relationships derived for Ca are given in Table 7.15. As with K, the variation in Ca concentration that could be explained by environmental factors was relatively low (29-47% using the original data).

Table 7.15 Overview of the predictor variables explaining foliar calcium concentrations of 4 tree species of the Intensive Monitoring Plots with the number of plots (N) and the percentage variance accounted for ($R^2_{adj.}$).

Predictor variables	Scots pine (Pinus sylvestris)		Norway spruce (Picea abies)		Pedunculate oak (Quercus robur)		Beech (Fagus sylvatica)	
	log	normal	log	normal	log	normal	log	normal
Deposition								
Ca^{2+}	++							
Acid deposition	--	--						
Meteorology								
Temperature		++						
Precipitation								
Soil Chemistry								
Ca organic layer		-	++	++				
Base saturation min. layer		+			++	++	+	++
Site characteristics								
Soil type	-	--						
Altitude			--	--				
Stand characteristics								
Stand age								
N	42	42	88	88	17¹⁾	17¹⁾	23¹⁾	23¹⁾
$R^2_{adj.}$	29	33	32	29	43	47	16	33

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable
1) All plots including data of less acceptable methods to allow a regression analysis

The strongest relationship was found for the Ca concentration of oak. Remarkably, only one variable was included in the model, e.g. the base saturation of the mineral layer, which on it's own explained 43-47% of the variation in the foliar Ca concentration of oak. The Ca^{2+} concentration of the organic layer proved to be a significant variable for Norway spruce. For Scots pine also the acid deposition contributed significantly to the percentage variance accounted for.

Relationships derived for Mg

Results of the regression relationships derived for Mg are given in Table 7.16. The variation in Mg concentration that could be explained by environmental factors was generally much higher than for K and Ca (30-74%, depending on tree species and the use of either original or log-transformed data).

Table 7.16 Overview of the predictor variables explaining foliar magnesium concentrations of 4 tree species of the Intensive Monitoring Plots with the number of plots (N) and the percentage variance accounted for ($R^2_{adj.}$).

Predictor variables	Scots pine (Pinus sylvestris)		Norway spruce (Picea abies)		Pedunculate oak (Quercus robur)		Beech (Fagus sylvatica)	
	log	normal	log	normal	log	normal	log	normal
Deposition								
Mg^{2+}	+	+	++	++			++	++
Acid deposition	--	--	--	--				
Meteorology								
Temperature						-	-	
Precipitation						+		
Soil Chemistry								
Mg organic layer	+				++	++	++	
Base saturation min. layer		+				++	++	++
Site characteristics								
Soil type						++		
Altitude		-	-					
Stand characteristics								
Stand age								
N	43	43	91	91	24$^{1)}$	24$^{1)}$	23	23
$R^2_{adj.}$	56	53	33	30	46	68	74	58

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable
$^{1)}$ All plots including data of less acceptable methods to allow a regression analyses

The variation in Mg concentrations in pine and spruce was mainly related to the deposition of Mg (positive) and acidity (negative). The Mg concentration of the organic layer and/or the base saturation of the mineral layer turned out to be an important variable for the foliar Mg concentration of the deciduous trees (Table 7.16). For the beech the Mg deposition also contributed significant to the foliar Mg concentration. Besides the variables mentioned, relevant explaining variables differed for all tree species.

In general the relationships between foliar nutrient concentrations and explaining parameters are comparable with the results from a similar study performed for the Netherlands (Hendriks et al., 1997). Despite the larger availability of soil chemical characteristics, the relationships found by Hendriks et al. (1997) have similar or lower percentages variation accounted for than in the current study. A possible explanation for this may be found in the wider ranges of the foliar nutrient concentrations on the European scale, as well as the wider ranges for the explaining parameters.

7.4 Conclusions

Foliar composition data at the Intensive Monitoring plots were evaluated with respect to: (i) the ranges in nutrient concentrations and nutrient ratios in the foliage of pine, spruce, oak and beech in view of critical levels and (ii) the relationship between the foliar concentrations of major nutrients in the considered tree species as a function of stand age, meteorological parameters, atmospheric deposition and chemical soil composition. Major conclusion related to those aspects are given below.

Ranges in nutrient concentrations and nutrient ratios in the foliage in view of critical levels
As expected, nutrient concentrations of N, S, K and Ca in the foliage of the deciduous tree species oak and beech are 1.5 to 2 times higher than in the foliage of the coniferous species pine and spruce. For P and Mg the difference between coniferous and deciduous species is (much) less pronounced. Considering single nutrients, only a small percentage of the plots have an unbalanced nitrogen/cation ratio. There are, however, some clear differences between tree species and nutrients. The percentage stands with a sufficient and balanced Mg status is low for beech, viz. 68% for example. Further a relatively high percentage of the pine and beech stands had an unbalanced N/K ratio. In approximately 30% of the stands, the nutrient status of the foliage can be judged as insufficient and unbalanced for at least one nutrient (see also Chapter 10 with respect to the validity of this statement).

Relationships between the foliar concentrations of major nutrients and environmental factors
From the statistical analysis it follows that deposition, meteorological parameters, soil chemistry, and site characteristics contribute significantly to the explanation of the foliar nutrient concentration. The percentage variation accounted varies considerable per nutrient and within nutrient per tree species. Relative high percentages explained variation were found for N with the exception of beech (51-79%) and for Mg with the exception of spruce (46-74%). Low percentages variation accounted for were found for P (20%-34%), K (26%-40%) and Ca (16-47%). The N and S deposition were significantly related to the foliar N and S concentrations for the coniferous species, especially pine. With exception for Mg, no effect could be demonstrated of the deposition of basic cations on the foliar basic cation concentration. Acid deposition showed a significant negative correlation with the foliar Mg and Ca concentration of coniferous tree species. In general the foliar concentration of the basic cations was positively correlated to the concentration of the cation concerned in the organic and or mineral layer.

8 Soil condition

8.1 Introduction

Data on the chemical soil composition, such as the concentrations of the major nutrients N, P, S, Ca, Mg and K and the exchangeable cation concentrations (or base saturation), give information on the nutrient availability and the acidity status of the soil. This type of information has been presented in a previous Technical Report using available data up to 1995. A better insight in the long-term nutrient availability and buffer capacity of the soil can be derived by calculating pools of major nutrients and exchangeable base cations, respectively. This kind of information can also be used to calculate expected relative changes in those pools, considering the net input (deposition minus net growth uptake) of those elements from the atmosphere and their possible retention in relation to e.g. the C/N ratio or acidity status of the soil. Furthermore, data on the standard deviation of the pool of soil material in the organic or mineral layer and of the element concentration, based on repeated measurements, do give information on the required changes in both element concentrations and element pools before a statistically significant difference can be observed. Combining this information with atmospheric inputs and simple element retention models allows the calculation of the time period that is needed before a significant difference in element pools can be derived. This kind of information, which is relevant for planning a repetition of the soil survey, is presented in the chapter.

This chapter also focuses on the possibility to extrapolate soil data by using relationships with known environmental factors, such as stand and site characteristics, meteorological conditions and atmospheric deposition. A European wide overview of e.g. the retention (sequestration) of carbon or nitrogen or on soil acidification requires the availability of data on the C/N ratio and base saturation on a European wide scale. This is because an increase in nitrate and aluminium concentrations at elevated N and S inputs, respectively is more likely at low C/N ratios (e.g. Gundersen et al., 1998) and a low base saturation (e.g. De Vries et al., 1995), respectively. Information on the geographic variation of element concentrations and element pools is available at many so-called Level 1 plots, occurring in a systematic grid of (a multiple) of 16 km x 16km (Vanmechelen et al., 1997). Nevertheless, information is missing at many plots. An estimate of those values based on readily available environmental factors would be helpful for European wide assessments of soil acidification and N saturation.

Apart from an overview of various methodological aspects (Section 8.2), this chapter gives information on:

- Ranges in the pools of major nutrients and exchangeable base cations in the organic layer and the mineral soil and the required changes in those pools to derive significant differences (Section 8.3.1).
- The variation in time periods that are relevant with respect to the repetition of soil surveys as a function of soil characteristics and atmospheric inputs (Section 8.3.2).
- Relationships between element pools and concentrations in the organic layer and the mineral soil and various environmental factors (Section 8.3.3).

8.2 Methodological aspects

8.2.1 Locations

Fig. 8.1 shows the location of all the 604 plots at which soil analyses were carried out up to 1997. Most soil surveys were carried out in 1995 (approximately 65% of the plots). The map also indicates those plots that were used in a multiple regression analysis, relating element pools to environmental stress factors. Actually, this number changed depending on the element considered. The map is related to the regression of N in the organic layer as a function of N deposition and other environmental factors (190 plots). The geographical distribution of the "regression" plots is highly comparable to the geographical distribution of the plots where atmospheric deposition has been measured (see Fig. 5.1), since atmospheric deposition is generally the limiting environmental variable in the regression analyses (see also Section 8.2.4).

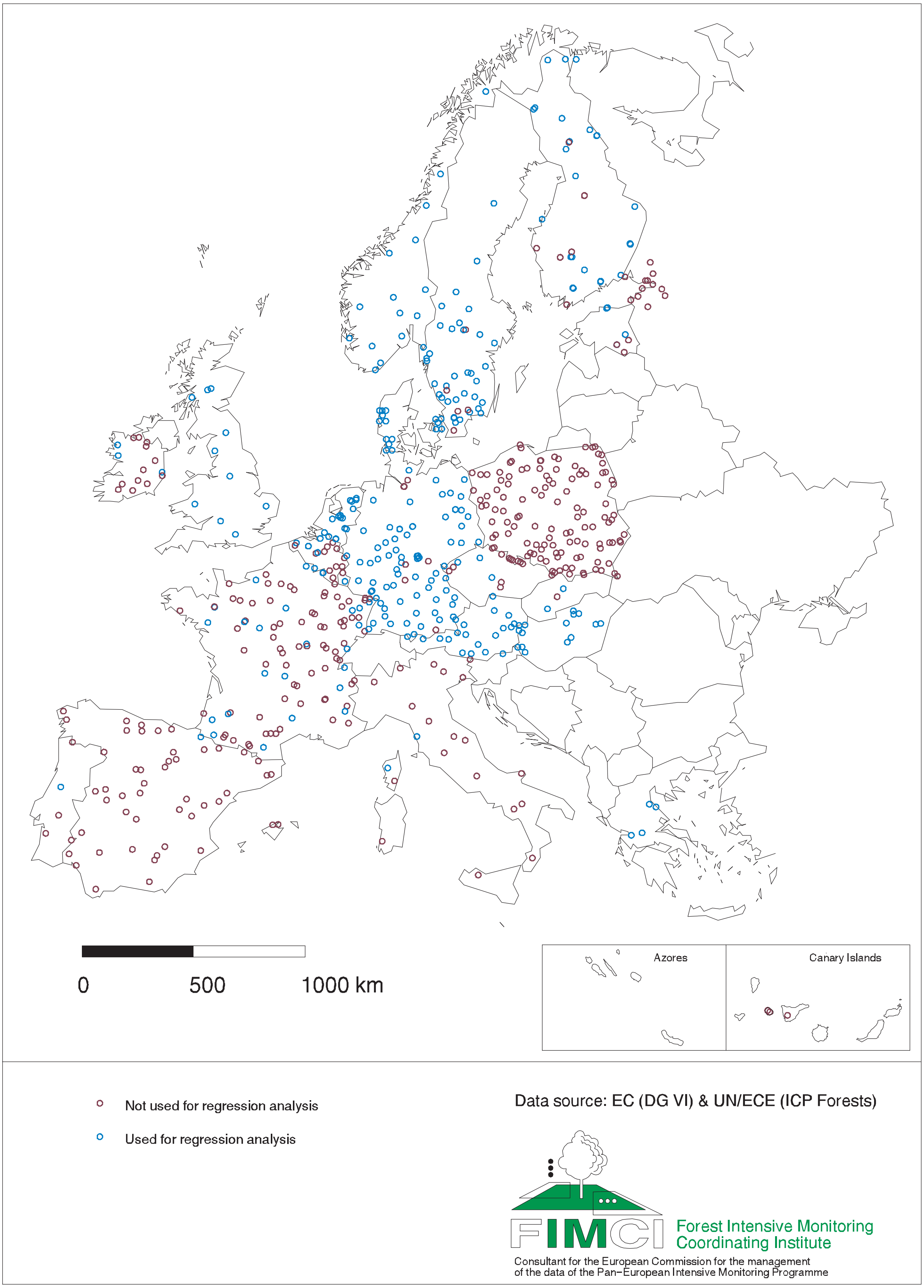
8.2.2 Data assessment methods

Information on data assessment methods for the soil condition survey up to 1997 was received of 23 countries. For only 5 of the 604 plots that were used in the data evaluation (see Section 8.2.1), no information on 'sampling set-up and layout' and 'analysis' was received. The information on data assessment methods presented below is thus based on DAR-Q's of 599 plots.

Sample preparation, digestion and analysis

Sample preparation was generally carried out by similar methods. Most of the samples were dried, sieved and/or ground. For 17 plots the samples were analysed as they were received at the laboratory. Air drying temperatures ranged from approximately 15-65ºC. In 84% of the reported cases, temperatures did not exceed 40ºC, as recommended in the Manual.

In the guidelines for the soil survey, dry combustion is indicated as the reference method for the analysis of the total C and N concentrations. Aqua regia is the reference method for the total element concentrations of major nutrients (P, S, K, Mg and Ca) and of minor nutrients and heavy metals (Fe, Mn, Cu, Zn, Pb and Cd). The agreed reference method for pH is an extraction with 0.01M $CaCl_2$ followed by a potentiometric measurement, whereas the CEC should be determined by an extraction with 0.1M $BaCl_2$.



Data source: EC (DG VI) & UN/ECE (ICP Forests)

Figure 8.1 Geographic distribution of the plots with soil analyses data up to 1997.

An inventory of the applied methods showed that reference methods were used for the majority of the plots. Fig. 8.2 presents the methods used for total analyses of C, N, P and S in mineral and organic layers respectively. For C-organic and N in mineral layers the approved method (dry combustion) has been applied on nearly all plots. In the organic layer, however, the Kjehldahl method was used to determine total N in approximately 30% of the plots. Aqua regia, the reference method for the extraction of P and S, was applied for approximately 55% of the plots. Other methods used included various other acid extractions (see also Annex 5 in the Technical Report of 1998, De Vries et al., 1998). Even though deviation from the reference methods may cause variation, this is likely to be small in the case of C, N and S, which mainly occur in organic material. This will also be the case for P in the organic layer. In the mineral layer, however, the HF-acid digestion methods may lead to larger P concentrations (see below).

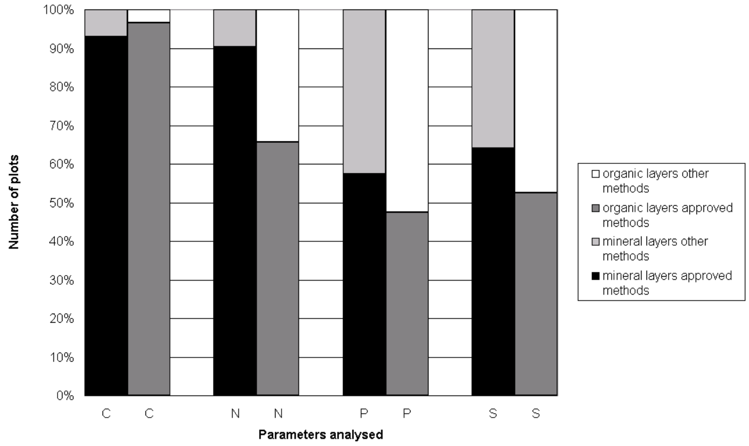


Figure 8.2 Methods used for the determination of total C, N, P and S concentrations in organic and mineral soil layers (approved methods: C, N: dry combustion; P, S: aqua regia).

Applied methods for the determination of major elements (Ca, Mg, K) and heavy metals (Pb, Cd, Cu and Zn) in organic and mineral layers are presented in Fig. 8.3. The reference method for all these elements (digestion with aqua regia) was applied at approximately 50-55% of the plots.

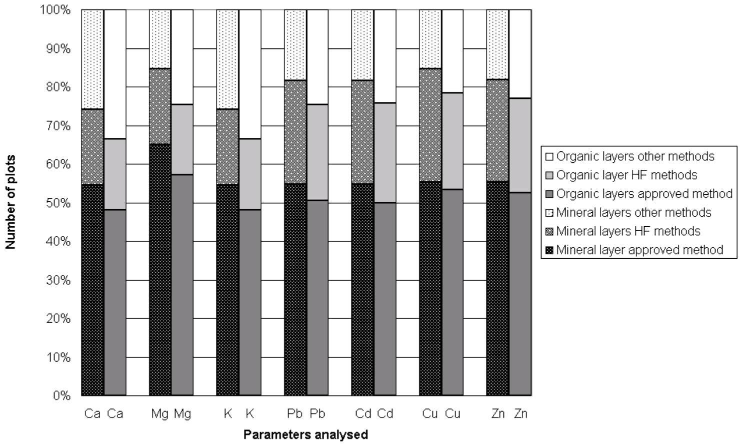


Figure 8.3 Methods used for the determination of total Ca, Mg, K, Pb, Cd, Cu and Zn concentrations in organic and mineral soil layers.

For the assessment of total concentrations of major cations and heavy metals a distinction should be made between the HF-methods, which is a 'real' total analysis and other 'so-called' total analysis methods. These methods do not release all cations fixed in mineral lattices. In general, the measured element concentrations will decrease according to HF > aqua regia > other methods (Houba, pers. comm.). The deviating HF method was reported for 20-25% of the plots but those plots all occurred in 3 countries. In this chapter, we only report the results of major nutrients (P, S, K, Mg and Ca) in the organic layer. Differences in measured element concentrations as a result of application of the deviating HF method can be considered negligible in this layer, since minerals hardly occur in organic layers, unless the sample has been strongly contaminated.

Measurement methods for the determination of pH were reported for 79% (mineral layers) and 99% (organic layers) of the plots for which soil methods were described. pH was always determined with the approved pH($CaCl_2$) method followed by a potentiometric determination. Base saturation was nearly always measured according to the approved unbuffered 0.1M $BaCl_2$ method (90% of the reported methodologies).

8.2.3 Data reliability

Sampling numbers

Information on the number of samples is important to gain insight in the accuracy of the plot-mean data. Fig. 8.4 gives an overview of the number of sampling points per plot used at different plots. The number of sampling points per plot ranged from 1 to 100 of which the majority (59%) was lower than 10. Sampling numbers between 21 - 30 occurred also relatively often (20%). Sampling was mostly carried out using soil pits (64% of the reported plots). On 19% of the plots sampling has been carried out using bores, whereas combinations of bores and soil pits were reported for 15% of the plots. No information is available for 2% of the plots.

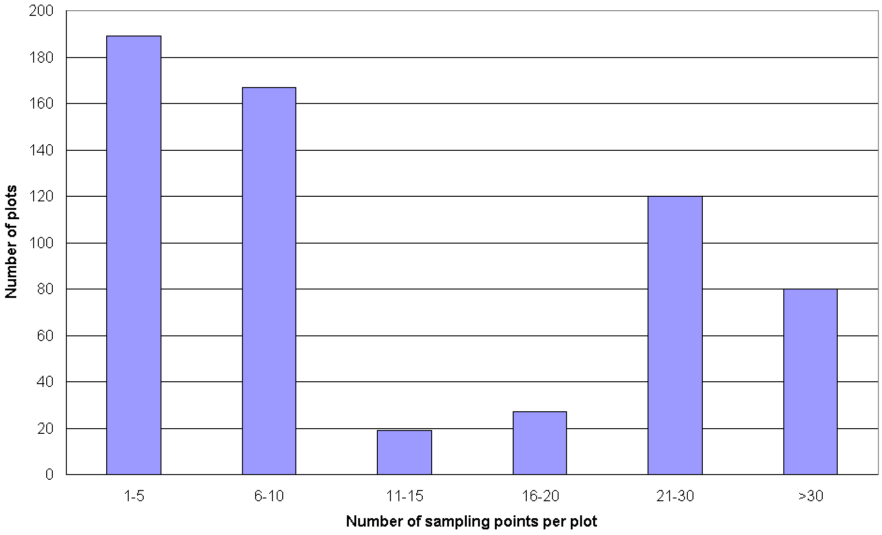


Figure 8.4 Number of soil sampling points used for the determination of soil chemistry.

Intercalibration tests

An indication of the quality of the collected soil data can be derived from the results of intercalibration exercises. A first intercalibration exercise using 4 standard samples was performed in 1992 by 22 participating countries. Results indicated that several national methods produce strongly deviating results, but even laboratories using the same analyses often recorded deviating results (Van der Velden and Orshoven, 1992). A second intercalibration exercise using 2 standard samples was performed in 1993, in which the use of both reference methods and national methods was recommended.

Results of the second intercalibration exercise (Table 8.1) indicate that the transnational comparability for key nutrient parameters (C and N concentrations) and for the acidity indicators (pH and base saturation) is good. Results for the total concentrations of base cations and specifically for heavy metals are, however, generally poor (Table 8.1). Note, however, that use of the reference aqua regia method hardly improved the comparability (see values in brackets in Table 8.1). This indicates that there is not a systematic difference between the applied methods (HF was not used by any of the laboratories) but a stochastic difference due to differences in laboratory quality control.

Table 8.1 Interlaboratory variation for soil key parameters based on results of a ringtest with two mineral soil samples (Source: EC_UN/ECE Vanmechelen et al., 1997)

Element	Participating Labs	Relative variation (%) 1)			Evaluation 2)
		Median	Average	Range	
C	22	9 (6)	11 (9)	1-25	Good
N	22	9 (5)	10 (7)	0-23	Very good
P	20	18 (28)	24 (32)	6-46 3)	Acceptable-poor
Ca	19	23 (19)	27 (24)	3-61 3)	Poor
Mg	20	16 (12)	18 (11)	1-45	Acceptable
K	20	36 (21)	82 (23)	3-137	Poor
pH 4)	22	13 (13)	23 (16)	0-63 3)	Good
Bsat	13	8 (8)	10 (9)	2-17 3)	Very good
Pb	10	34 (25)	37 (30)	17-50 3)	Poor
Cd	8	23 (23)	25 (23)	1-58	Poor
Cu	11	13 (29)	23 (32)	4-43 3)	Acceptable-poor
Zn	11	21 (14)	21 (18)	12-35	Poor

1) Values in brackets are related to those laboratories that used the reference methods (mostly half of the labs)

2)

Very good:	both median and mean are ≤ 10%
Good:	both median and mean are ≤ 15%
Acceptable:	both median and mean are ≤ 20%
Poor:	both median and mean are > 20%

3) Excluding one outlier

4) The interlaboratory variation for the pH is based on the delogarithmised values (the H-concentration). For the pH the variation is much lower and consequently the comparability is considered as good (Vanmechelen et al., 1997).

8.2.4 Data evaluation methods

Calculation of element pools

Element pools were calculated for the organic layer and for different mineral layers, while focusing on the topsoil (0-10 cm, 10-20 cm and 20-80 cm). Elements were limited to carbon and the major nutrients being N, P, S, Ca, Mg and K. The results refer to total concentrations (or pools), except for the base cations (Ca, Mg and K) in the mineral soil which refers to exchangeable concentrations or pools. Element pools in the humus layer are calculated by multiplying the measured organic layer pool with the element concentration in that layer according to:

$$AmX_{org} = Am_{org} \cdot ctX_{org} \cdot f_c \tag{8.1}$$

where:

AmX_{org} = pool (amount) of element X in organic layer ($kg.ha^{-1}$ or $kmol_c.ha^{-1}$)
Am_{org} = pool (amount) of solid material in organic layer ($kg.m^{-2}$)
ctX_{org} = concentration of element X in organic layer ($g.kg^{-1}$ for C and N, $mg.kg^{-1}$ for total P, S, Ca, Mg and K and $cmol_c.kg^{-1}$ for exchangeable base cations.
f_c = conversion factor (10 for C and N, 10^{-2} for total P, S, Ca, Mg and K and 10^{-1} for exchangeable base cations)

The pool of organic material in the humus layer is calculated by multiplying the humus layer pool with the organic matter content. Element pools in the mineral topsoil were calculated by multiplying an estimated bulk density of the soil with the soil thickness (10 cm or 60 cm), the element concentration in the soil and an estimated coarse fraction (stones) according to according to:

$$AmX_{min} = \rho_{sl} \cdot T_{sl} \cdot ctX_{min} \cdot (1 - cf) \cdot f_c \qquad (8.2)$$

where:
AmX_{min} = pool (amount) of element X in mineral layer ($kg.ha^{-1}$ or $kmol_c.ha^{-1}$)
ρ_{sl} = bulk density of soil layer ($kg.m^{-3}$)
T_{sl} = thickness of soil layer (m)
ctX_{min} = concentration of element X in mineral layer ($g.kg^{-1}$ for C and N and $cmol_c.kg^{-1}$ for the sum of exchangeable Ca, Mg, K and Na)
cf = coarse fraction ($m^3.m^{-3}$)

In the present calculations, the coarse fraction was estimated from an overlay with the FAO soil map, because field data were missing. The fraction coarse material for each plot was derived by assigning a soil phase from an overlay between the Intensive Monitoring Plots and the soil map of Europe (1:1,000,000 for the EU-13 member states and central European countries and 1:5,000,000 for Russia, Finland, Sweden and Norway). For the phases ‘Gravelly’, ‘Stony’ and ‘Concretionary’ the percentage of coarse materials was set to 40 %, whereas for a ‘Lithic’ phase the percentage of coarse materials was set to 20 %. For all other phases a percentage of coarse materials of 0 % was assumed. Actually, the soil map contains information on soil association consisting of several soil types with its own ‘soil phase’. The soil type determined in the soil survey was therefore matched against each soil type in the soil association. If the soil type (e.g. Haplic Podzol) from the survey occurred in the association, the phase from that soil type in the association was assigned to the Intensive Monitoring plot. If there was no exact match, the phase from the soil in the association that has the same soil group (e.g. Podzol, Cambisol) as the soil type at the plot was used. If there was also no match on soil group level, the dominant phase within the association was assigned to the plot. The coarse fraction thus estimated for the different plots is given in Fig. 8.5.

Since only few data on bulk density are available (not a mandatory parameter) bulk densities of the earth were derived by a pedotransfer function. In the literature, several transfer functions between bulk density and organic matter and/or clay content have been presented (e.g. Curtis and Post, 1964; Alexander, 1980; Harrison and Bocock, 1981; Hoekstra and Poelman, 1982; Huntington et al., 1989). Following Perruchoud et al. (1999), we used a transfer function with the measured organic carbon concentration according to Grigal et al. (1989) for the topsoil (0-20 cm):

$$\rho_{sl} = 0.44 + 0.65 \cdot e^{(-0.014 \cdot ctC_{org})} \qquad (8.3)$$

where:

ρ_{sl} = bulk density of the fine earth in a given soil layer ($kg.m^{-3}$)

ctC_{org} = organic carbon concentration (%)

For the subsoils (20-80 cm), we used a function adapted from Hoekstra and Poelman (1982) according to:

$$\rho_{sl} = 1000/(0.70 + 0.05 \cdot ctC_{org}) \tag{8.4}$$

Statistical data evaluation in view of soil monitoring

Repeated measurements of the concentration of an element X at times t_1 and t_2 gives information on the change in that concentration. Similarly, repeated measurements of the amount of solid material (or of the bulk density) and the element concentration gives information on the change in element pools. Whether the calculated differences, based on repeated measurements are significant, depends on (i) the standard deviation (s) of the concentration of the considered element (and the amount of solid material in case of pools) and (ii) the number of samples (n) that were taken at each survey. An estimate of the required changes in element concentrations and element pools to assess a statistically significant difference can already be derived from results of the first survey by assuming that:

- The standard deviation in element concentration and pools of solid material remains constant, which is reasonable when n is large. This assumption implies that one only needs a value of s at the first sampling period.
- The number of samples stays constant in the first and second survey.
- The analytical precision stays constant during both surveys, so that there is no systematic bias in the results, but a stochastic difference with respect to the analyses.

Using these assumptions, one can derive that the difference between element concentrations $\hat{X}_1$ and $\hat{X}_2$ is significant when (see also Annex 1):

$$\left|\hat{X}_2 - \hat{X}_1\right| \geq t_\alpha \cdot s_{x_1} \cdot \sqrt{2/n} \tag{8. 5}$$

where:

t_α = tabled student t factor for a given uncertainty; for $\alpha = 0.05$, $t_\alpha \approx 2$

s_{x_1} = standard deviation in element concentration in the first survey

n = number of samples

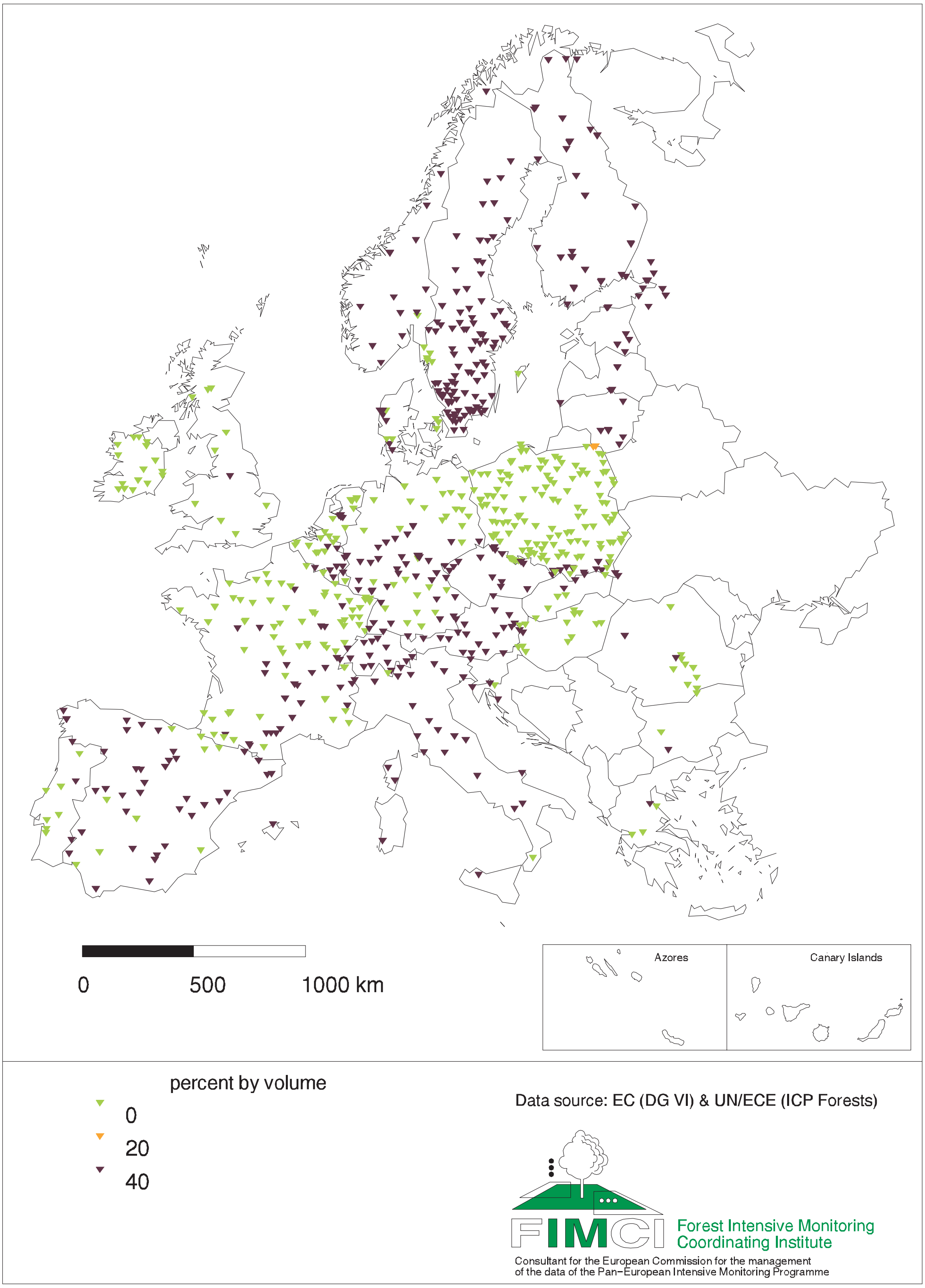


Figure 8.5 Estimated coarse fraction at the different soil plots.

Using the same assumptions, one can also derive that the measured difference in element pools between two time periods $\hat{Z}_1$ and $\hat{Z}_2$ is only statistically significant when (see Annex 1):

$$\left|\hat{Z}_1 - \hat{Z}_2\right| \geq t_\alpha \cdot \sqrt{\frac{2}{n^2} \cdot S_X^2 \cdot S_Y^2 + \left(\frac{2\hat{Y}^2}{n}\right) \cdot S_X^2 + \left(\frac{2\hat{X}^2}{n}\right) \cdot S_Y^2} \qquad (8.\,6)$$

where:

$\hat{X}$ = the estimated average element concentration

$\hat{Y}$ = the estimated average pool of solid material

S_x^2 = variance in element concentration

S_y^2 = variance in solid material pool

Calculation of the time period that is needed before a soil survey should be repeated in order to derive statistically significant differences requires information on the external atmospheric input and a model that estimates the retention in the soil. Combination of such a simple model with the required pool changes given in Eq. (8.5), assuming that the pool of solid material either stays constant or increases at a constant rate, leads to a formula that can be solved iteratively to derive this time period. More information is given in Annex 2. This formula was used to calculate those periods for all the Level 2 plots for which atmospheric deposition data were available. The methods and results were focused on the change in N in the organic layer in relation to N deposition and on the change in base saturation in the mineral topsoil in relation to the acid deposition (see also Annex 2).

Assessment of relationships between element pools and environmental factors

Element pools in organic layers and mineral layers are influenced by various stand and site characteristics, by meteorological characteristics and by the external input from the atmosphere. The influence of these environmental variables on the element pools was investigated by a multiple regression analysis, combining categorical variables (tree species, soil type) and continuous variables. Such an analysis gives some insight in factors influencing historical sequestration rates of carbon and nutrients. Supposed relationships were of the form:

$$\log \text{soil concentration/pool} = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \cdots\cdots + \alpha_n x_n \qquad (8.7)$$

where log soil concentration/pool is the expectation value of the response variable, x_1 to x_n are predictor variables (stand and site characteristics, meteorological parameters etc.) and α_1 to α_n are the regression coefficients. The regression analysis was applied by using a so-called Select procedure (Section 3.3.3).

The predictor variables used in explaining the soil chemistry in the humus layer and mineral soil are summarised in Table 8.2. Soil type in combination with altitude, temperature, precipitation and pH affects the decomposition or mineralisation, thus influencing the pool of carbon and of all related elements in that pool. Tree species (and tree age) affects the nutrient input by litterfall. Furthermore, it influences the input of nutrients by dry deposition due to its effect on the surface roughness. This is also true for the tree height. Information on the clusters used for soil type and tree species is given in Section 3.3.3.

Table 8.2 Environmental variables affecting element concentrations and element pools in organic layers and mineral layers that were included in the regression analyses.

Variable	Organic layer				Mineral layer		
	C	N, P, S	K, Ca, Mg	BC_{exch}	C	N	BC_{exch}
Stand characteristics							
Soil type cluster	X	X	X	X	X	X	X
Tree species	X	X	X	X	-	-	-
Tree height (age)	X	X	X	X	-	-	-
Altitude	X	X	X	X	X	X	X
Meteorology							
Precipitation	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X
Deposition							
N, P, S1)	-	X	-	-	-	X	-
Ca, Mg, K	-	-	X	X	-	-	X
Soil Chemistry							
pH-$CaCl_2$	X	X	X	X	X	X	X

1) S data are not available for the mineral layer

Meteorological variables were derived from interpolation of 30-year averaged data on precipitation and temperature (after Leemans and Cramer, 1991), which gives a better impression of the average meteorological circumstances than actual data. Furthermore, the latter data were only available at part of the plots. For atmospheric deposition of N and S, use was made of measured throughfall data. For Ca, Mg and K, total deposition was calculated based on bulk deposition and throughfall data of Ca, Mg, K and Na, using a procedure described in Section 8.2.4.

8.3 Results and discussion

8.3.1 Ranges in element pools and in required pool changes to derive significant differences

Ranges in element pools

In presenting element pools, a distinction has to be made between carbon, nitrogen and exchangeable base cations, that were measured in both the organic layer and all four mineral layers (0-10 cm, 10-20 cm, 20-40 cm and 40-80 cm) and other nutrients (total P, S, K, Ca and Mg), that were measured in the organic layer only. An overview of the ranges in element pools in the organic layer is presented in Table 8.3.

Table 8.3 Ranges in element pools in the organic layer

Element	Unit	No of plots	5%	50%	95%
C	$ton.ha^{-1}$	449	1.9	14	74
N	$kg.ha^{-1}$	449	71	474	2597
P	$kg.ha^{-1}$	297	3.8	32	125
S	$kg.ha^{-1}$	72	9.8	101	267
K	$kg.ha^{-1}$	438	14	51	331
Ca	$kg.ha^{-1}$	361	41	130	664
Mg	$kg.ha^{-1}$	428	8.3	33	263
BC1)	$kmol_c.ha^{-1}$	172	0.51	7.6	37

1) Stands for the exchangeable pool

Table 8.3 shows that the range in element pools is the largest for the exchangeable cations. The highest pools are approximately 75 times higher than the lowest pools. This large range is partly due to the large range in carbon pools, determining the CEC, and partly to the range in exchangeable cation concentrations. The ranges in carbon and nitrogen are comparable, which is to be expected since carbon and nitrogen are highly correlated. The ranges in the other nutrient pools are generally smaller, especially for the Ca pools where the upper levels are approximately 15 times higher than the lower levels.

A comparison of the range in N pools with the range in total N deposition (approximately 5-40 kg.ha^{-1}.yr^{-1}, see Section 8. 3.1) shows that the average N pool is approximately 50 times as large as the average N deposition, with a range of 5-500. This range does already give an indication about the possible change in N concentration or N pool with time (see below) and the time period that is required between two soil surveys to detect significant differences (Section 8.3.2). Similar comparisons can be made for the exchangeable cation pool compared to the acid input, but that comparison is specifically relevant for the mineral layer (see below). In the organic layer the base saturation is mainly determined by element cycling due to litterfall, mineralisation and root uptake. More detailed information on the frequency distribution of the nutrient pools is given in Fig. 8.6.

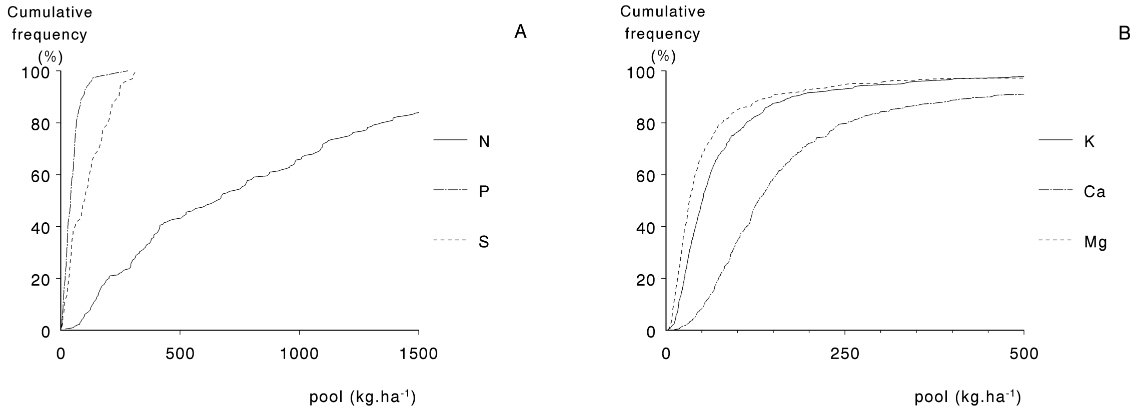


Figure 8.6 Cumulative frequency distributions of the pools of N, P and S (A) and of K, Ca and Mg (B) in the organic layer.

Results show that the distribution of N and Ca pools is rather even. The distributions of P and S pools and to a lesser extent the Mg and K pools are however skewed. High pools were found only in circa 10- 20% of the plots. None of the considered elements had a normal distribution. Consequently, analyses of the relationships between carbon, nutrient and exchangeable base cation pools in the organic layer and environmental factors were done with log-transformed values.

Ranges in the pool of carbon, nitrogen and base cations for the mineral soil profile are given in Table 8.4. Results were limited to plots where information for all mineral soil layers was available. The results of the layers 20-40 cm and 40-80 cm were lumped since information is most interesting for the topsoil where possible changes are more likely. To get insight in the differences in the mineral pools and organic pools, the latter pools were also included while limiting them to the plots where information for all mineral soil layers was available.

Table 8.4 Range in carbon, nitrogen and base cation pools (5%-95%) as a function of soil layer

Soil layer	No of plots	Carbon pool (ton.ha^{-1})			No of plots	Nitrogen pool (kg.ha^{-1})			No of plots	Exchangeable base cation pool (kmol$_c$.ha^{-1})		
		5%	50%	95%		5%	50%	95%		5%	50%	95%
Organic	384	1.8	12	75	378	66	396	2731	129	0.44	6.2	50
0-10 cm	522	6.7	21	55	515	358	1190	3291	471	1.0	5.4	77
10-20 cm	522	3.2	12	35	515	211	709	2312	471	0.44	2.7	55
20-80 cm[1]	522	10	47	197	515	834	3119	13854	471	2.6	20	559
Total	522	20	80	287	515	1403	5018	19457	471	4.0	28	691

[1] The pools per 10 cm are six times as low.

As with the organic layer, the largest ranges in element pools in the mineral layers are again observed for the exchangeable cations (Table 8.4). This range is mainly caused by the differences in parent material. The ranges on carbon and nitrogen pools are again very similar. The ranges in both pools are relatively smaller in the mineral layers than in the organic layer and there are no great differences with depth.

It is clear that the C, N and exchangeable BC pools are larger in the mineral layers than in the organic layer. Furthermore, the range is larger in the first mineral layer (0-10 cm) than in the underlying layer (10-20 cm) illustrating that the concentrations and pools of the various elements decrease with depth. This is also the case below 20 cm, but the sixfold increase in soil thickness (20-80 cm) causes the pools to be much larger. Despite the decrease of element concentrations with depth, the results show that the largest part of the element pool occurs in the subsoil. This part is, however, less dynamic than the topsoil. More insight in the distribution of element pools in the various soil layers is given in Fig. 8.7.

The cumulative frequency distributions show that the carbon and nitrogen pools are more evenly distributed than the exchangeable base cation pools in all the considered soil layers. Furthermore, C and N pools in the subsoil (20-80 cm) are more evenly distributed than in the organic layer and in the mineral topsoil (0-20 cm). Apart from the C and N pools in the subsoil, none of the considered elements had a normal distribution. As with the organic layer, analyses of the relationships between carbon, nitrogen and base cation pools in the mineral layer (0-10 cm) and the environmental factors were thus done with log-transformed values.

Required changes in element pools

Changes that are required in element pools to detect significant differences will depend on the pool size, the standard deviation in the pool size (bulk density and element concentration) and in the number of samples that were taken (see Annex 1). Actually, no information is readily available in the standard deviation or coefficient of variation. As an example, Table 8.5 gives information on the required relative changes for a number of 25 samples and a coefficient of variation varying between 0.1 and 0.3.

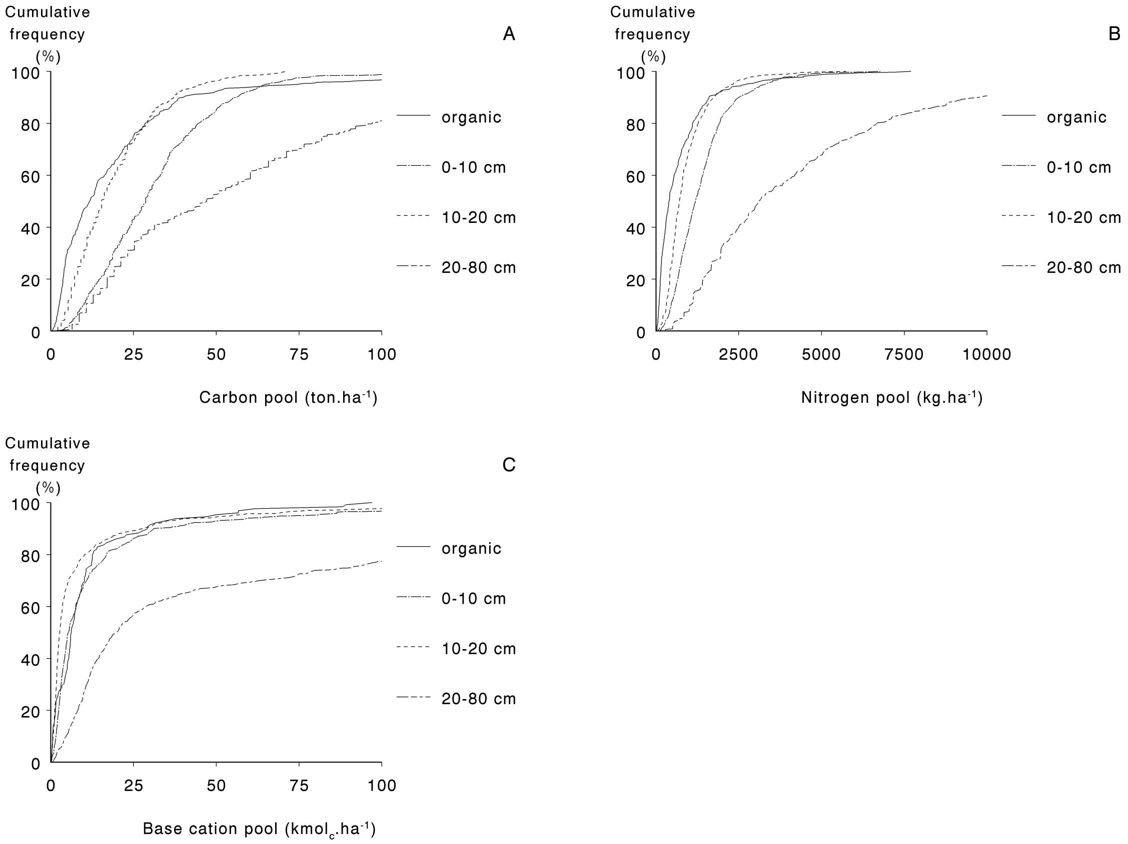


Figure 8.7 Cumulative frequency distributions of the pools of carbon (A), nitrogen (B) and exchangeable base cations (C) for different soil layers. Beware of the difference in soil thickness for the lower mineral layer (20-80 cm).

Table 8.5 Required changes (%) in concentrations and pools to assess significant differences as a function of the coefficient of variation.

Coefficient of variation	Needed changes (%)	
	Concentrations	Pools
0.1	6	8
0.2	11	16
0.3	17	24

Application of the percentages from Table 8.5 on nitrogen pools in the organic layer and base cation pools in the mineral top soil (0-10 cm) gives required pool changes as presented in Table 8.6. Those pools were chosen since they are liable to change due to nitrogen deposition and acid deposition, respectively. Ranges in required changes in pools of nitrogen and exchangeable base cations to assess significant differences strongly differ as a function of the coefficient of variation. The required changes in pools become proportional greater with a rising coefficient of variation.

Table 8.6 Ranges in required changes in pools of nitrogen and exchangeable base cations to assess significant differences at Intensive Monitoring plots as a function of the coefficient of variation, assuming a use of 25 samples per plot.

Coefficient of variation	N pool in organic layer (kg.ha^{-1})			BC pool in mineral topsoil (keq.ha^{-1})		
	5%	50%	95%	5%	50%	95%
0.1	5.5	38	239	0.073	0.60	8.5
0.2	11	77	478	0.15	1.2	17
0.3	17	115	717	0.22	1.8	26

The number of samples and sub-samples used per plot varies per country. This information, which was available in the DAR-Q's, was used to calculate required pool changes in C, N and base cations in various layers, assuming a coefficient of variation of 0.2 (Table 8.7).

Table 8.7 Ranges in required changes in carbon, nitrogen and base cation pools, using the actual number of samples and assuming a coefficient of variation of 0.2 at each plot.

Soil layer	No of plots	Carbon pool (ton.ha^{-1})			No of plots	Nitrogen pool (kg.ha^{-1})			No of plots	Exchangeable base cation pool (kmol$_c$.ha^{-1})		
		5%	50%	95%		5%	50%	95%		5%	50%	95%
organic	384	0.48	2.2	19	378	14	81	793	129	0.08	1.1	11
0-10 cm	522	1.1	4.5	22	515	43	254	1276	471	0.15	1.2	17
10-20 cm	522	0.61	2.5	12	515	32	154	794	471	0.07	0.61	12
20-80 cm	522	1.7	9.9	64	515	115	715	4767	471	0.34	4.8	141
total[1)]	522	3.4	17	98	515	190	1123	6837	471	0.56	6.6	170

[1)] The pools per 10 cm are six times as low.

Results for nitrogen in the organic layer and exchangeable base cations in the first mineral layer (0-10 cm) appear to be comparable with those assuming a constant number of 25 soil samples (Table 8.7). The only exception is the 95 percentile for nitrogen, which is much higher when calculated with the exact number of samples per plot. The ranges do indicate that in many cases, substantial changes in carbon, nitrogen and base cation pools are needed before a significant difference can be detected. Smallest changes are required in the organic layer, followed by the mineral topsoil. Considering the processes occurring in soils, significant differences are therefore detected at first in those layers. A second soil survey might therefore concentrate on those layers.

8.3.2 Variation in relevant time periods to repeat soil surveys

The calculation of time periods that are needed to assess a significant difference has been limited to N in the organic layer and base cations in the mineral layer. Those pools are liable to change caused by nitrogen or acid deposition and a simple model was used to calculate these periods (Annex 2). Results for nitrogen and base cations are given in Fig. 8.8. The results show that a time interval of 10 years, which is generally considered for a repetition of the soil survey, might give a significant difference in nitrogen pools in the organic layer in approximately 25% of the plots, assuming a variation coefficient ranging between 0.1 and 0.3. For the exchangeable base cation pool in the mineral layer, this percentage appears to be much lower (generally less than 10%).

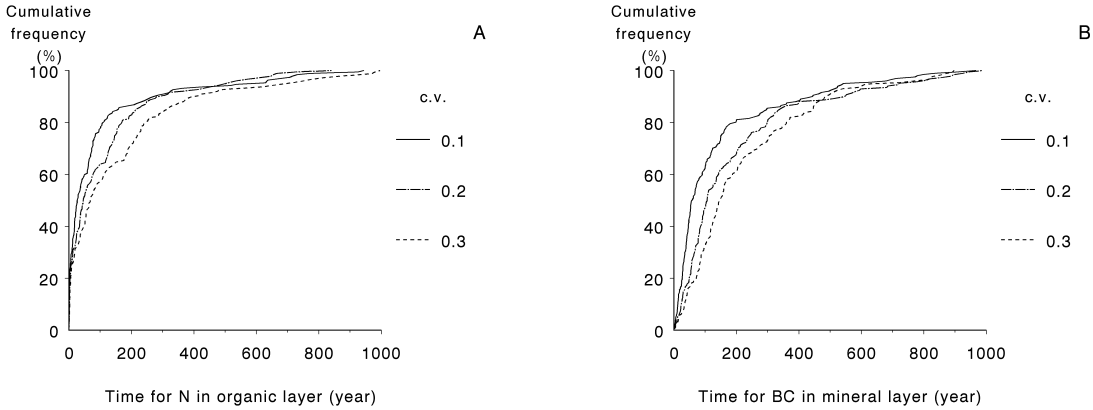


Figure 8.8 Cumulative frequency distributions of the time periods that are needed to assess a significant difference in the pool in the organic layer (A) and in the exchangeable BC pool in the mineral layer (B).

It is likely that the time period needed to assess significant differences in N pools is influenced by the N pool itself, by the external N input due to deposition and by the C/N ratio, which influences the N retention. This is illustrated in Fig. 8.9.

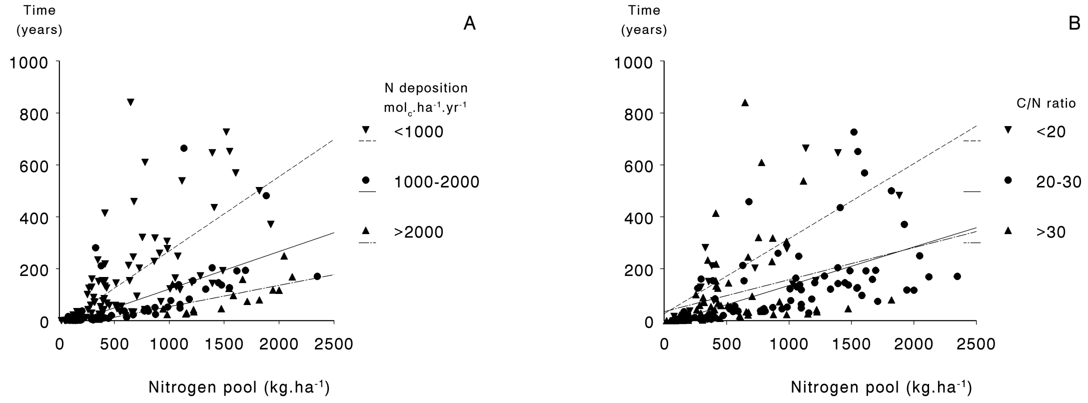


Figure 8.9 The calculated relationships between required time periods to assess significant differences in N pools and the original nitrogen pools for different N deposition fluxes (A) and C/N ratios (B) for all investigated plots.

Results showed that the required time period to assess significant differences significantly increased with an increased N pool and decreased N deposition. Linear regression analyses resulted in R^2_{adj} values of 0.49, 0.46 and 0.56, respectively for the three considered increasing ranges of N deposition (Fig. 8.9A). The results also indicated that the impact of C/N ratio could only be discerned above a value of 30. Linear regression analyses resulted in R^2_{adj} values of 0.54, 0.42 and 0.09, respectively for ranges in C/N ratio of < 20, between 20-30 and >30. The relationship at a C/N ratio above 30 is thus very weak (Fig. 8.9). Even though it may take hundreds of years before significant changes can be expected at certain plots, there is a considerable number of plots where such changes are likely within a 10 year period. This is illustrated in Fig. 8.10.

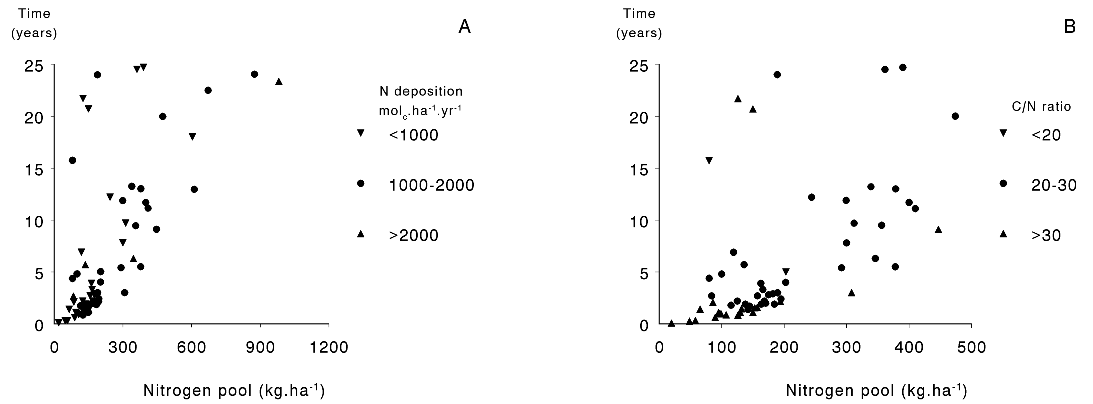


Figure 8.10 *The calculated relationships between required time periods to assess significant differences in N pools and the original nitrogen pools for different N deposition fluxes (A) and C/N ratios (B) for plots with a predicted time period of less than 25 years.*

Comparable to N, the time period needed to assess significant differences in exchangeable base cation pools is influenced by the base cation pool itself, the acid deposition and by the base saturation, which influences the BC release in response to acid inputs. This is illustrated in Fig. 8.10. As expected, the figure illustrates that the required time period to assess significant differences significantly increased with an increased base cation pool and a decreased acid deposition. Results are, however, less convincing than for N. Linear regression analyses resulted in R^2_{adj} values of 0.14, 0.38 and even less than 0.01 (no relationship) at an acid deposition range increasing from less than 1000 mol$_c$.ha^{-1}.yr^{-1} to more than 2000 mol$_c$.ha^{-1}.yr^{-1} (Fig. 8.11A). For the base saturation, linear regression analyses resulted in R^2_{adj} values of less than 0.01 (no relationship), 0.28 and 0.07, respectively for three increasing ranges in base saturation from less than 10% to more than 25% (Fig. 8.11A).

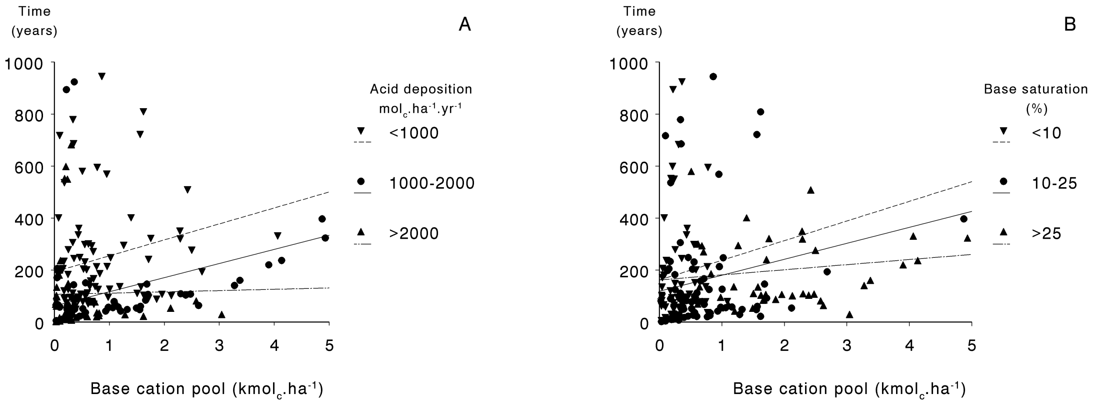


Figure 8.11 *The calculated relationships between required time periods to assess significant differences in exchangeable base cation pools and the original base cation pools for different acid deposition fluxes (A) and base saturation ranges (B) for all investigated plots.*

The number of plots at which significant changes can be expected within 10 years was calculated to only 10%. Those plots are indicated in Fig. 8.12.

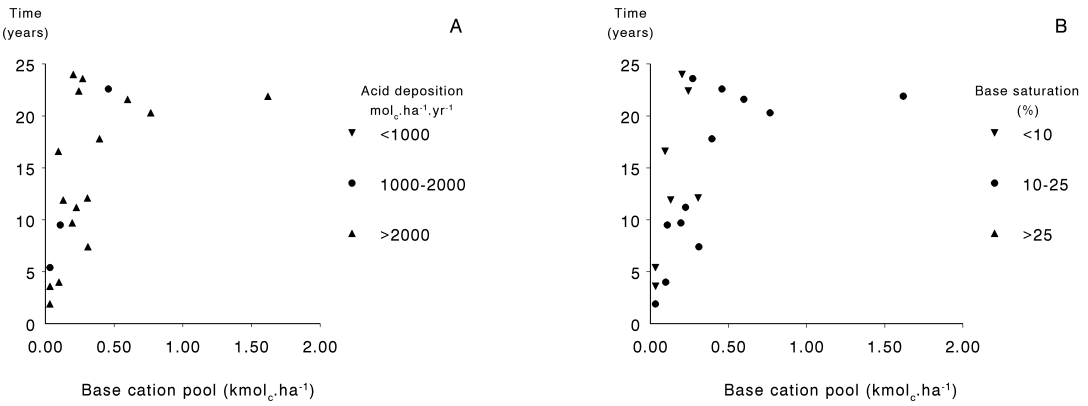


Figure 8.12 The calculated relationships between required time periods to assess significant differences in exchangeable base cation pools and the original base cation pools for different acid deposition fluxes (A) and base saturation ranges (B) for plots with a predicted time period of less than 25 years.

8.3.3 Relations between element pools and environmental factors

Element pools and element concentrations in the organic layer

Relations between element pools in the organic layer and the environmental factors were derived with subsets of the total available number of plots. These subsets differ per derived relation. In Table 8.8 the ranges of the response and predictor variables are given for plots limited by the occurrence of information about the N deposition.

For all the nutrient pools, the range between the 5 and 95 percentile in the regression data set was only slightly smaller than for the total set (compare Table 8.3 and Table 8.8) indicating that the plots included in the regression analyses are quite representative. The distribution of the pools of K, Ca, Mg and exchangeable base cations is very similar to that of the total set, whereas it differs slightly for C, N and P. Because of the skewness of the distributions of the nutrient pools, the relations were derived with the log-transformed values.

Tree age ranged from 10 to 130 years with a fairly normal distribution. Since tree ages are given in 20 year intervals, the mean age was taken. There is, however, also a class ‘uneven’ for forest stands consisting of trees of different ages. Ignoring the ‘uneven’ class means that you cannot include this plot in the regression analyses. Therefore not the variable age but the interaction between age and a qualitative variable even age or uneven age was used to derive relationships with age.

Altitude, precipitation and temperature are correlated variables. Altitude ranged from 25 m up to more than 1000 or 1800 m. Forest at the highest altitudes is only possible in warmer areas. The ranges in precipitation and temperature were smaller than for most variables because 30 year averaged data were used. For altitude and precipitation the values were also log-transformed. Looking at the deposition values, the range between the 5 and 95 percentile is largest for the N deposition. The ranges for the deposition of the base cations are smaller, especially for K. The deposition of Mg is relatively large in regard to Ca an K. Also because of skewness, these values were log-transformed.

Table 8.8 Ranges in response variables (element pools) in the organic layer and predictor variables (environmental factors) used in the regression analyses

Variable	Unit	No of plots	Minimum	5%	50%	95%	Maximum
Element pools							
C	ton.ha^{-1}	215	0.69	3.3	19	67	134
N	kg.ha^{-1}	215	20	98	658	2522	7192
P	kg.ha^{-1}	152	0.80	7.2	41	120	282
S	kg.ha^{-1}	72	4.4	9.9	101	267	316
K	kg.ha^{-1}	208	6.5	14	48	230	868
Ca	kg.ha^{-1}	185	19	48	137	553	2559
Mg	kg.ha^{-1}	206	2.8	8.7	35	191	1938
BC	kmol$_c$.ha^{-1}	105	0.11	0.58	7.6	40	89
Stand characteristics							
Tree age	yr	288	10	30	70	130.0	130
Altitude	m	302	25	25	275	1075	1875
Meteorology							
Precipitation	mm.yr^{-1}	297	411	520	759	1536	1887
Temperature	ºC	297	-3	1	8	11	16
Deposition							
N	mol$_c$.ha^{-1}.yr^{-1}	302	19	64	797	2682	4490
S	mol$_c$.ha^{-1}.yr^{-1}	302	51	115	564	2494	6347
Ca	mol$_c$.ha^{-1}.yr^{-1}	273	27	41	248	872	1537
Mg	mol$_c$.ha^{-1}.yr^{-1}	273	3.6	20	116	596	2509
K	mol$_c$.ha^{-1}.yr^{-1}	270	12	22	66	187	657
Soil chemistry							
pH-CaCl$_2$	-	221	2.1	2.8	3.3	5.2	6.3

Predictor variables explaining the variance in element pools in the organic layer are given in Table 8.9. Ultimately, the deposition of acidity was not included, since pH-CaCl$_2$ was a better predictor variable being more directly related to the element pools. When relationships are, however, derived with the intention to predict element pools in areas with no information on soil data or for future situations, the predictor variable acidity would be more suitable, since acid deposition can be predicted by atmospheric deposition models.

Table 8.9 Overview of the predictor variables explaining element pools in the organic layer with the number of plots (N) and the percentage variance accounted for (R^2_{adj}).

Variable	Element							
	C	N	P	S	K	Ca	Mg	BC$_{exch}$
Stand characteristics								
Soil type			-					++
Tree species			++	--	++		++	
Tree height (age)								
Altitude	--	-	--					--
Meteorology								
Precipitation	++	++	+		++	++	++	
Temperature	--		--	++				
Deposition								
N, S								
Ca, Mg, K								
Soil Chemistry								
pH-CaCl$_2$	--	--	--	--	--			
N	311	190	243	68	167	155	169	99
R^2_{adj}	51	37	47	72	29	13	28	17

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable

The explanation of the variation in element pools in the organic layer, in terms of percentage of variation accounted for, ranged from 13% for the exchangeable base cations pools up to 72% for the S pools (Table 8.9). The number of plots to derive the relationship was, however, low for both the base cation and S pools. There exist a chance that these relationships are influenced by several extreme plots. For most element pools circa 30% to 50% of the variance was accounted for.

The meteorological factors precipitation and/or temperature appeared to be very significant in explaining part of the variation of all element pools, except for the exchangeable base cations. pH-$CaCl_2$ was also very significant in explaining the pools of C, N, P, S and K. Actually the combination of precipitation or temperature and pH-$CaCl_2$ explains the major part of the variation in C, N, P and S. In explaining the K pool, precipitation in combination with tree species seems to have a larger contribution to the percentage variance accounted for than the pH-$CaCl_2$. Precipitation is even the only significant variable in explaining the Ca pools and the main variable in explaining the Mg pools. The effects of soil type, altitude and tree height were marginal, except for the exchangeable base cation pools where soil type is the main explaining variable.

The relationships between various element pools and precipitation were all positive, meaning that the element pools are larger in wetter situations. Combined with lower temperatures for C and P pools this confirms an expected relation; namely higher pools under colder and wetter conditions. This is most likely due to decreased mineralisation, and sometimes increased litterfall, thus leading to an accumulation of organic carbon and pools of related elements. The relationships between several element pools and pH-$CaCl_2$ were all negative, meaning that the element pools are larger in situations with higher acidity. This is also in accordance with the expectation, since mineralisation decreases when acidity increases. In the case of exchangeable base cations, the relation with soil type is very significant. The relation with soil type is indicated as positive, which means that the pools of exchangeable base cations were significantly higher in the Cambisols and Luvisols than in the Podzols and Arenosols. This is according to the expectations, namely less acidic and mineralogically richer soil have larger pools of exchangeable base cations.

No significant relationship was observed between element deposition and element pools, indicating the overwhelming influence of meteorological variables on element pools. With respect to N, this result should be interpreted with care. High N deposition during a long time period most likely causes a larger N pool. An indication for this is the fact that the ranges in element pools are highly comparable to those observed in 150 forest stands in the Netherlands, except for nitrogen (De Vries and Leeters, 2000). N pools are generally higher in this country, indicating the impact of N deposition on the N pool in the organic layer.

Results for the regression analysis between element concentrations in the organic layer and environmental factors are shown in Table 8.10. The explanation of the variation in the concentrations of C, N, P and S in the organic layer was much lower than for the pools of those elements, but it was higher for the total and exchangeable concentrations of base cations compared to the pool (compare Table 8.9 and 8.10). The percentage of variance accounted for ranged from 15% for N up to 62% for Mg. In a previous Technical Report (De Vries et al., 1998), similar values were found by including tree species, soil type, climatic region and altitude as predictor variables, except for C and N. In the previous assessment, including more plots, the value of R^2_{adj} was approximately 40% for both elements. The number of plots used to derive the relationships for the element concentrations were generally higher, than with element pools, especially for C.

Table 8.10 Overview of the predictor variables explaining element concentrations in the organic layer with the number of plots (N) and the percentage variance accounted for (R^2_{adj}).

Variable	Element							
	C	N	P	S	K	Ca	Mg	BC_{exch}
Stand characteristics								
Soil type			+					++
Tree species	++	++	++	--	++		+	
Tree height (age)						++		
Altitude	--	--			++		++	
Meteorology								
Precipitation	++	++	++					
Temperature	--		--	++			--	
Deposition								
N, S								
Ca, Mg, K							++	
Soil Chemistry								
pH-$CaCl_2$					++	++	++	+
N	467	215	394	70	192	179	193	99
R^2_{adj}	21	15	29	31	38	60	62	21

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable

As with the element pools, atmospheric deposition was not significantly related to the concentration of any element. This result should, however be interpreted with care. On the long-term, elevated N deposition most likely causes higher N concentrations in the organic layer (see before). For the concentrations of most elements, the influence of tree species was larger than on the pools. Tree species and precipitation and/or temperature explained the major part of the variation in C, N, P and S concentrations. For the concentrations of K, Ca, Mg and exchangeable base cations, pH-$CaCl_2$ was the main explaining variable, in combination with altitude for K, tree age for Ca, deposition of Mg for Mg and soil type for the exchangeable base cation concentrations. The greater impact of tree species on the element concentrations compared to element pools is likely. Tree species influence the atmospheric deposition and foliar concentrations and thereby the element concentrations, while element pools are more directly related to amounts of organic matter.

Element pools and element concentrations in the mineral layer

As with the organic layer, relations between element pools in the mineral layer 0-10 cm and the environmental factors where derived with subsets of the total number of plots. These subsets differ per derived relation. In Table 8.11 the ranges of the response and predictor variables are given for the plots limited by the occurrence of information about the N deposition.

The range between the 5 and 95 percentile of the exchangeable base cations in the mineral layer of plots used in the regression analysis (0-10 cm) was comparable to the total data set (compare Table 8.4 and Table 8.11). In comparison to the total set (Table 8.4), there were more high C pools and more low N pools in the subset, while the range was slightly smaller. The range and distributions of the environmental factors were the same as for the organic layer (Table 8.8).

Table 8.11 Ranges in response variables (element pools) and predictor variables (environmental factors) used in the regression analysis.

Variable	Unit	No of plots	Minimum	5%	50%	95%	Maximum
Nutrient pools							
C	$ton.ha^{-1}$	264	3.1	6.6	22	61	110
N	$kg.ha^{-1}$	264	125	284	1074	3061	5012
BC	$mol_c.ha^{-1}$	242	0.22	0.44	4.2	84	501
Stand characteristics							
Altitude	m	302	25	25	275	1075	1875
Meteorology							
Precipitation	$mm.yr^{-1}$	297	411	520	759	1536	1887
Temperature	ºC	297	-3	1	8	11	16
Deposition							
N	$mol_c.ha^{-1}.yr^{-1}$	302	19	64	797	2682	4490
Soil chemistry							
pH-$CaCl_2$	-	259	2.8	2.9	3.6	5.1	7.3

Results of the regression analysis are given in Table 8.12. The variation in the C, N and exchangeable cation pools in the mineral layer that could be explained (in terms of percentages accounted for) was 38%, 46% and 18%, respectively (Table 8.12).

Table 8.12 Overview of the predictor variables explaining element pools and concentrations in the mineral layer (0-10 cm) with the number of plots (N) and the percentage variance accounted for (R^2_{adj}).

Variable	Element pools			Element concentrations		
	C	N	BC_{exch}	C	N	BC_{exch}
Stand characteristics						
Soil type	++	++		++	++	++
Altitude		++	++	++	++	
Meteorology						
Precipitation	++	++	+	++	++	++
Temperature	++	++				
Deposition						
N					++	
Ca, Mg, K			++			
Soil Chemistry						
pH-$CaCl_2$	--			-		++
N	563	253	184	563	253	216
R^2_{adj}	31	48	18	36	46	23

++ significant at the p 0.01 level and t>3 and positive correlated with response variable
+ significant at the p 0.05 level and t>2 and positive correlated with response variable
-- significant at the p 0.01 level and t>3 and negative correlated with response variable
- significant at the p 0.05 level and t>2 and negative correlated with response variable

Unlike the organic layer, soil type was the most important explaining variable. Soil type is a qualitative variable, the relations differ therefore for each soil type. One soil type is taken as a reference (in this case the Arenosols) and for the other soil types we investigated whether or not they differ significantly from the reference type. The positive mark in our presentation means that most soil types have significant larger element pools than the Arenosols which are the most acidic and sandy soils included in this study. For the C and N pools the percentages accounted for by soil type and precipitation were already 35% and 38%, respectively. For soil type, 9 groups were distinguished (Section 3.3.3; De Vries et al., 1998) to derive the relationships in the mineral layer. Compared to using the 3 soil groups distinguished for the organic layer, this lead (as expected) to a higher percentage variance accounted for, namely plus 13% and plus 4% for the C and N pools, respectively. However when the other explaining variables were also taken into account the differences decreased to 8% and 3% for C and N pools respectively.

Unlike the expectations, soil type was not significant in explaining the pool of exchangeable base cations. The exchangeable cation pools were mainly explained by the atmospheric deposition of Ca, Mg and K in combination with the altitude (16%), although the total percentage variance accounted for was very low. The insignificant relationship between soil type or pH-$CaCl_2$ and base cation pool might be due to confounding with bulk density and CEC, since both variables do affect the exchangeable base cation concentrations.

As with the relationships with the element pools of the organic layer, precipitation and temperature were important predictor variables for the element pools in the mineral layer. The relations between the explaining variables and the element pools in the mineral layer are all positive, meaning that the pools are larger under wetter circumstances, in higher situated plots and when the atmospheric deposition of the element is higher, all according to expectations. The positive relationship between soil temperature and N pools is unlike expectations, showing that regression results should always be interpreted with care.

The results of the relations between environmental factors and the concentrations of C and N in the mineral layer are almost similar to the results for the C and N pools. The N concentrations were more related to the total N deposition than the N pools. For the exchangeable base cations there was a higher percentage variance accounted for with the concentrations (23%) than with the pools (18%). In the relationship with soil concentrations, soil type and pH-$CaCl_2$ were the major explaining variables (19%).

8.4 Conclusions

Soil chemical data at the Intensive Monitoring plots were evaluated with respect to: (i) ranges in element pools in the organic layer and the mineral soil and the required changes in those pools to derive significant differences, (ii) the variation in time periods that are relevant with respect to the repetition of soil surveys and (iii) relationships between element pools in the organic layer and the mineral soil and various environmental factors. Major conclusion related to those aspects are given below.

Ranges in element pools and the required changes in those pools to derive significant differences

Changes that are required in element pools to detect significant differences depend on the pool size, the standard deviation in the pool size (bulk density and element concentration) and in the number of samples that were taken. The required changes in pools to assess significant differences become proportional greater with an increasing coefficient of variation. The ranges do indicate that in many cases substantial changes in carbon, nitrogen and base cation pools are needed before a significant change can be detected. Smallest changes are required in the organic layer, followed by the mineral topsoil. A second soil survey might therefore concentrate on those layers.

Variation in time periods that are relevant with respect to the repetition of soil surveys

Time periods that are needed to assess a significant difference have been limited to N in the organic layer and base cations in the mineral layer, since those pools are liable to change caused by nitrogen or acid deposition. Results showed that a time interval of 10 years, which is generally considered for a repetition of the soil survey, might give a significant difference in N and exchangeable base cation pools for approximately 25% and 10% of the plots, respectively. The time period needed to assess significant differences in N pools increased with an increase in the N pool and decreased with an increase in the N deposition and C/N ratio. For exchangeable base cation pools, this time period increased with an increase in base cation pool and base saturation and decreased with an increased acid deposition.

Relationships between element pools and concentrations versus environmental factors

Approximately 30-50% of the variation in element pools in the organic layer could be explained by various stand and site characteristics, precipitation, temperature and pH. The meteorological factors mostly explain the major part of the variation in element pools in the organic layer. Pools increased in more acid, wetter and colder situations, related to an inhibited mineralisation under those circumstances. Soil type was the most important explaining variable in the mineral layer. As with the organic layer, precipitation and temperature were also important predictor variables for the element pools in that layer. Apart from the pool of exchangeable base cations, pH did not have a significant influence on the element pools. Atmospheric deposition did not have a significant relationship with element concentrations or pools in both the organic and mineral layer.

9 Soil solution chemistry

9.1 Introduction

In general, soil solution chemistry has a fast response to changes in atmospheric deposition. This is specifically true for elements with few interactions with the mineral soil, such as Cl and SO_4. For other elements, the concentration in the soil solution is not only a result of atmospheric deposition and hydrology, but also of the interaction with the mineral soil.

This chapter only includes an update of the evaluation of soil solution chemistry presented in the previous Technical Report (De Vries et al., 1999). As with atmospheric deposition, there is a large increase in the number of plots compared with 1996, due to the inclusion of Germany. This chapter focuses on the chemistry of major ions in soil solution influenced by N and S deposition, either directly (SO_4, NO_3, NH_4) or indirectly through soil buffering reactions (H, Al, Ca, Mg, K), comparable to the previous report. Element concentrations are simple annual average concentrations, since water flux calculations can not yet be carried out. Apart from a description of various methodological aspects (Section 9.2), this chapter includes results with respect to:

- Ranges in ion concentrations and ion ratios at various soil depths in view of critical levels for (i) NO_3 related to N saturation and groundwater pollution, (ii) Al related to acidification and groundwater pollution and (iii) ratios of NH_4 and Al to base cations related to nutrient unbalances (Section 9.3.1).
- Relationships between element concentrations in soil solution (e.g. Al concentration versus pH or Al versus SO_4+NO_3 in acid soils) (Section 9.3.2).
- Relationships between environmental factors and soil solution chemistry such as (i) NO_3 concentration versus N deposition and C/N ratio of the soil or (ii) the Al concentration versus SO_4 and NO_3 concentration (reflecting inputs of S and N compounds) and the base saturation of the soil (Section 9.3.3).

9.2 Methodological aspects

9.2.1 Locations

Data for the soil solution chemistry in 1997 were stored for a total of 192 plots in twelve countries. New countries compared to 1996 are Finland, Denmark, Germany and Austria. The total number of countries where soil solution chemistry measurements take place equals thirteen. Spain did, however, not yet submit data for 1997 (Fig. 9.1). Sweden and Denmark only measured the chemical composition in the subsoil (40-80 cm) whereas Finland, Norway and Greece concentrated their measurements in the topsoil (0-40 cm). U.K. and France measured in both topsoil and subsoil, whereas Ireland, the Netherlands, Belgium and Germany measured the chemical composition of the soil solution in the organic layer, mineral topsoil and mineral subsoil (Table 9.1). Apart from Greece, all plots are concentrated in Western and Northern Europe (Fig. 9.1).

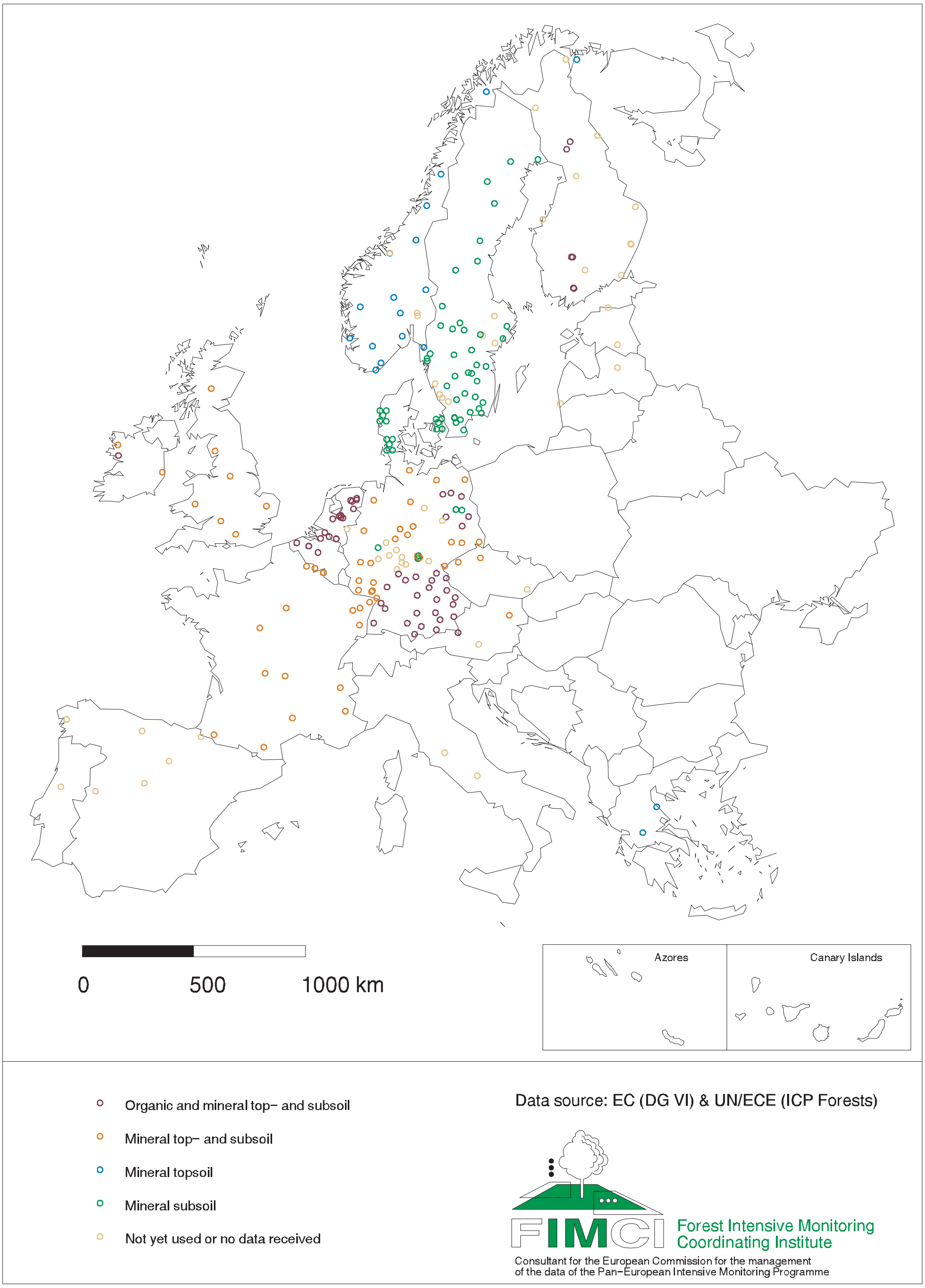


Figure 9.1 *Geographic variation of locations with soil solution data in 1997.*

Table 9.1 Number of plots at which soil solution chemistry was measured in 1997 in the various participating countries[1)]

Country	Number of plots			
	Organic layer	Mineral topsoil[2)]	Mineral subsoil[2)]	All layers
Finland	6[3)]	-	-	6
Sweden	-	-	39	39
Norway	-	16	-	16
Denmark	-	-	15	15
U.K.	-	7	7	7
Ireland	3	3	3	3
Netherlands	14	14	14	14
Belgium	6	8	7	8
Germany	43	52	66	66
France	-	15	15	15
Austria	-	1	1	1
Greece	-	2	-	2
All	72	118	167	192

1) Numbers refer to the data that were stored and used in the data evaluation.

2) Mineral topsoil is 0-40 cm and mineral subsoil is 40-80 cm.

3) Actually, the zero-tension lysimeters were placed immediately below the organic layer.

9.2.2 Data assessment methods

In total methodological DAR-Q information has been submitted and stored for 142 monitoring plots. As with deposition data, some countries, with a considerable number of plots where soil solution is measured, have not yet submitted information on data assessment methods. Information on the methodology, described below, is based on 130 of the 192 plots for which data have been submitted. Whenever relevant, additional to the submission files for soil solution information on the applied monitoring approach was also used.

Sampling devices

Soil solution can be collected by various methods. Either soil solution collectors (zero tension lysimeters or suction cups) can be placed or soil solution samples can be obtained by taking soil samples and extraction of soil solution using either centrifugation or extraction methods. Depending on the aim and frequency of the monitoring and the soil condition, use can thus be made of tension lysimetry, zero-tension lysimetry, centrifugation and the saturation extract method. The ion concentrations obtained do depend on the measuring devices, since different types of soil water are extracted. In general, concentrations increase going from zero tension lysimeters to suction cups and to centrifugation. Information on the most appropriate use of lysimeters and on differences resulting from various extraction methods has been presented in the previous Technical Report (De Vries et al., 1999).

On the majority (97%) of plots, (zero)tension lysimeters, being the reference method for soil solution collection, have been applied (Table 9.2). On 35 plots combinations of types of samplers are reported. In these cases, suction plates or zero tension cups/plates are applied in addition to suction cups.

Table 9.2 Soil solution collection methods applied in the Intensive Monitoring Programme

Collectors	Number of plots
Tension lysimeters / suction cups	91
Zero tension lysimeters	2
Tension lysimeters/ suction cups + zero tension lysimeters	35
Soil sampling and saturation extraction	2
Total	130

Lysimeters used should be made of materials that are considered sufficiently free of contaminants, such that the sample solution is not influenced by the sampler itself. In the submanual for soil sampling (UN-ECE, 1998) a list of appropriate materials is presented. The majority of used lysimeters is made of those materials (Table 9.3). Only the materials aluoxide and INOX were not mentioned in the above mentioned list and thus require special attention. Note that Table 9.3 only presents information on the 128 plots where lysimeters were applied.

Table 9.3 Type and construction material of lysimeters used.
Numbers between brackets are additional measurements.

Lysimeter	Material	Number of plots
Suction cup	Ceramic	57
	Teflon	29
	Plastic	9
	Aluoxide	29
Suction plate	Aluoxide	2
	Plastic	1 (+8)
	Ceramic	(5)
Zero tension cup	Aluoxide	(3)
	Plastic	1 (+5)
Zero tension plate	Plastic	(22)
	INOX	(6)
	ceramic	(1)
Total		128 (+50)

Sampling numbers

Due to high spatial variation in both soil solution chemistry and percolation water fluxes, caused by e.g. variation in tree cover, ground vegetation and soil properties, a sufficient number of samples is needed to obtain a reliable estimate of the average concentration on a plot scale. This number increases when the spatial variability is larger (Section 3.2). Figure 9.2 gives the number of samplers used per plot, divided in organic layer, mineral topsoil (0-40 cm) and mineral subsoil (>40 cm).

Numbers of samplers per soil layer ranged from 1-5 in the organic layer, 1-23 in the mineral topsoil and 1-12 in the mineral subsoil. An indication of the adequacy of the number of samplers or samples can be derived from the results of a comparative study of three methods to extract soil solution at two forest stands in the Netherlands at fifteen spots. The relative standard deviation of the estimated mean concentration at each depth varied nearly always between 20 and 60% (see also De Vries et al., 1999). Considering the variation in the two Dutch forest plots to be representative, the number of suction cups or zero tension lysimeters generally used seem quite low. Requiring that the number of samples should be such that the plot mean is within ± 20% of the population mean with a confidence level of 95%, at least 10 samples are needed, assuming a relative standard deviation of 30% (compare Table 3.1).

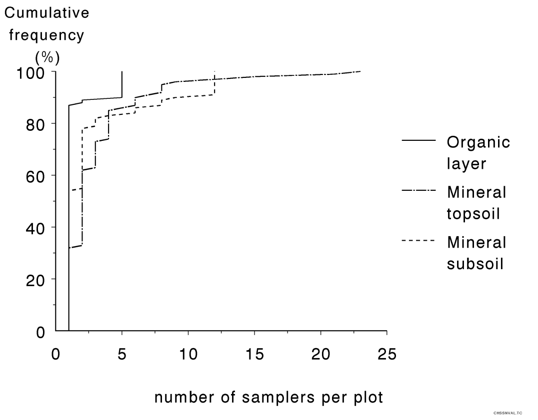


Figure 9.2 The number of samplers (lysimeters and/or zero tension lysimeters) used at the Intensive Monitoring plots

Sampling layout and sampling depths

Samplers are placed either randomly or systematically (50 plots). For the remaining plots, no information was given. The depths of the sampled layers were similar to those presented the previous Technical Report. Mostly soil solution collection has taken place in mineral layers. Measurements in the organic layers were reported for 72 plots. Mostly countries carry out one measurement in the topsoil (0-40 cm) and one measurement in the sub-soil (40-80 cm): see also Table 9.1.

Conservation and analysis of the samples

Good quality of the soil solution data requires a careful treatment of the sample water. Contamination of the samples (by e.g. algae) is prevented by keeping the samples cool and dark in the field and cleaning or replacing collection bottles periodically. DAR-Q's report these measures for all plots. Also preservatives are used to diminish biological activity in the sample. All countries conserve their sample water in cool places. Cooling temperatures range from –20 up to 10 ºC, mostly varying between 4-6 ºC.

The submanual on soil solution sampling (UN-ECE, 1998) states that samples should by analysed as soon as possible on the untreated samples for pH and conductivity. Furthermore filtration (0.45 mm membrane filtration) should be applied. Hereafter at least the other mandatory parameters, dissolved organic carbon (DOC), K, Ca, Mg, Al total (if pH<5), NO_3-N and SO_4-S and optional parameters, should be measured. Based on a first inventory of the DAR-Q information no specific problematic pre-treatment and analysis methods were noticed. However the use of ringtests on a European scale like the ones applied for foliage chemistry and deposition data is needed here as well to improve the insight into the data quality of the various analyses. Of the countries that have submitted DAR-Q information about 70% reported to be involved in such ringtests already.

9.2.3 Data quality assurance

As with atmospheric deposition, the procedures for quality assurance and quality control (QA/QC) included a check on:

- the balance between cations and anions
- the difference between measured and calculated electric conductivity
- the ratio between ion concentrations

A description of the various procedures and results is given in Annex 3. A summary of the results related to the charge balance and conductivity checks is given in Table 9.4.

Table 9.4 Percentage of measurements in an acceptable[1)] range with respect to the difference in cation-anion balance and calculated versus measured conductivity.

Type of measurement	Cation-anion balance (%)		Conductivity (%)	
	1996	1997	1996	1997
Including DOC	87	52	-	-
Excluding DOC	58	43	84	79

[1)] For both the cation-anion balance and the conductivity, the acceptable range was set at ±20%

As with atmospheric deposition, the quality of the results appeared to decrease going from 1996 to 1997, especially with respect to the cation-anion balance. Only 50% of the data was in an acceptable range. Results for the conductivity check slightly improved in 1997 compared to 1996, with 60-70% of the measurements in acceptable range. A strict comparison of both years cannot be made, since the number of samples on which the checks were carried out mostly increased by a factor of two.

A comparison of the annual average Na/Cl ratios in soil solution in 1996 and 1997 is shown in Fig. 9.3. Results show that in 1997 the Na/Cl ratio was within a range of 0.5-1.0 at approximately 63% of the plots for the topsoil (Fig. 9.3A) and 65% for the subsoil (Fig. 9.3B). In 1996 this number was 33% and 38%, respectively. High values were also observed less frequently in 1997 indicating that Na contamination hardly occurs. Again, a strict comparison can not be made considering the increase in plots in 1997 compared to 1996.

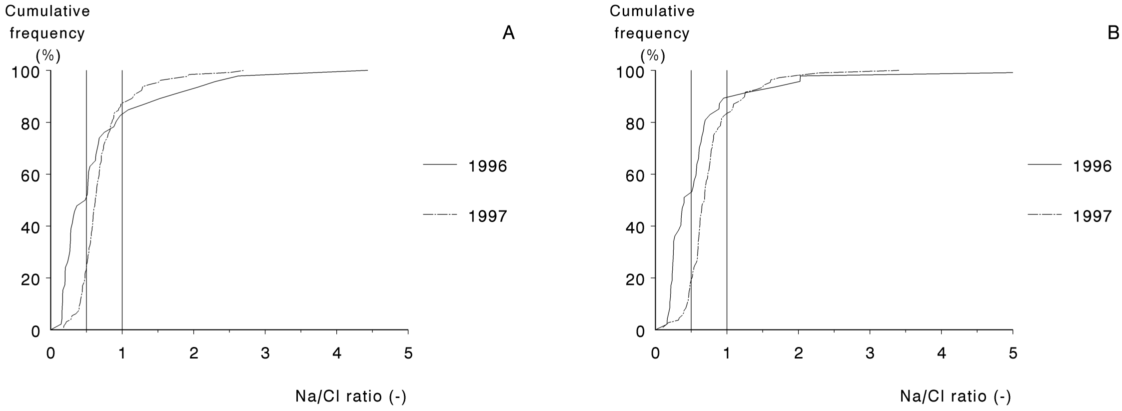


Figure 9.3 Cumulative frequency distributions of the Na/Cl ratios in 1996 and 1997 based on annual average concentrations in soil solution in the topsoil (A) and the subsoil (B).

9.2.4 Data evaluation

Use of class limits to present results

In order to evaluate the results of the soil solution chemistry in terms of possible negative impacts, use was made of critical chemical values for the concentrations of NO_3 and Al and the molar ratios of Al/(Ca+Mg+K) and NH_4/Mg. Criteria thus used with an explanation of its background, are given in Table 9.5.

Table 9.5 Critical chemical values for the concentrations of NO_3 and Al and the molar ratios of Al/(Ca+Mg+K) and NH_4/Mg

	Concentration ($mmol_c.m^{-3}$)		Molar ratio ($mol.mol^{-1}$)	
	NO_3	Al	NH_4/Mg	Al/(Ca+Mg+K)
1 (low)	<100[1)]	<20[2)]	<1	<0.5
2 (intermediate)	100 - 400[2)]	20 – 200[3)]	1 – 5[4)]	0.5 – 1.0[5)]
3 (high)	>400	>200	>5	>1.0

[1)] Clearly elevated NO_3 concentration (Gundersen et al., 1998) that may be related to vegetation changes (Warfinge et al., 1992)

[2)] Target value for ground water quality

[3)] Critical value related to effects on tree roots (Cronan et al., 1989)

[4)] Critical value related to decreased base cation uptake (Roelofs et al., 1985; Boxman et al., 1988)

[5)] Most common range of critical values related to adverse impacts on roots, such as root growth and root uptake, depending upon tree species (Sverdrup and Warfinge, 1993).

Assessment of relationships between ion concentrations in soil solution

Relationships between the concentrations of Al, Ca, SO_4 and NO_3 and the pH, which are all key parameters with respect to the soil solution chemistry, were investigated by simple regression relationships. With respect to Al, the relation with SO_4 and NO_3 was investigated, while focusing on acid soils (pH < 4.5 or base saturation below 25%) where the acid input is assumed to be buffered by Al release mainly. Similarly, relationships between Ca and SO_4 and NO_3 were investigated, while focusing on slightly acid soils (pH > 4.5 or base saturation above 25-50 %) where the acid input is assumed to be buffered by Ca release mainly. The relationship between Al concentration and pH was further investigated by relating the logarithmic free Al activity to the pH. Slopes of this relationship give some insight in the buffer mechanism of Al. Information on the calculation of free Al^{3+} has been given in the previous Technical Report.

Assessment of relationships between soil solution chemistry, stand and site characteristics, soil chemistry and atmospheric deposition

Soil solution chemistry is not only influenced by the atmospheric input to and the chemical interactions in the soil, but also by the impacts of nutrient cycling, especially in the forest topsoil, and the water fluxes through the system. In order to investigate such relationships, use was made of multiple regression models relating soil solution concentrations to all predictor variables affecting this response. A logarithmic transformation was performed on the concentration data that were highly skewed. An overview of the predictor variables included in the various regression models is given in Table 9.6.

With respect to atmospheric inputs, use was made of throughfall since calculations of total deposition are not so adequate on a plot basis. Furthermore, throughfall is the best estimate for the input to the soil solution. Precipitation data were taken from the deposition survey, since (more detailed) data from the meteorological survey were limited. Furthermore, on an annual basis precipitation data appeared to be comparable in both surveys. The precipitation excess was calculated by subtracting potential evapotranspiration from the precipitation, using an external database. The external database was used because the number of Intensive Monitoring plots with meteorological data, allowing the calculation of potential evapotranspiration was too limited.

Table 9.6 *Overview of the predictor variables used to explain the chemical composition of the soil solution at 100 Intensive Monitoring plots where both deposition data (throughfall) and soil solution chemistry data were available.*

Predictor variables	SO_4	NO_3	NH_4	N	Ca	Mg	K	Al	pH
Site/Stand characteristics									
Tree species	X	X	X	X	X	X	X	X	X
Soil type	X	X	X	X	X	X	X	X	X
Throughfall									
SO_4	X								
NO_3		X							
SO_4+NO_3					X	X	X	X	X
NH_4		X	X		X	X	X	X	X
NH_4+NO_3 (N)				X					
Ca					X				
Mg						X			
K							X		
BC^{*} [1]								X	X
Meteorology									
Precipitation	X	X	X	X	X	X	X	X	X
Prec. excess	X	X	X	X	X	X	X	X	X
Soil chemistry									
C/N ratio		X	X	X					
Base saturation					X	X	X	X	X
pH-$CaCl_2$								X	

[1] $BC^{*} = Ca + Mg + K + Na - Cl$

9.3 Results and discussion

9.3.1 Ranges in ion concentrations and ion ratios in view of critical levels

Information on annual average ion concentrations and ion ratios is given below for the organic layer, mineral topsoil (0-40 cm) and mineral subsoil (40-80 cm) at all Intensive Monitoring plots. The number of plots depends on the layer considered since not all layers are included at all plots. Furthermore, several ions, such as NO_3 and Cl were measured at less plots. The number of plot-layer combinations that were used for the various ions are given in Table 9.7. In comparing frequency distributions of different ions, those differences in data availability should be kept in mind. Compared to 1996, the numbers increased by approximately 30%.

Table 9.7 *Numbers of plot/layer combinations that were used to describe the concentration ranges for the major ions in soil solution*

Soil layer	Number[1]											
	pH	Al	Ca	Mg	K	Na	NH_4	SO_4	NO_3	Cl	Alk	DOC
Organic layer	58	60	60	60	54	54	60	60	54	52	0	58
Topsoil (0-40 cm)	184	193	195	195	130	129	195	193	130	113	10	120
Subsoil (40-80 cm)	157	160	161	161	109	104	161	135	108	86	10	87

[1] Note that the number can be larger than the number of plots since several layers may be sampled in both the topsoil and subsoil.

Ion concentrations

As with the previous year, concentrations of SO_4 and NO_3 were mostly lower than 2000 $mmol_c.m^{-3}$ (Fig. 9.4 A,B). A striking difference with 1996, however, were the much lower concentrations of NH_4 and total N, specifically in the organic layer (Fig. 9.4C,D). Differences in the concentrations of SO_4 and NO_3 between the organic layer and the mineral soil were small, but this result is influenced by the different number of measurements in the various layers (Fig. 9.4A,B).

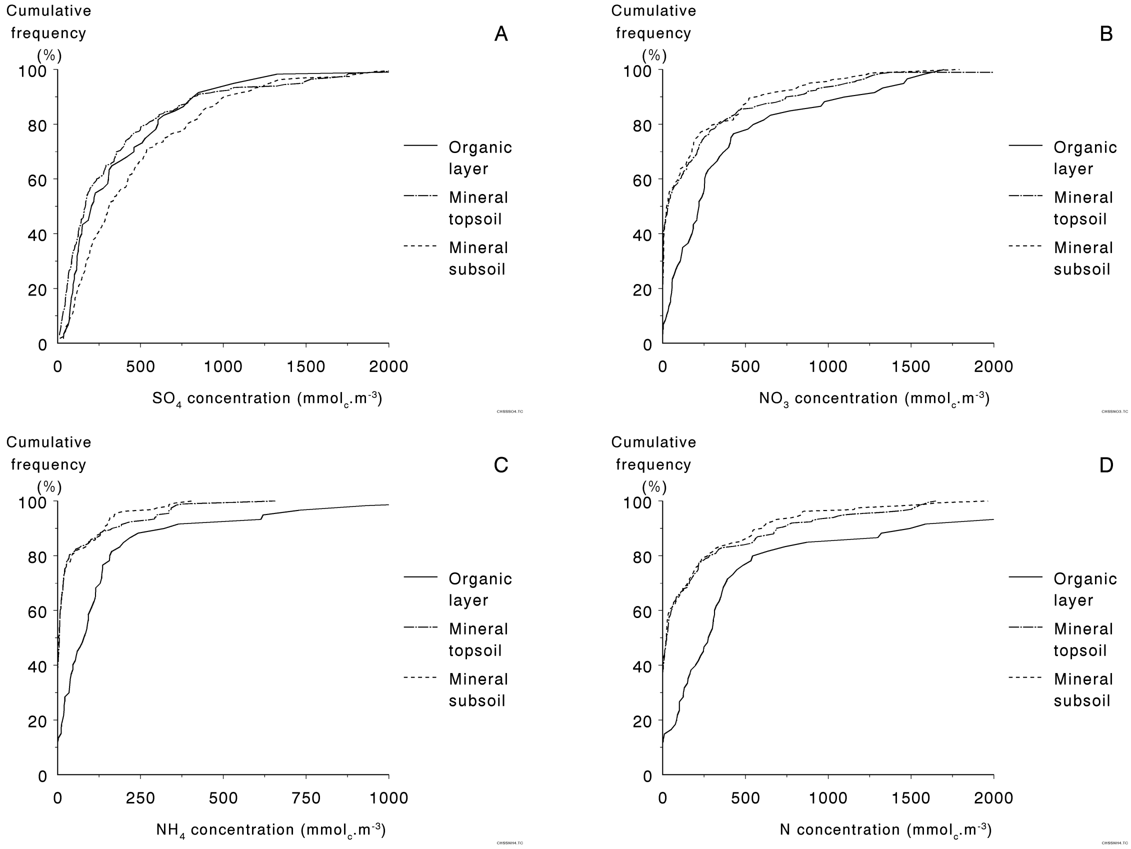


Figure 9.4 *Cumulative frequency distributions of the concentrations* SO_4 *(A),* NO_3 *(B),* NH_4 *(C) and total N (D) in the organic layer, mineral topsoil (0-40 cm) and mineral subsoil (40-80 cm) of Intensive Monitoring plots in 1997.*

Sulphate concentrations increase from the organic layer to the mineral layer, partly due to a decrease in water flux in this direction. As expected, NH_4 and N clearly decreased going from the organic layer to the mineral topsoil and the mineral subsoil but the change was much less pronounced than in 1996 (Fig. 9.4C,D).

As with the results from previous year, concentrations of the major cations Al and Ca in the mineral soil occurred in a similar range as SO_4 and NO_3 (Fig. 9.5A,B), The concentration of Al again increased significantly going from the organic layer to the mineral topsoil and the mineral subsoil due to Al dissolution from amorphous compounds in the mineral soil followed by complexation on organic matter.

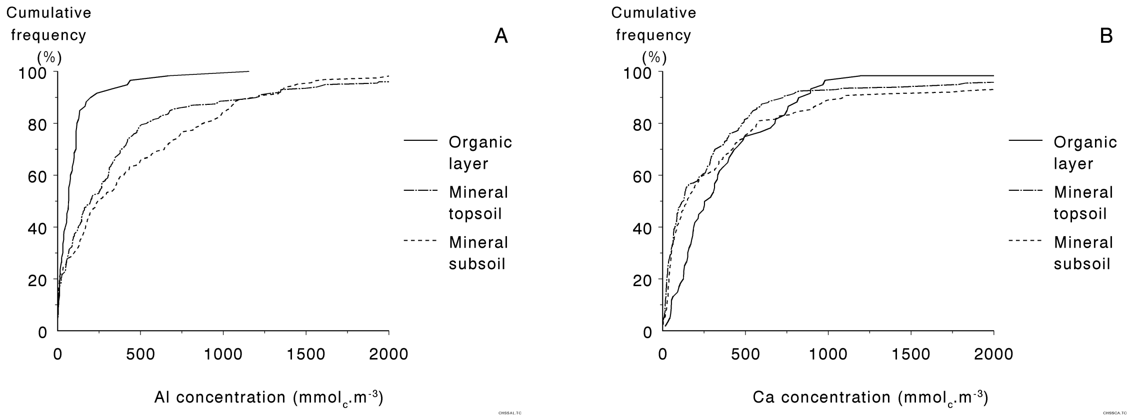


Figure 9.5 *Cumulative frequency distributions of the concentrations of Al (A) and Ca (B), in the organic layer, mineral topsoil (0-40 cm) and mineral subsoil (40-80 cm) of Intensive Monitoring plots in 1997.*

A comparison of the results for NO_3 and Al concentrations in the subsoil in 1996 and 1997 in view of critical levels is presented in Figure 9.6. It shows that NO_3 concentrations are higher in 1996 compared to 1997, whereas the reverse is true for Al. The concentrations of NO_3 in the subsoil exceeded the official ground water quality standard of 800 mmol$_c$.m^{-3} at 9% of the plots compared to 24% in 1996. The ground water quality standard of 20 mmol$_c$.m^{-3} for Al in the subsoil was exceeded at 82% of the plots compared to 89% in 1996. An Al concentration of 200 mmol$_c$.m^{-3}, that has sometimes been considered indicative for negative impacts on tree roots, was exceeded at 57% of the plots compared to 40% in 1996 (Table 9.8). Note, however, that the concentration of the uncomplexed (free) aluminium, which is considered toxic to roots is much lower. This implies that the actual number of plots exceeding a critical value is probably lower as well.

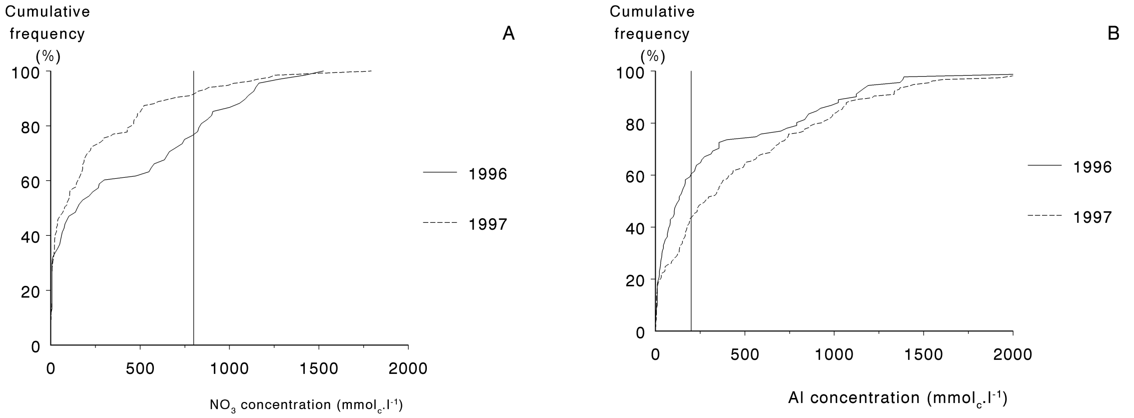


Figure 9.6 *Cumulative frequency distributions of the concentrations of NO_3 (A) and Al (B), in the mineral subsoil (40-80 cm) of Intensive Monitoring plots in 1996 and 1997 (beware of the differences in the number of plots.*

To gain insight in changes between the years, it is necessary to use data from the same plots. Results thus derived show that a decrease in NO_3 concentration and an increase in Al concentration (Table 9.8).

Table 9.8 The percentage of observations of NO_3 and Al concentrations in the mineral topsoil and subsoil between different class limits in 1996 and 1997.

NO_3					Al				
concentration	%topsoil		%subsoil		concentration	%topsoil		%subsoil	
class	1996	1997	1996	1997	class	1996	1997	1996	1997
($mmol_c.m^{-3}$)	(99)	(99)	(59)	(59)	($mmol_c.m^{-3}$)	(93)	(93)	(84)	(84)
< 100	57	60	37	39	< 20	16	5	19	10
100 – 800	21	28	36	47	20 – 200	51	26	37	20
> 800	22	21	27	14	>200	33	69	44	70

[1] Numbers in brackets denote the number of plots on which the results are based

pH and DOC

The pH varied between 3 and 7 in the organic layer and between 3 and 8.5 in all mineral layers. The pH values increased with depth, indicating the occurrence of buffering reactions (release of base cations and Al by weathering and cation exchange) in this direction (Fig. 9.7A). Compared to 1996, pH values are slightly higher in the organic layer but comparable in the mineral layers. The higher pH values in the organic layer may have induced nitrification, thus explaining the decreased NH_4 concentrations in that layer.

Apart from pH, dissolved organic carbon (DOC) also has a profound influence on the concentration (activity) of the free Al ion, which is most toxic to roots. This is due to complexation of Al with DOC. As with previous year, DOC concentrations decreased strongly by going from the organic layer to the mineral topsoil, but the decrease with depth in the mineral soil was much smaller. Concentrations of DOC generally ranged between 20 and 150 $mg.l^{-1}$ in the organic layer and between 10 and 50 $mg.l^{-1}$ in the mineral subsoil, being comparable to the previous year (Fig. 9.7B).

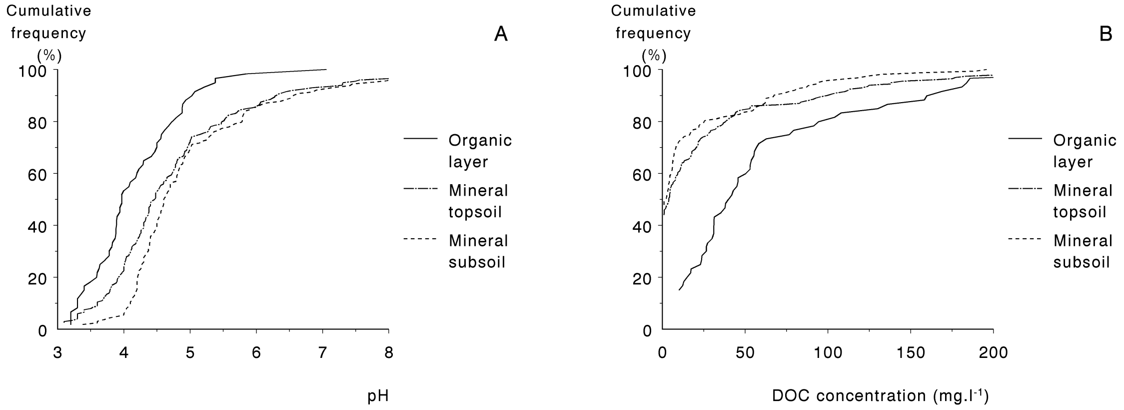


Figure 9.7 Cumulative frequency distributions of the pH (A) and the DOC concentration (B) in the organic layer, mineral topsoil (0-40 cm) and mineral subsoil (40-80 cm) of Intensive Monitoring plots in 1997.

Ion ratios

As with Al concentrations, the ratios of Al to the sum of Ca, Mg and K increased with depth (Fig. 9.8A), whereas the ratio of NH_4 to base cations decreased with depth (Fig. 9.8B).

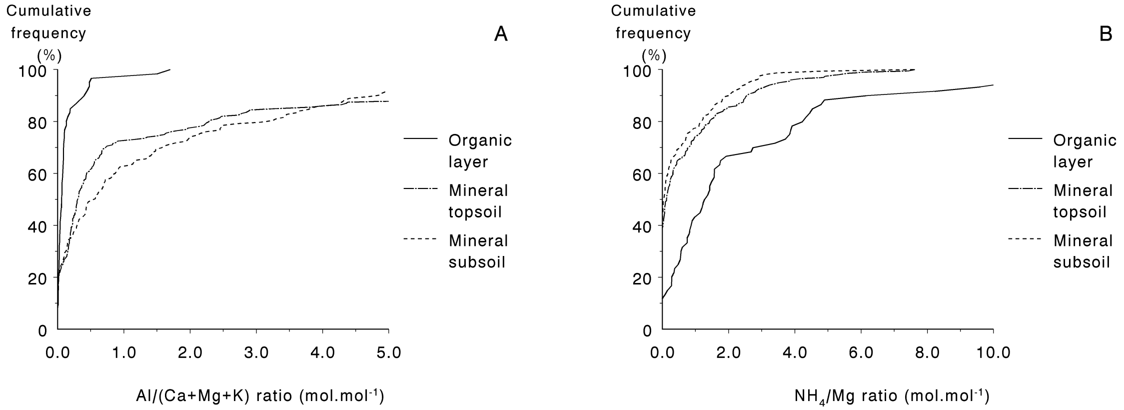


Figure 9.8 *Cumulative frequency distributions of the ratios of Al/(Ca+Mg+K) (A) and NH_4/Mg in the organic layer, mineral topsoil (0-40 cm) and mineral subsoil (40-80 cm) of Intensive Monitoring plots in 1997.*

A comparison of the results in 1996 and 1997 in view of critical Al/(Ca+Mg+K) and NH_4/Mg ratios is given in Figure 9.9. Compared to 1996, the number of plots exceeding a critical Al/(Ca+Mg+K) ratio was higher in 1997 (30% in the topsoil compared to 11% in 1996). Using a critical Al/Ca ratio of 1.0, as suggested by Ulrich and Matzner (1983), this number increased to approximately 50%. Note, however, that critical ratios refer specifically to the concentration of free (uncomplexed) Al, that is toxic to roots, whereas the calculated ratios refer to total Al. This is because free Al could not be calculated in most plots, due to missing DOC concentrations. Furthermore, critical ratios do depend on the tree species considered (Sverdrup and Warfinge, 1993). Consequently, those percentages should be seen as worst case estimates. Comparable to the results in 1996, critical NH_4/Mg (and NH_4/K ratios) of 5.0 were hardly ever exceeded in the mineral soil (see also Fig. 9.8).

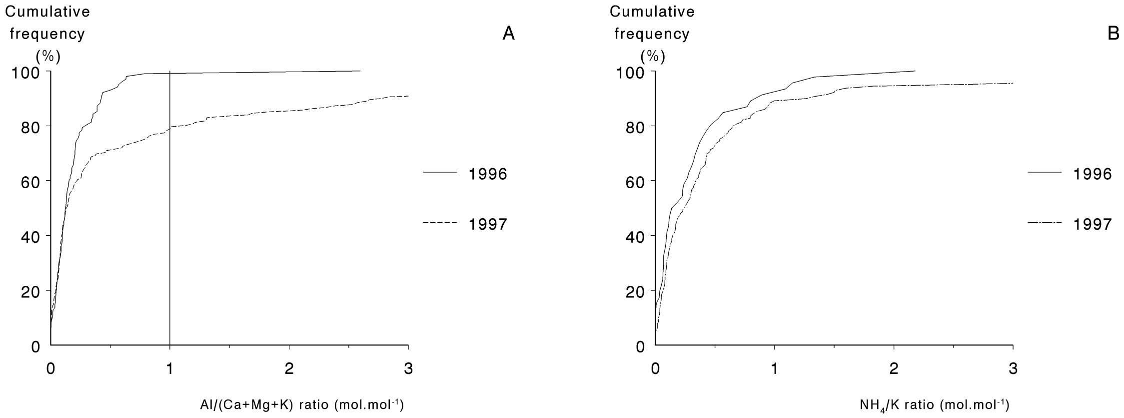


Figure 9.9 *Cumulative frequency distributions of the concentrations of Al/(Ca+Mg+K) (A) and NH_4/K (B), in the mineral topsoil (0-40 cm) of Intensive Monitoring plots in 1996 and 1997 (beware of the differences in the number of plots).*

A comparison of both ratios at the same plots also shows a strong increase in the Al/(Ca+Mg+K) ratio (Table 9.9).

Table 9.9 The percentage of observations of Al/(Ca+Mg+K) and NH_4/Mg ratios in the mineral topsoil and subsoil between different class limits in 1996 and 1997

Al/(Ca+Mg+K)					NH_4/Mg				
ratio class	%topsoil		%subsoil		ratio class	%topsoil		%subsoil	
(eq.eq^{-1})	1996	1997	1996	1997	(eq.eq^{-1})	1996	1997	1996	1997
	(93)[1]	(93)	(84)	(84)		(46)	(46)	(47)	(47)
< 0.5	69	49	54	38	< 1	63	59	81	60
0.5 – 1.0	21	10	23	16	1 – 5	35	39	19	40
> 1.0	10	41	23	46	> 5	2	2	0	0

[1] Numbers in brackets denote the number of plots on which the results are based

9.3.2 Relationships between ion concentrations in soil solution

Aluminium and strong acid anions

The Al concentration in the subsoil was clearly related to the concentration of SO_4 and NO_3 at a base saturation below 25% or a pH below 4.5 (Fig. 9.10B). This implies that the acid deposition is mainly neutralised by Al release in those acid soils. This result is in line with model simulations (Reuss, 1983) and laboratory experiments (De Vries, 1994) indicating a significant Al release below a base saturation of 25%. Above a base saturation of 25%, there was no relationship between the concentration of Al versus SO_4 plus NO_3, indicating that the acidity is mainly neutralised by the release of base cations. Unlike the results for the previous year, there was no relationship, however, between Al and SO_4 plus NO_3 in the topsoil (R^2_{adj} = 2%) for a pH below 4.5 (Fig. 9.10A). In the subsoil R^2_{adj} was 55% at a pH below 4.5 (Fig. 9.10B). Similar results were obtained using a base saturation of 25% (R^2_{adj} = 1% for the topsoil and 53% for the subsoil). Even for the subsoil, the relationships are less convincing than the previous year (R^2_{adj}= 86%).

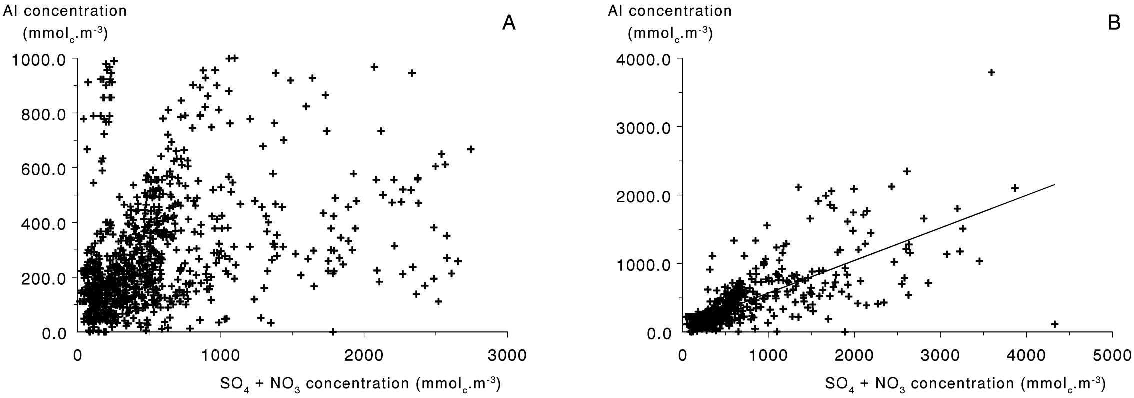


Figure 9.10 Relationship between the concentration of Al and the SO_4+NO_3 concentration in the topsoil (A; 1396 measurements) and subsoil (B; 593 measurements) of Intensive Monitoring plots with a pH < 4.5. The solid line represents a regression line.

Base cations and strong acid anions

The concentration of base cations was clearly related to those of strong acid anions, specifically at plots with a high base saturation, as illustrated in Fig. 9.11. The figure shows that (i) the correlation increased with an increased in base saturation (R^2_{adj} = 14% at a base saturation below 25% and 65% at a base saturation above 50%) and (ii) the slope much more strongly resembles the 1 : 1 line at high base saturation. Results are comparable to 1996, even though the relationships were more convincing for that year.

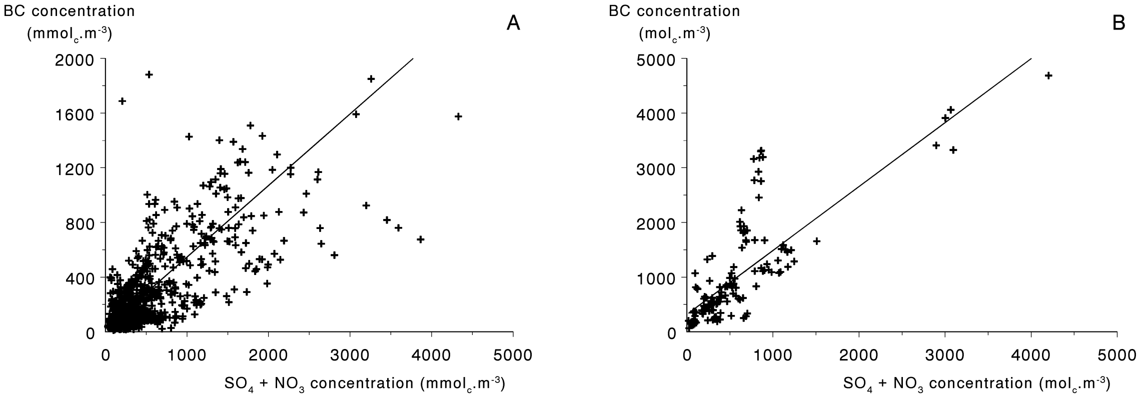


Figure 9.11 Relationship between the concentration of BC and the SO_4+NO_3 concentration in the subsoil of Intensive Monitoring plots with a base saturation below 25% (A; 928 measurements) and above 25% (B; 147 measurements). The solid line represents a regression line.

Aluminium and pH

The logarithmic concentration of Al was clearly related to the pH, when using all available data for the topsoil (Fig. 9.10A) and subsoil (Fig. 9.10B). However, the relationship was not very strong, especially in the topsoil since the occurrence of complexation strongly influences the total Al concentration without having a strong effect on pH (R^2_{adj} = 23% for the topsoil and 56% for the subsoil). In 1996, values of R^2_{adj} were 56% and 60%, respectively.

A much better relationship with pH is to be expected with the concentration (or even better, the activity) of free Al. Free Al could, however, only be derived for a very limited number of measurements in the mineral soil, since DOC which is crucial to calculate the free Al activity because of the dominating influence of organic Al complexes, was hardly measured there. Information of DOC was, however, only largely available for the organic layer. Comparable to 1996, the results of the relationship between the calculated logarithmic free Al concentration and pH in this layer, indeed, appeared to be much stronger than between the logarithmic total Al concentration and pH.

9.3.3 Relationships between soil solution chemistry and environmental factors

As with the previous year, the results from a multiple regression analysis showed that tree species and soil type never had a significant influence on the concentrations of the considered ions in both topsoil and subsoil. Results presented are thus limited to relationships with atmospheric deposition (throughfall), meteorology (precipitation or precipitation excess) and soil chemical data (C/N ratio, base saturation and/or pH-$CaCl_2$) whenever relevant.

Sulphur and nitrogen compounds

A summarising overview of the results of multiple linear regression, using log-transformed data for the concentration and deposition (throughfall) of S and N compounds, is given in Table 9.10. The number of plots on which the results are based varied between 80 and 99 for SO_4 and NO_3 and between 53-66 for NH_4 and total N. The limited number for the latter compounds is due to the fact that several countries do not measure NH_4. Compared to the results obtained for 1996, the variation in the concentrations of all ions was less explained by the included environmental factors. This holds specifically for NH_4. The variation in this ion could hardly be explained (R^2_{adj}=4-7%), whereas this value ranged between 58-79% in 1996. This is most likely due to the much lower concentrations in 1997 than in 1996. The explanation of SO_4 and NO_3 in the topsoil, also decreased substantially from approximately 80% in 1996 to 55% in 1997.

Table 9.10 Overview of the predictor variables explaining the concentrations of SO_4, NO_3, NH_4 and total N in the topsoil (0-40 cm) and subsoil (40-80 cm) at 53-110 Intensive Monitoring plots, with the percentage variance accounted for[1)].

Predictor variables	SO_4		NO_3		NH_4		N	
	topsoil	subsoil	topsoil	subsoil	topsoil	subsoil	topsoil	subsoil
Stand and site char.								
Soil type								
Tree species	--	--	--					
Throughfall								
SO_4	++	++						
NO_3								
NH_4			++	++		+		
N							++	++
Meteorology								
Precipitation	--	--	--					
Precipitation excess					-			
Soil chemistry								
C/N ratio								
N[2)]	99	99	90	80	66	53	66	56
R^2_{adj} (%)[3)]	63	58	58	32	7.5	6.8	28	26

[1)] +/- = significant: t value > 2.0
++/-- = highly significant: t value > 3.0
A '+' sign implies that the response variable (the concentration of SO_4, NO_3, NH_4 or total N) increases with an increase in the predictor variable, whereas a '-' sign implies the opposite. Signs in brackets are related to results in which the logarithmic concentrations were used against the logarithm of the deposition and precipitation (excess).

[2)] N = number of plots.

[3)] R^2_{adj} = percentage variance accounted for.

The impact of the included predictor variables on the soil solution chemistry is, however, quite comparable in both years. In all situations, atmospheric deposition of the considered compound was the most important influencing factor with the exception of NO_3. For this element, NO_3 deposition had no significant impact, not in the topsoil nor in the subsoil, whereas NH_4 deposition was highly significant (t value > 3.0) in both cases. The inclusion of either the measured precipitation or a calculated precipitation excess was generally insignificant, except for SO_4.

Comparable to the results obtained with the data from 1996, the influence of the C/N ratio on the measured NO_3 and NH_4 concentration was mostly negligible. The small to insignificant influence of the C/N ratio on NO_3 and NH_4 concentrations was also observed in 150 forested stands in the Netherlands (De Vries and Leeters, 2000) but Dise et al. (1998) and Gundersen et al. (1998) presented data indicating a more significant influence.

Base cations, aluminium and pH

Results of the multiple regression analysis, using log-transformed data for the concentration of base cations and Al and the deposition of base cations, S and N compounds are presented in Table 9.11.

Table 9.11 Overview of the predictor variables explaining the concentrations of SO_4, NO_3, NH_4 and total N in the topsoil (0-40 cm) and subsoil (40-80 cm) at 59-103 Intensive Monitoring plots, with the percentage variance accounted for[1]*.*

Predictor variables	Ca		Mg		K		Al		pH	
	top.	sub.	top.	sub.	top.	sub.	top.	sub.	top.	sub.
Stand and site char.										
Soil type				--						
Tree species	-		--		-	++				
Throughfall										
Ca										
Mg			++	++						
K						++				
BC^{*} [2]										
SO_4+NO_3					++		--		--	--
NH_4	++	++			--			--		
Meteorology										
Precipitation	--	--	--	--	--			--	+	
Precipitation excess						--				
Soil chemistry										
Base saturation	++	++	+	+					++	++
pH-$CaCl_2$							--	--		
N[3]	87	61	90	62	90	62	85	59	103	61
R^2_{adj} (%)[4]	47	54	51	59	20	34	17	43	54	64

[1] +/- = significant: t value > 2.0
++/-- = highly significant: t value > 3.0
A '+' sign implies that the response variable (the concentration of Ca, Mg, K, Al or pH) increases with an increase in the predictor variable, whereas a '-' sign implies the opposite. Signs in brackets are related to results in which the logarithmic concentrations were used against the logarithm of the deposition and precipitation (excess).

[2] $BC^{*} = Ca + Mg + K + Na - Cl$

[3] N = number of plots.

[4] R^2_{adj} = percentage variance accounted for.

As with the S and N compounds, the explained variation in cation concentrations was generally less in 1997 than in 1996. This holds specifically for Al. Values of R^2_{adj} in 1997 were 17% for the topsoil and 44% for the subsoil, whereas those values equalled 77% and 83%, respectively in 1996. A striking difference with the results from 1996 is the generally insignificant impact of NH_4 deposition. In 1996, results showed that the deposition of NH_4 had a (highly) significant impact on all the considered compounds, increasing the concentration of base cations and Al and decreasing the pH. This was explained by the acidifying impact of NH_4 deposition, caused by the conversion of NH_4 to NO_3 (nitrification) in the soil. As with 1996, the deposition of SO_4+NO_3 did neither have a significant impact on the cation concentrations, but only on the pH (Table 9.11).

The influence of base cation deposition on cation concentrations was comparable to 1996, being highly significant for Ca and Mg and not for K, Al and for the pH. As with the results for 1996, either the precipitation or the precipitation excess was mostly significant to highly significant, except for the pH. Similarly, base saturation did have a significant influence on the concentrations of Ca and Mg in both topsoil and subsoil and on the pH but not on K and Al. Al concentrations were mainly explained by the pH-$CaCl_2$, being different from the results in 1996. Comparable to 1996, however, the pH was most significantly influenced by the base saturation of the soil, followed by the SO_4+NO_3 deposition.

9.4 Conclusions

Soil solution chemistry data at the Intensive Monitoring plots have been evaluated with respect to (i) the range in ion concentrations at various soil depths in view of available critical levels, (ii) relationships between element concentrations in soil solution, such as Al vs. pH or SO_4+NO_3 in acid soils, and (iii) the simultaneous impact of atmospheric deposition, meteorological conditions and soil chemistry on the soil solution chemistry. Major conclusions related to those aspects are given below.

Range in element concentrations in view of critical levels
NO_3 concentrations generally decreased, whereas Al concentrations increased compared to 1996. For example, the concentrations of NO_3 in soil solution exceeded the official ground water quality criterion of 800 $mmol_c.m^{-3}$ in the subsoil at 9% of the plots, compared to 24% in 1996. An Al concentration of 200 $mmol_c.m^{-3}$, that is sometimes considered indicative for negative impacts on tree roots, was exceeded in the subsoil at 57% compared to 34% in 1996. The Al/(Ca+Mg+K) ratios exceeded a critical ratio of 1.0 in approximately 30-39% of the plots, depending on the layer considered, compared to 9-21% in 1996. As with 1996, both the NH_4/K ratio and NH_4/Mg ratio hardly ever exceeded a critical value of 5.0 in the mineral soil.

Relationships between element concentrations in soil solution
The concentration of potentially toxic Al in the subsoil was strongly related to the concentration of SO_4 and NO_3 in acid soils (soils with a base saturation below 25% or a pH below 4.5). Above those base saturation and pH levels, there was no relationship. In this situation there was a strong relationship between Ca and strong acid anions, indicating that the acidity is neutralised by the release of base cations at high base saturation. The correlation increased with depth and the slope of Ca against SO_4 plus NO_3 strongly resembled a 1: 1 line at plots with a high base saturation.

The simultaneous impact of atmospheric deposition, meteorological conditions and soil chemistry on the soil solution chemistry.
As with previous year, the variation in concentrations of major ions in the soil solution could to a large extent be explained by differences in atmospheric deposition, but the variation that could be explained was less. Furthermore, meteorological conditions (specifically precipitation) had a significant impact on all ions, except N compounds and the pH. Another comparable result was that base saturation is significantly related to base cation concentrations and pH, while the C/N ratio is not significantly related to N compounds. Unlike the previous results, however, the deposition of NH_4 did not have a significant impact on the considered compounds, except for K in the topsoil and Al in the subsoil. This result shows that results based on a correlative study with a limited amount of plots should be interpreted with care.

10 Discussion and conclusions

The conclusions of the evaluations carried out for the various surveys were presented in the last sections of each chapter. Below, we summarise those conclusions while discussing the validity of the presented results. A distinction is made in the results of (i) relationships between forest ecosystem condition and environmental factors, (ii) required changes in soil pools, (iii) atmospheric deposition and the foliar and soil solution chemistry in view of critical levels and (iv) the possibility of upscaling results for atmospheric deposition and soil solution chemistry.

Relationships between forest ecosystem condition and environmental factors

The main aim of this year's report was to gain insight in relationships between crown condition, foliar composition and soil chemistry on one hand and various environmental factors, including meteorology and atmospheric deposition, on the other hand, taking differences in stand and site characteristics into account. Such relationships were all investigated by means of statistical analyses, based on hypotheses about the possible impact of predictor variables. This implies that available literature information or general knowledge was used in defining predictors and describing its possible impacts. The approach thus consisted of testing the hypotheses using presently available data, instead of deriving insight in possible new influencing factors. The latter approach is dangerous since correlation does not necessarily mean a causal relationship. Below, we focus on the relative contribution of atmospheric deposition in the explanation of the variation in crown condition and the foliar and soil chemistry as compared to natural meteorological differences.

Crown condition

Results of the statistical analyses for crown condition showed that apart from stand age, 15-30% of the variation in defoliation of pine, spruce, oak and beech could be explained by the variation in meteorological variables (precipitation, temperature) and atmospheric N and S deposition. Impacts of foliar concentrations on defoliation were generally not significant. Atmospheric deposition sometimes explained up to 15% of the variation, but the impact differed for the different tree species. Sometimes, higher values were related to a higher defoliation, whereas sometimes the reverse is true. A similar result was found with respect to precipitation.

The validity of the presented results is, however, limited due to several methodological limitations. First of all, it only compares the average defoliation at a plot with the average meteorological conditions and pollution. With respect to meteorology, it is more useful to use a drought stress indicator and to include information on the deviation of e.g. rainfall, from the average situation. Such analyses can only be made when site specific meteorological data are available. The direct impact of meteorological stress furthermore requires the evaluation of a time series of crown condition data versus those stress factors. Another limitation is the occurrence of methodological differences among countries with respect to the assessment of defoliation, limiting the comparability of defoliation data between countries. In a study carried out at Level 1 plots, Klap et al. (1997, 2000) concluded that methodological differences among countries accounted for >30% of the variation in defoliation. This so-called country effect was yet not included, since the number of plots did not allow this. Apart from systematic differences between countries the occurrence of (stochastic) variations between observers or even biases hampers a correct evaluation. Intercalibration courses are an important tool for harmonising the assessments.

Also digitising the assessments with the aid of cameras is a possibility to overcome this major constraint. Inclusion of the country effect might also be possible in future regression analysis when the number of plots does allow this. An in-depth interpretation is finally hampered by a lack of information on stand history, pests and diseases at most of the plots. Those possible important predictor variables have thus been neglected. Since the causes of damage to the crown are to be assessed in detail in the future, these biotic stress factors can be included in future analysis.

Despite the limitations of the study, it is already encouraging that weather condition and atmospheric deposition could explain a relative large percentage of the variation in average defoliation. More in-depth analyses in the future might allow us to gain more insight in the relative contribution of air pollution, meteorological stress and biotic stress on forest crown condition.

Foliar concentrations

Atmospheric deposition, meteorological parameters, soil chemistry and site characteristics all contributed to the explanation of foliar nutrient concentrations. The percentage variation accounted for and the impact of various predictor variables differed varied considerably per nutrient and tree species. A relative high percentage of the variation in foliar N and Mg concentration could be explained, whereas relative low percentages were found for the other elements. The impact of meteorological variables (precipitation and temperature) and of site and stand characteristics (soil type, altitude and stand age) was ambiguous, since the effects were not consistent for different nutrients and tree species.

The impact of atmospheric deposition was always according to the expectations, but the impact varied strongly depending on the ion considered and the tree species. N and S deposition were significantly related to the foliar N and S concentrations for the pine and spruce, explaining most of the variation in case of pine and to a lesser extent spruce, whereas no relationship was found for the deciduous tree species. The foliar basic cation concentration showed a significant negative correlation with acid deposition but not with the deposition of basic cations with the exception of Mg. The validity of the latter results is however, strongly hampered by the limited number of plots. The requirement that the number of plots is at least 4 times as high as the number of predictor variables (Section 3.3.3) was only fulfilled for the coniferous trees. Another limitation is the comparability of foliar concentrations. This is, however a problem for sulphur only. Despite those limitations, the results do indicate that N and S deposition do increase the foliar concentrations of N and S and decrease those of base cations, at least of coniferous trees. A stronger focus on deciduous trees is needed in the future when the number of plots is such that reliable statistical analyses can be made.

Element concentration and element pools in the soil

Apart from various stand and site characteristics, the variation in element pools in the organic layer was mostly explained by meteorological variables (precipitation, temperature) and to a lesser extent the pH. Soil type was the most important explaining variable in the mineral layer, followed by precipitation and temperature. According to the expectations element pools were larger in more acid, wetter and colder situations, related to an inhibited mineralisation under those circumstances.

The absence of a relationship between atmospheric deposition and both concentrations and pools in the organic and mineral layer was a striking result, especially for the organic layer. Results are however, in line with those from a field experiment by Sogn et al (1999), who found that the total

N pool in the organic layer was not significantly increased after a six year input of 90 $kg.ha^{-1}.yr^{-1}$. This result was explained by an increased uptake of N by trees. Several other studies have demonstrated a similar growth response and fertiliser N recovery by adding single large fertiliser N doses for trees growing at nutrient (nitrogen) poor sites (Aronsson and Elowson, 1980, Ingestadt, 1980, Landsberg, 1986). Johnson and Todd, however, found evidence that hetrotrophs benefit from a continuous small dose of N fertiliser more than trees. It is thus likely that a continuous elevated input of N deposition will ultimately increase the N concentration in the humus layer. In areas with a high N input, such as the Netherlands, N concentrations in the humus layer are higher than those observed at all Intensive Monitoring plots (De Vries and Leeters, 2000). The results for the organic layer should thus be interpreted with care, since long-term (strongly) elevated input of N compounds is known to increase the N concentrations in the humus layer. At present, the increased N supply might however mainly stimulate tree growth at most of the plots. A focus on tree growth in response to N inputs is therefore worthwhile in the future (see also Spiecker et al., 1996).

Required pool changes and time periods to derive significant differences

In many cases, substantial changes in carbon, nitrogen and base cation pools are needed before a significant difference can be detected. Smallest changes are required in the organic layer, followed by the mineral topsoil. A second soil survey might therefore concentrate on those layers. Time periods that are needed to assess a significant trend have been calculated with respect to N in the organic layer and base cations in the mineral layer, since those pools are liable to change caused by nitrogen or acid deposition. Results showed that a time interval of 10 years, which is generally considered for a repetition of the soil survey, might give a significant trend in N and exchangeable base cation pools for approximately 25% and 10% of the plots, respectively.

The above mentioned result is based on the assumption that total litterfall and root decay equals maintenance uptake to resupply nutrients to the forest canopy (steady-state forest canopy) and that the input in each soil layer by mineralisation equals the maintenance root uptake. The element retention in each layer is thus simply related to the input from the atmosphere. When these assumptions do not hold, the internal cycling of elements (nutrients) by litterfall and root decay followed by mineralisation and root uptake may cause a reallocation of elements in different layers while the external net input (deposition minus net uptake) is negligible. Sogn et al (1999) for example estimated an average increase of 1.6 $kg.ha^{-1}.yr^{-1}$ in the organic layer based on a chronosequence of spruce forests in the same region in South eastern Norway, where N input has been limited in the last decades/century. They also found that the N accumulation varies with the development of the stand. A positive accumulation was observed in young stands (less than 25 years), whereas older stands (especially between 40 and 80 years) have lower N concentrations due to mining of N from lower soil horizons to fulfil the trees N demand. This example illustrates that changes can be expected but they can not simply be related to atmospheric inputs. Repetition of the soil survey may thus be felt adequate in view of soil and stand development but interpretations with respect to atmospheric inputs should be made extremely cautious.

Atmospheric deposition and the chemistry of the foliage and soil solution in view of critical levels

In all surveys, results were interpreted in view of critical levels. A summary and evaluation is given below.

Ranges of atmospheric inputs in view of critical loads

At approximately 55% of the considered plots received an N input above 1000 $mol_c.ha^{-1}.yr^{-1}$, being a deposition level at which the species diversity of the ground vegetation may decrease. The total input of acidity ranged mostly between 200-4000 $mol_c.ha^{-1}.yr^{-1}$. At inputs above approximately 1500-3500 $mol_c.ha^{-1}.yr^{-1}$, Al/(Ca+Mg+K) ratios above critical levels can be expected. Results of the soil solution survey do indicate that those situations occur frequently (see below). Despite uncertainties in critical loads and levels it likely that N and S deposition will have an adverse impact on part of the plots. On the other hand it is likely that an elevated N deposition will stimulate tree growth at part of the plots.

Ranges in foliar concentrations and foliar ratios in view of critical values

In the majority of the stands (mostly more than 80%), the nutrient status of the foliage can be judged as sufficient and balanced considering the various nutrients separately. Nevertheless, in approximately 30% of the stands the nutrient status of the foliage can be judged as insufficient and unbalanced for at least one of the nutrients. This interpretation is however, based on criteria for the foliar composition that are subject of uncertainty. Furthermore, concentrations below the lower do not necessarily indicate nutrient deficiency. A more objective expression is to call it low (see also Table 7.2 and 7.3) but this does not give an indication of stress. Despite the uncertainties it is likely that real nutrient stress is limited considering all the plots but nutrient problems do occur at part of the plots. A clear relationship with crown condition could, however, not be detected.

Range in dissolved element concentrations in view of critical levels

The results for soil solution chemistry showed that the concentrations of NO_3 in soil solution exceeded the official ground water quality criterion of 800 $mmol_c.m^{-3}$ in the subsoil at 9% of the plots. An Al concentration of 200 $mmol_c.m^{-3}$, that is sometimes considered indicative for negative impacts on tree roots, was exceeded in the subsoil at 57%. The Al/(Ca+Mg+K) ratios exceeded a critical ratio of 1.0 in approximately 30-39% of the plots, depending on the layer considered. Both the NH_4/K ratio and NH_4/Mg ratio hardly ever exceeded a critical value of 5.0 in the mineral soil.

Care should be taken with the information about the percentages of plots exceeding certain critical values. First, the considered critical levels are subject to uncertainty. Regarding the use of groundwater quality criteria, one has to be aware that NO_3 concentrations are generally lower in groundwater than in soil solution draining to ground water, due to the occurrence of denitrification. Critical Al/(Ca+Mg+K) ratios are mostly based on laboratory studies with seedlings and not on actual field data (Sverdrup and Warfinge, 1993). Secondly, results vary each year due to hydrological differences. The number of plots exceeding critical concentrations of NO_3 decreased compared to 1996, whereas the opposite was found for Al. Furthermore, the results refer to plots that are mainly located in Western and Central Europe and can not be used as an indication of the situation at a European wide scale. The percentages are only an indication of potential problems at the investigated. Possibilities for generalisation of the results are discussed below.

The possibility of upscaling results for atmospheric deposition and soil solution chemistry

Results of a multiple regression analysis showed that the geographic region has a dominant influence on the deposition data. The atmospheric deposition of all ions was increased going significantly from the Northern Boreal regions to Western Europe. There was also a highly significant positive correlation of atmospheric deposition and rainfall for all elements except for

NO3. Furthermore the deposition of most S and N compounds appeared to be lower at higher altitudes for most of the compounds. The variation in concentrations of major ions in the soil solution could to a large extent be explained by differences in atmospheric deposition, but the variation that could be explained was less. Furthermore, meteorological conditions (specifically precipitation) had a significant impact on all ions, except N compounds and the pH. Finally, base saturation is significantly related to base cation concentrations and pH, but the C/N ratio is not significantly related to N compounds.

The results of the various regression relations do indicate the possibility of upscaling response variables such as soil solution chemistry to the European scale by using information on predictor variables at a systematic 16 km x 16 km grid at so-called Level 1 forest monitoring plots. This is, however, only relevant or acceptable when (i) the relationships do explain a large part (e.g. more than 60%) of the variation in the response variable and (ii) the predictor variables are all available at the Level 1 plots or can be estimated with a reasonable accuracy. A comparison of measured and modelled atmospheric deposition data is further needed to investigate the possibility of upscaling the results.

Overall conclusions

Despite the limitations indicated above, the following conclusions can be drawn:

- Both bulk and total deposition of N appeared to be higher than S deposition at nearly all the plots in 1997 and the average calculated total N deposition was approximately twice the S deposition. As with previous year, atmospheric deposition was significantly influenced by the geographic region and to a lesser extent by altitude, tree height and rainfall.
- Stand age alone explained 5-36% of the variation in crown condition, depending on tree species. Apart from stand age, 15-30% of the variation in defoliation could be explained by the variation in precipitation, temperature, N and S deposition and foliar chemistry.
- In approximately 30% of the stands, the nutrient status of the foliage can be judged as insufficient and unbalanced for all nutrients. Atmospheric deposition, meteorological parameters, soil chemistry and site characteristics all contributed to the explanation of foliar nutrient concentrations, but the percentage variation accounted for generally decreased going from N > Mg> S> Ca> K> P. The N and S deposition were significantly related to the foliar N and S concentrations for the coniferous species, especially pine.
- A time interval of 10 years, which is generally considered for a repetition of the soil survey, might give a significant difference in N and exchangeable base cation pools for approximately 25% and 10% of the plots, respectively. The variation in element pools in the organic layer was explained for approximately 30-50% by various stand and site characteristics, precipitation, temperature and pH.
- Concentrations of NO_3 and ratios of Al to Ca+Mg+K above levels, that are indicative for adverse effects, occurred as a substantial percentage of the plots, respectively. As with the previous year, the variation in concentrations of major ions in the soil solution can to a large extent be explained by differences in atmospheric deposition and to a lesser extent by variations in meteorological conditions (specifically precipitation) and soil chemistry.

References

Alexander, E.B., 1980. *Bulk densities of Californian soils in relation to other soil properties.* Soil Science Society of America Journal 44:689-692.

Aronsson, A., 1980. *Frost hardiness in Scots pine. II Hardiness during winter and spring in young trees of different mineral status*. Studia Forest Suecica 155: 1-27.

Aronsson, A. and S. Elowson, 1980. *Effects of irrigation and fertilisation of mineral nutrients in Scots pine needles.* In: Structure of northern coniferous forests - an ecosystem study. T. Persson (Ed.). Ecol. Bull. (Stockholm) 32:219-228.

Beier, C and L. Rasmussen, 1989. *Problems related to collection of rain and throughfall water.* In: A.H.M. Bresser and P. Mathy (eds), Monitoring air pollution and forest ecosystem research, Air Pollution Report Series, 21, 101-110.

Berg, B. 1986. *Nutrient release from litter and humus in coniferous forest soil - a mini review.* Scand. J. For. Res. 1:359-369

Bobbink, R., M. Hornung and J.G.M. Roelofs, 1996. *The effects of air-borne nitrogen pollution on vegetation-critical loads.* In: WHO Europe. Updating and revision of air quality guidelines for Europe.

Bolte, A., 1998. *Canopy thinning, light climate and distribution of Calamagrostis epigejos (L.) Roth in a Scots pine forest (Pinus sylvestris L.).* Verhandlungen der Geselschaft für Ökologie, Band 29, 1999.

Boxman, A.W., H.F.G. Van Dijk, A.L.F.M. Houdijk and J.G.M. Roelofs, 1988. *Critical loads for nitrogen with special emphasis on ammonium.* In: J. Nilsson and P. Grennfelt (Eds.) Critical loads for sulphur and nitrogen. Report from a workshop held at Skokloster, Sweden, 19-24 March, 1988. Miljø rapport 1988 15. Nordic Council of Ministers, København: 295-322.

Bredemeier, M., 1988. *Forest canopy transformation of atmospheric deposition.* Water, Air and Soil Pollution, 40, 121-138.

Cape, N., P.H. Freer Smith, I.S. Paterson, J.A. Parkinson, and J. Wolfenden, 1990. *The nutritional status of Picea abies (L.) Karst. across Europe, and implications for 'forest decline'.* Trees, 211-224.

Cronan, C.S., R. April, R.J. Bartlett, P.R. Bloom, C.T. Driscoll, S.A. Gherini, G.S. Henderson, J.D. Joslin, J.M. Kelly, R.M. Newton, R.A. Parnell, H.H. Patterson, D.J. Raynall, M. Schaedle, C.T. Schofield, E.I. Sucoff, H.B. Tepper and F.C. Thornton, 1989. *Aluminium toxicity in forests exposed to acidic deposition.* Water, Air and Soil Poll. 48: 181-192.

Curtis, R.O. and B.W. Post, 1964. *Estimating bulk density from organic matter content in some Vermont forest soils.* Soil Science Society of America Proceedings 28:285-286.

De Vries, W., 1993. *Average critical loads for nitrogen and sulphur and its use in acidification abatement policy in The Netherlands*. Water, Air and Soil Pollution 68: 399-434.

De Vries, W., 1994. *Soil response to acid deposition at different regional scales. Field and laboratory data, critical loads and model predictions.* Wageningen, the Netherlands, Agricultural University, Ph.D. Thesis, 487 pp.

De Vries, W., 1996. *Critical loads for acidity and nitrogen for Dutch forests on a 1 km x1 km grid.* Wageningen, The Netherlands, DLO Winand Staring Centre for Integrated Land, Soil and Water Research, Report 113, 46 pp.

De Vries, W. and E.E.J.M. Leeters, 2000. *Effects of acid deposition on 150 forest stands in the Netherlands. 1. Chemical composition of the humus layer, mineral soil and soil solution.* Wageningen, the Netherlands, DLO Winand Staring Centre for Integrated Land, Soil and Water Research, Report 69.1, pp.

De Vries, W., J.J.M. Van Grinsven, N. Van Breemen, E.E.J.M. Leeters and P.C. Jansen, 1995. *Impacts of acid atmospheric deposition on concentrations and fluxes of solutes in Dutch forest soils.* Geoderma 67: 17-43.

De Vries, W., G.J. Reinds, E.M. Vel and H.D. Deelstra, 1996. Pan European Programme for the Intensive Monitoring of Forest Ecosystems. *Strategy plan for the validation and evaluation of data.* Heerenveen, the Netherlands, Forest Intensive Monitoring Coordinating Institute, Report, 60 pp.

De Vries, W., G.J. Reinds, J.M. Klap, H.D. Deelstra and E.M. Vel, 1998. *Intensive Monitoring of Forest Ecosystems in Europe*. Technical report 1998. EC-UN/ECE, 1998, Brussels, Geneva, 193 pp.

De Vries, W., G.J. Reinds, H.D. Deelstra, J.M. Klap, E.M. Vel, 1999. *Intensive Monitoring of Forest Ecosystems in Europe, 1999 Technical Report.* EC, UN/ECE 1999, Brussels, Geneva, 160 pp.

De Vries, W., Klap, J.M. and J.W. Erisman, 2000. Effects of environmental stress and crown condition in *Europe. I Hypothesis and approach to the study.* Water, Air and Soil Pollution 119: 317-333

Derome, J. and A.J. Lindroos, 1997. *Comparison of soil water and percolation water quality.* Finland, the Finnish forest Research Institute, Pilot Study Technical Report.

Dise, N.B., E. Matzner and P. Gundersen, 1998. *Synthesis of nitrogen pools and fluxes from European forest ecosystems*. Water, Air and Soil Pollution, 105: 143-154.

Draaijers, G.P.J., R. Van Eck and R. Meijers, 1992. *Measuring and modelling dry deposition in complex forest terrain.* In: T. Schneider (Ed*.),* Acidification Research Evaluation and Policy Applications, Studies in Environmental Science 50, Elsevier Science Publishers, Amsterdam, The Netherlands: 285-294.

Draaijers, G.P.J., J.W. Erisman, N.F.M. van Leeuwen, F.G. Römer, B.H. te Winkel, G.P. Wyers and K. Hansen, 1994. *A comparison of methods to estimate canopy exchange at the Speulder* *forest.* National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands, report no. 722108004.

Draaijers, G.P.J., J.W. Erisman, G. Lövblad, T. Spranger and E. Vel, 1998. *Quality and uncertainty aspects of forest deposition estimation using throughfall, stemflow and precipitation measurements*. TNO Institute of Environmental Sciences, Energy Research and Process Innovation, Apeldoorn, The Netherlands, report no. TNO-MEP-R98/093.

EC, 1996. *European programme for the intensive monitoring of forest ecosystems.* General information on the permanent observation plots in Europe (level II). EC, 1995, 85pp

EC, 2000. *EU- Manual on Remote Sensing Applications on Forest Health Assessment*

Flückiger, W. and S. Braun, 1998. *Nitrogen deposition in Swiss forests and its possible relevance for leaf nutrient status, parasite attacks and soil acidification.* Env. Pollution 102, 69-76.

Grigal, D.F., S.L. Brovold, W.S. Nord and L.F. Ohmann, 1989. *Bulk density of surface soils and peat in the north central United States.* Canadian Journal of Soil Science 69:895-900.

Gundersen, P., I. Callesen and W. de Vries, 1998. *Nitrate leaching in forest soils is related to forest floor C/N ratios.* Environmental Pollution: 403-407.

Hammond, R. and P.S. McCullagh, 1978. *Quantitative techniques in geography.* Clarendon Press, Oxford.

Harrison, A.F. and K.L. Bocock, 1981. *Estimation of soil bulk density from loss-on-ignition.* Journal of Applied Ecolcogy 8:919-927.

Hendriks, C.M.A., J. van den Burg, J.H. Oude Voshaar and E.P. van Leeuwen, 1997. *Relationship between forest condition and stress factors in the Netherlands in 1995.* DLO Winand Staring Centre for Integrated Land, Soil and Water Research, Report 148, 134 pp.

Hendriksen, A. and H.M. Seip, 1980. *Strong and weak acids in surface waters of Southern Norway and Southwestern Scotland.* Water Res. 14: 809-813.

Hoekstra, C. and J.N.B. Poelman, 1982. *Dichtheid van gronden gemeten aan de meest voorkomende bodemeenheden in Nederland.* Wageningen, Stichting voor Bodemkartering, Rapport nr. 1582, 47 pp.

Huntington, T.G., C.E. Johnson, A.H. Johnson, T.G. Siccama and D.F. Ryan, 1989. *Carbon, organic matter and bulk density relationships in a forested spodosol.* Soil Science 148:380-386.

Ingestad, T., 1980. *Nutrition and growth of birch and grey alder seedlings in low conductivity solutions and at varied relative rates of nutrition addition.* Physiol. Plant. 52:454-466.

Ivens, W.P.M.F., 1990. *Atmospheric deposition onto forests: an analysis of the deposition variability by means of throughfall measurements.* Ph.D. thesis, University of Utrecht, The Netherlands, 153 pp.

Johnson, D.W. and S.E. Lindberg, 1992 (eds). *Atmospheric deposition and forest nutrient cycling.* Ecological Studies 91, Springer, New York.

Johnson, D.W. and D.E. Todd, 1998. *Nitrogen fertiliser of younger yellow-poplar and loblolly pine plantations at differing frequencies.* Soil Sci. Soc. Am. J. 52:1468-1477.

Journal, A.G. and C.J. Huijbregts, 1978. *Mining geostatistics*. Academic Press. London

Klap, J.M., W. de Vries, J.W. Erisman and E.P van Leeuwen, 1997. *Relationships between forest condition and natural and anthropogenic stress factors on the European scale ; pilot study.* Wageningen, the Netherlands, DLO Winand Staring Centre for Integrated Land, Soil and Water Research, Report 150,

Klap, J.M., J. Oude Voshaar, W. de Vries and J.W. Erisman, 2000. *Effects of environmental stress and crown condition in Europe. IV Statistical analyses of relationships.* Water, Air and Soil Pollution 119: 363-386.

Kros, J., G.J. Reinds, W. de Vries, J.B. Latour and M. Bollen, 1995. *Modelling of soil acidity and nitrogen availability in natural ecosystems in respons to changes in acid deposition and hydrology.* Wageningen, the Netherlands, DLO Winand Staring Centre for Integrated Land, Soil and Water Resarch, Report 95, 90 pp.

Landsberg, J.J., 1986. *Experimental approaches to the study of effects of nutrients and water on carbon assimilation by trees.* Tree Physiol. 2:427-444.

Leemans, R. and W.P. Cramer, 1991. *The IIASA database for mean monthly values of temperature, precipitation, and cloudiness on a global terrestrial grid*. International Institute for Applied Systems Analysis, IIASA, Laxenburg, Austria, Report RR-91-18, 62 pp.

Lövblad, G., 1994 (ed). *Submanual on deposition for ICP-Forests level 2 plots.* Presented at the UN-ECE Task Force on Forest meeting in Lillehammer (Norway), May 1994).

Lövblad, G., 1997. *Results of the ICP Forests laboratories in the framework of the intercomparison AQUACON MedBas 1/96, subproject 6, Acid rain analysis. Annex to the final Report.* Internal Document.

Oliver, B.G., E.M. Thurman and R.L. Malcolm, 1983. *The contribution of humic substances to the acidity of coloured natural waters.* Geochemica and Cosmochemica Acta 47: 2031-2035.

Oude Voshaar, J.H., 1994. *Statistiek voor onderzoekers: met voorbeelden uit de landbouw- en milieuwetenschappen.* Wageningen, Wageningen Pers. 253 pp.

Perruchoud, D., L. Walthert, S. Zimmerman and P. Lüscher, 1999. *Estimating contemporary carbon stocks of forest soils in the Swiss Alps.* Biogeochemistry in pres.

Raitio, H. and T. Kilponen (ed), 1999. *Forest Condition Monitoring in Finland. National Report 1998.* The Finnish forest research institute, Parkano, Finland. Research papers 743 147 p.

Reuss, J.O., 1983. *Implications of the Ca-Al exchange system for the effect of acid precipitation on soils.* J. Environ. Qual. 12: 591-595.

Roberts, T.M., R.A. Skeffington and L.W. Blank, 1989. *Causes of type 1 spruce decline*. Forestry 62 (3): 179-222.

Roelofs, J.G.M., A.J. Kempers, A.L.F.M. Houdijk and J. Jansen, 1985. *The effect of air-borne ammonium sulphate on Pinus nigra var. maritima in the Netherlands.* Plant and Soil, 84: 45-56.

Schulze, E.-D. and Freer Smith, P.H., 1991. *An evaluation based on field observations focussed on Norway spruce, Picea abies.* Proceedings of the Royal Society of Edinburgh, 97B: 155-168.

Seidling, W., 2000. *Multivariate statistics within Integrated Studies on tree crown condition in Europe: an overview.* UN/ECE and EC, Geneva, Brussels, 45 pp.

Sogn, T.A., A.O. Stuanes and G. Abrahamsen, 1999. *The capacity of forest soil to absorb Anthropogenic N.* Ambio Vol. 4 No. 4.

Solberg, S. 1999a. *Crown density of Norway spruce and the influence from increased age on permanent monitoring plots in Norway during 1988 – 1997.* Eur. J. For. Path. 29, 219-230

Solberg, S. 1999b. *Forest health monitoring. Evaluation of methods, trends and causes based on a Norwegian nationwide set of monitoring plots.* Norgeslandbrukshøgskole, Dr. agric. thesis 1999.

Solberg, S and K. Tørseth, 1997. *Crown condition of Norway spruce in relation to sulphur and nitrogen deposition and soil properties in Southeast Norway.* Environmental Pollution vol 96 no 1, 19-27

Spiecker, H., K. Mielikäinen, M. Köhl and J.P. Skovsgaard (eds.), 1996. *Growth Trends in European Forests.* EFI Res.Rep. 5. Springer. Berlin. 372 pp.

Šrámek, V. 1998. *SO_2 air pollution and forest health status in Northwest Czech Republic.* Chemosphere vol 36 no 4-5, 1067-1072

Stefan, K. A. Fürst, R. Hacker and U. Bartels, 1997. *Forest Foliar Condition in Europe. Results of large-scale foliar chemistry surveys (survey 1995 and data from previous years).* EC-UN/ECE, 1997, Brussels, Geneva, 207 pp.

Stevens, P., 1987. *Throughfall chemistry beneath Sitka spruce of four ages at Beddgelert Forest, North Wales.* Plant and Soil 101: 291-294.

Strand, L. (ed) 1997. *Monitoring the environmental quality of Nordic forests*. Nordic Council of Ministers, Copenhagen, Denmark. 77p.

Stumm, W. and J.J. Morgan, 1981. *Aquatic chemistry. An introduction emphasizing chemical equilibria in natural waters.*Wiley, New York, 780 pp.

Sverdrup, H.U. and P.G. Warfvinge, 1993. *The effect of soil acidification on the growth of trees, grass and herbs as expressed by the (Ca+Mg+K)/Al ratio.* Reports in Ecology and Environmental Engineering 1993: 2, Lund University, Department of Chemical Engineering II, 108 pp.

Ter Braak, C.J.F., 1995. *Ordination*. In : R.H.G. Jongman, C.J. F. ter Braak and O.F.R. van Tongeren (Eds), Data analysis in community and landscape ecology. Cambridge University Press, Cambridge : 91-173.

UN-ECE, 1998. *Manual on methodologies and criteria for harmonised sampling, assessment, monitoring and analysis of the effects of air pollution on forests.* (4th edition). Hamburg, Geneva.

Ulrich, B., 1983. *Interactions of forest canopies with atmospheric constituents: SO_2, alkali and earth alkali cations and chloride.* In: B. Ulrich and J. Pankrath (Eds.), Effects of air pollutants in forest ecosystems. Reidel Publ. Co., Dordrecht, the Netherlands: 33-45.

Ulrich, B. and E. Matzner, 1983. *Abiotische Folgewirkungen der weitraümigen Ausbreitung von Luftverunreinigung.* Umweltforschungsplan der Bundesminister des Inneren. Forschungsbericht 10402615, BRD, 221 pp.

Ulrich, E. and R. Mosello, 1998. *Quality assurance and quality control for atmospheric deposition monitoring within ICP-forest.* Background document 4, 25 pp.

Van Breemen, N., P.A. Burrough, E.J. Velthorst, H.F. Van Dobben, T. De Wit, T.B. De Ridder and H.F.R. Reynders, 1982. *Soil acidification from atmospheric ammonium sulfate in forest canopy throughfall.* Nature 299: 548-550.

Van den Burg, J., 1985. *Foliar analysis for determination of tree nutrient status – a compilation of literature data.* Rijksinstituut voor onderzoek in de bos- en landschapsbouw “De Dorschkamp” Wageningen, Rapport nr. 414, 615 pp.

Van den Burg, J., 1988. *Voorlopige criteria voor de beoordeling van de minerale-voedingstoestand van naaldboomsoorten op basis van de naaldsamenstelling in het najaar.* Rijksinstituut voor onderzoek in de bos- en landschapsbouw “De Dorschkamp” Wageningen, Rapport nr. 522, 20 pp.

Van der Maas, M.P., N. Van Breemen and I. Van Langenvelde, 1991. *Estimation of atmospheric deposition and canopy exchange in two douglas fir stands in The Netherlands.* Internal publication, Department of soil science and geology, Agricultural University of Wageningen, The Netherlands.

Van der Velden, M. and J. Van Orshoven, 1992. *Report on the Intercalibration Exercise of methods for forest soil analysis.* KU Leuven, Belgium, 661 pp.

Vanmechelen, L., R. Groenemans and E. van Ranst, 1997. *Forest soil condition in Europe. Results of a Large-Scale Soil Survey.* EC-UN/ECE, 1997, Brussels, Geneva, 261 pp.

WMO, 1992. *Chemical analysis of precipitation for GAW: laboratory analytical methods and sample collections standards.* World Meteorological Organization, Global Atmosphere Watch. Internal Document, WMO/TD-NO 550, 32 pp.

Warfinge, P., H. Sverdrup and K. Rósen, 1992. *Calculating critical loads for N to forest soils*. In: P. Grennfeld and E. Thörnelöf (Eds.): Critical loads for Nitrogen. NORD 1992:41, Nordic Council of Ministers, Copenhagen: 403-418.

Wolff, B., Habermann, R., Arendt, K. 1999. *Evaluierung der Luftbildeinsatzes im Rahmen des deutschen Level II-Monitorings.* Arbeitsbericht Inst. f. Forstökologie und Walderfassung 99/3, Abschlußbericht EU-Vorhaben 96.60.DL.020.0.

Annex 1. Calculation of the required changes in element concentrations and element pools to derive significant differences

Element concentrations

Repeated measurements of the concentration of an element X at times t_1 and t_2 gives information on the change in that concentration according to:

$$\Delta\hat{X} = \hat{X}_2 - \hat{X}_1 \qquad \text{(A1.1)}$$

with $\hat{X}$ being equal to the estimated average concentration of element X based on a number of samples (or a number of subsamples in a pooled sample). Whether the calculated differences, based on repeated measurements are significant, depends on (i) the spatial variability (in terms of the standard deviation (s) of the concentration of the considered element and (ii) the number of samples (n) that were taken at each survey to assess an estimated average element concentration ($\hat{X}$). Statistically spoken, repeated measurements are two random samples from one population with characteristics n_1 and n_2, $\hat{X}_1$ and $\hat{X}_2$ and s_1 and s_2. The standard deviations (sd) of the two estimated means are equal to:

$$\mathrm{sd}(\hat{X}_1) = s_1/\sqrt{n_1} \qquad \text{(A1.2a)}$$

$$\mathrm{sd}(\hat{X}_2) = s_2/\sqrt{n_2} \qquad \text{(A1.2b)}$$

The standard deviation of the difference in the two estimated means equals:

$$\mathrm{sd}(\Delta\hat{X}) = \mathrm{sd}(\hat{X}_2 - \hat{X}_1) = s_X\sqrt{1/n_1 + 1/n_2} \qquad \text{(A1.3a)}$$

with s_X being equal to:

$$s_X = \sqrt{\frac{(n_1 - 1)\cdot s_{X_1}^2 + (n_2 - 1)\cdot s_{X_2}^2}{(n_1 - 1) + (n_2 - 1)}} \qquad \text{(A1.3b)}$$

Assuming that the same number of soil samples are taken at two repeated measurements ($n_1 = n_2$), this leads to the following simplification:

$$\mathrm{sd}(\Delta\hat{X}) = \mathrm{sd}(\hat{X}_2 - \hat{X}_1) = \sqrt{\left(s_{X_1}^2 + s_{X_2}^2\right)/n} \qquad \text{(A1.4)}$$

Assuming that there is no change in standard deviation (s_{X_1} = s_{X_2}), further simplifies Eq. (A1.4) to:

$$\mathrm{sd}(\hat{X}_2 - \hat{X}_1) = s_{X_1}\cdot\sqrt{2/n} \qquad \text{(A1.5)}$$

Assuming that the standard deviation is similar in both cases (which is to be expected in the same population when n is large) implies that one only needs a value of s during one sampling period. In statistical terms, the difference between $\hat{X}_1$ and $\hat{X}_2$ is only significant when:

$$\left|\hat{X}_2 - \hat{X}_1\right| \geq t_\alpha \cdot s_{X_1} \cdot \sqrt{2/n} \tag{A1.6}$$

where:

t_α = tabled student t factor for a given uncertainty; for $\alpha = 0.05$, $t_\alpha \approx 2$

The term $t_\alpha \cdot s_{X_1} \cdot \sqrt{2/n}$ equals the 95% probability interval for the difference between the two means $\hat{X}_1$ and $\hat{X}_2$ ($\Delta\hat{X}$).

Element pools

The variation in element pools is the variation of the product of the amount of solid material and the element concentration in the organic layer (Eq. 8.1) or of the bulk density, thickness and element concentration in the mineral layer (Eq. 8.2). In order to reduce the costs of analyses use is made of pooled samples in which both the amount of solid material and the element concentration is determined separately. Assuming that the element concentrations are spatially independent of the amount of solid material or bulk density and thickness, one can say that the expectation of the product equals the product of the expectations (Eq. A1.7a).

$$E\left[\hat{X}\hat{Y}\right] = E\left[\hat{X}\right] \cdot E\left[\hat{Y}\right] \tag{A1.7a}$$

We also assume that the values for the element concentration and the amount of solid material or bulk density and thickness are the average values of a simple random sample. Therefore, the average of the sample is an unbiased estimator and equals the expectation of the average (Eq. A1.7b).

$$E\left[\hat{X}\right] \cdot E\left[\hat{Y}\right] = XY \tag{A1.7b}$$

With:

X = the actual average element concentration

Y = the actual average pool of solid material in the humus layer or the bulk density times thickness in the mineral layer

$\hat{X}$ = the estimated average element concentration

$\hat{Y}$ = the estimated average pool of solid material in the humus layer or the bulk density times thickness in the mineral layer

Because $\hat{X}$ and $\hat{Y}$ are unbiased estimators, the variance error of the estimated element pool equals the expectation of the square of the difference of the estimated average with the actual average (which is unknown) and can be given as:

$$\operatorname{var}\left[\hat{X}\hat{Y} - XY\right] = E\left[\left(\hat{X}\hat{Y} - XY\right)^2\right] \tag{A1.7c}$$

Substitution of $\hat{X} = X + X'$ and $\hat{Y} = Y + Y'$ with $E\left[X'\right] = E\left[Y'\right] = 0$ and using the fact that $\hat{X}$ and $\hat{Y}$ are independent, Eq. (A1.7c) can also be written as:

$$\operatorname{var}\left[\hat{X}\hat{Y} - XY\right] = Y^2 E\left[X'^2\right] + X^2 E\left[Y'^2\right] + E\left[X'^2\right] \cdot E\left[Y'^2\right] \tag{A1.7d}$$

or

$$\sigma^2_{\hat{X}\hat{Y}} = Y^2\sigma^2_{\hat{X}} + X^2\sigma^2_{\hat{Y}} + \sigma^2_{\hat{X}} \cdot \sigma^2_{\hat{Y}} \tag{A1.7e}$$

Repeated sampling of element pools in both humus and mineral layer at two different times gives information on the change in element pools. If both samples are taken independently, the variance of this difference can be given as:

$$\operatorname{var}\left[\hat{Z}_2 - \hat{Z}_1\right] = \hat{Y}_1\sigma^2_{\hat{X}_1} + \hat{X}_1\sigma^2_{\hat{Y}_1} + \sigma^2_{\hat{X}_1} \cdot \sigma^2_{\hat{Y}_1} + \hat{Y}_2\sigma^2_{\hat{X}_2} + \hat{X}_2\sigma^2_{\hat{Y}_2} + \sigma^2_{\hat{X}_2} \cdot \sigma^2_{\hat{Y}_2} \tag{A1.8}$$

with:
$\hat{Z} = \hat{X}\hat{Y}$
$\hat{Z}_1 =$ estimated Z at time t=1
$\hat{Z}_2 =$ estimated Z at time t=2

The variance of the average values for X and Y at time t_1 and t_2 can be estimated by the variance in those values divided by the number of samples as illustrated for X_1 :

$$\sigma^2_{\hat{X}_1} = \frac{S^2_{X_1}}{n} \tag{A1.9}$$

Assuming that the variance remains constant ($S^2_{X_1} = S^2_{X_2} = S^2_X$) and combining Eq. (A1.8) and Eq. (A1.9) gives the following estimation for the variance (Eq. A1.10a) or standard deviation (Eq. A1.10b) for the differences in the element pools:

$$\operatorname{var}\left[\hat{Z}_2 - \hat{Z}_1\right] = \frac{2}{n^2} \cdot S^2_X \cdot S^2_Y + \left(\frac{\hat{Y}_1^2 + \hat{Y}_2^2}{n}\right) \cdot S^2_X + \left(\frac{\hat{X}_1^2 + \hat{X}_2^2}{n}\right) \cdot S^2_Y \tag{A1.10a}$$

or

$$\operatorname{sd}\left(\Delta\hat{Z}\right) = \sqrt{\frac{2}{n^2} \cdot S^2_X \cdot S^2_Y + \left(\frac{\hat{Y}_1^2 + \hat{Y}_2^2}{n}\right) \cdot S^2_X + \left(\frac{\hat{X}_1^2 + \hat{X}_2^2}{n}\right) \cdot S^2_Y} \tag{A1.10b}$$

Information on the standard deviation in the element concentration (X) and the solid phase pool (Y) in the first assessment can be used for a first indicator of the required change by assuming that $\hat{X}_1 = \hat{X}_2$ and $\hat{Y}_1 = \hat{Y}_2$. Eq. (A1.10b) then simplifies to:

$$\mathrm{sd}\left(\Delta\hat{Z}\right) = \sqrt{\frac{2}{n^2} \cdot S_X^2 \cdot S_Y^2 + \left(\frac{2\hat{Y}^2}{n}\right) \cdot S_X^2 + \left(\frac{2\hat{X}^2}{n}\right) \cdot S_Y^2} \qquad \text{(A1.11)}$$

The measured difference in element pools between two time periods is only statistically significant when:

$$\left|\Delta\hat{Z}\right| \geq t_\alpha \cdot \mathrm{sd}\left(\Delta\hat{Z}\right) \qquad \text{(A1.12)}$$

Annex 2. Calculation of the time period that is needed to derive a significant difference in element pools

Calculation procedure

The expected difference in element pool for a variable X between two measurements will depend on the external input from that element and the fraction that is retained in the soil. In formula:

$$\left|\Delta\hat{Z}\right| = \left|\hat{X}_2\hat{Y}_2 - \hat{X}_1\hat{Y}_1\right| = frX_{ret} \cdot AD_x \cdot t \qquad \text{(A2.1)}$$

where:

frX_{ret} = fraction of element that is retained in the soil (-)

AD_x = annual atmospheric input of element X ($kg.ha^{-1}.yr^{-1}$)

t = time period between two repeated measurements (yr)

An estimate of the time period that is needed to derive a significant difference in nutrient pools can be derived by combining the Eqs. (A1.10b), (A1.12) and (A2.1) when one assumes that the pool of solid material in the organic layer or in the miner soil stays constant in time. This is a reasonable assumption for the mineral layer, where both the bulk density and thickness (certainly when samples are taken at fixed depths) do not change in time. In this case $\hat{Y}_1 = \hat{Y}_2 = \hat{Y}$ and $\hat{X}_2$ can be estimated from $\hat{X}_1$ according to (cf. Eq. A2.1):

$$\hat{X}_2 = \hat{X}_1 + \left(\frac{frX_{ret} \cdot AD_x \cdot t}{\hat{Y}}\right) \qquad \text{(A2.2)}$$

Combining Eq. (A1.10b), (A1.12), (A2.1) and (A2.2) with $\hat{Y}_1 = \hat{Y}_2 = \hat{Y}$ gives:

$$t \geq t_\alpha \cdot \frac{\sqrt{\frac{2}{n^2} \cdot S_X^2 \cdot S_Y^2 + \left(\frac{2\hat{Y}^2}{n}\right) \cdot S_X^2 + \left(\frac{\hat{X}_1^2 + \left\{\hat{X}_1 + \left(\frac{frX_{ret} \cdot AD_x \cdot t}{\hat{Y}}\right)\right\}^2}{n} \cdot S_Y^2\right)}}{\left|frX_{ret} \cdot AD_x\right|} \qquad \text{(A2.3)}$$

Since the time t is both in the left and right hand side of the equation, Eq. (A2.3) has to be solved iteratively. A Fortran program was thus written to solve the equation and to calculate the required time period before a significant difference can be detected. The expected element concentration after that period was calculated with Eq. (A2.2). It is recommended to check if the expected difference in element concentration is not only significant from a statistical point of view, but also in view of errors in the sampling, sample preparation and sample analyses, which are not accounted for in this procedure.

In the organic layer, the assumption of a constant pool is not always valid. As an alternative, one may assume that the pool of organic matter in the humus layer changes by the difference between the external input and decomposition, using a first order decay process:

$$\frac{\delta Y}{\delta t} = -kY + I \tag{A2.4}$$

where:
k = mineralisation rate constant (yr^{-1})
Y = pool of organic matter ($kg.ha^{-1}$)
I = input of organic matter by litterfall and root decay ($kg.ha^{-1}.yr^{-1}$)

Solving Eq. (A2.4) leads to:

$$Y = Y_{max} \cdot \left(1 - e^{-kt}\right) \tag{A2.5}$$

where:
Y_{max} = maximum pool of organic matter, being equal to I/K ($kg.ha^{-1}.yr^{-1}$)

The change in organic layer pool between two different time periods can thus be given as:

$$\hat{Y}_2 = \hat{Y}_1 + Y_{max} \cdot \left(e^{-k \cdot age} - e^{-k\,(age+t)}\right) \tag{A2.6}$$

where:
k = a constant depending on tree species and pH (-)
age = the age of the forest stand (yr)
t = time period between two repeated measurements (yr)

The combination of Eq. (A2.1) and Eq. (A2.6) enables the expression of the element concentration at time t=2 in terms of the element concentration and organic layer pool at time t=1. In formula:

$$\hat{X}_2 = \frac{\hat{X}_1 \hat{Y}_1 + frX_{ret} \cdot AD_x \cdot t}{\hat{Y}_1 + Y_{max} \cdot \left(e^{-cl} - e^{-c\,(l+t)}\right)} \tag{A2.7}$$

(note that in this case $\hat{X}$ and $\hat{Y}$ are no longer unbiased estimators)

The required time period for measurement of significant differences between element pools in the humus layer can now be calculated by combining Eq. (A1.10b), (A1.12), (A2.1) and (A2.7) according to:

$$t \geq t_{\alpha} \cdot \frac{\sqrt{\frac{2}{n^{2}} \cdot S_{X}^{2} \cdot S_{Y}^{2} + \left(\frac{\hat{Y}_{1}^{2} + \left\{ \hat{Y}_{1} + Y_{max} \cdot \left(e^{-cl} - e^{-c\,(l+t)} \right) \right\}^{2}}{n} \right) \cdot S_{X}^{2} + \left(\frac{\hat{X}_{1}^{2} + \left\{ \frac{\hat{X}_{1}\hat{Y}_{1} + frX_{ret} \cdot AD_{x} \cdot t}{\hat{Y}_{1} + Y_{max} \cdot \left(e^{-cl} - e^{-c\,(l+t)} \right)} \right\}^{2}}{n} \right) \cdot S_{Y}^{2}}}{\left| frX_{ret} \cdot AD_{x} \right|} \qquad (A2.8)$$

As with Eq. (A2.3), this equation has to be solved iteratively. A fortran programme was written to perform the solution.

In performing the calculations, the standard assumption of a constant pool was used for both the organic and mineral layer. The impact of a constantly increasing organic pool was only investigated to gain insight in the sensitivity of the assumption. Note that Eq. (A2.3) simplifies significantly when one assumes that the standard deviation in the pool of solid material S^{2}_{Y} is negligible, according to :

$$t \geq \frac{t_{\alpha} \cdot \sqrt{2/n} \cdot \hat{Y} \cdot S_{x}}{frX_{ret} \cdot AD_{x}} \qquad (A2.9)$$

Such an assumption is, however, not defensible when one takes a pooled sample in which the pool of solid material and the element concentration are determined separately. An approach comparable to Eq. (A2.9) is, however, useful when various samples are taken and analysed at one plot instead of using a pooled sample, which is the standard procedure. In this case one may calculate the element pool at each point in the plot and assess the standard deviation in the pool (instead of using separate standard deviations in both the amount of solid material and the element concentration). This can easily be deduced by combining Eq. (A1.6) and Eq. (A2.1) and replacing the element concentration X in Eq. (A1.6) by the element pool Z used in Eq. (A2.1). Combination of both equations gives :

$$t = \frac{t_{\alpha} \cdot \sqrt{2/n} \cdot S_{z}}{frX_{ret} \cdot AD_{x}} \qquad (A2.10)$$

with S_{z} being the standard deviation in the element pool.

Assumptions

It should be realised that Eq. (A2.3) is based on the following assumptions:

- the pool of solid material stays constant, an assumption that is not likely for the humus layer. This assumption will cause an underestimation of the required time period to assess a significant difference. To estimate the impact of this assumption we also calculated time periods for a humus layer that is increasing in thickness in time using a first order decay model.
- the standard deviation in element concentration and pools of solid material remain constant. It is more likely that the coefficient of variation remains constant, thus causing an increasing

standard deviation when the element concentrations or pools of solid material increase and vice versa. The impact of this assumption on the required time period thus depends on the situation. Compared to the uncertainty in the standard deviation, the impact of this assumption is likely to be small.

- a simple random sample is taken. Actually this is generally not the case; samples are taken according a firm pattern. One might argue that this assumption will also cause an underestimation of the required time period to assess a significant difference. On the other side there is a positive effect of sampling. Repeated sampling according to a firm pattern on almost the same locations, however, reduces the variance and therefore the results of Eq. (A2.3) may actually give an overestimation.
- the element retention in each layer can simply be related to the input from the atmosphere as described in Eq. (A2.1). This equation is based on the implicit assumptions that total litterfall and root decay equals maintenance uptake to resupply nutrients to the forest canopy (steady-state forest canopy) and that the input in each soil layer by mineralisation equals the maintenance root uptake. When these assumptions do not hold, the internal cycling of elements (nutrients) by litterfall and root decay followed by mineralisation and root uptake may cause a reallocation of elements in different layers while the external net input (deposition minus net uptake) is negligible.

Data needs

The required time period to assess a significant difference depends on (see Eq. A2.3):

- the average pool of solid material in the considered soil layer and the standard deviation in that pool.
- the average element concentration in the considered soil layer and the standard deviation of that element concentration.
- the external element input by atmospheric deposition.
- the element retention fraction in the considered soil layer.
- the number of soil samples taken to assess an average value.

Information on the average pool of solid material, the average element concentration and the number of soil samples taken to assess an average value can be derived from the soil survey, whereas the external element input by atmospheric deposition can be assessed from the deposition survey. Information on the standard deviation in pools of solid material and element concentrations can only be derived when separate samples have been taken at the plot, apart from the pooled sample. Accordingly, it is to be recommended to add at least two and preferably three random samples to assess those standard deviations. Otherwise, an estimate of those standard deviations has to based on the literature.

The fraction of the external element input that will retain in the soil depends on the atmospheric input, the element flux that is needed for net growth uptake (determined by the tree species, tree age and site quality), on the status of the soil affecting different processes (e.g. C/N ratio in case of net N mineralisation/immobilisation, base saturation in case of base cation release/retention, soil moisture content in case of denitrification etc) and on the soil layer considered. In general, changes are likely to be largest in the organic soil layer, especially when considering C and N (comparatively low element pools and largest inputs). Consequently, for these elements the required time period can best be related to this layer. In case of N, one can estimate the N retention by multiplying the N deposition corrected for net N uptake by a C/N related N retention (immobilisation) fraction according to De Vries et al. (1995). This may lead to the following situations:

1. atmospheric input is less than the required net N uptake and the C/N ratio is relatively high (N availability is low) : small or no change in N pools expected
2. atmospheric input is higher than the required net N uptake but the C/N ratio is very low (N availability is high; N saturated soil): small or no change in N pools expected
3. atmospheric input is higher than the required net N uptake and the C/N ratio is relatively high (N unsaturated soil): increase in N pools expected
4. atmospheric input is less than the required net N uptake and the C/N ratio is very low or N availability is high (e.g. reduced N inputs on an N saturated soil) : decrease in N pools expected

A problem in using the above mentioned approach is that net N uptake data are not available. Furthermore, total N deposition data have to be derived by adding an estimated foliar uptake to the available throughfall and stemflow data. Such an estimate can be made from bulk deposition, throughfall and stemflow data, using a canopy exchange model. Foliar uptake data thus obtained for 77 Intensive Monitoring plots ranged between approximately 50 and 750 $mol_c.ha^{-1}.yr^{-1}$ (De Vries et al., 1999a), being comparable to the range in net N uptake. One may thus assume that available throughfall data are a reasonable estimate for AD_x (the net input of N from the atmosphere), which in turn have to be multiplied by a C/N related retention fraction, frN_{ret}. Using this approach will, however, always cause an increase in N pool (throughfall is positive), unless the soil is N saturated.

In case of exchangeable base cations (Ca, Mg, K and Na), the response will not only depend on the deposition of the considered elements, but also on the net input of acidic elements (S and N compounds). For these elements AD_x has to be read as the acid deposition instead of the deposition of the considered element, being the sum of the net S and N input minus the Cl corrected base cation deposition. The value of $frBC_{ret}$ is therefore negative. In areas with a negative acid input, where the Cl corrected base cation deposition is larger than net S and N input, one may expect an increase in base saturation. Inversely, when the acid input is positive, one can expect a decrease in the base saturation, due to a net release of base cations buffering the acid input, unless the base saturation is very low. The value of $frBC_{ret}$ thus have to be related to the base saturation.

Illustration of the calculation procedure

The use of Eq. (A2.3) can be illustrated by the following example for nitrogen in an organic layer of a forested soil, assuming that:

- the pool of organic matter is 6 kg m^{-2} (60 ton ha^{-1}).
- the standard deviation in the pool of organic matter is 1.2 (a coefficient of variation of 0.2), being constant time.
- the average N concentration in that layer is 15 g kg^{-1} (1.5%).
- the standard deviation in the N concentration is 3 g kg^{-1} (a coefficient of variation of 0.2), being constant in time.
- the external N input is 20 kg ha^{-1} yr^{-1}.
- the N retention fraction in the organic layer is 0.5 (the rest is taken up, denitrified or leached)
- the number of soil samples taken to assess an average value equals 25.

Results of the required time period for both an organic matter pool not changing in time (derived by solving Eq. A2.3) and an organic matter pool that changes (constantly increases) are given in Table A2.1. Results for a changing pool of organic matter pool has been calculated using tree species dependent litterfall fluxes and mineralisation rate constants, based on data given in Kros et al. (1995).

Table A2.1 The influence of number of subsamples, and the assumed standard deviation on the time period (yr) that is needed to measure significant differences in element pools (values in brackets equal the time periods when the standard deviation of both the pool of organic matter and the N concentration in that layer is twice as low.

number of subsamples	organic matter pool			
	Constant	Changing		
		Pine	Spruce	Deciduous
25	43 (22)	52 (25)	50 (24)	50 (24)
50	31 (15)	36 (17)	34 (16)	35 (17)
75	25 (12)	29 (14)	28 (13)	28 (13)
100	22 (11)	25 (12)	24 (11)	24 (11)

The result show that using a changing pool of organic matter has a relatively small influence on the required time period. The influence of the number of samples that are taken to derive a pooled sample is much larger. A fourfold increase in the number leads to a reduction of a factor two (the square root of 4) in the required time period, whereas a decrease in the standard deviation by a factor of 2 causes a nearly similar reduction as can be expected from Eq. (A2.3). In the example given above, the time period that is needed to derive significant changes is relatively large. This period can only be influenced by increasing the number of subsamples in a pooled sample. Even when using 100 samples, the time period is at least 10 years. Lower values can be expected in areas with a higher deposition and/or N retention rate and/or a lower initial N pool. Exploration of Eq. (A2.3) shows that an increase in atmospheric deposition or in retention rate will lead a similar decrease in time period. Similarly a decrease in the initial element pool will cause a nearly linear decrease in the time period, since the ratio between N retention and available N becomes lower.

Annex 3. Procedures and results of data quality checks for atmospheric deposition and soil solution

1 Ionic balance

Methods

On an equivalent basis, the sum of all major cations should equal the sum of all major anions. The percentage difference was therefore calculated according to:

$$\mathrm{PD} = 100 * \frac{(\quad \mathrm{cat} - \quad \mathrm{an})}{0.5 * (\quad \mathrm{cat} + \quad \mathrm{an})} \tag{A3.1}$$

$$\mathrm{cat} = [\mathrm{Ca}^{2+}] + [\mathrm{Mg}^{2+}] + [\mathrm{Na}^{+}] + [\mathrm{K}^{+}] + [\mathrm{H}^{+}] + [\mathrm{NH}_4^{+}] \tag{A3.2}$$

$$\mathrm{an} = \mathrm{Alk} + [\mathrm{SO}_4^{2-}] + [\mathrm{NO}_3^{-}] + [\mathrm{Cl}^{-}] + [\mathrm{RCOO}^{-}] \tag{A3.3}$$

where:

PD = percentage difference (%)

Alk = alkalinity ($\mathrm{mmol_c.m^{-3}}$)

In principle, H should be neglected when alkalinity is positive. The basic assumption is that the charge of the other cations and anions present in solution can be neglected. Unlike last years report, the concentration of organic acids in bulk deposition and throughfall was calculated from measured concentrations of DOC (when available), using an empirical correction. As with the method used for soil solution (see De Vries et al., 1999a), the charge of those organic anions was calculated according to (Oliver et al., 1983):

$$\mathrm{RCOO}^{-} = \mathrm{m} \cdot \mathrm{DOC} \cdot \frac{\mathrm{Ka}}{\mathrm{Ka} + [\mathrm{H}]} \tag{A3.4}$$

with

$$\mathrm{pKa} = 0.96 + 0.90 \cdot \mathrm{pH} - 0.039 \cdot \mathrm{pH}^2 \tag{A3.5}$$

where:

DOC = the concentration of dissolved organic carbon ($\mathrm{mg.l^{-1}}$)

m = the concentration of acidic functional groups on DOC ($\mu\mathrm{mol_c.mg^{-1}}$ C)

Ka = the dissociation constant for organic acid ($\mathrm{mol.l^{-1}}$)

[H] = the proton concentration ($\mathrm{mol.l^{-1}}$)

For m a value of 5.5 $\mu\mathrm{mol_c.mg^{-1}}$ C was used, based on Hendriksen and Seip (1980). When DOC was not measured, the charge balance check was still made assuming that the influence was small. This is specifically true in bulk deposition, where concentrations of low molecular organic acids, such as formic and acetic acid, only have a minor role in the ionic balance.

The difference between the sum of all major cations and anions in soil solution was calculated similarly. However, unlike atmospheric deposition, Al was included in the calculation of cations. Checks on the ionic balance were only made when all cations and anions were measured. The only allowances made were situations where (i) Al was missing at a pH > 5, (ii) alkalinity was missing at a pH < 5 and (iii) DOC was missing (separate calculation). Checks on ionic balance could only be made for part of the measurements due to neglection of Na and Cl (for those ions only 6102 measurements were available) and quite often also NH_4 and NO_3. Actually, Na and Cl were optional parameters, but for a quality check it is absolutely necessary to include them. From a total number of 14463 measurements, checks on the complete ionic balance could be made at 2251 measurements only. For another 670 measurements, checks could be made without including DOC, whereas no checks could be made at the remaining 11542 measurements.

Results for deposition

Figure A3.1, shows the relationship between the sum of cations and anions in bulk deposition and throughfall using all the individual measurements at all Intensive Monitoring plots. The checks were limited to those measurements where all major ions mentioned in Eq. (8.2) and Eq. (8.3) were available. Only alkalinity was allowed to be missing in plots were the pH is less than 4.5. In that case the alkalinity, which stands for the sum of HCO_3^-, CO_3^- and OH^- corrected for H^+, was assumed to be negligible (see section on ionic ratios). This included approximately 43% of the measurements (See also Table A3.2).

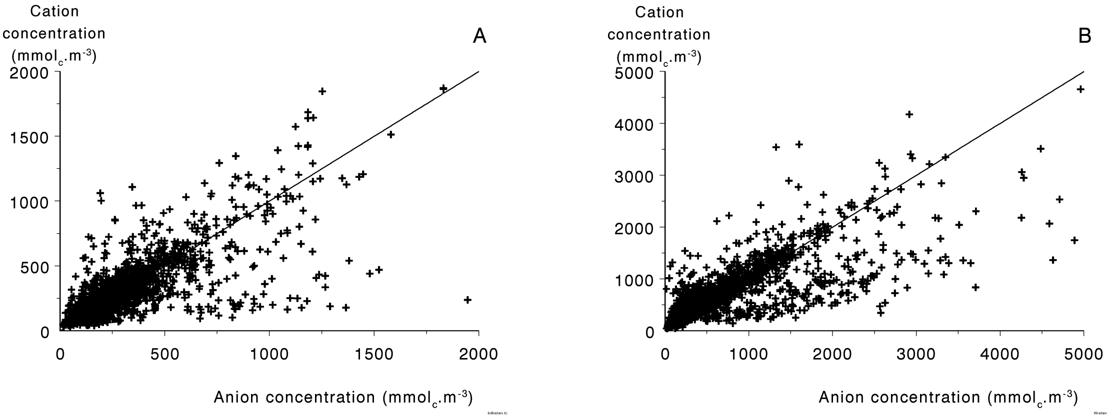


Figure A3.1 Relationships between the sum of cations and the sum of anions in bulk deposition (A) and throughfall (B) of 1997, using all individual measurements at all Intensive Monitoring plots. Beware of the difference in axes between bulk deposition and throughfall. The solid line represents the 1:1 line.

As with the deposition data for 1996 (De Vries et al., 1999a), the results for 1997 show large differences varying from a strong anion excess to a large cation excess. Comparable results were obtained for stemflow, for which the number of measurements is much less. Unfortunately, also this year, the results are far from satisfactory. In general, it is required that PD is less than 10% for bulk deposition and less than 20% for throughfall when the sum of cations and anions is larger that 500 mmol$_c$.m^{-3} (WMO, 1992; Ulrich and Mosello, 1998). Larger relative differences are acceptable at low concentrations of the sum of cations and anions (Table A3.1).

Table A3.1 The required criteria for the ionic balance (WMO, 1992).

Cations+anions (mmol$_c$.m^{-3})	Acceptable difference (%)
≤ 50	≤ 60
50 – 100	≤ 30
100 – 500	≤ 15
> 500	≤ 10

Approximately 50% of the measurements only appears to fulfil the requirement of a difference within 20% (Table A3.2), implying that 50% of the data is not within an acceptable range.

Table A3.2 Percentage of measurements in different ranges for the relative difference in sum of cations and sum of anions.

Difference	Percentage of measurements[1]		
(%)	Bulk deposition[2]	Throughfall[3]	Stem flow[4]
< -30	13.2	10.4	17.9
-30 - -20	4.5	2.2	3.7
-20 - -10	5.5	4.3	4.7
-10 – 0	9.6	10.6	15.2
0 – 10	18.9	17.6	12.5
10 – 20	17.1	16.3	15.2
20 – 30	10.1	13.5	8.6
> 30	21.1	25.5	22.2

[1] This includes measurements where all ions including alkalinity have been measured or alkalinity has not been measured but pH is less than 4.5.

[2] The number of complete measurements equals 2387 (total number of measurements is 8452)

[3] The number of complete measurements equals 2586 (total number of measurements is 7040)

[4] The number of complete measurements equals 487 (total number of measurements is 1343)

Results showed that the percentage difference between cations and anions only slightly decreased with an increase in ionic concentrations, especially in throughfall. Even at very high concentrations of cations and anions, the differences were often still very large (Fig. A3.2).

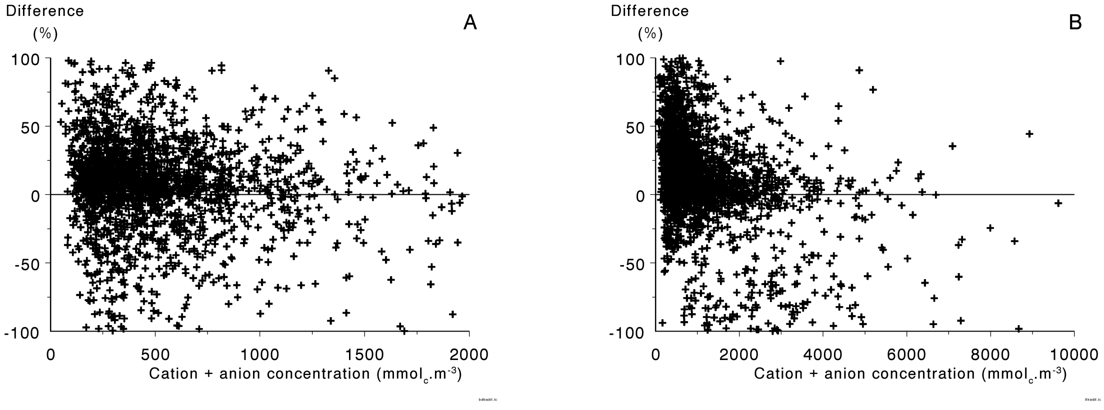


Figure A3.2 The percentage difference between cations and anions as a function of the sum of the concentrations of cations and anions in the bulk deposition (A) and throughfall (B).

Results of the cation-anion balance varied per country as illustrated in Table A3.3.

Table A3.3 Ranges between which 90% of the differences between cations and anions (%) varied in bulk deposition and throughfall as a function of country.

Country	Difference (%)					
	Bulk deposition			Throughfall		
	5%	50%	95%	5%	50%	95%
Finland	-6	1	20	-9	11	37
Sweden	-6	7	26	-1	15	58
Norway	-6	4	17	0	11	41
Denmark	-1	7	9	-13	2	53
U.K.	-10	11	49	-2	9	69
Ireland	-6	7	18	-3	13	50
Netherlands	-13	0	9	-11	-3	3
Belgium	-61	-20	6	-22	-1	19
Luxembourg	-7	12	29	2	8	23
Germany	-106	13	67	-100	10	72
France	-3	10	33	0	21	50
Estonia	8	48	101	5	55	101
Poland	-47	16	60	-	-	-
Czech Republic	-37	-20	-3	-93	-12	-3
Hungary	-151	-46	50	-114	-60	32
Austria	-59	8	92	-28	25	112
Switzerland	-2	16	78	4	18	128
Slovak Republic	-85	24	137	-34	31	122
Portugal	-111	-6	38	-38	18	73
Italy	-20	15	65	-1	31	78
Greece	-99	-32	2	-38	-5	24
All	-68	9	69	-75	13	77

The results appear to be comparable for throughfall and bulk deposition. On average, the sum of cations and anions in throughfall appears to be nearly equal but in some countries, there is generally an anion excess (e.g. Hungary) or a cation excess (e.g. Estonia). The unbalance may partly be due to inaccuracies in less relevant ions, such as Na and Cl (see later). In general, however, there was no clear relationship between the difference in cations and anions and the Na to Cl ratio.

Results for soil solution

As with atmospheric deposition, graphs of the sum of cations versus the sum of anions for soil solution showed large differences. (Fig. A3.3).

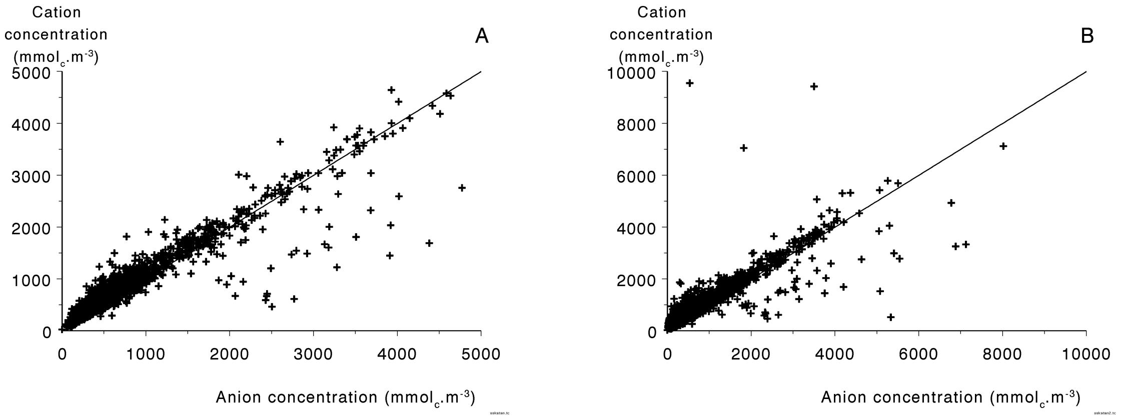


Figure A3.3 Relationships between the sum of cations and the sum of anionsin soil solution using measurements including DOC (A; 2251 measurements) and excluding DOC (B; 2921 measurements). The solid line represents a 1:1 line.

The percentage of measurements in an acceptable range of ±20% was also here near 50%, independent whether DOC was taken into account or not (Table A3.4). This is worse than in 1996, where this percentage equalled nearly 90% when DOC was included and to 60% when DOC was excluded.

Table A3.4 Percentage of measurements in different ranges for the difference in the sum of cations (and the sum of anions) relative to the sum of cations

Difference (%)	Percentage Complete ionic balance[1]	 Complete balance except DOC[2]
< -30	1.6	1.5
-30 - -20	1.2	1.0
-20 - -10	2.7	2.1
-10 – 0	9.8	7.3
0 – 10	20.7	16.8
10 – 20	18.7	16.6
20 – 30	14.7	12.9
> 30	30.7	41.8

[1] The total number of measurements equals 2251

[2] The total number of measurements equals 2921

2 Electric conductivity

Methods for deposition and soil solution

Another quality check is the difference between measured and calculated electric conductivity, which should be less than 20% when the measured conductivity is larger than 30 μS.cm^{-1} (WMO, 1992; Ulrich and Mosello, 1998). Electric conductivity (EC) is a measurement of the ability of an aqueous solution to carry an electric current. Apart from temperature, this ability depends on the type and concentration (activity) of ions in solution according to:

$$EC = \sum_{i} \lambda_i \cdot f_i \cdot c_i \qquad (A3.6)$$

where:

EC = electric conductivity (μS.cm^{-1})

λ_i = equivalent ionic conductance, being the capacity of a single ion to carry an electric current in ideal conditions of infinite solution at 20˚C ($kS.cm^2.eq^{-1}$)

c_i = concentration of ion i with i = H, Ca, Mg, K, Na, Al, NH_4, NO_3, SO_4, Cl, Alk ($mmol_c.m^{-3}$)

f_i = activity coefficient of ion i.

Values of λ_i for the various ions, together with the equivalent weight by which the concentrations (submitted in $\mu g.l^{-1}$) are divided (to get $mmol_c.m^{-3}$) are given in Table A3.5.

Table A3.5 Equivalent ionic conductance at 20˚C and equivalent weights for the various considered ions in deposition.

Element	Equivalent ionic conductance ($kS.cm^2.eq^{-1}$)	equivalent weight ($g.eq^{-1}$)
H	0.3151	1
Ca	0.0543	20
Mg	0.0486	12
K	0.0670	39
Na	0.0459	23
Al$^{1)}$	0.0600	9
NH_4-N	0.0670	14
NO_3-N	0.0636	14
SO_4-S	0.0712	16
Cl	0.0680	35.5
Alk	0.0394	1

$^{1)}$ Only used for soil solution

The EC values of each individual measurement were calculated using Eq. (A3.6) and using the values given in Table A3.5. Even though DOC is generally not measured, which unbalances the difference between cations and anions (see before), this does not have an important influence on the calculated conductivity. Activity coefficients were calculated as a function of the ionic strength (I), using the Davies equation (Stumm and Morgan, 1981). The percentage difference between calculated and measured conductivity was calculated as:

$$PD = 100 \cdot \frac{(EC_{calc} - EC_{meas})}{EC_{calc}} \qquad (A3.7)$$

According to WMO (1992), the discrepancy between measured and calculated conductivity should therefore be no more than 20% at a measured conductivity above 30 $\mu S.cm^{-1}$. Only at low ionic strength, the acceptable differences are higher, but this occurred not so often. A check on the difference between measured and calculated electric conductivity (EC) was only possible for 2844 measurements, since the calculation of EC requires the availability of all major cations and anions (only DOC is not necessary). Furthermore, the number of EC measurements was limited, because EC is an optional parameter for the soil solution.

Results for deposition and soil solution

Results of the calculated conductivity in comparison to measured values appeared to be slightly better than the difference between the sum of cations and anions. In many cases there were, however, large differences between the measured and calculated conductivity (Fig. A3.4).

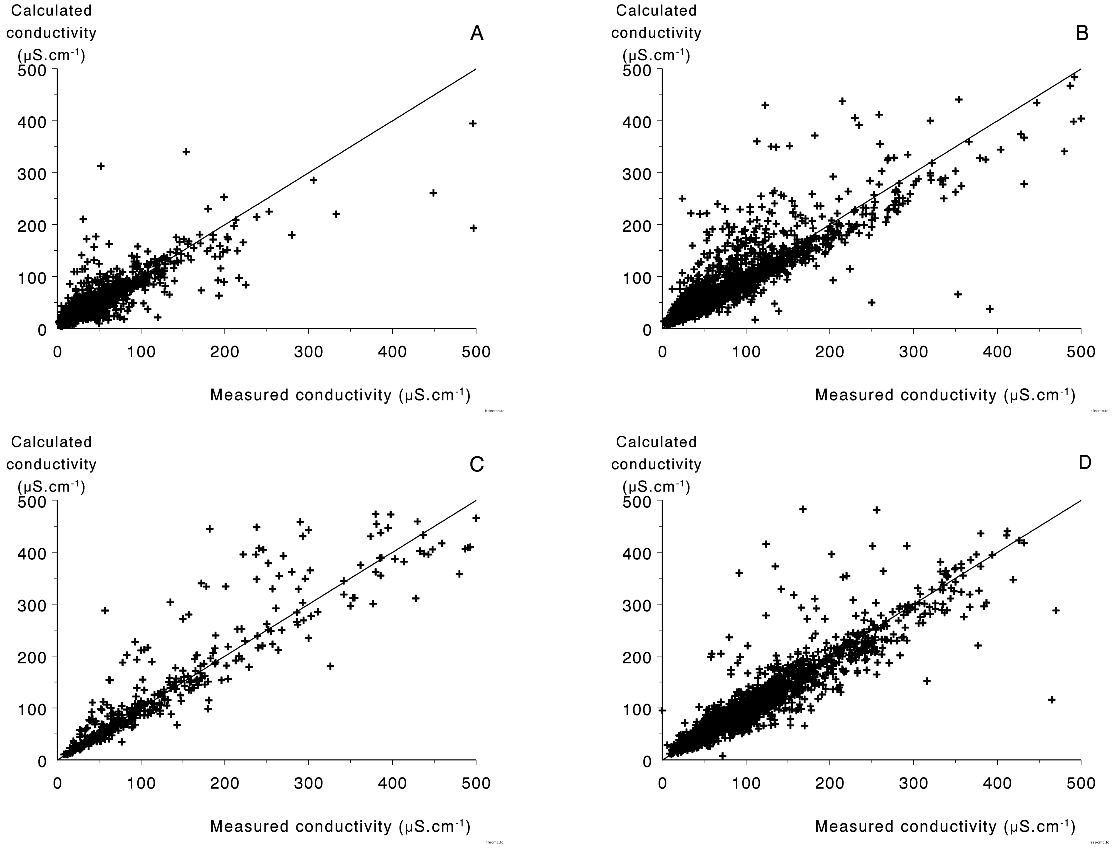


Figure A3.4 Relationship between the calculated and measured conductivity in bulk deposition (A), throughfall (B), stemflow (C) and total deposition (D) using all individual measurements at all Intensive Monitoring plots. The solid line represents the 1:1 line.

Results (Table A3.6) show that the percentage of measurements within a difference of ±20% increased from approximately 60% for bulk deposition to 70% for throughfall and stemflow (Table A3.6). Although better than the charge balance check, a large percentage of the measurements does not fulfil the requirements. A much stricter quality control on the measurements by the various laboratories (and NFC's) before submitting the data thus appears to be crucial.

Table A3.6 Percentage of measurements in different ranges for the difference between calculated and measured conductivity.

Difference (%)	Percentage of measurements			
	Bulk deposition	Throughfall	Stem flow	Soil solution
< -30	4.3	3.2	3.9	3.7
-30 - -20	5	8.3	8.6	4.8
-20 - -10	17.7	26.6	25.9	20.1
-10 – 0	20.4	25.7	23.3	28.9
0 – 10	14.6	10.8	15.6	20.0
10 – 20	8.9	6.3	5.1	10.1
20 – 30	6.8	3.7	4.3	4.7
> 30	22.3	15.4	13.2	7.6

As with the charge balance, the results of the conductivity checks for deposition varied per country as illustrated in Table A3.7. The results show that on average, the calculated conductivity equals the measured conductivity. In most cases, however, calculated conductivity is larger than the measured values.

Table A3.7 Ranges between which 90% of the differences between calculated and measured conductivity (%) varied in bulk deposition and throughfall as a function of country.

Country	Difference (%)					
	Bulk deposition			Throughfall		
	5%	50%	95%	5%	50%	95%
Finland	-12	-7	17	-24	-11	9
Sweden	-37	-13	3	-25	-15	1
Norway	-12	-5	16	-13	-6	1
Denmark	-	-	-	-33	-19	-15
U.K.	-11	10	65	-5	12	30
Ireland	-20	-13	-7	-26	-16	-4
Netherlands	1	9	10	-1	7	15
Belgium	-15	-4	14	-16	-4	9
Luxembourg	-37	-23	4	-23	-16	-1
Germany	-41	-3	106	-27	-6	67
France	-22	-12	-1	-23	-13	-4
Estonia	-16	11	73	-26	-6	24
Poland	-26	9	49			
Hungary	-9	55	161	-12	70	180
Austria	-26	42	251	-39	7	127
Switzerland	-10	2	55	-19	2	12
Slovak Republic	-31	0	422	-26	2	288
Portugal	-58	-26	78	-22	11	86
Italy	-19	1	44	-15	-3	14
Greece	-25	4	74	-22	-7	21
All	-28	1	122	-26	-6	96

3 Sodium to chloride ratios

Method

The correlation between ions in solution and the covariance between ion concentration ratios is a third possibility to check the quality of the data. An important check is the ratio between Na and Cl. Assuming that seasalt is a dominant source of both ions, the Na to Cl ratio should resemble the ion ratio in seawater being equal to 0.858 $eq.eq^{-1}$. Ivens (1990) found a Na to Cl ion ratio mostly varying between 0.7 and 1.0 in annual bulk deposition and throughfall fluxes with a median value resembling the ratio in seawater (0.84 in bulk deposition and 0.88 in throughfall). Draaijers (pers. comm.) stated that on an annual basis, the Na to Cl ratio should vary between 0.5 and 1.0.

Results for deposition and soil solution

At the Intensive Monitoring plots, the ratios in Na and Cl concentration showed a wider variation, specifically in the individual measurements (Fig. A3.5) but also on an annual basis.

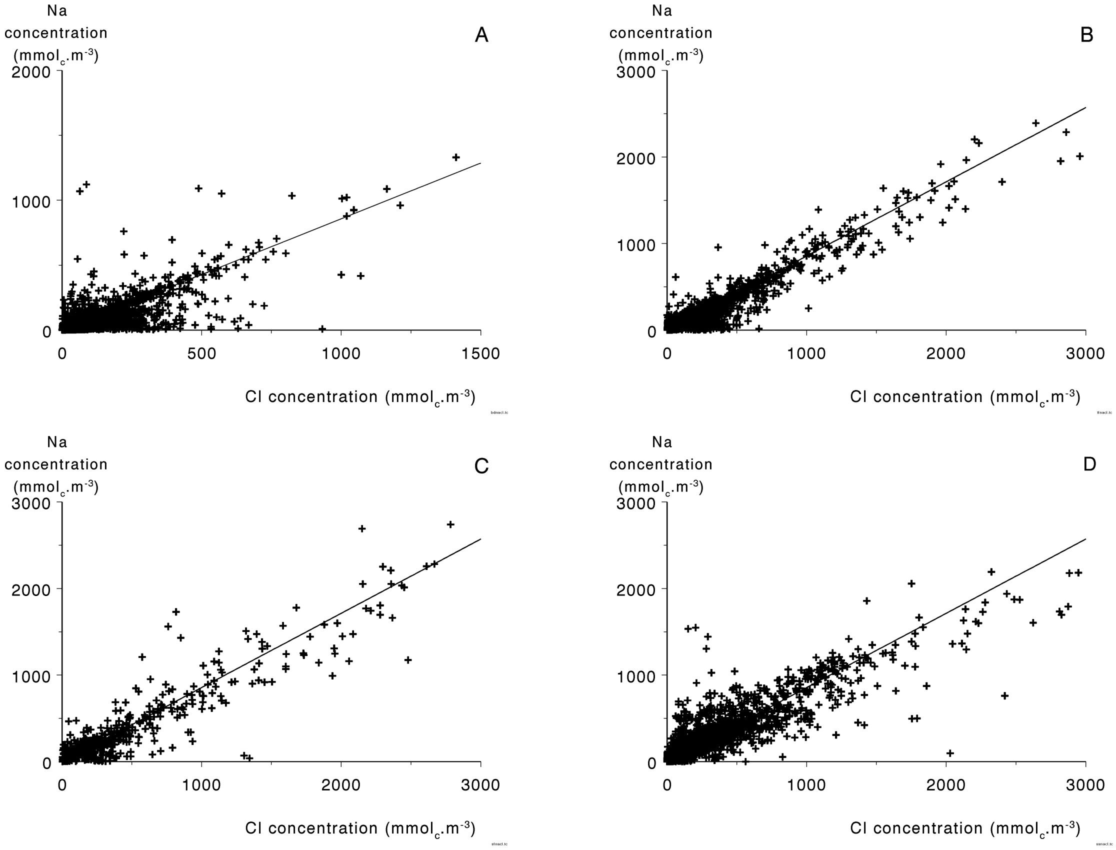


Figure A3.5 Relationships between the concentrations of Na and Cl in individual measurements of bulk deposition (A), throughfall (B), stemflow (C) and soil solution (D). The solid line represents the Na/Cl ratio in sea water (0.858 eq.eq^{-1}). Beware of the difference in axes between bulk deposition and throughfall.

As with atmospheric deposition, the Na/Cl ratios varied strongly. 90% of the values ranged between approximately 0.4 and 3.6. The high Na concentrations at relative low Cl concentrations (below 500 mmol$_c$.m^{-3}) specifically in bulk deposition (see Fig. A3.5A) may be due to Na release from ordinary glass (sodium borosilicate) bottles, that are often used to collect samples in the field situation (Derome and Lindroos, 1997). In general, ratios stronger resembled seawater at higher concentrations. Furthermore, results were better for throughfall than for bulk deposition. Especially at low Cl concentrations (and fluxes), there were quite a lot of measurements with high Na concentrations. In those situations, extremely high Na/Cl ratios were found, exceeding values of 10. Such ratios do indicate Na contamination. The earlier mentioned relationship between a consistent cation excess and extremely high Na/Cl ratios confirms this indication. Application of linear regression analyses without an intercept, while using the individual measurements, resulted in a slope (being the 'average' Na/Cl ratios) of 0.72 for bulk deposition (R^2_{adj} = 46%), of 0.74 for throughfall (R^2_{adj} = 91%), of 0.74 for stemflow (R^2_{adj} = 90%) and of 0.74 for soil solution (R^2_{adj} = 78%).

Again, results for Na/Cl ratios in deposition varied per country as illustrated in Table A3.8. Median values in bulk deposition and throughfall equalled 0.85 and 0.80, being very close to the ratio of approximately 0.86 in sea water. Wider ranges were specifically observed in Central Europe (specifically Hungary, Austria and the Slovak Republic), where the influence of seasalt on the Na and Cl deposition is likely to be less. In countries with a large influence of the sea, the Na to Cl ratio in all individual measurements generally varied between 0.5 and 1.5. The median values in those countries varied mostly between 0.8 and 1.0 eq.eq^{-1}, strongly resembling the ionic ratio in sea water (0.858 eq.eq^{-1}).

Table A3.8 Ranges between which 90% of the Na to Cl ratios (eq.eq^{-1}) varied in bulk deposition and throughfall as a function of country.

Country	Na/Cl ratio (eq.eq^{-1})					
	Bulk deposition			Throughfall		
	5%	50%	95%	5%	50%	95%
Finland	0.66	1.09	2.56	0.51	0.95	1.89
Sweden	0.51	0.89	1.54	0.46	0.81	1.25
Norway	0.62	0.92	1.54	0.59	0.88	1.37
Denmark	0.84	0.91	1.16	0.59	0.86	1.32
U.K.	0.72	0.88	1.16	0.66	0.83	1.19
Ireland	0.31	0.77	0.96	0.70	0.87	1.31
Netherlands	0.25	0.73	0.83	0.55	0.67	0.93
Belgium	0.62	0.87	1.36	0.39	0.84	1.16
Luxembourg	0.68	0.84	1.00	0.48	0.65	0.82
Germany	0.30	0.92	2.93	0.26	0.75	1.59
France	0.48	0.89	1.22	0.35	0.73	1.02
Estonia	0.44	0.89	1.53	0.54	0.86	1.30
Poland	0.10	0.41	1.19	-	-	-
Czech Republic	0.15	0.48	1.23	0.17	0.50	0.87
Hungary	0.03	1.76	7.72	0.03	1.54	9.43
Austria	0.23	1.09	5.91	0.20	0.79	5.27
Switzerland	0.61	1.19	2.77	0.34	0.93	2.09
Slovak Republic	0.18	1.07	8.14	0.12	0.77	4.63
Spain	0.39	0.96	4.63	0.44	0.88	2.93
Portugal	0.11	0.56	1.84	0.28	0.68	1.14
Italy	0.57	0.95	1.54	0.42	0.77	1.54
Greece	0.16	0.39	0.86	0.31	0.62	0.90
All	0.19	0.85	2.42	0.29	0.80	2.12

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