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Element fluxes through European forest ecosystems and their relationships with stand and site characteristics

W. de Vries [a,*], C. van der Salm [a], G.J. Reinds [a], J.W. Erisman [b]

[a] Alterra, Wageningen University and Research Centre, Droevendaalse steeg 3, P.O. Box 47, NL-6700 AA Wageningen, The Netherlands
[b] Energy Research Centre of the Netherlands (ECN), P.O. Box 1, NL-1755 ZG Petten, The Netherlands

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An assessment of element budgets, using available data on deposition, meteorology and soil solution chemistry at 121 Intensive Monitoring plots in Europe.

Abstract

This paper describes a European wide assessment of element budgets, using available data on deposition, meteorology and soil solution chemistry at 121 Intensive Monitoring plots. Input fluxes from the atmosphere were derived from fortnightly or monthly measurements of bulk deposition and throughfall, corrected for canopy uptake. Element outputs from the forest ecosystem were derived by multiplying fortnightly or monthly measurements of the soil solution composition at the bottom of the root zone with simulated unsaturated soil water fluxes. Despite the uncertainties in the calculated budgets, the results indicate that: (i) SO_4 is still the dominant source of actual soil acidification despite the generally lower input of S than N, due to the different behaviour of S (near tracer) and N (strong retention); (ii) base cation removal due to man-induced soil acidification is limited; and (iii) Al release is high in areas with high S inputs and low base status.

Keywords: Element budgets; Atmospheric deposition; Leaching; Nitrogen; Sulphur; Aluminium; Base cations

1. Introduction

A comparison of element inputs from the atmosphere and element outputs leaching from the bottom of the root zone give insight into the fate (accumulation or release) of sulphur (S), nitrogen (N), base cations (BC) and aluminium (Al) in the ecosystem. More specifically, budgets of SO_4, NO_3 and NH_4 give insight into: (i) the actual rate of acidification due to anthropogenic sources; and (ii) the potential rate of acidification by immobilisation of S and N (e.g. De Vries et al., 1995; Van Breemen et al., 1984). Results on the input and output of Al and BC give information about the mechanisms buffering the acid input (e.g. De Vries et al., 1995; Mulder and Stein, 1994; Wesselink, 1994). In general, the ratio of Al to BC release is a crucial aspect with respect to soil mediated effects of acid inputs (e.g. Cronan et al., 1989; Sverdrup and Warfvinge, 1993). These insights can therefore be used to derive critical deposition levels for forest soils (ecosystems). Comparison with available data on present loads leads to insight into the stress of air pollution on the chemical ecosystem condition (e.g. De Vries et al., 2000a). As such, it is of crucial importance to assess the present and future impacts of atmospheric deposition on the element cycle and nutrient availability.

Element budgets have already been carried out at Intensive Monitoring plots by several countries including Ireland (Boyle et al., 2000; Farrell et al., 2001), Germany (Block et al., 1999; Sprangenberg, 1997; Wetzel, 1998) and Slovakia (FIMCI, 2000). Furthermore, there are several literature compilations of element budgets, focusing on the behaviour of N (e.g. Dise et al., 1998a,b; Gundersen et al., 1998a,b; MacDonald

* Corresponding author. Tel.: +31 317 474353; fax: +31 317 419000.
E-mail address: wim.devries@wur.nl (W. de Vries).

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et al., 2002), base cations (Armbruster et al., 2002) and Al (Dise et al., 2001). A European wide assessment of element budgets, using all available data on deposition, meteorology and soil solution chemistry at Intensive Monitoring plots has, however, not yet been carried out.

This paper aims to fill this gap. It describes methods used to calculate output and retention or release of major elements (SO_4, N, BC and Al) and gives results on the range and geographic variation of all these fluxes. In Van der Salm et al. (2007) the methods used to calculate water fluxes and the results obtained are described, whereas in Bleeker et al. (submitted for publication) more information is given on total atmospheric deposition, based on measurements of both throughfall and bulk deposition. Furthermore, relationships between leaching or retention/release of elements and readily available environmental variables, such as stand and site characteristics, soil and foliar chemistry, precipitation and bulk deposition, are presented. Relationships can be used for upscaling the results to the European scale.

2. Methods

2.1. Locations

Element budgets were calculated for sites where precipitation and throughfall fluxes and element concentrations in soil solution have been measured up to 1998 for a period of more than 300 days. The criterion of 300 days was included because yearly average fluxes may differ substantially from those observed during a short measurement period. Furthermore, sites were selected where (see Van der Salm et al., 2007):

- soil solution is sampled with tension lysimeters;
- reliable throughfall fluxes could be calculated, based on measured rainfall and calculated potential evapotranspiration, using the Gash model;
- the soil type does not indicate the presence of ground water in the soil profile, since the hydrological simulations were made assuming free drainage.

All these criteria were matched at 121 of the 228 sites with soil solution data (Table 1), located in Belgium, France, Denmark, Germany, Great Britain, Ireland, Norway, Sweden, Finland and Austria (Fig. 1). The number of selected sites for which budgets could be calculated based on annual input and output fluxes increased from 16 plots in 1995 to 85 plots in 1996, 113 in 1997 and 121 in 1998 over the period where the network gradually expanded.

Table 1
Number of monitoring sites for which sufficiently long records of precipitation, throughfall and soil solution concentration measurements were available to calculate annual element budgets up to 1998

Quality aspects	Number of sites	
	Bulk deposition[a] and throughfall	Soil solution chemistry
Total number	309	228
Input available	309	204
Calibrated Gash parameters	245	138
Period of at least 300 days	–	164
Acceptable techniques	–	128
Well drained soils	–	121
Available for budgets	121	121

[a] Equal to precipitation.

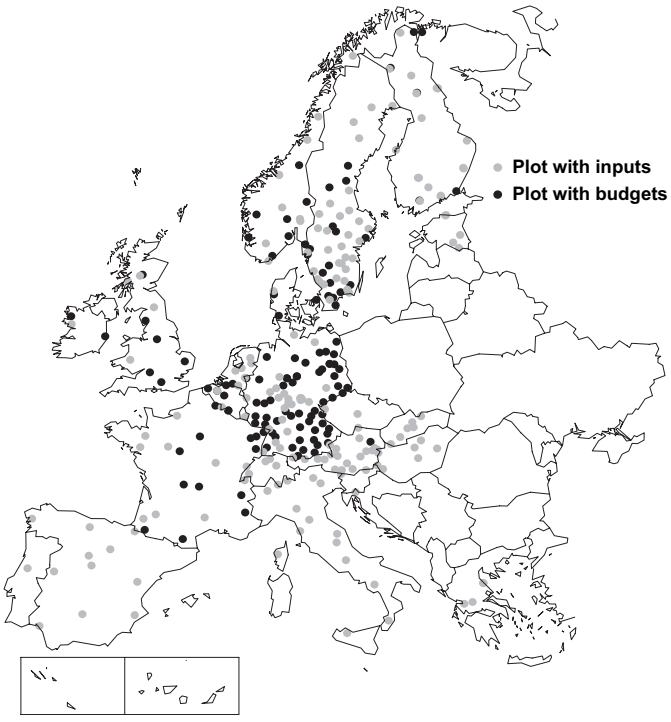

Fig. 1. Geographical distribution of Intensive Monitoring plots for which element inputs (309 plots) and element budgets (121 plots) have been calculated.

The element inputs were not only assessed at the 121 plots for which budgets could be calculated but also at all 309 plots with bulk and throughfall data (see Bleeker et al., submitted for publication). Fig. 1 shows the geographic variation of: (i) the 121 plots for which budgets could be calculated; and (ii) the remaining 188 plots (309–121; see Table 1) with data on bulk deposition and throughfall where no budgets could be calculated.

2.2. Data assessment and data quality assurance

2.2.1. Data assessment and data comparability

The countries involved in the program all used the relevant EC Regulations and manual of ICP Forests providing standard methods for the sampling and analysis of bulk precipitation, throughfall, stemflow and soil solution. Nevertheless, sometimes countries use their own specific sampling equipment, sampling strategy, sample handling and analytical procedures. Results from ring tests for the chemical analyses of atmospheric deposition (bulk precipitation and throughfall), however, generally indicated no large comparability problems for the concentrations of major ions (Lövblad, 1994) and the same is true for soil solution.

Through Data Accompanying Report Questionnaires the participating countries submitted information on the applied methods for most of the plots. Comparable methods were used at most of the plots. For monitoring of throughfall data, use was mostly made of funnels. The number of funnels usually ranged between 10 and 15 (61%) but more than 15 funnels were used at 32% of the plots. Results of a joint field campaign in the Dutch Speulder forest showed that the spatial variability is such that 15–25 funnels are needed to estimate the deposition at a required accuracy of 90% (Bleeker et al., submitted for publication). For monitoring of the soil solution, use was made of suction cups (sometimes combined with zero tension lysimetry) at the majority of the plots. The number of samplers ranged from 1 to 5 in the organic layer, 1–23 in the mineral topsoil and 1–12 in the mineral subsoil. The majority of used lysimeters are made of materials that are considered appropriate, such that the sample solution is not influenced by the sampler itself (De Vries et al., 2000b).