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A decennial control of N-cycle in the Belgian Ardenne forest ecosystems

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Abstract

As a rule, N-supply of mature Ardenne forest ecosystems is satisfactory. Mineralization rates of soil organic matter are generally high and nitrogen is not a frequent nor an important growth limiting factor. Light N-deficiency is likely to depend on unsatisfactory root absorbing power in very acid soils with dysmoder humus. For other major elements, especially for Mg, Ca and P, near optimal nutrition is rarely observed.

During the late sixties, fertilizer experiments have shown that nutrition equilibrium of stands growing on acid soils, poor in exchangeable Mg, is very sensitive to artificial NH_4-addition. Mg-deficiency symptoms have been induced. The present continuing atmospheric NH_4 input is believed to produce similar but lasting nutritional stress which might be accentuated by additional acidity generated during nitrification of excess NH_4. Evolving Mg deficiency leads to trees' death and developing forest decline is likely to enhance N-output under NO_3-form.

Awaiting adequate air purification, fertilizing should restore nutrition equilibrium in order to save damaged stands, to slow down soil acidification and to incorporate excess atmospheric N-input into improved biomass production.

Introduction

The Ardenne area is situated in southern Belgium at elevations ranging from 300 to 700 m above sea level. The climate is of subatlantic to medio-european feature without summer drought (Galoux, 1967). Western winds are dominant. Slow atmospheric fluxes transport aggressive pollutants which cause necrotic spots on exposed needles (Weissen and van Praag, 1984) (Figs. 1 and 2; conv. no. 86/B/I/1 CEC, DG VI-UCL, rapports nos. 3 and 5).

Acid brown soils with moder humus have developed in quaternary solifuxion deposits made of loamy material of local origin mixed with stony residues of the underlying poor and acid Cambrian and Devonian bedrock (sandstone, shale . . .). Podzolic soils are scarce and acid pseudogleys develop on flat plateau areas.

Forest land covers some 400,000 ha. Beech and oak stands represent about 50% of the forested area. Since the end of the 19th century coniferous forest has been planted on degraded coppice or heath land. Norway spruce is the most common species. Scots pine is becoming less common while larch and Douglas fir are extending in area.

Broadleaf forest soils might be richer than soils under coniferous stands but we need more information about the subject. Soils are frequently very poor in exchangeable P, Ca and Mg (Table 1).

Beside available water (Weissen and André, 1970), the most meaningful site factor is organic matter cycling. Forest litter decomposing rate (L/L + 0, %) is correlated with productivity (r = .95***) of natural beech stands (Delecour and Weissen, 1981). Moreover, the stock of or-

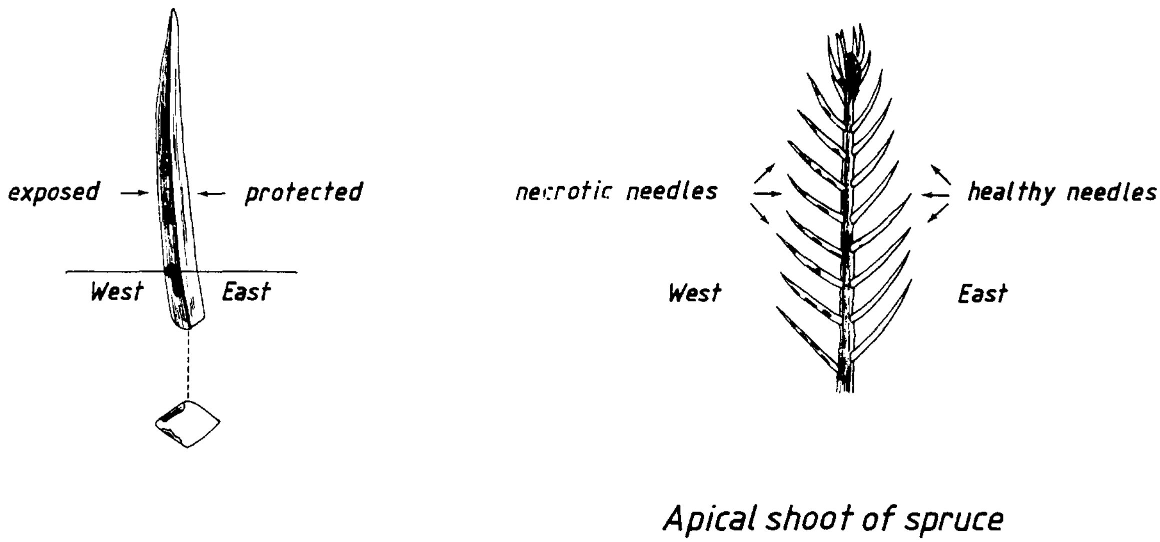

Fig. 1. Necrotic spots on exposed spruce needles.

ganic matter (*e.g.* total C or N) of the soil down to 50 cm depth is negatively correlated with site quality.

As a rule, there is only little or no lack of available nitrogen in mature stands. In field experiments net N-mineralization was estimated at about 50 kg ha^{-1} $year^{-1}$ in the sole dysmoder 0-horizons under spruce, where 80% of rootlets are present, and about 100 kg mineral-N ha^{-1} $year^{-1}$ in soils under beech down to 15 cm, containing some 70% of active rootlets (Van Praag *et al.*, 1974; Van Praag and Weissen, 1984). A general outline of N-nutrition of the Ardenne forest ecosystem is given by Van Praag and Weissen (1976) and special attention is drawn to absorbing power of rootlets (Van Praag and Weissen, 1973).

As a concluding remark it can be stated that N-mineralization rate is high (1–4%) and is not considered to be a frequent and important growth limiting factor. Nitrification rate and N-absorbing power are site dependent. They are best in sites with acid mull humus, moderate or rather low in sites with dysmoder humus.

Ardenne forest ecosystem and artificial N-input

Fertilizer N-input

During the late sixties N-fertilization seemed likely to become a widespread technique because of most encouraging results coming from Sweden. Trials with urea-N (100-300 kg N ha^{-1})

Table 1. Frequency distribution (%) of fertility classes for major elements in brown acid soils under spruce based on soil and foliar threshold values

Elements	Very deficient				Deficient		Sufficient			
	Soil		Foliage		Soil foliage		Soil		Foliage	
	a)	b)	a)	b)	b)	b)	a)	b)	a)	b)
P	<4	49	<.10	30	49	70	>9	2	>.15	0
K	<3	4	<.35	7	94	93	>8	2	>.70	0
Mg	<2	76	<.06	89	20	11	>4	4	>.10	0
Ca	<5	55	<.20	51	45	49	>30	0	>.50	0

a) Threshold values: soil, exch. elements, mg/100 g d.m. (see Table 2) – foliage, total elements % d.m.
b) Observed frequency, %.

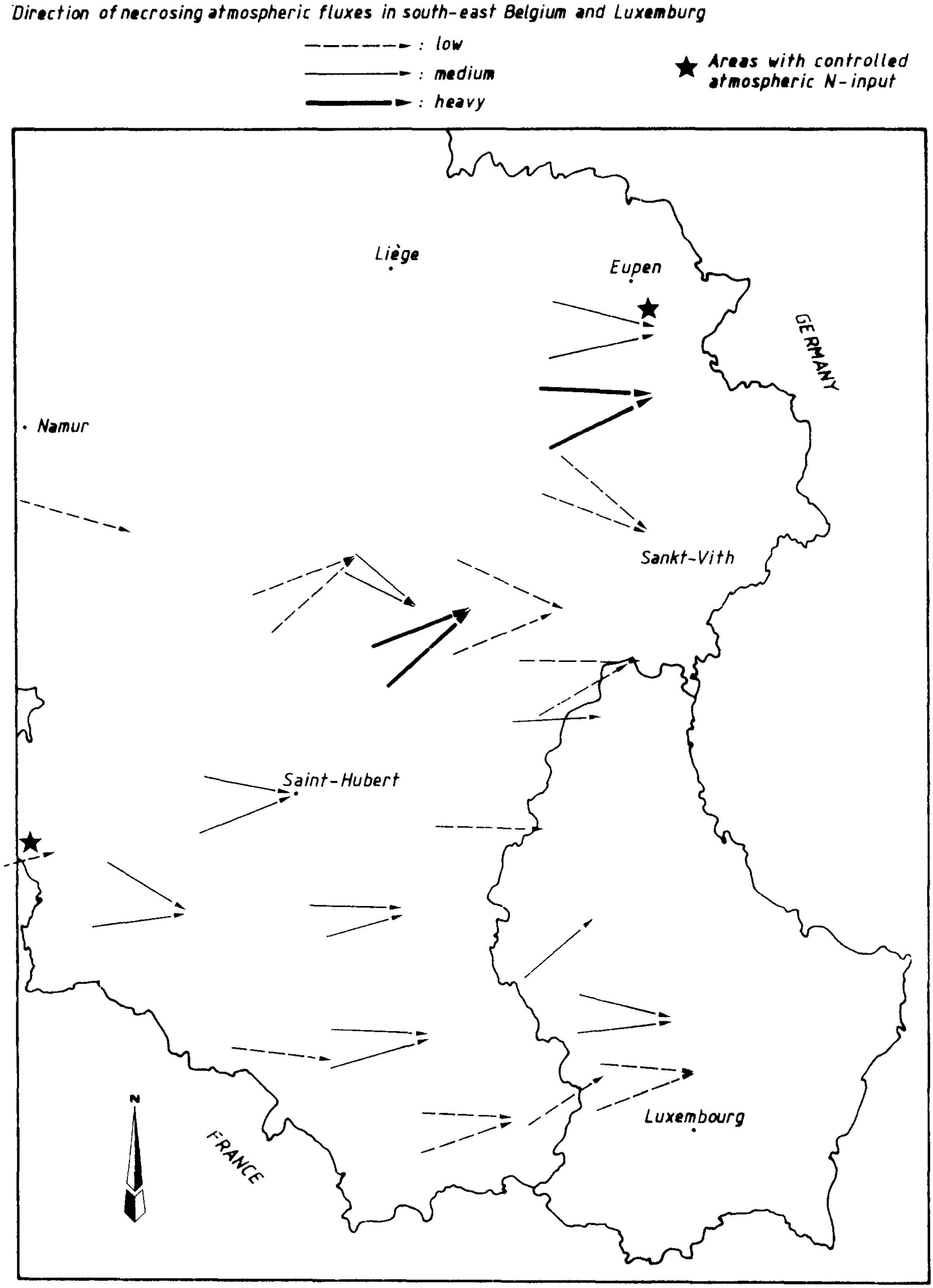

Fig. 2. Necrosing fluxes in south-east Belgium and Luxemburg.

were laid out to identify possible risks due to unsatisfactory soil conditions.

Results were rarely positive and were generally absent or negative (Delince and André, 1978). The latter results were most pronounced when yellowing of the needles followed urea application. Magnesium deficiency was a constant explanation for observed symptoms in stands on acid brown soils low in exchangeable Mg (NH_4Cl 1%). (Weissen *et al.*, 1988) (Table 2).

On sandy podzols, urea fertilization induced K-deficiency. Stands on richer and chemically more equilibrated soils did not show any yellowing of needles after N-fertilization. The experimental conclusion was that the nutrition equilibrium of stands growing on acid soils poor in exchangeable Mg, K (or Ca) is very sensitive and that even moderate NH_4 nitrogen input may rapidly disturb this equilibrium or generate stress situations. Similar conclusions are drawn by Nys (personal comm.) investigating N-fertilizer trials in the French Ardennes.

Atmospheric N-input

Since 1983, yellowing of spruce needles and beech leaves has developed strongly, especially in the south-west Ardennes along the French border in sites formerly known for being Mg-deficient. It has also appeared in other areas where the symptom has not been observed until now (Table 3).

It has been suggested that the development of yellow foliage could be a consequence of the increase in N inputs from the atmosphere (Weissen *et al.*, 1988). This extra N-input probably explains high N-levels in needles of spruce growing on soils with dysmoder humus. Where moderate N-levels of 1.2–1.3% were expected some 20 years ago, levels of 1.5–1.7% are measured today. Sometimes needles are very long but turn yellow on becoming older than one or two years. This is related to N/Mg-ratio increasing beyond 30–40.

Around 1975, abnormal NO_3-contents were measured in dysmoder litter layers where it is traditionally believed that nitrification does not take place. This NO_3-N was thought to be of atmospheric origin. The measured total N-input was about 20 kg ha^{-1} $year^{-1}$, half of it being NH_4-N. More recent measurements made in the French Ardennes by Nys (1987), less than 2 km away, show that total N-input was some 40% higher (28 kg ha^{-1} $year^{-1}$) during the period

Table 2. Exchangeable elements in acid brown soil (0–20 cm depth) and yellowing of spruce needles after urea-fertilization (1970–1971)

Sites	Exchangeable elements(*) mg/100 g dry m				Yellowing of needle
	P	K	Ca	Mg	
Bruly	2.7	4.3	26.5	2.5	+
Freux	6.1	4.1	12.9	3.0	–
Langlire	6.5	8.3	4.3	0.6	+ +
Samrée	–	4.1	4.3	0.6	+ + +
Stoumont	4.4	10.0	7.1	1.2	+
Very poor <. . .	4	3	5	2	

* 1% citric acid for P, 1% NH_4Cl for K, Ca, Mg.

Table 3. Evolution of health status of spruce in the Ardenne area (Vielsalm; 320 trees observed; interpretation of colour IR pictures; scale 1:5000) (P. Maréchal, Unité EFOR, Louvain-la-Neuve)

Crown characteristics	Trees exhibiting symptoms in each year (%)			
	1983	1985	1986	1987
Healthy	52	37	25	22
Yellowing	22	41	57	65
Needle loss (*)	26	22	18	13

(*) Lophodermium attack in 1982–1983.

going from 1977–1983. NH_4-N reaches 20 kg ha^{-1} $year^{-1}$, which is 71% of the total and 100% greater than our previous measurements. Very recent estimates of Nys go up to 50 kg N ha^{-1} $year^{-1}$ (Nys, pers. comm.) and an NH_4-N-input of more than 30 kg ha^{-1} $year^{-1}$ is likely to occur.

In the North-east Ardennes, along the German border, N-input is also high with a tendency for NH_4-N to increase the NO_3-N to decrease.

Comparison of the mean N-concentrations computed for two sampling periods in a watershed area covered with spruce are given in Table 4.

During the last observation period the mean total N-input is about 28 kg ha^{-1} $year^{-1}$, 75% of it being as NH_4-N (21 kg). During the previous period NH_4-N was only 61% of the total N-input, somewhat lower than the 71% calculated for south-west Ardennes at more or less the same time.

The NH_4-N input difference between the two periods is not significant. Fluctuations of individual values are reproduced in Figure 3. NO_3-N fluctuations are also high (Fig. 4).

For throughfall, both N-forms showed a similar decline in concentration (Table 4) with time (some 30–35%). This could be explained partially by a developing forest decline and associated rather large needle loss. In throughfall the relative proportion of NH_4-N doesn't change between the two sample periods. As NH_4-N input by open rain is higher during the second period this could mean that some modification of transfer from needle surface to inner leaf tissues has occurred.

Comparisons of the concentrations of nitrogen in the stream output water is difficult to interpret because of the time and flow dependence. Therefore, Lettenmaiers (1976) adaptation of Man-Whitney test for dependent observations has had to be used to compare the weekly concentrations recorded at the lowest flow. This test could not detect any difference between the two sampling periods. However, it appears clear that N-output is mostly as NO_3-N (some 93%). To obtain a rough preliminary estimate it can be assumed that NH_4-N input could generate 1.5 to 3 kg H^+ ha^{-1} $year^{-1}$ in the soil, depending on the proportion taken up by the biomass and on the proportion that is nitrified and so associated with partial or total loss. This extra quantity of protons is equal to or even twice the direct proton-input by rain for the observed situation. Hence it could favour Al liberation with supposed detrimental effect on root growth (Ulrich, 1987).

Our figures for NH_4-N input are somewhat higher than those given by Asman and Drukker (1988) and by Buijsman and Erisman (1988) for the early eighties. The N-deposition distribution maps presented by the authors show that the risks of nitrogen imbalance could be similar for forests situated in the Ardenne and Eifel region, and perhaps also for the Vosges and the Black Forest area, where nitrate deposition and soil conditions are supposed to be equivalent.

General conclusions

All these observations enable us to conclude that N-nutrition of the Ardenne forest ecosystem is rather satisfactory but that the general nutrition equilibrium of acid soils poor in Mg, K or Ca is

Table 4. Mean N concentrations (mg/L) observed during two sampling periods (1979–1984 and 1986–1988): significant differences at level .001 (**)

	N-form	Observation periods		Significant level
		1979–1984	1986–1988	
Open rain	NH_4-N	1.49 (61%)	1.67 (75%)	
	NO_3-N	0.94	0.56	**
Throughfall	NH_4-N	3.22	2.05	**
	NO_3-N	2.33	1.42	**
Stream output	NH_4-N	0.06 (3%)	0.17 (7%)	
	NO_3-N	2.17	2.15	

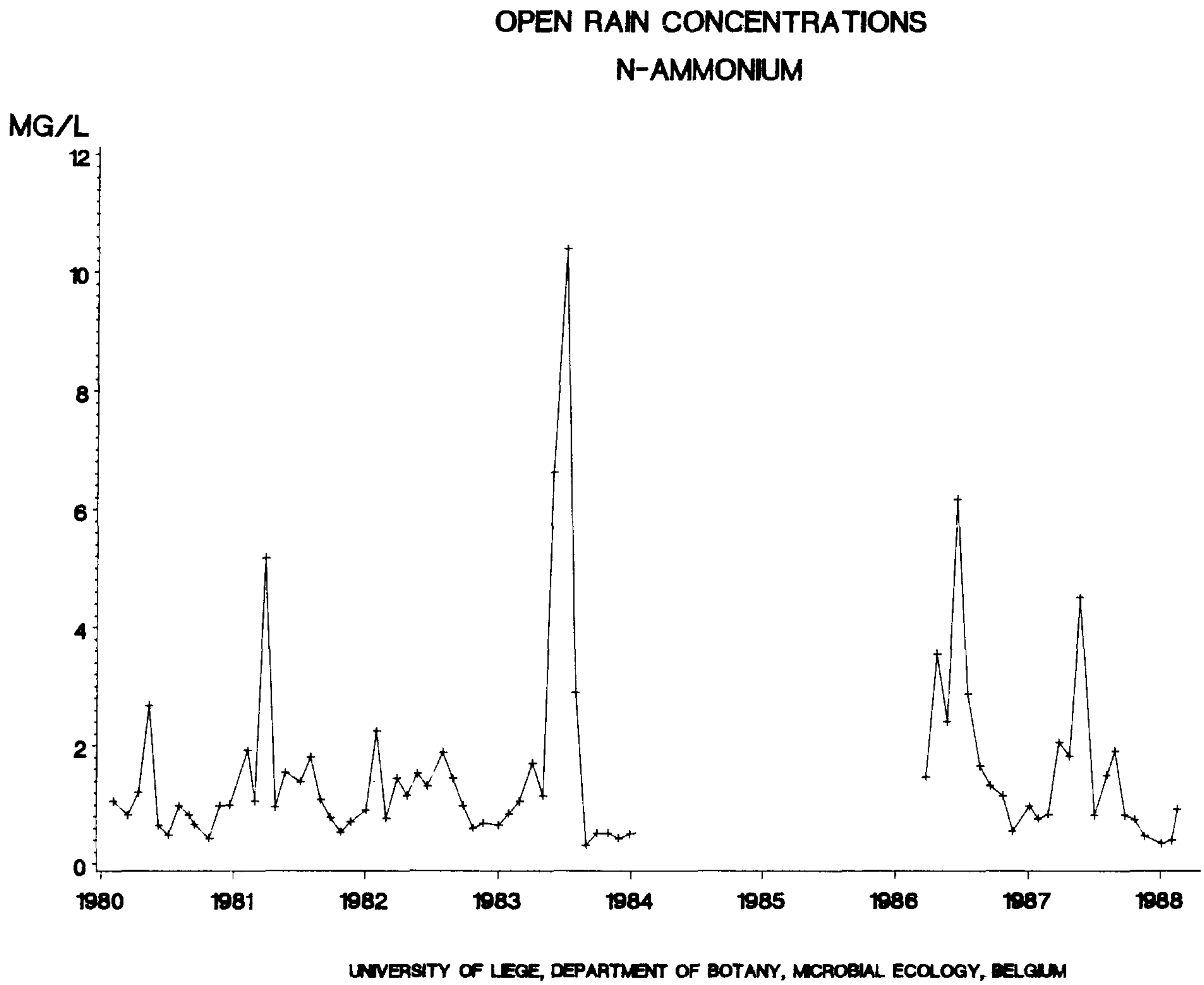

Fig. 3. Concentration of ammonium nitrogen in open rainwater measured in the Ardennes.

very sensitive to stress situations, *e.g.* increasing NH_4-input. Moreover, extra N-input by pollutants is not likely to be fully integrated into tree biomass especially when tree nutrition becomes unbalanced. Net N-immobilization in acid brown soils seems to be negligible, so, excess N-input must be lost both by leaching, *e.g.* after nitrification, and partially by denitrification as has been shown in lysimeter experiments under forest canopy (Van Praag and Weissen, 1984). Nitrate output is likely to grow with continuing high atmospheric N-input and forthcoming forest decline. This is also supported by Ulrich (1988) for forested areas in Germany.

Due to extra H^+ production during nitrification of imported atmospheric NH_4, Al-toxicity risks may be enhanced in mineral soil horizons and additional stress in already decaying forest ecosystems will eventually be induced (Ulrich, 1987).

It is suggested that fertilizing should restore adequate nutrition for trees and slow down soil acidification. As a consequence excess nitrogen input will be incorporated into improved general biomass production (Sougnez and Weissen, 1977) and the declining forests will be saved. Liming can decrease mineralization rate, favour denitrification, and enhance root activity (Weissen and Jacqmain, 1978) which reduces the risk of higher nitrate export by percolating water. However, liming and fertilizing should be done cautiously in order to avoid undesired down-

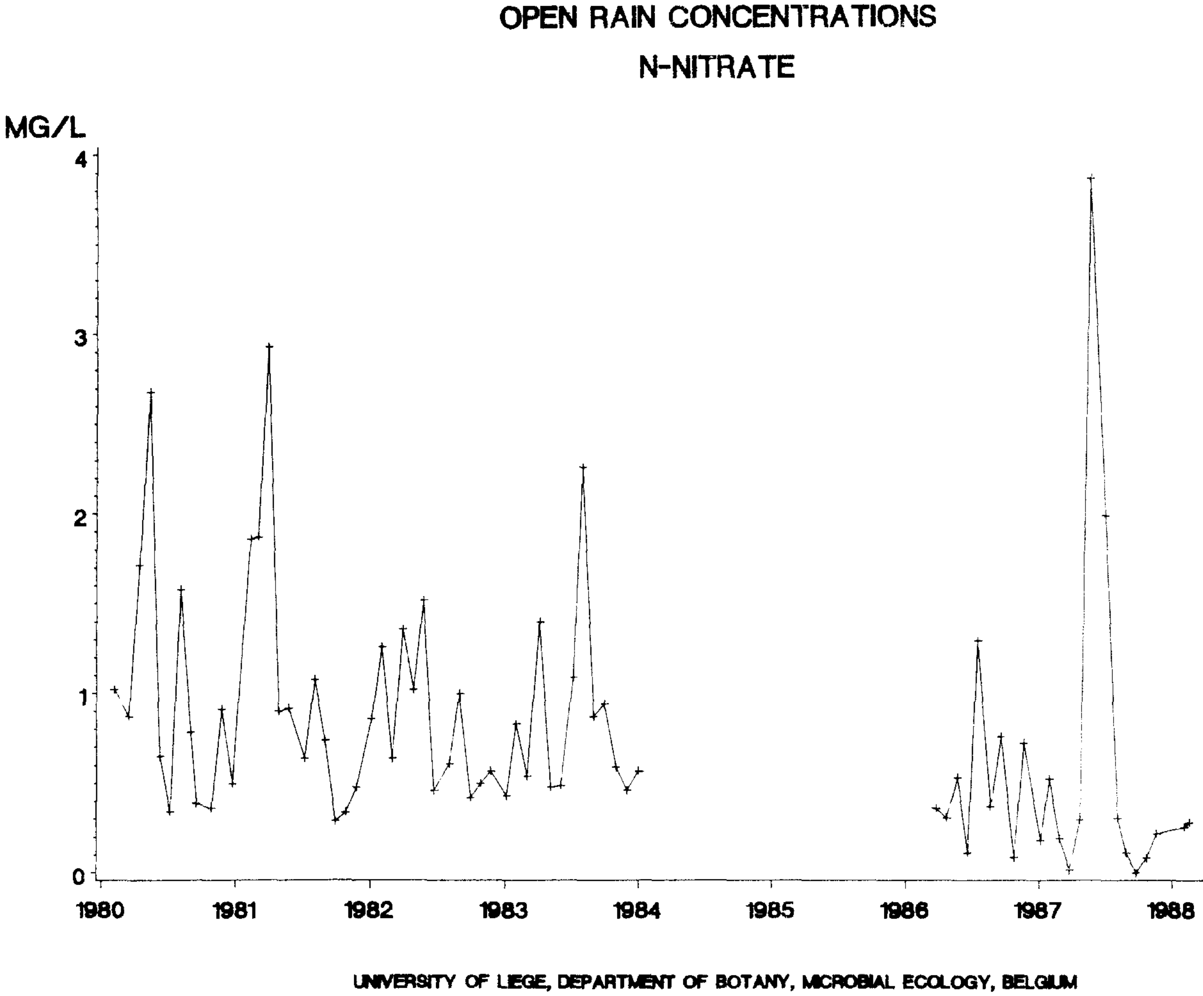

Fig. 4. Concentration of nitrate nitrogen in open rainwater measured in the Ardennes.

stream eutrophication (Buldgen, 1984). Nevertheless, we think that liming and/or fertilizing with Ca/Mg compounds is a pressing need when stands on acid brown soil low in Mg are declining because of excess N and H^+ input. Over and above this, air purification is the primary requirement if repeated fertilizer applications are to be avoided. Emissions of nitrogen, especially ammonia and acid compounds, seem to be most harmful for forest ecosystems growing on Ardenne soils.

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