NUTRITIONAL STATUS OF DECLINING SPRUCE (Picea abies (L.) Karst.): EFFECT OF SOIL ORGANIC MATTER TURNOVER RATE

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Abstract. Foliar analysis was undertaken in two plots of *Picea abies* (L.) Karst., located in a watershed of Haute Ardenne, Belgium, in order to estimate the decline of the trees. Apart from a general Mg deficiency, the concentrations of the needles were in the same range as those determined in other European stands. Comparisons between healthy and declining trees within each plot revealed a general pattern of decline similar to that observed elsewhere in Western Europe. This was shown as lower Ca, Mg, Zn concentrations and water content and higher N and P concentrations of the needles collected from declining trees. It is concluded that this decline could be due to N over fertilization by the atmospheric deposition. The difference of decline between the two plots was attributed to the turnover rate of the soil organic layer which was less intensive in the most damaged plot.

1. Introduction

Nutrient fluxes have been studied since 1980 in a Norway spruce *Picea abies* (L.) Karst. watershed located in the Haute Ardenne region, Belgium (Buldgen *et al.*, 1984). As the forest growth induces an impoverishment of the soil nutrient pool, this approach can be used to determined how natural ageing of the forest effects nutrient cycling. However, spruce decline was first reported in the Haute Ardenne region in 1982 (Weissen *et al.*, 1983) and infra-red aerial pictures of the watershed showed a significant increase of trees with symptoms of decline between 1983 and 1984 (Farcy, C. and Maréchal, P., personal communication). On the one hand, the forest decline could be associated with nutrient cycling changes in forested watersheds (Hauhs and Wright, 1986). On the other hand, the alteration of forest vitality could be related to soil perturbations inducing changes in the nutritional status of the trees (Ulrich *et al.*, 1980; Andersson, 1986; Matzner *et al.*, 1986; Kandler *et al.*, 1987; Oren *et al.*, 1988a, b; Hauhs and Ulrich, 1989; Schulze, 1989).

In this work, the nutritional status of the trees was examined in relation to their vitality and the properties of the surrounding soil in order to investigate the occurrence of decline in the watershed. The observations were conducted on two plots stocked by spruce of two age classes (55 yr-old and 95 yr-old).

2. Material and Methods

The plots were located in the watershed 'La Robinette', as previously described (Buldgen *et al.*, 1984). The first plot (plot A) comprises 7.5 ha and is stocked with 55 yr-old-trees (483 trees ha^{-1}) while the other one (plot B) is 12 ha and is stocked with 95 yr-old trees (288 trees ha^{-1}).

The ground vegetation was very poor in plot A, while plot B has a 50% cover. It was chiefly composed of *Molinia caerulea* (L.) Moench, *Polytrichum commune* (L.), *Vaccinium myrtillus* (L.), *Deschampsia flexuosa* (L.) Trin. and *Pteridium aquilinum* (L.) Khun.

The trees showing symptoms of decline, needle yellowing and loss, were spread throughout the plots. However, the symptoms were less distinct in plot B where trees with abundant yellow needles were sometimes well needled, while the needles of trees with higher needle loss were often green. Needles were collected in December 1987 from 8 trees in each plot. As the branches were cut by hand, it was difficult to increase the number of sampled trees because climbing was particularly dangerous. However, it seems that it would be enough for the assessment of the nutrient status since Bonneau (1988) recommends 10 trees per plot. Four trees showing no decline symptoms and 4 damaged trees were sampled in plot A while 3 trees showing no decline symptoms and 5 damaged trees were samples in plot B. The current needles and needles of the three preceding growing periods were randomly taken, when present, from one branch of the 5th, 10th and 15th verticils. Needles older than 4 yr were very rare. The needles were ashed in a mixture of HNO_3, $HClO_4$ and HF (4/1/0.5, V/V/V) in teflon vessels according to Van Loon (1985). The solutions were taken to dryness, and the ash dissolved in 6N HCl. Ca, Mg, K, Fe, Zn, Na and Al were determined by flame spectrometry; Pb and Cd by graphite furnace spectrometry and total S by nephelometry. Total N and P were assessed colorimetrically after Kjeldhal digestion following Schneider (1976) and APHA (1980). Ammonium concentrations were estimated only on the needles collected from the branches of the 10th verticil in a 0.5 M KCl extract by the micro-diffusion method of Bremner (1965). The chlorophylls contents were determined according to Bruinsma (1963).

The nutrient status of the soil was studied by determining the exchangeable cations. The decomposition of the humus layers was compared on the ground of the thickness and the CEC. The nutrient supply to the soil pool by the humus layers was estimated by analyzing the leachates under these layers. The soil sampling scheme was conducted following the judgement sampling method outlined by Petersen and Calvin (1965); it means that the soil was randomly sampled from both sites but in similar areas which were free of ground vegetation. For the analysis, ten soil samples of 400 cm^2 were taken from the organic layer (Ol+Of+Oh) and from the two 10 cm thick deeper layers. Each sample was homogenized before a subsample was taken for analysis. Exchangeable cations were determined in soil extract obtained after shaking 10 g of dry soil in 100 mL 1 M NaCl for 15 hr; exchangeable acidity was determined as the pH of this solution. Cation exchange capacity was assessed following Aubert (1978). Ten g of humus layers were leached with 500 mL 1 N $CaCl_2$ buffered with 0.11 M triethanolamine-HNO_3 (pH 7) overnight. The excess of $CaCl_2$ was washed with distilled water and the Ca was extracted by shaking the soil in 100 mL 1 M NaCl for 15 hr. Leachates under the humus layers were collected monthly from 16 root-free lysimeters of 283.5 cm^2 (Buldgen *et al.*, 1983) located in both plots. Cations and other nutrient concentrations, organic C in the leachates and in soil extracts were determined as described elsewhere (Buldgen *et al.*, 1983).

Comparisons of mean were performed following the Wilcoxon range test as described in SAS (1985). Variance analysis was computed by the GLM procedure (SAS, 1985) which handles unbalanced data sets. Significance was assumed when the probability to observe a larger score of $|Z|$ or $|F|$ under the null hypothesis (absence of difference) was smaller than the usual levels (0.10, 0.05, 0.01). The data were pooled on the basis of tree age and/or health status to compute the means and determine the sign of the differences.

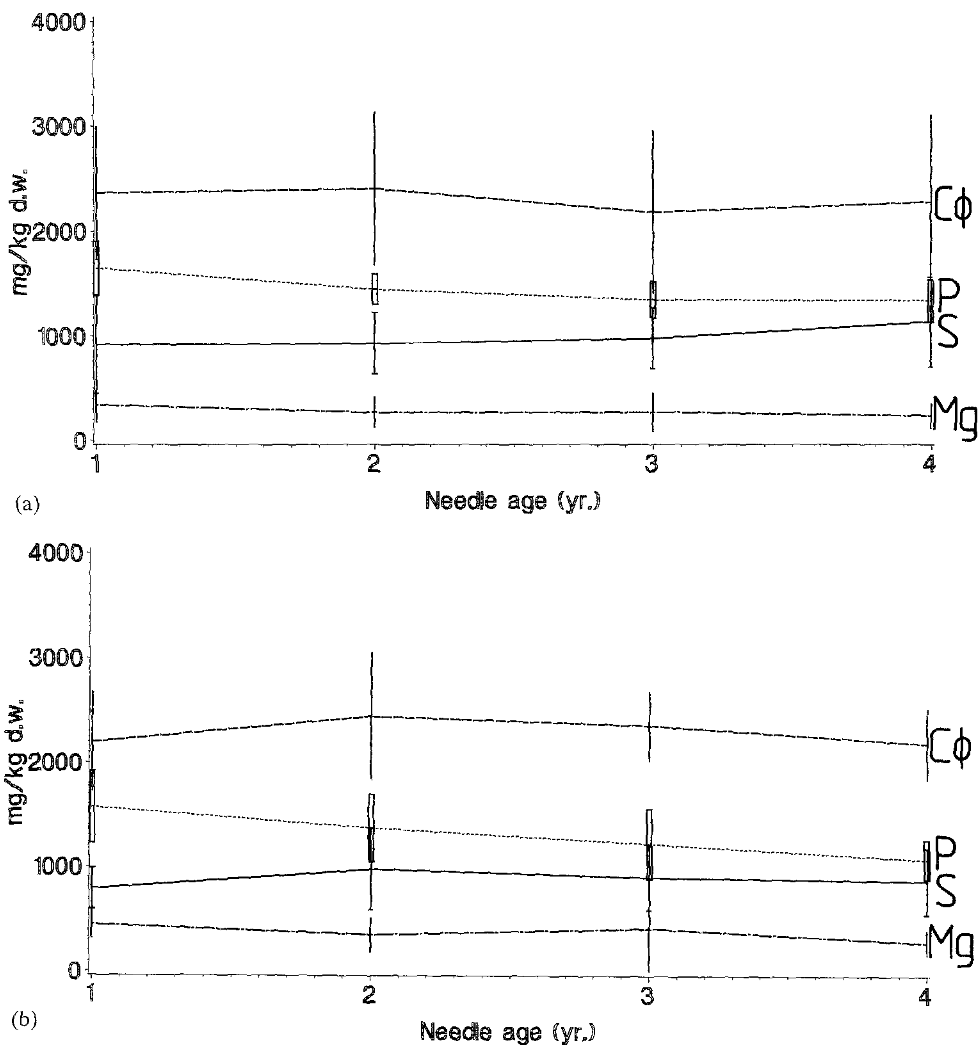
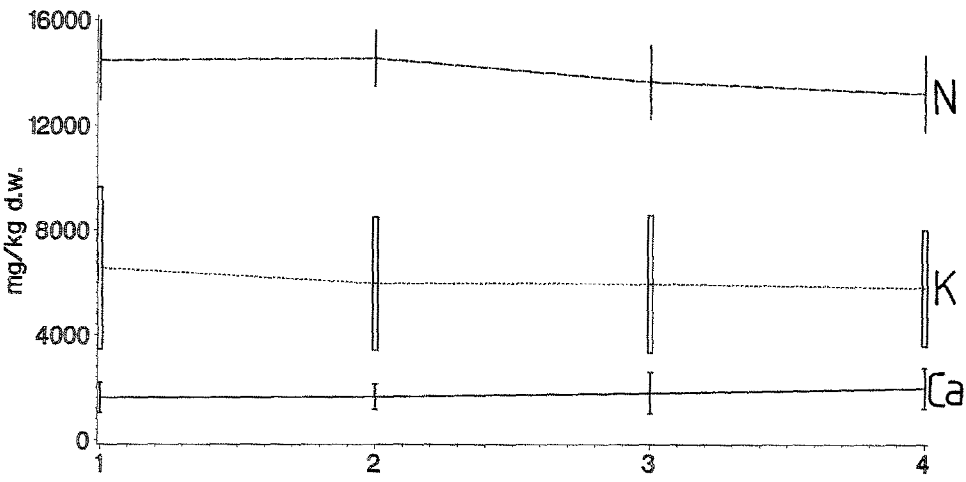


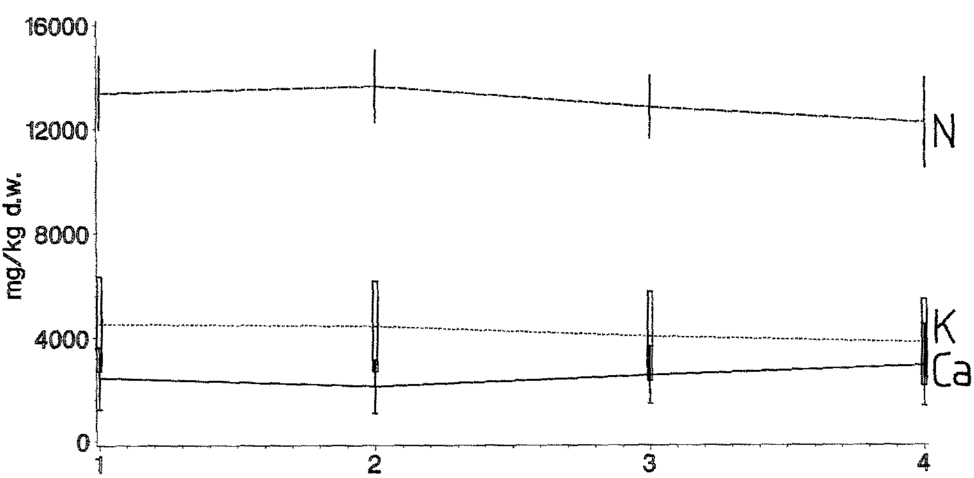
Fig. 1. Means and standard deviations of the concentrations of chlorophylls (cΦ), total P, S and Mg determined in the needles collected from the trees of the plot A (Figure 1a) and the plot B (Figure 1B) *vs* the needle age.

3. Results

The needle content of chlorophylls and major nutrients is shown in the Figures 1 and 2. It cannot be concluded that significant trends occur for most of the nutrient and chlorophyll concentrations since the standard deviations were large and the composition of the 1 to 4 yr-old needles was only assessed. Therefore, comparisons of mean of the nutrient and chlorophyll concentrations and the water contents of the needles were performed by variance analysis. The effects of age class (55



(a)



(b)

Fig. 2. Means and standard deviations of the concentrations of total N, Ca and K determined in the needles collected from the trees of the plot A (Figure 2a) and the plot B (figure 2b) *vs* the needle age.

yr-old and 95 yr-old) and tree vitality (healthy or declining trees) were tested in a four-way factorial model including also needle age and verticil. Only the results concerning the age class and the tree vitality are presented (Table I). By assuming a Gaussian distribution, it appeared at the 0.05 level that the content of chlorophylls, ammonium, Zn, and Pb only depended on the health status and the content of Ca, Fe and Cd was related to the age of the trees; both the health status and the age affected total P and N, Mg and K. Table II shows that the declining trees were characterized by lower needle contents of chlorophylls, Mg and Zn and higher contents of total N and P, ammonium, K and Pb. Table II also shows that the needles of the 95 yr-old trees had higher levels of Ca, Mg and Fe and lower levels of total P and N, K and Cd. The plots were also assessed separately to show the effect of health status, discarding the tree age influence. Three-way variance analysis were performed including the effects of health status, needle age and verticil. Table III shows that healthy trees in the plot A differ from the declining ones by having higher water contents and higher concentrations of chlorophylls, Ca, Mg, Al, Na and Zn and lower concentrations of K and Pb, while only small differences occurred in the P concentrations. The healthy trees in the plot B also showed lower concentrations of K, N and P and to a less extent of ammonium (Table IV).

Forest ageing could influence the turnover of organic matter and thus the characteristics of the soil. For this reason, the humus layers of the plots were characterized by the thickness, the CEC, the exchangeable cations, the exchangeable acidity and the composition of the leaching solution. The exchangeable cations

TABLE I

Four-way variance analysis of water content, chlorophyll and mineral concentrations of the needle including the effects of health status, plot, needle verticil (except ammonium) and needle age: effects of health status and plot (probability to observe a larger $|F|$ under null hypothesis than the observed $|F|$: health status, $P>|F_{hs}|$; plot, $P>|F_{plot}|$).

	$P>\|F_{hs}\|$	$P>\|F_{plot}\|$
Water content	0.0919	0.0801
Chlorophylls	0.0001	0.4367
Total N	0.0077	0.0001
Total P	0.0001	0.0007
Total S	0.3067	0.0622
Ammonium-N	0.0508	0.1190
Ca	0.8002	0.0001
Mg	0.0001	0.0005
K	0.0001	0.0001
Al	0.0612	0.9093
Fe	0.2258	0.0282
Na	0.1885	0.7954
Zn	0.0041	0.9860
Pb	0.0043	0.2395
Cd	0.1421	0.0369

TABLE II

Means values of water content (% of fresh weight), chlorophyll and mineral concentrations (mg kg^{-1} of dry weight) of the needles collected from healthy or declining trees and from plot A or plot B. For significance of comparison, see Table I.

	Plot A + Plot B		Healthy + declining	
	Healthy	Declining	Plot A	Plot B
Water content	55.1	53.9	55.1	53.7
Chlorophylls	2613	2113	2430	2299
Total N	13307	13956	14188	12590
Total P	1284	1441	1441	1290
Total S	901	954	978	877
Ammonium-N	91.5	105.7	93.4	103.8
Ca	2123	2100	1774	2438
Mg	394	272	286	380
K	4038	5971	5929	4082
Al	176	148	165	159
Fe	160	168	158	170
Na	184	153	171	167
Zn	21.5	18.6	20.4	19.8
Pb	0.61	0.76	0.71	0.66
Cd	0.17	0.20	0.20	0.17

TABLE III

Mean values of water content (% of fresh weight), chlorophyll and mineral concentrations (mg kg^{-1} of dry weight) of the needles collected from healthy and declining trees of plot A and three-way variance analysis including the effects of health status, needle verticil (except ammonium) and needle age: effect of health status (probability to observe a larger $|F|$ under null hypothesis than the observed $|F_{hs}|$: $P > |F_{hs}|$

	Healthy	Declining	$P > \|F_{hs}\|$
Water content	56.2	54.0	0.0001
Chlorophylls	2972	1882	0.0001
Total N	14079	14277	0.5280
Total P	1404	1470	0.1029
Ammonium-N	87.2	99.6	0.02978
Ca	2007	1527	0.0003
Mg	378	193	0.0001
K	4623	7233	0.0001
Al	200	129	0.0027
Fe	157	159	0.8331
Na	223	118	0.0102
Zn	24.0	16.8	0.0001
Pb	0.57	0.84	0.0002
Cd	0.18	0.22	0.2865

TABLE IV

Mean values of water content (% of fresh weight), chlorophyll and mineral concentrations (mg kg^{-1} of dry weight) of the needles collected from healthy and declining trees of plot B and three-way variance analysis including the effects of health status, needle verticil (except ammonium) and needle age: effect of health status (probability to observe a larger $|F|$ under null hypothesis than the observed $|F_{hs}|$: $P>|F_{hs}|$

	Healthy	Declining	$P>\|F_{hs}\|$
Water content	53.8	53.7	0.9568
Chlorophylls	2249	2332	0.4084
Total N	12537	13634	0.0024
Total P	1164	1413	0.0001
Total S	848	906	0.3941
Ammonium-N	95.8	111.8	0.1006
Ca	2219	2662	0.1299
Mg	410	351	0.2465
K	3447	4701	0.0007
Al	152	166	0.5597
Fe	163	176	0.1292
Na	145	188	0.1553
Zn	18.9	20.7	0.1880
Pb	0.64	0.67	0.7025
Cd	0.16	0.17	0.2453

and the exchangeable acidity were also determined on the 0 to 10 and 10 to 20 cm deep mineral soil. The thickness of the organic layer was significantly higher in plot A than in plot B (Table V). According to Duchafour (1977), CEC increases as the degree of humification but it did not differ significantly between the both plots. The exchangeable Ca was significantly higher in the organic layer of the plot B while in the deeper soil layers, the exchangeable Fe was higher and the exchangeable Cd was lower. Leachates under the organic layer showed significant differences between the plots (Table VI). At the 0.05 level, ammonium, Ca, Mg, Fe, Na and organic C were significantly more concentrated in the leachates of plot B while nitrate was less concentrated.

4. Discussion

Table I shows that the needle concentrations of the major nutrients N, P, Ca, Mg, and K could be controlled in part by the tree age or the characteristics of the plot. It corroborated the conclusions of Oren *et al.* (1988a) who stressed the point that the nutrient concentration of the foliage always reflects the site characteristics more than the symptoms of decline. Moreover, individual heterogeneity, micro-variability in soil fertility, combined with social status and genetical diversity of trees were important factors which influence the extent of the decline of individual trees or their nutrient status in each plot.

However it seems that general comparisons can be made by reference to data collected in other forests in order to establish the nutritional status of the sites

TABLE V

Soil organic layer thickness (cm, N=100), CEC (mmol$_c$ kg^{-1} of dry soil, N=10), exchangeable acidity (pH, N=10), exchangeable cations (mmol$_c$ kg^{-1} of dry soil, N=10) in plot A and plot B, and Wilcoxon range test (probability to observe a larger $|Z|$ under null hypothesis than observed $|Z|$: $P>|Z|$)

	Plot A	Plot B	$P>\|Z\|$
Organic layer			
Thickness	8.43	5.43	0.0000
CEC	259	272	0.5708
Acidity	3.49	3.53	0.4265
Ammonium	9.14	9.21	0.9097
Ca	12.30	30.05	0.0757
Mg	7.87	9.14	0.2413
K	9.74	10.74	0.2413
Al	70.78	58.11	0.1211
Fe	21.90	28.07	0.3447
Zn	1.06	1.29	0.1405
Pb	1.90	2.10	0.9097
Cd	0.02	0.01	0.3254
0 to 10 cm under the organic layer			
Acidity	3.71	3.75	0.6775
Ammonium	6.79	5.96	0.5205
Ca	1.14	2.32	0.5205
Mg	3.60	4.35	0.1859
K	4.48	5.14	0.3847
Al	82.78	77.67	0.1303
Fe	18.09	45.20	0.0002
Zn	0.59	0.48	0.6232
Pb	1.34	1.56	0.3843
Cd	0.04	0.01	0.0017
10 to 20 cm under the organic layer			
Acidity	3.94	4.04	0.5205
Ammonium	3.91	3.60	0.8205
Ca	0.54	0.54	0.7913
Mg	1.83	2.26	0.3847
K	2.69	2.94	0.4274
Al	70.44	73.56	1.0000
Fe	8.43	27.70	0.0002
Zn	0.38	0.28	0.9698
Pb	0.57	0.69	0.3642
Cd	0.03	0.02	0.2411

TABLE VI

Water fluxes (mm d^{-1}), mean concentrations (mg L^{-1}) and pH of the leachates collected under organic layer of plot A and plot B, number of observations (*N*) and Wilcoxon range test (probability to observe a larger $|Z|$ under null hypothesis than observed $|Z|$: $P>|Z|$)

	Plot A	N	Plot B	N	P>|Z|
Water fluxes	2.53	425	2.50	429	0.9025
Ammonium-N	10.9	416	13.0	418	0.0001
Nitrate-N	7.93	417	6.27	418	0.0004
Ca	1.63	418	1.73	421	0.0001
Mg	0.56	418	0.64	421	0.0135
K	3.19	418	3.12	420	0.9728
Al	1.35	96	1.32	95	0.7071
Fe	1.03	418	1.90	420	0.0000
Na	3.00	418	3.46	421	0.0001
Zn	0.21	96	0.22	95	0.7792
Pb	0.077	96	0.064	95	0.0993
Cd	0.0038	96	0.0054	95	0.8845
pH	3.53	424	3.60	424	0.2879
Organic-C	50.7	365	58.2	370	0.0005
Phosphate-P	0.44	418	0.45	420	0.0925
Sulphate-S	2.49	416	2.51	420	0.9876

under study. The needles from both plots were characterized by normal or sufficient levels of total N, P, S, Ca, Fe, Zn, Pb, Cd and Al (Tables II, III and IV) according to the values and the step values of Weissen *et al.* (1983), Reemstma (1986), Van Praag and Weissen (1986), Wyttenbach *et al.* (1985), Zöttl and Hüttl (1986), Forschner and Wild (1987), Kandler *et al.* (1987), Bonneau (1988), Oren *et al.* (1988a). Potassium concentrations appeared also to be sufficient except for the healthy trees of plot B where they were below the critical value suggested by Bonneau (1988) and Zöttl and Hüttl (1986). All the Mg concentrations were below the critical value of these authors. The Na contents were higher than the value determined by Wyttenbach *et al.* (1985). These authors have shown that the foliar pool is highly dependent upon the atmospheric deposition. The high Na levels could therefore result from the fact that the site mainly receives precipitations with westerly winds loaded with sea spray. Water contents of the needles were lower than the values obtained by Badot *et al.* (1988) but these values were dependent upon the sampling time and the season. The mineral levels determined in the needles showed two factors: (I) the occurrence of a Mg deficiency which was already described in the Haute Ardenne region (Weissen and Van Praag, 1982); (II) the total S concentration in the needles was well below the level of toxicity *i.e.* 1900 mg kg^{-1} of dry needles (Knabe, 1984) or of 1500 mg kg^{-1} (Bonneau, 1988) which suggests that the forest was not polluted by SO_2.

In other respects, most of the differences in concentrations between the needles of healthy and declining trees suggest that the decline occurring in the watershed should be related to the observations made in Western Europe. Lower Ca and

Mg concentrations have been often reported in the needles collected from declining trees by comparison with healthy ones (Van Praag *et al.*, 1986; Zöttl and Hüttl, 1986; Forschner and Wild, 1987; Kandler *et al.*, 1987; Badot *et al.*, 1988; Oren *et al.*, 1988a; Schulze, 1989); the same differences were also reported for water content (Badot *et al.*, 1988), Zn (Zöttl and Hüttl, 1986) and chlorophylls (Kandler *et al.*, 1987). Otherwise, the difference in K concentration between the needles of declining and healthy trees is assumed to originate from cation antagonism between Ca, Mg and K (Leggett and Gilbert, 1969). Al should not be a problem in those sites since exchangeable Al is in the range of other Belgian soils (Van Praag and Weissen, 1985) and Van Praag *et al.* (1985) have shown that the Al status encountered in the Ardenne soils does not inhibit the development of spruce.

Schulze (1989) suggested that the atmospheric deposition of ammonium, nitrate and sulphate disturbs the mineral nutrition of the tree; spruce roots take up ammonium rather than nitrate, with antagonistic effect on uptake of Mg. Moreover, the deposition of nitrate and sulphate would accelerate the soil acidification, decreasing the Ca/Al and Mg/Al ratios and affecting the root development and the water and nutrient uptake. Finally, canopy uptake of atmospheric N, in addition to root uptake, would stimulate growth and cause N imbalance. It was shown that excessive ammonium supply results on the one hand in higher ammonium, total N and P contents and on the other hand in lower Ca, Mg and K contents (Haynes and Goh, 1978; Findenegg, 1987). As the needles of the declining trees exhibited most of the same trends, except K, our observations fit to the Schulze model (1989). Two following observations support this hypothesis: (I) the total wet deposition of N in the open rain on the watershed would be as high as 28 kg ha^{-1} yr^{-1} (Weissen *et al.*, 1990); (II) it was previously assumed that on this site, ammonium could be taken up by the needles as the ammonium throughfall deposition was lower than open site deposition (Hambuckers and Remacle, 1987).

Lead and Cd contents of the needles as well as differences in concentration between healthy and declining trees lead us to suggest that these metals could also be implicated in the process of decline. It has been shown that increased heavy metal concentrations in the soil solution could result in decrease chlorophyll concentrations and root elongation (Mitchell and Fretz, 1977; Godbold *et al.*, 1987; Godbold and Hütterman, 1986; Schlegel *et al.*, 1988). However, the concentrations used in these experiments were often higher than the *in situ* level and it must be pointed out that the synergistic effects occurring in forest environment were also not taken into account.

The symptoms of decline (needle yellowing and loss) allow the conclusion that the plot B was less damaged than the plot A. However, this is not supported by the lower K contents of the needles of plot B (Tables II) but is by the higher Ca and Mg concentrations and the lower P and N concentrations. The same differences in the concentration of mineral elements of the needles were observed between the plots as between the healthy and declining trees. The overall higher vitality of plot B could be the result of a better turnover of the organic layer. This is supported by the following observations. The organic layer was thinner in plot B than in plot A (Table V). Martinez *et al.* (1980) observed that microbial activities were more intensive in thinner litter layers. Therefore a better supply to the nutrient pool in the soil should exist. Since the water fluxes through the humus layers in the lysimeters were not significantly different in both plots (Table VI), the comparison of the nutrient concentrations in the leachates reflect the nutrient supply of the humus. The leachates of plot B had higher concentrations of ammonium, Ca, Mg, Fe, Na and organic C and lower concentrations of nitrate (Table VI). This may have resulted from the microbial activity which promoted the ammonium and soluble organic C production, this latter production inhibiting the mobilization of nitrate (Buldgen *et al.*, 1982) and enhancing the release of Fe (Buldgen *et al.*, 1983). In addition, the higher exchangeable Ca in the organic layer of plot B indicated that the Ca mineralization was greater, and the higher exchangeable Fe in the deeper soil layers of plot B than in plot A (Table V), gave evidence of increased amount of Fe transported by organic C.

The better turnover of the organic matter in the plot B should be the consequence of the tree density. This was lower in plot B than in plot A (288 and 483 trees ha^{-1}, respectively). This means that more light could reach the ground in plot B, which was shown by the enhanced growth of the ground vegetation. The litter receiving more energy, the decomposition and the release of nutrients should be higher through microbial activity, inducing a better physiological response of the trees against the environmental stresses.

5. Conclusions

Foliar analysis showed a general pattern of typical forest decline. In the needles of the declining trees, enhanced ammonium, total N and total P levels, in combination with lower base cation concentrations, suggest physiological responses to N over-fertilization by the atmospheric deposition. The difference of decline state between the two plots could originate from the unequal turnover rate of the organic layer, due to stand density. Further developments should involve on the one hand comparisons of energy reaching the ground and of soil temperatures in both plots and on the other hand a more acute approach of the physiological status of the foliage in particular the influence of nitrogen oversupply.

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