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Deposition of Atmospheric Pollutants and its Impact on Forest Ecosystems of the Northern Tyrolean Limestone Alps

By

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Key words: Atmospheric input, throughfall, soil solution, litter fall.

Summary

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The present subproject of the interdisciplinary project "Achenkirch Altitude Profiles" focuses on the deposition of long-term effective atmospheric pollution and its impact on forest ecosystems of two spruce (mixed wood) stands (*Picea abies*) located at altitudes of 1400 m and 1050 m. The deposition input was monitored by bulk sampling of throughfall and the soil water was investigated by lysimetry.

The results obtained during a two-years period (August 1992 to July 1994) indicate very little input by deposition of atmospheric pollutants. Deposition rates under the canopy were 9-12 kg N ha^{-1} $year^{-1}$ and 7-8 kg S ha^{-1} $year^{-1}$. Proton rates ranged from 0.1-0.3 kmol H^{+} ha^{-1} $year^{-1}$. No indication of a correlation between stress and altitude was observed along the given difference in elevation (350 m).

It is very unlikely that soil acidification is the cause of a decreased vitality, especially since the buffering capacities of the investigated soils are very high. The significance of the proton buffering and of the increased leaching of nutrients from the canopy is, however, evident by the fact that leaching reduces the stand's pool of elements needed for the formation of the foliage by approximately 22 to 78 % (K, 72-78 %; Mg, 36-40 %; Ca, 22-24 %). Renewed uptake of these elements requires a higher amount of energy and transfers the buffering effect to the ecotoxicologically highly sensitive area of the immediate rhizosphere.

The highest mean annual nitrate concentrations of the soil solution amounts to only 2.8 mg l^{-1} $year^{-1}$. This fact and N foliar analyses prove that nitrogen is the limiting element for stand growth. As the investigated spruce stands are not nitrogen-saturated, the nitrogen inputs measured

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serve to meet the N demand of the stands. Nitrate leaching therefore does not cause soil acidification or associated nutrient losses.

Introduction

Reduced vitality of the protection forests in the Northern Tyrolean Limestone Alps has become a serious concern manifested by the occurence of below average crown densities (AMT DER TRIOLER LANDESREGIERUNG 1993). Numerous hypotheses have been put forward to explain this decline and its cause. Biotic (e.g. deer, cattle grazing) and abiotic factors (e.g. deposition of pollutants, climatic conditions, historic land use) are just some of the recently published explanations (HERMAN & SMIDT 1995). So far there is a lack of knowledge about deposition of long term atmospheric pollutants and nutrient budgets for these sensitive ecosystems. Hence, this study was performed to provide these missing basic data and to test the hypothesis that deposition of atmospheric pollutants must be considered a serious threat to the stability of these forests. A further aspect of this work is an evaluation of the potential long term effects of the deposition of atmospheric constituents on these spruce stands (*Picea abies*) of the Northern Tyrolean Limestone Alps. For this purpose deposition rates, soil solution chemistry and litter fall were examined.

Material and Methods

Study sites

The research of this partial project was performed on the study sites 1a (1400 m) and 5 (1050 m), which are located along the west-east axis of the Christlum profile. The exact location is published elsewhere (HERMAN & SMIDT 1995a). The study sites represent an area (11°40' - 11°50' E, 47°30' - 47°36' N) which is characterized by abundant precipitation, sub-Atlantic influences, and oceanic climate (MARGL 1994). Bedrock material for soil formation is mainly dolomite (30 % CaO, 20 % MgO; FABICH & PRODINGER 1957) and various forms of limestone (ENGLISCH 1992).

Study site 1a

This study site is located on a steeply inclined (20-30 %) east-exposed upper slope, at an elevation of 1400 m. The mean calculated precipitation (1931-1990) at this elevation (MARGL 1994) amounts to 1800-1900 mm, the mean annual temperature is 4.1 °C. The stand within the fenced area (500 m^2, Fig. 1) consists of 7 spruces (*Picea abies*) 1 larch (*Larix decidua*) and 1 beech (*Fagus sylvatica*), the mean height is 17 m, the diameter at breast height (DBH) 38 cm and the growing stock 0.3. The age of this stand is between 150 and 200 years. Average crown density of spruce trees is 2.2 on a scale from 1 to 5 (1 = no needle loss, 5 = dead; KREHAN & TOMICZEK 1992). The original forest vegetation at this elevation is predominantly *Adenostyleo-glabrae-Abieti-Fagetum*. The most common soil plants (values for combined abundance and dominance on a scale from +, 1 to 5 are put in parentheses) are *Apóseris foétida* (3), *Sesleria varia* (3), *Carex humilis* (2), *Carex ferruginea* (2) and *Polýgala chamaebuxus* (2). The soil is classified as a shallow Rendzina, the horizons (symbols according to BLUM & al. 1986) are: L/F (1.5-1 cm), H (1-0 cm), A_{biog} (0-8 cm) A_{biog}/C (8-20 cm), C_v (20-30 cm), C_n (30 cm +). Soil properties are given in Table

1 (source of data: MUTSCH, pers. comm.; the methods of the soil analyses were published by MUTSCH 1995).

Study site 5

This study site is located on a strongly inclined (10-20 %) east-exposed middle slope, at an elevation of 1050 m. The mean calculated precipitation (1931-1990) at this elevation (MARGL 1994) amounts to 1500-1600 mm, the mean annual temperature is 5.2 °C. The stand within the fenced area (600 m^2, Fig. 1) consists of 9 spruces (*Picea abies*), 1 pine (*Pinus sylvestris*) and 1 beech (*Fagus sylvatica*), the mean height is 20 m , the DBH 40 cm and the growing stock 0.8. The age of this stand is between 150 and 200 years. Average crown density of spruce trees is 1.3. The original forest vegetation at this elevation is predominantly *Asperulo-Abieti-Fagetum*. The most common soil plants are *Carex alba* (4), *Sesleria varia* (4), *Apóseris foétida* (3) and *Polýgala chamaebuxus* (3). The soil is classified as a calcareous brown loam, interlocked with Rendzina. The soil profile is: L (4-2 cm), F (2-0.5 cm), H (0.5-0 cm), A_{biog} (0-12 cm), B_{vrel} (12-40 cm), B_{vrel}/C (40-50 cm), $C_v^{\cdot}$ (50 cm +). Soil properties are given in Table 1.

Table 1. Soil properties at the study sites 1a and 5.
(Source of data: MUTSCH, pers. comm.).

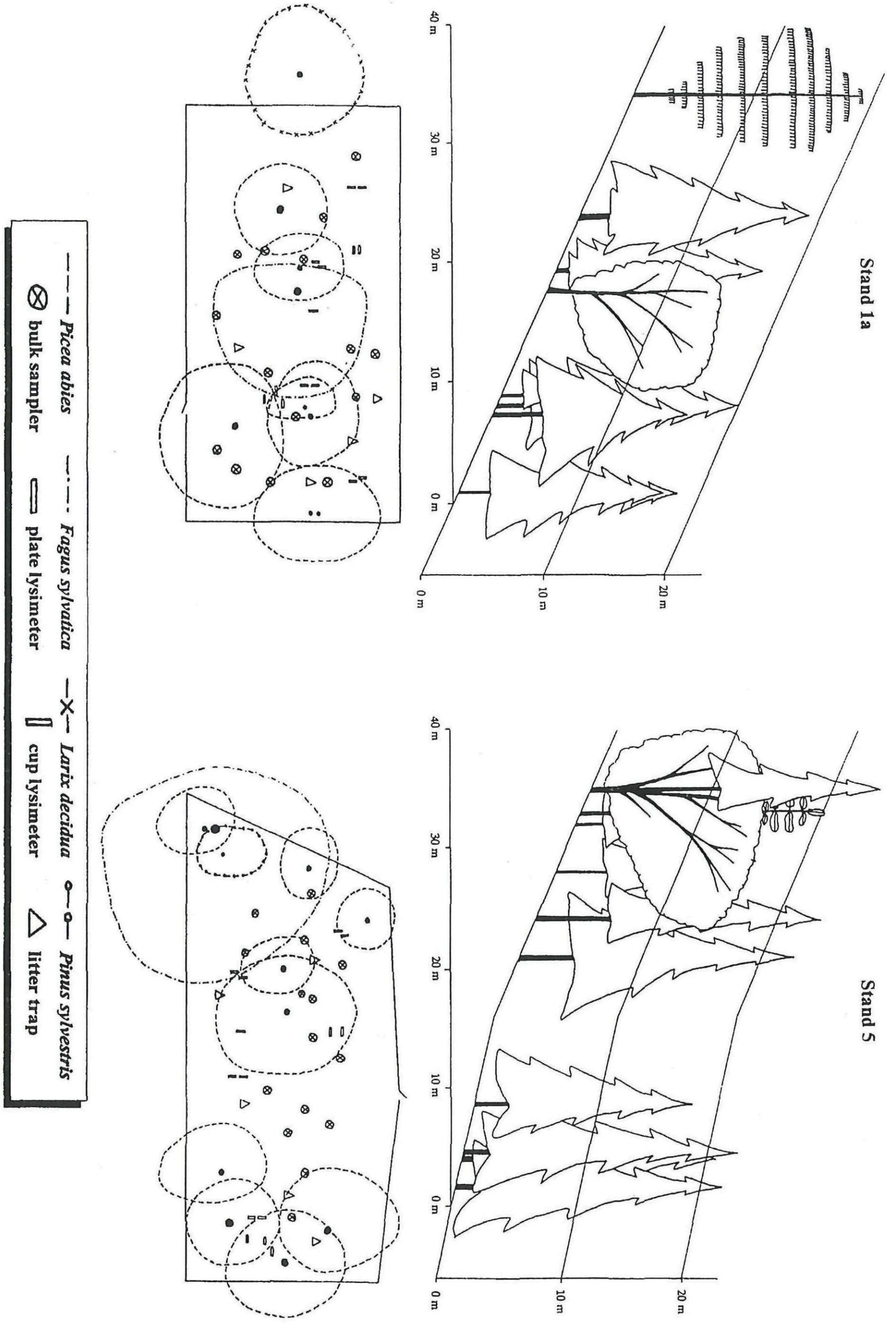
Depth (cm)	Total $CaCO_3$ ($g\ kg^{-1}$)	Total $C_{(org)}$ ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Total P ($g\ kg^{-1}$)	pH	CEC $CaCl_2$ ($mmol_c\ kg^{-1}$)	Exch. Ca ($mmol_c\ kg^{-1}$)	Exch. Mg ($mmol_c\ kg^{-1}$)	Exch. K ($mmol_c\ kg^{-1}$)	Base sat. (%)
Site 1a										
0-5	25	113	7.6	0.44	6.2	450	334	114	1.3	100
5-10	61	71	4.6	0.33	6.3	325	236	88	0.7	100
10-20	65	50	2.8	0.25	6.5	249	180	70	0.4	100
20-30	500	56	1.3	0.15	7.2	149	110	39	0.3	100
Site 5										
0-5	84	163	8.9	1.08	6.9	638	469	166	2.1	100
5-10	25	105	6.0	0.47	7.0	472	352	118	0.6	100
10-20	365	57	3.0	0.37	7.2	280	212	67	0.4	100
20-30	929	14	0.1	0.10	7.4	41	27	13	0.2	98
30-50	785	37	0.1	0.07	7.4	31	20	11	0.2	98

Atmospheric deposition

Deposition input was monitored from August 1992 to July 1994. Each stand was equipped with 15 randomly distributed bulk samplers (200 mm diameter; SMIDT & SONDEREGGER 1983; Fig. 1) for collecting throughfall. Throughfall was sampled once a week. All samples of the individual collectors at each stand were pooled together. Metal cations were analysed by atomic absorption spectrophotometry, NH_4 colorimetrically with a flow injection analyser, anions by ion chromatography, and pH electrometrically.

Reference samples (bulk deposition) were collected in an open field (Talboden, 930 m) at the beginning of the Christlum profile by SMIDT (methods are given by SMIDT 1995). Throughfall and precipitation fluxes were calculated by measured solution volumes.

In the winter each throughfall sample is represented by the average of 10 polyethylene pails (255 mm diameter). Since snowdrift affects the sampled volume of snow, the edge of the pail was kept about 5-10 cm above snowcover. This was arranged by moveable pails, so that the proper


Stand 1a
Stand 5
0 m
10 m
20 m
30 m
40 m
Picea abies
Fagus sylvatica
Larix decidua
Pinus sylvestris
bulk sampler
plate lysimeter
cup lysimeter
litter trap

height could be adjusted after each time of sampling. If the pails could not grasp the whole amount of new fallen snow, samples were taken by means of a 100 cm long PMMA snow core sampler (Polymethylmethaacrylate, 7 cm diameter) with a high graded steel crown down to the bottom of the pail.

Soil solution chemistry

Each stand was equipped with 5 ceramic plate lysimeters (8 cm diameter) at 5 cm soil depth. A constant suction was provided by a 140 cm (- 14 kPa) hanging water column.

Ceramic cup tension lysimeters were installed at depths of 15 cm and 30 cm (5 respectively 4 replications on each plot; Fig. 1). The soil solution of all lysimeter was sampled once a week from August 1992 to July 1994, whenever conditions permitted. The applied suction was - 50 kPa. Interruptions occurred from middle of November to April, when the soil water was frozen. Samples were pooled by depth and plot and analysed as described for the throughfall samples above.

Litter fall

Litterfall was sampled from August 1992 to July 1993 with five collectors (80 cm diameter, 150 cm above ground) at monthly intervals. The samples were analysed for N (Kjeldahl) and major nutrients (P colorimetrically, metals by atomic absorption spectrophotometry, both after digestion with HNO_3 and $HClO_4$).

Results and Discussion

Atmospheric deposition

Precipitation and throughfall are given in Table 2. The year 1992/93 is characterized by a higher throughfall than calculated by MARGL 1994 for average precipitation in the open (1931-1990) for these elevations while throughfall in the year 1993/94 is below these values. In both years of monitoring, precipitation at the reference site (Talboden) is lower than throughfall under the canopies of the stands.

Table 2. Throughfall and precipitation (Talboden; SMIDT, pers. comm.) in the first and second years of monitoring (mm year^{-1}) as well as the long term mean of precipitation, recorded at a nearby meteorological station.

Study site	Elevation	Period	Amount (mm)
1a	1400 m	Aug. 92-July 93	
		Aug. 93-July 94	1404
5	1050 m	Aug. 92-July 93	1898
		Aug. 93-July 94	1327
Talboden	930 m	Aug. 92-July 93	1582
		Aug. 93-July 94	1206
Long-term mean	920 m	1931-1960	1456

Fig. 1. Ground and vertical projections of the study stands 1a and 5 and installations.

The fact that throughfall is higher than precipitation is remarkable since interception of spruce stands is reported to be between 30 and 50 % (LANG 1971, GÜNTHER & KNABE 1976, EVERS 1985, HÜSER & REHFUESS 1988, BRECHTEL 1989, BLOCK & al. 1991). These results indicate cloud- and fogwater deposition - an important factor in the water balance of mountain ecosystems (GRUNOW 1955). This is in accordance with research performed in North America, demonstrating that deposition rates are increased substantially at high-elevation sites by enhancement of wet, dry, and especially, cloud deposition (LOVETT 1994).

Deposition flux densities of elements are listed in Table 3 (bulk collected throughfall, precipitation in the open, and ratios).

Table 3. Element fluxes (g m^{-2} $year^{-1}$) in throughfall at the study sites 1a and 5 and in precipitation in the open at the station Talboden (Tal; SMIDT, pers. comm.), as well as the ratios of element fluxes for the periods July 1992-August 1993 and July 1993-August 1994.

Station	Ca	Mg	K	Na	NH_4-N	NO_3-N	SO_4-S	Cl	H^+
Throughfall (TF) 1992/93									
1a	1.56	0.46	1.10	0.48	0.40	0.80	0.79	0.81	0.03
5	1.33	0.45	0.76	0.39	0.44	0.71	0.78	0.62	0.02
Precipitation (PD) 1992/93									
Tal	0.63	0.15	0.16	0.31	0.59	0.52	0.66	0.46	0.02
Ratios of element fluxes (TF/PD) 1992/93									
1a/Tal	2.5	3.1	6.9	1.5	0.7	1.5	1.2	1.8	1.5
5/Tal	2.1	3.0	4.8	1.3	0.8	1.4	1.2	1.4	1.0
Throughfall (TF) 1993/94									
1a	1.09	0.38	0.76	0.37	0.29	0.59	0.65	0.51	0.02
5	0.95	0.28	0.59	0.36	0.38	0.55	0.66	0.48	0.01
Precipitation (PD) 1993/94									
Tal	0.64	0.20	0.15	0.29	0.56	0.47	0.52	0.31	0.01
Ratios of element fluxes (TF/PD) 1993/94									
1a/Tal	1.7	1.9	4.8	1.3	0.51	1.3	1.3	1.6	2.0
5/Tal	1.5	1.4	3.9	1.2	0.68	1.2	1.3	1.5	1.0

The observed nitrogen throughfall fluxes of between 9 and 12 kg ha^{-1} $year^{-1}$ are in the lower range of values reported for Austrian spruce forests (GLATZEL & al. 1988). The ratios of reduced to oxidized nitrogen is on the oxidized side (0.6-0.7 of total N) because there is little livestock farming in this area and thus emissions of ammonia are low. Elevation (350 m difference) does not affect fluxes of total nitrogen (NH_4 + NO_3), but there is a trend, that NH_4 fluxes decrease and NO_3 fluxes increase with increasing level above sea. This is in accordance with STÖHR

1988 ("Altitudinal Profile Zillertal") and KÜHNERT 1988 (altitudinal profile Judenburg).

Sulphur fluxes (7-8 kg ha^{-1} $year^{-1}$) are much lower than reported for other Austrian spruce, beech and oak stands (SONDEREGGER 1984, GLATZEL & al. 1988, BERGER & al. 1991) and do not change with altitude. Proton fluxes (0.1-0.3 kg ha^{-1} $year^{-1}$) increase slightly with elevation and are in the same range as the cited values for Austrian spruce forests but higher as measured for oak stands in eastern Austria. Lower H^+ fluxes (0.01-0.04 kg ha^{-1} $year^{-1}$) in throughfall of these deciduous forests are caused by higher canopy buffering, lower leaf area index for less than half a year and high proton buffering by basic soil particles, produced by agricultural land use (BERGER & GLATZEL 1994, KENNEL & LECHLER 1993).

All element fluxes in precipitation are lower than throughfall fluxes (indicated by ratios *TF/PD* in Table 3), except for ammonium. These results (data from SMIDT, pers. comm.) are in accordance with SMIDT & RENDL 1994 and other Tyrolean long term (1984-1993) precipitation data (WADOS, Table 4).

Table 4. Long term (1984-1993) element fluxes in precipitation (g m^{-2} $year^{-1}$) at Tyrolean WADOS stations. Source of data: KOVAR & PUXBAUM 1992, KALINA, pers. comm.

Station	H^+	SO_4-S	N (NO_3 + NH_4)
Achenkirch - Mühleggerköpfel	0.014-0.039	0.35-1.03	0.56-1.36
Kufstein	0.017-0.056	0.53-1.25	1.01-1.69
Reutte	0.009-0.034	0.51-0.88	0.81-1.34

According to these throughfall measurements and precipitation data (compare Table 4) the study area is characterized by low deposition rates of sulphur and nitrogen, while proton inputs are in the medium range when compared to other sites in Austria.

The estimate of total deposition (*TD*) is based on the model of ULRICH 1983, according to the equations in Table 5.

ULRICH assumes that for the elements sodium, chlorine and sulphur, neither plant uptake (-*Q*) nor leaching (+*Q*) exists. Sodium is used to calculate particlate interception deposition, because it has no gaseous compound. For the spruce ecosystems in this study, the two years ratio of interception deposition to precipitation deposition: *(TF-PD)/PD* for Q_{Na}=0, where *TF* is measured throughfall and *PD* is measured precipitation deposition in the open, ranges between 0.25 (stand 5) and 0.42 (stand 1a). This factors suggest that the forest stand 1a at the higher elevation is more efficient in filtering particulates. These ratios were used to estimate interception depositions of the two studied stands for all other elements except for sulphur (Table 5). This method is appropriate for Ca, Mg and K but it is

Table 5. Turnover of elements in the canopies (2 year average) (g m^{-2} $year^{-1}$).

Element	Station	*TF*	*PD*	*ID*	*Q*	*TD*
Ca	1a	1.33	0.64	0.27	0.42	0.91
	5	1.14	0.64	0.16	0.34	0.80
Mg	1a	0.42	0.18	0.08	0.16	0.26
	5	0.37	0.18	0.05	0.14	0.23
K	1a	0.93	0.16	0.07	0.70	0.23
	5	0.68	0.16	0.04	0.48	0.20
Na	1a	0.43	0.30	0.13	--	0.43
	5	0.38	0.30	0.08	--	0.38
NH_4-N	1a	0.35	0.58	0.24	-0.47	0.82
	5	0.41	0.58	0.15	-0.32	0.73
NO_3-N	1a	0.70	0.50	0.21	-0.01	0.71
	5	0.63	0.50	0.13	0.00	0.63
SO_4-S	1a	0.72	0.59	0.13	--	0.72
	5	0.72	0.59	0.13	--	0.72
Cl	1a	0.66	0.39	0.16	0.11	0.55
	5	0.55	0.39	0.10	0.06	0.49
H^+	1a	0.025	0.035	0.015	-0.025	0.050
	5	0.015	0.035	0.009	-0.029	0.044

TF: Throughfall (measured): $TF=PD+ID+Q$
PD : Precipitation deposition in the open (measured)
ID : Interception deposition: $ID_X=(ID/PD)_{Na} \times PD_X$ (x: Ca, Mg, K, NH_4-N, NO_3-N, Cl, H^+)
Q : Foliar leaching (+) or foliar uptake (-)
TD : Total deposition: $TD=PD+ID$

a very rough estimate for nitrogen compounds, for which gaseous interception deposition is a major sink. In contrast to the model of ULRICH, Q_{Cl} was not assumed zero, because according to KAZDA 1990 crown leaching of chloride occurs in situations where this element is scare (far away from sea).

The comparision of deposition rates in the open with sub-canopy fluxes (Table 3) provides an estimate of interaction with tree nutrition. High flux rates of potassium, magnesium and calcium are an indication of leaching which must, at least partially, be considered a natural process. It is interesting, that the ratios *TF/PD* for these elements are higher at the study site 1a, where the proton fluxes under the canopy are also higher. The figures in Table 5, despite the assumptions and limitations discussed above, permit the following conclusions. During the growing season there is nitrogen uptake by the canopy, indicating a capacity to assimilate nitrogen as well as contributing to nitrogen gain in these systems. Nitrogen uptake by leaves (beech) and needles (spruce) is preferred in form of ammonium. The two years average for nitrate uptake (Table 5) is zero, since partial uptake during the summer months is cancelled by additional filtering during the winter months (BERGER & GLATZEL 1995). Total nitrogen input (NH_4-N + NO_3-N) for these ecosystems is estimated between 14 and 15 kg ha^{-1} $year^{-1}$, indicating that N fluxes in throughfall considerably underestimate actual input. Buffering of H^+ (*Q*, Table 5) by these spruce dominated canopies is estimated between 50 and 66 % of total deposition (*TD*), which must be considered a stress to the acid neutralizing capacity of the trees. Interception deposition of sulphate in Table 5 was calculated as net throughfall (*TF-PD*), which is in accordance with GARTEN & al. 1987 and BERGER & GLATZEL 1994. Dry S deposition at both sites amounts only 1.3 kg ha^{-1} $year^{-1}$. These low values are supported by SMIDT & GABLER 1995, who determined annual means of SO_2 between 2 and 3 μg m^{-3} in the area of Achenkirch, far below the IUFRO limit (IUFRO 1978/1980).

Soil solution chemistry

Ionic concentrations in the soil solution are given in Table 6. Concentrations of cations reflect the cation exchange capacity (CEC), which is much higher at the study site 5 (loam) for the upper 20 cm of the soil than at 1a (sandy loam). Chloride, nitrate and sulphate contribute only about 10 % to the total of anions in the soil solution. Bicarbonate ion is assumed to dominate because of the high pH values (7.2-7.8), which are typical for the carbonate puffer range. It is not known, how far dissolved organic carbons (DOC, Table 6) contribute to the unanalysed anions. Sulphate and nitrate are not considered important mobile anions, which would reduce the CEC by the equivalent amount of cations, when draining out of the the system. The high Ca and Mg values, increasing with soil depth, are caused by the weathering of dolomite, the bedrock material for the soil formation. The high pH of the studied soils causes concentrations of manganese and aluminium below the detection limit, which are therefore not listed in Table 6. Distinct trends within the two years of monitoring were not obvious, except that nitrate and amonium concentrations peaked during the summers 1992 and 1994 (very hot temperatures) and May 1993 (beginning nitrification, reduced plant uptake). A slight increase of nitrate concentrations in November 1993 was propably caused by concentration effects (partly freezing of soil water).

Table 6. Mean ion concentrations (mg l^{-1}) in the soil solution (standard deviations in parentheses) from August 1992 to July 1994.

	n	Ca	Mg	K	Na	NH_4
Site 1a						
5 cm	*45*	8.94	4.74	0.24	0.41	0.11
		(1.78)	(1.14)	(0.25)	(0.34)	(0.11)
15 cm	*38*	20.26	12.30	0.27	0.41	0.07
		(6.08)	(3.80)	(0.29)	(0.26)	(0.12)
30 cm	*37*	29.50	18.26	0.30	0.37	0.06
		(3.89)	(2.81)	(0.23)	(0.17)	(0.03)
Site 5						
5 cm	*50*	17.08	10.72	0.77	0.60	0.16
		(2.75)	(2.28)	(0.54)	(0.35)	(0.19)
15 cm	*48*	30.46	18.53	0.64	0.50	0.12
		(5.68)	(5.72)	(0.33)	(0.32)	(0.22)
30 cm	*49*	35.44	20.68	0.39	0.57	0.06
		(4.81)	(3.17)	(0.53)	(0.15)	(0.10)

	n	NO_3	SO_4	Cl	DOC	pH
Site 1a						
5 cm	*45*	0.53	1.63	0.44	18.21	7.2
		(0.82)	(0.85)	(0.53)	(2.78)	(0.3)
15 cm	*38*	1.30	2.30	0.51	11.87	7.4
		(2.37)	(2.12)	(0.64)	(1.40)	(0.2)
30 cm	*37*	0.96	1.84	0.34	10.73	7.8
		(1.81)	(0.64)	(0.42)	(2.14)	(0.3)
Site 5						
5 cm	*50*	1.40	2.99	0.98	25.65	7.6
		(1.98)	(1.89)	(1.23)	(6.89)	(0.4)
15 cm	*48*	0.61	3.32	1.18	12.65	7.7
		(0.93)	(1.76)	(1.69)	(3.62)	(0.2)
30 cm	*49*	2.79	3.52	1.01	8.54	7.7
		(2.19)	(1.39)	(1.34)	(1.89)	(0.2)

These data (soil solution chemistry, Table 6; soil properties, Table 1) suggest sufficient nutrition of the studied stands. Short term lacks of nutrients (e.g. K, P, Mn) might occur at these high soil pHs, due to element antagonisms or soil fixations. It is risky to judge nitrogen gain or loss of the studied stands, since emissions of N gases and N output with the drainage water are not known. But low NO_3 concentrations in the soil solution and compareable data by LIU & al. 1993 justify the statement that nitrogen is a limiting factor for the studied stands and, hence, atmospheric N deposition has a positive affect on the nutrition of these forests. LIU & al. 1991 and LIU & al. 1993 measured low N values in the needles of spruce (10-14 mg g^{-1} DM) and nitrate concentrations mostly below the detection limit after a short peak in spring (75 mg l^{-1}) at the Wank (Bavaria), concluding a lack of nitrogen for these spruce ecosystems on calcereous soils. Needle analyses by HERMAN 1994 reveal N data (11.0-11.7 mg g^{-1} DM) for the studied stands below the suggested limit for sufficient N nutrition (13.0 mg g^{-1} DM). Possible shortage of nitrogen appears much more severe for the stand 1a, because at site 5 soils are deeper, nitrate concentration in the soil solution higher and the total N budget amounts ca. 3500 kg ha^{-1} (0-20 cm, C/N = 16.3, ENGLISCH & STARLINGER 1995). Both systems are not nitrogen saturated and soil acidification by nitrification and associated nutrient losses are not issues.

Presently, the Critical Loads discussions focus - besides proton and nitrogen inputs - on the deposition of sulphur. At current S deposition rates and sulphate concentrations in the soil solution, the soil conditions will not change. The effort to specify a certain threshold value, that guarantees no long term changes within the soil, must be appreciated but seems impossible, considering the complexity of theses ecosystems. The contribution of sulphate to the total of anions (equivalent sum of cations) amounts to between 1.3 and 3.9 %. Since the pH of the soil is in a range where sulphate sorption is low, sulphate will be leached and the dolomite will supply enough equivalent amounts of cations for its neutralization over the long term. LIU & al. 1993 calculated for soils at the Wank, where atmospheric inputs are higher and bedrock material is more silicate, that only 7 % of Ca output is balanced by acid deposition. Also in this study Mg and Ca leaching, caused by acid deposition is considered very low and is produced by internal production of acids and high CO_2 concentrations in the soils. The threshold values for indication of atmospheric sulphur concentrations in the AUSTRIAN FORESTRY LAW of 1975 (2nd Regulation Against Air Pollution Causing Damages to Forests; BGBl No. 199/1984) is 0.11 % sulphur content in the needles of spruce and was not exceeded in any year of monitoring at the studied stands (0.07-0.08 %, HERMAN 1994).

Litter fall

Litter production and fluxes with litter fall are given in Table 7.

Table 7. Litter production (dry matter, DM) and element fluxes with litter fall (g m^{-2} $year^{-1}$) at the study sites 1a and 5.

Study site	DM	N	P	Ca	Mg	K	Mn
1a	132	1.24	0.05	1.32	0.28	0.20	0.010
5	124	1.27	0.07	1.18	0.21	0.19	0.014

Litter production was similar from August to September for both stands but autumnal litter fall peaked earlier (October) at the higher site 1a (at site 5 in November). From November to beginning of April the litter traps were not emptied, because the traps were partly filled with snow. Hence, the given figures for litter production must be considered an underestimation of actual flux with litter fall. Since litter fall can be reasonable approximated from measurement of autumnal litter fall for deciduous trees (beech) and of litter fall during autumn and spring for coniferous trees (spruce), this mistake seems negligible. Nevertheless, the calculated fluxes of 1.3 (1a) and 1.2 (5) t dry matter (DM) ha^{-1} $year^{-1}$ are very low. LÜSCHER 1989, for example, reports annual litter production of 1.94-7.11 (spruce) and 2.52-7.64 (beech) t DM ha^{-1} in Switzerland (Kanton Zurich). Neglecting the possible systematically error (see above), this low production of litter is caused by a specific vegetation pattern in this area, where trees grow on small patches in order to protect each other, surrounded by open fields within the forest.

Depending on the element, leaching (*Q*, Table 5) amounts to between 22 and 78 % (K, 78-72 %; Mg, 36-40 %; Ca, 24-22 %; first value obtained at site 1a, the second at site 5) of the stand's yearly uptake (leaching + litter fall minus annual wood increment). Proton buffering in the canopy causes uptake of the leached cation by the root system and accelerates nutrient cycling (REUSS & JOHNSON 1986), affecting the energy household of the plant. Foliar leaching of cations does not decrease the canopy pool size as long the root uptake is not disturbed (ULRICH 1989), which is the case for the studied stands. In fact, SKEFFINGTON & ROBERTS 1985 and GUDERIAN & al. 1987 found an increase in foliar nutrients while foliar leaching was increased. However, the transfer of the buffered H^+ by the canopy to the surrounding of the rhizosphere might cause a limited uptake, although nutrient pools are high. These data suggest, that foliar leaching of the studied stands on these calcareous soils is very high (base saturation between 98 and 100 %, Table 1), which must be considered a stress to the acid neutralizing capacity of the trees.

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