

# Field microcosms, a new method for investigations of soil processes: calculation of mineralization and nitrification by using chloride as tracer

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## Synopsis

The overall objective was to quantify the biogeochemical processes which are known to affect forest ecosystems by acidification. In covered columns of a coniferous soil, to which distilled water was added in place of throughfall,  $\text{Cl}^-$  was used as a tracer and its rate of leaching was used to calculate internal N mineralization and  $\text{NO}_3^-$ -production. In the present investigation root uptake was excluded. Under these conditions the importance of biological nitrogen turnover in proton production processes was investigated and it was demonstrated that internal acidification, resulting from ammonification and subsequent nitrification, was greater than acidic input by throughfall.

*forests, transplanted soils, mineralization, nitrification, soil acidification, anion tracer*

## Synopsis

Das Ziel dieser Studie war es die biogeochemischen Prozesse zu quantifizieren, die zu einer Versauerung von Waldökosystemen führen können. Überdachte Bodensäulen aus einem Fichtenbestand wurden mit demineralisiertem Wasser statt mit der Kronentraufe beregnet. Dabei wurde  $\text{Cl}^-$  als Tracer benutzt, um die interne N Mineralisation und Nitratproduktion zu berechnen. Die Wurzelaufnahme wurde in dieser Studie ausgeschlossen. Unter diesen Bedingungen wurde gezeigt, daß die interne Bodenversauerung, bedingt durch Ammonifizierung und die anschließende Nitrifizierung den versauernden Eintrag mit der Kronentraufe überstieg.

*Wälder, getauschte Böden, Mineralisation, Nitrifikation, Bodenversauerung, Anionentracer*

## Introduction

Major changes to terrestrial ecosystems in the future will arise from changes in atmospheric composition and climate (GOUDRIAAN & al. 1995). Acidic deposition, resulting mainly from emissions of  $\text{SO}_2$  and N has been linked to the destabilisation of forest eco-

systems (VAN BREEMEN & al. 1982; ULRICH 1986; LAMERSDORF & MEYER 1993). Furtheron it has been shown that seasonal internal proton production through nitrification may be an important acidifying influence (ULRICH 1981). Especially, in low density forest stands, if roots are damaged by soil acidification, or immediately after clear-felling, nitrogen mineralization coupled to nitrification and nitrate leaching becomes an important factor in soil acidification (WIKLANDER & NORDLANDER 1991). These processes are temperature related and it is discussed that they may become an important factor for stressing ecosystem stability by uncoupling ion cycles (mineralization, nitrification and root uptake) under changing climatic conditions (GOUDRIAAN & al. 1995).

The impact on terrestrial ecosystems and involved mechanisms require new methods for research, experimental testing and modelling. This study was part of the EU-funded 'CORE'-project (Regulation of organic matter and nutrient turnover in the soil compartment of European forests). Field microcosms were installed along European transects containing undisturbed soil columns to look on the impact of climate and/or atmospheric composition. The central aim of the here presented study was to quantify mineralization and nitrification and its acidifying potential in forest soils.

The investigation was started based on the hypothesis, that acidifying potential of internal processes may exceed that of acidic input by throughfall.

## Material and Methods

### Sites and soils

The soil was collected from the UK (Haldon) (CORE & al. 1992). The forests were Norway spruce (*Picea abies*) at the samling site Haldon and the host site Solling (Germany). There was no significant ground vegetation in any of the forests. Site characteristics are given in Table 1. The soil from Haldon, was a cambico with a moder humus form (thickness of organic layers 3.2 cm  $\pm$ 1). The pH and the molar fractions of exchangeable cations indicated that Haldon soil falls within the cation exchange buffer range (CBR = pH 4.2–5.0) (ULRICH 1986).

## Sampling

Soils were sampled using Plexiglas cylinders (15 cm diam. \* 24 cm deep) fitted onto a metal corer in October 1988 (Figure 1a). After checking that the soil core was undisturbed, the base was trimmed and a cap fitted and sealed with silicone adhesive. The soil solution was sampled by a ceramic cup (P80 of Fa. KPM, Berlin), which was kept at a negative tension of 0.2 to 0.4 bar in 15–20 cm depth. Soils were installed at the Solling site during December 1988 such that the surface of the soil in the cylinder was level with that in the surrounding site Figure 1b.

Table 1  
Characterization of the sites and characteristics of Haldon soil.

Site characteristics													
Site	Latitude	Longitude	Elevation	Precipitation*	Temperature °C*	Stand	Age (years)	Soil texture	Soil type				
Haldon	50°4'N	3°4'W	90 m	1320 mm	11.0	<i>Picea abies</i>	45	clay loam/ silty clay loam	brown soil				
Solling	51°8'N	9°5'E	500m	968mm	6.4	<i>Picea abies</i>	109	silt loam/ silty clay loam	podsolc brown soil				
Soil chemical and soil physical parameters of Haldon soil													
Depth (cm)		pH <sub>H2O</sub>	CEC <sub>e</sub> Σmmol <sub>c</sub> kg DW <sup>-1</sup>	AlX <sub>si</sub> (%)	CaX <sub>si</sub> (%)	KX <sub>si</sub> (%)	MgX <sub>si</sub> (%)	NaX <sub>si</sub> (%)	C (% DW)	N (% DW)	Dry density (g cm <sup>-3</sup> )	pore volume (%)	pore volume (ml)
0-5	MEAN	4.5	99	46	28	3	8.	4	8.3	0.4	1.1	44	362
	SD	0.1	52	20	13	2	3	2	2.1	0.1	0.3	13	112
5-19	MEAN	4.8	83	52	29	4	11	3	2.6	0.2	1.1	40	900
	SD	0.2	13	10	9	1	2	0	0.5	0.0	0.4	13	296

X<sub>si</sub> = molar fractions of exchangeable cations\* = Annual Mean in period March 1989 to March 1990 DW = Dry Weight  
SD = Standard Deviation

## Field installations and analyzation

The experiment started in January 1989 and finished in September 1990. The site operated seven replicates. The covered lysimeters were watered during the course of the experiment once every two weeks with distilled water. The amount of water applied was determined by the volume of throughfall at the site.

Soil solution was collected from each lysimeter at two-week intervals. The solutions from individual lysimeters were collected over a period of three months and combined to proportional samples.

Tab. 1  
Flächenbeschreibung und Beschreibung des Bodens von Haldon.

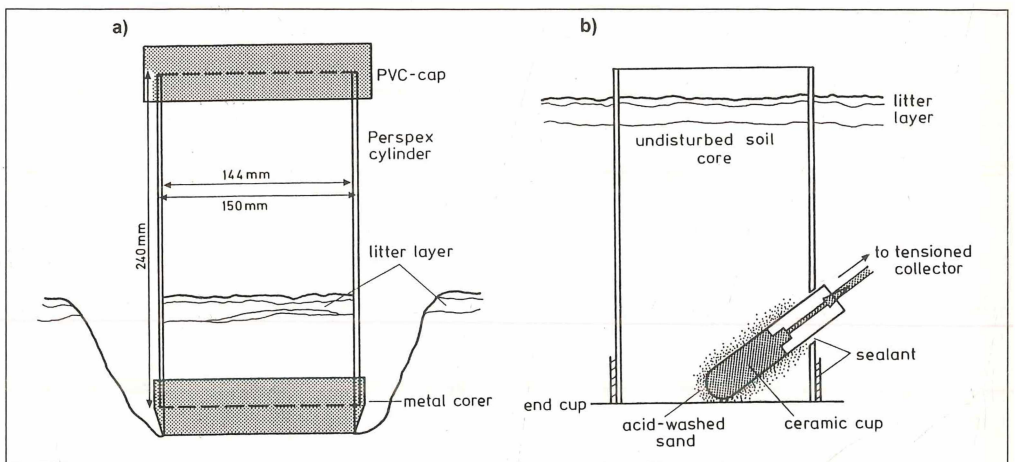


Fig. 1  
Sampling and field installations of microcosms  
a: Sampling of microcosms  
b: Field installations of microcosms.

Abb. 1  
Probenahme und Installation der Mikrokosmen  
a: Probenahme der Mikrokosmen  
b: Installation der Mikrokosmen im Freiland.

Table 2  
Atmospheric input in Solling site and output from with distilled water rained microcosms from Haldon.

Mean and coefficient of variation (CV %) of element input (kmol ha <sup>-1</sup> y <sup>-1</sup> ) by rainfall and throughfall January 1989 to September 1990 in Solling site														
		H <sup>+</sup>	Na	K	Ca	Mg	Al	NO <sub>3</sub> -N	NH <sub>4</sub> -N	∑ N	Cl	SO <sub>4</sub> -S	Ma cations	Acid Degree
Rainfall	Mean	0.34	0.36	0.09	0.22	0.10	0.01	0.55	0.92	1.47	0.39	0.84	1.27	62.0%
	CV %	0.8%	1.8%	5.4%	1.2%	2.8%	0.5%	0.4%	3.2%	2.1%	1.8%	1.3%	2.1%	0.6%
Throughfall	Mean	1.00	0.82	0.64	1.02	0.34	0.10	1.32	1.33	2.66	1.03	2.72	2.44	46.3%
	CV %	9.3%	6.1%	9.8%	3.2%	3.8%	12.2%	6.3%	4.8%	5.5	5.7%	5.2%	2.0%	2.5%
Output from artificially rained Haldon soil (kmol ha <sup>-1</sup> y <sup>-1</sup> ) January 1989 to September 1990														
		H <sup>+</sup>	Na	K	Ca	Mg	Al	NO <sub>3</sub> -N	NH <sub>4</sub> -N	∑ N	Cl	SO <sub>4</sub> -S	Org. Ani.	Acid load
Haldon	Mean	0.05	2.11	0.27	4.13	2.79	0.12	6.96	0.01	6.96	0.73	0.72	1.05	8.73
	CV %	47.9%	15.7%	87.1%	20.2%	13.8%	63.1%	13.8%	244.9%	13.9%	27.6%	37.0%	41.1%	18.2%
Acid Degree = (∑ Ma cations) * (∑ Ma cations + ∑ Mb cations) <sup>-1</sup>							Org. Anions = ∑ cations - ∑ anions			Acid load = ∑ anions				

Tab. 2  
Eintragsbedingungen im Solling und Austräge aus den mit destilliertem Wasser berechneten Mikrokosmen von Haldon.

NH<sub>4</sub><sup>+</sup>Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> were detected by colour reaction in »continuous flow« (Cenco, The Netherlands).

Throughfall was collected within the site. Volume of all water samples was noted in the field and pH (combination electrode) was measured on the day of sampling.

Seven additional soil cores were taken in order to determine initial values of the characteristics for the soil columns. The first 22 cm of the soil cores were separated into surface horizons (Ol, Of, Oh) and mineral horizons (Ah, Aeh, Bv) and then sieved through a 2-mm mesh.

## Results and discussion

ULRICH (1994) defined potential proton donors Ma-cations (Al<sup>3+</sup>, NH<sub>4</sub><sup>+</sup>, H<sup>+</sup>) and neutral salts building Mb cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, N<sup>+</sup>, K<sup>+</sup>) and Acid Degree (AD % = ∑ Ma / (∑ Ma + ∑ Mb) \* 100). In our study, acidic input by Ma-cations doubled to 2.44 kmol ha<sup>-1</sup> y<sup>-1</sup> when deposition passed canopy (Table 2). But Acid Degree decreased. These observations are in accordance to earlier investigations. A limited amount of deposited acidity can be buffered by the canopy through the leaching of cations, such as Ca<sup>2+</sup> and Mg<sup>2+</sup>. Additional dry deposition, due to interception by the canopy, often results in throughfall with a greater potential to acidify than the incident rainfall (LAMERSDORF & MEYER 1993, ULRICH 1994). The data show that Solling was highly polluted by acidifying components like it was reported by other studies (ULRICH 1981, ULRICH 1986, MATZNER 1988, LAMERSDORF & MEYER 1993).

ULRICH (1994) presented a new calculation procedure to calculate Acid Load and to describe under-

lying processes of soil acidification [Sum of a) retention of acid input, b) release of anions, c) retention of deposited Mb-cations]. Under the conditions of zero input for cations and anions (microcosms were artificially rained with distilled water) Acid Load was driven completely by the leaching of anions and reached an average value of 8.73 kmol ha<sup>-1</sup> y<sup>-1</sup> (Table 2). The dominating underlying processes were the N-mineralization and nitrification (6.96 kmol ha<sup>-1</sup> y<sup>-1</sup>) which exceeded external acidic input of Ma-cations drastically (Table 2). These results emphasize the importance of mineralization and nitrification for soil acidification while 1 mol H<sup>+</sup> is produced per mol NO<sub>3</sub><sup>-</sup>. But these values are rough estimations on the basis of the fluxes and they are discussed to overestimate the mineralization processes especially by an initial mineralization push resulting from root cutting. Also other methods for netto-N-mineralization studies are discussed to result in overestimations. RUNGE (1974) used sieved and homogenized samples. Netto-N-mineralization rates were calculated by the difference of mineral N-contents before and after the incubation but it was discussed that the disturbance of soil may lead to overestimation. BAUHUS (1994) used the »Encore«-method and incubated undisturbed soil profiles in covered tubes. This method did not disturb soils by sieving before incubation but may have enhanced mineralization rate by cutting roots by destructive sampling for each investigation period. In the here presented study we intended to avoid an overestimation of mineralization.

In our study patterns of chloride leaching from the covered lysimeters, which had received distilled water instead of throughfall, were used in order to get a detailed and comprehensive description of the acidification potential of the nitrification of mineralized N. Cl<sup>-</sup> can be used as a tracer and is neither

Table 3  
Leaching of chloride and nitrate and calculation of N-mineralization.

Tab. 3  
Chlorid- und Nitratverlust und Berechnung der N-Mineralisation.

Leaching of chloride and nitrate and calculation of N-mineralization							
period	output (ml)	Cl <sup>-</sup> (mg l <sup>-1</sup> )	Cl <sup>-</sup> output (kmol ha <sup>-1</sup> )	Cl <sup>-</sup> (%)	NO <sub>3</sub> <sup>-</sup> -N output (kmol ha <sup>-1</sup> )	stored NO <sub>3</sub> <sup>-</sup> -N (kmol ha <sup>-1</sup> )	mineralized NO <sub>3</sub> <sup>-</sup> -N (kmol ha <sup>-1</sup> )
1. Quarter	1338	32.5	0.52	100	0.42	0.42	0.00
2. Quarter	1781	7.5	0.22	45.1	0.56	0.19	0.37
3. Quarter	1680	6.1	0.17	36.7	1.84	0.15	1.69
4. Quarter	2213	5.1	0.19	41.1	3.74	0.17	3.57
5. Quarter	1442	2.7	0.06	12.6	1.82	0.05	1.77
6. Quarter	2317	1.1	0.04	8.4	1.70	0.04	1.66
7. Quarter	1173	1.1	0.02	4.7	1.53	0.02	1.51
Sum	11944		1.22	248.6	11.61	1.04	10.57
∑ 2.Qu.-7.Qu.				148.6			
stored*			0.03		2.27	0.03	2.24

\* = {∑ Cl<sup>-</sup> % (2.Qu. - 7. Qu.)} \* x (kmol ha<sup>-1</sup>) 100<sup>-1</sup> X = Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup>-N, stored NO<sub>3</sub><sup>-</sup>-N or mineralized NO<sub>3</sub><sup>-</sup>-N

stored nor specifically adsorbed in soils and was therefore used for anion transport investigations and for calculations of element fluxes and budgets in ecosystem studies (BEESE & WIERENGA 1983; MATZNER 1988). As expected chloride-concentration in soil solution decreased after first sampling period dramatically and than distinctly smoother (Table 2). This effect is in accordance to earlier anion transport investigations that maximum of chloride output can be expected within one pore space volume of the soil (BEESE & VAN DER PLOEG 1979, BRUMME 1986). In the first sampling period 1.34 l of soil solution was washed out and exceeded the pore space volume (1.25 l). The experiment was stopped after 20 months when leached volume was 9–10 times of the amount of pore space and the absolute output of chloride decreased down on a level below 5 % of initial chloride leaching in first sampling period and below 2 % of total chloride leaching respectively.

The calculation procedure was simplified on the observation that in this not acidified soil NH<sub>4</sub><sup>+</sup>-loss was nearby zero. The storage of mineralized NH<sub>4</sub><sup>+</sup> was neglected while mineralization and nitrification rate could be set identical (1:1). Furtheron it was assumed that there is no storage form for NO<sub>3</sub><sup>-</sup> and Cl<sup>-</sup> and they show similar transport behaviours as was shown earlier (BEESE & VAN DER PLOEG 1979, BRUMME & BEESE 1991). As well it could be expected that internal N-immobilization by microorganisms is balanced by mobilization with regard to long terms (PENG-CHENG GUO & al. 1983, AUGUSTIN 1991).

The calculations of microbial N-transformations were based on the patterns of absolute chloride leaching (Table 3). The amount of Cl<sup>-</sup> output of the first sampling period was set at 100 % and the

amounts output on the following sampling periods (Quarter n for n = 2–7) were represented as a percentage of this value for each sampling period:

$$\text{Cl}^- \% = (\text{Quarter } n \text{ kmol ha}^{-1}) * (\text{Quarter } 1 \text{ kmol ha}^{-1})^{-1} * 100$$

On this basis the NO<sub>3</sub><sup>-</sup> output was related to the average percentages of Cl<sup>-</sup> output to calculate output of initially stored (NO<sub>3</sub><sup>-</sup>)<sup>stored</sup> for each Quarter: (NO<sub>3</sub><sup>-</sup>)<sup>stored</sup> kmol ha<sup>-1</sup> = (Quarter 1 NO<sub>3</sub><sup>-</sup> kmol ha<sup>-1</sup>) \* (Quarter n Cl<sup>-</sup>%) \* 100<sup>-1</sup>.

The mineralization rate was the difference between NO<sub>3</sub><sup>-</sup> output and leaching of stored nitrate.

The likelihood that not all of the NO<sub>3</sub><sup>-</sup> produced by mineralization in summer 1990 was leached during the experiment was taken into consideration. The nitrate leached during the seventh sampling period was also set for 100 % and the sum of the output averages of the sampling periods 2–7 (148.6 %) were assumed to be the possible nitrate storage. The calculations and results are given in Table 3. The internal proton production resulting from nitrification from mineralized N was estimated at approximately 12.81 kmol<sub>e</sub> ha<sup>-1</sup> and 7.7 kmol<sub>e</sub> ha<sup>-1</sup> y<sup>-1</sup> respectively during the experiment.

The here presented calculation procedure should avoid overestimations as well underestimations for mineralization and nitrification. The setting of leachate as stored for first three months minimized the overestimation caused by sampling and cutting fine roots during sampling in October to November. Underestimation of the processes should be low for two reasons. In first three months when frost occurred frequently, mineralization and nitrification were low, which could lead to a slight underestimation of these processes. Secondly a possible storage of mineralized N at the end of experiment was taken into account.

## Conclusion

To conclude, it could be shown that acidifying potential by mineralization and nitrification in the forest soil from Haldon exceeded that of the acidic input by throughfall under highly polluted conditions of Solling by about three times. The two estimations for N-mineralization presented in this study showed similar results for the whole experimental period of 20 months. By chloride transport calculated mineralization rate exceeded the rate of the fluxes by 0.74  $\text{kmol}_c \text{ ha}^{-1} \text{ y}^{-1}$  what was within the range of the coefficient of variation. Therefore it can be concluded that element fluxes can quantify internal soil processes with regard to long terms. Nevertheless, the values indicate an overestimation of about 20 % for the first year of investigation with an increasing tendency for shorter periods. Therefore the here presented field microcosms connected to the method for modeling mineralization and nitrification rate can be helpful for investigations of mineralization and nitrification processes in soils under field conditions.

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