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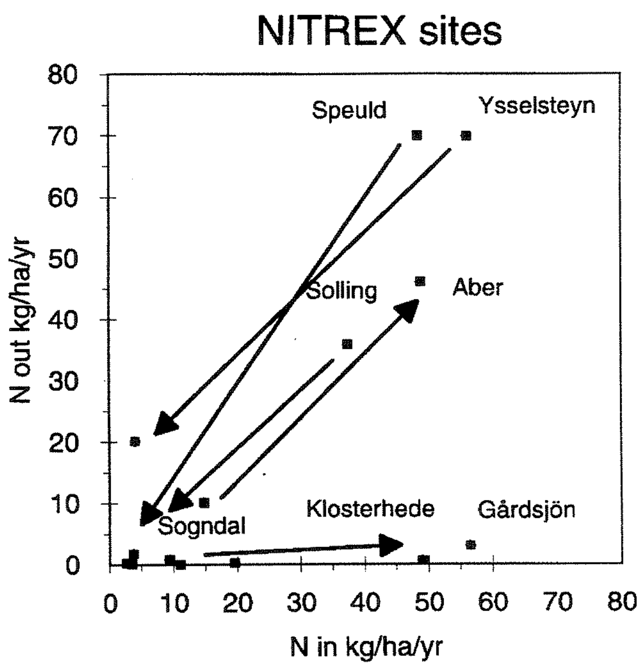
NITREX: Phase 3 Final Report



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Abstract

NITREX-3 comprises the third phase of the European NITREX project (Nitrogen saturation experiments). This report contains the abstracts of work performed during phase 3, which ran from 1 April 1995 - 31 March 1996. The full material will be published in a special issue of *Forest Ecology and Management* the NITREX and EXMAN projects to be published in 1997.

4 keywords, Norwegian	4 keywords, English
1. nitrogen	1. nitrogen
2. vannkjemi	2. water chemistry
3. jord	3. soil
4. skog	4. forest

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Contents

0. Introduction

This report comprises the final report to the Commission of European Communities for NITREX phase 3.

NITREX (Nitrogen Saturation Experiments) began with national funding as parallel large-scale experiments with nitrogen deposition at 8 sites in Europe. These joined to form NITREX with partial funding from the Commission of European Communities, STEP programme, contract number CT90-0056. NITREX phase 1 ran for 24 months from 1 August 1991 to 31 July 1993.

NITREX phase 2 was supported in part by the Commission of European Communities, Environment research programme, contract CT93-0264. NITREX phase 2 ran for 17 months from 1 November 1993 to 31 March 1995.

NITREX phase 3 was supported in part by the Commission of European Communities, Environment research programme, contract CT94-0436. NITREX phase 3 ran for 12 months from 1 April 1995 to 31 March 1996.

This report consists of abstracts of the 18 manuscripts dealing with NITREX submitted to the journal Forest Ecology and Management for the special issue on the NITREX and EXMAN projects. A list of the titles and authors of manuscripts for this issue is given in Appendix A.

1. Compilation of abstracts

1.1 Wright, R.F.[a] and Rasmussen, L.[b] Introduction to the NITREX and EXMAN projects.

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European concern over the cause and consequences of forest decline, acidification of soils and surface waters, and the nutrient enrichment of terrestrial and aquatic ecosystems led to the establishement of the NITREX and EXMAN projects, two research networks of large-scale manipulation experiments under the auspices of the EU Commission of European Communities. NITREX (Nitrogen saturation experiments) comprises 10 experiments at 8 sites in 7 countries at which nitrogen is either added to or removed from ambient atmospheric deposition to simulate major changes in nitrogen deposition. EXMAN (Experimental Manipulation of Forest Ecosystems in Europe) comprises experiments at 6 sites in 4 countries at which ambient atmospheric deposition is experimentally altered in chemical composition and/or quantity. The ultimate goal of this research is to contribute to the scientific basis required for the refinement of EU policy on atmospheric quality and the legislation which will emanate from that policy.

Key words: forest, soil, water, nitrogen, sulphur, drought, experiment, ecosystem

1.2 Emmett, B.A.,[1] Kjønaas, O.J.,[2] Gundersen, P.,[3] Koopmans, C.,[4] Tietema, A.,[4] and Sleep, D.[5] Natural abundance of ^{15}N in forests across a nitrogen deposition gradient.

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Chronic atmospheric nitrogen deposition can alter the rate of internal nitrogen cycling and increase the magnitude of N leaching losses in forested ecosystems. As fractionation of nitrogen in favour of the lighter ^{14}N is known to occur during various transformations associated with N-enrichment and nitrogen loss, it has been proposed that the ^{15}N signal of vegetation may provide a useful tool in evaluating the past and current N status of forested ecosystems. A series of nitrogen deposition manipulation experiments in coniferous forests within the NITREX project provided an opportunity to test the relationships between nitrogen supply from atmospheric deposition, soil N transformations, and the relative ^{15}N-enrichment of vegetation to soil, across a large geographical area. $\delta^{15}N$ values for above-and below-ground tree components, soil at four depths, bulk precipitation and/or throughfall water and soil solution or outflow water are presented. Most values were within those observed elsewhere except for a few notable exceptions which are discussed. When the relationship between ^{15}N enrichment in the vegetation and soil pools was investigated, a highly significant positive relationship between the $\delta^{15}N$ enrichment of the tree foliage relative to the upper two soil horizons (or the enrichment factor), and nitrogen in the throughfall was observed, with the exception of one outlying site in N.Wales; Aber forest. An unusually high enrichment factor at the Welsh site was attributed to the high rate of N cycling at the site in excess of that predicted from N deposition, due to ploughing of the site prior to tree planting, the associated effects on soil biological functioning, and an unusually high stand density. Highly significant relationships ($P < 0.01$) between enrichment factors and the litterfall N flux, N uptake by trees, temperature and nitrification rates in upper soil horizons, were identified across all the sites including Aber, supported this conclusion. There therefore appears to be a strong link between the rate of N cycling and the $\delta^{15}N$ enrichment factor, rather than N deposition or nitrate leaching *per se*. These results confirm the potential use of the $\delta^{15}N$ enrichment factor to identify sites influenced by nitrogen deposition in the short to medium term (5 - 30 years). However, care has to be taken when comparing across sites that other vegetation characteristics and land management practises which also influence soil N dynamics and N cycling are taken into consideration.

1.3 Tietema, A.,[1] Emmett, B.A.,[2] Gundersen, P.,[3] Kjønaas, O.J.[4] and Koopmans, C.[1] The fate of ^{15}N-labelled nitrogen deposition in coniferous forests.

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4. Norwegian Forest Research Institute, Høgskoleveien 12, 1432 Ås, Norway,

As part of four European ecosystem manipulation experiments in coniferous forests, fieldscale ^{15}N tracer experiments have been carried out. The experiments involved a year-round addition of ^{15}N to experimental plots with different N inputs. The fate of this applied throughfall-^{15}N in the important ecosystems pools trees, ground vegetation, forest floor and mineral soil, as well as in drainage is discussed.

In the studied forests 10-30% of throughfall N was taken up by the trees and 10-15% was retained in the mineral soil. Both retention rates were found to be independent of the N input. The part of throughfall-N retained in the organic layer was relatively high (20-45% of applied) at low N inputs (0-30 kg N ha^{-1} y^{-1}) and low (10-20%) at high N inputs (30-80 kg N ha^{-1} y^{-1}). The relation between the loss of throughfall-N and the N input was complementary to the relation between the retention in the organic layer and N input: throughfall-N losses by drainage increased as a function of N input. These results suggest that at increased N inputs the retention capacity of the microbial population responsible for the retention of throughfall-N in the organic layer was exceeded, which eventually resulted in increased N leaching.

1.4 Tietema, A. Microbial carbon and nitrogen transformations in litter from coniferous forest ecosystems along an atmospheric nitrogen input gradient.

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Microbial C and N cycling was studied in litter from five coniferous forests, situated along a present-day gradient of N deposition across northwestern Europe. Results from the European NITREX project, a consortium of eight field-scale manipulation experiments with N deposition, indicated that three of these sites could be considered to be N saturated, whereas the other two sites were N limited.

Compared to the N saturated sites, microbial C and N cycling in N limited sites was characterized by low gross NH_4^+ transformation rates, low respiration rates, high microbial C efficiencies and high microbial C:N ratios. In none of the litters, a significant microbial immobilization of NO_3^- was detected.

Keywords: Microbes; Carbon, Nitrogen; NITREX; Coniferous forest; Litter

1.5 Gundersen, P.,[1] Emmett, B.A.,[2] Kjønaas, O.J.,[3] Koopmans, C.J.,[4] and Tietema, A.[4] Impact of nitrogen deposition on nitrogen cycling in forests: a synthesis of NITREX data.

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Impact nitrogen (N) deposition was studied by comparing N fluxes, N concentrations and N pool sizes in vegetation and soil in five coniferous forest stands at the NITREX sites: Gårdsjön (GD), Sweden, Klosterhede (KH), Denmark, Aber (AB), Wales, UK, Speuld (SP), the Netherlands, and Ysselsteyn (YS), the Netherlands. The sites span a N deposition gradient from 13 to 59 kgN $ha^{-1}yr^{-1}$. Measurements of soil N transformation rates by laboratory and field incubations were part of the site comparison. Further, results from 4-5 years of NH_4NO_3 addition (35 kgN $ha^{-1}yr^{-1}$) at low deposition sites (GD, KH, AB) and 6-7 years of N removal (roofs) at high deposition sites (SP, YS) were included in the analysis.

Significant correlations were found between a range of variables including N concentrations in foliage and litter, soil N transformation rates and forest floor characteristics. A principal component analysis (PCA) summarized these variables to one variable interpreted as an indicator of site N status that asigned the lowest N status to GD and the highest to YS. Site N status increased with N deposition with the exception that AB was naturally rich in N. Nitrate leaching was significantly correlated with N status but not correlated with N deposition. Forest floor mass and root biomass decreased with increased N status. Characteristics of the mineral soil were not correlated with vegetation and forest floor variables. High C/N ratios in the mineral soil at the high N deposition sites (SP, YS) suggest that the mineral soil pool change slowly and need not change for N saturation to occur. Nitrogen transformation rates measured in laboratory incubations did not compare well with rates measured in the field except for a good correlation between gross mineralization in the laboratory and net mineralization in the field.

The of changes in N concentrations and fluxes after manipulation of N input followed the direction expected from the site comparison: increases at N addition and decreases at N removal sites. Nitrate leaching responded within the first year of treatment at all sites, whereas responses in vegetation and soil were delayed. Changes in N status by the manipulation treatments were small compared to the differences between sites. Changes in nitrate leaching were small at the low N status sites and substantial at the high N status sites. By the analysis, N limited and N saturated forest ecosystems could be characterized quantitatively. The findings supported and refined the current N saturation hypothesis.

1.6 Bredemeier, M.,[a] Blanck, K.,[a] Xu, Y-J.,[a] Tietema, A.,[b] Boxman, A.,[c] Emmett, B.A.,[d] Moldan, F.,[e] Gundersen, P.,[f] Schleppi, P.[g] and Wright, R.F.[h] Input/Output budgets at the NITREX sites.

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[b] Landscape and Environmental Resaerch Gruop, University of Amsterdam, Nieuwe Prinsengracht 130, NL-1018 VZ Amsterdam, Netherlands

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This paper considers input/output budgets of chemical constituents across the NITREX ecosystem research network. The sites cover gradients of maritime to inland climates, lowland to alpine elevations, and low to high anthropogenic atmospheric deposition levels in northern and central Europe. Scenarios of changing N (and S) deposition are simulated by experimental manipulations of input fluxes to the soils. Nitrogen addition is performed at various levels; input reduction is acheived by means of roof installations with application of artificially prepared "clean rain" underneath the roofs. The paper focuses on the regional differences of budgets at the control sites and changes in the nitrogen budgets of the manipulated ecosystems.

The results from the budget studies indicate that nitrogen saturation has been attained in many forest ecosystems under high anthropogenic N load in Europe, as evidenced by N leaching losses balancing or even exceeding actual inputs. Nitrogen inputs largely govern outputs in saturated forest ecosystems. The response to experimental input manipulations in such systems is strong and rapid. The results indicate that emission reductions will directly improve environmental conditions by reducing nitrogen output in seepage and runoff waters.

key words: nitrogen, deposition, outputs, ecosystem, experiments, Europe

1.7 Boxman, A.W.,[a] Blanck, K.,[b] Brandrud, T.E.,[c] Emmett, B.A.,[d] Gundersen, P.,[e] Hogervorst, R.,[f] Kjønaas, O.J.,[g] and Persson, H.A.[h] Cross-site comparison of vegetation and soil biota responses to experimentally changed nitrogen inputs in coniferous ecosystems in the EC-NITREX project.

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Enhancement of the atmospheric nitrogen deposition is a serious threat for the structure and function of ecosystems. In this paper ecological effects of excess nitrogen are evaluated with respect to changes in vegetation and soil biota in a serie of experiments along a nitrogen gradient across Europe. The aim of this project (NITREX - NITRogen saturation EXperiments) is to assess either the risk of nitrogen saturation or the reversibility of nitrogen saturation. At the experimental sites with a low input, nitrogen was added (n=3), while at sites with a high input, nitrogen was removed by means of a transparent roof (n=4). The experiments have started between 1989 and 1991. Across the nitrogen gradient a positive correlation was found between the deposition or soil solution chemistry of nitrogen with the nitrogen concentration in the needles and in general a negative correlation with the base cations potassium and magnesium. In the addition plots there was a tendency towards a deteriorating nutrient status of the needles, whereas at one site effects of a input reduction led to an improvement. Addition of nitrogen hardly effected fine-root biomass production, whereas signs of recovery were recorded when the input was reduced. Tree growth was accelerated upon input reduction at two (out of three) sites. Manipulation of the nitrogen input did not alter the decomposition rate, although significant differences between sites were noticed. A clear negative relation was found between the nitrogen input and soil fauna among the sites, but manipulation of the nitrogen input hardly affected the biomass of fungi and bacteria, but a negative relation between the nitrogen input and part of the soil fauna may be present among sites.

Keywords: decomposition, fine-roots, ground vegetation, mycorrhizae, nitrogen addition, nitrogen removal, conifers, soil fauna

1.8 Reynolds, B.,[1] Wilson, E.J.,[2] and Emmett, B.A.[1] Evaluating critical loads of nutrient nitrogen and acidity for terrestrial systems using ecosystem-scale experiments (NITREX).

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Critical loads (CL) for nitrogen as a nutrient (CL_{nut}(N)) and total acidity (CL(S+N)) for the terrestrial ecosystem have been calculated and evaluated for all NITREX sites. NITREX constitutes a series of N addition or removal experiments in coniferous forest stands and one alpine site across a European deposition gradient (2 - 60 kgN ha^{-1} yr^{-1}). As S and N inputs have been experimentally manipulated at these sites, they provide a valuable opportunity to test the validity of the mass balance approach to computing CLs at the ecosystem scale. CL_{nut}(N) values calculated using the sustainability (nutrient limitation) approach were 3 - 8 kgN ha^{-1} yr^{-1} for sites on acidic geology, and 19 kgN ha^{-1} yr^{-1} for sites on basic geology. Where N uptake was computed using N removed in bolewood, critical load values increased to 11 - 15 kgN ha^{-1} yr^{-1} for acidic sites. These values will increase substantially if whole-tree rather than stem-only harvesting is employed. Mean annual uptake rates of nitrogen into bolewood were observed to be in excess of sustainable sources of phosphorus at all sites indicating the probable need for fertiliser applications in the long-term. CL(S+N) values were computed as 1.7 - 6.9 keq ha^{-1} yr^{-1} reflecting differences in weathering rates, deposition and uptake of base cations, and the $(Ca+Mg+K)/Al_{crit}$ ratio in soil solution for the dominant vegetation at the various sites. Comparison of ambient deposition loadings and calculated CL values indicated that the sites were in three categories; (1) sites with deposition below both CL_{nut}(N) and CL(S+N) (Sogndal and Alptal), (2) sites where deposition was equal to or exceeded CL_{nut}(N) but not CL(S+N) (Gårdsjön, Aber and Klosterhede, and (3) sites in which both CL_{nut}(N) and CL(S+N) were exceeded (Speuld, Solling and Ysselsteyn). Exceedance of CL_{nut}(N) was positively related to nitrate leaching if the larger CL_{nut}(N) values were used, highlighting the importance of this removal pathway for excess nitrogen in coniferous forest ecosystems. With respect to CL(S+N), there was some evidence of a link between observed changes in nutritional balance and root functioning at one site in which the (Ca+Mg+K)/Al ratio had increased following reductions in S+N deposition. Evidence at other sites was less clear as shifts in (Ca+Mg+K)/Al ratio and recovery in ecosystem functioning were surprisingly slow following major changes in acidic deposition. This demonstrates that long term experiments are extremely important in ecosystem scale work and essential if current approaches to calculating CLs are to be rigorously tested.

1.9 Boxman, A.W., van der Ven, Paul J.M., and Roelofs, J.G.M. Ecosystem recovery after a decrease in nitrogen input to a Scots pine stand at Ysselsteyn, the Netherlands.

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In a highly nitrogen-saturated Scots pine stand atmospheric nitrogen input to the forest floor was reduced to pre-industrial levels by means of a transparent roof. Since 1989 clean, simulated throughfall water was given below the roof thus reducing the nitrogen input from ±60 kg N ha^{-1} yr^{-1} to <5 kg N ha^{-1} yr^{-1}. The aim of this experiment (which is part of the EC-NITREX project) is to assess the reversibility of nitrogen saturation. The results of this experiment showed a close correlation between the input and output of nitrogen. The timing of this response is fast in contrast to the vegetation response which lags for some years. After this lag-phase signs of ecosystem recovery were noticed. The nitrogen concentration in the needles tended to decline while the nutritional balance in the needles improved. In this respect free arginine-N concentrations in the needles may be indicative for tree response to changes in nitrogen input. Although the total-nitrogen concentration in the needles is still high, the first signs of recovery could be noticed by the rapid drop in arginine-N concentrations. The trees have reacted with a growth improvement, significantly correlated with decreasing arginine-N concentrations. The aboveground biomass of the nitrophilous groundvegetation decreased distinctly during the experimental period, whilst there was a re-colonization of fruitbodies of mycorrhizal fungi. Ecosystem recovery from nitrogen saturation is a slow, but ongoing process and it may take many years before the ecosystem conditions meet our requirements.

Keywords: NITREX, ecosystem response, mycoflora, nitrogen removal, tree-growth, groundvegetation

1.10 Gundersen, P. Effects of enhanced N deposition in a spruce forest at Klosterhede, Denmark, examined by moderate NH_4NO_3 addition.

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The fate and effects of increased N deposition were investigated by experimental manipulation in a mature Norway spruce plantation at Klosterhede, western Denmark. Ambient N deposition was 15-20 kg N $ha^{-1}yr^{-1}$. Addition of 35 kg N $ha^{-1}yr^{-1}$ as ammonium nitrate to a 500-m^2 plot was carried out by handspraying monthly for 4 years. During the first year the spray was label with ^{15}N.

Tree growth was depressed by 4 successive spring or summer droughts throughout the treatment years. Nitrogen concentration in needles increased in the third year of treatment and a P deficiency (0.6-1 mg P g^{-1}) developed possibly as a combined effect of drought and N stress on roots and mycorrhiza. Reduced retranslocation of N was indicated by increased concentration and flux of N in needle litterfall. Increased uptake of deposition N was observed in all parts of the trees and the fraction of the deposition taken up was increased from 32 to 43%, whereas the fraction immobilized in the soil was decreased from 40 to 33% of the deposition N.

Decomposition remained unchanged, whereas net N mineralization was increased 85% over the control. The effect on net mineralization may have resulted from saturation of the immobilization process and rather than from an increase in gross mineralization. The CO_2 efflux and thus soil respiration was not affected indicating unchanged microbial activity. Nitrification and denitrification were not important processes in either control or treated soils.

Soil solution chemistry responded promptly to the nitrogen application. Nitrate concentrations increased at all depths, and nitrate leaching increased from <.3 to 4.2 kg N $ha^{-1}yr^{-1}$ by the third year. Reduced biological control on nitrate leaching was indicated by increased nitrate concentration in soil water at the end of the growing season. Ammonium concentrations were increased down to 15 cm depth, but all ammonium was retained in the system. Despite the increased nitrate leaching, 92% of the total inputs were retained. No changes in concentrations of other major ions due to the N additions were detectable. The effects of the successive droughts on growth and nutrient cycling caused significant interaction on the response to N addition. Continuation of the N addition treatment will be necessary to observe the full response of the simulated deposition increase in this forest.

Key words: drought, mineralization, ^{15}N, NITREX-project, nitrate leaching, nitrogen cycling, Norway spruce, nutrient deficiency, phosphorous.

1.11 Emmett, B.A.,[1] Reynolds, B.,[1] Silgram, M.,[2] Sparks, T.[3] and Woods, C.[4] The consequences of chronic nitrogen additions on N cycling and soilwater chemistry in a N saturated Sitka spruce stand.

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Major changes in soil water chemistry and dissolved nitrogen fluxes during five years of weekly applications of nitrogen to the forest floor of a 30 year-old Sitka spruce in N.Wales are described. Nitrogen was applied as sodium nitrate at rates of 35 and 75 kgN ha^{-1} yr^{-1} and ammonium nitrate at 35 kgN ha^{-1} yr^{-1}, representing either a 125% or 270% increase in total nitrogen deposition. A close relationship was observed between nitrate inputs and leaching losses from below the rooting zone over the five year period despite mobilisation of nitrogen from upper soil horizons in N treatments for two years. This was due to retention of the mobilised nitrogen in lower mineral horizons. The long-term stability of the nitrogen retained in the mineral horizons is not known but, after five years, there has been no positive feedback of nitrogen deposition on nitrogen leaching as a result of changes in soil N dynamics in these horizons. Other consequences of nitrogen and high salt loading were acidification of forest floor leachate in the ammonium nitrate treatment and elevated aluminium and hydrogen ion concentrations in the mineral soil in all N treatments due to ion exchange reactions. These effects were not persistent in the highest N treatment possibly because of exhaustion of the pool of freely exchangeable aluminium due to the prolonged salt loading. Persistent reductions in Ca/Al and (Ca+Mg+K)/Al ratios were however observed in the AN35 treatment. Decreases in DOC and iron concentrations, associated with the acidification of the mineral horizons, were also observed in some treatments. As no effect on tree growth has been observed to date, the main implications of elevated nitrogen deposition are predicted to be a decline in streamwater quality, although treatments continue at Aber to resolve long-term implications for tree growth.

1.12 Schleppi, P.,[a] Muller, N.,[a] Feyen, H.,[b] Papritz, A.,[b] Bucher, J.[a] and Flühler, H.[b] The nitrogen addition experiment at Alptal, Switzerland.

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As a part of the European NITREX project, a nitrogen addition experiment was set up in an alpine spruce forest in the Alptal valley (central Switzerland). The site is located at an altitude of 1200 m and has an average of 2300 mm precipitation a year. It is moderately impacted by atmospheric nitrogen deposition: 12 kg N ha^{-1} $year^{-1}$ bulk deposition (nitrate and ammonium). Two different gley soils occur atop a Flysch substratum. The spatial heterogeneity of the soil is related with both the microtopography of the site and the vegetation.

The NITREX experiment is run as a collaboration between the Swiss Federal Institute for Forest, Snow and Landscape Research in Birmensdorf and the Institute for Terrestrial Ecology of the ETH Zurich. It aims to simulate higher atmospheric nitrogen deposition rates by chronically treating a small headwater catchment (approx. 1500 m^2) with a solution of ammonium nitrate (40 kg N ha^{-1} $year^{-1}$). The small treatment and control catchments were made by digging 80 cm deep trenches into the shallow gleyic soils of the site. Because of the low permeability of the clay-rich subsoil, these trenches are able to collect the lateral water flow generated in the plots. The catchments were equipped with gauging stations (V-notch weirs) and automatic, runoff-proportional water samplers. Along with meteorological parameters and deposition measurements, the water and solute discharge were monitored during one reference year before starting the nitrogen treatment.

A correct water balance was obtained from the experimental catchments. It allows the calculation of biogeochemical element cycles. The leaching of mineral nitrogen was estimated to be 4 kg N ha^{-1} $year^{-1}$, mainly as nitrate. It is, however, not clear if this nitrate is leached because the ecosystem is already nitrogen saturated. Quick preferential water flow occurs through the soils of the site and this may allow nitrate from rain or snowmelt to bypass the soil matrix and directly enter the water runoff pathways.

Both mini-catchments were shown to behave similarly. The time series of the reference period will thus allow us to quantitatively assess the effects of the ongoing nitrogen addition.

Keywords: Nitrogen cycling; Forest ecosystem; Headwater catchment; NITREX project

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1.13 Moldan, F.,[a] Wright, R.F.[b] Changes in runoff chemistry after five years of N addition to a forested catchment at Gårdsjön, Sweden.

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Deposition of N from the atmosphere to coniferous forests poses the risk of N saturation and disruption of the N cycle. The risk and consequences of N deposition is the focus of the NITREX experiment at Gårdsjön, SW Sweden. Beginning April 1991 we have added in weekly portions about 40 kg NH_4NO_3-N ha^{-1} yr^{-1} in 5% extra water to the ambient 11 kg NH_4 NO_3-N ha^{-1} yr^{-1} in throughfall. The Gårdsjön experiment is part of the European NITREX project (Nitrogen saturation experiments).

Concentrations of nitrate in runoff have increased dramatically in response to the chronic additions of N. Both annual mean concentrations and peak concentrations have increased every year. Both the seasonal pattern and the yearly amount of N loss have changed during the 5 years of treatment. Whereas during the first years of treatment concentrations of nitrate were low during the growing season and high during the winter, during the 4th and 5th year of treatment elevated concentrations were present also during the summer. Ammonium concentrations, although generally much lower than NO_3^-, followed the same seasonal pattern. The inorganic nitrogen lost during the five years of treatment was 0.6%, 1.1%, 5.0%, 5.7% and 4.5% respectively, of the annual inorganic N input. In the fifth year drought and generally very low runoff led to only moderate N loss despite high NO_3^- and NH_4^+ concentrations. Sulphate and inorganic Al also showed significantly lower concentrations during the treatment period relative to the untreated control catchment.

The N input-output data indicate that the forested catchment ecosystem G2 NITREX has proceeded rapidly through several stages of "nitrogen saturation". Both, the frequency and magnitude of nitrate peaks in runoff increased during the non-growing season in the first year and throughout the second year. The results from NITREX Gårdsjön demonstrate that N saturation can be induced over a relatively short time by increasing atmospheric deposition of N. The rate of response suggests that at ambient N deposition of 11 kg inorganic N ha^{-1} yr^{-1} the ecosystem is near the threshold at which additional N inputs cause significant nitrate leaching.

Key words: nitrogen, NITREX project, Norway spruce, Sweden, water, catchment

1.14 Persson, H., Ahlström, K. and Clemensson-Lindell, A. Fine-root response to nitrogen addition and removal at Gårdsjön - results from ingrowth cores.

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Investigations were carried out on the experimental impact on Norway spruce fine-root growth in three catchment areas subjected to decreased nitrogen and sulphur deposition (G1 ROOF), increased nitrogen deposition (G2 NITREX) and ambient levels of nitrogen and sulphur deposition (F1 CONTROL), respectively, within the Lake Gårdsjön basin, SW Sweden. Root sampling was performed using ingrowth cores, which were installed and resampled in two year intervals at three catchments.

There was a gradual, in most cases significant, decline in fine-root growth in the F1 CONTROL catchment from 1991 onwards, whereas reduced nitrogen and sulphur deposition in the G1 ROOF resulted in a tendency towards stabilisation and a gradual recovery. The G2 NITREX exposed to increased nitrogen and sulphur exhibited also a tendency towards decline, but not as consistent as for the F1 CONTROL. Similar ingrowth pattern was shown in both *Vaccinium myrtillus* and *Dicranum* dominated parts of all catchments. Considerable differences in the two year ingrowth pattern were found in all catchments except for the G1 ROOF.

1.15 Brandrud, T.E.,[a] and Timmermann, Vo.[b] Ectomycorrhizal fungi in the NITREX site at Gårdsjön, Sweden; below and above-ground responses to experimentally changed nitrogen inputs 1990-1995.

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Botanical Garden & Museum, University of Oslo, Trondheimsvn. 23B, 0560 Oslo

Changes in the above-ground ectomycorrhizal fruit body production and below-ground mycorrhizal fine roots densities were studied Norway spruce forest at Gårdsjön, W Sweden 1990-1995, in experiments with addition and removal of ammonium nitrate, as part of the NITREX programme.

The addition and removal of N led to almost mirror image effects, with a rapid and substantial decrease versus increase in fruit body production of most species, representing one of very few biological responses to the treatments at Gårdsjön. In the N-addition treatment (NITREX), a considerably decrease in species diversity was also seen, with almost disappearance of stress-intolerant groups such as *Cortinarius* after five years of treatment. Only one, dominant, apparently nitrophilous species (*Cantharellus tubaeformis*) increased fruit body production after treatment.

No response to the treatments were found in the below-ground mycorrhiza and fine root density, vitality and diversity. The fine roots were 100% mycorrhiza infected. The very different response above-ground and below-ground indicates that (i) the fruit body producing macrofungi plays a minor role below-ground (ca. 90% or more of the mycorrhizae are formed by non-fruit body producing fungi), and that (ii) there is probably a considerable lag-time in the mycorrhizal fine root versus fruit body production response to enhanched N-levels.

1.16 Stuanes, A.O.[1] and Kjønaas, O.J.[2] Soil solution effects after four years addition of NH_4NO_3 to a forested catchment at Gårdsjön, Sweden.

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Nitrogen has been added to a forested 0.52 ha headwater catchment at Gårdsjön, Sweden, to study the ecosystem response to elevated nitrogen deposition. The catchment is dominated by naturally generated, mixed-age conifers, mainly Norway spruce, with Scots pine in dry areas. After a pre-treatment period of about 1 year, nitrogen was added to the whole catchment as ammonium nitrate by means of sprinklers. Total nitrogen input as throughfall to the catchment increased from the ambient 13 kg N ha^{-1} yr^{-1} in the pre-treatment year to a total of about 50 kg N ha^{-1} yr^{-1} in the treatment years. Soil solutions were collected using tension lysimeters at four locations covering a moisture gradient from the dry upper to the wet lower parts of the catchment. Results from these locations were compared with soil solution composition at two locations in a nearby control catchment and with two locations in an adjacent catchment where the ambient deposition is kept out by a roof and unpolluted precipitation added by sprinklers. After 4 years of nitrogen addition, the volume-weighted average nitrate concentrations in the treated catchment were higher than the pre-treatment values. Concentrations showed a progressive increase over time. In the two first treatment years this increase was only measured in the rooting zone but during the two last treatment years a pronounced increase was also seen in deeper layers. The lack of the same increasing trends in the control and roof catchments precludes natural variations in climatic conditions as the main cause for this increase. Relative to inputs, nitrate concentrations in soil solution were low and showed large variations between the drier and wetter locations with peak concentrations in late fall and spring. Nitrate in soil solution generally constitute less than 10 % of the inorganic mobile anions and thereby contribute much less to the leaching of H^+, Al, and base cations than chloride and sulfate which are the driving mobile anions. Soil solution ammonium has not changed compared to the control and roof catchments. The soil solution nitrate concentrations below the rooting zone do not meet the criteria for nitrogen saturation.

Keywords: Soil solution response; Nitrogen addition; NITREX project.

1.17 Kjønaas, O.J.,[1] Stuanes. A.O.,[2] and Huse, M.[1] Effects of chronic nitrogen additions on N cycling in a coniferous forest catchment, Gårdsjön, Sweden.

[1]Norwegian Forest Research Institute,
Høgskoleveien 12, N-1432 Aas, Norway

[2]Agricultural University of Norway,
Department of Soil and Water Sciences, N-1432 Aas, Norway

To study the ecosystem response to elevated chronic nitrogen deposition, nitrogen was added to a 0.52 ha forested headwater catchment in Gårdsjön, Sweden. The catchment was dominated by naturally generated, mixed-age Norway spruce, with Scots pine in dry areas. After a pre-treatment period of about one year, nitrogen was added to the whole catchment as ammonium nitrate in weekly portions by means of sprinklers. Total nitrogen input as throughfall increased from the ambient 13 kg N ha-1 yr.-1 in the pretreatment year to a total of about 50 kg ha-1 yr.-1 in the treatment years. The impact of increased nitrogen deposition on soil nitrogen transformation, nitrogen status of the vegetation, leaching of nitrate in the upper soil profile, and nitrogen cycling was studied and compared to a nearby control catchment and an adjacent catchment with a roof beneath the canopy. No effect of nitrogen addition was found in the nitrogen content of foliage and litter, or on the total weight of litterfall. There was a significant increase in net mineralization in all the three subplots of the nitrogen manipulated catchment the third year of treatment, and the variation of nitrogen transformation rates within the nitrogen manipulated catchment was large. No significant difference between years was found in the control catchment. A highly significant correlation was found between nitrate concentrations in 20 cm lysimeter water and ion exchange resins from incubated soil cylinders during the dormant season. Output of both nitrate and ammonium from the soil cores during winter was significantly larger in the nitrogen manipulated catchment relative to subplots with similar ground vegetation and moisture regime in the control and roof catchments. Although the output of nitrate increased especially during dormant season, the major part of the inorganic nitrogen was still retained within the system. The dominant sink for both externally added and internally produced inorganic nitrogen was found to be the soil organic matter.

Keywords: Nitrogen addition; Nitrogen cycling; Soil nitrogen transformation; NITREX project

Appendix A. Manuscripts submitted for NITREX/EXMAN special issue of Forest Ecology and Management

1. Wright, R.F. and Rasmussen, L. Introduction to the NITREX and EXMAN projects.

Integration papers NITREX

2. Emmett, B.A., Kjønaas, O.J., Gundersen, P., Koopmans, C., Tietema, A. and Sleep, D. Natural abundance of ^{15}N in forests across a nitrogen deposition gradient.
3. Tietema, A., Emmett, B.A., Gundersen, P., Kjønaas, O.J. and Koopmans, C. The fate of ^{15}N-labelled nitrogen deposition in coniferous forests.
4. Tietema, A. Microbial carbon and nitrogen transformations in litter from coniferous forest ecosystems along an atmospheric nitrogen input gradient.
5. Gundersen, P., Emmett, B.A., Kjønaas, O.J., Koopmans, C.J., and Tietema, A. Impact of nitrogen deposition on nitrogen cycling in forests: a synthesis of NITREX data.
6. Bredemeier, M., Blanck, K., Tietema, A., Boxman, A., Emmett, B.A., Kjønaas, O.J., Moldan, F., Gundersen, P., Schleppi, P. and Wright, R.F. Input/Output budgets at the NITREX sites.
7. Boxman, A.W., Blanck, K., Brandrud, T.E., Emmett, B.A., Gundersen, P., Hogervorst, R., Kjønaas, O.J., Persson, H.A. and Stuanes, A.O. Cross-site comparison of vegetation and soil biota responses to experimentally changed nitrogen inputs in coniferous ecosystems in the EC-NITREX project.
8. Reynolds, B., Wilson, E.J. and Emmett, B.A. Evaluating critical loads of nutrient nitrogen and acidity for terrestrial systems using ecosystem-scale experiments (NITREX).

Site-specific papers NITREX

9. Boxman, A.W., Van der Ven, P.J.M. and Roelofs, J.G.M. Ecosystem recovery after a decrease in nitrogen input to a Scots pine stand at Ysselsteyn, the Netherlands.
10. Gundersen, P. Effects of enhanced N deposition in a spruce forest at Klosterhede, Denmark, examined by moderate NH_4NO_3 addition.
11. Emmett, B.A., Reynolds, B., Silgram, M., Sparks, T. and Woods, C. The consequences of chronic nitrogen additions on N cycling and soilwater chemistry in a N saturated Sitka spruce stand.
12. withdrawn.
13. Schleppi, P., Muller, N., Feyen, H., Papritz, A., Bucher, J. and Flühler, H. The nitrogen addition experiment at Alptal, Switzerland.
14. Moldan, F. and Wright, R.F. Changes in runoff chemistry after 5 years of N addition to a forested catchment at Gårdsjön, Sweden.
15. Persson, H., Ahlström, K. and Clemensson-Lindell, A. Fine-root response to nitrogen addition and removal at Gårdsjön - results from ingrowth cores.
16. Brandrud, T.E. and Timmermann, V. Ectomycorrhizal fungi in the NITREX site at Gårdsjön, Sweden; below and above ground responses to experimentally changed nitrogen inputs 1990-1995.
17. Stuanes, A.O. and Kjønaas, O.J. Soil solution effects after four years addition of NH_4NO_3 to a forested catchment at Gårdsjön, Sweden.
18. Kjønaas, O.J., Huse, M. and Stuanes, A.O. Effects of chronic nitrogen additions on N cycling in a coniferous forest catchment, Gårdsjön, Sweden.

Integrated papers EXMAN

19. Beier, C., Blanck, K., Bredemeier, M., Lamersdorf, N., and Rasmussen, L. Responses of soil and vegetation to reduced input of S, N, and acidity to two Norway spruce stands of the EXMAN project.
20. Lamersdorf, N.P., Beier, C., Blanck, K., Bredemeier, M., Cummins, T., Farrell, E.P., Rasmussen, L., Ryan, M., and Xu, Y. Drought experiments by roof installations in European forest ecosystems.
21. Kreutzer, K., Weis, W., et al. Characterization of the EXMAN sites by their ion budgets.
22. Withdrawn.
23. Withdrawn.
24. Warfvinge, P., Walse, and Sverdrup, H. Biogeochemical modelling of the EXMAN sites -- experiences and constraints.

Site specific papers EXMAN

25. Ahrene, J., Sverdrup, H., Farrell, E.P., and Cummins, T. Modelling soil chemistry at Ballyhooly.
26. Beier, C. Water and element fluxes calculated in a sandy forest soil in Denmark taking spatial variability into account.
27. Walse, Warfvinge, P., Blanck, K., Bredemeier, M., and Lamersdorf, N. Application of the SAFE model to the Solling clean rain roof project.
28. Warfvinge, P. et al. Modelling the effects of acid deposition and irrigation on the biogeochemistry at the Höglwald spruce stand, Bavaria, Germany..
29. Bredemeier, M., Blanck, K., Lamersdorf, N.P., Wiedey, G.A. The Solling roof experiments - site characteristics, experiments and results.

NITREX-EXMAN integrated papers

30. Gundersen, P. Experimental manipulation of forest ecosystems: lessons from the roof experiments.
31. Rasmussen, L., and Wright, R.F. Large-scale ecosystem experiments: ecological research and European environmental policy.

Appendix B. List of publication and reports from NITREX 3

Coordinator (full address):

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Contract N°. EV5VCT940436

Title of project: NITREX - Nitrogen saturation experiments phase 3

Duration: 18 months **Starting date:** 1.10.94 **End:** 30.3.95

Number of partners involved: **9**

A. Publications

Alewell, C., Bredemeier, M. and Matzner. E., In review. Reconstruction of a deacidification experiment at Solling by the MAGIC model with special consideration of soil SO_4^{2-}-dynamics. J. Environ. Qual.

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Cosby, B.J., Ferrier, R.C., Jenkins, A., Emmett, B.A., Tietema A. and Wright, R.F., In review. Modelling the ecosystem effects of nitrogen deposition: Model of Ecosystem Retention and Loss of Inorganic Nitrogen (MERLIN). Biogeochemistry.

Emmett, B.A. and Reynolds, B., In Press. Nitrogen Critical Loads for conifer plantations in Wales -is there too much nitrogen? Forestry.

Emmett, B.A., Cosby, B.J., Ferrier, R.C., Jenkins, A., Wright, R.F. and Tietema, A. In review. Modelling the ecosystem effects of nitrogen deposition: Simulation of nitrogen saturation at a Sitka spruce forest, Aber, Wales, UK. Biogeochemistry.

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