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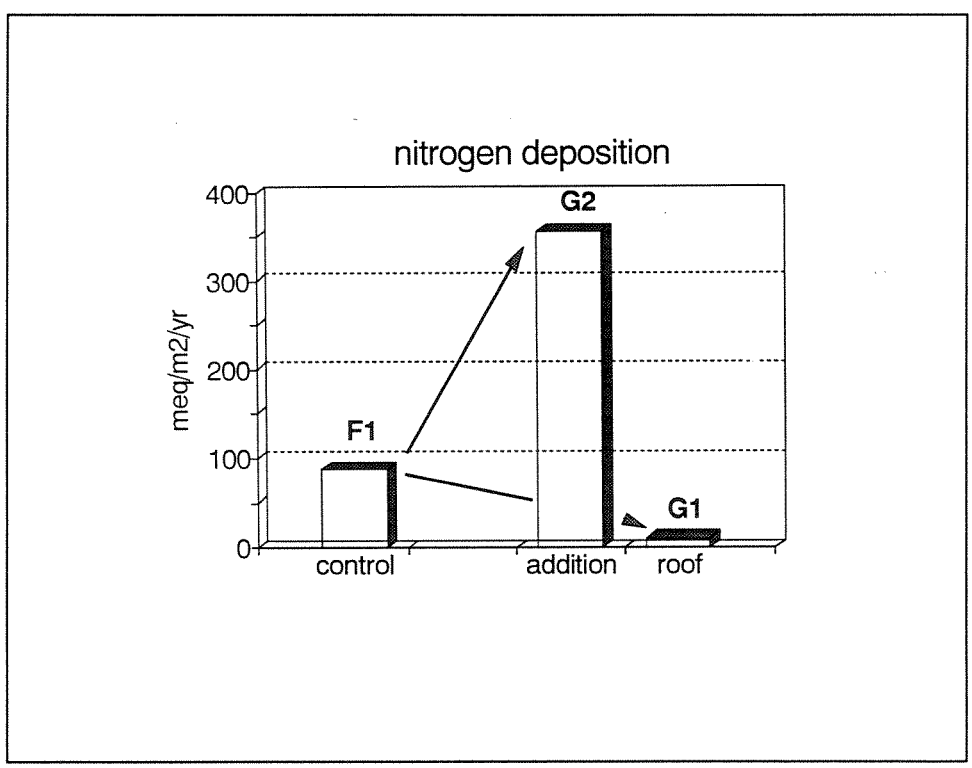
NITREX

Gårdsjön

Status report for 1990-1991



Report no 2/92 from NITREX Gårdsjön

Norwegian Institute for Water Research NIVA

NIVA – REPORT

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Abstract:

At the NITREX site at Gårdsjön, Sweden, ambient nitrogen deposition of 90 meq m^{2-} yr^{-1} will be experimentally increased by 286 meq m^{2-} yr^{-1} to an entire forested catchment (G2) to study the potential for nitrogen saturation. Investigations include measurements of catchment inputs and outputs as well as studies of vegetation, soil, mycorrhiza fine roots and fish response. Results from the pre-treatment period 1990-91 show acidic runoff and soil solution with high concentrations of inorganic aluminum. Concentrations of nitrate and ammonium are very low, indicating no nitrogen saturation. The trees are slightly-to -moderately defoliated, and the needles are discolored. The nutrient contents of needles indicate that no elements are in the deficiency or the toxic range. The mycorrhiza of the root mat at the forest floor are generally 100% alive and healthy. At catchment G2 nitrogen addition began in April 1991.

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NITREX project - Gårdsjön

Status report for 1990-91

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SUMMARY

NITREX (Nitrogen saturation experiments) is an interdisciplinary, international research project comprised of 9 large-scale experiments at 7 sites (Dise and Wright 1992). Gårdsjön, on the Swedish west coast, is one of these sites. At Gårdsjön nitrogen (280 meq m^2 yr^{-1} as NH_4NO_3) is added weekly to the 0.5 ha coniferous forested catchment G2, while ambient nitrogen (and acid and sulfur) deposition is excluded by means of a roof beneath the canopy at the adjacent catchment G1. A third catchment, F1, serves as an untreated reference. Treatments at both G1 and G2 began April 1991, following collection of pre-treatment background data for at least 1 year. The NITREX-Gårdsjön experiment is described in detail by Wright et al. (1991). The pre-treatment data covering the period through March 1991 are presented here.

The Gårdsjön area receives high deposition of seasalts (about 240-290 meq Cl m^{-2} yr^{-1}) and moderately high deposition of acid pollutants (130 meq S m^{-2} yr^{-1}; 90 meq N m^{-2} yr^{-1}). During the 2-year pre-treatment period (April 1989-March 1991) 2018 mm precipitation was measured (1007 mm yr^{-1}), somewhat less than the long-term average precipitation at the site of about 1100 mm yr^{-1}.

Runoff chemistry is similar at the 3 catchments. Runoff is characterized by low pH (3.8-4.2), high concentrations of seasalt ions such as Cl and Na, high concentrations of sulfate, and high concentrations of inorganic aluminum. Concentrations of nitrogen components in runoff are very low. Although these general characteristics hold for all three catchments, the catchments do differ significantly, with F1 (control) generally intermediate between G1 and G2.

Concentrations of inorganic nitrogen compounds are very low in runoff from all 3 catchments. Levels of both NO_3 and NH_4 are often at or below the analytical detection limit. Thus the pre-treatment data show that the catchments are not nitrogen-saturated.

The soils in the NITREX catchment are fairly acid, with pH increasing slightly in the lower peaty region. The fairly high C/N ratio (larger than 30 in the organic and A horizons), suggests that immobilization of added nitrogen will be an important process during seasons of microbial activity. Cation exchange capacity (measured at soil pH) is low in the mineral soil due to low clay content. Base saturation (measured at soil pH), is relatively high in the upper organic horizons, and very low in the mineral soil.

Chloride is the dominant anion in the soil solution, followed by sulfate. Despite the low pH values, aluminum concentrations are fairly low. Most of the aluminum is probably bound in organic compounds (high levels of organic C). The concentrations of NO_3-N and NH_4-N are generally close to the detection limit of 1 μeq/L, indicating that most of the soluble nitrogen in the catchment is in an organic form.

The hydrological response at G2 is very fast and leads to stormflow peaks within few hours after the start of rainfall. The response of the water potential in the soils matches this quickflow, but the data so far indicate no preferential flowpaths. Preliminary results indicate that transport within the upper organic layers can be fast, reaching rates up to $5*10^{-3}$ m sec^{-1}.

Results of fine roots sampled October 1990 indicate a pronounced superficial root distribution. The two root vitality classes 1 and 2 (most vital), however, were only found in the humus layer and then only in very small amounts compared with the total fine root mass. Fine roots in the mineral soil were in very poor condition. The fine roots were represented in approximately the same proportions among the four vitality classes within all catchments and vegetation types. The total amount of root tips (both

mycorrhizal and non-mycorrhizal) corresponded well with the vitality of the fine roots. This is also reflected in the distribution of root tips in the soil profile.

The mycorrhiza of the root mat at the forest floor sampled autumn 1990 were generally 100% alive and healthy, although there had been a severe dry period in July. Thus, healthy mycorrhizal development is assumed to be the normal background situation prior to nitrogen addition.

Most of the trees in all three catchments are in crown density classes 1 and 2 (slightly defoliated with crown density 75-89%, and moderately defoliated with crown density 40-74%). The needles are slightly-to-moderately discolored.

The nutrient contents of needles sampled in March 1990 show no consistent differences between the three sampled vegetation/soil moisture groups in G1 and G2. No elements are in the deficiency or the toxic range.

Fish toxicity experiments conducted 4 times during 1991 indicate that runoff from G2 was generally more toxic than G1. Calcium is probably the most important single ion determining the differences in toxicity level at G1 and G2, as the H^+ and the aluminum concentrations are high at both sites.

NORSK SAMMENDRAG

NITREX (Nitrogen saturation experiments) er et internasjonalt, tverrfaglig forskningsprosjekt. Samarbeids prosjektet består av 9 stor-skala eksperimenter fordelt på 7 lokaliteter i seks forskjellige land (Dise and Wright 1992). Gårdsjön i Vest-Sverige, er en av disse lokalitetene. Ved Gårdsjön blir nitrogen (280 meq m^2 yr^{-1} som NH_4NO_3) tilført ukentlig, over et 0.5 ha stort nedbørfelt i barskog (G2-feltet), mens den nitrogen, svovel og syre-mengden som tilføres i nedbøren blir fjernet ved hjelp av et tak i plexiglass over det nærliggende G1-feltet. Det tredje feltet, F1 tjener som et kontroll felt. Forsøkene ved både G1 og G2 begynte i april 1991, forut for dette ble det gjort en forundersøkelse med bakgrunnsdata og materiale over en ett-års periode. NITREX-Gårdsjön forsøket er beskrevet i en tidligere rapport, Wright et al. (1991). Data fra forundersøkelsen t.o.m. mars 1991 er presentert i denne rapporten.

Gårdsjön området mottar store mengder av sjøsalter (ca. 240-290 meq Cl m^{-2} yr^{-1}) i nedbøren og moderate mengder av sur nedbør (130 meq Sm^{-2} yr^{-1}; 90 meq N m^{-2} yr^{-1}). Gjennom denne 2-års perioden før behandling (april 1989 - mars 1991) ble nedbøren målt til 2018 mm (1007 mm yr^{-1}), noe mindre enn langtids-gjennomsnittet av nedbøren for området (ca 1100 mm yr^{-1}).

Avrenningskjemien er lik i de 3 feltene. Avrenningen er karakterisert ved lav pH (3.8-4.2), høye konsentrasjoner av sjøsalt-ioner som Cl og Na, høye konsentrasjoner av sulfat, og høye konsentrasjoner av uorganisk aluminium. Konsentrasjonen av nitrogenkomponenter i avrenningen er veldig lave. Selv om disse generelle forholdene gjelder for alle tre feltene, viser det seg at feltene forøvrig skiller seg endel fra hverandre, oftest med F1 (kontrollfeltet) som mellomliggende mellom G1 og G2.

Konsentrasjonen av uorganiske nitrogen forbindelser er veldig lave i avrenningen fra alle tre feltene. Nivåene av både NO_3 og NH_4 er på eller under deteksjonsgrensen for analyse. Således viser data fra forundersøkelsen at feltene ikke har oppnådd nitrogen-metning.

Jordsmonnet ved NITREX feltet er surt, med svakt høyere pH-verdi i det nedre, forsumpete-området. Det ganske høye C/N forholdet (større enn 30 i det organiske og i A horisonten), antyder at immobilisering av tilført nitrogen vil bli en viktig prosess i perioder med mikrobiell aktivitet. Ionebyttekapasiteten (målt ved jordsmonnets pH-verdi) er lav i mineraljorden på grunn av lavt innhold av leir-mineraler. Basemetningsgraden (målt ved jordsmonnets pH-verdi) er relativt høy i de øvre organiske sjiktene, og veldig lav i mineraljorden.

Klorid er det dominerende anion i jordvannet, etterfulgt av svovel. Tiltross for den lave pH-verdien, er aluminiumskonsentrasjonene meget lave. Det meste av aluminiumet er antageligvis bundet til de organiske forbindelsene (høye nivåer av organisk C). Konsentrasjonen av NO_3-N og NH_4-N er som oftest nær deteksjons-grensen på 1 meq/L. Dette indikerer at det meste av det oppløste nitrogenet i feltet foreligger på en organisk form.

Den hydrologiske responsen i G2-feltet er rask og fører til avrenningstopper innen få timer etter at regnet startet. Resultatene så langt indikerer at transporten til øvre organiske lag kan være rask, opp mot nivåer på $5*10^{-3}$ m sec^{-1}.

Foreløpige resultater når det gjelder finrøtter innsamlet i oktober 1990 indikerer en tydelig konsentrasjon av røtter mot overflaten. De to rot-vitalitets klassene, 1 og 2 (de mest vitale), ble bare funnet i humussjiktet og kun i veldig små mengder sammenlignet med total mengde røtter. Finrøtter i mineraljorda var i dårlig forfatning. Finrøttene hadde nogenlunde samme fordeling på de fire vitalitets

klassene i de forskjellige feltene og vegetasjonstypene. Den totale andel av rot-spisser (med og uten mykorrhiza) var i overenstemmelse med vitaliteten til finrøttene. Dette er også reflektert i fordelingen av finrøtter i jordprofilen.

Mykorrhiza røttene i rot-matten i overgangen strø-humussjiktet innsamlet høsten 1990 var generelt 100 % levende og vitale, til tross for at det hadde vært en kraftig tørkeperiode i juli. Således er en vital mykorrihiza utvikling antatt å være den normale bakgrunns situasjonen før nitrogen tilførselen.

Mesteparten av trærne i alle de tre feltene er i kronetetthets-klassene 1 og 2 (svakt nåletap med kronetetthet 75-89%, og moderat nåletap med kronetetthet 40-74%). Nålene er svakt - til moderat misfarvet.

Næringsinnhold av nålene innsamlet i mars 1990 viser ingen gjennomgående forskjeller mellom de forskjellige vegetasjon/jordsmonn typene i G1 og G2. Ingen av elementene er i underskudd eller opptrer i giftige nivåer.

Fiskeforsøk som ble utført 4 ganger i løpet av 1991, indikerer at avrenningen fra G2 var generelt sett mere giftig enn G1. Kalsium er antageligvis en avgjørende enkeltfaktor som bestemmer forskjellen på giftighets nivået mellom G1 og G2, i det aluminiums-konsentrasjonen var like høye på begge felter.

ACKNOWLEDGEMENTS

In 1990-91 NITREX-Gårdsjön received financial support from the Norwegian National Committee for Environmental Research (NMF/NAVF), the Swedish Environmental Protection Board (SNV), the Nordic Council of Ministers (NMR), the Commission of the European Communities (CEC-STEP program) and from internal funds from the Norwegian Forest Research Institute (NISK), the Norwegian Institute for Water Research (NIVA), and the Swedish Environmental Research Institute (IVL). We thank our co-workers at our institutes for able and enthusiastic assistance with the field, laboratory and office work and our colleagues from other institutes participating in the NITREX experiment and other research projects at Gårdsjön for professional assistance and advice.

1. INTRODUCTION

NITREX (Nitrogen Saturation Experiments) is an international, interdisciplinary research project focused on the impact of nitrogen on forest ecosystems. The project addresses the role of nitrate and ammonium in acidification of soil and water by adding or removing nitrogen to precipitation falling on headwater catchments and forest stands. These experiments comprise a six-nation European network spanning the gradient in nitrogen deposition from <5 kg N ha^{-1} yr^{-1} in Norway >50 kg N ha^{-1} yr^{-1} in the Netherlands.

One of these NITREX sites is located at Gårdsjön, on the Swedish west coast. At the Gårdsjön site, nitrogen deposition is experimentally increased to an entire forested catchment. Here the objectives to determine the nitrogen saturation threshold of the site, relate that threshold to physical factors such as site history and geology, and estimate the role of nitrogen in ecosystem acidification and forest decline.

Nitrogen is usually the key growth-limiting nutrient in terrestrial ecosystems, and an adequate supply is central to maintaining the health and diversity of the biota. Forest ecosystems have typically very tight nitrogen cycles, with little or no release of the nutrient into groundwater or runoff.

In regions that are relatively unimpacted by humans, the primary source of available nitrogen is biological fixation. In central Europe, however, nitrogen oxides and ammonia from fossil-fuel combustion and intensive agriculture account for over 90% of the total atmospheric nitrogen load to forests (Pacyna 1989). With chronic exposure to these contaminants a threshold may be reached where increased nitrogen inputs no longer stimulate growth but begin to disrupt ecosystem structure and function. This threshold, called "nitrogen saturation" (Ågren 1983), becomes evident when nitrate appears in runoff, signalling a breakdown of the normal geochemical cycling of elements. Recent data from a variety of sites in southern Scandinavia indicate that leaching of nitrate from terrestrial catchments has increased over the past 20 years, although nitrogen deposition has changed only little over this period.

Disruption of the nitrogen cycle can have consequences downstream of the forest. As a strong acid anion, nitrate can mobilize toxic aluminum into soils and waters, indirectly causing stream and lake acidification. Nitrogen deposited directly from the atmosphere or delivered by streams and rivers can contribute to coastal marine eutrophication, and has been implicated in recent algal blooms (Hinga et al. 1991).

The Gårdsjön NITREX study began in late 1988. The site chosen for the nitrogen addition experiment is catchment G2. The adjacent catchment G1 was chosen at the same time for a pollution exclusion experiment (by means of roof beneath the canopy). The NITREX and roof experiment make use of a common untreated reference catchment F1. At both G2 and G1 sampling of throughfall and runoff at the site began in December 1988. Tensiometers were installed in the summer of 1989. Weirs, equipment for continuous gauging of runoff, and lysimeters were brought into operation in early 1990. Vegetation and soil analyses (including mineralization studies) also began in early 1990, and the first in-growth cores were implanted. The mycorrhizal fungi were first investigated in late summer 1990, and fish toxicity experiments began in early 1991. Treatment commenced April 1991. Wright et al. (1991) give a status report of Gårdsjön-NITREX for the years 1988-1990. Here we report the results from the NITREX catchment G2 for the pre-treatment period April 1990-March 1991. Andersson et al. (in prep.) report pre-treatment data from the roof experiment at G1.

2. SITE DESCRIPTION

2.1. GÅRDSJÖN, GENERAL

The lake Gårdsjön research area (58° 04' N, 12° 01' E) has been the focus of acidification research since the 1960's (Hultberg and Grennfelt 1986, Andersson and Olsson 1985). The entire drainage basin encompasses 2.11 km^2 (5 lakes) and sits 14 km from the west coast of Sweden (Figure 2.1), a region receiving moderately high deposition of both sulfate and nitrogen. Soils and waters here are chronically acidified (Hultberg and Grennfelt 1986) although most of the incoming nitrogen is still retained by the terrestrial ecosystems.

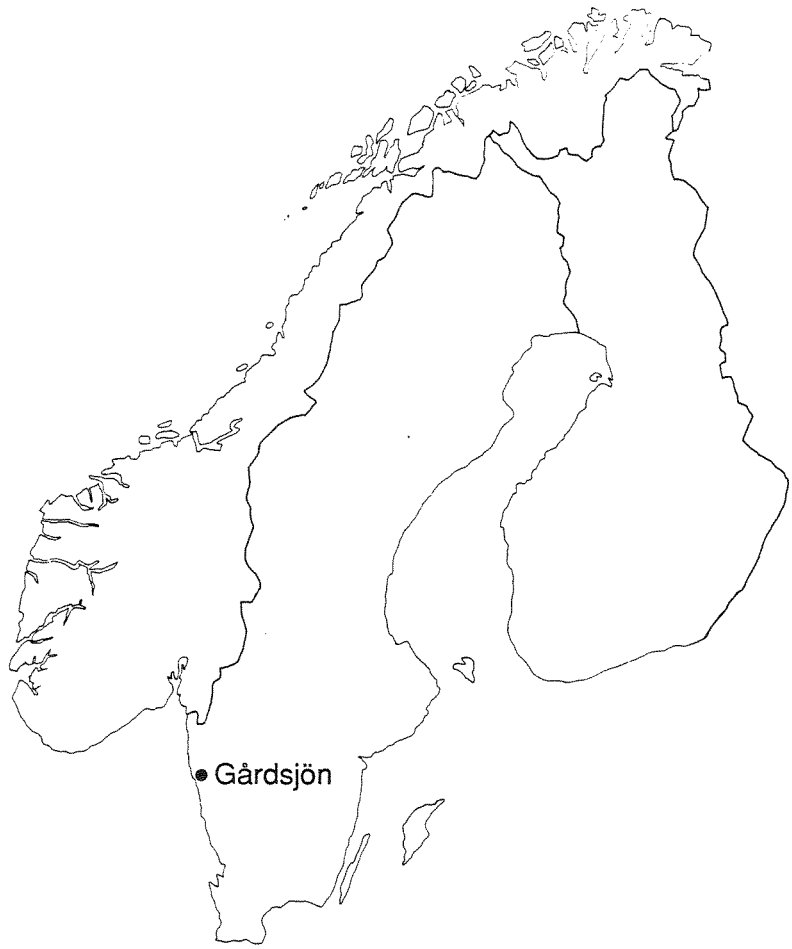

Figure 2.1. Location of Gårdsjön NITREX site.

The Gårdsjön region has a humid maritime climate, with 1100 mm mean annual precipitation and a mean temperature of 6.4°C. Winters are mild (mean January temperature -2.4 °C), and summers are fairly cool (mean July temperature 15.6 °C). The 5-lake basin ranges from 113 to 170 meters above sea level, and inclines toward the southwest. The topography is rough, with steep valleys and frequent bedrock outcrops. Geology is characteristic of acidified regions of the Swedish west coast and southern Norway, with granitic and gneissic bedrock overlain by thin patchy podzolic and peaty soils. The soils are developed from glacial till predominantly of local origin and of the same or similar lithology. Gårdsjön contains a mixed-age coniferous forest dominated by Norway spruce (Picea abies) >110 years of age; Scots pine (Pinus sylvestris) occurs in dry areas (Olsson et al. 1985). The area has supported a low level of grazing and selective forest cutting for centuries; current active land use is restricted to forestry.

Smaller experimental sub-catchments within the whole catchment were identified for detailed hydrochemical study in the mid 1980's (Figure 2.2). Whole-system manipulation experiments in these catchments have included liming, clearcutting, and sulfur addition (Hultberg and Grennfelt 1986). These experiments and the long record of background data (control catchment F1 monitored since 1979) provide an extensive base for the NITREX experiment. Nitrogen addition (NITREX) and nitrogen exclusion (roofed catchment) are the most recent manipulation experiments at Gårdsjön.

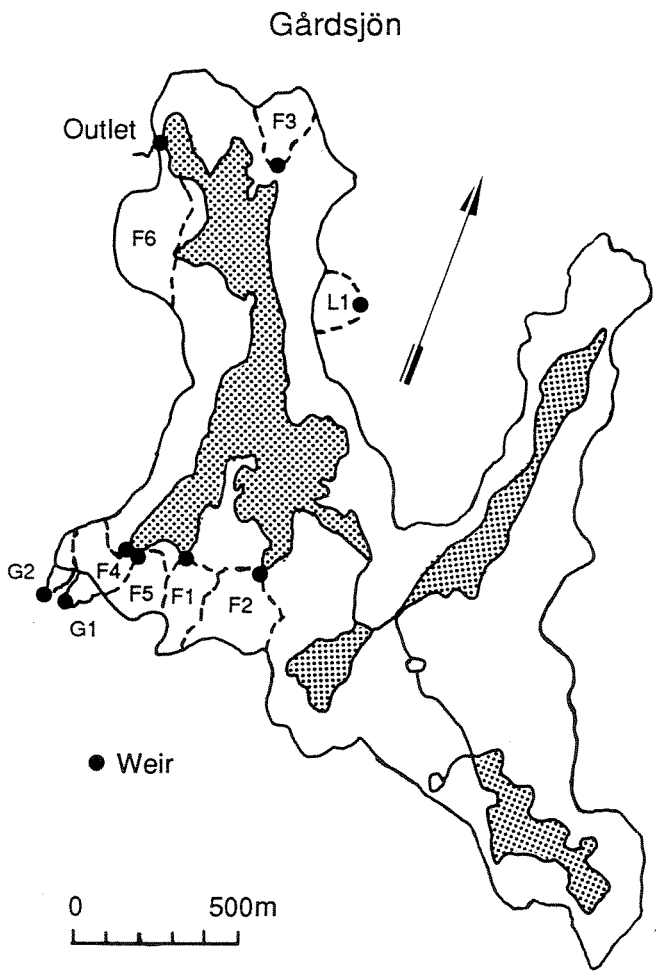

Figure 2.2. Experimental sub-catchments within the Lake Gårdsjön basin used for large-scale manipulations. F1 is control (since 1979). The NITREX catchment (G2) and adjacent roofed catchment (G1) lie just outside Gårdsjön's catchment. Details on manipulations in remaining sub-catchments may be found in Hultberg and Grennfelt (1986).

2.2. NITREX SITE

The Gårdsjön NITREX site (G2) is a 0.52 ha headwater catchment adjoining the Gårdsjön drainage basin (Figs. 2.2, 2.3). Like the surrounding area, it is forested with Norway spruce and some Scots pine, with slight to moderate defoliation and needle discoloration (damage classes 1 and 2). Ground vegetation roughly segregates with the topography of the catchment: it is dominated by mosses (Dicranum majusm, Leucobryum glaucum (Hedw.) and the grass Deschampsia flexuosa (L.) in the upper catchment, Vaccinium myrtillus (L.)/Vaccinium vitis-idea (L.) in drier outcrops, Sphagnum (predominantly Sphagnum girgensohnii (L.)) in the wetter lower parts of the catchment, and Calluna vulgaris (L.) among the most exposed ridges. Many of the NITREX investigations in Gårdsjön compare the first three subgroups. Soils are predominantly acidic silty and sandy loams (Orthic Humic Podzols, Orthic Ferro-Humic Podzols, Gleyed Humo-Ferric Podzols, and Typic Folisols (Canada Soil Survey Committee 1978)), drier in the upper catchment and more peaty in the lower part. The depth of the soil varies between 0 and >100 cm, with a mean depth of 38 cm. Boulder outcrops are common, and soil cover is especially thin in the western and northern part of the catchment (Figure 2.4).

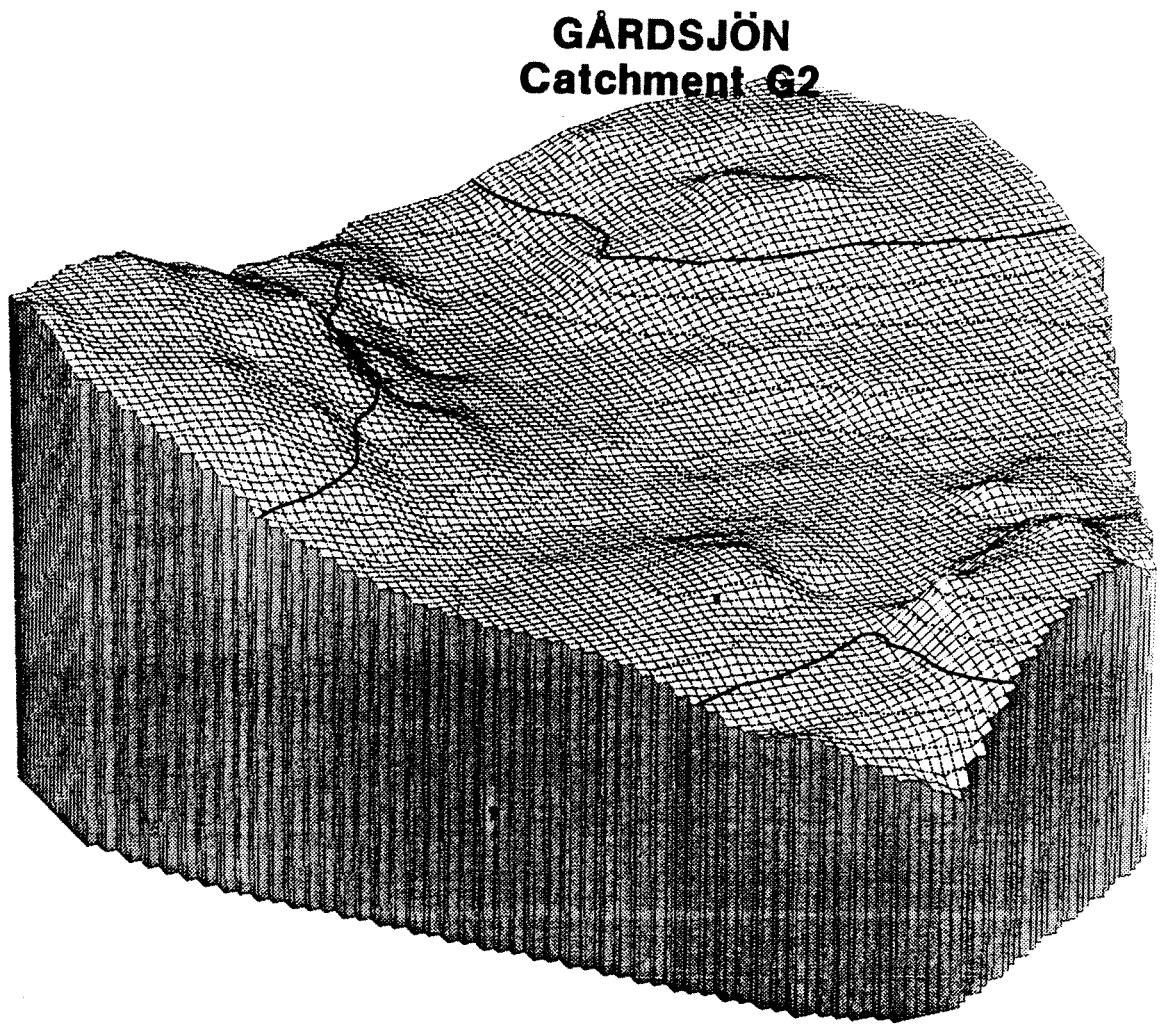

Figure 2.3. The topography of the NITREX site at Gårdsjön (G2). (Map produced by Kevin Bishop, Swedish Agricultural University, Umeå)

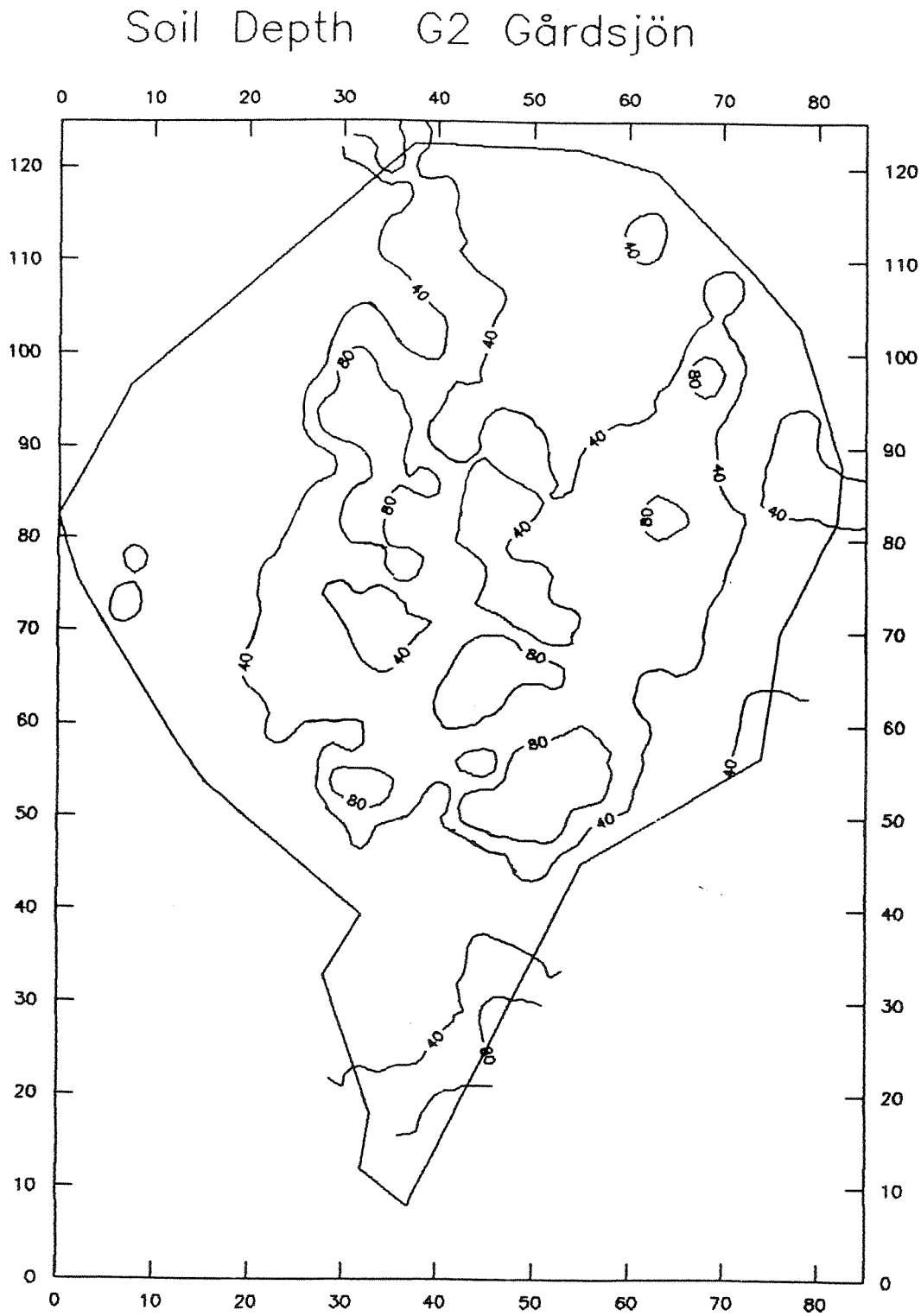

Figure 2.4. The soil depth in the NITREX catchment at Gårdsjön (G2). (Map produced by Lars Nyberg, Swedish Agricultural University, Uppsala and Arne O. Stuanes, NISK)

3. EXPERIMENTAL DESIGN

3.1. NITROGEN ADDITION IN G2

In G2, 40 kg N ha^{-1} yr^{-1} as ammonium nitrate (286 meq m^{-2} yr^{-}) is added to augment the natural N load of ca 13 kg N ha^{-1} yr^{-1} (90 meq m^{-2} yr^{-1}). The sum loading of about 50 kg N ha^{-1} yr^{-1} (357 meq m^{-2} yr^{-1}) is in the range of the deposition received by damaged forest ecosystems in central Europe. The excess nitrogen is added to deionized water and distributed with a sprinkler system each week in proportion to the amount of natural precipitation falling the previous 7 days. The vegetation is washed off for 3 minutes with deionized water following each application. The sprinklers are placed in a grid of 5 by 5 meters. Their height is adjusted to release the effluent solution above the ground vegetation. This addition scheme minimizes any nitrogen shock effects. The volume of additional water is about 5% of natural precipitation. Treatment began on 1 April 1991, after nearly one year of background measurements. It is planned to last for at least 3 years.

3.2. NITROGEN REMOVAL IN G1 (ROOF PROJECT)

G2 lies adjacent to a similar catchment G1 (Fig. 2.2) which is covered by a transparent roof beneath the canopy. The G1 Roof project investigates the processes of catchment recovery from pollution by removing sulfur and nitrogen from the input deposition. Incoming throughfall is intercepted by the roof and channeled from the catchment. For each precipitation event an equivalent amount of water is pumped from Lake Gårdsjön, ion-exchanged, resupplied with seasalt ions at assumed pre-industrial concentrations, and sprinkled below the roof. Treatment at G1 began at the same time as G2, in April 1991. Both catchments drain away from the lake. The removal experiment at G1 is funded independently of NITREX, but runs in parallel and with many of the same procedures and personnel. A full description of the roof experiment and results from the first half year of treatment at G1 are in a companion report (Andersson et al. 1992).

3.3. CONTROL SITE F1

F1 catchment is used as a common untreated reference for the manipulations in the G2 and G1 catchments. Discharge of chemical composition of runoff at F1 have been monitored since 1979.

4. INSTALLATIONS, MONITORING PROGRAM AND DISCUSSION

A diagram of the installations at NITREX-Gårdsjön is given in Figure 4.1.

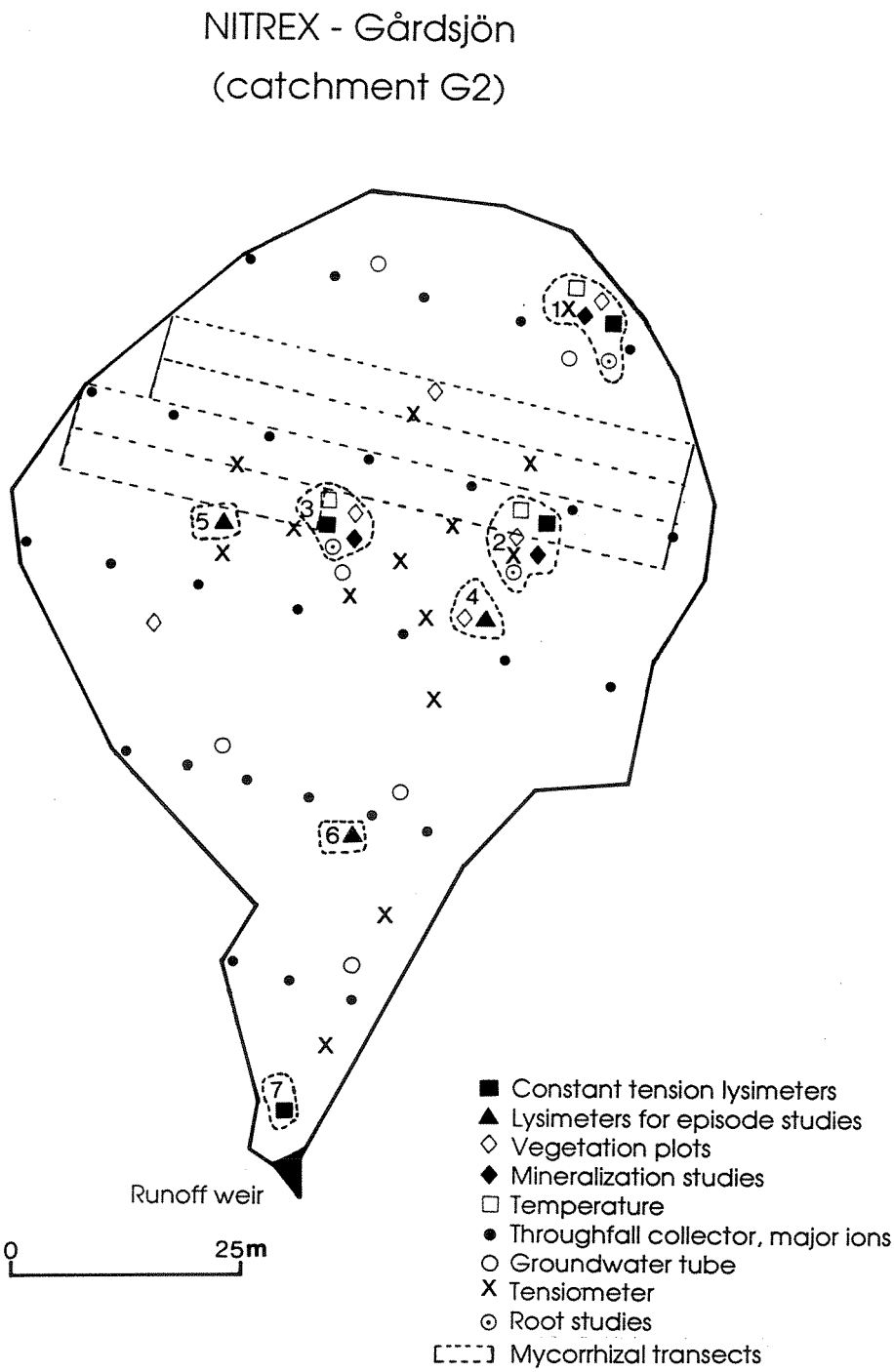

Figure 4.1. Map of the NITREX catchment G2 at Gårdsjön showing location of vegetation plots, lysimeters, tensiometers, throughfall collectors, mineralization studies, mycorrhiza transects, and groundwater wells.

4.1. INPUTS AND OUTPUTS: CONCENTRATIONS AND FLUXES

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Determination of ecosystem input-output budgets is a central objective of NITREX-Gårdsjön. Nitrogen saturation is defined in terms of changes in output of nitrogen at the ecosystem scale. The whole-catchment nitrogen addition at Gårdsjön G2 is aimed at evoking changes in nitrogen contents in runoff. At all three catchments F1, G1, and G2, therefore, a great deal of effort is devoted to determining ecosystem inputs and outputs.

Ion concentrations and water volume are used to calculate fluxes of all major chemical elements in bulk precipitation, throughfall, litterfall, soil solution and runoff. These fluxes are monitored in order to trace as exactly as possible when and where changes in element cycles occur as an effect of the increased nitrogen input (NITREX catchment) or decreased input (roof catchment).

4.1.1. Installations and Monitoring

Bulk deposition: Open-field precipitation is monitored at three stations: at the outlet of lake Gårdsjön (tipping bucket), at 0.5 km north of the outlet (SMHI standard gauge), and at F1 (tipping bucket). A meteorological tower provides data on wind speed, temperature, relative humidity and solar radiation which are transferred to IVL via modem. Bulk precipitation is collected for chemical analysis on a monthly basis, twice-monthly for pH, NH_4 and color in the summer. Samples are analyzed at IVL for pH, conductivity, color, Ca, Na, K, Mg, Mn, SO_4, Cl, NH_4, NO_3, and DOC, and at the Limnological Institute of the University of Uppsala for Kjeldahl-N and total-P. These same chemical parameters are measured in throughfall, stemflow, groundwater (with the addition of Al and Fe), and runoff (with the addition of Al and Fe). Standard methods are used for all chemical analyses. pH is determined potentiometrically, cations by atomic adsorption spectroscopy, anions by ion chromatography, and NH_4 colorimetrically. DOC is measured as CO_2 by infra-red spectrophotometry following oxidation by persulfate. Aluminum species are determined colorimetrically with (organic) or without (total reactive) cation exchange.

Throughfall: A total of 28 throughfall collection sites are arranged in 5 rows across each catchment. Each site contains a pair of plastic funnels in the summer or a single bucket in the winter. Throughfall was initially collected and analyzed every month (except for fortnightly analysis of pH, NH_4 and color), but was changed to fortnightly beginning in January 1992.

Groundwater: Groundwater is sampled from wells 8-12 times per year and analyzed for the same constituents as runoff.

Runoff: Runoff is sampled weekly for chemical analysis. Discharge from G1 and G2 is measured by automatic filling and emptying of tanks. F1 is gauged by weir and level recorder.

4.1.2. Inputs

During the 2-years prior to treatment (April 1989-March 1991) 2018 mm precipitation was measured (1009 mm yr^{-1}) (Table 4.1), somewhat less than the long-term average precipitation at the site of about 1100 mm yr^{-1}. Bulk precipitation at Gårdsjön is acidic and contains high concentrations of pollutant components such as sulfate, nitrate and ammonium (Table 4.1).

Table 4.1. Volume-weighted average concentrations of major components in bulk precipitation, throughfall (IN) and runoff (OUT) for the pre-treatment period April 1989-March 1991 at the 3 experimental catchments at Gårdsjön (F1 control, G1 roof, and G2 NITREX). Values for G1 are from April 1989 until construction of the roof in January 1991. Organic anions (A^-) are determined by difference from the ionic balance. SBC = Sum of Base Cations (including NH_4), SAA Sum of Acid anions, ANC = acid neutralizing capacity (SBC-SAA). Units: μeq L^{-1}; Al-org mmol L^{-1}; N-org, tot-P μmol L^{-1}; DOC mmol L^{-1}.

	Concentrations μeq/l						
	Bulk	F1 IN	F1 OUT	G1 IN	G1 OUT	G2 IN	G2 OUT
H2O (mm)	1009	667	473	661	473	658	473
H^+	51	81	84	92	63	86	149
Ca	14	82	74	88	66	59	35
Mg	20	101	167	99	181	87	110
Na	85	339	472	319	645	316	493
K	4	83	19	69	23	60	16
Ali	0	0	83	0	209	0	161
NH4	33	46	0	48	0	41	0
NO3	40	85	2	99	2	80	0
SO4	69	201	282	195	386	177	332
Cl	95	431	581	392	786	362	605
A^-	4	16	34	30	12	29	27
SBC	156	652	732	624	914	562	653
SAA	203	717	865	685	1174	618	936
ANC	-47	-65	-133	-62	-260	-56	-283
Al-org mmol			9.3		9.3		15.7
N-org μmol		82.2	12.8	71.1	12.4	63.5	22.3
tot-P μmol		0.97	0.12	0.39	0.14	0.39	0.21
DOC mmol		1.07	0.67	0.65	0.46	0.64	0.98

The Gårdsjön area receives high deposition of seasalts (about 240-290 meq Cl m^{-2} yr^{-1} = 85-100 kg ha^{-1} yr^{-1}) due to proximity to the coast and the predominant westerly winds (Table 4.2). It also receives moderately high deposition of acid pollutants (130 meq S m^{-2} yr^{-1} = 21 kg ha $^{-1}$ yr^{-1}; 90 meq N m^{-2} yr^{-1} = 13 kg ha $^{-1}$ yr^{-1}). The difference in fluxes in throughfall measured at the catchments over the 2-year period may be related to catchment aspect relative to the prevailing winds, or perhaps to sampling design which may not sufficiently capture the natural spatial heterogeneity in volume and chemical composition of throughfall in these mature forests.

Inputs to the forested catchments are considerably enhanced by dry deposition of gases and particles. For most ions throughfall provides an estimate of total inputs (Hultberg and Grennfelt 1986). Concentrations and fluxes of major chemical components in throughfall are similar at all three catchments (Tables 4.1 and 4.2). Throughfall volume is considerably less than bulk precipitation volume. Pollutant components are also enriched in throughfall (Table 4.2.).

Table 4.2. Fluxes of major ions in bulk precipitation, throughfall (IN) and runoff (OUT) for the 2 years prior to treatment (April 1989-March 1991) at 3 experimental catchments at Gårdsjön (F1 control, G1 roof, and G2 NITREX). Values for G1 are from measurements April 1989 until construction of roof January 1991 scaled up by the factor G2 long period/G2 short period. Organic anions (A^-) are determined by difference from the ionic balance. SBC = Sum of Base Cations (including NH_4), SAA Sum of Acid anions, ANC = acid neutralizing capacity (SBC-SAA). Units: meq m^{-2} yr^{-1}; Al-org mmol m^{-2} yr^{-1}; N-org, tot-P µmol m^{-2} yr^{-1}; DOC mmol m^{-2} yr^{-1}.

	Fluxes meq/m2/yr						
	Bulk prep.	F1 IN	F1 OUT	G1 IN	G1 OUT	G2 IN	G2 OUT
H_2O (mm)	1010	667	473	661	473	658	473
H^+	51	54	40	61	30	56	71
Ca	14	55	35	58	31	39	16
Mg	19	68	79	65	86	57	52
Na	86	226	223	211	305	208	233
K	4	55	9	46	11	39	7
Al_i	0	0	39	0	99	0	76
NH_4	33	31	0	32	0	27	0
NO_3	40	57	1	65	1	52	0
SO_4	70	134	133	129	183	116	157
Cl	95	287	275	259	372	238	286
A-	4	10	16	20	6	19	13
SBC	158	435	346	413	433	370	309
SAA	205	478	409	453	555	407	443
ANC	-47	-43	-63	-41	-123	-37	-134
Al-org mmol			4.4		4.4		7.4
N-org µmol		54.8	6.1	47.0	5.9	41.8	10.5
tot-P µmol		0.6	0.1	0.3	0.1	0.3	0.1
DOC mmol		715	316	430	220	422	464

4.1.3. Runoff

Only at the control catchment F1 does a continuous record of discharge exist for the entire pre-treatment period (1 April 1989 - 31 March 1991). The automatic system for measurement of discharge at G1 and G2 came on line in mid-1991. Daily mean discharge for the period during which data are available from all three catchments indicates that runoff volume from G2 is very similar to that from F1. At G1, runoff volume measured at the weir is significantly lower than G2 and F1; apparently here a portion of the water leaves the catchment without passing the weir, either by deep seepage, leakage at the saddle point or leakage under the weir. Additional hydrologic investigations are now underway at G1 to determine the cause of the differences in discharge between the catchments.

The total discharge at F1 during the 2-year pre-treatment period amounted to 946 mm (average 473 mm yr^{-1}), somewhat less than the long-term average runoff at Gårdsjön of about 650 mm yr^{-1} (Hultberg 1985). The seasonal pattern of discharge at F1 was characterized by moderate-to-high flow during the winter half-year (October-April) and little or no flow during the summer growing season (May-September) (Figure 4.2).

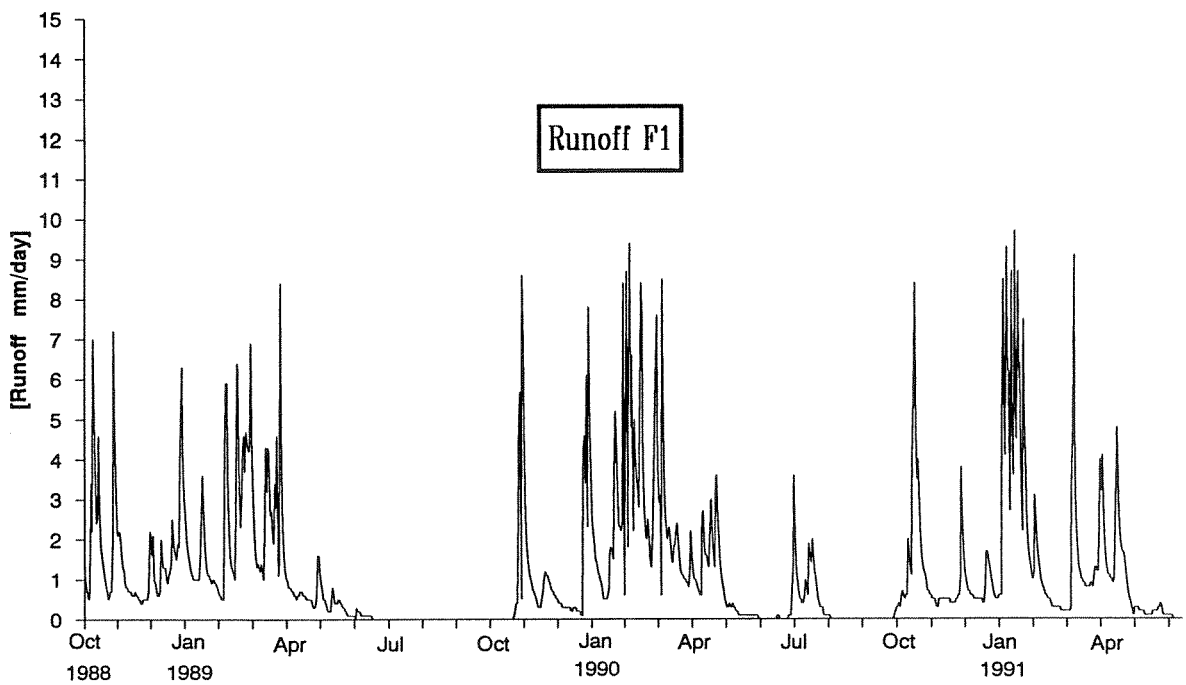

Figure 4.2. Daily runoff at the control catchment F1 over the period October 1988-June 1991.

Runoff chemistry is similar at the 3 catchments. Runoff is characterized by low pH (3.8-4.2), high concentrations of seasalt ions such as Cl and Na, high concentrations of sulfate, and high concentrations of inorganic aluminum (Table 4.1). Concentrations of nitrogen components in runoff are very low. Although these general characteristics hold for all three catchments, the catchments do differ significantly, with F1 (control) generally intermediate between G1 and G2.

Of the strong acid anions, concentrations of both Cl (Fig. 4.3) and SO_4 (Fig. 4.4) in runoff are lowest in F1 (control), highest in G1 (roof), and intermediate in G2 (NITREX) (Table 4.1).

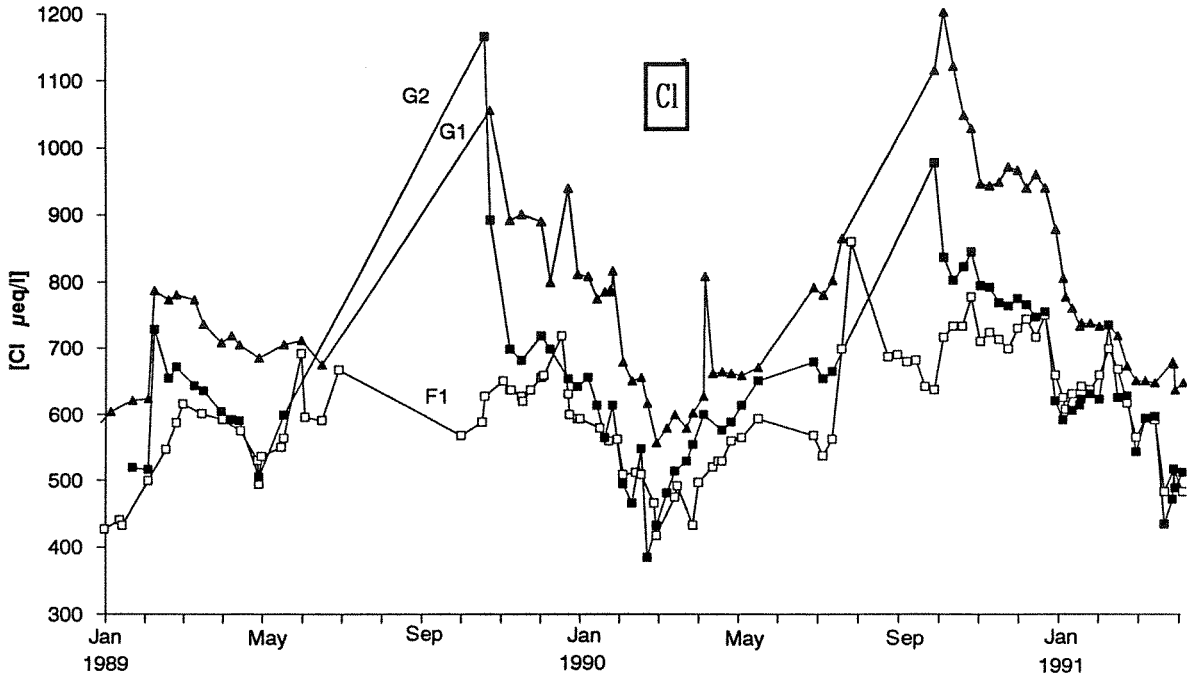

Figure 4.3. Concentrations of Cl measured in runoff at catchments F1 (control), G1 (roof) and G2 (NITREX) over the period January 1989-April 1991.

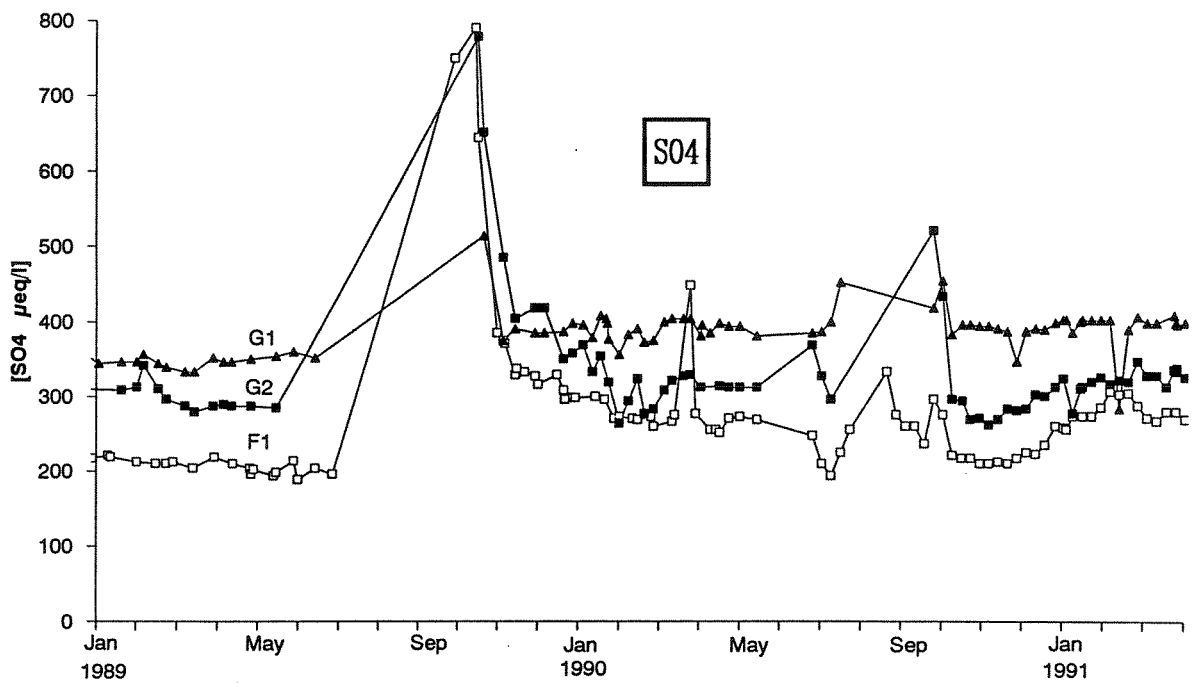

Figure 4.4. Concentrations of SO4 measured in runoff at catchments F1 (control), G1 (roof) and G2 (NITREX) over the period January 1989-April 1991.

Concentrations of base cations indicate that the catchments differ slightly in sensitivity to acid inputs, with catchment F1 lying intermediate between G1 (less sensitive with higher Ca levels) and G2 (more sensitive with lower Ca levels) (Table 4.1, Figure 4.5).

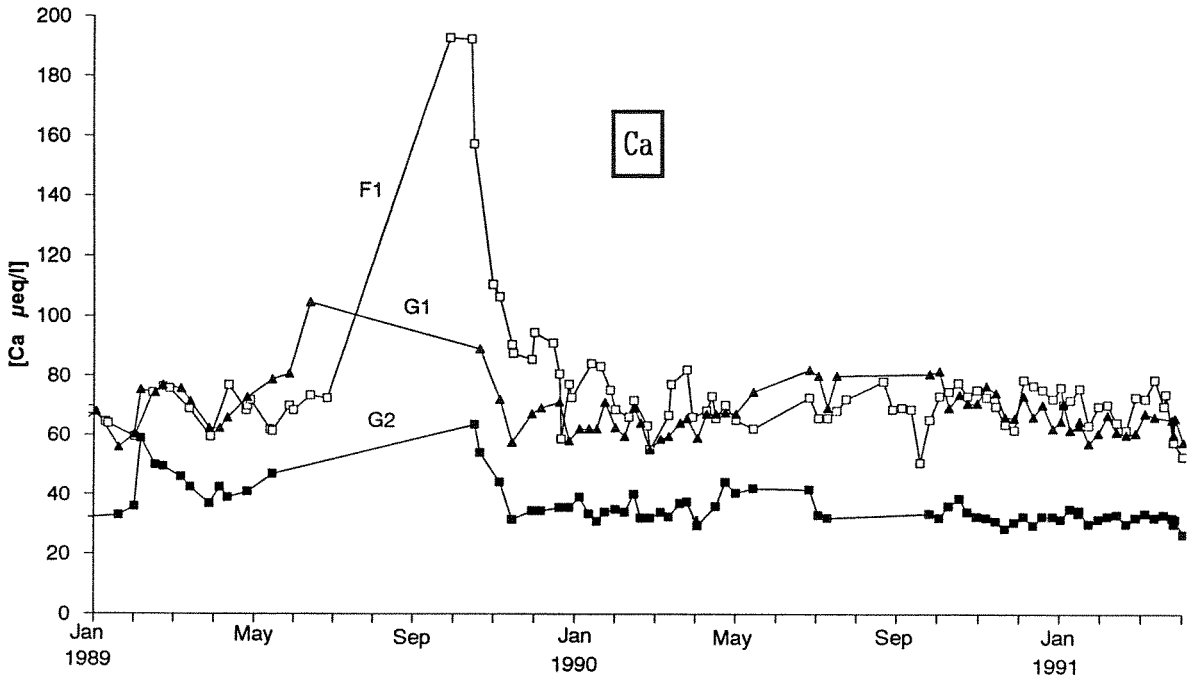

Figure 4.5. Concentrations of Ca measured in runoff at catchments F1 (control), G1 (roof) and G2 (NITREX) over the period January 1989-April 1991.

As a result of the slightly higher levels of strong acid anions combined with the slightly lower levels of base cations, alkalinity and pH are lower in runoff from catchment G2 relative to F1 and G1 (Table 4.1, Figure 4.6).

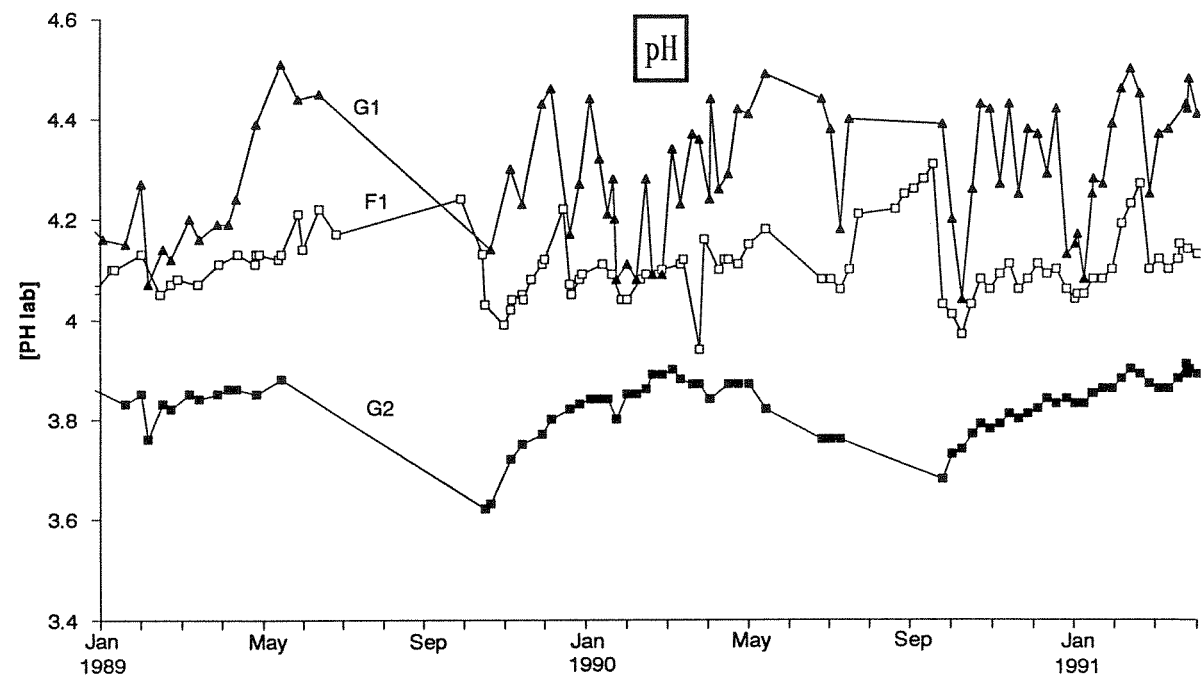

Figure 4.6. pH levels measured in runoff at catchments F1 (control), G1 (roof) and G2 (NITREX) over the period January 1989-April 1991.

Runoff contains high levels of inorganic Al (Figure 4.7). The Al_i - H^+ relationship in runoff at G2 corresponds to a solubility constant with respect to $Al(OH)_3$ of $10^{-8.2}$.

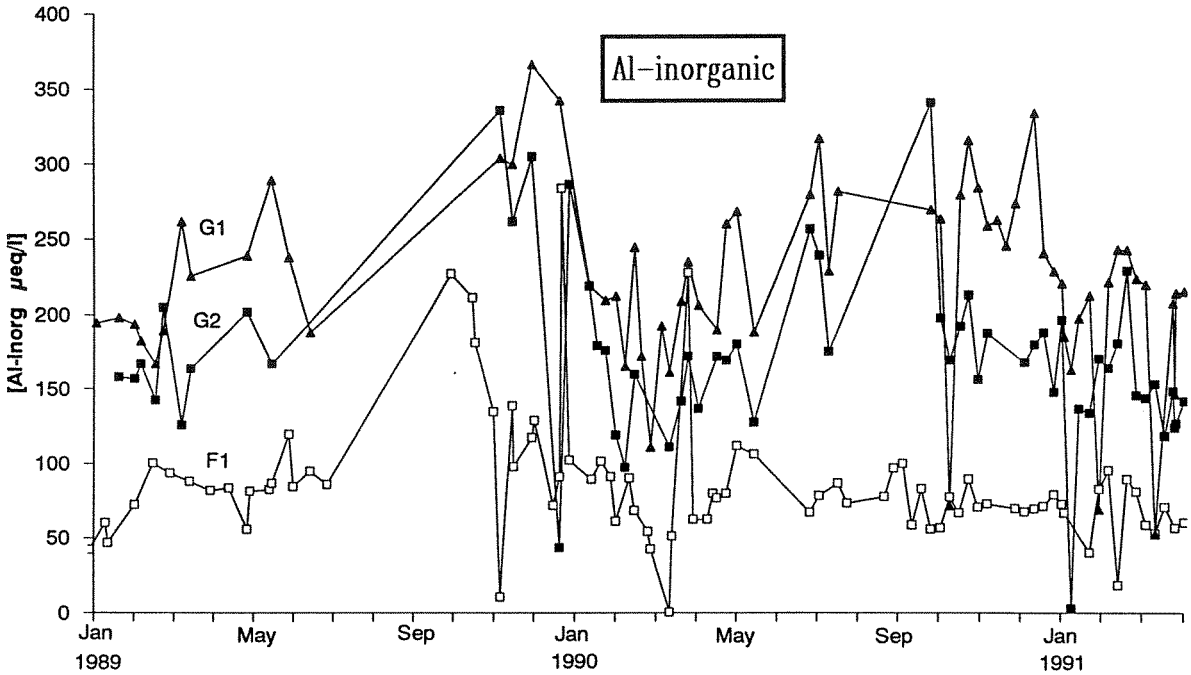

Figure 4.7. Concentrations of inorganic aluminum (defined as difference between measured reactive Al and measured organic Al) measured in runoff at catchments F1 (control), G1 (roof) and G2 (NITREX) over the period January 1989-April 1991.

The catchments also differ slightly with respect to concentrations of dissolved organic carbon (DOC) in runoff. Here G2 has somewhat higher levels than F1 and G1 (Figure 4.8).

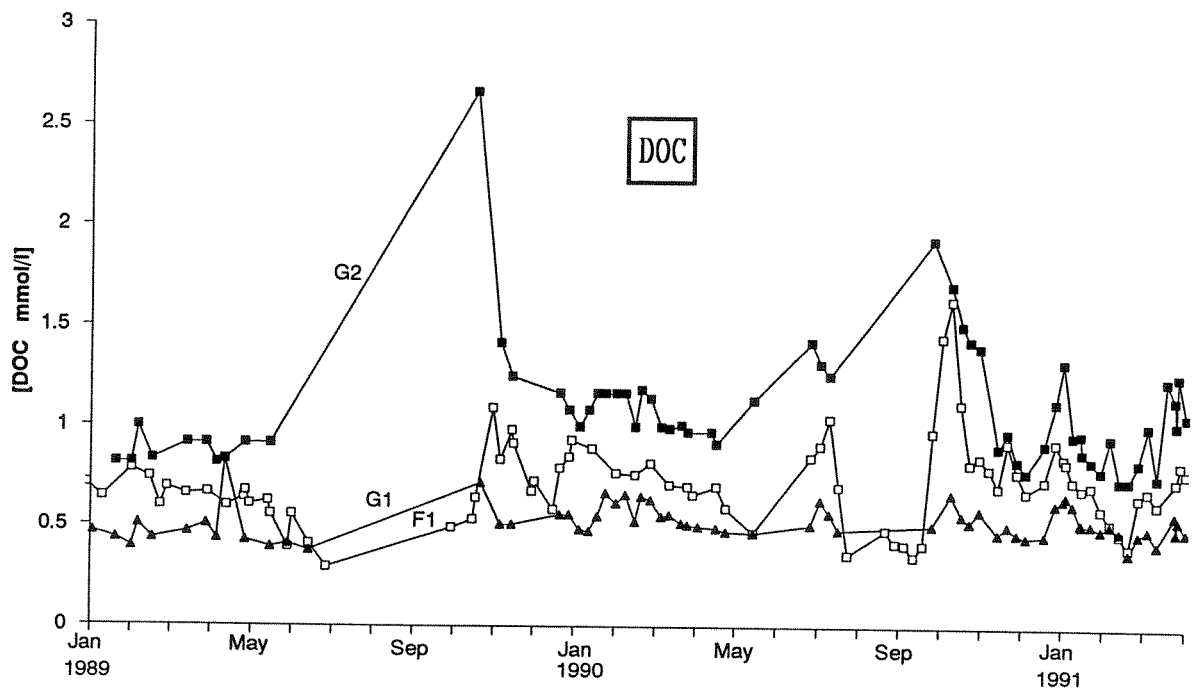

Figure 4.8. Concentrations of DOC measured in runoff at catchments F1 (control), G1 (roof) and G2 (NITREX) over the period January 1989-April 1991.

Concentrations of inorganic nitrogen compounds are very low in runoff from all 3 catchments (Table 4.1). Levels of both NO_3 and NH_4 are frequently at or below the analytical detection limit (Figures 4.9 and 4.10). Thus the pre-treatment data show that the catchments are not nitrogen-saturated (by the usual definition of nitrogen saturation).

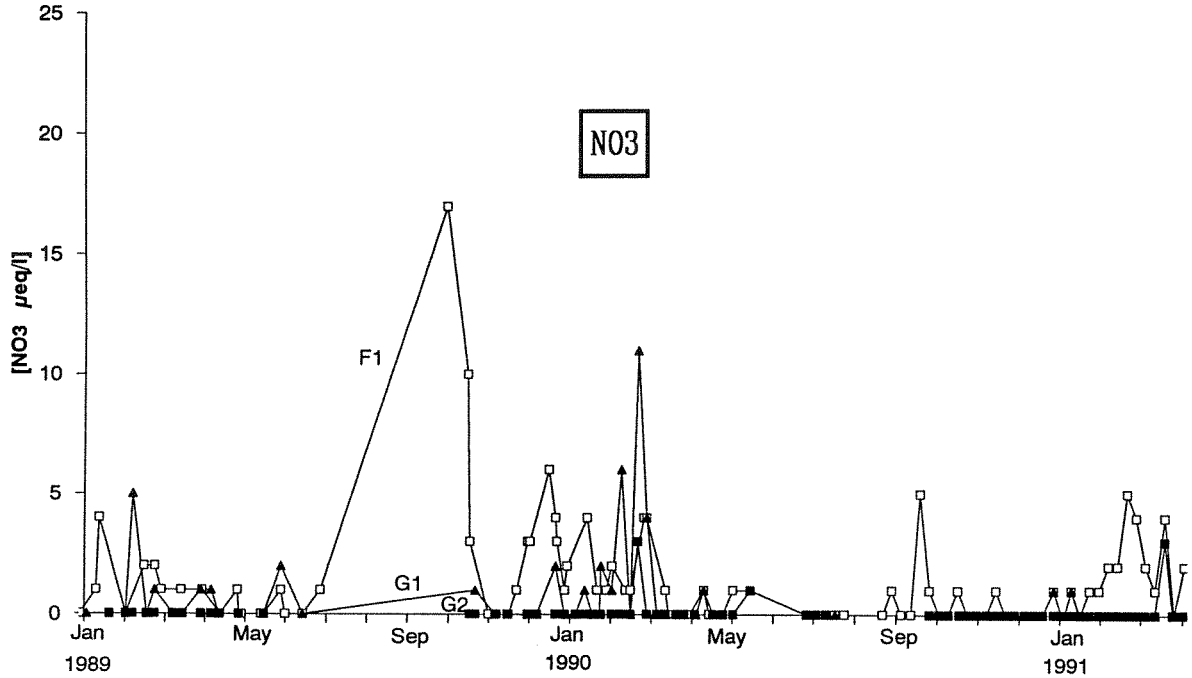

Figure 4.9. Concentrations of NO_3 measured in runoff at catchments F1 (control), G1 (roof) and G2 (NITREX) over the period January 1989-April 1991.

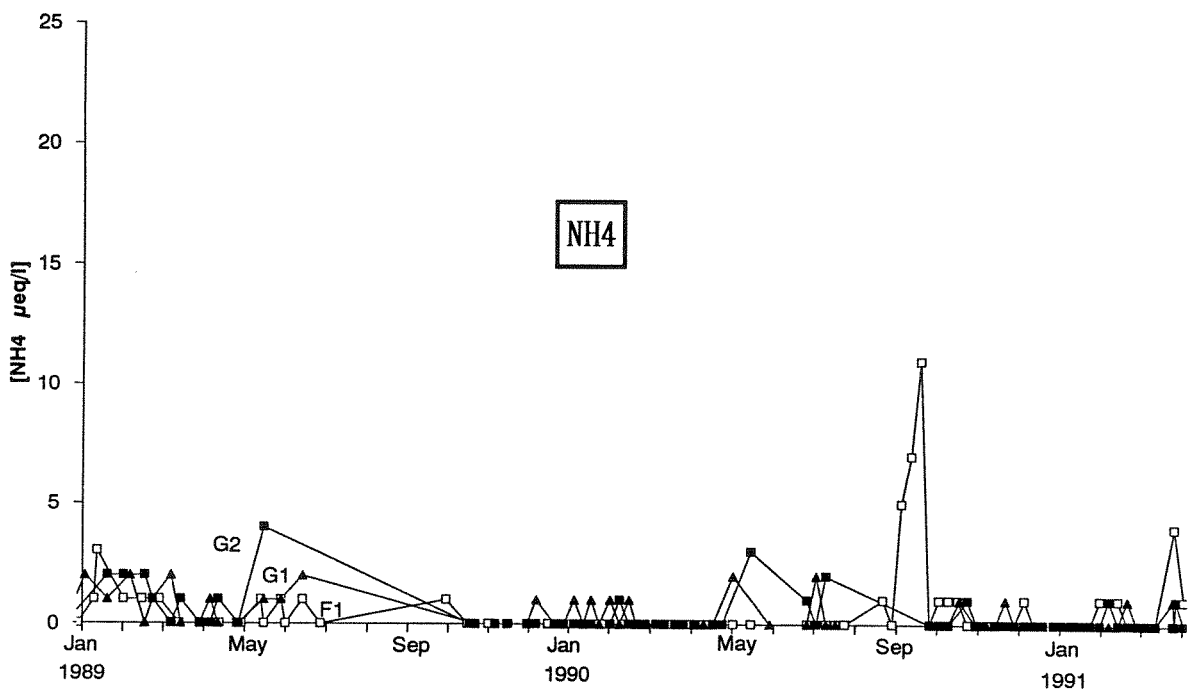

Figure 4.10. Concentrations of NH_4 measured in runoff at catchments F1 (control), G1 (roof) and G2 (NITREX) over the period January 1989-April 1991.

Organic nitrogen, on the other hand, is present at much higher concentrations in runoff from the 3 catchments, and the relative levels have the same rankings as DOC (Figure 4.11). These levels of organic N are probably natural and not related to pollutant inputs of nitrogen to the catchments.

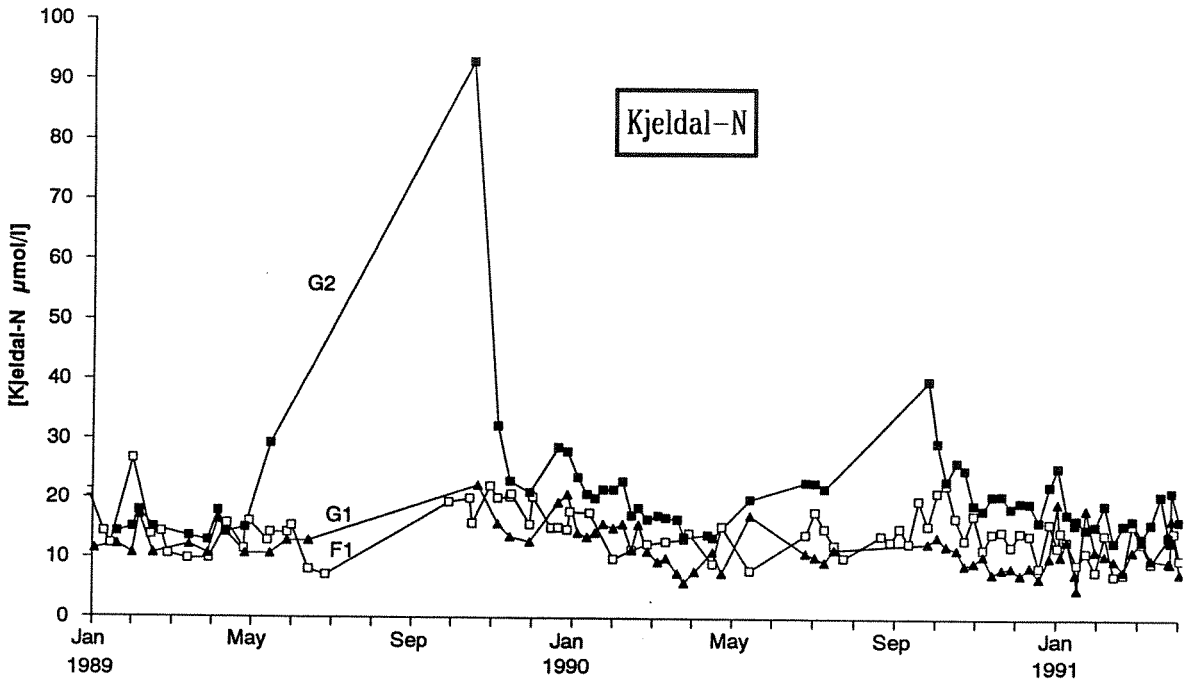

Figure 4.11. Concentrations of organic N (Kjeldal-N) measured in runoff at catchments F1 (control), G1 (roof) and G2 (NITREX) over the period January 1989-April 1991.

4.1.4. Input-Output Fluxes

The input-output budgets indicate an approximate balance for the seasalt ion Cl, as is expected in these catchments which have no other significant source of Cl than atmospheric inputs. The catchments have apparently also reached sulfate saturation, exporting approximately as much sulfur as they receive, but continue to accumulate nearly all of the input nitrogen. In these respect the 3 catchments are typical of catchments in the Gårdsjön area (Hultberg 1985), and of other catchments in similar areas in southern Scandinavia (Wright et al. 1988).

4.2. SOILS AND SOIL SOLUTION

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4.2.1. Soil chemical and physical characteristics

The physical and chemical status of the soil delimits the catchment sensitivity to acidification and its retention of nutrients. In aggregate, these soil properties characterize the available buffer and exchange capacities of the soil, and would be expected to change under continuous exposure to air pollution.

The soils at G2 (NITREX) were mapped thoroughly in 1990. Soil samples were taken in a grid across the catchment every 5x10 m for the humus layer and every 10x10 m for the mineral soil. Samples were collected before the start of treatments and will be re-surveyed after treatments end. They allow quantification of the soil physical and chemical variability in the catchment, and will also be used to produce a soil map. In addition, the upper 13 cm of soil is analyzed for available NH4 and NO3 four times a year in 10 cores from each of the three different moisture regimes with different ground vegetation.

Samples are chemically analyzed for base cations and N (some samples also for organic C and S) using the methods described by Ogner et al. (1991). Exchangeable cations and other extractable elements (Al, Ca, K, Mg, Na, P, and S) are determined in 1 M NH4NO3 extracts by ICP (inductively-coupled plasma emission spectroscopy). The cation exchange capacity (CEC) is defined as CECNH4NO3 = exchangeable acidity + Na^+ + K^+ + Mg^{2+} + Ca^{2+} + Mn^{2+} + $NH4^+$. The base saturation (BS) is defined as BSNH4NO3 = (Na^+ + K^+ + Mg^{2+} + Ca^{2+} + $NH4^+$)/CECNH4NO3 X 100%. The $NH4^+$ value is included in the calculations only if it is available from a separate extraction with 2 M KCl.

The soils in the NITREX catchment are classified as Orthic Humic Podzols, Orthic Ferro-Humic Podzols, Gleyed Humo-Ferric Podzols, and, at the shallow outcrops, Typic Folisols (Canada Soil Survey Committee 1978). The mineral components consist of moraine material that was influenced by water during the post-glacial isostatic rebound. This results in a soil texture gradient from loamy sand in the higher areas and sandy loam in the slopes to silty loam on the lower parts of the catchment. Table 4.3 gives some properties of four typical soil profiles from G2.

Table 4.3. Some selected properties of four soil profiles sampled 1990 from the NITREX catchment G2. Profile 1 is from the upper eastern slope of the catchment, profile 2 from the drier eastern slope of the catchment, profile 3 from the wetter, organic-rich lower part of the catchment and profile 4 from an area with thin soil cover.

PROFILE G2.1, Coord. X75Y105, sandy loam, Orthic Humic Podzol							
Horizon	LFF	HA	eh	Bf	Bhf	Bh	BC
Depth (cm)	14-5	5-0	0-4	4-8	8-18	18-30	30+
pH (H2O)	3.74	3.45	3.58	3.63	4.18	4.26	4.13
Loss on ignition (%)	93.79	93.14	10.10	7.25	11.65	6.94	3.54
Total N (mmol/kg)*	1128	857	115	74	134	91	44
C/N	39.4	52.1	46.4	48.4	34.8	29.3	28.4
% sand			50.5	50.5	48.2	52.1	53.4
% silt			44.3	42.9	46.9	44.8	42.9
% clay			5.2	6.6	4.9	3.1	3.7
CEC (mmolc/kg)	373.6	475.3	70.3	72.3	57.4	32.9	19.1
BS (%)	59.0	49.1	18.1	11.0	11.9	10.0	7.0
Exch. acidity (mmol/kg)	150.1	240.6	57.5	64.3	50.5	29.6	17.8
Exch. Al (mmol/kg)	6.28	10.30	12.66	18.97	19.28	11.31	6.53

PROFILE G2.2, Coord. X55Y80, sandy loam, Gleyed Humo-Ferric Podzol									
Horizon	LFH	Ae	Bf1	Bf2	BC	C	2Cg1	2Cg2	3Cg
Depth (cm)	14-0	0-4	4-8	8-28	28-38	38-52	52-65	65-87	87+
pH (H_2O)	3.66	3.74	3.85	4.22	4.24	4.32	4.45	4.31	4.33
Loss on ignition (%)	90.72	3.08	5.29	6.69	2.99	1.51	1.92	1.54	1.11
Total N (mmol/kg)*	945	36	62	82	36	16	25	16	9
C/N	45.8	44.0	37.6	32.5	30.1				
% sand		56.1	50.7	54.2	52.8	57.4	33.3	33.4	75.0
% silt		40.2	41.1	38.3	42.8	40.3	62.1	61.3	22.8
% clay		3.8	8.2	7.5	4.4	2.3	4.7	5.3	2.3
CEC (mmol$_c$/kg)	374.0	37.7	61.4	26.2	14.2	8.3	10.8	9.9	6.5
BS (%)	51.8	8.0	5.5	6.8	7.8	8.8	9.0	14.1	10.3
Exch. acidity (mmol/kg)	178.8	34.7	58.0	24.4	13.1	7.6	9.8	8.5	5.8
Exch. Al (mmol/kg)	7.89	8.65	21.56	10.00	5.44	3.13	4.18	3.49	2.17

PROFILE G2.3, Coord. X35Y90, Sandy loam over silt, Orthic Humic Podzol							
Horizon	LF	F	Oh1	Oh2**	Bh	CB	2Cg
Depth (cm)	33-21	21-17	17-0	17-0	0-11	11-26	26+
pH (H_2O)	3.98	4.00	4.13	4.41	4.40	4.42	4.42
Loss on ignition (%)	93.18	88.24	66.54	25.17	9.35	4.72	3.91
Total N (mmol/kg)*	1205	1019	1240	476	177	74	66
C/N	35.1	37.7	25.5	22.7	24.5	17.3	
% sand					41.8	58.9	15.2
% silt					50.8	37.8	79.0
% clay					7.4	3.4	5.9
CEC (mmol$_c$/kg)	482.8	573.4	223.1	72.2	41.3	26.5	16.9
BS (%)	11.4	6.7	8.3	8.2	6.2	5.4	6.2
Exch. acidity (mmol/kg)	427.3	534.8	204.6	66.3	38.8	25.1	15.8
Exch. Al (mmol/kg)	129.66	175.73	71.01	24.82	13.85	9.07	5.12

**Oh2 consist of large pockets in the Oh1 horizon, filled with oxides.

PROFILE G2.4, Coord. X50Y95, Loamy sand, Typic Folisol		
Horizon	LF	Aeh
Depth (cm)	10-0	0-5
pH (H2O)	3.57	3.76
Loss on ignition (%)	95.56	8.58
Total N (mmol/kg)*	1002	104
C/N		39.3
% sand		83.9
% silt		12.7
% clay		3.4
CEC (mmolc/kg)	385.1	45.4
BS (%)	45.1	8.8
Exch. acidity (mmol/kg)	210.1	41.4
Exch. Al (mmol/kg)	7.74	9.32

*Kjeldahl-N is measured, but no nitrate has been found in the soil in mineralization studies.

The soil is fairly acid, with pH increasing slightly in the lower peaty region. The fairly high C/N ratio (larger than 30 in the organic and A horizons), suggests that immobilization of added nitrogen will be an important process during seasons of microbial activity. Cation exchange capacity (measured at soil pH) is low in the mineral soil due to low clay content. Base saturation (measured at soil pH) is relatively high in the upper organic horizons, and very low in the mineral soil. The lower Sphagnum-rich area (profile G2.3) has low base saturation through the whole profile. The exchangeable aluminum in these organic layers is very high and dominates the cation exchange capacity (CEC). In contrast, base cations comprise most of the CEC in upslope organic layers. This difference may be due to binding of Al and Fe from water from the upslope B horizons which, because of the high groundwater table downslope, passes over the upper organic horizons. A similar phenomenon has been reported in the Birkenes catchment, Norway (Mulder et. al. 1992).

The soil in the control catchment F1 is slightly more stony than the NITREX site G2, but the soil from the F1.1 profile is comparable to G2.1. (Table 4.4). The differences between soils of the nitrogen manipulation site and the control underscore the importance of comparing time trends in the two areas.

Table 4.4. Some selected properties of the soil profile from the NITREX control site (F1).

PROFILE F1.1 Coord. X5Y20, Sandy loam, Orthic Ferro-Humic Podzol							
Horizon	LFH	Ae	Bhf1	Bhf2	Bf	BC	C
Depth (cm)	9-0	0-5	5-6	6-21	21-45	45-46	46+
pH (H_2O)	3.59	3.52	3.55	3.96	4.19	4.32	4.59
Loss on ignition (%)	88.28	2.19	9.74	11.76	8.55	1.10	0.75
Total N (mmol/kg)	1271	39	147	150	103	13	7
C/N	32.3	27.8	28.9	31.7	30.7	19.2	
% sand		47.2	41.4	43.4	57.1	75.2	86.8
% silt		48.8	45.8	47.9	34.5	22.5	12.0
% clay		4.0	12.7	8.7	8.4	2.3	1.2
CEC ($mmol_c/kg$)	370.7	22.1	104.5	72.4	52.1	13.4	11.2
BS (%)	50.1	12.2	5.6	7.2	14.9	13.2	9.4
Exch. acidity (mmol/kg)	183.1	19.3	98.6	67.1	44.3	11.6	10.1
Exch. Al (mmol/kg)	10.28	3.87	27.58	23.21	16.39	4.33	3.51

4.2.2. Soil solution chemistry

Soil solution is of central interest because the experimental N additions to the catchment may first be manifest in changes in the chemical composition of soil solution. Nitrogen compounds, of course, are of particular importance.

In G2 90 teflon tension lysimeters (PRENART) are located in seven plots, four with constant suction and three for event sampling. Lysimeters are installed at 5, 10, 20, 40 and 70 cm depths, with 2-3 lysimeters at each depth connected to the same sampling bottle. Catchments G1 and F1 each have two such lysimeter plots (same depths and frequency) corresponding to moisture regimes in G2. Three additional lysimeter plots were installed in G1 by the Roof project. Both ceramic cups and teflon lysimeters are used in these plots. Water samples for chemical analysis are collected fortnightly. Volume is recorded when samples are collected. Samples are analyzed at NISK for the same constituents as bulk deposition (except for Kjeldahl-N), with the addition of alkalinity, total N, total S, PO_4, Al, Fe, Cu, Si and Zn (Ogner et al. 1991).

Volume-weighted mean values for some soil solution constituents (March 1990 to March 1991) are shown in Figure 4.12. The means are calculated from fewer samples in the upper horizons because these are either dry or frozen for longer periods than the lower horizons. In the lysimeter plots dominated by mineral soil (LY1 and LY2) the chemical composition of the soil solution differs among horizons. The lysimeter plots dominated by organic soil (LY3 and LY7) show only small differences among horizons, except for pH and total N.

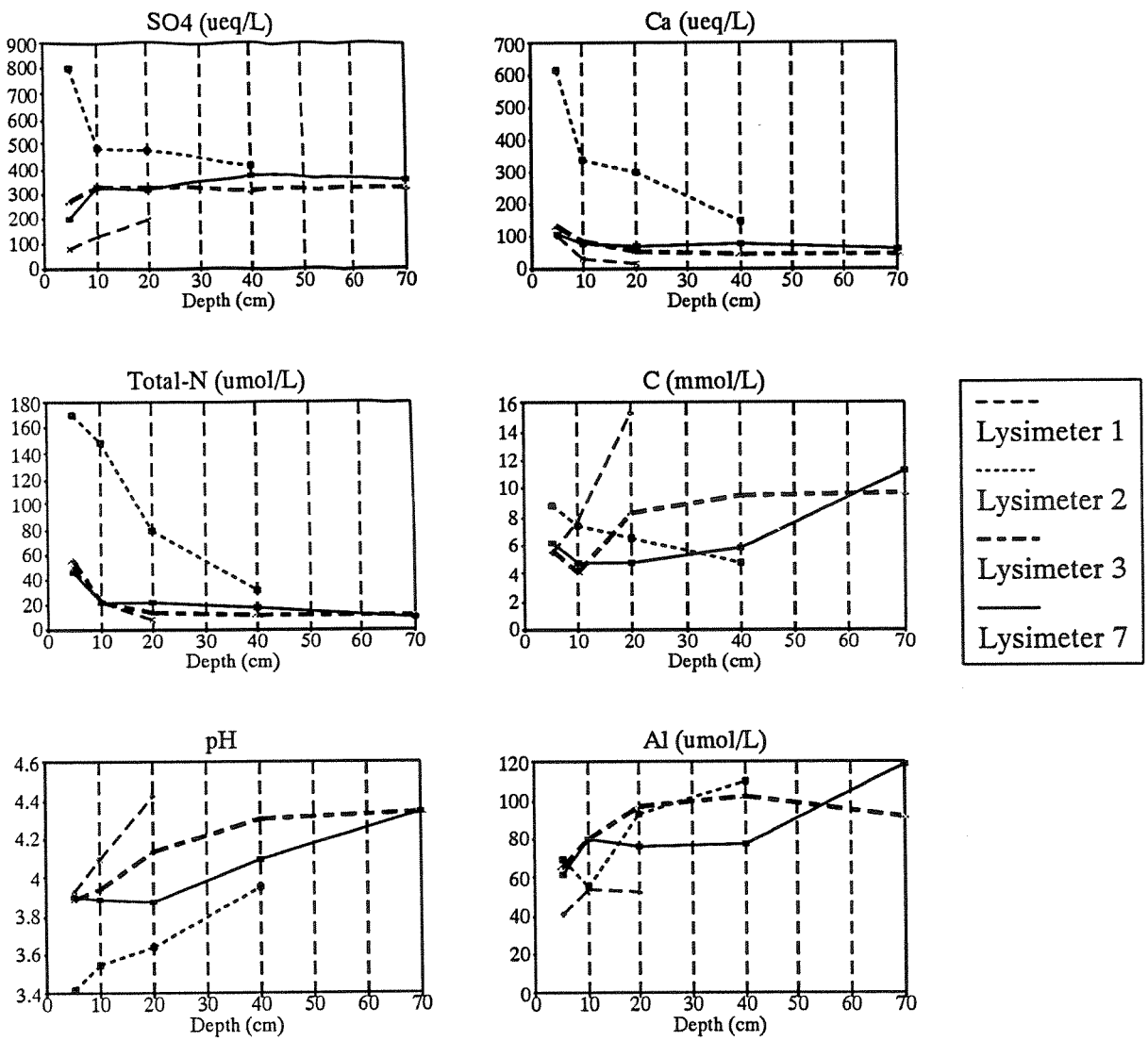

Figure 4.12. Volume-weighted concentration of the soil solution at different depths and locations in catchment G2. The samples were collected twice a month during the period March 1990 to March 1991.

Chloride is the dominant anion in the soil solution, followed by sulfate. Despite the low pH values, aluminum concentrations are fairly low. Most of the aluminum is probably bound in organic compounds (high levels of organic C); analyses for Al species have not yet been made to confirm this. The concentrations of NO_3-N and NH_4-N are generally close to the detection limit of 1 μeq/L, indicating that most of the soluble nitrogen in the catchment is in an organic form.

In addition to spatial variability, the composition of the soil solution varies over the year (shown for pH and total N in Figs. 4.13 and 4.14, respectively). The large variation in the concentration of total N in spring 1990 may be an artifact of soil disturbance during the lysimeter installation the previous February. During the dry late summer and early autumn no soil solution could be collected.

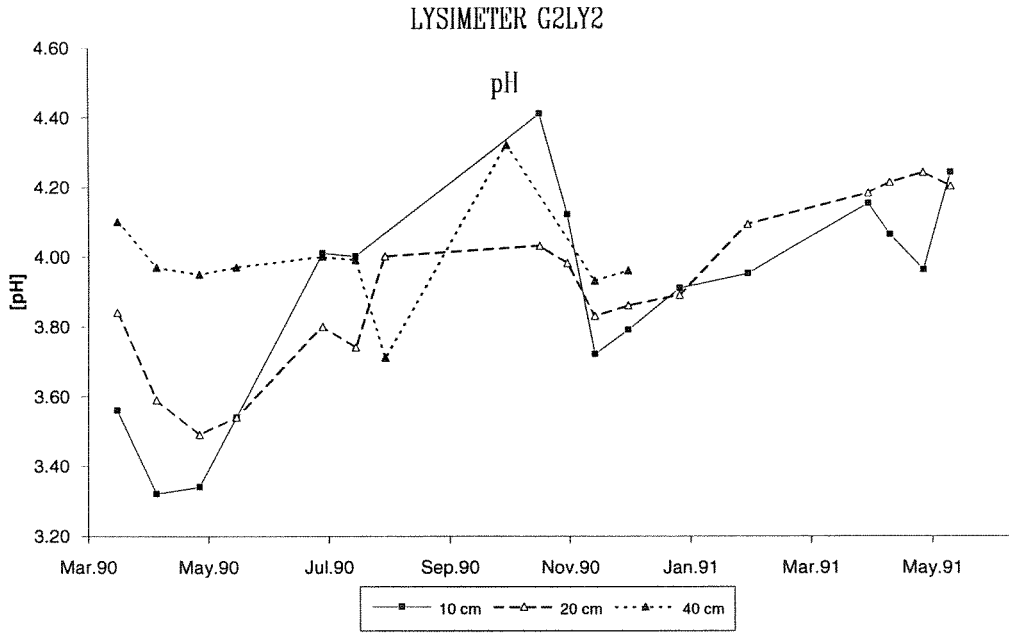

Figure 4.13. The variation in soil solution pH at lysimeter G2LY2 over time at different depths.

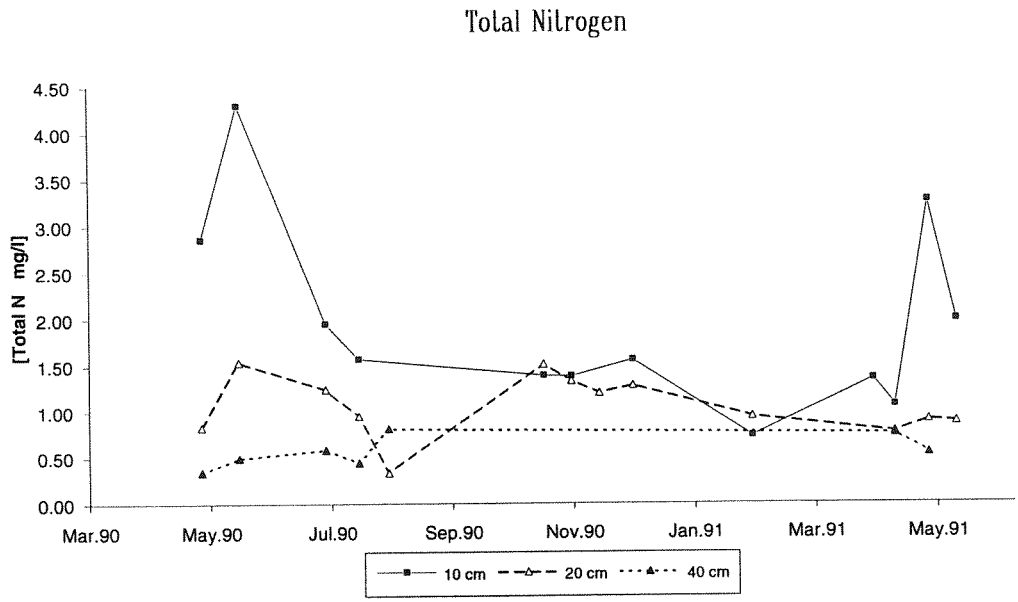

Figure 4.14. The variation in soil solution total nitrogen at lysimeter G2LY2 over time at different depths.

4.2.3. Soil microbial processes

Gårdsjön-NITREX investigations include monitoring the rate and amount of microbiological conversion of organic-N to ammonium (mineralization), ammonium to nitrate (nitrification), and nitrate to atmospheric-N2O/N2 (denitrification) using either soil core incubations or chamber techniques. These soil processes may be either disturbed by internal nitric acid production during dry periods (Ulrich 1983), or stimulated by the increased supply of available nitrogen. The studies at Gårdsjön compare rates of soil microbial transformations in similar soil moisture regimes in the NITREX (G2) and the Roof (G1) catchments with the common control (F1).

Mineralization capacity is studied in three soil moisture gradients with differing ground vegetation in G2, and a single (medium dry) moisture regime in the control site (Vaccinium-dominated) and the Roof catchment (Dicranum-dominated). The incubation is made *in situ* with ion-exchange resin bags placed in the bottom of soil cores. To estimate the relative contributions of input- versus mineralized-nitrogen, resin bags are also placed on the surface adjacent to the soil cores. Soil cores are collected before each mineralization study to measure pre-incubation levels of NH4, NO3 and total N.

Incubations are made over 2-month intervals in the spring-autumn (May-June, July-August, September-October) and over 5 months in the winter (November to May), with 10 replicate cores for each vegetation type. The cores are placed in a grid net, and vegetation in the grid is recorded in detail. The holes from collected samples are re-filled with soil from similar vegetation types (gathered from outside the catchments) to minimize mineralization in the catchments due to disturbance. Soil temperature is measured adjacent to the mineralization plots at 5, 10, 20, 40 and 70 cm. The mineralization studies are carried out close to the lysimeter installations (downslope) to facilitate comparison of $NH4^+$ and $NO3^-$ levels in soil and soil solution.

Preliminary results show no KCl-extractable NO3 in the soil cores, but it has been detected in the resin. Data are still too few to permit for meaningful comparisons among the catchments.

Denitrification rates will be measured in G2 beginning in the spring of 1992 using a closed chamber technique, with three chambers placed in each moisture/vegetation regime. Measurements began in G1 and F1 in 1991 as part of a separate study conducted by IVL.

Potential **nitrification**, microbial biomass and the activity and density of nitrifying bacteria are measured at irregular intervals. Samples are analyzed by IVL, NISK and the Institute for Microbiology, NLH (The Norwegian Agricultural University). These process-oriented studies are all coordinated to facilitate comparison among results.

4.3. SOIL HYDROLOGY

Michael Hauhs, BITÖK, Isabel Wohlfeil, NIVA and Dirk Müller, SI

The assumption of diffusive soil water transport is essential to link soil chemical, soil solution and budget data at Gårdsjön. The main task of the hydrological study is to evaluate this assumption and to identify periods when it is violated. The study tests if potential waves that move through the flow region in response to, for example, rainfall or root water uptake, are following a diffusive transport mechanism. If this test fails, water transport is by preferential flow paths that bypass most of the soil matrix (Beven and Germann 1982). These periods may be very important, for example, effects on the aquatic biota may be limited to times of "bypass flow" when soil lysimeter data are not representative

of mobile soil water. Experimental treatments (e.g., precipitation under the roofs) may alter the frequency of such events.

A two-dimensional hydrologic model is used to test this assumption (Hauhs 1986). It is based on numerical solutions of the Richard's equation (Hillel 1980) and appropriate initial and boundary conditions. It requires measurements of water transport across ecosystem boundaries, including 1) precipitation, 2) interception losses from the canopy (estimated with throughfall values), 3) transpiration by the vegetation, and 4) runoff or seepage water loss. In addition it requires information about soil water potentials.

Tensiometers, which provide data on the latter, are a vital part of the hydrologic study. They are used to identify which soil solution fractions potentially contribute to runoff under different hydrological conditions.

4.3.1. Installations and monitoring

Installations and monitoring of precipitation, throughfall and runoff are discussed in section 4.1.1. as part of the input-output measurements. Daily potential transpiration is estimated with the Penman-Monteith equation (Thom 1975) using measurements of daily temperature, vapor pressure deficits, solar radiation and soil water potentials together with values for effective canopy resistance from the literature.

Tensiometers were installed in late 1990. They are distributed across the catchment to cover the maximum range of soil hydrologic variability (Figure 4.1). There are 14 tensiometers in G2 at depths between 20 and 75 cm, 8 in G1 between 10 and 80 cm, and 5 in F1 between 30 and 70 cm. Tensiometers in each catchment are connected to a transducer system and a portable computer which records matrix potential every 15-30 minutes.

4.3.2. Results from 1991

The hydrological response at G2 is very fast and leads to stormflow peaks within a few hours after the start of rainfall. The response of the water potential in the soils matches this quickflow but the data so far indicate no preferential flowpaths. Some tensiometers in the deeper bog layers show little response to high intensity rainfall and are probably not within the active flow region for such events.

Initial modelling trials at G2 do not disprove the hypothesis of diffusive soil water transport (Figures 4.15 and 4.16). The soil characteristics fitted through these modelling trials will be compared to the measured pF and conductivity curves from nearby G1. The results obtained so far indicate that transport within the upper organic layers can be fast, reaching rates up to $5*10^{-3}$ m sec^{-1}.

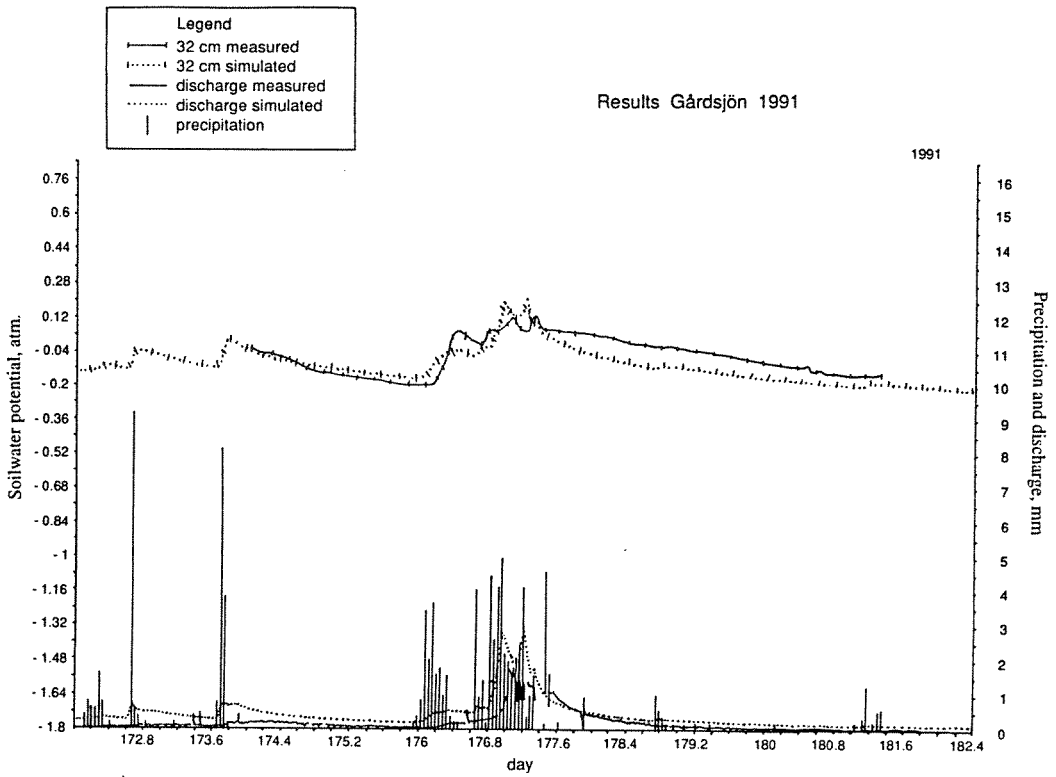

Figure 4.15. Measured and calculated water potentials and runoff for an event at G2 in 1991 (tensiometer group G).

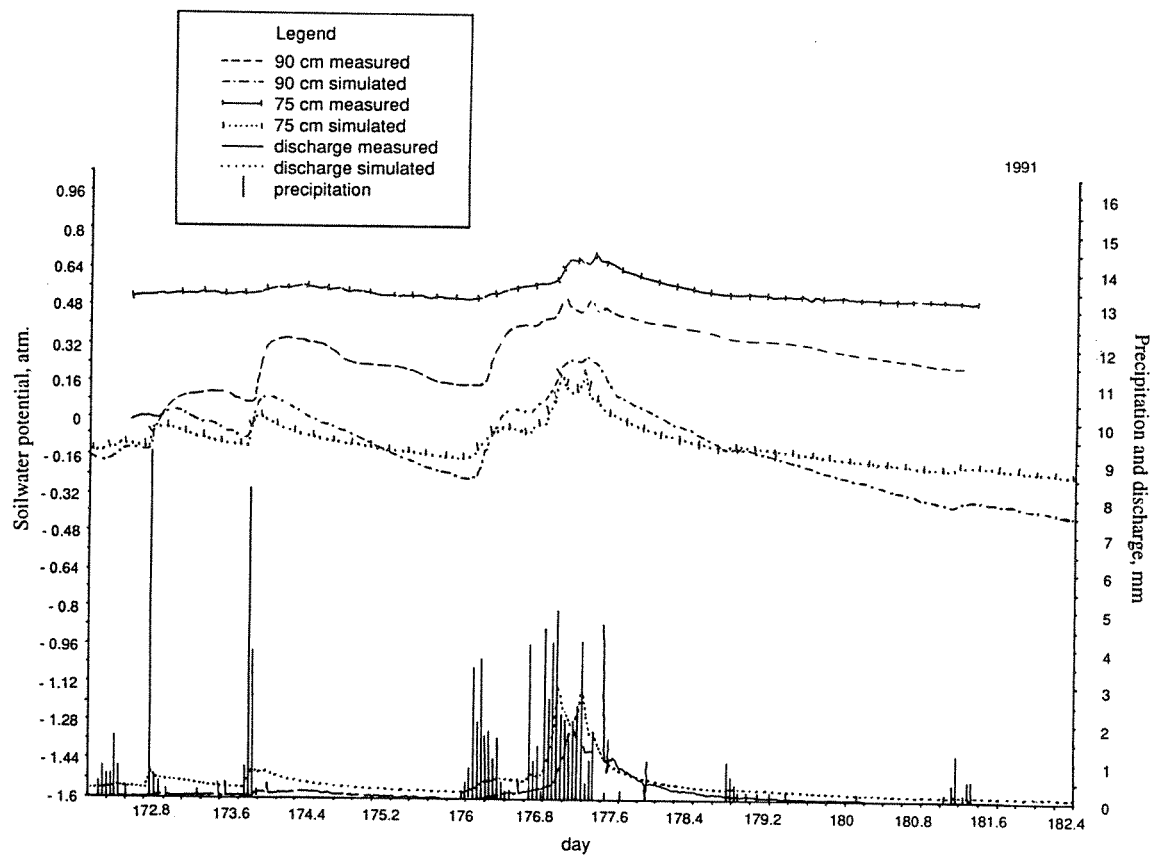

Figure 4.16. Measured and calculated water potentials and runoff for an event at G2 in 1991 (tensiometer group H).

4.4 FINE ROOTS

Anna Clemensson-Lindell and Hans Persson, SLU

The objective of the fine root study is to investigate the relationships among root vitality, rhizosphere soil chemistry, and bulk soil chemistry under conditions of increased and decreased nitrogen deposition. This is carried out by studying changes in fine root vitality and growth and changes in the chemical composition of rhizosphere and bulk soil in the N-fertilized catchment (G2), the roof catchment (G1), and the reference catchment (F1).

4.4.1. Installations and monitoring

In each of the dry and medium soil moisture gradients (Vaccinium-dominated and moss-dominated, respectively), 10-20 soil cores (diameter 4.5 cm) are removed near the lysimeter and mineralization plots. Cores are taken to a depth of about 30 cm, with sufficient space left between the holes for subsequent sampling. In the field each core is divided into humus and mineral soil, then sub-divided into slices of either 5 cm (humus and upper 10 cm) or 10 cm (rest of core). The rhizosphere soil and the bulk soil are sampled for later extraction in distilled water and chemical analysis (pH, N, P, K, Ca, Mg, Mn, S, Al and Fe). In the laboratory the roots from each layer are sorted by diameter and vitality, measured, dried and weighed. Soil core sampling started in March 1990 and was repeated in October 1990 and 1991.

An ingrowth core, a nylon net filled with perlite, is placed in each hole left by the soil sampling. The ingrowth cores are removed yearly for the same root sampling as the soil cores. They were installed in March 1990 and again in October 1990. The first were re-sampled in October 1991 but have not yet been processed.

Roots are picked out from each layer of the cores and sorted into three diameter classes: 0-1 mm, 1-2 mm, and 2-5 mm. Roots > 1mm in diameter are sorted as living or dead. Fine roots > 1 cm in length from the smallest diameter size are separated by stereomicroscope into vitality classes based on the following morphological characteristics:

Vitality class 1: The roots are light, yellowish, often with great amounts of white root tips. The stele is elastic and white. No brown-black parts on the root fragment.

Vitality class 2: The roots are darker, more suberized, but still well-branched. Smaller parts of the root can be dark brown or black, but the main part is still vital.

Vitality class 3: The roots are darkened, brown-black. White root tips are often lacking. The stele is still elastic and light to slightly brown.

Vitality class 4: The roots in this class are normally referred to as dead. The stele is brownish and easily broken off. No elasticity remains.

The root tips are counted in each vitality class and divided into four broad categories based on mycorrhizal infection and morphological appearance (in cooperation with T-E Brandrud, NIVA):

- Smooth, waxy mycorrhiza
- External, cottony mycelia
- Cenococcum
- Zonated root tips.

4.4.2. Preliminary results

Preliminary results (October 1990 sampling) indicate a pronounced superficial root distribution. The two root vitality classes 1 and 2 (most vital), however, were only found in the humus layer and then only in very small amounts compared with the total fine root mass. Fine roots in the mineral soil were in very poor condition. The fine roots were represented in approximately the same proportions among the four vitality classes within all catchments and vegetation types (Figures 4.17 and 4.18). Coarse roots (1-2 mm and 2-5 mm in diameter) were also found in very low amounts in the soil profile (Figure 4.19).

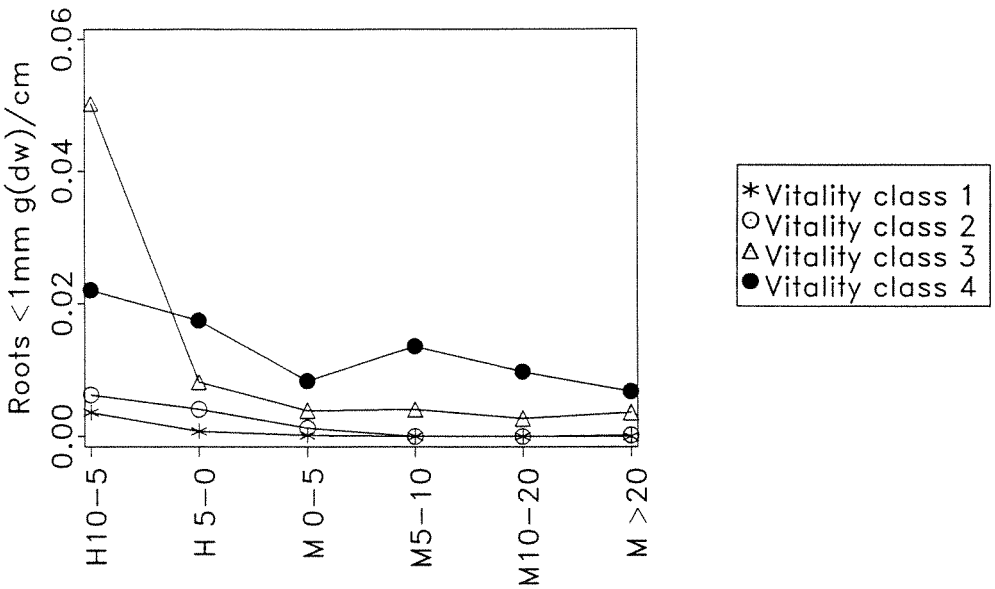

Figure 4.17. Fine root distribution in the G2 catchment, medium soil moisture (moss-dominated). H= humus layer (cm), M=mineral soil (cm).

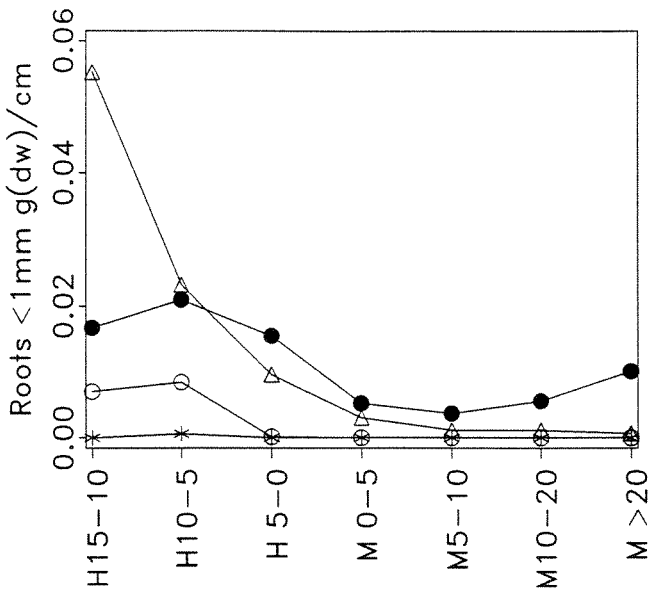

Figure 4.18. Fine root distribution in the F1 catchment, dry soil group (Vaccinium-dominated). H= humus layer (cm), M=mineral soil (cm). Legend: see Figure 4.17.

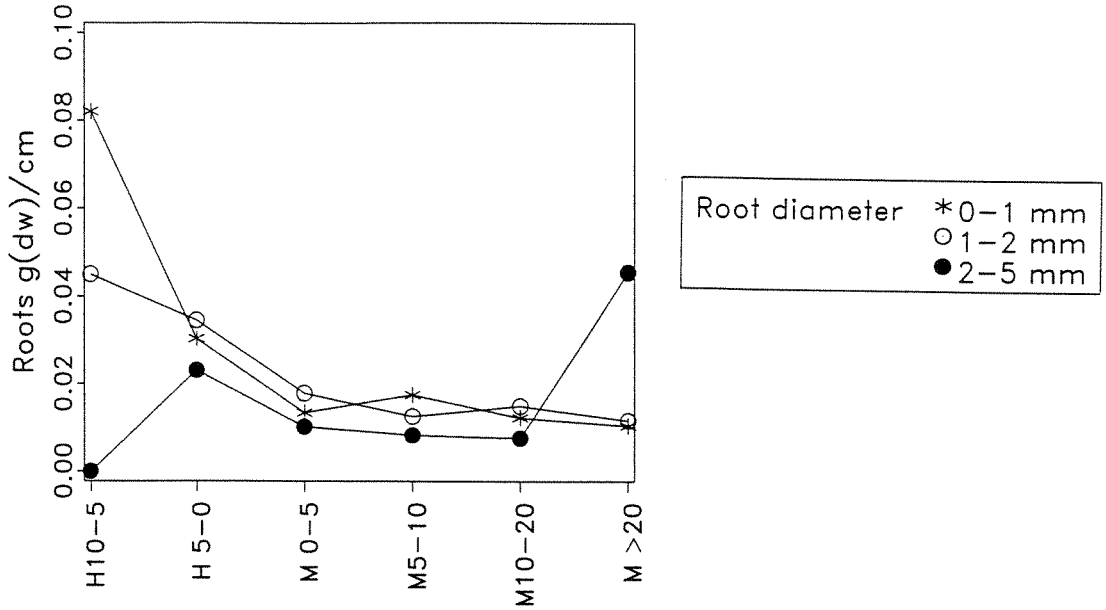

Figure 4.19. Distribution of roots of different diameter classes, catchment G2, medium soil moisture (moss-dominated).

The total amount of vital root tips (both mycorrhizal and non-mycorrhizal) corresponded well with the vitality of the fine roots (Fig. 4.20). This was also reflected in the distribution of root tips in the soil profile (Figure 4.21).

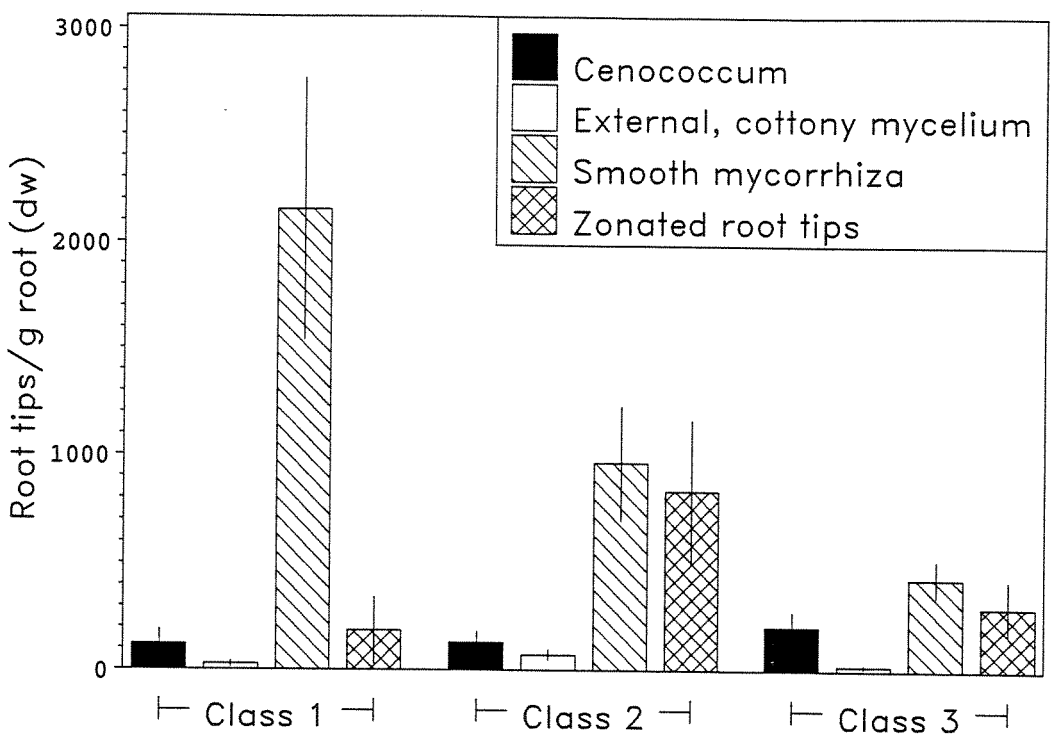

Figure 4.20. Type of mycorrhizal infection and root tips in each fine root vitality class. Mean values +- SE.

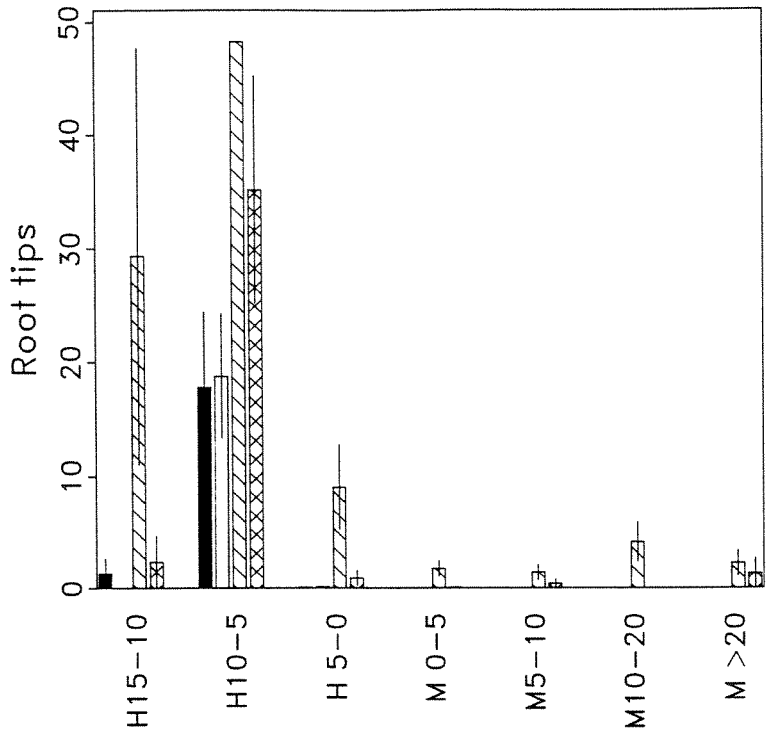

Figure 4.21a. Distribution in the soil profile of root tips with different mycorrhizal infections. F1 catchment, medium soil moisture (moss-dominated). Legend: see Figure 4.20.

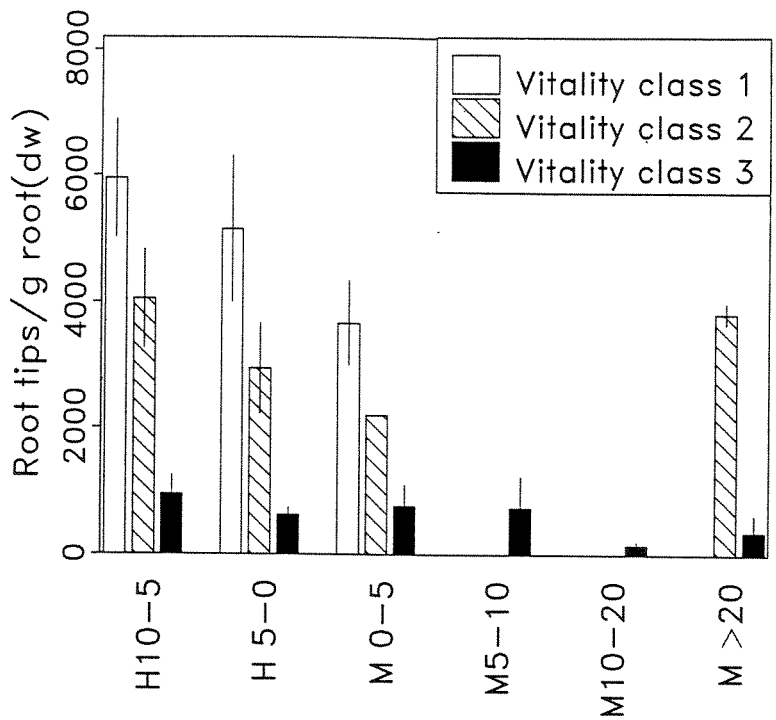

Figure 4.21b. Total amount of vital root tips in the fine root vitality classes in the soil profile. G2 catchment, medium soil moisture (moss-dominated). Mean values +- SE.

4.5. ECTOMYCORRHIZAL FUNGI

Tor Erik Brandrud, NIVA

By greatly increasing the surface area of the fine roots, mycorrhizal fungi increase the effectiveness of roots to extract water and nutrients from the soil solution. Most fine roots in an oligotrophic forest ecosystem have developed (ectotrophic) mycorrhiza. Experience both from fertilization experiments and from heavily polluted forests indicates that the mycorrhizal fungi are particularly sensitive to increased levels of N-input. Our hypothesis is that the mycorrhizal fungi will respond at an early stage of the experimental change in the N-deposition. This rapid response is due to high turnover rates and high sensitivity to pollution.

4.5.1. Installations and monitoring

The above-ground production of fungal fruit bodies in G2 is recorded approximately four times from August to October in 3 transects. The transects are divided into 52 5x5 m relevees. Below-ground production of mycorrhiza is investigated in 25 soil cores collected in September (method slightly modified from Vogt & Persson 1991). Mycorrhizal roots from the organic layers are counted and classified as living or inactive/dead. The living mycorrhiza are further classified into four morphologic categories corresponding to species or species groups. Background values were obtained in 1990.

4.5.2. Results

Below-ground study: At Gårdsjön a distinct and dense root mat approximately 1-2 cm thick is developed just beneath the litter layer. The humus layer just below this root mat generally has a much higher percentage of inactive/dead and easily fragmented mycorrhizal roots.

The background year 1990 was estimated by local mycologists to be a moderate- to slightly less than moderate year for fungus production in this area of western Sweden. Nevertheless, a high density of well-developed mycorrhizal roots was found in 1990 (Wright 1991). In fact, the mycorrhiza of the root mat at the forest floor were frequently 100 % alive and healthy, although there had been a severe dry period in July. Thus, healthy mycorrhizal development is assumed to be the normal background situation prior to nitrogen addition.

There are indications from the 1991 material studied to date that the vitality of the surface-layer mycorrhiza has decreased substantially (Figure 4.22). This applies especially to the Vaccinium myrtillus -dominated sample area, which was the most healthy in 1990. In this sample area, the number of inactive/dead and fragmented mycorrhiza increased from 0-2 to 41-269 mycorrhizal root tips per cm^3 from 1990 to 1991 for the samples studied so far.

The number of living mycorrhizal root tips decreased by approximately 30% from 1990 to 1991 (Figure 4.22a). Among the mycorrhizal categories, the development of the presumed stress-tolerant black Cenococcum mycorrhiza was unchanged, while the (heterogeneous) group of mycorrhiza with a smooth surface decreased by approximately 27%. Mycorrhiza with white, external mycelia apparently had suffered the most: density was reduced by approximately 65%, and overall vitality was poor. For the catchment as a whole, the living/dead ratio of the surface root mat mycorrhiza decreased from 7.5 to less than 1.0 during the period.

Above-ground fruitbody production: The overall fruitbody productivity was not greatly changed from 1990 to 1991 (2279 versus 2456 fruit bodies, respectively), but there was large variation at the genus

and species level (Figure 4.22b). For instance, 1991 was a fairly good year for the genus Russula (smooth mycorrhiza) but a less productive year for the genus Cortinarius and other types of fungi producing mycorrhiza with white external mycelia. A few of these, however (e.g. Cantharellus tubaeformis), were more abundant in 1991 than in 1990. This was a general trend over all of southern- and central Scandinavia in the fall of 1991: members of the Cortinariaceae had a poor season, while members of Cantharellaceae (and some related families) had a comparatively productive season.

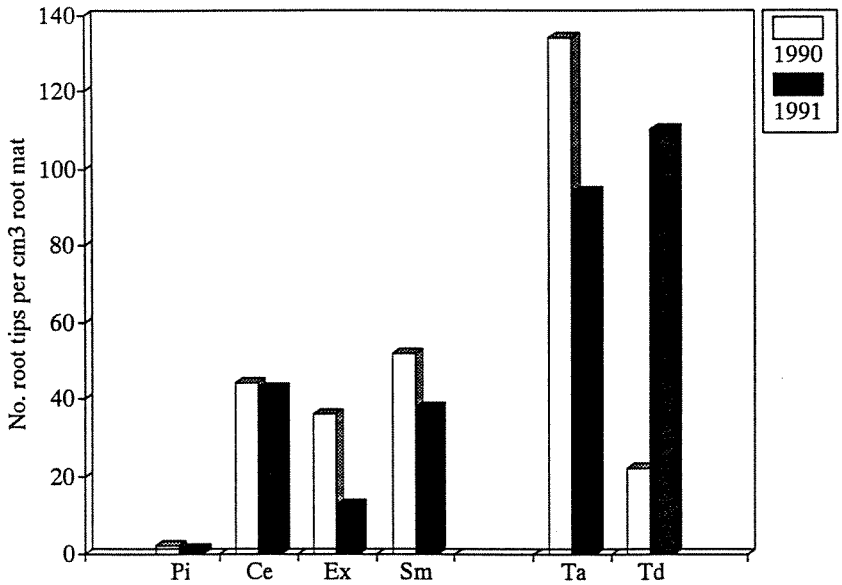

Figure 4.22a. Histogram showing the changes in mycorrhizal populations in the surface root mat from 1990 to 1991. Pi = Piloderma croceum mycorrhiza (bright yellow), Ce = Cenococcum graniforme mycorrhiza (black), Ex = External mycelium mycorrhiza (white, cottony), Sm = Smooth surface mycorrhiza (usually pale brownish). Ta = total number of active mycorrhiza. Td = total number of dead/inactive mycorrhiza.

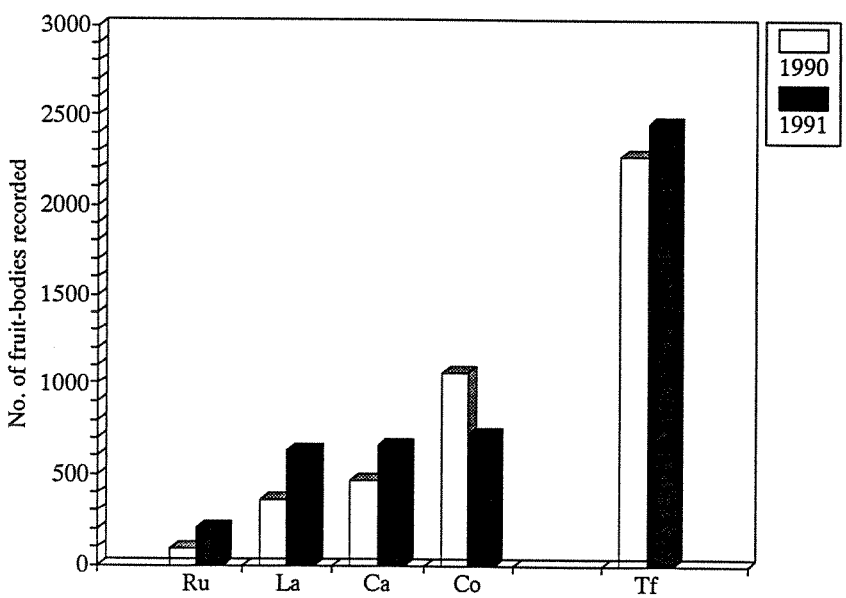

Figure 4.22b. Histogram showing the changes in fruit-body production of the most important groups of macrofungi from 1990 to 1991. Production is given as number of fruit-bodies recorded in the 52 5x5 m transect plots (ca. 1300 m^2). Co = Cortinarius, Ca = Cantharellus tubaeformis, La = Lactarius, Ru = Russula, Tf = total number of fruit-bodies.

4.5.3. Discussion

The results concerning mycorrhizal root vitality are preliminary since fungal populations normally show year- to-year fluctuations. At least one more year is needed before any preliminary statements about the effects of the N-treatment can be made. From 1992 onward a complete mycorrhiza comparison between the control, the Roof and the NITREX catchments at Gårdsjön will also be carried out. With an N-input gradient established both in time and space, the effects of increased N-levels may be easier to distinguish.

It is, however, of some interest to note that the changes in mycorrhizal fungi vitality from 1990 to 1991 were most pronounced in the below-ground mycorrhizal root development (a decrease), and not so much in the total above-ground fruitbody production (a slight increase). Evidence from the literature indicates a correlation between fruitbody production and mycorrhizal activity in the soil (Agerer 1985). At Gårdsjön, some groups (especially Russula spp.) showed an increase in fruitbody production, while the morphotype of mycorrhiza they form in the soil ("smooth") showed a decrease. From this it seems probable that species like Russula play a minor role in the mycorrhizal root fraction. The majority of the "smooth" mycorrhiza at Gårdsjön (and in other oligotrophic spruce forests examined) probably are non-fruitbody-forming microfungi.

A better correlation between above-ground and below-ground production was observed with the white external mycelium ("cottony") mycorrhiza. Both above- and below-ground production showed a decrease, particularly the dominant genus Cortinarius (722 fruit bodies in 1991 versus 1065 in 1990, Figure 22b). It is tempting to take this as a first sign of a negative response to the N-addition, since this category of mycorrhizal fungi is regarded to be the most sensitive to environmental changes (Olsen 1986). But these changes may simply indicate that this group is characterized by larger year-to-year fluctuations relative to other groups. An increase in the productivity of Cortinarius in a number of plots in October 1991 - apparently due to favorable weather conditions - suggests that this group of fungi still has the potential to repeat its high 1990 "background" levels of fruitbody production.

The mycorrhiza study is coordinated with the study of higher plants and their fine roots. The study will be expanded in 1992 with mycorrhizal analysis of ingrowth cores and litterbags, as part of the proposed integrated study of soil biota in the NITREX project (Dise and Wright 1992). The control and roof catchments will also be included in the study beginning in 1992.

4.6. VEGETATION

Per Holm Nygaard, O. Janne Kjønaas, Arne O. Stuanes, and Magne Huse, NISK

4.6.1. Litterfall

Disruption of the soil biota through acidification affects the amount and rate of litter decomposition, a process of central importance for the recycling of nutrients through the ecosystem.

Litter is sampled from collectors placed approximately 1 meter above the ground and sheltered from the nitrogen spraying. There are 23 collectors in G2 and 20 in G1 arranged in rows across the catchment parallel to the throughfall collectors (Fig. 4.1). In F1, five collectors are along each slope (east, west) and three are placed randomly in the more intensively studied area in the lower part of the catchment, and an additional 10 at regular intervals on each slope. The samples are bulked according to vegetation and soil type, dried, weighed and sorted ("needles" and "rest"). They are

currently analyzed on a monthly basis but if variation is low, the frequency will be reduced to annual analysis.

4.6.2. Vegetation composition

Community composition can affect the nitrogen cycle through the quality of litterfall: species which grow under high inputs of nitrogen produce labile litter which more easily decomposes than litter from plants grown under nitrogen deficient conditions. Thus, through decomposition, vegetation provides a positive feedback into the cycling of nitrogen (Pastor and Post 1986). Species changes may occur quickly in response to changes in deposition, they may lag the treatments by years (and lag the cessation of the treatments), or it is possible that no changes occur within the span of the experiments.

Vegetation analyses are carried out on 22 permanent 1 m^2 plots spanning the natural moisture gradient. Percent cover is recorded for all species in the plots. Each sample plot is divided into 25 sub-plots (total of 550) in which presence/absence of all species is recorded. The data are analyzed by the technique of detrended correspondence analysis (DCA) (Hill & Gaush 1980; ter Braak 1987).

Every third year the plots will be re-analyzed and photographed, and the dominant species will be chemically analyzed for major elements including nitrogen reductase activity and arginine content (Ogner et al. 1991).

4.6.3. Trees

Overall health and growth of trees is monitored regularly. Trees are assigned into damage classes based on needle yellowing and crown density, and changes in the proportion of these classes over the course of the treatment are followed. This information on the resilience of the vegetation to pollution stress will be used to test forest decline and critical load models.

For calculating above-ground standing biomass, height and diameter at breast height (dbh) of all trees were measured in 1990 in G1 and G2 catchments and will be re-measured at the end of the experiment. Six Norway spruce in F1 were also measured. Standard forest decline parameters such as crown density and color were measured in 1990 for 100 trees each in G1 and G2, and 10 trees in F1, and will be re-assessed every autumn.

Foliage is collected once a year in the autumn from the 7th and 15th whorl from the top of the tree. The needles from each branch are sorted by age (current-year, previous-year, and remainder) and analyzed for total elements by simultaneous ICP technique (Ogner et al. 1991). Six spruce from each of the three soil moisture regimes in G2 and G1 are sampled together with six from one vegetation type (Vaccinium) in the more intensively-studied area of F1. Additionally, six pines were also sampled in G2 in 1991. Needles were collected in March 1990 and October 1991, and will be collected annually in October.

The position of the trees in the catchment and their crown projection are shown in Figure 4.23. Most of the catchment is covered by trees with only a few clearings. Catchment G1 has more and larger trees than G2; mean height and diameter at breast height for Norway spruce and Scots pine are nearly equal (Table 4.5). Height and diameter distribution plots of trees in G2 are given in Figures 4.24 and 4.25 (Norway spruce and Scots pine not distinguished).

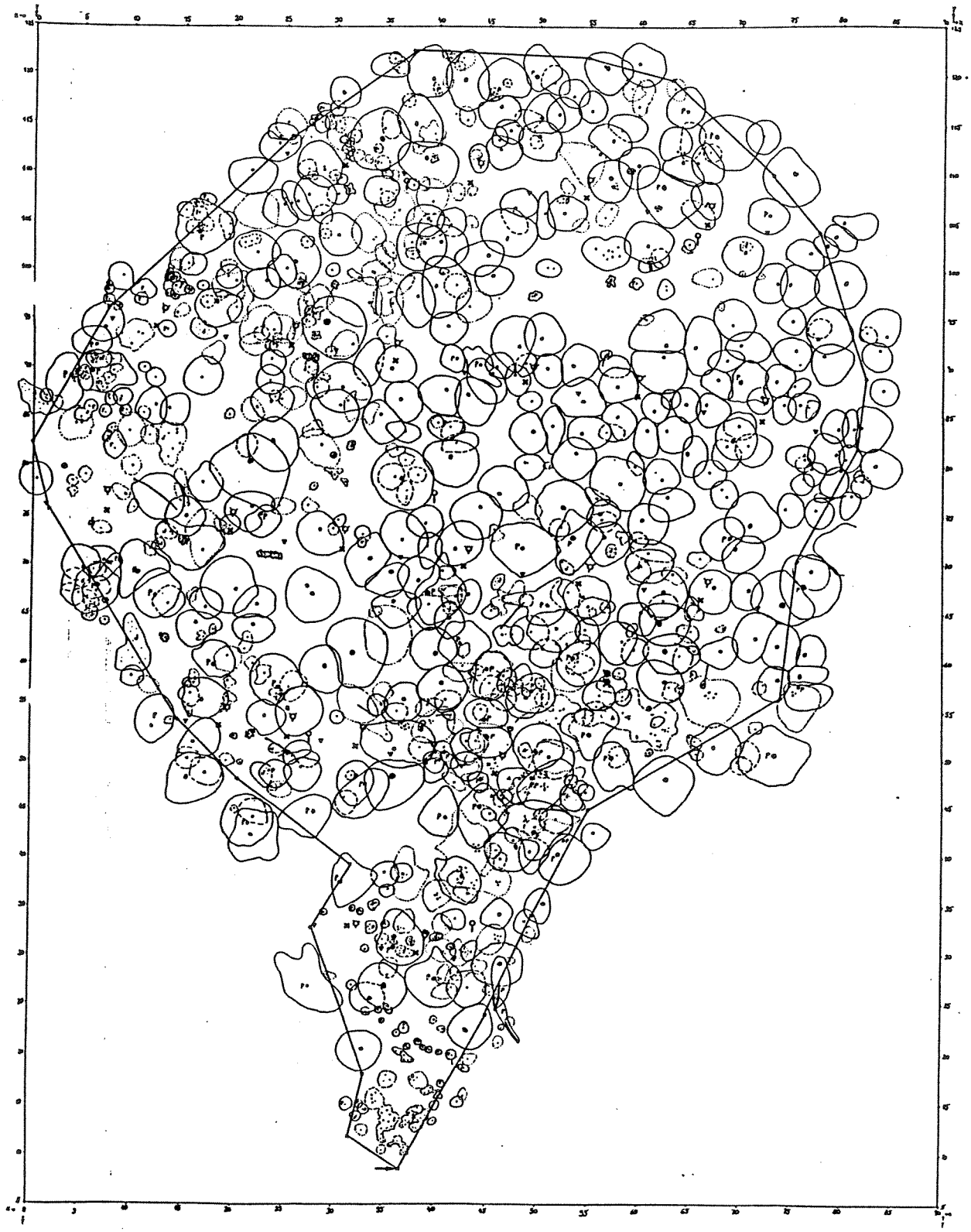

Figure 4.23. The position of the trees and their crown projection in the NITREX catchment (data from IVL.

Table 4.5. Number, height and diameter of the measured trees in catchments G1, G2 and F1.

	G2-NITREX	G1-ROOF	F1-CONTROL
No. of Norway spruce	224	308	6
No. of Scots pine	54	62	0
% of Scots pine	19	17	0
Mean height (m) of spruce (range)	15.9 (5.4-25.6)	18.1 (6.6-28.0)	24.0 (21.3-25.8)
Mean height (m) of pine (range)	15.0 (6.1-21.2)	17.6 (12.0-26.2)	
D.B.H. (cm) of spruce (range)	22.6 (7.7-48.7)	24.7 (8.4-51.1)	31.6 (26.8-35.0)
D.B.H. (cm) of pine (range)	26.2 (11.3-34.9)	25.4 (11.9-39.7)	

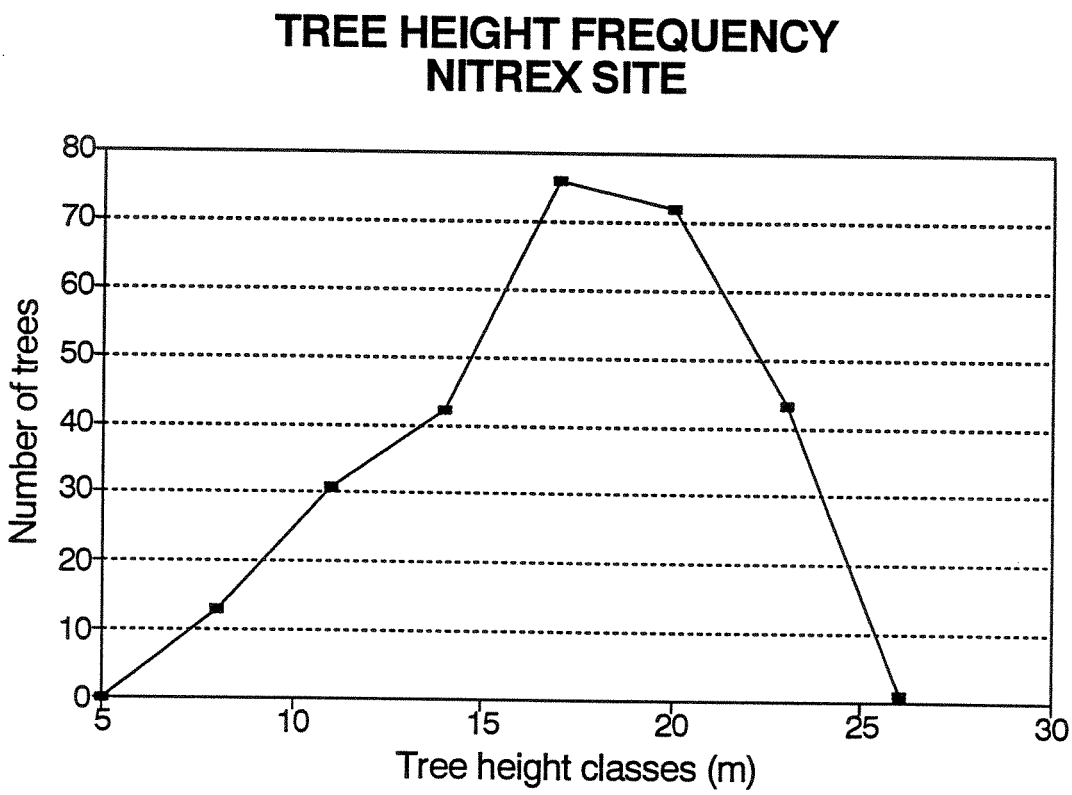

Figure 4.24. Number of trees within the different height classes for the NITREX site (G2).

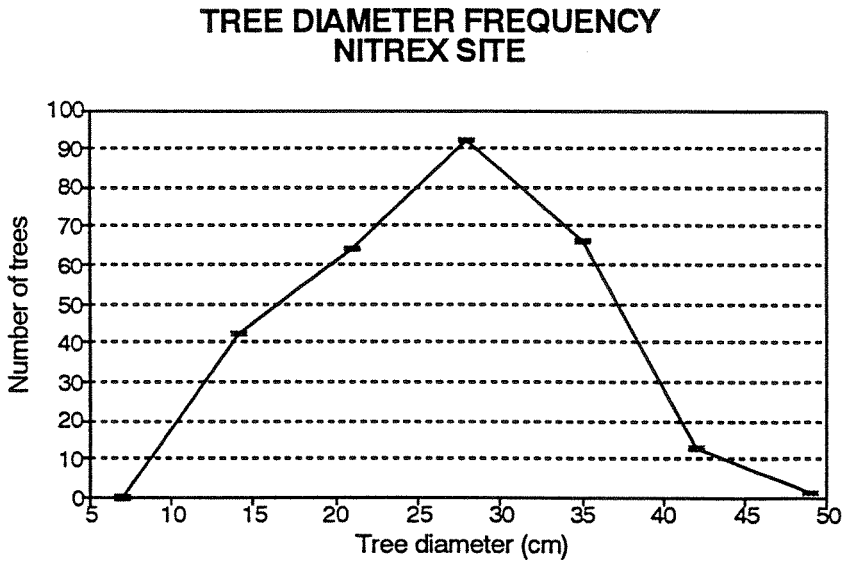

Figure 4.25. Number of trees within the different diameter classes for the NITREX site (G2).

Most of the trees in all three catchments are in crown density classes 1 and 2 (Figure 4.26). Class 1 is slightly defoliated with a crown density between 75 and 89%, class 2 is moderately defoliated with a crown density between 40 and 74%. The needles are slightly to moderately discolored. The mean crown density of all monitored trees in G1, G2, and F1 was 73%, 70%, and 81%, respectively. Since only 10 trees in F1 were measured, the values for this catchment are only very approximate. Continued monitoring can reveal differences in the health of the trees after the different treatments.

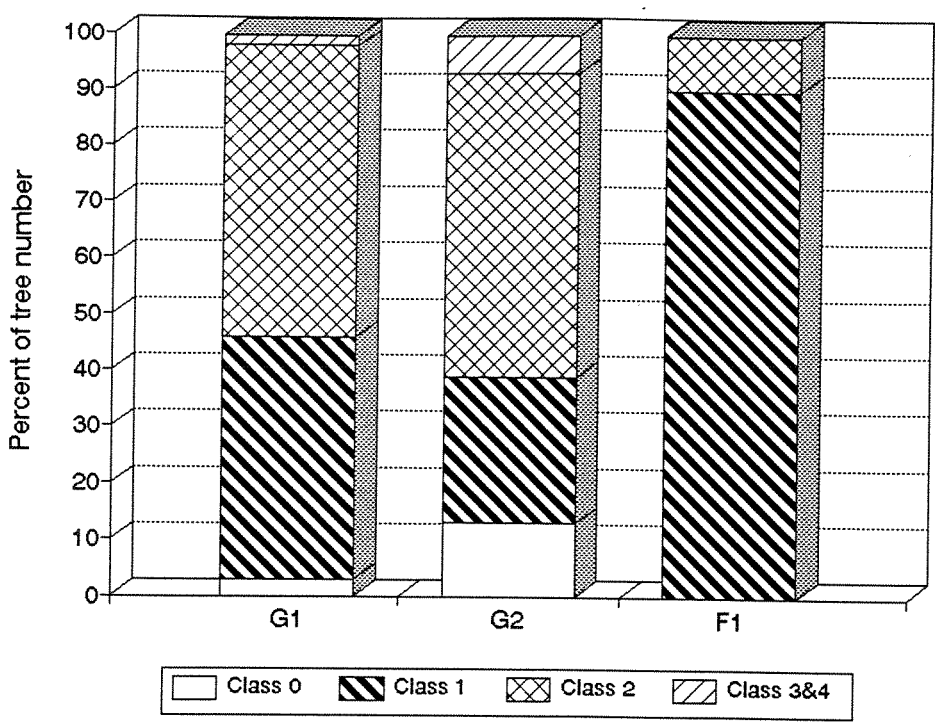

Figure 4.26. Percent of trees in the different crown density classes in catchments G1, G2, and F1.

The needle content in March 1990 is shown in Table 4.6. There were no consistent differences between the three sampled vegetation types in G1 and G2; the values given are means for all trees and vegetation types.

Table 4.6. Needle content in March 1990. Figures are means for all sampled trees in the different catchments. Units are mmol kg^{-1}, µmol kg^{-1} for Zn.

	N	S	P	K	Mg	Ca	Al	Mn	Zn
G2, Curr. Year -- 7th whorl	933	31	45	173	45	107	4	9	680
--15th whorl	842	29	40	155	50	117	4	11	784
G2, Prev. Year -- 7th whorl	885	30	44	150	50	119	5	9	689
--15th whorl	815	28	37	149	50	123	4	11	806
G1, Curr. Year -- 7th whorl	1023	32	47	175	43	110	5	13	662
--15th whorl	934	30	44	161	49	110	4	14	728
G1, Prev. Year -- 7th whorl	963	32	47	153	46	114	5	14	613
--15th whorl	887	31	41	146	48	123	5	15	722
F1, Curr. Year -- 7th whorl	947	33	44	163	44	123	4	11	685
--15th whorl	855	29	36	131	51	147	4	14	807
F1, Prev. Year -- 7th whorl	960	36	46	132	58	140	6	14	643
--15th whorl	839	29	35	131	51	152	5	15	775

Concentrations of N, S, P, K, and Zn were higher in the current-year needles whereas concentrations of Mg, Ca, Al, and Mn were higher in the previous-year needles. Element concentrations were lower in the needles from the 15th branch whorl than from the 7th branch whorl with the exception of Mg, Ca, Mn, and Zn. No elements are in the deficiency or the toxic range. The needle nitrogen content ranges from 1.1 to 1.4% of dry matter.

4.7. ^{15}N TRACER STUDY

Janne Kjønaas, NISK

The main objectives of the NITREX project are to measure the threshold for nitrogen saturation and nitrogen saturation reversibility. The large pools of nitrogen already present in the vegetation and forest floor makes changes due to experimental treatments difficult to detect. The use of the stable isotope ^{15}N is being used by many of the NITREX sites to overcome this problem.

To enable the fate of one years's input to be followed, the ^{15}N is to be applied over one full year. Its fate followed into tree, soil and leachate, by sampling of the following pools: precipitation, throughfall, runoff, mineral soil, soil water, forest floor, litter roots needles, branches, ground vegetation, and the N fertilizer.

Nitrogen will be added at an enrichment of 1500 ‰ $\delta^{15}N$. This level of enrichment is for the total inputs to the forest floor, i.e. both the throughfall and fertilizer inputs. Additional ^{15}N will be added to the fertilizer to compensate for the (predicted) throughfall nitrogen inputs. The method chosen is a combination of the ^{15}N tracer technique and analytical techniques normally required for natural abundance studies. Very low enrichment levels of ^{15}N are applied that can be detected just above the range of natural ^{15}N abundances. The precision of the analytical method must therefor be very high, 0.02 - 0.05 ‰ $\delta^{15}N$. One of the main benefits of the method is that there is no need for the extremely expensive high enrichment N compounds although analytical costs are increased. The method has been tried with success at the Bear Brook study in the US (Knute Nadelhoffer, pers. comm.).

Because of small enrichments of the added nitrogen, the actual changes of the isotopic composition of the different compartments of the ecosystem are quite small. The method requires thus detailed information on the ^{15}N levels in different parts of the ecosystem prior to ^{15}N additions. According to Högberg (1990) excessive additions of nitrogen may lead to the retention of the heavier ^{15}N isotope due to fractionation processes in the microflora. The low ^{15}N abundance of many forest soils is seen as a result of a tightly closed cycle of nitrogen. The pollution gradient within the different NITREX sites gives a possibility to study the natural abundance of ^{15}N in relation to "nitrogen saturation".

Even though the levels of ^{15}N additions is quite small, there is still a chance of contamination of the natural ^{15}N abundance in the surrounding area. To minimize the risk of such contamination, care will be taken to minimize spillage of water samples and transfer of litter and soil on boots from different treatment plots.

4.8. FISH TOXICITY STUDIES

Ulf Carlsson (IVL) and Frode Kroglund (NIVA-Sørlandet)

The objective of the fish toxicity studies at the two experimental catchments G1 and G2 is to document the biological response resulting from changed water chemistry in the runoff due to the treatments. Fish give an integrated response to water chemistry, and may be more sensitive to minute changes in water quality than simple measurement of individual chemical parameters. The fish toxicity studies follow the same setup as those conducted at the experimental catchments of the RAIN project, at Risdalsheia, Norway (Kroglund 1992).

4.8.1. Installations and monitoring

The toxicity study is conducted by piping runoff from each of the two experimental catchments to a series of five 90-l tanks, each containing a different strain of brown trout (Salmo trutta). There are 25 fish in each tank (Figure 4.27). Brown trout is used because it is a common and commercially important fish that is sensitive to acidification and because many similar studies on the fish exist for comparison with our data. Mortality tests last for several days, with water quality measured at regular intervals. Tests will be conducted regularly as the runoff chemistry begins to change as a result of nitrogen addition at the NITREX catchment and acid removal at the roof catchment.

Fish were exposed in January, March, June and December in 1991. This corresponds to two exposures before N-treatment began, and two afterwards. During each experimental period, water chemistry was sampled on a daily basis from each rig. The water was analyzed at IVL by standard methods.

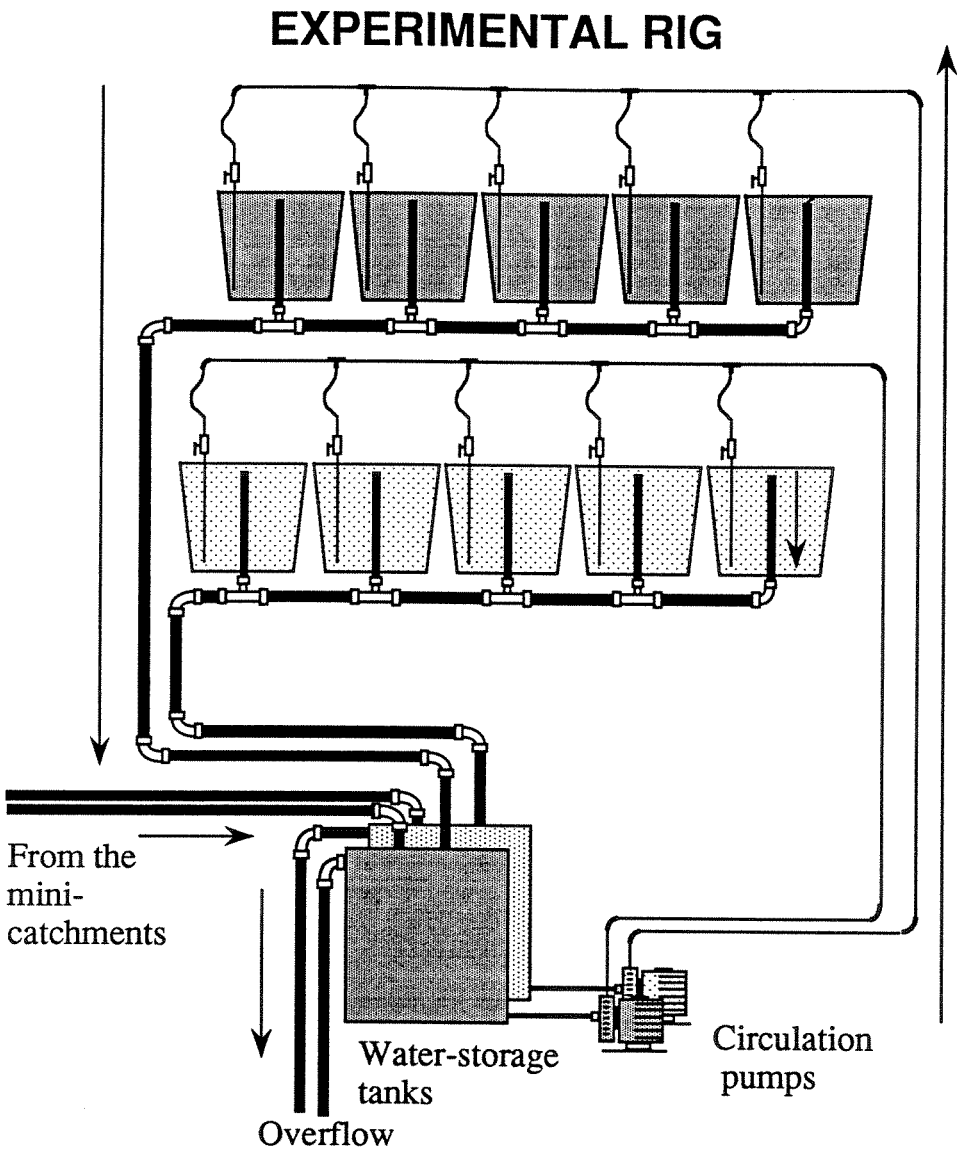

Figure 4.27. Experimental setup used for the fish experiments at G1 and G2, Gårdsjön.

4.8.2. Preliminary results

Water chemistry for each experimental period is presented in Table 4.7. The water quality at G1 differs substantially from that of G2 for all parameters presented. G1 had the lowest H^+ concentration and color, and the highest calcium and inorganic aluminum concentrations. This should render the water quality at G1 more toxic than G2 based on inorganic aluminum but less toxic based on calcium and pH. Water analysis from week 45 is not available.

Table 4.7. Water chemistry values at ROOF (G1) and NITREX (G2).

	January (Week 3)		March (Week 13)		June (Week 26)		November (Week 45)	
	G2	G1	G2	G1	G2	G1	G2	G1
pH	3.90	4.32	3.92	4.14	3.89	4.51	3.83	4.31
Ca (µeq/L)	38	65	33	66	25	80		
Ali (µeq/L)	60	31	127	179	165	198		
Altot (mmol/L)	63	82	58	70	72	79		
Color (Pt units)			45	15	64	15	59	13
Temp (°C)	5	4	8	6	12	14	8	6

Several strains of brown trout are used as test organisms (Table 4.8). This eliminates possible vagaries due to strain-dependent response. Accumulated mortality data from each period is presented in Figures 4.28-4.31.

Table 4.8. Strains and average lengths (cm) of the fish used at NITREX and ROOF experiments in 1991. Number of fish used at G1 and G2 together is given in parentheses.

Strain	January (Week 3)	March (Week 13)	June (Week 26)	November (Week 45)
Konovesi	12.1 (35)	9.3 (30)		
Gullspång	10.5 (30)	11.4 (30)	14.8 (33)	
Mjørn	10.1 (37)	10.2 (31)	14.3 (45)	16 (111)
Heligeå	10.7 (34)	12.4 (31)		
Lygern	9.3 (28)	10.2 (31)	13.1 (48)	

Week 3

Mortality was highest in G2 (Figure 4.28), with 4 strains having LT50 values between 32 and 39 hours. Konovesi had a higher mortality rate than the other strains, with LT50 value = 26 hours. At G1, 3 strains had LT50 values ranging from 44 to 48 hours, with Heligeå having a LT50 = 54 hours and Gullspång = 62 hours. The higher mortality rate at G2 was probably caused by the lower calcium concentration and higher H^+ and inorganic aluminum concentration than measured at G1 (Table 4.7).

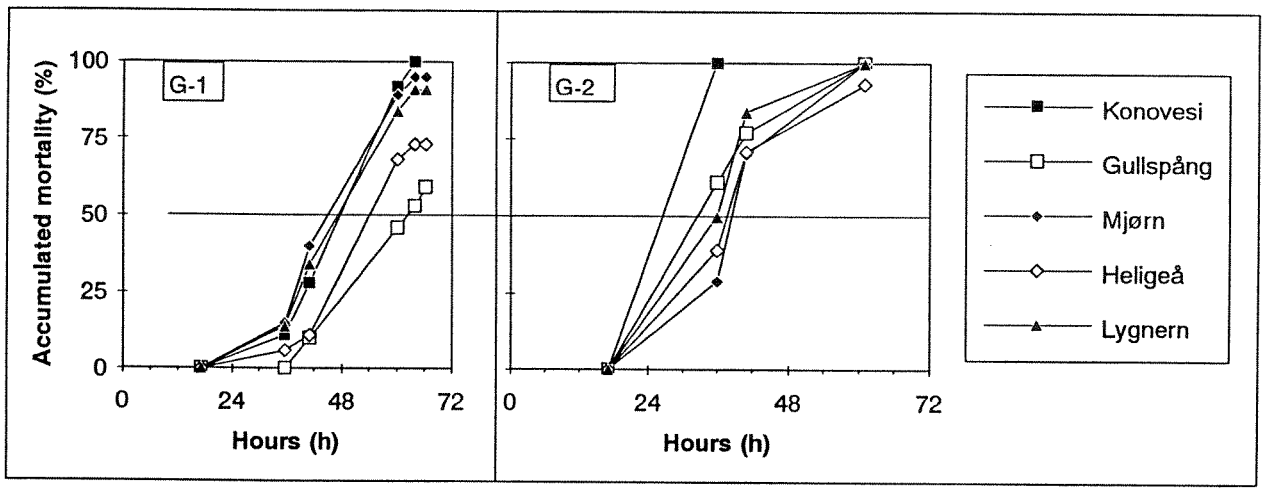

Figure 4.28. Accumulated mortality at G1 and G2, January 1991.

Week 13

The LT_{50} values at both G1 and G2 varied between 31 and 40 hours, apart from the Konovesi strain with an LT_{50} of 19 hours at G2 (Figure 4.29). The main chemical changes from week 3 to week 13 were the increase in the Al_i concentration at both G1 and G2 (Table 4.7) and the lowering of pH at G1. The chemical changes caused the water from the two sites to have nearly identical toxicity levels.

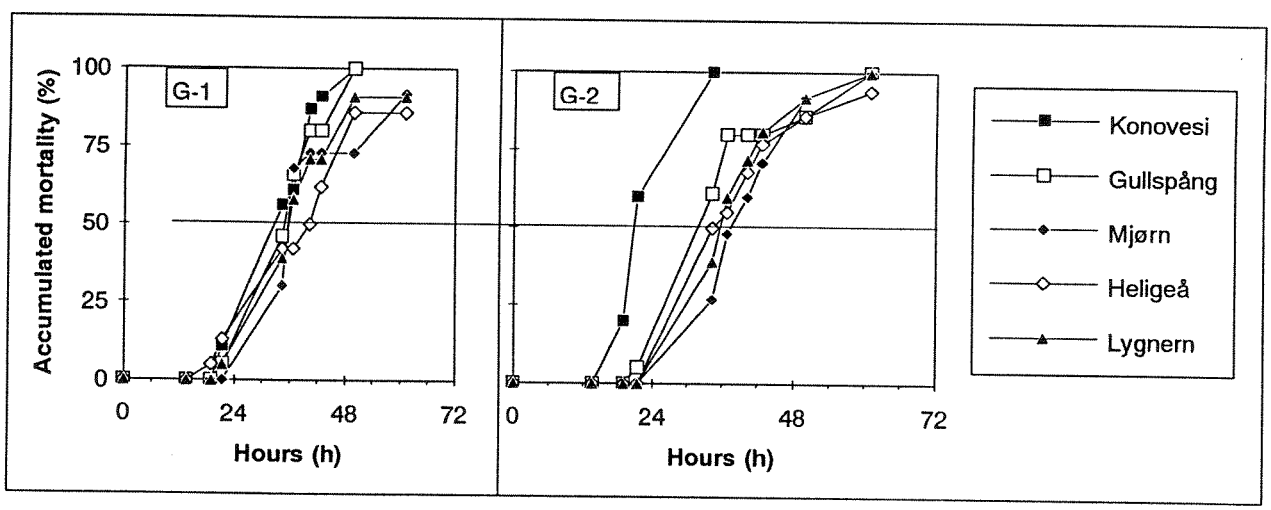

Figure 4.29. Accumulated mortality at G1 and G2, March 1991.

Week 26

LT_{50} at G1 was high for all strains tested (LT_{50} = 7 - 7.5 hours) (Figure 4.30). At G2, Lygern had the highest mortality rate (LT_{50} = 8 hours), while Mjørn and Gullspång had LT_{50} values between 17 and 20 hours. As opposed to the first two experimental periods, the water quality in period 3 was more toxic at G1 than at G2. The reason for this is not apparent, as only pH showed any major change from earlier periods.

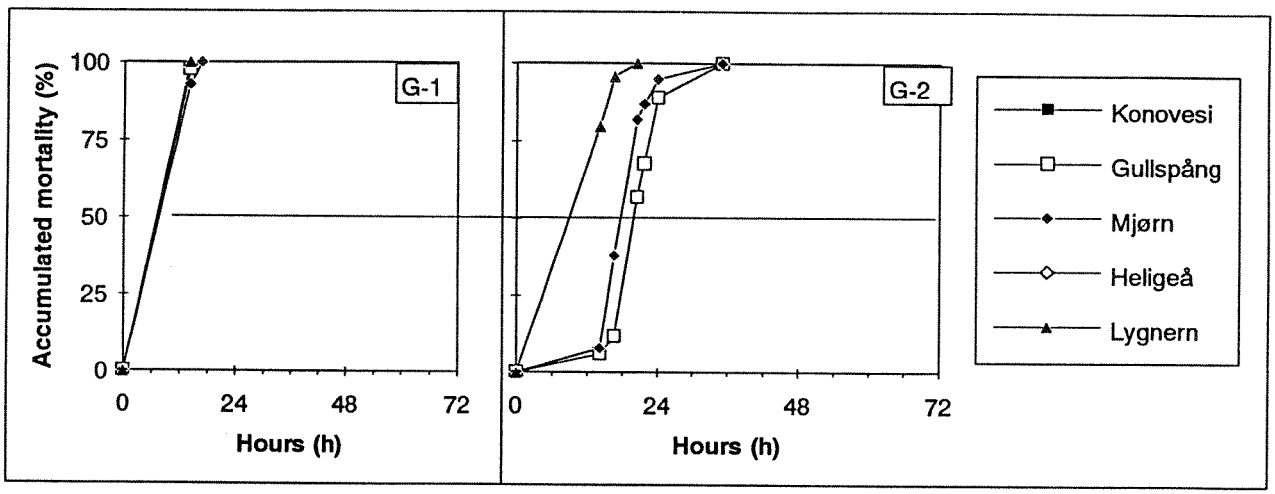

Figure 4.30. Accumulated mortality at G1 and G2, June 1991.

Week 45

Only one strain was tested, but parallel exposures were conducted. The LT_{50} values within G1 and G2 varied only over a 10% range, indicating that the water quality was the main parameter determining the mortality rate (Figure 4.31). The mortality rate was highest at G2, with LT_{50} = 14 hours, compared to 20 hours at G1.

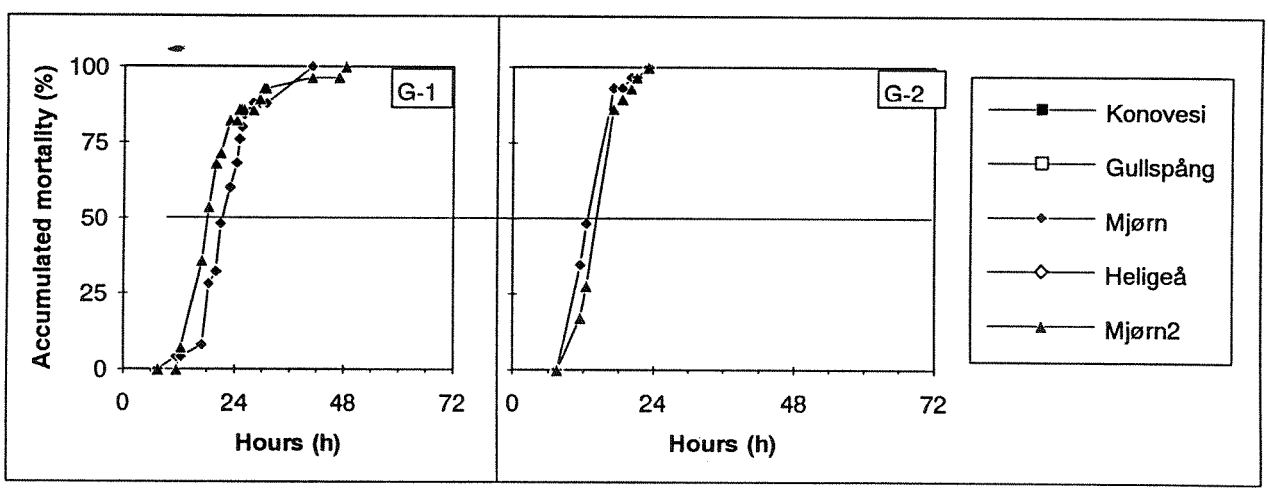

Figure 4.31. Accumulated mortality at G1 and G2, November 1991.

4.8.3. Discussion

G2 was generally more toxic than G1 in 1991. Calcium and the Ca/Al ratio are probably the most important factors determining the differences in toxicity level at G1 and G2, as both the H^+ and the aluminum concentrations are high at both sites. The effects of the N-addition and acid exclusion are still too slight to indicate any major trend in toxicity level. The fish studies will continue in 1992.

Experiments performed at the RAIN site at Risdalsheia, Norway, showed an increased mortality rate of trout kept in the runoff of the acid exclusion site (Kroglund 1992). This is probably due to lower concentrations of calcium in the runoff caused by the reduced concentration of mobile anions in the precipitation. Increasing the calcium concentration of the runoff at Risdalsheia by 45 μeq Ca L^{-1} increased the LT50 value (time for 50% mortality) from 12.5 hours to 23 hours (Kroglund et al. 1992). From the fish's perspective, changes in aluminum, calcium and H^+ concentration in the runoff all amount to changes in the toxicity level. The central issue at NITREX is whether the increased nitrogen input will give the same (negative) chemical and biological response as has been observed with sulphate acidification. At the clean rain site (G1), the question is whether the reduced deposition of sulphate and nitrate will increase fish survival as reported from Sudbury (Gunn and Keller 1990), or result in increased mortality as at Risdalsheia. If increased toxicity is the effect of reduced sulfate and nitrogen deposition in the short term, over what time span will this be the case?

5. RELATION TO OTHER EUROPEAN SITES

Gårdsjön is intermediate in acid deposition loading relative to clean regions in northern Scandinavia and heavily polluted forest ecosystems in central Europe. Reflecting this, Gårdsjön (together with the Klosterhede, Denmark site) is intermediate in the N-deposition gradient among the experimental ecosystems in the NITREX network (Dise and Wright 1992) (Figures 5.1, 5.2). It is not, however, intermediate in outputs of nitrogen. Rather, the NITREX sites clearly segregate between those which receive <150 meq m^{-2} yr^{-1} total N and leach little or no nitrogen (Sogndal, Gårdsjön, Klosterhede) and those which receive >200 meq m^{-2} yr^{-1} and leach significant amounts of nitrogen (Speuld, Solling, Ysselsteyn) (Figure 5.2). This observation of greatly enhanced fluxes of inorganic nitrogen in runoff or soil leachate beyond a certain "threshold" input level is not unique, but has been observed at other forested sites in Europe where N-inputs exceed ca. 100 meq m^{-2} yr^{-1} (Hultberg and Grennfelt 1986, IVL 1992).

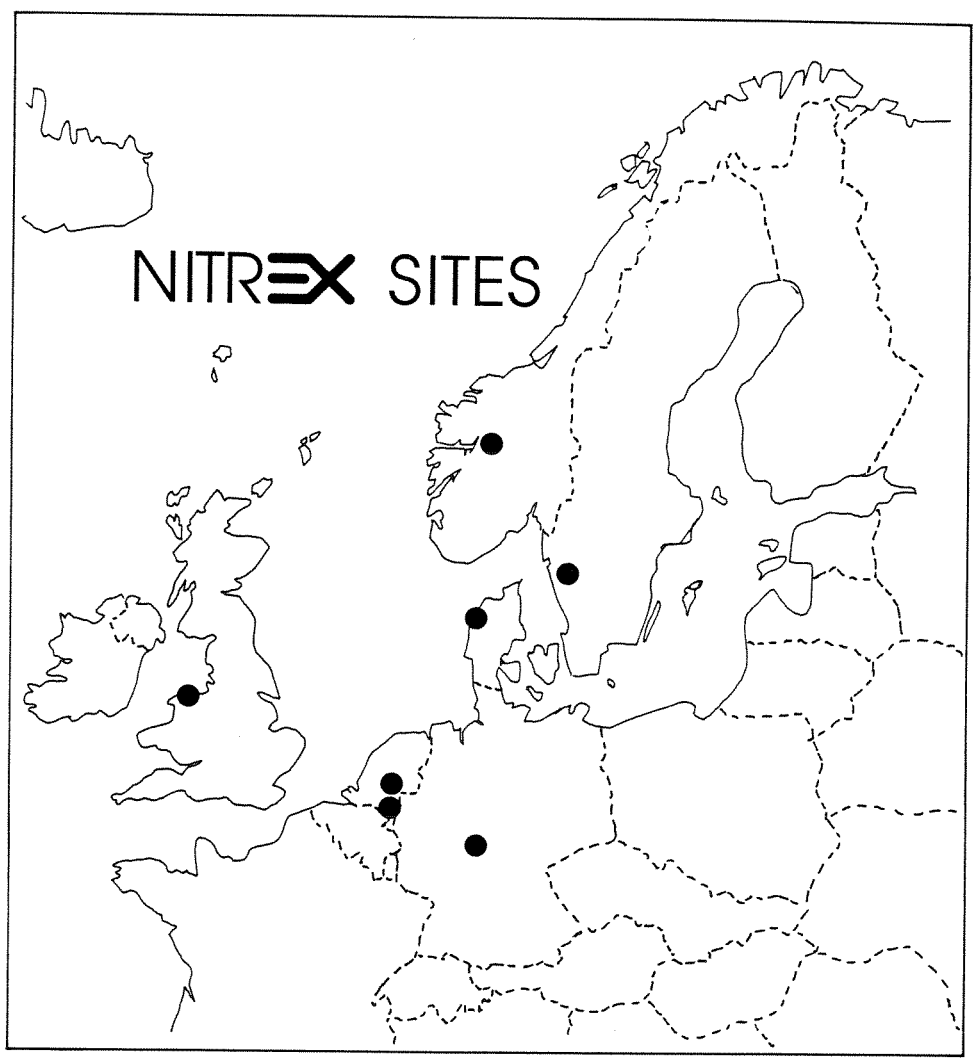

Figure 5.1. Map of Europe showing location of NITREX sites.

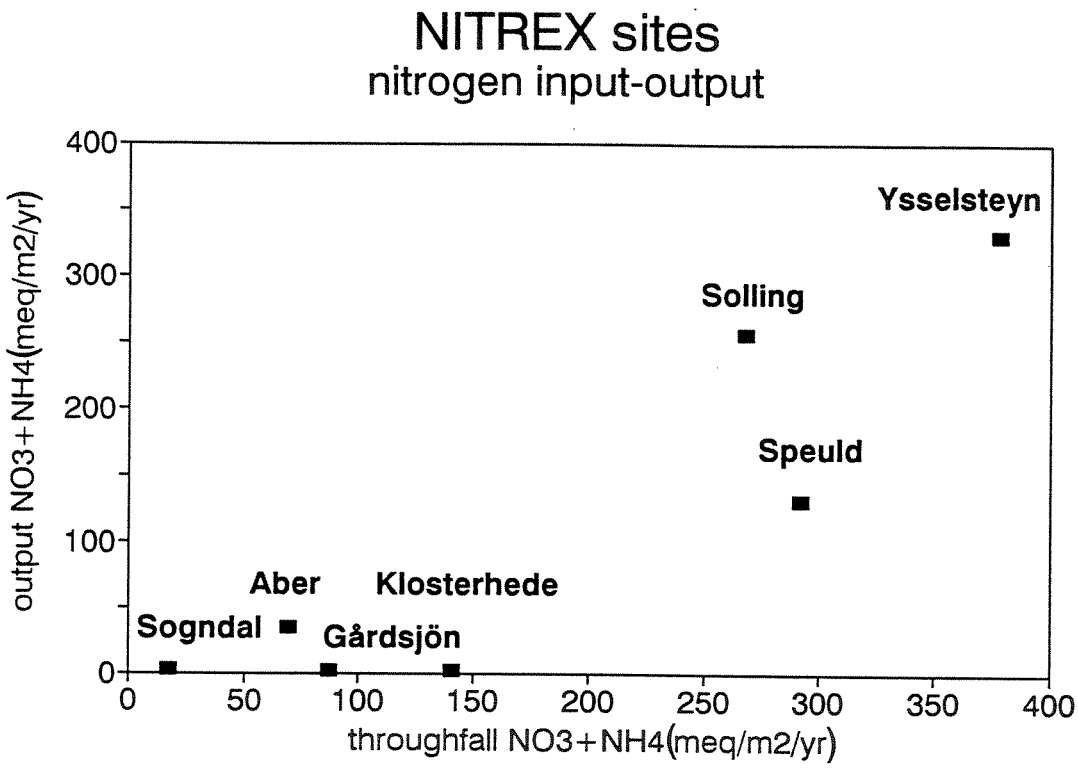

Figure 5.2. Input-output budgets for inorganic nitrogen (NH_4 + NO_3) at the NITREX sites. Inputs include both wet and dry deposition.

The appearance of significant proportions of nitrogen in runoff can be linked with other signs of ecosystem acidification such as increased levels of soil aluminum or soil base cations (removed from exchange sites). Here again in the NITREX network, Gårdsjön and Klosterhede are a link between those sites which show few signs of acidification -- i.e., relatively low soil Al and low leaching of Ca (Norway, Wales), and those for which concentrations of those elements in soil solution are an order of magnitude higher (Germany, Netherlands) (Table 5.1). With respect to soil pH and % base saturation, the sites segregate roughly into three groups: Sogndal, with pH 5.3 and 27% B.S., Aber-Gårdsjön-Klosterhede, with pH 3.9-4.1 and 7-15% B.S., and Solling-Ysselsteyn, with pH 3.7-3.8 and 4-6% B.S. There is no CEC gradient (in acidified soils most of the CEC is from aluminum). The vegetation data also show differences that may reflect nitrogen inputs. Needle % N is fairly low at Gårdsjön (1.2), intermediate in Solling, Speuld and Aber (1.5-1.8), and very high at Ysselsteyn (2.3).

Table 5.1. Soil characteristics and needle %N, NITREX sites. Values are averages of A&B horizons. Sites are ordered left to right from the lowest total-N inputs to the highest.

	Sogndal, Norway	Aber, Wales	Gårdsjön, Sweden	Klosterhede, Denmark	Solling, Germany	Speuld, Netherlands	Ysselsteyn, Netherlands
N inputs, total meq m^{-2} yr^{-1}	18	60	90	141	268	292	380
SO4 retained (%)	9	n.d.	0	0	0	62	0
(NO3+NH4) retained (%)	83	50	99	98	4	55	13
soil solution Al (µeq/l)	1	200	300	900	1300	3800	2200
soil solution Ca (µeq/l)	20	20	100	90	170	240	430
soil pH	5.26	4.14	3.87	4.1	3.65	n.d.	3.75
CEC (meq/kg)	39	60	36	11	63	n.d.	26
% BS	27	12	7	15	4	n.d.	6
% LOI	22	26	4	2	4	n.d	4
%N	0.51	0.38	n.d.	0.07	0.12	n.d.	n.d.
C/N (by weight)	22	46	40	36	18	18	n.d.
%clay	n.d	9	5	3	25	n.d.	n.d.
[1]needle %N	--	1.8	1.2	n.d.	1.5	1.6	2.3

[1]Current-year needles sampled at the following locations in the tree: Aber - top whorl, Gårdsjön - avg. 7th and 15th whorl, Solling - 7th whorl, Speuld - mid-crown, Ysselsteyn - mid-crown.

Surveys of above-ground mycorrhiza abundance at four locations in Europe (Gulden et al. 1992) showed lower species diversity at Gårdsjön compared to two sites in central and southern Norway (Figure 5.3). While this could be due to many factors (e.g., Gårdsjön was surveyed over 2 years whereas the other sites were surveyed over 3 years), it is possible that the lowered diversity, comparable to levels in the highly impacted Black Forest in Germany, is an early indication of pollution stress. Factoring out those species which are exclusive to birch and pine (rare or absent at Gårdsjön) does not change the ranking (Figure 5.3, "reduced numbers"). A more comprehensive study of both mycorrhizal abundance and fine root densities will be conducted at the NITREX sites beginning in spring 1992 to further study these interesting trends.

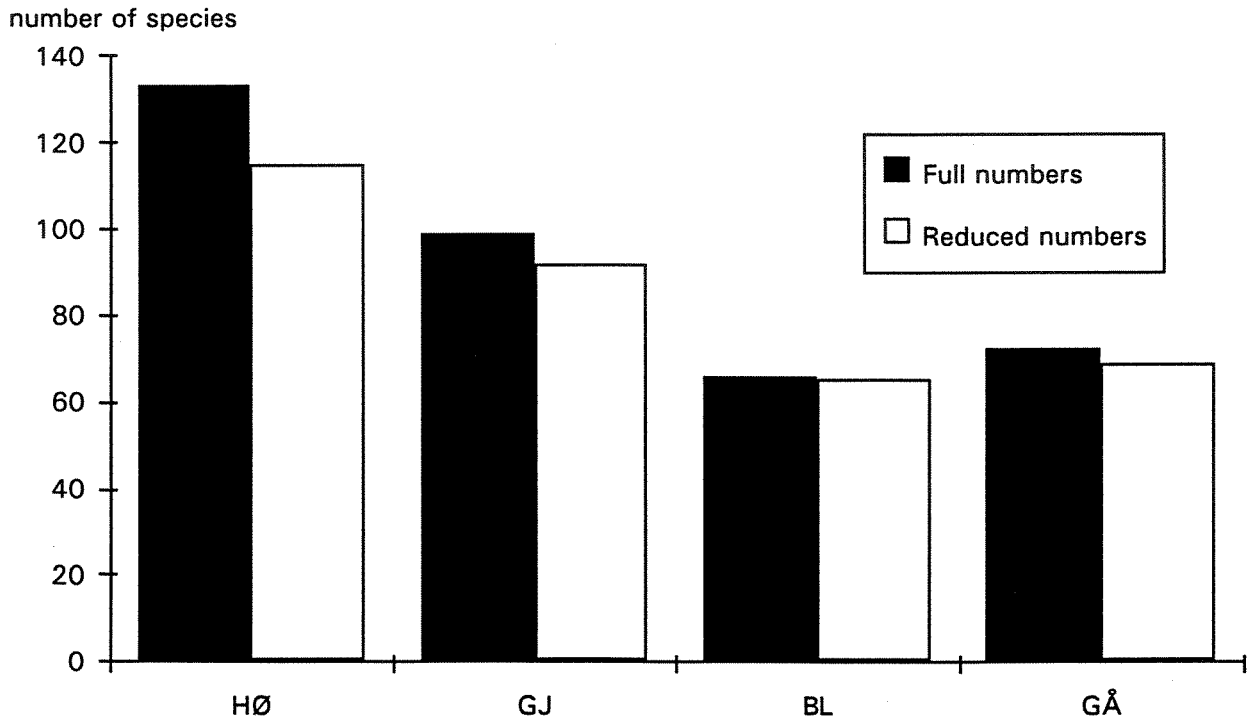

Figure 5.3. The diversity of the (above-ground) mycorrhizal fungus flora at Gårdsjön compared to the diversity of some other European spruce forest sites receiving different loads of nitrogen and other pollutants. Hø = Høylandet, central Norway (low N-deposition), Gj = Gjerstad, southern Norway (moderate N-deposition), Bl = Black Forest, Germany (high N-deposition), Gå = Gårdsjön. "Reduced" = species forming mycorrhiza exclusively with pine and birch are excluded. Data from Norway and Germany from Gulden et al. 1992. (Numbers from Gårdsjön from a two-year study, others from a three-year study).

Gårdsjön can be thought of as lying in time and space in a "transition zone" between the highly impacted acidified forest sites of central and eastern Europe, which have a long history of pollution stress and intensive management dating back for hundreds of years, and the relatively pristine Scandinavian sites which have, until fairly recently, escaped significant impact. By increasing nitrogen inputs at the low-deposition sites, and decreasing them at the high-deposition sites, the NITREX experiments are designed to move all the ecosystems across the "threshold" of nitrogen saturation (Figure 5.4), either forward or backward. Because it lies between the two types, Gårdsjön is a vital link between them; here (as at Klosterhede), nitrogen is both increased and decreased. The clear break between the N-saturated and the N-unsaturated sites supports the hypothesis that nitrogen saturation may be both induced and reversed. The major unknown factor is time -- how fast will Gårdsjön respond to substantially changed nitrogen inputs? Will the rate of recovery be different from the rate of nitrogen saturation? Will the rate at the intermediate sites Gårdsjön and Klosterhede be different from the rate of N-saturation at the unimpacted sites or the rate of recovery at the degraded sites?

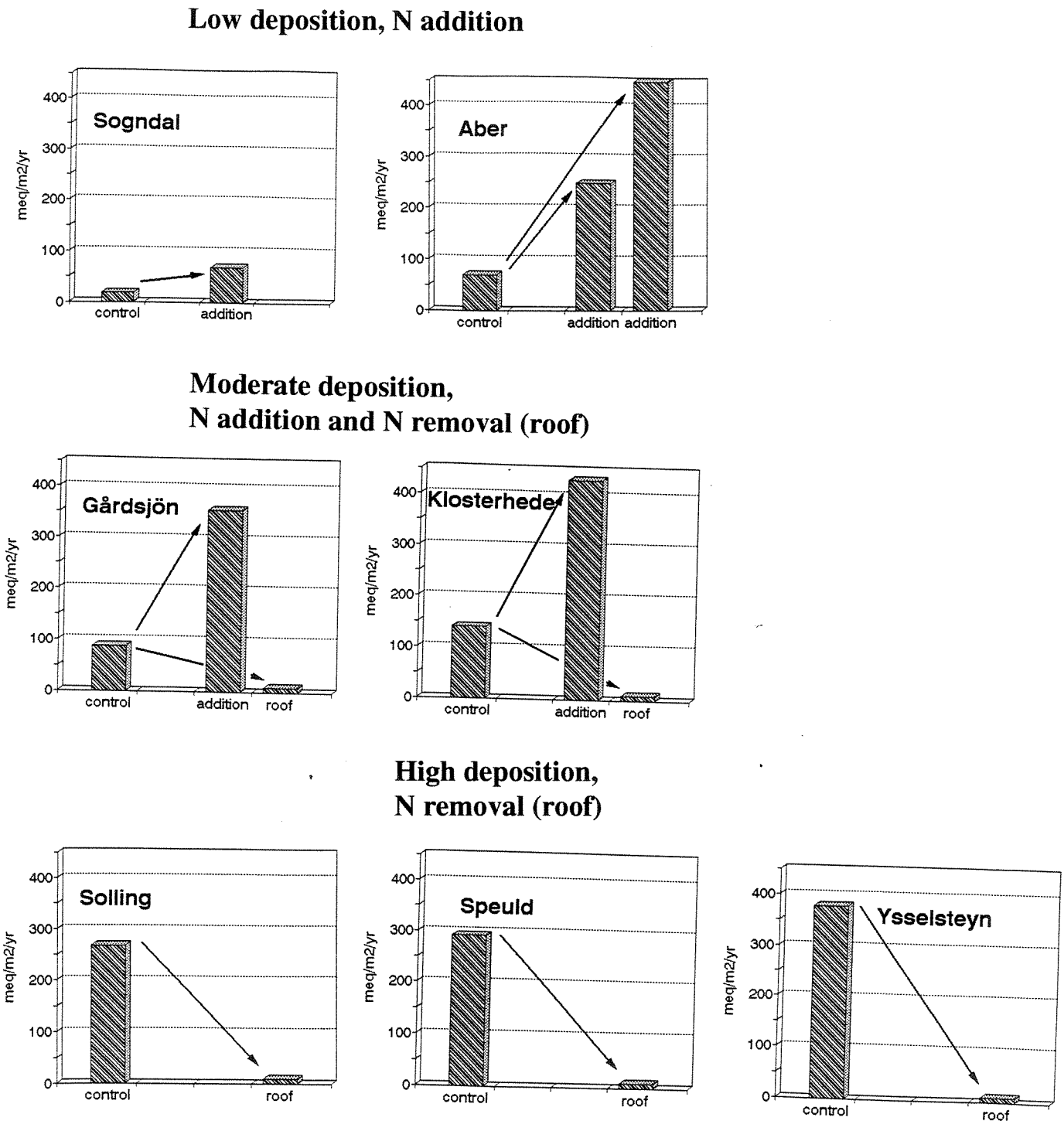

Figure 5.4. NITREX sites ranked by present-day nitrogen input and showing the nitrogen inputs achieved by experimental addition or removal at each site.

6. CONCLUSIONS

1. The Gårdsjön area receives high deposition of seasalts (about 240-290 meq Cl m^{-2} yr^{-1} =85-100 kg ha^{-1} yr^{-1}) due to the proximity of the coast and the predominant westerly winds (Table 4.2). It also receives moderately high deposition of acid pollutants (130 meq S m^{-2} yr^{-1} = 21 kg ha^{-1} yr^{-1}; 90 meq N m^{-2} yr^{-1} = 13 kg ha^{-1} yr^{-1}). During the 2-year pre-treatment period (April 1989-March 1991) 2018 mm precipitation was measured (1007 mm yr^{-1}), somewhat less than the long-term average precipitation at the site of about 1100 mm yr^{-1}.

2. The total discharge at F1 during the 2-year pre-treatment period amounted to 946 mm (average 473 mm yr^{-1}), somewhat less than the long-term average runoff at Gårdsjön of about 650 mm yr^{-1} (Hultberg 1985). The seasonal pattern of discharge at F1 was characterized by moderate to high flow during the winter half-year (October-April) and little or no flow during the summer growing season (May-September).

3. Runoff chemistry is similar at the 3 catchments. Runoff is characterized by low pH (3.8-4.2), high concentrations of seasalt ions such as Cl and Na, high concentrations of sulfate, and high concentrations of inorganic aluminum. Concentrations of nitrogen components in runoff are very low. Although these general characteristics hold for all three catchments, the catchments do differ significantly, with F1 (control) generally intermediate between G1 and G2.

   Concentrations of base cations indicate that the catchments differ slightly in sensitivity to acid inputs, with catchment F1 lying intermediate between G1 (less sensitive with higher Ca levels) and G2 (more sensitive with lower Ca levels). As a result of the slightly higher levels of strong acid anions combined with the slightly lower levels of base cations, alkalinity and pH are lower in runoff from catchment G2 relative to F1 and G1. The Ali - H^+ relationship in runoff at G2 corresponds to a solubility constant with respect to Al(OH)3 of $10^{-8.2}$.

   Concentrations of inorganic nitrogen compounds are very low in runoff from all 3 catchments. Levels of both NO3 and NH4 are often at or below the analytical detection limit. Thus the pre-treatment data show that the catchments are not nitrogen-saturated.

4. The soils in the NITREX catchment are classified as Orthic Humic Podzols, Orthic Ferro-Humic Podzols, Gleyed Humo-Ferric Podzols, and, at the shallow outcrops, Typic Folisols. The soil is fairly acid, with pH increasing slightly in the lower peaty region. The fairly high C/N ratio (larger than 30 in the organic and A horizons), suggests that immobilization of added nitrogen will be an important process during seasons of microbial activity. Cation exchange capacity (measured at soil pH) is low in the mineral soil due to low clay content. Base saturation (measured at soil pH), is relatively high in the upper organic horizons, and very low in the mineral soil.

5. Chloride is the dominant anion in the soil solution, followed by sulfate. Despite the low pH values, aluminum concentrations are fairly low. Most of the aluminum is probably bound in organic compounds (high levels of organic C). The concentrations of NO3-N and NH4-N are generally close to the detection limit of 1 µeq/L, indicating that most of the soluble nitrogen in the catchment is in an organic form.

6. The hydrological response at G2 is very fast and leads to stormflow peaks within few hours after the start of rainfall. The response of the water potential in the soils matches this quickflow, but the data so far indicate no preferential flowpaths. Transport within the upper organic layers can be fast, reaching rates up to $5*10^{-3}$ m sec^{-1}.

7. Preliminary results of fine roots sampled October 1990 indicate a pronounced superficial root distribution. The two root vitality classes 1 and 2 (most vital), however, were only found in the humus layer and then only in very small amounts compared with the total fine root mass. Fine roots in the mineral soil were in very poor condition. The fine roots were represented in approximately the same proportions among the four vitality classes within all catchments and vegetation types. The total amount of root tips (both mycorrhizal and non-mycorrhizal) corresponded well with the vitality of the fine roots. This is also reflected in the distribution of root tips in the soil profile.

8. The mycorrhiza of the root mat at the forest floor sampled in autumn 1990 were generally 100% alive and healthy, although there had been a severe dry period in July. Thus, healthy mycorrhizal development is assumed to be the normal background situation prior to nitrogen addition.

9. Most of the trees in all three catchments are in crown density classes 1 and 2. Class 1 is slightly defoliated with a crown density between 75 and 89%, class 2 is moderately defoliated with a crown density between 40 and 74%. The needles are slight to moderately discolored. The mean crown density of all monitored trees in G1, G2, and F1 was 73%, 70%, and 81%, respectively. Since only 10 trees in F1 were measured, the values for this catchment are only very approximate.

10. The nutrient contents of needles sampled in March 1990 show no consistent differences between the three sampled vegetation/soil moisture groups in G1 and G2. No elements are in the deficiency or the toxic range.

11. Fish toxicity experiments conducted 4 times during 1991 indicate that runoff from G2 was generally more toxic than G1. Calcium is probably the most important single ion determining the differences in toxicity level at G1 and G2, as the H^+ and the aluminum concentrations are high at both sites.

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