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N retention after N addition in four experimental stands of *Norway spruce* in southern Sweden

– SITE DESCRIPTION AND BASE-LINE DATA FOR AN EXPERIMENTAL SERIES IN SOUTHERN SWEDEN

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Introduction

Human activities, especially during the last century, have altered the pools and fluxes of nitrogen (N). For example, the rate of N input into the terrestrial global N cycle has approximately doubled (Vitousek et al., 1998). The main sources of additional N are fossil fuel combustion and various agricultural measures (such as the production and use of N fertilizer and use of N_2-fixing crops).

Nitrogen is regarded to be the nutrient that has proximal control on net primary production in many of the world's ecosystems (Tamm, 1991; Fenn et al., 1998), and the boreal and nemoral forests on mineral soils in Sweden is not an exception from this. Despite the recent decades of substantial N deposition, N-fertilization still usually causes increased tree growth on mineral soils in Sweden (Pettersson, 1994; Sikström & Jacobson, 2002).

A major part of the N pool in Swedish forest ecosystems on mineral soils is bound in organic matter in the soil and amounts at 1 000–10 000 kg ha^{-1} (Nohrstedt, 1993). Since the last glaciation the historical 'natural' input of N might have averaged about 1–2 kg ha^{-1} yr^{-1}, consisting of biological fixation of N_2 and some baseline N deposition (Högberg et al., 2000). Today the deposition of N is higher. The southern part of Sweden has been subjected to a substantial deposition of airborne N pollution for several decades. During the most recent decades up to 15–25 kg ha^{-1} yr^{-1} of N has been deposited in forested areas (Lövblad et al., 1995). However, species composition and the height of forest stands have strong influences on the amounts reaching the forest floor. In southern Sweden, it has been shown that the throughfall of e.g. ammonium-N (NH_4-N) and nitrate-N (NO_3-N) to mature Norway spruce (*Picea abies*) stands was 1.5–3 times greater than those to mature Scots pine (*Pinus sylvestris*), European beech (*Fagus sylvatica* L.) and birch (*Betula* spp.) stands (Westling et al., 1992; Bergqvist & Folkesson, 1995). During the period 1980–1990, there were no indications of a change in the deposition of N (Lövblad et al., 1995). However, in the late 1990's there have been indications of a slight reduction in the wet deposition of N (Lövblad, 2000). Högberg et al. (2000) estimated the cumulated anthropogenic N deposition to be 500–1 000 kg ha^{-1} for the last 100 years in the most exposed areas of southern Sweden. This corresponds to an increase in the total N pool of ecosystems of 5–100 %, depending on forest type.

At present in southern Sweden, the major part of deposited N is retained in the soil (Nilsson et al., 1998). Generally, the N cycle in Swedish forests is closed and the small amount of leaching that occurs is mainly of organic N (Nohrstedt, 1993). However, quite high leaching of inorganic N has occasionally been observed in some areas, especially in southwestern Sweden (Nohrstedt et al., 1996; Nilsson et al., 1998). Denitrification, fires and harvest of biomass all cause losses of N.

There are concerns that the input of N into forest ecosystems will lead to N saturation (e.g. Aber et al., 1989, 1998). However, the term N saturation has been defined in several different ways, by various authors, to refer to all of the following (cf. Högberg et al., 2000): (i) cases where the loss of N is larger or equal in magnitude to the input in an ecosystem (Ågren & Bosatta, 1988), (ii) systems where an elevated level of N leaching can be observed in relation to a given natural back-

ground level, and (iii) states in which the supply of N exceeds the N requirements of plants and microorganisms (Aber et al., 1989). In this study, we have adopted the chemical Ågren & Bosatta (1988) definition.

The retention of N in the soil has been demonstrated to be a function of the C to N ratio in the soil (Dise et al., 1998; Emmet et al., 1998). An increased retention of N could affect the C to N ratio of the soil, and it is therefore possible that the retention capacity is affected. Other soil processes like potential net N-mineralization and net-nitrification have, at least partly, been demonstrated to be a function of this ratio. For example, nitrification tends to start at a C to N ratio of about 20–25 (Rudebeck, 2000).

Forest N-fertilization causes an increased input of N, and, hence, the risk of N-saturation might be increased. In a review that covers a large number of N-fertilization experiments from various parts of the world, Johnson (1992) demonstrated that for conditions similar to those in Sweden, c. 20 % of the added N was recovered by the trees, and 50–60 % was recovered in the soil. The remaining part had been leached out or by other means been removed from the system.

A number of fertilization experiments have been used for postulating the long-term ecological effects of elevated N deposition. However, there is a large difference in the application pattern that could at least have some effect on the outcome. Nitrogen fertilization is normally an addition of relatively large dosages of N that causes high concentration of N in the soil solution during a short period of time (Johnson, 1992). Deposition of N, on the other hand, is characterized by a more constant input of low amounts of N resulting in a slight enhancement of N concentration in the soil throughout the year. Other fundamental differences are that fertilizers are applied in selected stands during the growing season at a favourable time of the year, while deposition occur in all forested ecosystems mainly during less favourable times of the year in respect to plant uptake. Hence, the risk for losses is increased. These differences could have important effects on the retention of N. Hence, it is possible that the effects of N-deposition, both in terms of N-retention and forest production, differ from those of N-fertilization.

Given the same total amount of N applied, it could be argued that the soil retention is likely to be higher, and that stem-wood production benefits less, from low continuous N-deposition than from higher N doses at fertilization. This is based on the fact that, i) the proportion of added N taken up by the trees seems to decrease with reductions of the applied dose (Melin, 1986), ii) splitting the dose has been shown to give lower stem-growth respose than a single-shot dose (Pettersson, 1994), iii) there is an established more or less linear relationship between the amount of added N, as a single-shoot application, and stem-growth response, starting from c. 60 kg N ha^{-1} up to c. 150–250 kg N ha^{-1} depending on site quality (Pettersson, 1994). In a field experiment, annual addition of N during five years, equivalent to approximately a doubling of the ambient deposition rate, did not significantly affect stem growth (Sikström, 2002).

One possibility is that increased tree growth may be more likely to occur directly after low-dose N additions on fertile sites that are rich in N, but do not have N in excess, compared with sites where plant-N availability is very low, since the trees may have a better chance to compete with decomposer microorganisms for the

extra N input in an environment that is already rich in N. However, the growth response might be weak. This was also indicated in the study with annual low-dose N addition (Sikström, 2002).

On the other hand, increased net N mineralization has been observed after soil N enrichment, at least after fairly high inputs with an accompanying decrease in soil C to N ratios (Andersson et al., 2001; Högbom et al., 2001). It is possible that this might stimulate tree growth in a more long-term perspective. However, whether or not net rates of N mineralization increase after rates of N addition similar to those of N deposition is unclear. At the sites studied by Sikström (2002), the net N mineralization was not affected four years after annual low-dose N additions (Nohrstedt, 2001).

At the point where N ceases to be the growth-limiting factor, another factor should become limiting, if the law of limiting factors (Liebig´s principle) is valid. In southern Sweden, there have been no reports of cases in which N-free fertilization alone clearly stimulated the growth of Scots pine and Norway spruce stands on mineral soils. However, there are a few cases in which growth of Norway spruce tended to be increased (Nilsson & Wiklund, 1992; Nohrstedt et al., 1993). In this region, addition of water has also been demonstrated to increase growth of Norway spruce (Nilsson & Wiklund, 1992; Bergh et al., 1999). Liljelund et al. (1990) suggested that application of nutrients other than N can increase the acquisition of N in soils with an excess of plant-available N. This could increase the uptake of N and reduce leaching of N from the soil.

An additive growth response of Norway spruce to P plus N has also been reported, since NP treatments have sometimes induced stronger growth than N alone (Kukkola & Saramäki, 1983), but in other cases no such response was found (Nohrstedt et al., 1993; Jacobson & Pettersson, 2001). Where N fertilization has been very intensive, an additive effect of simultaneous PK addition has been shown for Norway spruce (Tamm, 1985; Tamm & Popovic´, 1995), but this has not always been the case for Scots pine (Tamm, 1985). There have also been numerous fertilization experiments in which several tonnes per hectare of N have been applied to coniferous stands, without causing specific growth abnormalities or site deterioration (Kenk & Fischer, 1988; Miller & Miller, 1988; Tamm, 1985). Thus, Scots pine and Norway spruce, and many other coniferous trees, show great tolerance to N addition, even at heavy doses.

High concentrations of N in needles (Ericsson et al., 1993; Sikström, 1998) is one among other (Tietema & Beier 1995; Nohrstedt et al., 1996; Persson & Wirén, 1996) suggested indicators of forested sites rich in N. Several studies have demonstrated that addition of N at single-shot application (c. 150 kg N ha^{-1}) increases the N concentration in Scots pine and Norway spruce needles (Nohrstedt et al., 1993; Jacobson & Nohrstedt, 1993; Salih & Andersson, 1999). After more intensive repeated N fertilization (annual doses of at least 30–60 N ha^{-1}), the N concentration increases even more (Tamm, 1985, 1991; Linder, 1995; Nilsson & Wiklund, 1994; Rosengren-Brink & Nihlgård, 1995). However, the effect seems to last only as long as the addition continues (Quist et al., 1999).

After annual low-dose N applications (2 × 10 kg N ha^{-1}), which were equivalent to approximately double the ambient deposition rate of N, there was no significant effect on the needle N concentration of Norway spruce, as measured during the six–seven years following the start of an N-addition experiment (Sikström, 2002). Furthermore, sheltering the ground from ambient throughfall did not affect the N concentrations in needles in some cases (Beier et al., 1998; Stuanes et al., 1998), whereas a reduction in needle N concentrations has also been indicated at high ambient deposition (up to c. 60 kg N ha^{-1} yr^{-1}) (Boxman et al., 1998; Breidemeier et al., 1998).

The deposition of air-borne N pollutants may have a minor direct influence on the N concentration in coniferous foliage, at least in a short-term perspective. However, the observed increase in net N mineralization that generally follows repeated N additions (Andersson et al., 2001; Högbom et al., 2001) may induce long-term retention of N in the trees, and possibly raise N concentrations in the foliage of coniferous trees. However, a small, gradual increase in foliar biomass may keep the concentration constant, as hypothesised by Aber et al. (1989).

An evaluation of the need for new long-term field experiments in Sweden concluded that there are few experiments in the southern part of Sweden including annual addition of low N doses in order to simulate effects of an elevated N deposition (Nohrstedt et al., 1999). This was one of the reasons for establishing a new series of field experiments including N addition to forest ecosystems in southern Sweden. The intention was to establish the experiments in stands of two different site productivity classes within two regions with differences in N deposition. Furthermore, the stands should be quite young, i.e. at the stage of first thinning, to enable long-term monitoring.

Objectives

The main objectives of the field experiments was to study effects on several ecosystem properties of low N-dose additions as well as of conventional practical forest N fertilization. Studies on the effect of PK additions were also included. The monitored properties include: deposition, tree growth, needle element chemistry, and bottom- and field layer vegetation, soil and soil water chemistry, as well as studies on the retention of ^{15}N-labelled ammonium and nitrate. The aim of this report is to serve as a general description of the experimental sites, the experimental setup and provide baseline data for future publications.

Hypotheses

Before the start of the experiment a number of hypotheses were formulated, namely:

- Given the same total amount of N, repeated N additions (simulating increased N deposition) compared with a single-shot application lead to:

  - reduced uptake of N by the trees, and, thus, lower needle N concentrations and tree growth.
  - increased retention of N in the soil, and, thus, increased soil N concentrations and/or storage.
  - reduced leaching of N (mainly NO_3-N) from the soil.

- The capacity to retain deposition of N varies among forested sites in southern Sweden, and depends on deposited N and soil type. Soils that during a long time have received high deposition of N have higher N storage, reflected by low C-to-N ratio, have elevated net N-mineralization and nitrification rates, as well as larger leaching of N (mainly NO_3-N) than soils that have received low N deposition. Sites with thick humus layers (i.e. podzols) have a larger capacity to retain N than sites with thin or absent humus layers (i.e. cambisols). Thus, the risk for leaching of N is, therefore, increasing as follows: low deposition + podzol < high deposition + podzol < low deposition + cambisols < high deposition + cambisols.

- In the long run, both frequently repeated low-dose N additions, as well as, additions of higher doses of N at longer intervals, will lead to a lack of other nutrients than N, most likely P and/or K, and, addition of these elements will lead to:

  - increased tree growth as a result of an extensive uptake of N, P and K.
  - reduced concentrations of inorganic N, both ammonium and nitrate, in the soil.
  - reduced leaching of N (NO_3-N) from the soil.

- The fate of added N will depend on the form of N applied. Addition of (^{15}N labelled) ammonium will be retained predominantly in the upper soil horizons as organic N (i) in the microbial biomass, (ii) in the fine-root and mycorrhizal system, and (iii) in the dead organic matter. As time goes on, N in the microbial biomass will be (iv) remineralised as ammonium and/or (v) transformed to dead organic matter. Addition of (^{15}N labelled) nitrate will be retained in both the upper and lower soil horizons and, due to its mobility, be taken up by roots/mycorrhiza rather than by the soil decomposers. Nitrate will also be leached to a larger extent than ammonium. Depending on the soil N status, more ^{15}N will stay in the topsoil in low deposition/podzolic soils and more ^{15}N in the subsoil in the high deposition/cambic soils.

Materials and methods

THE EXPERIMENTS

Four experimental sites were established in southern Sweden during the winter of 2000/2001 and spring of 2001 (265 Asa; 266 Kågeröd; 267 Tönnersjöheden; 268 Toftaholm) (table 1). All experiments were established in *P. abies* stands (table 1).

Table 1.
Location of and stand data of the experimental sites. The stands consist of *Picea abies* trees. Means of three blocks (most cases).

	Site 265 Asa	Site 268 Toftaholm	Site 267 Tönnersjöheden	Site 266 Kågeröd
Location				
Latitude (° ' N)	57 08	57 01	56 40[1] / 56 42[2]	56 00
Longitude (° ' E)	14 47	14 05	13 04 / 13 07	13 07
Altitude (m a.s.l.)	225	155	60 / 110	75
Stand[3]				
Site index[4] (m)	G33	G35	G31 / G35	>G38
Total age (years)	33	34	32 / 34	Ca 27
Before thinning				
Trees/ha	2 060	1 730	2 710 / 2 640	2 950
Basal area (m^2 ha^{-1})	31,1	36,9	33,6 / 42,2	44,9
Harvest at thinning				
Trees (%)	32	29	36 / 38	14
Basal area (%)	22	21	25 / 26	17
After thinning				
Trees/ha	1 390	1 220	1 740 / 1 650	2 540
Basal area (m^2 ha^{-1})	24,1	29,3	25,1 / 31,3	37,2
Volume (m^3 ha^{-1})	180	240	160 / 250	260

[1]Means of block 1 and 2; [2] Block 3; [3] In 2001 (spring); [4] Upper height at age 100 years.

EXPERIMENTAL DESIGN AND TREATMENTS

A randomized block design with six different treatments was used at all sites. Based on basal area and number of trees, 900 m^2 plots were arranged in three blocks. For individual plots, a deviation from the block mean value of ±5 % and ±10 % for basal area and number of trees, respectively, was allowed. All blocks were established within the same forest stands at the different sites, except for 267 Tönnersjöheden, where two stands (c. 5 km apart) was used with one and two blocks within each stand. Apart from double controls, the treatments included three different regimes of N addition, one PK treatment and one combined N + PK treatment (table 2).

Table 2.
Experimental treatments.

Treatment	Description
81	Control
82	Control
3[1]	30 kg P ha^{-1} + 60 kg K ha^{-1} once every 6th year
4[2]	20 kg N ha^{-1} once every year
5[2]	60 kg N ha^{-1} once every 3rd year
6[2]	120 kg N ha^{-1} once every 6th year
7[1,2]	(20 kg N + 5 kg P[1] + 10 kg K[1]) ha^{-1} once every year

[1] PK 11–21 manufactured 1997 (P 10,9 %; K 20,8 %). [2] TN 5-7-1 (99,64 % NH_4NO_3; 0,25 % H_2O; 0,05 % organic; 0,03 % $(NH_4)_2HPO_4$; 0,03 % H_3BO_3).

After six years of treatment (i.e. in 2006), the total amount of N given will be the same in treatments 3–7, as well as the total amount of P and K in treatments 3 and 7. Most treatments started in 2001 (June 26 for 268 Toftaholm; July 3 for 265 Asa; July 25 for 266 Kågeröd and July 27 for 267 Tönnersjöheden). The PK addition in treatment 3 was an exception and was conducted during springtime in 2002.

CLIMATE

The annual mean temperature (°C) and annual precipitation (mm) at the nearest climate station is given in table 3.

Table 3.
Normal annual precipitation and annual mean temperature at SMHI climate stations (mean of the period 1960–1989) in the vicinity of the experiments. The corresponding experimental site is given in parenthesis. Data from Alexandersson et al. (1991).

Climate station	Precipitation (mm)	Temperature (°C)
Berg (265 Asa)	688	5.5
Ljungby (268 Toftaholm)	743	6.4
Simlångsdalen (267 Tönnersjöheden)	1 053	6.4
Svalöv (266 Kågeröd)	688	7.8

DEPOSITION

Deposition was measured both as bulk deposition (open field) and as throughfall. Throughfall was measured on one of the control plots, located as central as possible, within each experimental site (block 3 at 266 Kågeröd and block 1 at the other sites). On these plots, ten collectors were used, each having a funnel or bucket (depending on season) with an opening diameter varying between 7.75 cm during December to March and 10.7 cm during April–November. These collectors were placed 0.5 m above ground and distributed along two borders of the gross plot. Bulk deposition was determined by collecting precipitation with one collector in an open area close to the experimental stands. The bulk deposition collectors was placed 1.5 m above ground and equipped with a funnel having a diameter of 9.75 cm during the winter months and 10.7 cm during the rest of the year. The collectors were covered by aluminium foil on the outside to reduce the influence of light and heat. During winter, when snow is the normal form of precipitation, plastic bags replaced collectors for both bulk deposition and throughfall. All collectors were sampled once a month. Before chemical analyses, a composite sample

representing the plot was formed out of the ten sub-samples. Both installations of the collectors and chemical analysis were performed by the Swedish Environmental Institute (IVL) at Aneboda, using their standard procedures. Sampling and analysis of deposition are described in detail by Lövblad and Westling (1989). Bulk and throughfall deposition were calculated per hydrological years (October–September) by multiplying concentrations with the collected amount of water.

STAND DATA

All measurements of tree data were performed within a circle of 10 m radius located in the centre of each treatment plot. At the time of establishment, all trees with a diameter >5 cm at breast height (1.3 m above ground level) were permanently numbered. The heights (dm) and diameters (mm) of the sample trees were measured, the latter by cross-calipering at breast-height. At 265 Asa there were 39–47 trees per plot, at 266 Kågeröd 64–89 trees per plot, at 267 Tönnersjöheden 45–62 trees per plot, and 33–42 trees per plot at 268 Toftaholm. In all, 4 509 trees were included in the study. The stem volume of individual trees was estimated by empirical functions (Näslund, 1947) at the start of the treatments.

SITE HISTORY

At 265 Asa, the previous stands were clearcut in 1972 and 1974. At that time, one stand was 95-years old and held 250 m^3 ha^{-1} of *P. abies*, and the other stand was 55-years old and held 150 m^3 ha^{-1}, of which 10 % was *P. sylvestris* L. and 90 % was *P. abies*. The present stand was planted during 1972 and 1973 with 4-years old bare-rooted *P. abies* seedlings. The stand was cleaned in 1980. The present stand at 266 Kågeröd was planted in 1978, and it is the first generation of *P. abies* at the site. The previous stand was a mixture of broad-leaf trees (*Fagus silvatica*, *Querqus robur*, *Fraxinus excelsior* and *Carpinus betulus*). At 267 Tönnersjöheden (block 1 and 2), the major part of the former stand was clearcut in 1970 (after an extensive windthrow) and the rest was cut in 1972. Mechanical pre-regeneration cleaning was conducted in November 1972, and the present stand was planted at 2 m spacing in April 1973 (3-years-old bare-rooted *P. abies* seedlings, provenance Brezno, Czech Republic). Also, some replacement planting was done with similar seedlings in April 1974 and 1975. Before the last replacement planting, mechanical preparation (disctrenching) was done in some parts of the stand. Thereafter the stand has been cleaned twice. The previous stand at 267 Tönnersjöheden (block 3) was clearcut in 1970, and the present stand was planted in April 1972 at two m spacing (4-years-old bare-rooted *P. abies* seedlings, provenance Kovvari, Polen). Two cleanings have been conducted (1978 and 1986/1987). At 268 Toftaholm, the previous stand was cut in 1969, after an extensive windthrow, and the present stand was planted in 1971 using 4-years-old bare-rooted *P. abies* seedlings (a German provenance).

NEEDLE SAMPLING AND CHEMICAL ANALYSES

Current-year needles from the year 2001 were sampled on the control plots. Needles were taken during wintertime (December–February) from ten trees on each plot, growing immediately outside the 10-m circular plots. To do this, twigs from the upper third of the crown on the south side were shot down with a shotgun. A similar amount of needles from each of the ten trees was pooled into a single sample representing the plot. The composite sample was dried overnight at 70 °C, and

ground and mixed thoroughly before chemical analysis. The needle concentrations of P, K, Ca, Mg, Mn, S, Fe, Zn, B, Cu, Al and Na were determined on an ICP (JOBIN YVON JY-70 Plus) after wet oxidation in concentrated HNO_3 and $HClO_4$ (10:1 by volume). Nitrogen concentrations were determined on a Carlo Erba NA 1 500 elemental analyser after dry combustion. The chemical analyses were performed by the Department of Ecology and Environmental Research, Swedish University of Agricultural Sciences, Uppsala, Sweden.

FIELD- AND BOTTOM-LAYER VEGETATION

In August in 2001, the cover of field- and bottom-layer vegetation was monitored. Twelve permanent sub-sample plots (0.25 m^2) were established in a fixed grid system within each of the experimental plots in all experiments. If a hindrance (for example, a tree, a large boulder or an experimental installation) were present at a predetermined point, the sub-sample plot was moved one meter towards the centre of the experimental plot. On the sub-sample plots, the cover (e.g. the horizontal projection in percent) was estimated for stones, bare mineral soil, humus, litter, roots, bottom and field layer, as well as individual species. Since the bottom and field layers were classified separately, the total cover on a sub-plot may exceed 100 %. A lower cover than 1 % for an individual species was registered as <1 % in the vegetation registrations, and was set to 0.1 % when the total cover was calculated. Nomenclature of vascular plants follows Lid (1979) and Söderström & Hedenäs (1988) for mosses an liverworts.

SOIL SAMPLING AND CHEMICAL ANALYSES

In July–August of 2001, humus layer samples and mineral soil samples (from 0–5, 5–10 and 10–15 cm depth) were taken at each control plot at all experimental sites. Twenty sub-samples were taken systematically with a corer from each plot. The diameters of the corers were 50 mm for the O horizon (humus layer) and 27 mm for the mineral soil (two mineral soil samples were take at a sampling point). The sub-samples were pooled into one bulk sample per horizon for each experimental plot. The samples were stored at 5 °C before sieving and chemical analysis. The humus samples were sieved through a 6 mm mesh and the mineral soil through a 4 mm mesh. Fresh material was dried at 105 °C for 24 h to determine dry matter. The pH of soil suspensions (16.5 ml fresh material and 33.5 ml water) was measured using a PHM 82 Standard pH-meter equipped with a combination electrode (GK2401C) after shaking for 30 minutes, leaving them to stand overnight at room temperature, repeating the shaking and allowing them to stand once more for at least 30 minutes. Potassium (K) and phosphorus (P) were measured with an Auto Analyzer II (Technicon) after extracting 5 g fresh material in 100 ml 0.1 M ammonium lactate (pH 3.75) for 1.5 h and filtering the resulting suspension through pleated filters (00A, 125 mm). P was analysed using a colorimetric method (ammonium molybdate-ascorbic acid, abs. 660 nm) and K using a flame photometer. The same extract was used when analysing calcium (Ca) and magnesium (Mg), but these cations were measured with an inductively coupled plasma optical emission spectrometer (ICP) (Optima 300 DV, Perkin-Elmer). Total C and N concentrations of air-dried soil samples (0.5 g humus and 1.0 g mineral soil) were analysed by combustion at 1 250 °C with a LECO 2 000 analyzer (LECO Equipment Corp.). Inorganic N was extracted by revolving for 2 h

with a 1 M KCl solution and 20 g organic material and 40 g mineral soil. After filtration with Munktell filter paper (0K), the filtrate was analysed for NH_4-N and NO_2-N + NO_3-N using flow injection analysis (TRAACS 800).

SOIL-WATER SAMPLING AND CHEMICAL ANALYSES

Early in 2001, three suction cups were installed in each plot at all sites. These were installed in three systematically directions, c. 7 m from the plot centre. The cups were made of ceramic material (type P80, Staatliche Porzellan Manufactur, Berlin) and connected by a PVC tube to a PVC-container. The cups were vertically installed at about 50 cm depth in the mineral soil, and the sampling containers were installed about 30 cm away from the cup to minimize the disturbance. When installing the cups, the hole directly above the cups was filled with soil from the corresponding soil layer. Several soil-water samplings were conducted and the sampled water discarded before initiating sampling. At sampling, a suction of 70–80 kPa was applied by hand pumping. One week later, the water samples were collected in polyethene bottles, and immediately frozen. Later the samples were sent to the laboratory in Uppsala for subsequent chemical analyses.

The samples were pooled plot-wise, the same amount of solution was collected from each of the tree suction cups and mixed, and analysed for pH (SS 028122-2), NH_4-N (SS 028 143), NO_3-N (SS 028133), Tot-N (TRAACS), Ca (ISO 11885-1), Mg ISO 11885-1), K (ISO 11885-1), SO_4-S (EPA 300.0), Cl^-, (EPA 300.0) Cd (EPA 200.8 mod.), Zn (EPA 200.8 mod.) and Al (ISO 11885-1). The soil water constituents were analysed by standard methods (standard identification numbers are given in parentheses). The presented data in this report represent mean values from the control plots per site during 2001 and 2002.

Baseline data

The following data in tables and figures are presented in the order of 265 Asa, 268 Toftaholm, 267 Tönnersjöheden and 266 Kågeröd. This order refers to the stratification of the experimental sites regarding deposition of N and site productivity, i.e. moderate deposition/medium productivity (265 Asa), moderate deposition/high productivity (268 Toftaholm), high deposition/medium productivity (267 Tönnersjöheden), and, high deposition/high productivity (266 Kågeröd).

DEPOSITION

One year of sampling showed that the N deposition was higher at the two sites located mostly in south-west near the coast (266 Kågeröd and 267 Tönnersjöheden) compared with the inland sites further north-east (265 Asa and 268 Toftaholm), both regarding bulk deposition and, especially, throughfall, which was c. 4 times higher (table 4). Throughfall of inorganic N was lower than bulk deposition at all sites, although the ratio of throughfall/bulk deposition was much lower at 265 Asa and 268 Toftaholm (c. 0.25) than at 267 Tönnersjöheden and 266 Kågeröd (0.6 and 0.8). At all experimental sites, N deposition consisted of approximately equal parts of NH_4-N and NO_3-N (table 4). The throughfall of SO_4-S was about twice as high at the costal 267 Tönnersjöheden and 266 Kågeröd as at the 265 Asa and 268 Toftaholm. The precipitation during the observation year was higher (6–44 %) than the normal references (tables 3 and 4).

Table 4.
Precipitation, interception, bulk deposition in the open field (OF) and throughfall (TF) at the experimental sites in the hydrological year 2001–2002.

Element	Site 265		Site 268		Site 267		Site 266	
	OF	TF	OF	TF	OF	TF	OF	TF
Precipitation, mm	832	517	1 074	589	1 113	821	936	517
Interception, mm	–	315	–	485	–	292	–	419
Deposition, kg ha^{-1}								
H^+	0.106	0.023	0.188	0.028	0.236	0.082	0.187	0.024
Alkalinity	0.233	6.996	1.416	8.414	2.537	5.102	0.279	9.831
Tot-S	4.91	3.06	5.86	3.82	7.64	6.35	6.21	6.33
SO_4-S	4.02	2.46	4.46	2.78	5.70	4.49	5.06	4.85
Cl^-	19.2	12.8	30.5	22.7	42.0	40.3	24.9	32.2
NO_3-N	4.01	1.28	4.84	1.00	6.78	4.63	6.01	5.11
NH_4-N	3.82	0.84	4.43	1.03	5.93	3.03	5.36	4.09
Σ Inorganic-N	7.83	2.12	9.27	2.03	12.71	7.66	11.37	9.20

STAND DATA

Each experimental stand consisted of 27 to 34 year-old *P. abies* trees that were highly and medium productive compared with regional standards (table 1). During the winter of 2000/2001 and spring 2001, all experiments were established in previously not thinned stands (table 1). This was one of the criteria when choosing stands. After the establishment, all experimental plots, as well as the rest of the experimental stands were thinned in the spring 2001 before treatment. The harvest at thinning aimed at the same thinning grade (proportion of basal area) on all plots within a block, in order to get a similar thinning response on the retained trees. This is important in order to isolate the effects on growth of the experimental treatments, especially since quite small effects were to be expected at least for some treatments. At 265 Asa, the average thinning grade was 22 %, and the deviation on a single plot from the block mean was ±2 percent units (p.u.). The corresponding values for most plots at the other sites were: 17 % and ±3 p.u. (266 Kågeröd), 26 % and ±2 p.u. (267 Tönnersjöheden), and 25 % and ±2 p.u. (268 Toftaholm). At all these three latter sites, there was one plot having a deviation of 4–6 p.u. The thinnings were done from below at all sites except for at 266 Kågeröd where it was done from above.

NEEDLE NUTRIENT CONCENTRATIONS

The N concentrations in the needles at 265 Asa and 268 Toftaholm were higher than usual among Swedish coniferous stands on mineral soils (Sikström, 2001), but they were within the range commonly found in the region (Ericsson et al., 1995; Thelin et al., 1998), while the concentrations at 266 and 267 were quite high for the region (table 5). The other observed macro- and micronutrient concentrations (P, K, Ca, Mg, S, Mn, Fe, Zn, B and Cu) were within the ranges commonly reported from Swedish coniferous stands on mineral soils (Sikström, 2001).

Table 5.
Mean element concentrations in current-year needles from *Picea abies* on control plots in 2001 (n = 3). One standard error within parentheses.

Element	Site 265 Asa	Site 268 Toftaholm	Site 267 Tönnersjöheden	Site 266 Kågeröd
(mg g^{-1} d.w.)				
N	13.5 (0.29)	14.1 (0.72)	16.5 (0.42)	17.3 (1.3)
P	1.37 (0.11)	1.64 (0.06)	1.42 (0.04)	1.50 (0.06)
K	5.07 (0.18)	5.23 (0.27)	4.97 (0.12)	5.63 (0.55)
Ca	3.27 (0.27)	2.67 (0.47)	2.37 (0.66)	3.00 (0.36)
Mg	1.01 (0.05)	1.03 (0.08)	1.02 (0.03)	1.08 (0.06)
S	0.80 (0.02)	0.80 (0.02)	0.93 (0.03)	0.95 (0.04)
Mn	1.02 (0.12)	1.47 (0.21)	0.87 (0.23)	0.63 (0.21)
(µg g^{-1} d.w.)				
Na	38 (7.1)	80 (14)	285 (67)	89 (8.8)
Fe	32 (0.2)	36 (0.5)	45 (0.4)	50 (3.2)
Zn	25 (1.0)	21 (3.4)	17 (2.2)	21 (2.3)
B	9.9 (0.3)	9.8 (0.6)	18 (0.7)	15 (0.7)
Cu	3.5 (0.0)	3.2 (0.1)	3.6 (0.1)	3.8 (0.2)
Al	141 (7.5)	102 (9.4)	123 (1.5)	127 (10)

The rank of the N concentrations at the different sites was the same as the rank of the site indices (tables 1 and 5). This was also the case for the Fe concentrations. For B, the concentrations at the costal (267 Tönnersjöheden and 266 Kågeröd) showed 1.5 – 1.8 higher values than the inland sites.

FIELD- AND BOTTOM-LAYER VEGETATION

At all experimental sites, the cover of vegetation was sparse (table 6), especially the field layer, and both the field- and bottom-layer covers varied substantially both within and between experimental plots. A complete species list for the individual sites is given in appendix 1.

Table 6.
Cover of field layer (FL) and bottom layer (BL) vegetation (%) in 2001 (n = 3).

Treatment	Site 265		Site 268		Site 267		Site 266	
	FL	BL	FL	BL	FL	BL	FL	BL
81	1.67	14.3	0.38	4.59	0.06	9.96	0.00	0.09
3	1.39	13.0	0.10	5.56	0.23	13.3	0.03	0.42
4	0.72	9.43	0.06	3.55	0.11	7.96	0.00	0.31
5	0.89	10.9	0.21	6.60	0.04	8.45	0.03	0.11
6	0.36	7.99	0.43	5.23	0.19	8.98	0.00	0.14
7	0.97	13.2	0.13	4.08	0.11	10.6	0.08	0.11

At 265 Asa, *Deschampsia flexuosa* was the dominating species in the field layer in most of the plots, while *Hylocomium splendens* and P*lerurozium schreberi* were dominating in the bottom layer.

The dominant species in most of the experimental plots at 268 Toftaholm consisted of *Deschampsia flexuosa* and *Rubus idaeus* in the field layer, and, *Hylocomium splendens* and *Dicranum majus* in the bottom layer.

In all blocks at 267 Tönnersjöheden, the dominant species was *Deschampsia flexuosa* in the field layer and *Hypnum cupressiforme* in the bottom layer. In individual experimental plots, the cover varied between 0 % (for both layers) and c. 4 % for the field layer and c. 65 % for the bottom layer.

In general, both the field- and bottom layer vegetation were very sparse at 266 Kågeröd (table 6). The existing field layer was dominated by juvenile herbs, some of which were very difficult to identify at the time of the inventory. In the tractor roads, species like *Epilobium* sp. and *Rubus idaeus* were identified. In the bottom layer *Eurynchеum* spp. and *Thuidium tamariscinum* was dominating.

SOIL CHEMISTRY

The two most productive sites (i.e. 266 Kågeröd and 268 Toftaholm) had the lowest pH-values down to 15 cm in the mineral soil, whereas 267 Tönnersjöheden displayed intermediate, and 265 Asa the highest values (figure 1). This rank among the sites was the same for the pH in humus, except that 266 Kågeröd showed the highest value.

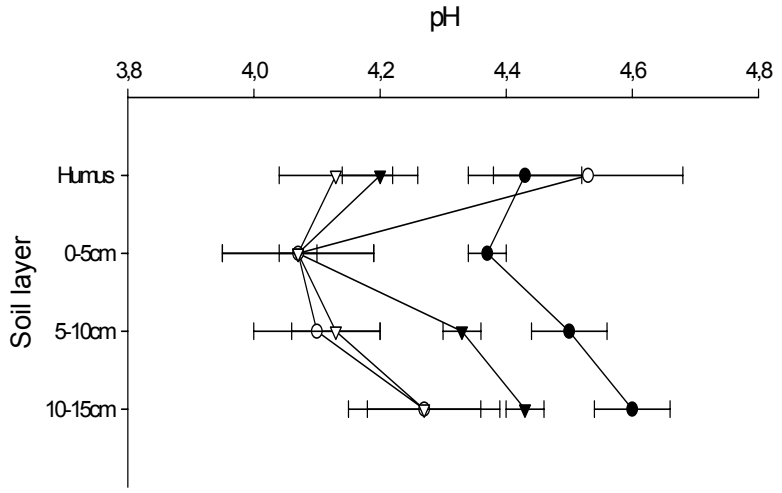

Figure 1.
pH (H2O) in the soil at the control plots at the experimental sites in 2001: ● = 265 Asa, = ○ 266 Kågeröd,▼= 267 Tönnersjöheden, and ▽= 268 Toftaholm. Error bars indicates ± 1 SE, n = 3.

Table 7.
Concentrations (mg g^{-1} DM) of total-C, total-N, NH_4-N and NO_3-N in the soil at the control plots in 2001 at the experimental sites. Means and standard error (SE), n = 3.

Variable	Soil layer[1]	Site 265 Asa		Site 268 Toftaholm		Site 267 Tönnersjöheden		Site 266 Kågeröd	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Total-C	Humus	352.5	6.7	367.0	16.6	333.5	19.4	396.6	5.0
	0–5 cm	58.6	3.2	87.9	10.9	57.7	2.9	72.6	5.7
	5–10 cm	42.3	0.7	51.0	3.9	42.9	5.5	34.9	5.7
	10–15 cm	31.4	2.3	36.7	5.5	35.9	2.6	27.4	1.0
Total-N	Humus	13.6	0.4	16.7	0.5	14.0	0.7	16.5	1.0
	0–5 cm	2.4	0.1	5.4	0.7	2.2	0.2	3.5	0.4
	5–10 cm	1.7	0.1	3.5	0.6	1.7	0.3	1.9	0.5
	10–15 cm	1.2	0.1	2.7	0.7	1.4	0.2	1.3	0.2
NH_4-N	Humus	0.157	0.038	0.128	0.022	0.167	0.015	0.119	0.019
	0–5 cm	0.010	0.001	0.008	0.002	0.012	0.002	0.017	0.002
	5–10 cm	0.004	0.000	0.003	0.000	0.006	0.001	0.007	0.000
	10–15 cm	0.003	0.000	0.002	0.000	0.003	0.001	0.004	0.001
NO_3-N	Humus	0.002	0.001	0.002	0.002	0.001	0.000	0.039	0.027
	0–5 cm	0.000	0.000	0.001	0.001	0.000	0.000	0.009	0.006
	5–10 cm	0.000	0.000	0.001	0.001	0.000	0.000	0.009	0.006
	10–15 cm	0.000	0.000	0.001	0.001	0.001	0.000	0.006	0.004

[1]Humus and mineral soil horizons.

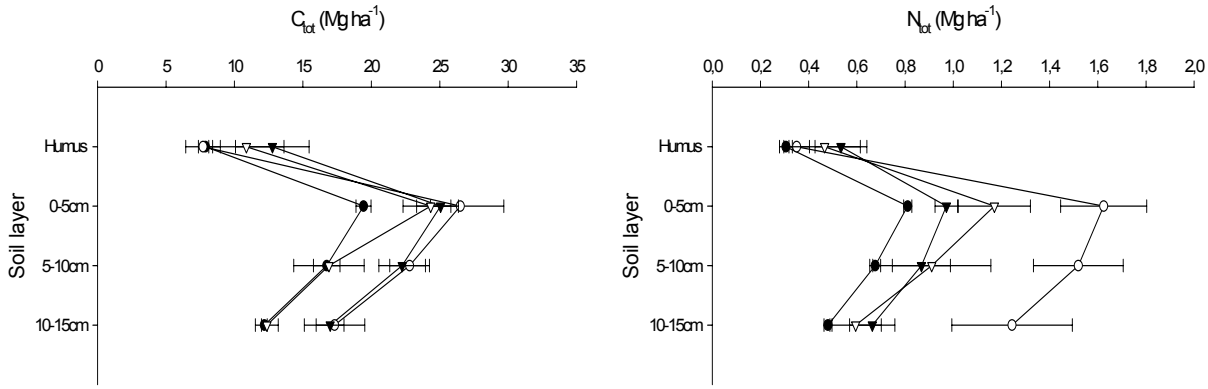

Figure 2.
Total amounts of C and N in the soil at various depths at the control plots at the experimental sites in 2001: ● = 265 Asa, = ○ 266 Kågeröd, ▼ = 267 Tönnersjöheden, and ▽ = 268 Toftaholm. Error bars indicate ± 1 SE, n = 3.

No great differences in total-C and total-N concentrations between the four investigated sites were observed (table 7). However, the total-N concentration in the humus layer at 266 Kågeröd and 268 Toftaholm was slightly higher than at the other two sites. In the mineral soil, the total-N concentrations were about twice as high at 266 Kågeröd as at the other three sites.

The highest amount of C, down to 15 cm in the mineral soil, was found at 267 Tönnersjöheden and 266 Kågeröd, 77.1 and 74.3 Mg ha^{-1}, respectively, followed by 268 Toftaholm (64.5 Mg ha^{-1}) and 265 Asa (56.2 Mg ha^{-1}) (figure 2). This rank of the sites was similar for all soil layers, except for the relatively low amount of C in the humus layer at 266 Kågeröd. The amount of N in the soil profile was about twice as high at 266 Kågeröd (4.7 Mg ha^{-1}) than at 265 Asa (2.3 Mg ha^{-1}), and the two other sites had intermediate amounts, 3.0 Mg ha^{-1} (267 Tönnersjöheden) and 3.2 Mg ha^{-1} (268 Toftaholm) (figure 2). The major differences between the sites were found in the mineral soil.

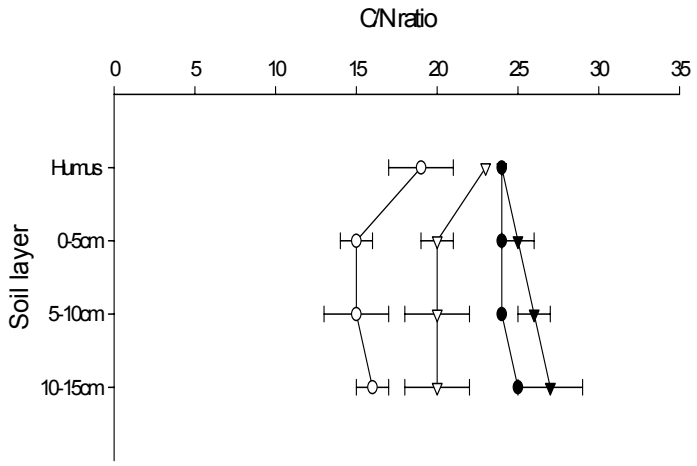

Figure 3.
The C to N ratio in the soil at the control plots at the experimental sites in 2001: = ● 265 Asa, ○ = 266 Kågeröd, = ▼ 267 Tönnersjöheden, and ▽ = 268 Toftaholm. Error bars indicate ± 1 SE, n = 3.

The C to N ratio in the different soil layers were lowest at 266 Kågeröd, somewhat higher at 268 Toftaholm and the highest at 265 Asa and 267 Tönnersjöheden (figure 3). At the two last sites, the ratio was quite constant in all investigated soil layers.

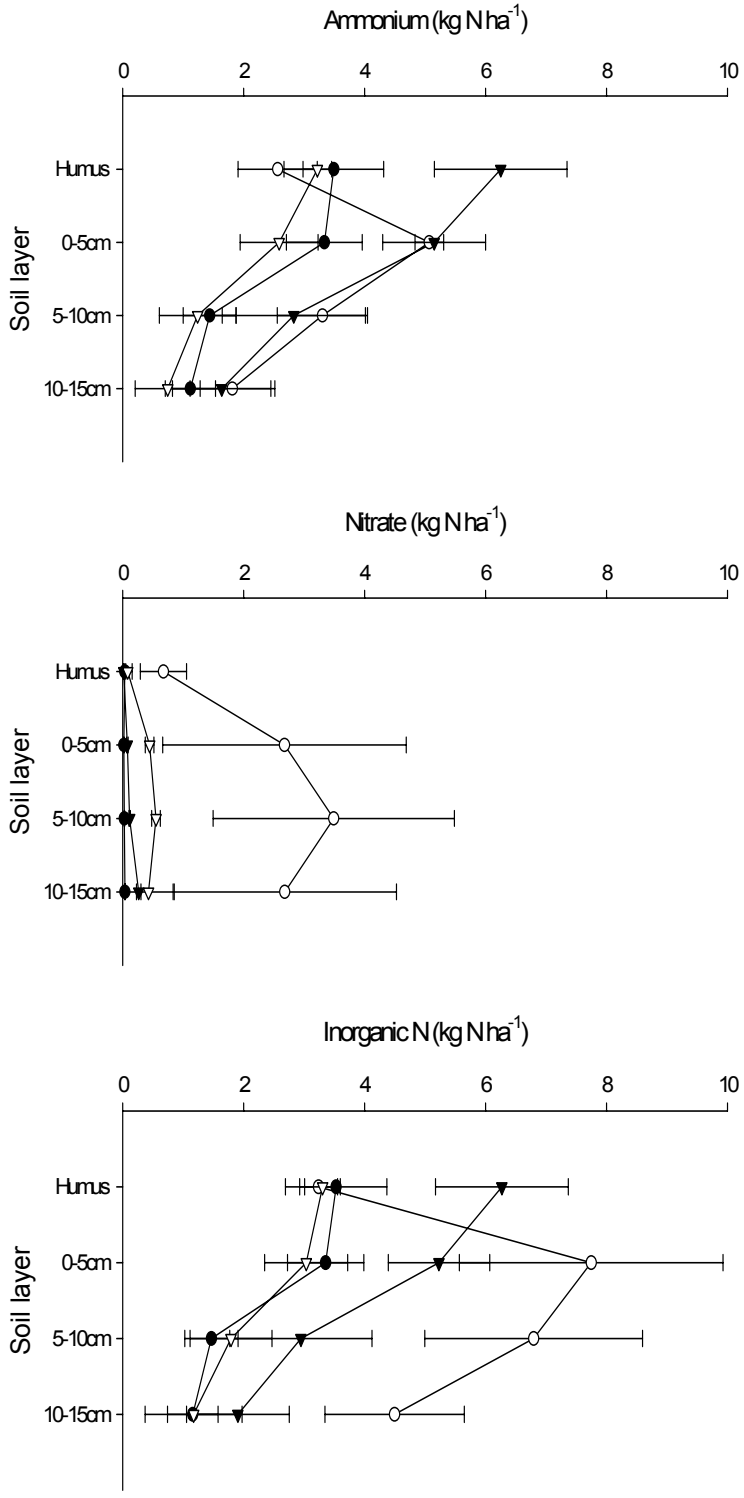

Figure 4.
Inorganic N in the soil at the control plots at the four experimental sites in 2001: ● = 265 Asa, ○ = 266 Kågeröd, ▼ = 267 Tönnersjöheden, and ▽ = 268 Toftaholm. Error bars indicate ± 1 SE, n = 3.

On an area basis down to 15 cm in the mineral soil, the highest total amount of inorganic N was found at 266 Kågeröd (22.3 kg ha^{-1}), followed by 267 Tönnersjöheden (16.3 kg ha^{-1}), and, the lowest amounts were found at 268 Toftaholm (9.3 kg ha^{-1}) and 265 Asa (9.5 kg ha^{-1}). Besides the high total amount of inorganic N, the 266 Kågeröd was different from the others in two respects. Firstly, the amount of inorganic N was relatively low in the humus, because of a thin humus layer. Secondly, the proportion of nitrate N was considerably higher than at the other sites, where NH_4-N dominated (figure 4). Regarding concentrations of inorganic N, the NH_4-N-concentrations were similar at all sites, whereas the NO_3-N-concentrations were somewhat higher at 266 Kågeröd, especially in the humus layer (table 7). This was mainly because of a high value in one of the blocks.

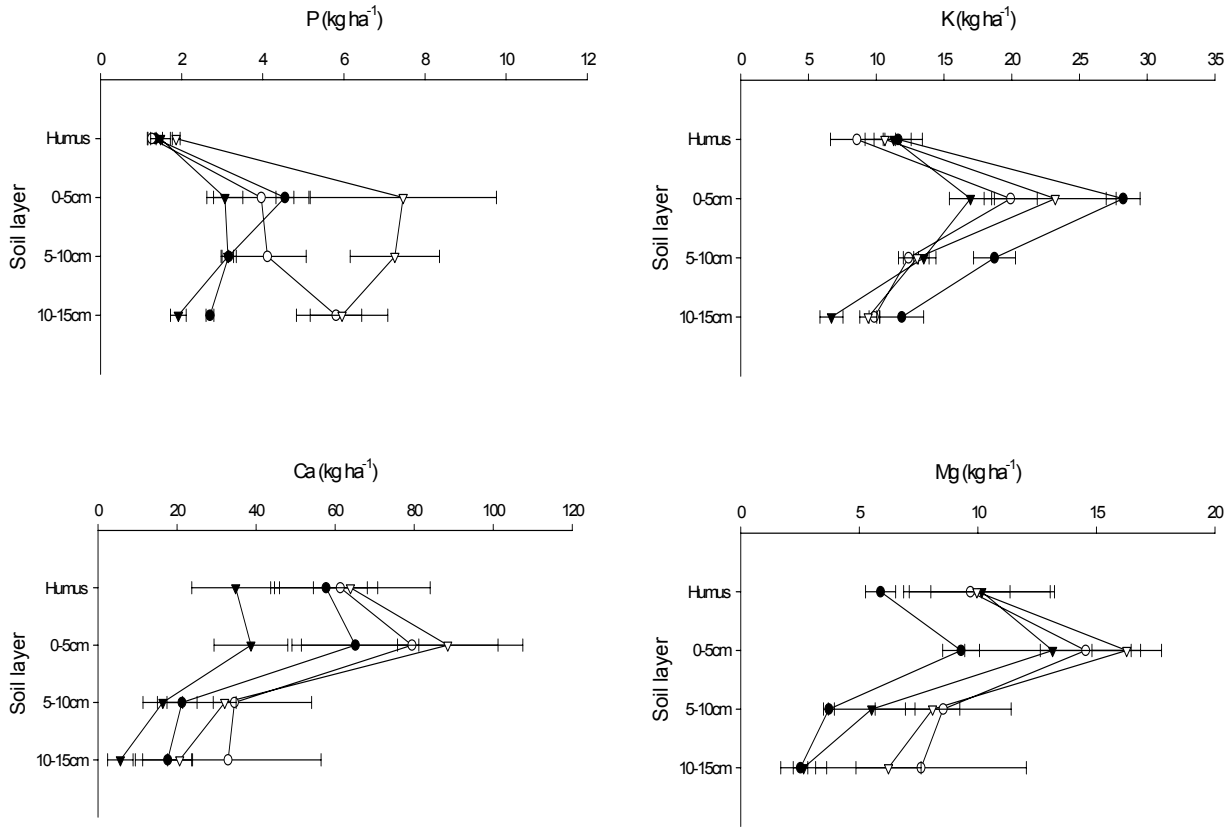

Figure 5.
Ammonium lactate extractable amounts of phosphorus (P) and base cations (K, Ca and Mg) in the soil at the control plots at the experimental sites in 2001: = ● 265 Asa, ○ = 266 Kågeröd, ▼ = 267 Tönnersjöheden, and ▽ = 268 Toftaholm. Error bars indicate ± 1 SE, n = 3.

Among all sites, 268 Toftaholm showed the greatest amount of extractable P in the soil, most explicitly in the mineral soil (figure 5). The highest amount of K was found at 265 Asa, while no obvious differences were found among the other three sites. As regards Ca and Mg, the highest amount was found at 268 Toftaholm closely followed by 266 Kågeröd (figure 5).

SOIL-WATER CHEMISTRY

There was almost one unit difference between the lowest (247 Tönnersjöheden) and the highest (266 Kågeröd) pH observed in the soil water (table 8). For most elements analysed, 266 Kågeröd showed higher concentrations by a factor of 2–4 compared with the other sites (table 8). Chloride was one exception, since the concentrations were similar at the two costal sites. Another exception was the high Al-concentration at 268 Toftaholm. This site also showed quite high NO_3-N-concentrations in the soil water. Potassium- and Zn-concentrations were about the same at all sites (table 8).

Table 8.
Mean values of pH and soil solution concentrations (mg l^{-1}, with an exception for Cd, µg l^{-1}) at the control plots at the experimental sites (n = 3). Sampling dates are denoted in the format: yymmdd.

Date	265 Asa		268 Toftaholm		267 Tönnersjöheden		266 Kågeröd		
	010703	011025	010621	010928	010614	010918	011105	020419	020603
pH	4.70	4.63	4.37	4.50	4.47	4.00	5.77	4.80	4.95
NH_4-N	0.011	0.005	0.004	0.006	0.005	0.01	0.015	0.038	0.012
NO_3-N	0.026	0.001	0.046	0.802	0.005	0.10	0.367	0.923	1.370
Tot-N	1.187	0.673	1.140	1.833	0.803	1.3	7.633	1.567	2.150
Ca^{2+}	1.267	1.127	0.663	0.583	1.033	0.800	7.367	3.463	4.620
Mg^{2+}	0.530	0.537	0.770	0.867	0.747	0.40	2.100	1.700	1.900
K+	0.307	0.323	0.350	0.390	0.303	0.60	0.693	0.220	0.260
SO_4^{2-}	10.67	11.00	11.63	13.33	8.00	8.7	17.33	19.33	26.00
Cl^-	5.33	6.43	9.00	7.96	14.66	12.3	20.00	13.33	14.00
Cd	0.160	0.130	0.173	0.197	0.230	0.200	0.383	0.330	0.300
Zn	0.017	0.023	0.025	0.026	0.042	0.031	0.045	0.039	0.026
Al	0.637	0.750	1.633	1.533	–	–	0.353	1.767	–

Concluding remarks

The intention with the study was to establish experiments in stands of (i) two different site productivity classes within (ii) two regions with differences in N deposition. Furthermore, (iii) the stands should be quite young, i.e. at the stage of first thinning, to enable long-term monitoring. All these criteria has been fulfilled according to the presented base-line data.

N deposition was higher at the two sites located mostly in southwest near the coast (266 Kågeröd and 267 Tönnersjöheden) than at the inland sites further northeast (265 Asa and 268 Toftaholm), both regarding bulk deposition and throughfall (table 4). Furthermore, the quotient throughfall/bulk deposition was much higher at 267 Tönnersjöheden and 266 Kågeröd (0.6 and 0.8, respectively) than at 265 Asa and 268 Toftaholm (c. 0.25), suggesting a lower net-uptake of N in the canopy at the former sites.

The monitored site indices indicate a higher productivity at 268 Toftaholm than at 265 Asa (the inland sites with moderate deposition), as well as at 266 Kågeröd than at 267 Tönnersjöheden (the coastal sites with high deposition) (table 1).

The costal sites (266 Kågeröd and 267 Tönnersjöheden) had higher amounts of inorganic N in the soil than the inland sites, and the mean N concentrations of current-year needles were the highest at these two sites.

Changes in ecosystems caused by deposition of anthropogenic air-borne S and N compounds, are probably fairly slow processes (with low doses added steadily, all year around) compared with artificial treatments in experiments (which usually involve quite high doses in one or a few applications). Thus, the experiments might produce artefacts, i.e. short-term shock effects, which may not occur in a natural forest ecosystem. This must be considered when recorded data are interpreted (cf. Skeffington & Wilson, 1988).

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Appendix 1

List of field- and bottom-layer species found at the four experimental sites during the first inventory in 2001. An X mark presence of the species in 2001. Names follow Lid (1979) for vascular plants and Söderström & Hedenäs (1988) for mosses and liverworts. Swedish names are given within parenthesis for convenience.

	Site			
Species	265	268	267	266
Liverworts				
Blepharostoma trichophyllum (L.) Dum. (Hårfliksmossa)		X		
Chiloscyphus pallescens (Hoffm.) Dum. (Skogsblekmossa)	X			
Jungermannia leiantha Grolle (Rörsvepemossa)				
Lepidozia reptans (L.) Dum. (Fingermossa)	X	X		
Plagiochila asplenoides (L.) Dum. (Bräkenmossa)		X		X
Ptilidium ciliare (L.) Hampe. (Franslevermossa)	X	X		
Other liverworts (could include species above)	X	X	X	X
Mosses				
Aulacomnium androgynum (Hedw.) Schweagr. (Liten räffelmossa)		X		
Brachythecium reflexum (Starke) Schimp. (Späd gräsmossa)	X	X	X	X
B. starkei (Brid.) Scimp. (Spärrgräsmossa)		X		
Dicranum majus SM. (Stor kvastmossa)	X	X	X	
D. montanum Hedw. (Stubbkvastmossa)	X	X	X	X
D. polysetum Sw. (Vågig kvastmossa)	X	X		
D. scorpidium Hedw. (Kvastmossa)	X	X		
Eurhynchium angustirete (Broth.) T. Kop. (Hasselsprötmossa)				X
E. praelongum (Hedw.) Schimp. (Spärrsprötmossa)		X		X
Hylocomium splendens (Hedw.) Schimp. (Husmossa)	X	X		
Hypnum cupressiforme Hedw. (Cypressfläta)	X	X	X	X
H. jutlandicum (Plattfläta)			X	
Mnium hornum Holmen & Warnecke (Skuggstjärnmossa)			X	X
Plagiomnium affine (Bland.) T. Kop. (Skogspraktmossa)	X	X		X
P. undulatum (Hedw.) T. Kop. (Vågig praktmossa)				X
Plagiothecium curvifolium Limpr. (Klosidenmossa)	X	X	X	X
P. undulatum (Hedw.) Schimp. (Vågig sidenmossa)	X	X	X	
Pleurozium schreberi (Brid.) Mitt. (Väggmossa)	X	X	X	
Pohlia nutans (Hedw.) Lind. (Nickmossa)	X	X		
Polytrichum commune Hedw. (Björnmossa)	X	X	X	X
Ptilium crista-castrensis (Hedw.) De Not. (Kammossa)	X	X	X	
Rhodobryum roseum (Hedw.) T. Kop. (Rosmossa)	X	X		
Rhytidiadelphus loreus (Hedw.) Warnst. (Västlig hakmossa)	X	X	X	
Sphagnum spp. (Vitmossor)			X	
Tetraphis pellucida Hedw. (Fyrtandsmossa)	X	X	X	
Thuidium spp. (Tujamossa)		X		X
Ferns				
Cystopteris fragilis (L.) Bernh. (Stenbräken)				X
Gymnocarpium dryopteris (L.) Newm. (Ekbräken)	X			

	Site			
Species	265	268	267	266
Vascular plants				
Betula sp. (Björk)		X		
Calamagrostis arundinacea (L.) Roth. (Piprör)	X			
C. canescens (Web.) Roth. (Grenrör)		X		
Carex spp. (Starr)		X		X
Chamaenerion angustifolium (L.) Scop. (Mjölkört)				X
Circaea lutetiana L. (Stor häxört)				X
Deschampsia flexuosa (L.) Trin. (Kruståtel)	X	X	X	X
D. cespitosa (L.) PB. (Tuvtåtel)		X		X
Epilobium montanum L. Bergdunört				X
Fagus sylvatica L. (Bok)			X	
Fraxinus excelsior L. (Ask)				X
Galeopsis tetrahit L. (Pipdån)	X			X
Galium spp. (Måra)		X		
Lactuca muralis (L.) Fres. (Skogssallat)			X	
Luzula pilosa (L) Willd. (Vårfryle)	X			
Luzula spp. (Fryle)			X	
Maianthemum bifolium (L) F.W. Schm. Ekorrbär	X			
Oxalis acetosella L. Harsyra	X			
Picea abies (L.) Karst. (Gran)				X
Ranunculus sp. (Smörblomma)	X			
Rubus ideaus L. (Hallon)	X			X
Senecio sylvaticus L. (Bergkorsört)	X			X
Sorbus aucuparia L. (Rönn)	X			X
Stellaria media (L) Will. (Våtarv)	X			X
Trientalis europaea (Skogsstjärna)	X			
Vaccinium myrtillus L. (Blåbär)	X		X	
V. vitis-idaea L. (Lingon)	X			
Viola spp. (Viol)	X			X
Lichens				
Cladonia spp. (Bägarlavar)	X		X	