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Air pollution - Tree vitality - Forest damage and production

The Skogaby Project

Project description

Per-Erik Jansson (editor)

Swedish University of Agricultural Sciences
and
University of Lund

Institutionen för markvetenskap
Avdelningen för lantbrukets hydroteknik

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Preface

The present report is a provisional document which, in its present state, should only be used as a description of objectives and the methods used in the project. The report has been continuously updated during discussions about the present direction of all subprojects. Examples of planned modifications are measurements programmes within many subprojects. Based on the experience from the first years of observations revisions will take place.

The document will be followed by yearly progress reports which will present preliminary results from different investigations. However, most results from the projects will be published in ordinary scientific journals.

Further details about the Skogaby project can be obtained by applying directly to the project or to the different investigators responsible (see address list).

April 27, 1990

Per-Erik Jansson

Editor

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Introduction

Background

Acid precipitation, deposition of nitrogen, acidification of soils, and high ozone concentrations, may change the productivity of forests in Sweden and large parts of northern Europe. Even if there is major concern about the changing environmental factors, there are still uncertainties concerning the degree to which different factors separately or together influence forest productivity and different types of forest damage. An important limitation in our present knowledge is either the difficulty to interpret the influence of individual factors from survey studies covering large areas, or the corresponding difficulty to generalize from detailed studies where individual factors are regulated but only covering small trees or short periods. Another aspect which makes it difficult to evaluate the present effects of the changed environmental conditions is the complex interaction between different factors and processes. One factor, like deposition of nitrogen, may be stimulating under certain conditions while the reverse effect may occur under slightly changed conditions.

To overcome these difficulties there is an obvious need of experimental studies dealing with sufficiently large plots and considering the interdisciplinary nature of ecosystem studies covering many biological, chemical and physical processes.

General objective

- To find out which climatic and nutritional conditions result in positive or negative effects of air pollutants on spruce forest growth and vitality.

The site

This site in SW Sweden represents high levels of deposition, an acid till soil and a homogeneous and relatively healthy young stand of Norway spruce. The climate is characterized by a high excess of precipitation with an annual precipitation around 1100 mm. The sandy till soil has a pH of around 4.0 which increases to about 4.5 in the subsoil, it is poor in base cations and rich in aluminium. The stand was planted in 1966 as the second generation of coniferous forest replacing former heath land. It is of Polish origin and presently highly productive. The site is located 30 km SE of Halmstad and 3 km NE of the small village of Skogaby.

The site was surveyed and the field plots were selected during 1987 and the treatments started during the growing season of 1988. The only exception is the ash treatment which started one year after the other treatments. The total area of the site is 20 ha of which 6.5 are used for the investigation. Totally there are 30 plots of 2000 m^2.

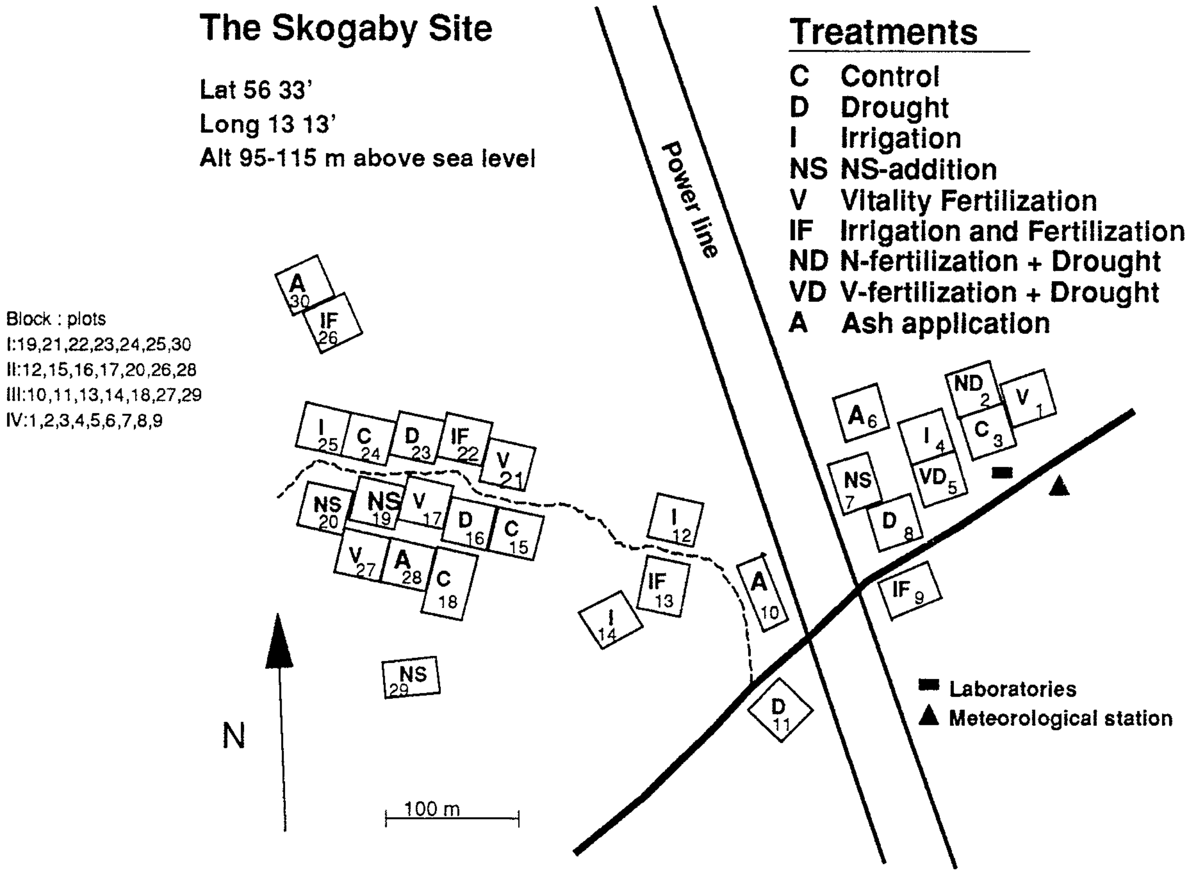
General approach and the treatments

The location of the site in an area influenced by air pollutants and with relatively unfavourable nutrient conditions means that the stand is exposed to a certain stress. The degree of stress will be influenced by the different treatments which will change the availability of water and nutrients in the soil. We will study the response of the trees to these changes in water and nutrient conditions. How the different treatments are expected to change the soil conditions and thereby the degree of stress is shown in the figure below.

		Nutrient Stress		
		higher		lower
Water stress	higher	NSD	D	VD
		NS	C	V,A
	lower		I	IF

It is important to remember that the whole stand, including the control plots, is affected by the air pollutants in the region. The direct influence of air pollutants as such must therefore be made by comparisons with other localities where similar treatments are used.

The research priorities are focused on the response of the spruce trees including both above- and below-ground parts. A major difficulty when interpreting the causes behind forest damage is to distinguish between direct influence on the forest canopy and indirect effects caused by impaired uptake of nutrients and water from the soil. The objective will sometimes be restricted to a detailed description of the effects caused by the treatments, while in other cases also the explanation will be looked for. To clarify the role of these different factors it was essential to use an interdisciplinary approach considering key processes for the function and behaviour of the whole forest ecosystem.


The Skogaby Site
Lat 56 33'
Long 13 13'
Alt 95-115 m above sea level
Treatments
C Control
D Drought
I Irrigation
NS NS-addition
V Vitality Fertilization
IF Irrigation and Fertilization
ND N-fertilization + Drought
VD V-fertilization + Drought
A Ash application
Block : plots
I:19,21,22,23,24,25,30
II:12,15,16,17,20,26,28
III:10,11,13,14,18,27,29
IV:1,2,3,4,5,6,7,8,9
Power line
N
100 m
Laboratories
Meteorological station

Symbol	Treatment	Description
C	Control	No treatment
D	Drought	A roof prevents 2/3 of the throughfall from reaching the ground in half the plot (D1) during the growing season. After two years of drought treatment, the roof is moved to the other half (D2). During winter all precipitation is allowed to infiltrate into the soil profile.
I	Irrigation	Irrigation is done using a sprinkler technique which gives an even distribution of water on the soil surface. The amount of water is adjusted to avoid any water storage deficits exceeding 20 mm of water during the growing season.
NS	NS-additition	Ammonium sulphate is added manually three times a year.
V	Vitality fertilization	1000 kg per ha of "Skog-vital" is added during a two year period. "Skog-vital" is a special fertilizer without any nitrogen but including other elements of importance for a high forest yield. The fertilizer is added once a year.
IF	Optimum fertilization with irrigation	100 kg of N per ha and year is added together with a complete set of nutrients essential for an "optimum" forest yield. The fertilizer solution is sprayed evenly above the ground with the same technique as for the irrigation treatment.
ND	NS-fertilization followed by drought	Like (NS) but followed by drought after 4 years of treatments.
VD	Vitality fertilization followed by drought	Like (V) but followed by drought after 4 years of treatments.
A	Wood ash application	4000 kg ha^{-1} of granulated wood ash is added as a single dose. The wood ash application is suggested as a possible form of vitality fertilization in areas with high N-deposition and poor soils with respect to the availability of other nutrients. This treatment is done in a separate project connected to the research program on forest energy and wood ash recycling supported by the Swedish Energy Board and the Swedish State Power Board.

Composition and amounts of macro nutrients in four treatments (kg/ha)

Treatment	N	P	K	Ca	Mg	S	Period of application
NS	100	0	0	0	0	114	Yearly
V	0	30	50	210	48	80	During the first two years
A	0	25	129	448	47	4	During the first year
IF	100	17	48	6[1]	6	9	Yearly

1 Was given as a single dos prior the start of the irrigation as ground lime stone.

The role of air pollutants

To make it possible to quantify the effects air pollutants per se it is necessary to make predictions on how the treatments would have affected the trees at Skogaby provided that there were no air pollutants present. There are mainly two concepts used to make these predictions, namely: light use efficiency and water use efficiency, defined as the ratios between tree growth and the amount of absorbed light and transpired water, respectively.

Hypotheses

- Forest stands which are exposed to similar nutritional conditions will also have similar levels of light use efficiency and nutrient use efficiency.
- The direct effect of air pollutants can be estimated as the difference between prediction based on data from less polluted sites and observations at polluted sites.

Similar field experiments with Norway spruce are being conducted by other projects at Flakaliden in the north of Sweden and at Asa in the south of Sweden. At all sites the treatments include the optimum fertilization with irrigation plus controls. The drought and irrigation treatments are present both at Skogaby and at Flakaliden. Flakaliden has only low concentration of air pollutants and a low deposition. Other sites which are being investigated in areas with higher levels of air pollutants are found in Denmark, Germany and in the Netherlands.

The subprojects

No.	Short title	Responsible
1.	**Studies of the "whole" tree**	
1.1	Above-ground biomass measurements	L-O Nilsson
1.2	Crown morphology	J. A. Lesinski
1.3	Water physiology	J-E Hällgren
2	**Studies of the roots**	
2.1	Fine roots and mycorrhiza	H. Persson
2.2	Chemical conditions at the rhizosphere	G. Gobran
2.3	Aluminium and the uptake of ions	S. Widell
3	**Studies of the needles**	
3.1	Nutrient dynamics and surface structures	B. Nihlgård
3.2	Canopy leaching of minerals	L. Folkeson
3.3	Nitrogen and sulphur metabolites	J-E Hällgren
3.4	Resistance against insects	S. Larsson
4	**Studies of environmental factors**	
4.1	Climate and air pollutants	P-E Jansson
4.2	Hydrology	P-E Jansson
4.3	Soil chemical properties and leaching of solutes	J. Bergholm
5	**Syntheses and modelling**	
5.1	Three growth models	L-O Nilsson
5.2	Effects of wood ash	H. Lundkvist
6.1	Project coordination	L-O Nilsson
6.2	Management of the field site	U. Johansson

1.1 Tree growth, above-ground budgets for nutrients and biomass.

Responsible investigator

Lars-Owe Nilsson

Co-worker

Karin Wiklund

General objective

- To quantify tree growth, budgets and distribution of above-ground biomass and nutrients in the stands.

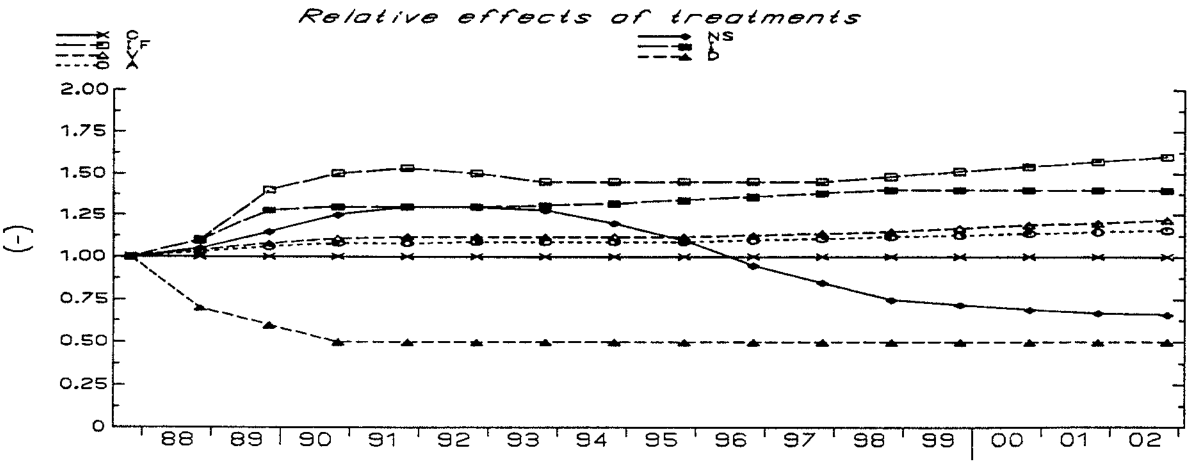
Short background

The development of above-ground biomass represents an integrated response to atmospheric factors such as climate and direct effects of air pollutants and soil factors like nutrient and water availability. The tree can in itself be considered as a biological sensor accumulating effects of biological, chemical and physical processes. The whole project is centred around the effects on tree growth and all other subprojects will be related to this subproject. Growth measured as stem diameter changes will also be of the greatest interest from an applied viewpoint. Changes in the allocation pattern of carbon will also be of general interest.

Different measurement techniques are used in this subproject to give as good estimates as possible both of the temporal and the spatial dynamics in above-ground growth patterns. Great interest is also devoted to making budgets for all essential nutrients for tree growth.

Hypotheses

The effects of the different treatments on the development of tree growth is shown in the figure below.



Hypotheses to be tested together with other subprojects

- The N-availability will change the allocation ratio between roots and above-ground parts.

Use of treatments and replicates of the Skogaby forest

All treatments and replicates within the project will be used.

Measurement programme at Skogaby

All trees (about 11 500) used in the experiment are measured annually for diameter at breast height. Trees within the net experimental area (the experimental unit, totally about 1100 trees) are also measured for tree height and crown base level. Destructive sampling of whole trees was performed before the treatments started during the winter of 1987/1988. Forty trees of two of the different provenances were examined (24+16). The next similar sampling is planned for the autumn of 1990 when trees within all treatments will be examined. Approximately 15 trees of each treatment will then be used. Trees of mean diameter and with 1xSD and 2xSD deviation from the mean value (greater and smaller) are sampled in numbers according to a normal distribution.

Field examinations will be made of the diameter at breast height, stem height and crown base level. The total fresh weight and number of branches on each main branch whorl will also be examined, as well as inter-node branches growing between the main branch whorls. In addition, the fresh weight of the bole is determined. Alive and dead branches are analyzed separately. One sample branch is collected from each main branch whorl as well as from the inter-node branches between each pair of branch whorls. This sample branch is weighed in the field and will represent all branches of the main branch whorl or of the inter-node branches between a pair of main branch whorls. These test branches are then examined carefully in the laboratory, while all other branches are discarded. Needle age classes c, c+1 and others are examined on all branches. For branch whorls 4, 7 and 10, all needle age classes are examined. Living and dead branch tissue are separated. Needles from the different age classes are investigated for dry weight, needle area and composition of nutrients. The dead branch wood below the crown base is examined separately.

Stem discs are collected at 10 and 130 cm level above ground and at 25, 50 and 75% relative height and at crown base level. The individual discs are investigated for volume, fresh and dry weight, dry weight content, density, sapwood area and concentrations of nutrients. An analysis of year-rings will also be performed.

Data from the destructive sampling will be used to find allometric relationships between diameter at breast height/crown base level/tree height (sapwood area in some applications) and weight of the bole, branches and needle weight, etc. (Whittaker & Marks, 1975; Nilsson, 1985). The allometric relations will then be used to quantify the same variables of the trees within the net area of the individual plots. The first sampling will also specifically answer how the two main provenances must be separated in the future sampling.

When preparing convenient samples of needles for nutrient analyses, the needles of a specific age class on similar branch whorls of all mean trees of the same provenance are put together into one sample. This creates a kind of model tree that represents the stand in terms of biomass and nutrient distribution. When determining the amount of nutrient distribution between needle age classes, as well as vertically within the crown, the total amounts of needles in a certain age class of a particular branch whorl from all investigated mean trees of the provenance are combined.

Nutrient analysis concerns the following elements: N, P, K, Ca, Mg, S, C, Mn, B, Al, Zn, Fe, Si, Na. (total N and C; ICP for other nutrients). On some occasions Cd, Cu, Mo and Ru are also investigated (AAS).

Combining biomass and nutrient content data will enable quantification of above-ground nutrient amounts on the stand level for each individual nutrient. By combining data on throughfall and data on litter fall with the above-ground nutrient storages at different points, it will be possible to quantify the above-ground nutrient flows.

Seasonal measurement programmes

Litter fall is measured on 12 occasions per year; week nos. 7, 16, 19, 21, 23, 25, 27, 29, 32, 36, 40 and 49 for all sites within the experiment. Thus 9 litter traps are used for each plot. The litter traps are placed within the net area and are emptied at the same points as throughfall water is collected. Measurements were started simultaneously on all sites during early August 1988. Except for biomass (needle and other), litter is analyzed for nutrient content on 3 occasions (litter from weeks 49-16, 16-36 and 36-49).

On selected trees within some of the treatments, especially those concerning drought, liquid fertilization and control, changes in diameter will be recorded with high time resolution at different levels of the stems and branches using dendrometers.

Leaf area index (LAI) in all plots will be estimated using the portable LAI-2000 equipment (LI-COR, cf. Lang, 1987). In the control and in one drought treatment, incident radiation (PAR 400-700 nm and short wave radiation 300-3000 nm) below and above the canopy is measured continuously. The sensor below the canopy is repeatedly moved a distance of 90 m (cross two neighbouring plots). Radiation is measured at each 1 m. Above the stand the reflected radiation is also measured. The sensors will be placed at one fixed position over a longer period. Data from the two types of measurements are stored on data loggers. The purpose of those measurements is twofold: to determine the amount of absorbed incident light and to non-destructively determine the LAI+branch and stem area of the stand. Comparison between different LAI estimations will be made using both the destructive and the non-destructive measurements.

Use of data from other sites in the testing of the hypotheses

Stem wood of Norway spruce will be utilized to investigate changes in nutrient ratios in year rings over time in relation to the soil acidification during the last century. Thus, Norway spruce of 25, 50 and 105 years of age will be utilized. Trees from the Skogaby site will be examined in a similar way. Trees of different development stages are used in order to compare trees of the same age (25-years-old) growing during different time periods.

Results from the pre-investigation

Table 1. Data on basal area, diameter breast height and number of trees at the initiation of the experiment during autumn 1987. Values within parentheses represent standard deviation between the four replicates of the same treatments except for NSD and VD which are not replicated.

Treatment/ Blocks		Diameter breast height (cm) Net area		Diameter breast height (cm) Whole plot		Basal area (m^2ha^{-1}) Net area		Basal area (m^2ha^{-1}) Whole plot		Number of trees (#ha^{-1}) Net area		Number of trees (#ha^{-1}) Whole plot
C	Control	11.4	(1.2)	11.9	(0.8)	23.8	(4.8)	25.5	(4.7)	2208	(448)	2118 (253)
D1	Drought	11.3	(1.8)	11.3	(1.7)	24.1	(6.6)	24.4	(6.4)	2205	(294)	2274 (262)
D2	Drought	11.0	(1.7)	11.1	(1.7)	24.3	(8.3)	24.6	(6.9)	2337	(195)	2358 (181)
NS	NS-fertilization	10.9	(0.8)	10.7	(0.8)	25.5	(5.2)	24.3	(4.1)	2512	(288)	2510 (391)
I	Irrigation	10.8	(1.2)	10.9	(1.1)	25.5	(5.9)	24.2	(5.1)	2640	(704)	2456 (594)
V	Vitality	11.6	(1.1)	11.6	(1.4)	25.5	(4.7)	25.6	(5.4)	2288	(403)	2215 (90)
IF	Optimum	11.4	(0.5)	11.8	(0.6)	24.3	(4.7)	24.8	(4.6)	2240	(358)	2126 (387)
NSD	NS+drought	11.2		10.5		18.5		18.4		1792		1985
VD	V+drought	10.2		10.4		23.8		20.8		2752		2321
I	7 plots	12.3	(0.4)	12.2	(0.6)	30.8	(1.7)	30.3	(0.9)	2438	(244)	2447 (203)
II	7 plots	11.5	(1.2)	11.7	(1.3)	28.0	2.0)	27.8	(1.1)	2581	(587)	2482 (482)
III	7 plots	10.5	(1.0)	11.0	(1.3)	19.1	(2.5)	21.3	(3.1)	2052	(214)	2097 (250)
IV	9 plots	10.5	(0.5)	10.4	(0.5)	21.0	(1.8)	19.6	(1.1)	2307	(345)	2150 (185)
All	30 plots	11.2	(1.1)	11.3	(1.1)	24.5	(5.2)	24.4	(4.8)	2342	(404)	2285 (330)

Data from the destructive sampling (1987/88) indicate that branch whorl 7 from the top of the tree, for nearly all investigated trees, contains the maximum amounts of needle biomass. Results from light absorption measurements show that about 95 % of the PAR (400-700 nm) radiation is extinguished when passing the stand down to the ground level. Nutrient analyses from the first investigation are not yet available.

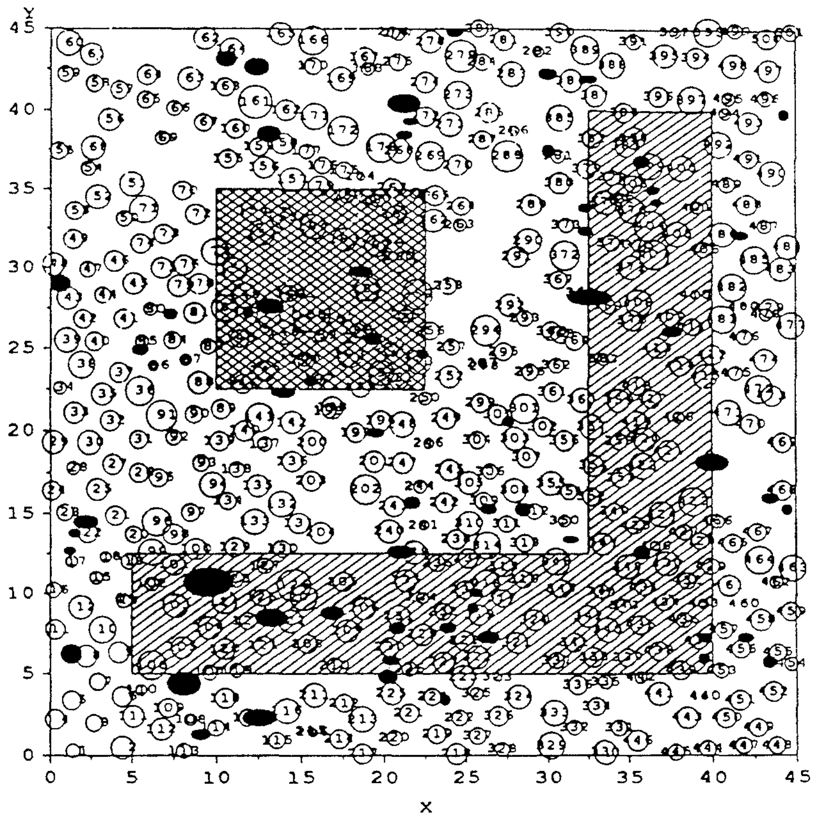


Figure 1 illustrates how an individual plot is organized. The example illustrates plot no. 25. Circles with a number show trees of varying breast height diameter, black ellipses illustrate where large stone blocks are situated. The width and length of an ellipse are in proportion to the size of a block. On the plot there is a square, which is the net plot area, and one L-shaped area, which is used for destructive sampling of, for example, whole trees. Trees within the net area define the experimental unit for the non-destructive production measurements.

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1.2 Crown morphology and its alterations

Responsible investigator

Jerzy A. Lesinski

General objective

- To describe the population diversities of tree morphology.
- To quantify how different tree morphological characteristics will be influenced by the different treatments.

Short background

Intrapopulation diversities of tree morphology may be very important for how individual trees respond to a change in environmental factors. Alteration patterns in branch and crown structures showing external symptoms of physiological disturbances will be studied for chosen morphological types of Norway spruce occurring in the Skogaby forest.

Norway spruce is known as the morphologically most differentiated tree species in Europe (Schmidt-Vogt, 1977). In any spruce population individuals substantially differing from each other appear. Studies carried out both in the laboratory and under field conditions showed that particular treatments applied to woody plants, such as fertilization, irrigation, fumigation with different chemical substances, etc., affect the morphology of the plants. The alterations in needle longevity, shoot length and tree height increment of coniferous species are much better documented than those in other morphological variables. There is a lack of experimental data on, e.g. the rate of primary shoots drying out and falling down, and on the efficiency of biomass regeneration by secondary shoots.

Hypotheses

- The treatments may result in different alterations in branch and crown structures depending on the morphological type of individual trees.

In large-scale field observations distinct links have been found between such alterations and branching habits in Norway spruce. However, this has been shown only in spruce trees more than 50 years old (Lesinski and Westman, 1989). Similar responses of individual treatments at the level of tree morphology seem to occur in a number of spruces belonging to the same morphological type. These responses may be classified qualitatively as the alteration patterns. The patterns are preferably expressed in terms of rate and distribution of shoot production, shoot destruction and shoot regeneration within the crown (lesinski and Landmann, 1988).

Field studies carried out on older spruce trees have shown that secondary (Adventitious, fire) shoots were produced more or less intensively when preceded by the loss of primary shoots (drying out, falling down when dried or when covered with needles). A sensitive indicator is the ratio between the rate of the production of primary shoots and secondary shoots. The rate and distribution within the crown of such biomass regeneration in individual trees were differentiated, even if the trees represented the same branching habits.

Hypotheses to be tested together with other subprojects

- The response of the different treatments in the annual increments of DBH is dependent on the morphological type.

The information about morphological types of all trees at the experimental field may be used in connection with other subprojects like (1.1), where the annual increments in DBH are considered for all individual trees.

Use of treatments and replicates in the Skogaby forest

All treatments and replicates will be included.

Measurement programme at Skogaby

The first stage included a complete survey of the morphological variability which was intended for making a proper choice of sample trees for further investigations. Each tree was classified using:

- crown density, i.e. distance between whorls;
- branch density, i.e. distance between shoots of the 1st order along a main axis;
- branching habit;
- needle length; and
- needle colour.

All trees in the plots were considered in the survey during autumn 1989. This first survey will be followed by a similar one after a five year period.

The aim of the second stage of the subproject will be to follow both spatial (within the crown) and temporal (within the duration of the project) alterations in the morphological structure of chosen trees. There will be five sample trees on each plot representing five distinctively different morphological types.

Variables to be measured on every chosen sample tree:

I. At each whorl	number of living branches; number of dead branches; length of each branch diameter of each branch at the stem; distance between particular whorls, i.e. tree height increment;
II. On a chosen branch from the fourth, seventh and tenth whorl, respectively	length of particular year sections, i.e. branch length increment; length of this part of branch (main axis) which is still covered with needles; number of living node shoots; number of dry node shoots; number of broken node shoots; number of living inter-node shoots; number of dry inter-node shoots; number of broken inter-node shoots; number of secondary shoots and their age, structure, form and distribution along a main axis.

These measurements will be made once a year starting in 1989 and continuing until the project is finished.

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1.3 Water relations of trees

Responsible investigator

Jan-Erik Hällgren

Co-workers

Emil Cienciala (Jan Cermak), Martin Strand, Magnus Svenningsson.

Short Background

Transpiration will be lowest in drought stressed stands followed by the control and the irrigated stands. Drought stress will cause premature needle loss. The drought stress will decrease the growth, partly due to needle loss. However, drought will also decrease growth through direct effects on cell turgor pressure and possibly by limiting carbon gain because of stomatal closure.

Hypotheses

The sap flow can be used to estimate transpiration from stands of trees and the results can be compared with independent measurements of changes in soil water storage (4.2)

- The sap flow rate measured at individual trees can be used to estimate transpiration rates from different treatments with a high temporal resolution.

Isotope ratios can be used to assess the drought stress of plants. δ C13 values are particularly useful.

- δ C13 values can be used to discriminate between drought stress and stress caused by air pollutants.

Inhibition of photosynthesis and carbon gain by drought stress has been attributed to a decrease in stomatal conductance as well as a depression of photosynthetic reactions at the chloroplast level. Measurements of chlorophyll fluorescence might be applied to assess the effects of physiological stress on photosynthesis. Measurements of predawn water potential and stomatal conductance can indicate the change of water relations in the shoots.

- A decrease in predawn xylem water potential is correlated with a decrease in maximum daily needle (leaf) conductance.
- A decrease in predawn xylem water potential is correlated with a decrease in sap flow.
- Slowly applied water stress predisposes photosynthesis to photoinhibition.

Hypotheses to be tested together with other subprojects

- Bleaching of needles is caused by photoinhibition predisposed by mineral imbalances (3.1).

Replicates and treatments used

Drought-stressed, control and irrigated plots. Nitrogen fertilization and "vitality" fertilization will later be of interest.

For the isotope ratios, the drought stress plot, No. 11, the control and the irrigated plot are used. Needles from different branches (7-9 whorls facing south) are collected from these plots, and from other plots in Sweden.

Measurement programme

Water relations in general will be followed

Continuously	predawn xylem potential (every month, fortnight and more frequently during the growing season) sap flow in stems
At campaigns	osmotic potential, xylem potential, cuticular transpiration needle conductance (assimilation rate)

For the isotope ratios, needles will be collected from different plots. Wood from stems (and branches) will be used after the trees have been felled.

During the growing season transpiration of single trees will be assessed from measurements of water flow in the conductive system. Details of the measurement programme will be planned following a preparatory study consisting of measurements of xylem flow profile in the stem:

- Anatomy; distribution of vessels with various diameters and their hydraulic and volume characteristics.
- Identification of flow profile, relative water content in the radial of stems.

To be able to scale up from one tree to the stand there are further prerequisites:

- Distribution of foliage in crowns, vertical, radial, age profiles, LAI and mass on each investigated plot.
- Determination of the so-called "solar equivalent leaf area". Data from other projects are needed.

For testing hypotheses concerning inhibition of photosynthesis, water stress sampling will begin in 1989. Dry periods during the growing season are of special interest. Sun and shade needles of at least two age classes will be investigated.

Other sites

Data from other areas, such as Flakaliden, will be complementary to these measurements. Other sites are not needed to test all the hypotheses but Flakaliden is a valuable site for testing some of the hypotheses since it has spruce trees of the same age but with different growth pattern, LAI and climate. Furthermore, this site is not subjected to high levels of air pollutants.

Other subprojects

There are a number of links to other projects related to water stress within the project.

The coupling to the water balance studies is very important since it makes it possible to compare and interpret independent estimates of transpiration and evapotranspiration valid for different scales of time and space. The coupling between soil water conditions and the corresponding water conditions in the trees are of major interest.

The linkage to canopy nutrient balances is evident. The physiological conditions of the needles are of general interest to researchers wishing to calculate ionic strength in water drops on needle surfaces. Wax properties of different age (e.g. water droplet contact angle) are of interest.

Biochemical parameters which influence the performance of insects (3.4) as well as the nutrient of needles (3.1) may be valuable for interpreting the effects of water stress on photosynthesis.

Results from the pre-investigation

Measurements in late August and mid September 1988 showed that the xylem water potential of shoots was significantly lower on the drought-stressed plots than on control plots in the afternoon. However, no effect of the drought treatment on the xylem water potential in the morning was observed.

Measurements of osmotic potential of current-year needles from the sampling in mid September 1988 indicate that osmotic adjustment as a result of the drought treatment had occurred.

2.1 Fine roots and mycorrhiza

Responsible investigator

Hans Persson

Co-worker

Hooshang Majdi

General objective

- To quantify the relationships between the soil rhizosphere and plant under stress factors such as drought, high nitrogen load and acid environment.

Short background

Widespread forest damage has been reported from most European countries and from the north-eastern United States (cf. McLaughlin 1985; Persson (Ed.) 1985; Blank et al. 1988). It is essential to resolve whether defoliated and healthy trees have different growth patterns. In particular, it is of great importance to know whether the growth pattern of the root systems is affected.

Fine-root inventories both in the FGR (Murach 1988; Ulrich et al. 1984) and in Southern Sweden (Puhe et al. 1985; Persson 1988), show less root biomass and high necromass/biomass ratios for the fine roots in stands with high needle losses (necromass = dry weight of dead roots; biomass = dry weight of living roots). The shedding of needles in this case may be an adaptation to the reduced amount of fine roots. From many field experiments (cf. among others, Ahlström et al. 1988) it is known that an increased needle mass in stands with a high nitrogen supply corresponds to a reduced amount of fine roots and mycorrhizal frequency. The soil chemistry and the degree of acidity in the soil is most important for the root-rhizosphere relationships. Forest trees with reduced or damaged below-ground parts may be more sensitive to various kinds of environmental stress (cf. Persson 1988).

Hypotheses

- Ion imbalance and increased concentrations of potentially toxic ions such as Al-, Fe- , H-ions and heavy metals, etc. in the rhizosphere cause a reduction in fine-root growth and mycorrhizal development (fine-root loss);
- A reduced water supply will cause a deeper root system.
- An increased nitrogen supply will cause a more shallow root system.
- High nitrogen deposition leads to a decreased mycorrhizal frequency.

Hypotheses to be tested together with other subprojects

Because of the mutual interest of the results from the present subproject to other colleagues within the Skogaby project, e.g. subproject 1.1, 2.2, 2.3, 4.2 and 4.3, some hypotheses will be tested jointly, viz.:

- Root damage and a decreased mycorrhizal frequency will cause a reduction in above-ground tree production.
- Cation imbalances are more pronounced in the rhizosphere than in the bulk soil solution.

Use of treatments and replicates in the Skogaby forest

Field sampling of soil cores for root excavations will be carried out once a year (during September) in the following treatments:

Treatment		Number of plots	Number of cores
C	Control	4	120
D	Drought	4	120
NS	NS-fertilization	4	120

Samplings will also be carried out on irregular occasions in the other treatments (I, IF, V, VD and VDN).

Measurement programme at Skogaby

Core sampling (diameter of the cylindrical corer = 7.2 cm in the LFH-layer and 4.4 in the mineral soil horizons) will be carried out in the C, D and NS treatments once a year (in September). Depending on how deep the core sample is driven into the stony soil substrate, it will be divided into 0-10, 10-20 and 20-V cm segments (V = 0-10 cm). No core is allowed to penetrate less than 20 cm into the mineral soil - the coring is repeated until a sufficiently deep soil core is obtained.

A complementary soil block sampling (monoliths) will be carried out every second year for the same treatments. All roots within a frame of 50 x 50 cm will then be excavated, starting with the LFH-horizon and continuing in 10 cm sections of mineral soil down to a depth of one metre.

The soil samples are stored in polyethylene bags in a deep freezer at -20°C until the final sorting is carried out. The living and dead root fragments (biomass and necromass, respectively) are sorted into the following diameter fractions: < 2 mm, 2-5 mm, 5-10 mm and > 10 mm (cf. Persson 1978; Vogt and Persson, in press). The root fragments with attached sand are excavated from the soil by dry sieving. Soil samples for chemical analyses (N, P, K, Mn, Fe, Al -both soluble and exchangeable ions) are taken from the bulk soil and from the rhizosphere soil. Chemical analyses are also to be carried out for the fine-root fraction.

Use of small-scale experiments

We intend to take part in this experiment.

Use of data from other sites in the testing of hypotheses

Extensive root data are available from a number of other sites investigated in different projects. Most of the projects have been completed and the root data have been reported and are available in open literature or in our data bank at the Department of Ecology and Environmental Research, Swedish University of Agricultural Sciences.

Results from the pre-investigations

In damaged forest stands a destabilization of root systems has been observed, viz. in four Norway spruce stands previously studied (cf. Puhe et al. 1986; Persson 1988), with varying degrees of damage in the canopy (needle loss), root damage was found in all stands (fine-root loss). Root damage was observed as a decline in the amount of living fine roots, an increase in the amount of dead fine roots, an increase in the amount of dead versus live fine roots (a higher live/dead ratio). A similar tendency was found in the results from the first year of sampling at Skogaby (the sampling was carried out during September in 1987).

Table 1. Distribution of living (biomass) and dead (necromass) fine roots (< 2 mm in diameter) at the Skogaby investigation area. Estimates are given as means ± 1 s e. The number of core samples were for the LFH-layer 49 and for the mineral soil layers, 47, 46 and 24, respectively. Diameter = 7.2 in the LFH-horizon and 4.4 in the 0-10, 10-20 and 20-V cm mineral soil horizons. The corer was driven to varying depths in the 20-V cm horizon - where V has a maximal depth of 30 cm.

Horizon	Biomass ($g\ m^{-2}$)	Necromass ($g\ m^{-2}$)	Necromass/ Biomass (%)
LFH	268±20	82±13	31
0-10	111±12	46±6	41
10-20	68±8	29±4	43
20-V	32±8	12±12	35

These results will be interpreted in relation to data from chemical analyses of the fine roots and of the rhizosphere and bulk soil. Earlier data from different stands in SW Sweden (Tables 2 and 3) indicate high concentrations of Al^{3+} in the soil solution - up to 95% of the base exchange capacity in the B2-horizon and a Ca/Al ratio < 0.05 % at Tönnersjöheden (ca 40 km N of Skogaby) in the fine roots.

Table 2. Al^{3+} expressed as a percentage of the base exchange capacity in different areas in SW Sweden (X±SD).

	Horizon		
Site	A	B0	B1
Hultåsvägen	60±14	75±13	87±6
Tönnersjöheden	70±12		86±9
Nytorp	51±8	74±11	86±6

Table 3. Ca/Al-ratio in root fragments from different areas in SW Sweden

	Hultåsvägen					Tönnersjöheden					Nytorp				
Diameter	LFH	A	B0	B1	B2	LFH	A	B0	B1	B2	LFH	A	B0	B1	B2
0-1	2.25		0.10	0.10		2.92		0.05	0.05	0.07	3.67		0.10	0.10	0.05
1-2	1.44		0.09	0.09	0.07	5.63		0.19	0.19		7.66				0.01
>2	5.43		0.30	0.30		1.32	0.12	0.18	0.18	0.03	3.87	0.58	0.16	0.16	0.08
2-5	8.44	3.79	2.71	1.17	1.00	9.30	3.76		1.47	0.91	21.21	7.28	4.85	1.58	1.44

It is obvious from these data that a Ca/Al ratio indicating root damage and Ca and Mg losses by leaching is to be expected at Skogaby. Thus, the available root data indicate so far:

- A high amount of living fine roots (fine root biomass) in the LFH-horizon (live/dead ratio = 3.2) compared with in the mineral soil (live/dead ratio 2.4);
- A high amount of dead fine roots (fine root necromass) in the mineral soil horizons LFH-horizon (66 % of the total fine root necromass in the soil profile);
- A concentration of fine roots to the LFH-horizon, compared with data from other sites (54 % of the total fine-root standing crop).

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2.2 Soil rhizosphere and nutrient dynamics

Responsible investigator

George R. Gobran

Co-workers

Stephen Clegg and a lab assistant.

General objectives

- To assess the relationship between soil, soil rhizosphere and plant under climatic stress such as drought and acidic environments.

Background

Forest decline indicated by the needle loss from three stands of Norway spruce has been reported in southern Sweden. This decline was not correlated with the soil chemistry, fine root biomass, and/or fine root chemistry (Bergholm, 1985). Relationships between soil chemistry and plant growth are complex. Unfortunately, the available information is fragmentary and incomplete. The changes in soil caused by the release of acids or bases from the surface of the roots, and the direct and indirect consequences of these changes to root development and plant uptake deserve more attention.

It must be pointed out that the acid-base chemistry of the rhizosphere is an important key factor regulating soil chemistry. Literature data clearly indicate that the cation-anion imbalance in plant absorption is responsible for the major pH changes in the rhizosphere (Nye, 1986). It is, therefore, reasonable to believe that chemical properties of the rhizosphere are more important than bulk soil properties in determining plant growth and nutrient uptake.

The cation exchange capacity of the root surface (CECR) may control the chemical composition of the soil solution and vice versa (e.g., Amory and Dufey, 1984). The CECR has been utilized in a qualitative way to explain differential uptake of mono- and divalent cations by different plants (e.g. Elgabaly and Wiklander,1949). Many investigators have reported that the relative absorption of Ca and Mg increased with an increase in the CECR. Chamucah and Dey (1982) showed that the CECR was inversely proportional to the K/(Ca) 0.5 ratio of the plant tops. Crooke and Knight (1971) demonstrated that crop yields were directly proportional to their root CEC. Moreover, the toxicity of elements such as Al (Van Cutsem and Gillet, 1983; Wacquant, 1987) was low when associated with low CECR. Calcium and/or Mg added to nutrient solution culture containing Al corrected the adverse effect of Al on the CECR of rice seedlings (Khobeis, 1984).

Hypotheses

Stress factors such as drought and high input of nitrogen and acids may cause nutrient imbalance in the soil rhizosphere.

- The bulk soil chemistry deviates from the rhizosphere soil chemistry, the latter being more representative of the nutrient conditions in the roots.
- Soil water chemistry is more related to the rhizosphere conditions than to the bulk soil.

The hypotheses will be tested in only three treatments; control, drought and NS fertilization. These treatments will exhibit very different conditions that will alter the chemistry of both soil and water. For example, acid application and drought will cause a change in the salt content in the soil solution, i.e., increasing the ionic strength. The salt may be as important as the acids. The ionic strength of solution (I) may have also an effect on total organic carbon dissolved (TOC) from forest floor.

Field measurements

The specific objectives of the field investigations are:

- to investigate the changes in soil and soil rhizosphere chemistry due to different treatments such as drought and high input of nitrogen. This work requires a close contact with subproject 4.3 for treating our results and trying to find possible relationships between bulk soil and soil-rhizosphere chemistry.
- to test the effect of the chemical changes in the soil rhizosphere on the root surface, namely, the cation exchange capacity of roots (CECR). Our common intention with (2.3) is to determine whether the CECR properties themselves affect ion uptake or whether some other property of the root is responsible and simply correlates with root CEC.
- to correlate such chemical changes to the root development and plant uptake. Our data and the data collected by (2.1) will be used.
- to simulate the relationship between the soil, rhizosphere and plant uptake. This will be undertaken in cooperation with (4.2).

Four profiles are selected in each of the three treatments. Due to the observed seasonal variations and expected changes in both soil and water chemistry, a lysimeter technique will be implemented. Soil solutions will be collected from each of the 5 soil horizons by inserting a lysimeter beneath each horizon. The total number of lysimeters needed will be 60 (4 profiles x 3 treatments x 5 horizons). Soil solution samples collected for chemical analysis will be sampled at least four times a year, i.e. during March-April, June-July, September and November. Altogether there will be 240 soil solution samples (4 x 60 lysimeters). The evaluation of these data will be made together with subproject (4.3).

Four additional profiles (4 replicates) in each treatment, close to the other three profiles will be used for soil and root sampling. In each profile, the soil horizons and plant root distribution throughout the profiles will be described. Some chemical analyses will be done in the field such as, for example, pH. Samples of soil and roots from each horizon will be collected. As to soil samples, forest floor (FF) samples will be taken using a 50x50 cm after clearing sampling points from vegetation and litter. The boundary between the FF (O horizon) and the mineral soil will be defined as the zero level. Mineral soil samples will be taken from the four sides of the profile to a depth of 100 cm. Horizons from Ah, AB, Bw and C will be divided and placed in sacks to form composite samples to represent each of the 5 soil horizons. The FF material will be sieved through a 3 mm mesh sieve and mineral soil through 2 mm mesh. Root samples will be sorted out as described by (2.1). Only the fine roots will be analyzed for chemical composition and the CECR determination.

It would be interesting to sample the soil for chemical analysis at the start of conducting our investigation (when the lysimeter will be inserted), say in July - August 89, and at about two years from the start. Altogether there will be 60 soil samples (5 horizons x 12 profiles). The number of root samples might be 50. These fine root samples will be divided into alive and dead roots.

1. Analysis of soil solution and soil extracts.
Immediately after collection of solution samples, pH and EC inorganic and organic anions and Al forms will be measured and the samples will then be frozen. Analysis of anions and organic acids will be done by HPLC using Dionex apparatus and ion exchange column. DOC will be measured by a Shimandu total organic carbon analyser (TOC 500). Aluminium specifications analysis will be done by a method described by Hanning (1988). The method is based on addition of a complexing agent, oxie (8-hydroxyquinoline) and photometric monitoring of the colour development. Cations will be measured using ICP spectrophotometry (IL Plasma 200) except for K which will be measured by AAS. Total Al, NH4 and NO3 will be measured using flow injection analysis (Tecator FIAstar). To measure total Al in the samples they will be acidified to pH 2 using HCL before analysis.

Use of small-scale experiments

The small plants are important for studies of the Calcium-Nitrogen interactions. The NS-deposition treatment would be interesting because of the high level of N and also the expected acidification. Our previous results suggest that at least three levels of Ca should be used; control, Ca/N applied=40% and Ca/N applied=80%.

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2.3 Aluminium and nutrient uptake

Responsible investigators

Susanne Widell and Paul Jensén

Co-workers

Marianne Sommarin and Håkan Asp

Background

Among other harmful effects, the acid rain releases toxic aluminium from soil particles. Al^{3+} may have detrimental effects on growth and survival of trees in Swedish forests. The decreased growth rate can partly be explained by disturbed ion uptake mechanisms (Asp et al., 1988). For example, plants that have been poisoned with aluminium usually show signs of depletion of Ca and P. Questions studied within the subproject are:

- Can plasma membranes of high purity be prepared from spruce roots as well as from needles, using aqueous polymer two-phase partition? We have successfully used this method with other plant materials, which results in a purity exceeding 90 % of plasma membrane. In the case of root preparations, can these plasma membranes be distinguished and separated from those originating from mycorrhizal fungi?
- Does aluminium affect the plasma membrane bound ATPase? If so, is the effect direct (e.g. by irreversible substitution for the magnesium that normally complexes with the ATP in the enzyme reaction) or indirect (through some other effect on the ATPase)?
- Does aluminium affect other processes at the plasma membrane, such as callose synthesis, processes that probably are involved in repair mechanisms after infection or injury?
- Can the amount of mycorrhiza in spruce roots be estimated and can a marker for the fungal plasma membrane be found?

Hypotheses

- Aluminium interacts with the mycorrhiza-forming fungi, thereby decreasing the flow of ions to the root tips.
- Aluminium at Ca^{2+}-binding sites in the cell wall induces Ca deficiency.

Results from the pre-investigation

1. Plasma membrane purification

We have developed the phase partition method for plasma membrane purification so that it now is suitable for spruce roots as well as needles. This separation method is based on differences in surface properties of the subcellular components (when the plant material is homogenized, the individual membranes are disintegrated and they immediately form vesicles). So far, we have mainly worked with uninfected roots, and hence not tried to separate the fungal plasma membrane from that of the host.

2. ATPase studies

We have studied plasma membrane bound ATPase; an enzyme that upon ATP hydrolysis transports protons across the membrane, thus creating an electric gradient, which is the driving force for uptake of ions, e.g. potassium. Liberated phosphate is determined spectrophotometrically by complexation to a molybdate reagent. Initially, we had trouble with too high backgrounds, but the assay now functions well, even when the amount of plasma membrane is low. Analyses have been made both on spruce cultivated on sand and in nutrient solution, with and without 1mM aluminium for an increasing number of weeks. The plants in nutrient solution 1 mM Al^{3+} have a stimulating effect on the ATPase. In these experiments we have not separated fungal plasma membranes from spruce plasma membranes. Hence, we do not know the contribution of fungal plasma membrane ATPase in our study. However, a stimulated plant ATPase agrees well with the result that 1mM Al^{3+} also stimulates the transport of potassium from the root to the shoot (Asp et al., 1988). Before final conclusions can be drawn we need to study if Al^{3+} leads to an altered proton pumping capacity (which we routinely measure in other research projects), since this is a more direct measure of ion transport capacity than the ATPase activity.

3. Fungal ATPase

In a separate study, we have isolated plasma membranes from fungal fruitbodies, and studied the effect of Al^{3+} on the ATPase (both during cultivation and in the ATPase assay). No effect has so far been seen, partly due to experimental problems, but the analyses will continue. The fungi so far used have been mushrooms and Hebeloma.

4. Effect of Al on the Ca uptake and extrusion

This part of the work has only recently been initiated. It is probable that the Ca-uptake (which is passive) is lowered when the cell wall, which functions as an ion exchanger, has been developed in Ca. The plasma membrane bound CaATPase (which regulates Ca extrusion) will also be examined.

5. Effect on callose synthesis

During the development of a procedure for plasma membrane purification, these membranes have been identified by the presence of glucan synthase II. This is an enzyme involved in callose biosynthesis, which seems to have its sole location in the plasma membrane. It has repeatedly been seen that Al^{3+}-grown spruce has a lower glucan synthetase II activity compared with control plants. We need to check whether the effect is an interaction with Ca^{2+}-binding sites in the assay system (Ca^{2+} is used to activate the enzyme), or if the enzyme is damaged in another way upon Al treatment. A lowered glucan synthetase II activity could be serious, since the plant then probably would have a lower repair capacity.

6. Determination of the degree of mycorrhiza

This can be performed in two ways, both based on the fact that the fungal cell wall contains chitin in contrast to the plant cell wall. Firstly, the amount of chitin can be determined after hydrolysis and spectophotometrical determination of the free glucosamine. This procedure is preferable when whole roots are studied. Secondly, chitin synthase localized in the fungal plasma membrane can be assayed for, thereby giving an estimate of the content of fungal plasma membranes in the plant plasma membrane preparation. This is necessary since when purifying plant plasma membranes from infected tissue, fungal plasma membranes could very well be co-purified. Both projects have recently started.

Plans for the future

In principle, the project sketched above will continue. Preparations will be made on spruce given different aluminium treatments and cultivated on sand as well as in nutrient solution. We feel that the enzyme assays (e.g. ATPase and glucan synthetase II) function well. After we have solved the problem of how to identify fungal plasma membranes, samples from Skogaby can be collected. We will thus extend our experience from the laboratory to the field. One major problem in this context is to estimate the degree of frost hardiness of the spruce in the forest at different times of sample collection, since the ATPase activity increases upon frost acclimation (Hellergren et al., 1983) . This part of the work will involve parallel experiments in the laboratory, using frost acclimated as well as non-acclimated spruce given different Al^{3+} supplies.

Since we now have a sensitive method for determination of the ATPase, we can probably also measure another ATPase in the plasma membrane, e.g. the one responsible for pumping Ca^{2+} out of the cell. This CaATPase is very important, since an effective Ca transport out from the cytoplasm is a prerequisite for regulating many cellular processes.

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3.1 Nutrient status and surface structure of needles.

Responsible investigator

Bengt Nihlgård

Co-workers

Ulrika Rosengren

General objective

- To study the effects of drought, nitrogen and mineral nutrient fertilization with and without additional water on the nutritional status and some structural characteristics, especially the cuticle structure of spruce needles.

Short background

Air pollution can be expected to have both direct and indirect effects on the nutritional status of spruce needles. Gaseous air pollutants cause direct effects by affecting the wax layer of the cuticle and cell membranes. They can also affect the nutritional status of the needle by uptake or leaching of mineral substances through stomata or through the cuticle. These effects can speed up the process of ageing and make the tree more susceptible to climatic stress and attacks by pathogens. It might also bring about an enhanced leaching of nutrients from the forest canopy.

Indirect effects of air pollutants are caused by deposition of nutrients, especially nitrogen and acids (H_2SO_4, HCL, HNO_3) on the soil. These substances change the nutritional status of the soil and thereby the efficiency of nutrient uptake by roots. Aluminium toxicity might occur due to a decreased pH of the soil solution. Fine roots and mycorrhizal activity might be negatively affected by aluminium and heavy metals released by soil acidification. As a result the nutritional status of the needles will be changed. The soil nutritional status can be improved by adding different fertilizers to the soil and thereby improving the nutritional status in the needles. This in turn is expected to make the trees more resistant to stress situations.

Hypotheses

As one basic stand-point we think that the nutritional status of spruce needles can be altered by air pollutants by their direct uptake or leaching through the needle surface (Turkey, 1971). Hypotheses to be tested in the laboratory and in the field experiment (mainly the small plant experiment) are:

- The mineral nutrient balance can be changed by uptake of nitrogen substances, especially ammonium, through the leaf surface.

- The mineral balance in the needles may also be changed by leaching of K, Ca, Mn, Zn and Mg from the canopy.

Deposition of air pollutants on the needles damages the cuticle (Kahru & Huttunen, 1986), leading to enhanced leaching of nutrients (Mengel et al., 1987). The needles will also be more prone to frost damage and attacks of specific pathogen species. Hypotheses to be tested mainly from the full-scale experiments are:

- Needles with a higher frequency of structural cuticular damages will have a poorer nutritional status compared to healthy needles.
- Nutritional imbalance will increase the number of fungi attacks of specific species.
- Branches where needles have impaired structure of the cuticular surface and with a nutritional imbalance will show higher frequency of damages caused by frost.
- Improvement of the nutritional status in the needles will lower the needle loss.
- Trees exposed to drought stress will show a different distribution pattern of pathogenic needle fungi compared to trees in the control and irrigated plots.

A third basic standpoint is that deposition of air pollutants on the ground will affect the nutrient content of the soil and partly root growth, whereby the uptake of nutrients through the roots will be affected. The relationships between nitrogen and other nutrients are especially changed. The result of these effects will be detected in the nutrient content of the needles (Hüttl, 1985) and our hypotheses, to be tested both in the full-scale and in the small plant experiments are:

- The nitrogen content of the needles is increased during the first years by a high input of ammonium sulphate to the soil.
- After some years phosphorus or magnesium will limit the nitrogen content of the needles in plots with a high ammonium sulphate input.

Hypotheses, to be tested together with other subprojects

- Temporal patterns of concentrations of air pollutants in the field are correlated with similar patterns of damage symptoms on the needle surfaces (4.1).
- There is a correlation between the mineral balance in the needle and/or a damaged cuticle and leaching from the canopy (3.2).
- The cuticular transpiration is affected by the mineral balance in the needle and/or by a damaged needle surface (1.3).
- The nitrogen uptake from the roots, and consequently the nitrogen content of the needles, is negatively affected by air pollutants due to enhanced soil water leaching, or by precipitation of phosphates and molybdates due to soil acidification (4.3).

Use of treatments and replicates in the Skogaby forest

All treatments and replicates will be used

Measurement programme at Skogaby

	Samples taken in July, September & April			Samples taken in February			
	plots	trees	age classes	plots	trees	age classes	Samples/ yr
Treatments	(#)	(#)	(#)	(#)	(#)	(#)	(#)
C	4	3	2	4	3	3	108
D1	4	2	2	4	2	3	72
D2	4	2	2	4	2	3	72
NS	4	3	2	4	3	3	108
V	4	3	2	4	3	3	108
A				4	3	3	36
I				4	3	3	36
IF	4	3	2	4	3	3	108
NSD				1	6	3	18
VD				1	6	3	18
Total							684

The trees have been selected on the basis of tree diameter in the border area between the net plot and the destructive zone. At each sampling a six meter long ladder is used to reach the branches in order to climb the trees. Care is taken not to damage the tree while climbing. Branches from the 7th whorl pointing west-south-west are selected as this is the main wind direction. Only nodular shoots of the 2nd and 3rd order are used in the sampling.

The samples are taken into the laboratory and the surface structures of the needles are analyzed visually in a microscope (x10 and x30) within 10 days. The variables on the needles that are being studied microscopically are colour, length, mass needle loss, frost damage, fungi and insect attacks, growth of green algae (Pleurococcus vulgaris), necrotic flecks and cuticle erosion. Needles are taken from each sample for chemical analyses of the following elements: N, P, K, Ca, Mg, S, Na, Mn, Fe, Al, Sr, Cu, Zn and B.

Use of small-scale experiments

A. Small-scale field experiment

It is very difficult and costly to control environmental factors valid for mature trees and even for 25-year-old spruce trees. This especially applies to wet and dry deposition. Much information could be gained by setting up a small-scale experiment using two-year-old spruce plants at the same locality. The soil can be treated before planting to achieve a specific pH or nutritional status. With a larger number of plants it is possible to use destructive sampling, and by using cloned spruce plants the number of samples needed to obtain an acceptable variance could be reduced. The same treatments as in the full-scale experiment should be used. It is also possible to add treatments where dry and wet deposition are varied, and the root environment is changed (pH and nutritional status). This would enable interesting comparisons to be made between the full-scale experiment and the plant experiment.

B.Laboratory experiment

- Effects of UV-light on cuticle erosion and structural damage.

The cuticle is important in protecting the underlying structures from being damaged by UV-light. But UV-light can severely damage the fibrillous wax layer so that it might be less efficient in absorbing the hazardous light. Once the UV-light has entered the cell it can disturb different metabolic processes and thereby cause various structural changes. The general objective is to study whether UV-light plays a major role in forming visible structural damage on the needle surfaces.

- Is there a difference in uptake efficiency of NO_3^- and NH_4^+ by the needle?

Several throughfall studies have indicated a difference in uptake efficiency between different nitrous compounds. It seems that NH_4^+ has a higher uptake efficiency than NO_3^-. The general objective is to determine whether $(NH_4)_2SO_4$ and $Ca(NO_3)_2$ are taken up through the needle surface, and whether this uptake affects the nitrogen status in the needle. The effect of acid rain and different soil conditions on the uptake efficiency will also be studied.

Use of data from other sites in testing the hypotheses

Sampling on other sites must be restricted to those where field experiments similar to ours are being performed, so that controlled and affected sample plots might be compared. This means that samples also may be taken from Asa in Småland and from Flakaliden in northern Sweden. To some extent this variation might also illustrate the effects of different regimes of air pollution.

Results of the pre-investigation

Results of the preinvestigation during the first year have revealed that the nutrient concentrations in the needles seem to be above the deficiency levels (Table 1). However, the phosphorus and potassium contents are too low in relation to nitrogen and the micronutrients zinc, copper, and boron are just above the deficiency level. Single trees reveal deficiencies in phosphorus especially but also in potassium and, in some cases, calcium. Magnesium, on the other hand, seems to be sufficient in all trees. When the nutrient contents of fifth and eighth branch whorls are compared, nitrogen (*), phosphorus (*) and potassium (**) turned out to be significantly higher on the fifth whorl, whereas calcium (***) and magnesium (***) are significantly higher on the eighth whorl of branches. Nitrogen, phosphorus and potassium are easily movable within the tree, compared to calcium, and can therefore be transferred to the active growing parts. This does not explain why magnesium, which is also easily movable, is higher in the lower part of the canopy. The levels of nitrogen, phosphorus, potassium and magnesium are highest in current year needles, whereas the calcium content is low in current year needles but increases as the needles grow older. This pattern is consistent with results revealed in earlier studies of nutrient status in spruce needles.

The structural damage on the needle surface increases significantly with needle age from one to five years of age (Fig. 1). As can be seen in Fig. 2, chlorotic flecks occur on current year needles but the damage gets worse in older needles. During the sampling period July - June 1988 different types of structural damage developed on current needles (Fig. 3). This is especially the case concerning growth of green algae on the needles. No differences between branch whorls 5 and 8 could be found in these parameters. When the trees are exposed to stress (drought, nitrogen deposition, etc.), the vitality of the trees might be impaired and when they get sufficient water and nutrient supply their status is expected to improve. As the trees grow older the effects of the nutritional status of the soil are also expected to become more apparent.

Samples taken in February 1988

Needle year class	N (mg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	K (mg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	P (mg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	Ca (mg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)
C	17.16	(2.00)	16.03	(1.97)	5.54	(1.52)	5.14	(1.32)	1.43	(0.28)	1.37	(0.22)	2.22	(0.92)	2.60	(1.04)
C+1	15.31	(1.84)	14.75	(1.77)	4.58	(1.01)	4.10	(0.98)	1.30	(0.23)	1.22	(0.18)	2.47	(0.96)	3.20	(1.43)
C+2	13.51	(1.53)	12.76	(1.69)	4.23	(0.79)	3.73	(0.88)	1.10	(0.14)	1.06	(0.16)	2.81	(1.33)	3.57	(1.62)
C+3	12.21	(1.73)	11.42	(1.41)	4.23	(0.96)	3.54	(0.81)	1.05	(0.18)	0.94	(0.17)	2.49	(1.03)	3.09	(1.62)

Needle year class	Mg (mg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	S (mg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	Na (µg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	Mn (µg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)
C	1.25	(0.21)	1.26	(0.25)	1.25	(0.19)	1.19	(0.17)	189	(146)	161	(108)	858	(327)	1022	(490)
C+1	1.09	(0.22)	1.28	(0.22)	1.33	(0.17)	1.26	(0.17)	276	(181)	220	(172)	917	(382)	1181	(584)
C+2	1.09	(0.29)	1.27	(0.27)	1.31	(0.19)	1.24	(0.18)	372	(274)	295	(232)	1008	(541)	1211	(625)
C+3	0.99	(0.24)	1.08	(0.24)	1.31	(0.21)	1.21	(0.21)	475	(330)	428	(327)	827	(432)	1012	(514)

Needle year class	Fe (µg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	Al (µg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	Zn (µg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	B (µg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)
C	53	(10)	55	(19)	127	(35)	117	(32)	28	(8.1)	32	(9.1)	41	(10)	41	(15)
C+1	60	(9)	60	(12)	201	(59)	163	(62)	21	(5.7)	28	(12.6)	40	(12)	38	(12)
C+2	57	(9)	54	(8)	251	(73)	195	(72)	20	(6.9)	25	(9.8)	42	(15)	38	(13)
C+3	58	(11)	54	(8)	299	(84)	248	(87)	18	(5.8)	24	(8.8)	37	(14)	39	(11)

Needle year class	Cu (µg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)	Sr (µg/g) 5:th whorl mean	(SD)	8:th whorl mean	(SD)
C	2.3	(0.5)	2.4	(0.7)	3.3	(2.0)	5.4	(2.8)
C+1	2.4	(0.6)	2.2	(0.3)	4.3	(2.3)	7.4	(3.4)
C+2	2.0	(0.3)	2.0	(0.4)	5.0	(2.5)	8.1	(3.2)
C+3	1.8	(0.4)	1.8	(0.3)	5.1	(2.0)	7.7	(2.7)

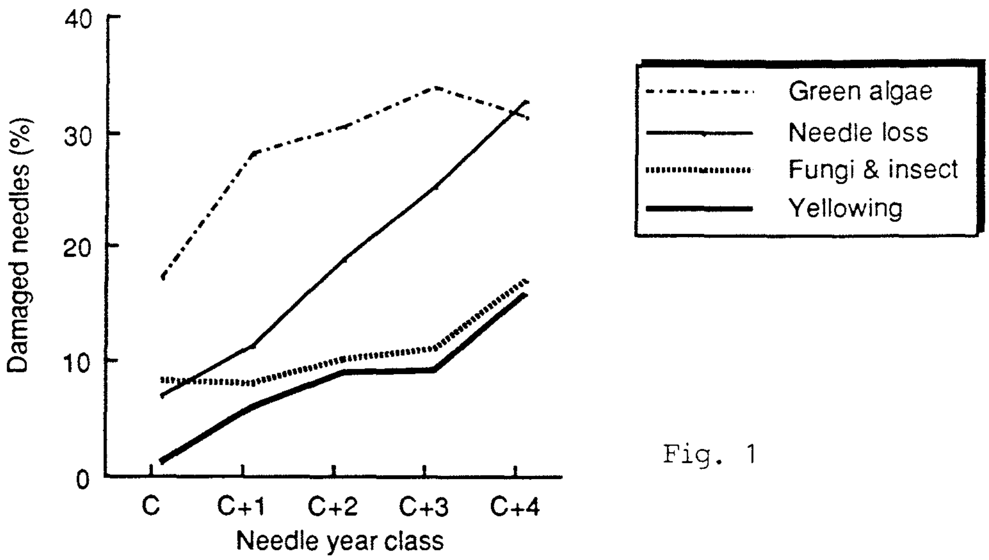

Fig. 1

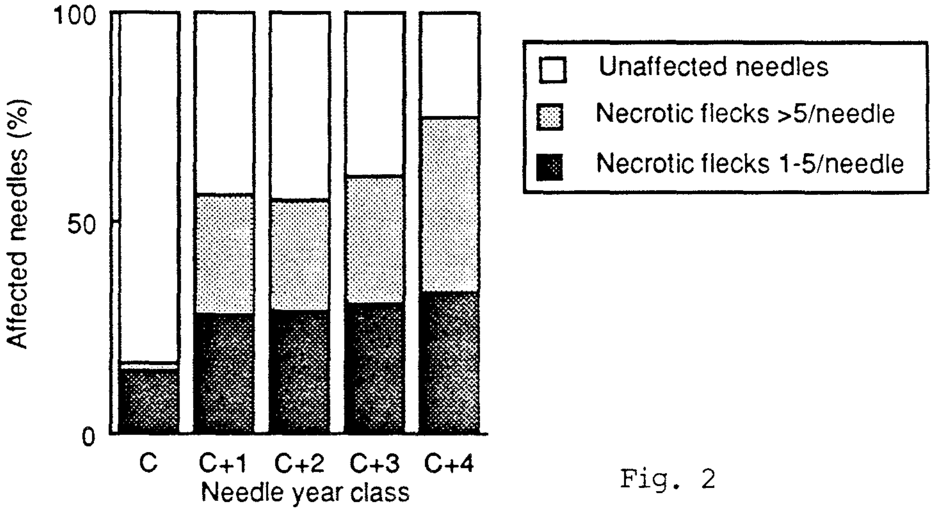

Fig. 2

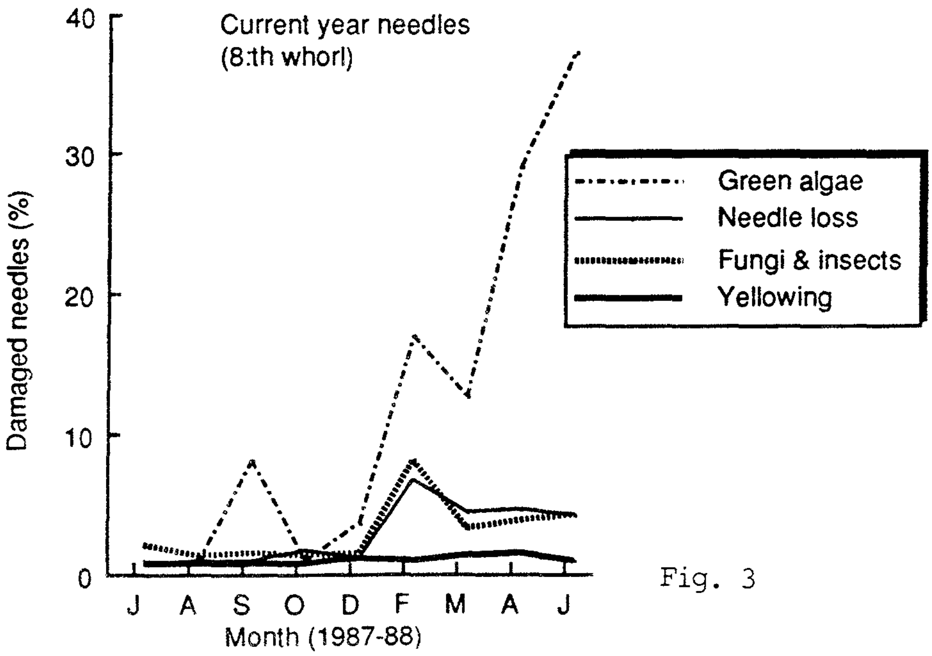

Fig. 3

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3.2 Canopy leaching of minerals

Responsible investigator

Lennart Folkeson

Co-worker

Kurt Olsson

General objective

- To quantify the influence of treatments on the leaching of minerals from the canopies.

Short background

Direct deposition and root uptake are the two principal pathways of mineral uptake into the foliage. The incorporation of minerals from the deposition is largely dependent not only on the concentrations of minerals in the wet and dry deposition but also on its acidity and overall chemistry. The structure and condition of the leaf surface as well as the nutrient status of the tree greatly affect the incorporation.

The root uptake of minerals, differing greatly between elements, is governed by the requirement and availability of nutrients, the condition of the root system including the function of the mycorrhizal structure, and the chemistry of the soil, including acid-base properties. The water factor and the condition of the whole tree also considerably influence the mineral uptake.

Throughfall comprises a major pathway of mineral transfer to the forest floor. It thus constitutes a significant part of the flux of minerals in a forest ecosystem. Throughfall chemistry is largely influenced by biotic factors like the condition of the leaf, the nutrient status of the foliage and the activity of consumers and pathogens. Enhanced leaching of some minerals has been shown to occur from canopies of injured conifers. Throughfall chemistry also varies greatly with the load of pollutants. Soil chemistry, especially soil acidity, also greatly influences the throughfall chemistry.

Stemflow water is usually very limited in volume in Norway spuce. Due to high concentrations of many elements, however, a significant transport of minerals will take place. Stemflow should therefore be included in the mineral budget of the stand.

An increase in the solubility of nutrients like K, Ca, Mg, Mn and Zn in acidified forest soils may facilitate the root uptake of these nutrients. On the other hand, the increase in solubility also enhances the loss of minerals from the forest soil. This poses a great risk of nutrient deficiency in forest soils that are originally poor in nutrients. Furthermore, toxic metals, being mobilized in acidified soils, form an additional problem, especially since they impair the function of the mycorrhizal fine roots.

Injured forest trees on acidified soils have been shown to suffer from an imbalance in their nutrition. Nitrogen, currently deposited in more than sufficient quantity in some areas, is of crucial importance in this connection. All these processes influence the flux of minerals in the throughfall, stemflow and litterfall.

All of the treatments in the Skogaby experiment may potentially alter the soil chemistry, the uptake efficiency of the roots, the transport of elements into the canopies and the nutrient status of the foliage. Studies on the subsequent changes in the flux of elements in throughfall, stemflow and litterfall will be limited to the NS, V, D, NSD and VD treatments.

Hypotheses

- The NS treatment will increase the canopy leaching of most elements, especially N, S and acidity-sensitive metals.
- The vitality fertilization will reduce the leaching of elements.
- Drought stress (which is expected to hamper the uptake of water and minerals) will reduce the canopy leaching of elements. This effect will be of limited duration, gradually ceasing if new roots are able to explore deeper soil layers.
- Drought stress following ammonium sulphate treatment will accentuate the increase in the canopy leaching of elements.
- The reduction in canopy leaching of elements in the vitality fertilized plots will not be influenced by the drought treatment that is to follow.

The time scale will be very different for the different responses to develop.

Hypotheses to be tested together with other subprojects:

- An aggravation in the nutrient imbalance of the foliage will increase the canopy leaching of elements (1.1 and 3.1).
- Injuries to the cuticle will increase the canopy leaching of elements (3.1).
- The flux of elements in the stemflow (as well as the throughfall and litterfall) of a tree with visible symptoms of injury is greater than from a healthy-looking tree (1.1 and 1.2).
- The temporal variation in air quality will be mirrored by the concentrations of air pollutants in bulk deposition, throughfall and stemflow (4.1)
- The canopy leaching of elements is elevated in trees where the function or vitality of the roots/mycorrhizal structures is impoverished (2.1).

Use of treatments and replicates

Treatment		Replicates
C	Control	4
D1	Drought 1988-1989	4
D2	Drought 1990-1991	4
NS	Nitrogen fertilization	4
V	Vitality fertilization	4
NSD	Nitrogen followed by drought	1
VD	Vitality followed by drought	1

Measurement programme

Throughfall and litterfall measurements

Treatments		Repli-cates	No. of funnels and bottles per plot	Total number of units	Total no. of samples for analysis	Total no. of snow collectors and samples
OF	Open field	1	4	4	4	2
C	Control	4	3+3	24	8	8
D1	Drought 1988-89	4	3+3	24	8	8
D2	Drought 1990-91	4	3+3	24	8	8
NS	Nitrogen	4	3+3	24	8	8
V	Vital. fertiliz.	4	3+3	24	8	8
NSD	NS+drought	1	3+3	6	2	2
VD	V+drought	1	3+3	6	2	2
Total				136	48	46

Stemflow measurements

Treatments		Replicates	No. of trees per plot
C	Control	2	1
D1	Drought 1988-89	2	1
NS	NS fertilization	3	1
V	Vitality fertilization	3	1
Total			10

Sampling schedule:

Open field samples are taken every week. Throughfall, litterfall and stemflow as given below.

Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Week		49		7		16	19 21 23	25 27	29	32	36	40
Duration (weeks)		9		10		9	3 2 2	2 2	2	3	4	4

Open field (bulk precipitation): four 20 cm diam. polyethylene funnels with PE sieve holes, 2 mm diam., 10 l shaded PE bottles placed in a c. 2.5 m high tower in a clear-cut area. Samples are taken during the whole year and treated individually.

Throughfall and litterfall: 20 cm diam. funnels with sieves, 5 l bottles, all year. Baskets with PE bags for snow collection during winter. Random distribution in plot > 5 m from outer plot border and from area of destructive tree sampling; >7 m in drought plots and plot parts facing drought plots; in plots 81 and 161 distance is >6 m. Location outside net plot except for plots 82, 111, 112, 162, 231 and 232. In each plot, the six bottles are pooled three and three. Litter is collected from the funnels when emptied. Snow samples are treated individually. Qualitative and quantitative (area-related) measurements are made.

Stemflow: randomly selected mean-diameter (± 0.5 cm) trees (in net plots) equipped with collectors made of polyurethane foam coated with silicon glue, PE funnels with sieves, 5 l PE bottles.

Total number of analyses per period: 4 bulk precipitation (open field) + 44 throughfall + 10 stemflow + occasionally 46 snow samples. Litter samples pooled to three composite samples per year.

Analyses:

conductivity, pH, DOC, Cl, NO3, NH4, S, P, Na, K, Ca, Mg, Mn, Fe, Al, Sr, Rb, Cu, Zn, Cd and B.

Use of data from other sites in the testing of hypotheses

A body of throughfall, stemflow and litterfall (and soil leachate) data is available from a recently completed project where spruce stands were compared with nearby beech and birch stands in Skåne. Starting in 1989/90 another set of throughfall data will be produced in a nitrogen-fertilization project in a beech stand in Skåne (Maglehem). From FRG (and Scandinavia) throughfall data are published from sites with varying loads of acidifying substances.

3.3 Nitrogen and sulphur metabolites in the needles.

Responsible investigator

Jan-Erik Hällgren

Co-workers

Gunnar Wingsle, Torgny Näsholm, Ann-Britt Edfast, Anders Ericsson, Martin Strand and Stig Larsson.

General objective

- To find out whether the treatments give general changes (accumulation or storage) in metabolites of sulphur and nitrogen metabolism and to investigate whether it is possible to find indicators that separate drought stress from air pollution stress.

Hypotheses

- Certain amino acids (arg) can be used as indicators of imbalance in the metabolism of nitrogen in needles.
- Certain substances can be used as indicators of stress caused by drought and air pollution, directly or indirectly (e.g. proethylen, GSH and SOD).

Other subprojects

Connections obvious to most other programmes where biochemical changes are of interest. It may be of interest to use amino acids and protective substances in testing hypotheses in connection with insect attacks.

Treatments used at Skogaby

The drought-stress plot, the control and the irrigated plot at Skogaby are used. Fertilized plots and acidified plots will be of interest. Needles from different branches are collected from these plots, and from other plots in the country.

Measurement programme

Needles will be collected from different plots at Skogaby, immediately killed in liquid nitrogen and analysed for "indicator" substances. The measurement programme is linked with analyses made in collaboration with insect studies.

3.4 Suitability of stressed trees as food for herbivorous insects.

Responsible investigator

Stig Larsson

Co-worker

Christer Björkman

General objective

- To compare the response in performance (survival, fecundity, growth rate) of insects with different feeding habits (feeding guilds) to stressed trees, in order to give more precise predictions about the risk of insect outbreaks in stands under environmental stress.

Short background

It is often assumed that insects are favoured by stressed trees. Two types of arguments are used in support of this hypothesis: (i) Data exist showing that there is a tendency for outbreaks of certain insect species to occur in stands of low vigor. (ii) Stress can induce changes in tree biochemistry that may lead to improvements in insect performance. A major problem with the first type of evidence is that fluctuations in insect numbers can be caused by a multitude of factors, and it is therefore difficult to determine the extent to which tree stress alone was responsible for a given outbreak (Larsson, 1989a). A more proper way of testing if insects are favoured by stressed trees would be to study insect responses in controlled experiments. In recent years, a number of studies have been carried out in which the performance of individual insects has been monitored on experimentally stressed trees. There is surprisingly little support for the stress hypothesis in its present, generalized form (Larsson, 1989b). However, data indicate that the response of insects belonging to different feeding guilds may vary; certain insect groups seem to be more favoured by stressed trees than others. If such patterns can be identified we will be in a better position to make specific predictions about the risk for insect outbreaks in stressed stands.

Hypothesis

- Among four feeding guilds, responses to drought stress are predicted to vary in the following manner: sucking insects > mining insects > chewing insects > gall-forming insects.

Hypotheses to be tested together with other subprojects

The mechanisms behind observed responses are to be found in increased concentrations of soluble amino acids and a concurrent increase in concentrations of secondary compounds in stressed trees. The increased concentrations of secondary compounds can be explained by different sink:source ratios. Data required to test these hypotheses include needle concentrations of soluble amino acids and of secondary compounds (resin acids and phenolics), and biomasses of needle fractions. Our approach hinges on a treatment effect on tree physiology. Thus, it is necessary that basic physiological parameters (e.g. water potential, stomatal conductance, photosynthetic capacity) will be monitored in enough detail. However, this cannot be carried out within this subproject.

Use of treatment and replicates at Skogaby

Initially we will use two drought-stressed plots (8 and 16) and two control plots (3 and 15). Depending on the results the programme may be expanded to include other plots and/or other treatments in the future.

Measurement programme at Skogaby

Insect response to tree stress will be evaluated from data on performance (survival, reproduction, growth rate). Insects will be raised in mesh bags on branches in the lower third of the crown (chewing and sucking insects), or will be collected when spinning to the ground for hibernation (miners). Mesh bag experiments will be carried out during May-July and collections of miners during October-December. In collaboration with other subprojects, needle samples will be taken (from the lower third of the crown) on two occasions (June and September) for analyses of soluble amino acids, carbohydrates, resin acids and phenolics.

Use of small-scale experiments

This approach may be of interest if we decide to look for mechanistic explanations of observed responses.

Results from the pre-investigation

Aphids were introduced into mesh bags on single branches and allowed to reproduce during six weeks in early summer on control plots and drought-stressed plots. Because the treatments had not started at the time for the experiment we do not expect any effects on insect performance. The study was meant as a test of the method of introducing aphids into caged branches, and if possible, as a pre-treatment documentation of aphid performance. The data are not yet analyzed in detail, but the results do show that the method seems to be reliable. Sampling of larvae of the spruce needle miner (*Epinotia tedella*) started in mid October. The method of collecting larvae spinning to the ground for hibernation seems to work as planned. So far, data do not indicate any differences between treatments with respect to miner performance.

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4.1 Climate and air pollutants

Responsible investigator

Per-Erik Jansson

Co-workers

Gunnel Alvenäs
Gun Lövblad

General objective

- To quantify the climatic factors of importance for forest growth.
- To monitor the chemical composition of the air, including the most important air pollutants at an open area.
- To estimate the dry deposition of S and N by using the measured data.

Background

The chemical climate may be equally important as the physical climate as a factor governing biological production. Unfortunately, the chemical climate cannot be measured using the simple standard technique that can be used for measurement of most physical variables. To provide the project with the most important information about air quality, a measurement programme has been started in collaboration with the Swedish Environment Research Institute (IVL).

Hypotheses

- The data on the air composition can be used as input to rough empirical calculations of deposition of S and N as functions of air concentrations, needle surface, aerodynamic resistance and transpiration rate.

The throughfall measurements (3.2), which include both dry and wet deposition, nutrient uptake and leaching from the foliage, will provide information complementary to the estimate of dry deposition. The collection of water from the drought treatments may be used to separate dry deposition from the net effect of canopy leaching and uptake of nutrient.

Measurement programme

A climatic station for measurements of the most important meteorological variables has been in operation from the autumn of 1987. The station was moved to an open area also suited for measurements of ozone in June 1988. The automatic recording system include the following variables, all stored as hourly mean values in a data base:

- Air temperature
- Air humidity
- Wind speed
- Wind direction
- Precipitation
- Global radiation
- Soil temperature (5 and 50 cm depth)
- Ozone concentration

Air temperature, air humidity and precipitation are also measured with conventional meteorological devices in addition to the automatic recording system. These values will be used during periods of malfunction in the automatic system. Precipitation is also measured on a weekly basis using gauges installed at the soil surface in two different plots in order to find gradients in the precipitation pattern over the whole site. In the winter, snow surveys will be made to estimate the spatial pattern in the stands and for estimations of total amounts of snow precipitation.

The soil temperature conditions are also measured in two plots with drought treatments, both in the area covered by the roof and in the uncovered area. The temperature sensors are installed at 5, 15, 30 and 70 cm depth and they are automatically read every 30 seconds and stored as hourly mean values with a similar system as used for the climatic station. In addition, soil temperature is measured with the soil moisture meter described below.

A detailed study of the throughfall will be made in the drought treatments (see also 1.3). The water that has been prevented from infiltration into the soil is collected in large tipping bucket units which are connected to a data logger and also read manually on a mechanical counter. These large and relatively precise measurements of throughfall will be of importance for the water balance estimate but they can also be useful for separating the influence of dry deposition from leaching.

The only chemical entity that can be recorded automatically (as made with climatic variables) is the ozone concentration. For the other gases and particles we are collecting samples with the filter technique used in a standard air quality station according to the recommendations from IVL. To minimize the cost of analyses and to get a similar resolution as for the throughfall measurements, we have decided to make analyses of weekly periods using daily samples.

The following elements will be analyzed:				
SO_2	SO_4	NO_2	NO_3	NH_4

4.2 Hydrology

Responsible investigator

Per-Erik Jansson

Co-workers

Monica Andersson

General objective

- To quantify the water balance with a daily resolution in the different treatments.

Background

The physical climate is the governing force for all biological production. We still lack good quantitative understanding of how biological processes interact with the physical processes in forest ecosystems. The principles and the mechanisms for the physical processes are known but uncertainties still exist about how they influence basic biological processes such as transpiration and photosynthesis. The system is also quite complicated since these biological processes will have feed back on the climate both within the forest canopy and in the soil.

Hypotheses

- The increased leaf area of a highly productive stand will cause higher evaporation and transpiration rates leading to drier soil moisture conditions.
- The occurrence of climatic stress, i.e. a high atmospheric demand of water in combination with a low availability in the soil, will increase in highly productive stands.

Hypotheses to be tested together with other subprojects

The climatic data will be used as a background when interpreting how different biological processes vary with time and between treatments. The measured climatic variables will be used as driving variables in the tree growth modelling and the calculated soil water flows will be used to estimate fluxes and leaching of chemical constituents measured in the soil solution. More specifically, we would like to test hypotheses about:

- Higher water use efficiencies will be found for trees at a good nutritional balance.

This would be possible to test by comparing the measured dry matter production (1.1) with the estimated transpiration rates. The time resolution will be low (year) because of uncertainties in short-term estimates of transpiration and the infrequent sampling and measurements of biomass. The between-year variations and the drought treatment will be of major interest.

- The climatic stress during winter and early spring may lead to injuries on needles during some winters.

The period in late winter and early spring will be of special interest since climatic stress may occur during conditions with a low availability of soil water because of frost or low temperatures in the soil. Injuries observed on the needles (3.1) and the corresponding measurements of water potentials and stomatal conductance (1.3) will be interpreted together with climatic data and the measured soil temperatures. Substantial variations are expected in soil temperature and climate between years which make it possible to correlate the climatic conditions with the corresponding pattern of injuries observed on the needles.

- The annual course of transpiration rate will be much more pronounced than the corresponding annual course of evaporation rate.

Throughfall will be measured both in (3.2) and by the measurements of all water which is redirected from infiltration into the soil in the drought treatments. This will give as good estimates of interception losses (evaporation direct from the surface water on the needles). The intercepted amounts and evaporation losses will be related with climatic variables and information about total leaf area and corresponding measurements of radiation interception.

Use of treatments and replicates in the Skogaby forest

All treatments and replicates will be considered but emphasis will be placed on different plots depending on measurement technique and expected effects of the treatments (see further details in the section of measurement programme).

Measurement programme at Skogaby

Soil moisture conditions are measured using three different approaches:

1. Sampling of the surface layers in transects covering large areas down to 20 cm depth. Gravimetric determination of soil water content is made for the organic layer, the illuvial horizon and the top of the eluvial horizon. The main purpose is to survey the spatial variability during conditions representing both moist and dry periods. The influence of the different treatments can be quantified by repeated samplings following the same transects as before and after the start of the treatments. To quantify the variability pattern caused by the roof, special sampling is made along small transects in the drought treatment.

2. Conventional tensiometers (soil moisture equipment) are installed during the growing season in all treatments except the covered area of the drought treatment of two blocks. Around 60 tensiometers are used and they are installed at depths of 15, 30, 45 and 60 cm. They are read manually once a week.

3. An electronic sensor for measurements of soil water potentials is used for the drought treatment. The sensors, which are based on the principle of measuring the thermal diffusivity in a porous cell in the soil, are connected to a data logger and the soil

temperature is measured simultaneously. 30 sensors have been installed in one drought treatment at depths of 15, 30, 45 and 60 cm both beneath the roof and in the uncovered part of the drought plot.

In addition to soil moisture measurements, the ground water level is also measured in each of the plots and in the boundary to some of them. The access tubes are only installed to follow the ground water fluctuations in the uppermost 2 meters and in many plots the ground water is below that level for long periods of the year.

Results from the pre-investigation

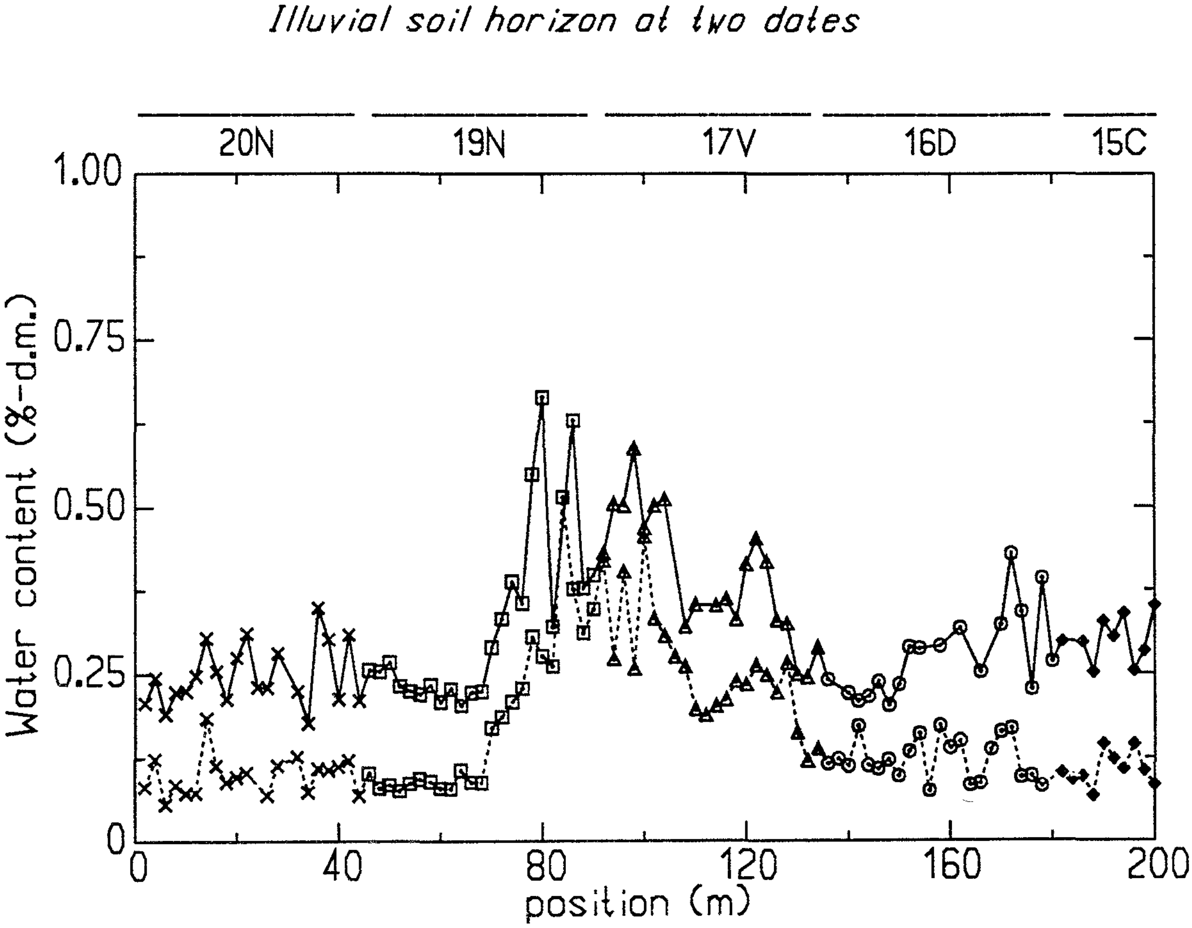

Figure 1. Measured water contents from two dates, solid line August 87 and short dashed line June 88. The solid lines above the figures show the extent of different plots representing different treatments along the transect.

Results from water content measurements along a 200 m long transect are shown below (Figure 1). The variability pattern is clearly different for the two periods representing a wet period in 1987 and a corresponding dry period in 1988. Three similar transects exist in the field and the transects are always crossing boundaries between differently treated plots which will make them very interesting to evaluate during later stages of the field study.

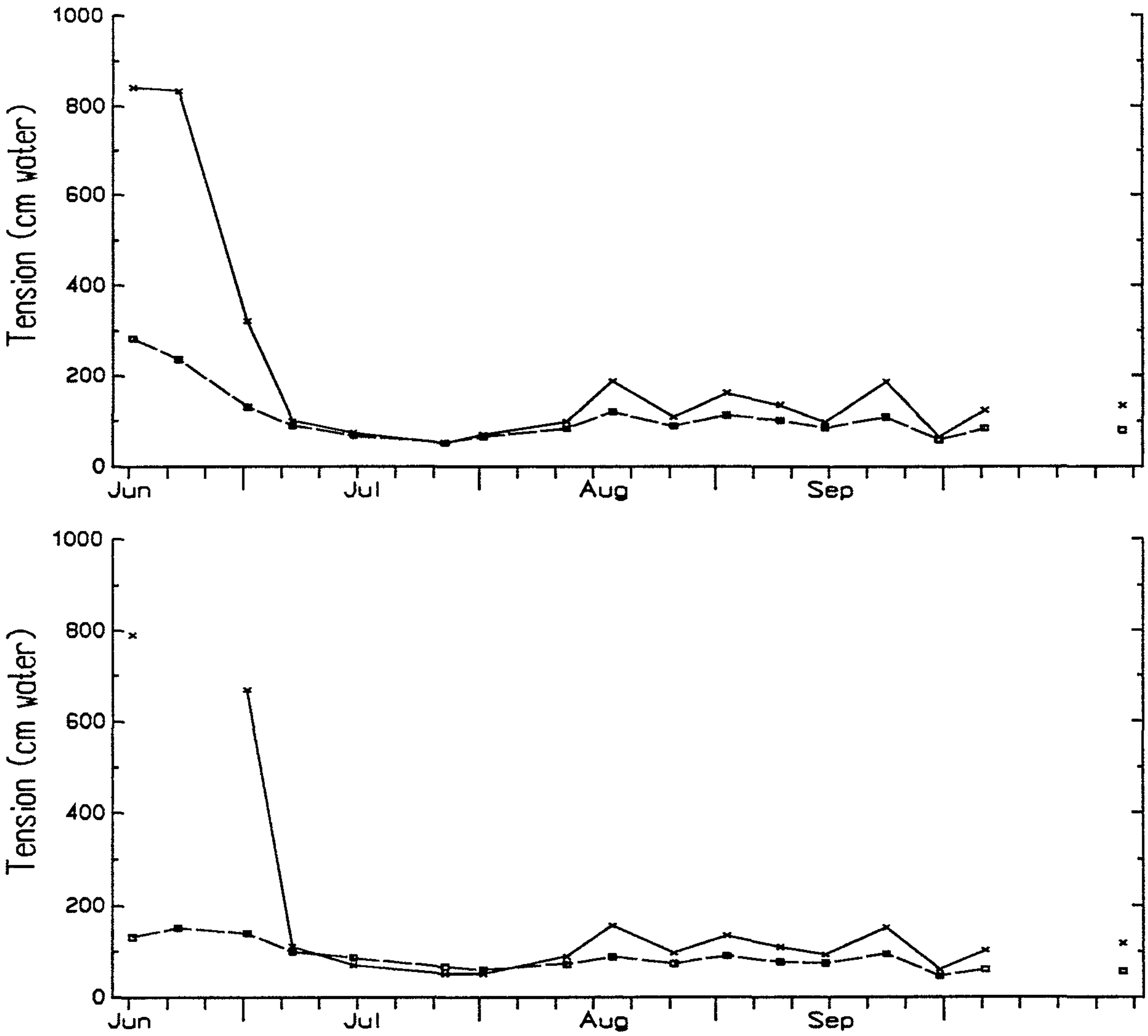

Figure 2. Mean values of water tension at 15 cm depth (top) and 45 cm depth (bottom) during 1988. Irrigated treatments are represented by the square symbol whereas the non-irrigated ones have crosses.

The typical temporal pattern of soil water potentials for the growing season of 1988 (Figure 2) shows that most of the summer was very wet except for the spring, which was dry and caused a drought in late June. The water potentials at depths from 15 to 45 cm followed each other closely for the whole period, showing that a substantial amount of total water uptake takes place below the uppermost 20 cm where most of the fine roots are assumed to exist (see subproject 2.2)

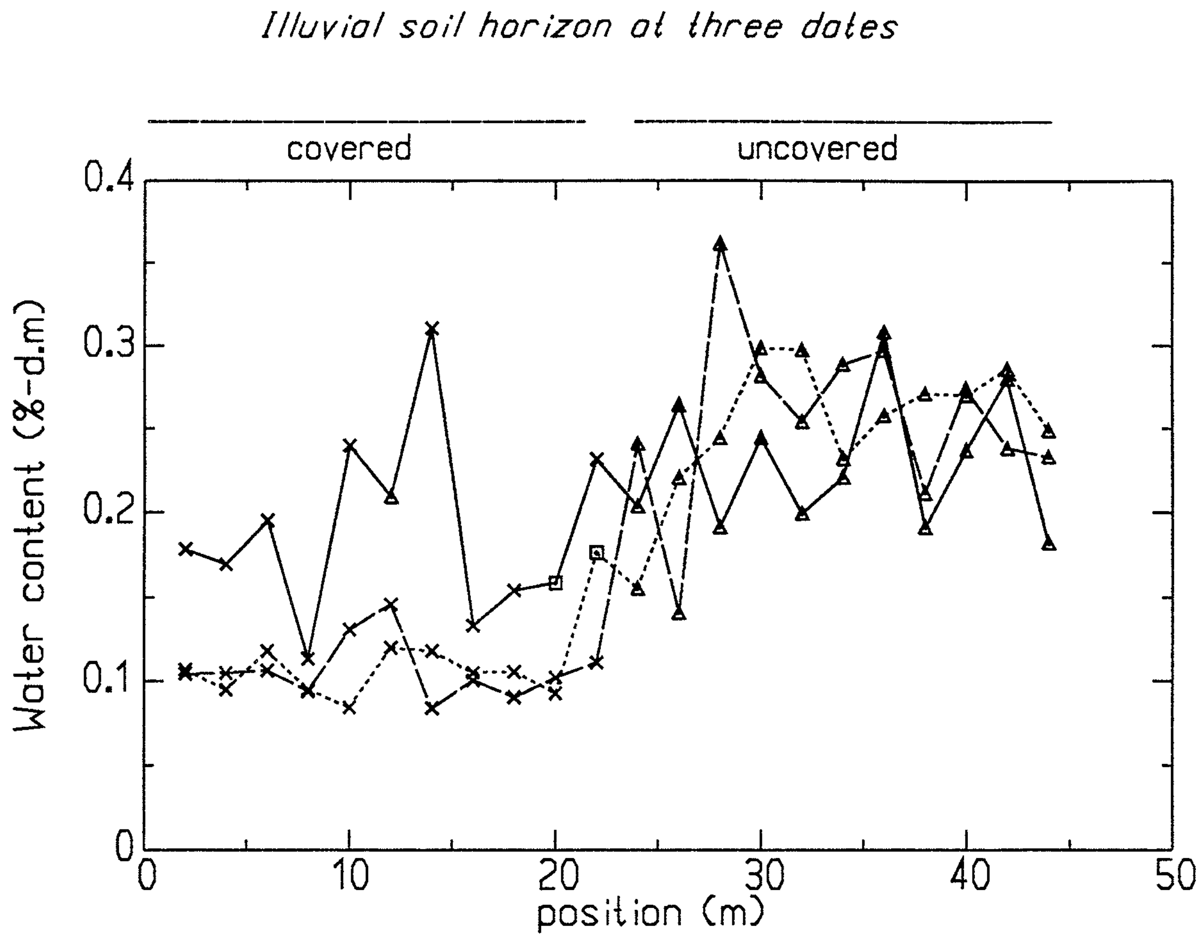

Figure 3. Measured water contents in the drought treatment (plot 16) on three occasions during 1988. Solid line - July, long dashed line - August and short dashed line - October.

The roof on the drought treatment was ready just before the rewetting of the soil occurred in late June - early July. The corresponding developments of the water contents in the uncovered area and beneath the roof were very different (Figure 3). The extremely high amount of precipitation could probably keep the trees at a reasonably good water status because of the gaps in the roof but the nutrient uptake must have been substantially influenced by the very dry conditions beneath the roof.

4.3 Nutrient flow in soil and soil chemical properties

Responsible investigator

Johan Bergholm

General objectives

- To quantify the soil nutrient storage, availability of nutrients and acidity of the soil.
- To quantify fluxes of nutrients: into the soil, in the soil and beneath the main part of the root zone.

Background

The acidity of forest soils has increased in west and south Sweden during the recent decades (Hallbäcken & Tamm, 1985; Falkengren-Grerup, 1987). A pH of 4.2 is often found in the mineral soils down to at least 50 cm and about 95% of the CEC(e) is occupied by Al and only about 2% by Ca and Mg (Bergholm, 1985). The total content of Al in the soil water is 2-3 mg/l. Of this 40-70% is inorganic monomeric Al. The DOC reaches 20 mg/l and it contains about 40 µg organic Al/mg C (Karltun, 1989). The contents of Mg and of Ca in the soil water are about 1 mg/l.

On these acidified areas spruce stands were found with a high degree of needle loss. The degree of needle loss on individual trees was not correlated to the bulk soil chemistry (Bergholm 1985), but the acid soil situation may have been one of several stress factors leading to the forest decline.

The drought in 1983 may have been one of the other stress factors leading to a water deficit, decreased availability of some nutrients and a change in soil chemical properties. These temporary changes in the soil could not be studied by the inventory method used. But it may be possible to study them in the Skogaby project by treating the spruce stands in different ways, such as creating drought, increasing the input of nitrogen and compensating the loss of nutrients by vitality fertilization. It will probably also be better to follow these changes in the soil by analysing the soil water than by analysing the bulk soil.

Hypotheses

The treatments at Skogaby will change both the soil chemical properties and the external sources and sinks of a number of important nutrients.

- The availability of different nutrients for root uptake will change because of changed acidity, base saturation or drought in the soil or because of a change in the external sources and sinks to the soil.
- The chemical composition of soil water will be a sensitive indicator both of how the root environment will change because of the specific treatment and it will also reveal differences in the efficiency for nutrient uptake between different treatments.

Hypotheses to be tested together with other subprojects

- The total fluxes of nutrients, which will be good indicators of how the trees respond to the treatment, can be estimated by use of the measured concentration in soil water solution and simulated water flows.

To be able to calculate the flow of elements in the soil water, data on the flow of soil water itself are needed. These data will be available from 4.2.

In cooperation with the soil-rhizosphere-plant project (2.1), we will study the relationship between bulk soil chemistry, rhizosphere-soil chemistry and soil water chemistry. (See details in 2.1).

To be able to quantify the flow of elements in the soil, information on the input from deposition and litterfall is needed (3.3 and 1.1).

There is a need for an additional project concerning mineralization and the mineralization rate of the organic matter in the soil in order to be able to quantify the turnover of nitrogen in particular.

Use of treatments and replicates in the Skogaby forest

All treatments will be followed; control, vitality fertilization, drought, irrigation fertilization and enhanced input of nitrogen.

Measurement programme

1.Chemical soil properties

Soil samples will be taken every third year on all plots as well as on the small scale experiment. It may be necessary to initiate a more intensive soil sampling programme on the small-scale experiment in the soil-rhizosphere-plant project.

Altogether 40 subsamples of the humus layer and 20 of the mineral soil will be taken on each plot. These samples are split up in four main samples, one from each quadrant. The mineral soil will be taken down to 50 cm in 10 cm sections.

The first sampling was carried out in October 1987 before the treatment of the plots to give the background situation. The next sampling will be made in 1990, when the following analyses will be made;

Texture	(1 mixed sample from each layer in the mineral soil per plot, only the first year)
pH (H2O)	on fresh samples
pH (1 M KCl)	"
Exchangeable cations and CEC(e)	"
Exchangeable SO_4	"
Total contents of:	C N P K Ca Mg S Cu Mn Zn B Mo in the humus layer and in the mineral soil.
	Al Fe in the humus layer.

2.Soil water studies

Soil water will continuously be sampled during the frost-free period of the year. Samples will be taken every fortnight. Zero lysimeters are used under the humus layer and suction lysimeters at 20 and 50 cm depth. The suction lysimeters were installed in September 1988. The suction will be -0.2 atm.

Two blocks with all treatments will simultaneously be followed every year. However, one of these blocks and all the control plots will be permanently followed throughout the whole experimental time period and the other block will alternate from year to year. One plot contains 7 replicates placed in a L-shaped figure 2 m outside the net plot. The plots with drought contain two sets, one outside and one under the shelter. In 6 of the replicates ceramic lysimeters of P80 material are used. In the 7th, teflon lysimeters are used which make it possible to analyse also the elements which are captured by or released from the ceramic lysimeters.

The following elements will be analysed on soil water samples:
pH Cond. Na K Mg Ca Al Mn Fe NH_4 NO_3 SO_4 Cl PO_4 DOC in some samples

Results from pre-investigation

Some chemical soil characteristics of the whole investigation area prior to the start of the different treatments are presented below.

Mean and standard deviation of exchangeable cations, the effective cation exchange capacity and base saturation (n=100)

Horizon (cm)		pH (H_2O)	Na	K	Mg	Ca	Al	H	CEC_e	BS (%)
			µmol(+)/g							
6-0	Mean	3.91	3.5	10.5	18.1	39.4	39.1	130.9	241.5	29.6
	sd	0.10	1.0	2.1	4.3	14.4	14.5	31.8	47.7	5.9
0-10	Mean	4.07	1.1	0.7	1.1	1.8	36.4	14.4	55.4	8.4
	sd	0.12	0.6	0.4	0.7	1.2	8.5	4.2	8.8	4.4
10-20	Mean	4.44	0.8	0.3	0.4	0.9	26.9	5.5	34.8	6.9
	sd	0.11	0.6	0.3	0.3	0.6	6.6	2.1	25.9	3.9
20-30	Mean	4.46	0.8	0.3	0.4	1.0	20.7	4.4	27.6	9.0
	sd	0.15	0.6	0.3	0.3	0.7	7.0	2.1	8.4	5.0
30-40	Mean	4.51	0.8	0.2	0.3	0.9	13.7	3.1	19.0	11.6
	sd	0.11	0.7	0.2	0.3	0.7	7.1	2.0	8.4	6.5
40-50	Mean	4.54	0.8	0.2	0.3	0.7	9.7	2.7	14.3	13.6
	sd	0.09	0.6	0.2	0.2	0.7	4.1	1.6	5.3	8.2

The soil pH is around 3.9 in the humus layer and 4.5 and relatively constant from 10 down to 50 cm depth in the mineral soil, indicating an acidifying process. Almost one third of the total content of exchangeable potasium, magnesium and calcium down to 50 cm depth is found in the humus layer but only a few per cent of the exchangeable aluminum. Magnesium and calcium is exchanged with aluminum and leached out of the mineral soil. The base saturation is low in the mineral soil and lowest in the lower root zone at 10-20 cm depth.

The soil does not show the most acidified status of soils in the area and there are possibilities to acidify the soil further by the ammonium sulphate fertilization.

References

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5.1 Tree growth modelling

Responsible investigator

Lars-Owe Nilsson

Co-workers

Per-Erik Jansson

Karin Wiklund

General objective

- To predict treatment effects on production and allocation of above-ground biomass assuming no air pollution at Skogaby.
- To evaluate differences between predicted tree growth (assuming no air pollution) and the observed tree growth in the different treatments at Skogaby.

Short background

Mathematical models can be used with many different purposes within interdisciplinary ecological research projects. In the Skogaby project we will use different types of mathematical models as ordinary methods to test different hypotheses and to evaluate measurements within different subprojects (eg. 4.2)

One important use of simulation models is that they can be used to produce predictions before a full scale experiment is designed. The most important use of models in this project will be to produce predictions for a treatment which is not present at Skogaby namely the one where the concentrations of air pollutants are reduced to a level that represents "clean air". These predictions can be simulated with a tree growth model which has been parameterized using data from other sites representing less polluted conditions.

Driving variables for the type of models we will use are meteorological variables, and other important growth-regulating conditions are nutrient and water availability in the soil. This information will be available from several sites which makes it possible to move the coefficients which represent the response at one site to another site.

Hypotheses

- The effect of air pollution is the residuals obtained between predictions assuming clean air and observed values at Skogaby.

Hypotheses, built into the models that will be used

- Water-use efficiency is constant for trees growing in different climatic conditions with similar nutrient availability but becomes lower for trees directly affected by air pollutants.

- Light-use efficiency is constant for trees growing in different climatic conditions with similar nutrient and water availability.
- The nitrogen productivity concept can be used to explain variations in response which are attributed to nitrogen as a growth regulating factor.

The two first hypotheses can be tested for explanation of variations obtained between treatments and between different years at one site. The nitrogen productivity will mainly be used to identify during which conditions other nutrients will limit growth. Major attention will be paid to evaluating differences in explanation of treatment effects between different sites which represent different levels of air pollution.

The model for simulation of forest growth that has been developed by Frits Mohren (Mohren, 1987) will be utilized. A general description of the model is given in Fig. 1 below. The model also contains a submodel for water flows and another for nutritient flows. The model is converted to PC/AT usage. Regarding the water-flow submodel, there are plans for combining the Mohren model with the SOIL model which is used in the hydrology subproject (4.2) and also for calculation of the water balance at Flakaliden (North Sweden). The SOIL model gives the best estimate of the transpiration rates (used in the water use efficiency concept) especially for northern localities which are influenced by low soil temperatures and soil frost.

Further, the various treatments within the project will be investigated through the nitrogen productivity concept (Ågren, 1983; Nilsson, 1987). This concept may answer how efficiently the nitrogen that is taken up in the above-ground components is utilized in the growth processes. A reduction in nitrogen productivity of a treatment will be indicative of other stress factors. If nitrogen is not the limiting factor for growth, this concept can be tested also for other nutrients that can be supposed to be limiting for growth.

Use of treatments and replicates in the Skogaby forest

All treatments will be considered.

Measurement programme at Skogaby

This subproject will not include measurements, but will rather indicate which investigations should be of interest.

Use of small-scale experiments

Results from the small-scale experiment will be valuable since some addressed questions cannot be answered using the mature stand. Particularly results dealing with direct effects on needles of ozone and acid rain are of interest. For example ozone may cause an influence through diminished growth at the rate we have already today and, further, ozone in combination with acid rain may have a negative influence on the water-use efficiency.

The small-scale experiment is also valuable since it represents a period in the life cycle of spruce that cannot be studied through the mature stand. A slowdown of seedling development in some years means that the period up to harvest will be elongated by the same length of time. Thus, the plant establishment phase also is of great importance when evaluating the influence of air pollution on the vitality of a forest stand.

Use of data from other sites in the testing of hypotheses

The success of this subproject is heavily dependent on cooperation with other research teams. We will take part in a joint European project (The Netherlands, Germany, Finland and Italy) with similar research aims. A close collaboration with the Swedish projects at Flakaliden and Asa is also part of the European project.

References

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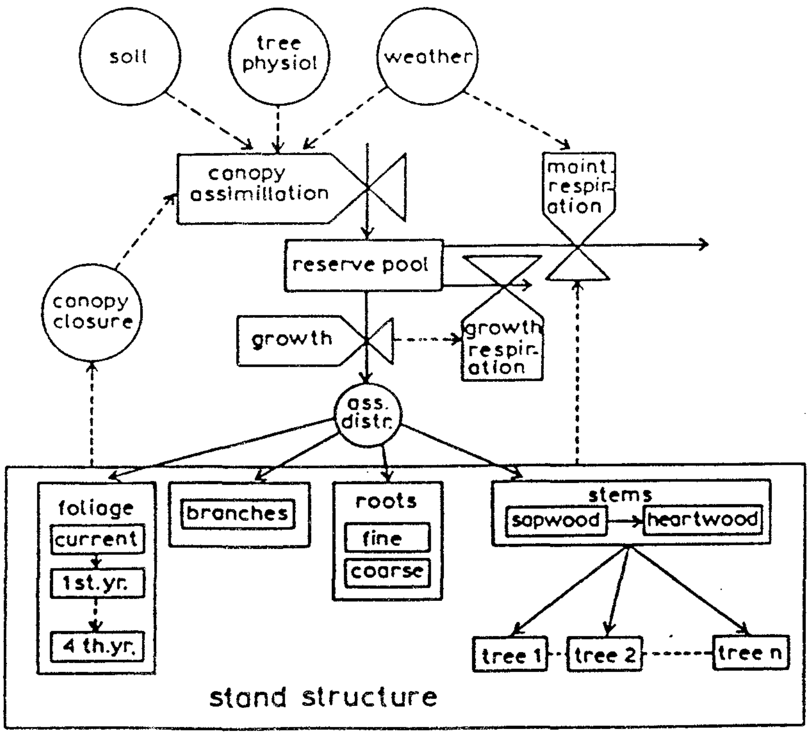

Figure 1.
General relational diagram of the simulation model. Solid lines: material flows; dotted lines: relationships between rate variables and state variables, and between driving, intermediate, and rate variables.

5.2 Effects of wood ash on tree growth and soil

Responsible investigator

Heléne Lundkvist

Co-workers

Marianne Clarholm

Anna Rudebeck

General objective

- To investigate effects on tree growth, soil and soil organisms of application of granulated wood ash from municipal heating plants.

Short background

Wood ash contains no nitrogen but has a high content of most of other plant nutrients (cf. Table X). Therefore it is likely to be a suitable alternative vitality fertilizer. At present large and medium sized municipal heating plants fuelled with wood chips produce about 35 000 tonnes of wood ash annually. Only half the potentially available forest energy resource is currently being used. The present wood ash production within the forest industry amounts to about 100 000 tonnes annually.

The reasons for recirculing wood ash to the forest are at least threefold;

1) to compensate for nutrient losses during forest production and harvest.

2) to compensate for base cation losses caused by forest production or by other environmental influence.

3) to avoid problems connected with storage of wood ash in deposits, i.e. leaching, explosions risks, etc.

The risks that have been recognized in connection with application of wood ash are the following;

1) An expected increase in soil pH increases the possibilities for nitrification to occur which, in turn, could lead to increased nitrogen losses through nitrate leaching and at high soil moisture conditions, possibly also through denitrification.

2) At high ash concentrations, or in the close vicinity to ash granules the wood ash might cause osmotic and/or toxic effects on parts of the soil organism community and on roots.

Hypotheses

Wood ash fertilization will lead to:

- Improved tree growth and reduced nutrient imbalance in tree canopy.
- Increased base saturation of the soil.
- Changed nitrogen dynamics of the soil.
- Changed availability of organic and inorganic phosphorus.
- Changes in the soil organism community.

Hypotheses 3 and 4 will partly be tested in laboratory experiments with soil taken from the Skogaby site. Only the work for testing the hypotheses in the field scale will be described below.

Hypotheses, to be tested together with other subprojects

The project will be dependent on particularly subproject 1.1 and 4.3 but also subproject 2.2.

Use of treatments and replicates in the Skogaby forest

Wood ash fertilization, vitality fertilization, control and to some extent nitrogen fertilization treatments will be used for comparisons. All replicates will be used.

Measurement programme at Skogaby

Tree growth will be measured as described in 1.1

Soil water chemistry will be measured as described in 4.3, but for the wood ash and control treatments all replicates will be used simultaneously during the whole investigation period.

The abundance of enchytraeids in the fertilized and the control treatments will be compared yearly in the autums. Enchytraeids (potworms) that, in terms of biomass, are dominating the soil faunal group in most coniferous forests, are known to be sensitive to environmental changes like, for example, increased salt concentration in the soil solution. Thus, they could serve as indicators of what effect a treatment might have on the soil system.

The protozoan population in the wood ash and the control treatment will be compared yearly. It has been suggested that an increase in soil pH will favour bacteria in the soil microorganism community. Protozoa feeds on bacteria and offers an indirect means of studying the response of the bacterial population to wood ash fertilization.

The earthworm population in the wood ash fertilization and the control treatments will be compared yearly in the autumns. In a longer perspective it is of interest to study if the wood ash fertilization will cause a persistent rise in soil pH which, in turn, will lead to important changes in the soil faunal community. High soil pH and high availability of calcium will improve the conditions for earthworms. If the earthworm population increases in number, and especially if digging earthworms manage to establish in significant numbers, this might lead to considerable changes in the soil profile.

Use of small-scale experiments

Two wood ash treatments with different doses of wood ash are suggested for the small scale experiment.

Use of data from other sites in the testing of hypotheses

The effects of wood ash fertilization on tree growth and soil status are investigated also in the optimum fertilization experiments at Flakaliden and Asa. However, since these sites are not exposed to high nitrogen deposition they are given 100 kg N ha-1 yr-1 in addition to wood ash fertilization. The wood ash is given in the same amount at all three sites.

6.1 Management of the field site

Responsible

Ulf Johansson

Co-workers

Erik Snygg and others in the staff of Tönnersjöheden Experimental Forest.

Field activities in the experimental area at Skogaby

	Treatment	**Description**
C	Control	No treatment
D	Drought	The roofs, located about one meter above ground, cover each half of a gross parcel (22.5 x 45 m = 1012.5 m^2). The water falling on the roof is collected in small grooves. Outside the edge of the plot the flow rate is measured using large tipping buckets.
NS	NS-fertilization	Fertilization with a total amount of 100 kg-N/ha as ammonium sulphate was applied on three occasions during the period from May to July divided into equal fractions.
V	Vitality fertilization	500 kg of "Skog-vital" was added during both 1988 and 1989. One-third of the total amount was spread during the month of May and the remaining amount during June.
IF	Optimum fertilization with irrigation	The nutrient mixture is spread using a sprinkler system where each sprinkler covered about 25m^2. The addition is split in a number of portions added during the whole growing season.
I	Irrigation	
ND	NS-fertilization followed by drought	Like (NS) during this first year.
VD	Vitality fertilization followed by drought	Like (V) during this first year.
A	Wood ash application	4000 kg ha^{-1} of granulated wood ash was applied at the end of June 1989.

Practical arrangements

- The area was electrified during the spring 1988. To avoid damage to electronic devices and from transients in the power system during thunderstorms, a lightning conductor was installed during the autumn.
- The irrigation system was installed during the spring 1988. The water source is Lake Råsjön, about 500 m south-east of the experimental area.
- All buildings in the area were equipped and painted during 1988. The following facilities are available: a small meeting room, a small field laboratory, a place for technical equipment (irrigation, fertilization system) and a store.

Small plant experiment

An area for a small plant experiment was selected during February 1988 and an initial soil investigation was carried out during the autumn. The plantation and establishment of the experiment started during 1989.

6.2 Project coordination

From the start of the fiscal year 89/90 a new leadership group was formed.

Lars-Owe Nilsson	Project leader from 1 January 1990
Bengt Nihlgård	
Jan-Erik Hällgren	Project leader 1 January - 30 June 1988
Per-Erik Jansson	Project leader 1 July 1988 - 31 December 1989
Ulf Johansson[1]	From November 1988
Jan-Erik Lundmark	SSFf representative after 1 January 1990
Stig Larsson	
Lars-Erik Liljelund[2]	SNV representative before May 1989
Hans Persson	from 1 January 1990
Håkan Staaf[3]	SNV representative after May 1989
Karin Wiklund	Sectretary from 1 January 1990
Lars-Olof Österström	SSFf representative before 1 January 1990[4]

The former principal investigator, Folke Andersson, has been consulted in many questions concerning the scientific development of the project.

Financial situation and budget

In addition to the funds from SNV (Swedish Environment Protection Agency), which are estimated to cover costs associated with the treatments D, NS and C, a total budget also including the I, IF and V treatments has been prepared. This budget covers only the three first years and the additional 1300 (KSEK) received from the Swedish Forestry Research Foundation is added to the total sum. Support is also given to some subprojects from: The Agricultural and Forestry Research Council and the Swedish National Research Council.

Project	Responsible	88/89	89/90	90/91	91/92	92/93	Total
Canopy studies							
1.1 Biomass	L-O Nilsson	200	285				
1.2 Crown morph.	J. Lesinski	100	160				
1.3 Water phys.	J-E Hällgren		200				
Total SNV		300	240	260	220	500	1460
Total SNV+SSFf		490	645	600			
Root studies							
2.1 Rhizosphere	G. Gobran	35	133				
2.2 Fine roots	H. Persson	75	332				
2.3 Physiology	P. Jensén	140	137				
Total SNV		250	470	440	400	400	1900
Total SNV+SSFf		680	700	700			
Nutrient balance canopy							
3.1 Needles	B. Nihlgård	250	400				
3.2 Leaching	L. Folkesson	200	247				
Total SNV		450	470	490	450	120	1920
Total SNV+SSFf		630	700	700			
Environmental factors							
4.1 Deposition	P-E Jansson	150	165				
4.2 Climate/hyd	P-E Jansson	180	290				
4.3 Soil chemistry	J. Bergholm	250	345				
Total SNV		580	600	620	580	500	2820
Total SNV+SSFf		750	800	800			
5.1 Modelling	L-O Nilsson	120	149	120	120	120	600
Total SNV+SSFf		150	150	150			
Central activities							
6.1 Field management	U. Johansson	300	403				
6.2 Coordination	P-E Jansson	100	100				
6.3 Project dev.	P-E Jansson	100	100				
Total SNV		500	400	470	430	560	2300
Total SNV+SSFf		600	650	750			
Total sum SNV		2000	2300	2400	2200	2200	11000
Total sum SNV+SSFf		3500	3600	3700			
Received grants							
SNV		2000	2300	2400			
SSFf		1300	1300	1300			

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Swedish summary

En utförlig beskrivning av ett större forskningsprojektet där forskare från både Sveriges Lantbruksuniversitet och Lunds Universitet är involverade har sammanställts. Projektets syfte är att klarlägga under vilka klimatiska och näringsmässiga omständigheter som vi kan förvänta oss negativa eller positiva effekter av luftföroreningar på granskogens tillväxt och vitalitet.

Försöksområdet och allmänna utgångspunkter vid studierna presenteras såsom detaljer rörande varje enskilt delprojekt. I mycket begränsad omfattning har vissa preliminära resultat medtagits.

Rapportens syfte är i första hand att informera forskare och andra med stort intresse av studier rörande effekter av luftföroreningar på skog om pågående aktiviteter. Populär information på svenska kommer att spridas genom en speciell skrift som kan tillhandahållas från projektet sekretariat (se adresslista). I övrigt planeras den vetenskapliga publikationen i sedvanliga vetenskapliga tidskrifter.

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