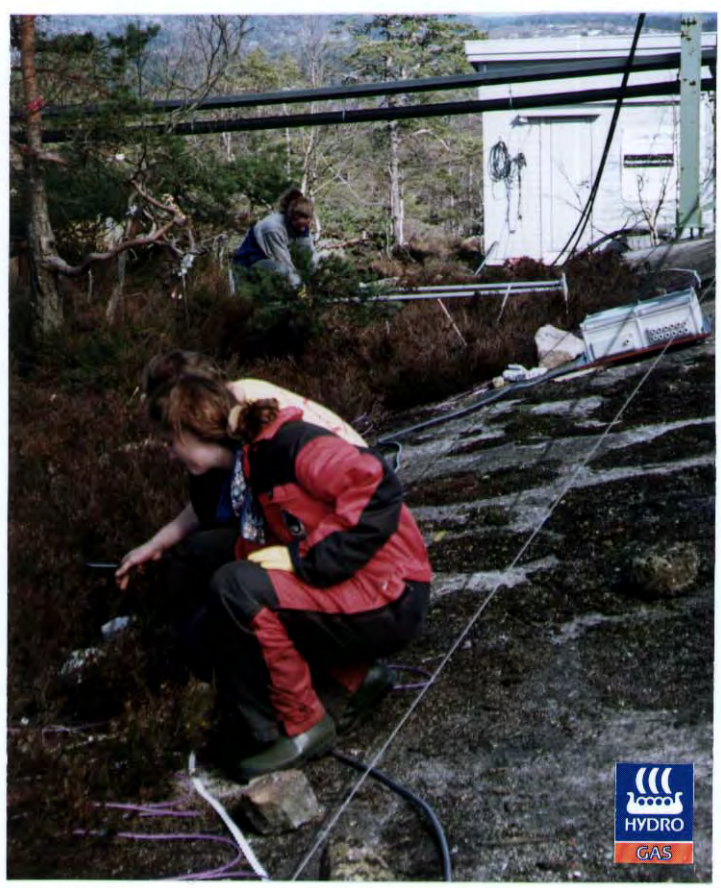
CLIMATE CHANGE RESEARCH

REPORT 2/1995

CLIMEX project: Progress report

July 1993 - December 1993



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Norwegian Institute for Water Research NIVA

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Abstract: This report describes data obtained during the pre-treatment period at the Risdalsheia site. Results from laboratory experiments with plants and soils are also reported.

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CLIMEX interim report (July 1993 - December 1993)

EC Contract No. EV5V 0047

CLIMEX (Climate change experiment) is an ongoing project to determine the ecosystem impact of enriching atmospheric CO_2 to 560 ppmv and raising air temperature by 5°C above ambient to an entire forested headwater catchment.

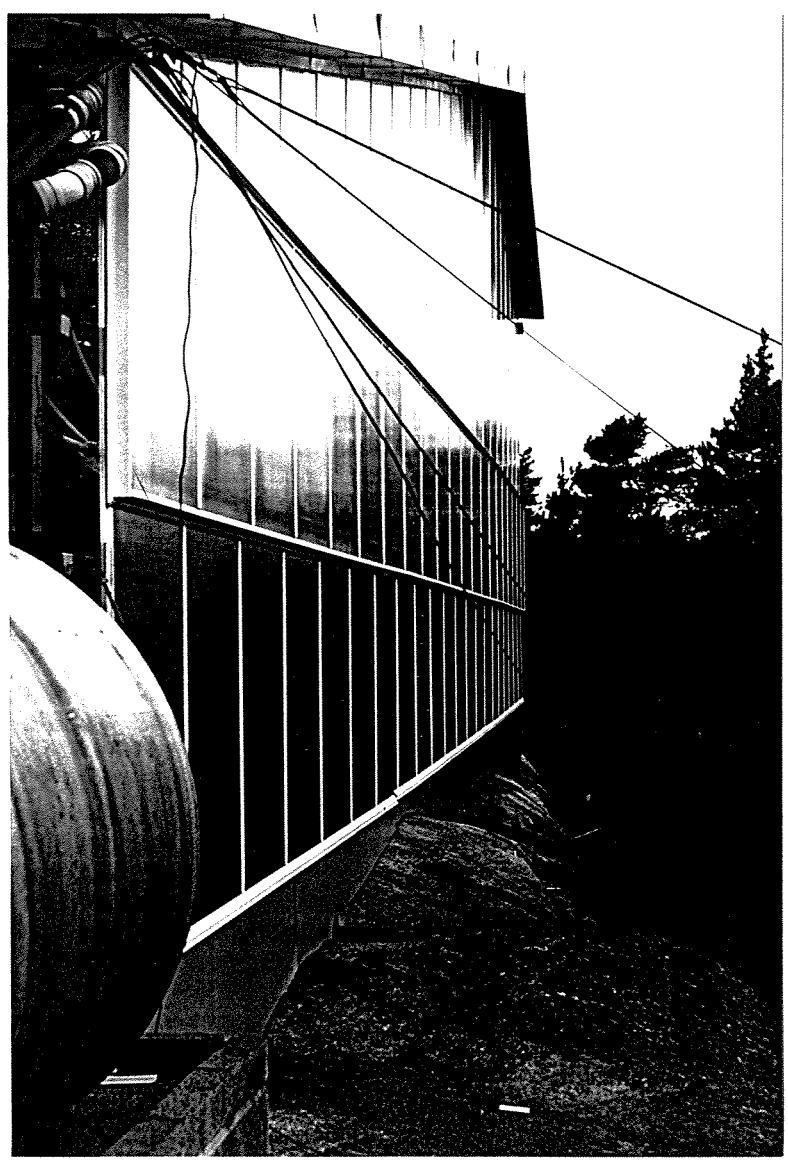
This work contributes to the GCTE (Global Change & Terrestrial Ecosystems) Core Project of the IGBP (International Geosphere-Biosphere Programme).

Technical Installations

Richard F. Wright (NIVA), Brit Lisa Skjelkvole (NIVA), and Ragnar Storhaug (Aquateam a/s)

Conversion of the existing RAIN project facilities at Risdalsheia to accommodate the new experimental design of CLIMEX requires major modifications of the existing enclosures as well as installation of equipment for dosing and monitoring CO_2 and temperature. The work was sent out for bids and Hannestad A/S, Tonsberg, received the general contract. Sub-contracts were let to a heating specialist, an electrician and a greenhouse supplier. In addition a separate contract was completed for the CO_2 tanks, evaporators and supply with Hydrogas Norge A/S.

At KIM catchment (CO_2 and warming) most of the necessary changes were carried out during the period June - November 1993 as specified under the contract with Hannestad A/S. The building received new sides with banks of panels to allow ventilation, the heating pipes were installed, a central equipment house was set up for the electric furnace and the climate computer, and the CO_2 and temperature sensors and dosing devices were installed. The work was essentially completed by 1 November 1993. The first CO_2 tank was delivered by Hydrogas A/S in January 1994. The facility is thus complete and ready for the start of the treatment in spring 1994.



At EGIL catchment (warming only) the technical design was completed in summer 1993 and installation of the soil heating cables and electronics began in October 1993. This work was not finished due to unfavourable weather conditions, including an exceptionally early onset of winter. Installation will be completed in April 1994.

Treatment will start at both catchments in April/May 1994. At KIM catchment CO_2 dosing will start in mid-April with the warming beginning about one month later. This staggered start is to allow testing of the climate computer under full-scale conditions. At EGIL catchment the soil warming will commence at the same time as at KIM catchment.

There were no major unforeseen technical problems at either catchment.

Water chemistry and input-output budgets

Richard F. Wright (NIVA) and Brit Lisa Skjelkvole (NIVA)

The existing 3 catchments (KIM - clean rain, roof; EGIL - acid rain, roof; ROLF - acid rain, no roof) at Risdalsheia operated during the period 1983-1993 by the RAIN project have been carried over to the CLIMEX project. In addition 2 new untreated reference catchments have been added (METTE and CECILIE) (Table 1). Precipitation volume is monitored daily under both roofs (KIM and EGIL) as well as outside (ROLF, METTE, CECILIE). Chemical composition of precipitation is measured in weekly bulk samples collected outside, and these concentrations are used in conjunction with the volume measurement to calculate input fluxes of major ions at EGIL, ROLF, METTE and CECILIE. At KIM catchment the precipitation chemistry is calculated from the total volume of water sprinkled and the quantity of sea salts added to the clean water.

Table 1. Overview of the 5 catchments at Risdalsheia included in the CLIMEX project.

catchment	area (m^2)	enclosure	rain quality	climate treatment	monitor start
KIM	860	roof	clean	CO_2 + temp	June 1983
EGIL	400	roof	acid	temp	June 1983
ROLF	220	no roof	acid	none	June 1983
METTE		no roof	acid	none	June 1993
CECILIE		no roof	acid	none	June 1993

Runoff water at all 5 catchments is sampled at least weekly with more frequent sampling during periods of high discharge. All runoff is gathered at the bottom of each catchment by means of fibreglass dam and led by PVC pipe to a sampling hut. Here the volume is measured by filling and automatic emptying of a calibrated 500-l tank. Samples for chemical analysis are collected by automatic water sampler. Output budgets are calculated by multiplying the volume of runoff with the weekly chemical concentrations with linear interpolation of concentration between sampling dates.

Input-outputs budgets are calculated for summer and winter seasons. The transition from winter to summer is taken to be the end of snowmelt (about 1 May) and the transition from summer to winter is the onset of persistent frost conditions (about 1 December) which necessitate the closing down of the sprinkling systems at KIM and EGIL catchments. Dry deposition is calculated for the each catchment under the assumption that Cl output equals Cl input, that the dry deposition of Cl is accompanied by Na, K, Ca, Mg and SO_4 in amounts equivalent to their ratios to Cl in sea water, and that dry deposition of pollutants SO_4, NO_3, NH_4 and H+ is comparable to that at the nearby Birkenes catchment. For the 3 catchments operated by the RAIN project, a total of 10 years of input-output data are available (June 1983-June 1993). Data from the 2 new catchments METTE and CECILIE are as yet incomplete.

Budgets for the last complete year (18 May 1992 - 14 May 1993) represent the 9th year of clean rain treatment at KIM catchment (Table 2). The data show that the clean rain treatment at KIM continues to have a major impact on runoff chemistry. Sulphate concentrations in runoff at KIM were 25 ueq/l as compared to 71 and 93 ueq/l at EGIL and ROLF, respectively. Also nitrate concentrations were much lower at KIM than at the 2 catchments receiving acid rain.

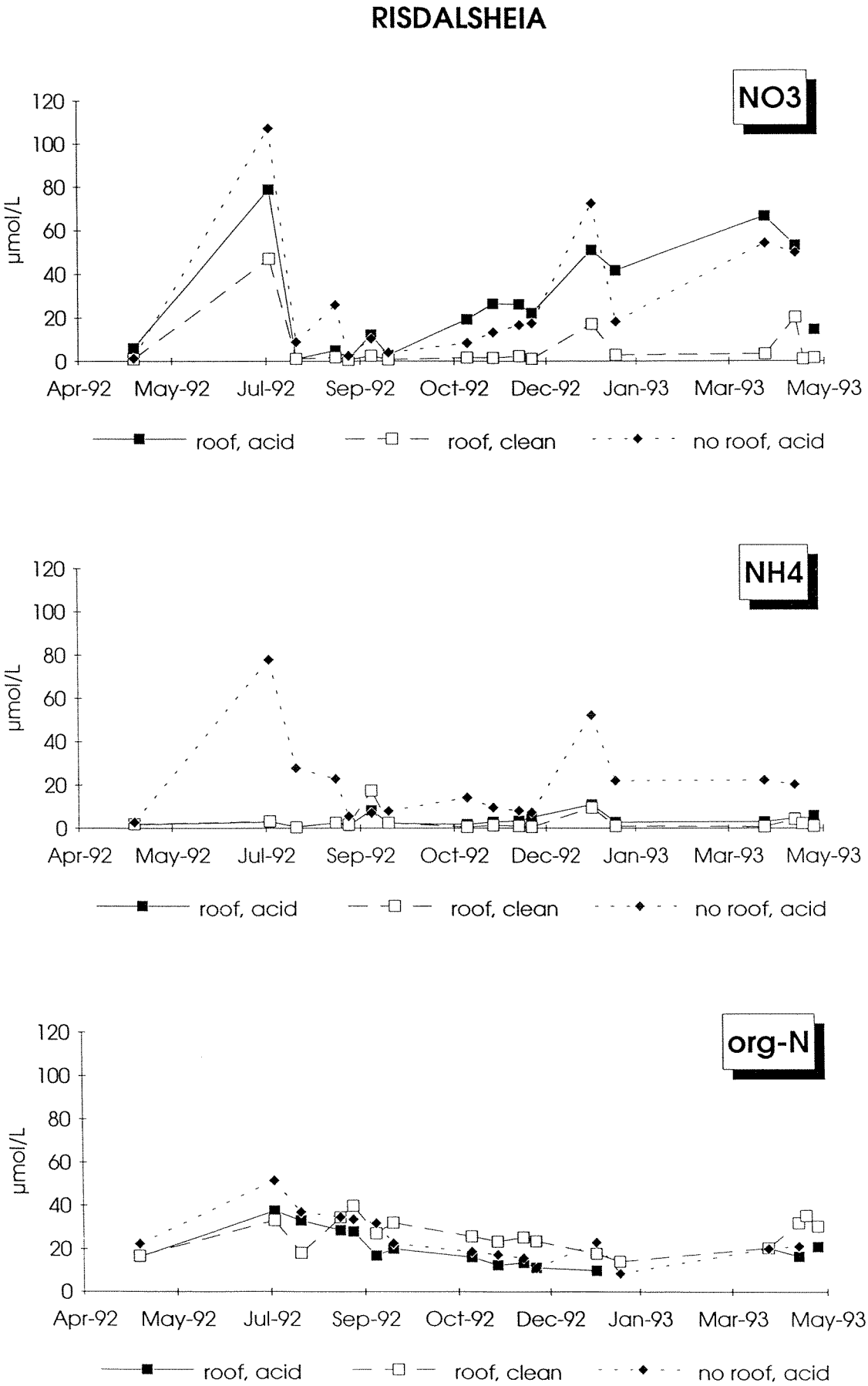
Nitrogen species in runoff are of central interest with respect to the effects anticipated following the onset of changed climate conditions under CLIMEX. At KIM catchment (roof, clean rain) concentrations of ammonium and nitrate are low in all samples collected during May 1992 - May 1993, with the notable exception of nitrate in the first runoff following dry periods (July 1993) (Figure 1). Concentrations of dissolved organic nitrogen (calculated as org-N = total-N - NH_4 -NO_3) were similar between the 3 catchments indicating little effect of the clean rain treatment.

Table 2 Volume-weighted average concentrations of major chemical components in deposition (wet and dry) and runoff at KIM (roof, clean rain), EGIL (roof, acid rain) and ROLF (no roof, acid rain) catchments for the year 18 May 1992 - 14 May 1993, the 9th year of treatment.

Concentrations (ueq/l)

	KIM		EGIL		ROLF	
	In	Out	In	Out	In	Out
H_2O	986	986	1119	1006	1230	1022
H+	20	55.8	66.4	77.7	63.4	82.2
Na	64.4	82.1	89.1	95.0	132.5	155.4
K	1.4	2.1	3.3	3.0	4.7	16.5
Ca	2.8	7.5	9.5	13.0	11.9	16.2
Mg	16.2	12.8	20.2	20.0	29.6	34.5
Al	0.0	5.1	0.0	8.6	0.0	7.7
NH_4	4.1	3.0	29.5	3.5	38.6	17.9
NO_3	11.2	4.0	45.4	23.1	51.3	24.5
Cl	75.2	85.8	101.6	113.0	154.3	185.6
SO_4	20.9	25.0	78.9	71.0	79.8	92.8
A-	1.8	53.5	-7.9	13.7	-4.6	27.5
sum+	109.2	168.4	217.9	220.8	280.8	330.4
sum-	109.2	168.4	217.9	220.8	280.8	330.4
SBC	88.9	107.4	151.5	134.5	217.4	240.5
SSA	107.3	114.8	225.8	207.1	285.4	302.9
alk	-18.5	-7.4	-74.3	-72.6	-68.0	-62.4
TOC		14.7		8.9		11.4
SiO_2		2.2		2.8		1.8
c.d.		3.6		1.5		2.4
RAL		291.1		265.0		253.3
ILAL		239.7		178.9		176.0
TOTN		477.2		615.4		883.8

Figure 1. Concentrations of nitrogen species in runoff from three catchments (KIM - roof, clean rain; EGIL - roof, acid rain; ROLF - no roof, acid rain) at Risdalsheia, May 1992 - May 1993. Organic-N = total-N - NH_4 - NO_3.



Soil Water Monitoring and Hydrological Response

R.Collins and A.Jenkins (IH)

Installation of the TDR system in the Kim catchment, completed during the summer, has provided a spatial and temporal record of soil moisture. Location of the sensors has been made with regard to topography, soil depth and vegetation and readings of soil moisture are currently made and stored on a 4 hour basis. Data is stored on Oracle and the database is readily accessed and linked to the geographical information system Arc/Info utilising a suite of programs. Analysis of the resultant time series reveals the response of the soil to regimes of wetting and drying and provides an indication of the effect of antecedent soil moisture in the generation of runoff.

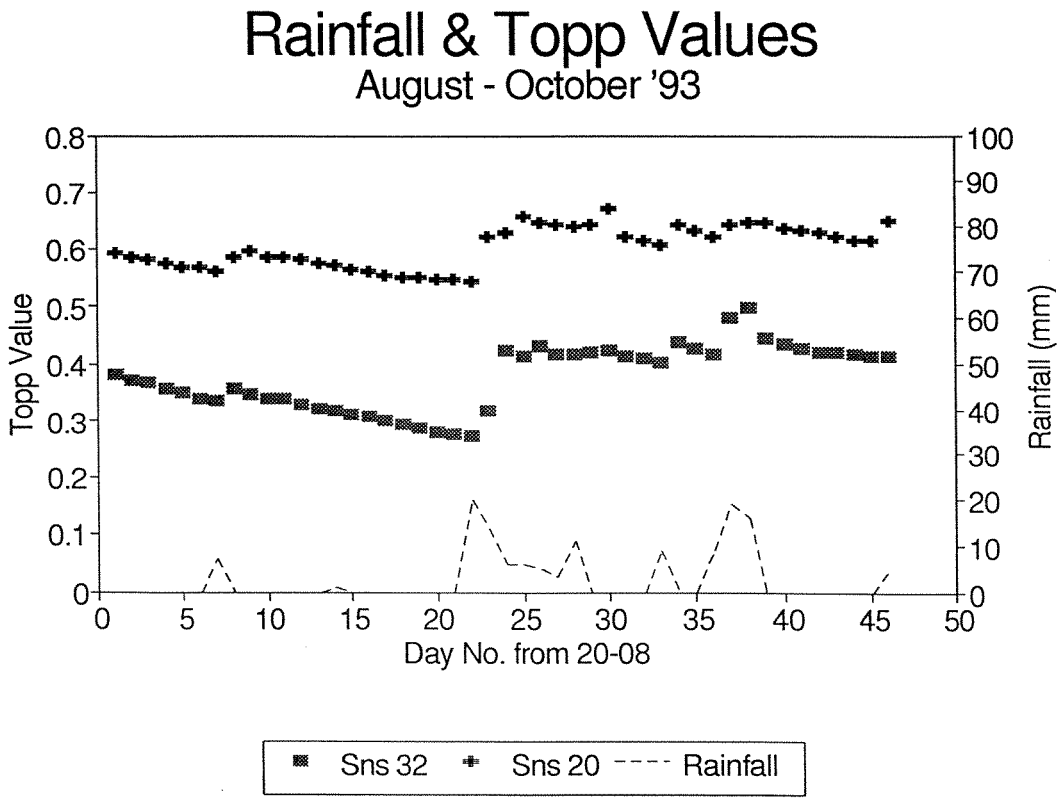


Figure 2. Time series data for two sensors, no's 20 and 32, both located in the lower slope region, Topp values are a volumetric water content (m^3/m^3). For reasons of clarity only one reading per day per sensor is illustrated.

Mathematical interpolation of each point value using the technique of kriging enables soil moisture to be extrapolated over the whole catchment, potentially highlighting preferential flow routes and regions of lateral flow. The sensors are located to depths of 0.10, 0.35 and 0.5m and thus, will be sensitive to any variation in depth of flow that may result from both natural seasonal climatic variations and those imposed by the proposed treatments. Utilisation of the extrapolated soil moisture values enables calculation of a water balance for the catchment. In particular, levels of evapotranspiration are readily quantifiable, since the change in soil moisture storage over time is derived from the TDR data and inputs through precipitation and outputs from runoff are automatically logged.

A trial tracer experiment was conducted in October, this involved bringing the catchment to a steady hydrological state before injecting the sprinkler system with a known concentration of lithium bromide, the concentration of bromide ions in both the rainfall and runoff were then closely monitored over the duration of the 'storm'. The results suggest high pore water velocities, possibly accentuated by macropore flow. Further tracer experiments are proposed to fully examine the hydrological response of the catchment.

Once sufficient climatic and soil moisture data is obtained to satisfy the input parameters, the IHDM model will be applied to the Kim catchment. The resultant values of soil suction derived by the model describe the strength to which the moisture is held in the soil matrix against the force of gravity and thus the susceptibility of soil water to downward and lateral movement. In addition, values of soil suction describe the available moisture for uptake by vegetation, defined as the water held between field capacity and the permanent wilting point. An earlier application of the model to the Egil catchment illustrated the steady wetting up of the catchment over a 45 hour storm period resulting in soil saturation, development of runoff and small positive pore water pressures in the lower slope region.

Decomposition rates of soil organic matter

P.S.J. Verburg and N.Van Breeman (WAU)

From October 1992, measurements have been carried out to collect background data before the start of the climate manipulations. The aim was to investigate whether decomposition rates of organic matter differ between the different catchments already. In addition, possible differences in decomposition rates between the control and treatment sections within KIM and EGIL catchment were investigated.

In cooperation with the Swedish University of Agricultural Sciences, a litterbag experiment was carried out where litterbags containing pine litter were incubated for one year in each catchment. The litter was incubated under different dwarfshrubs to investigate the effect of vegetation type on the decomposition rate. No distinction was made between the contol and treatment sections. As can be seen in Table 3, decomposition rates in the two roofed catchments (KIM, EGIL) were higher than in the uncovered reference catchment. It is likely that the differences in decomposition rate are caused by a higher (between 1.5 and 2°C) temperature in the litter layer in EGIL and KIM as opposed to ROLF.

Table 3. Mass loss of pine litter after 1 year

		Mass loss (%)[1]	n
KIM	Calluna	30.7 (5.3)	25
	Vaccinium	28.5 (5.0)	24
EGIL	Calluna	25.0 (3.9)	25
ROLF[2]	Calluna	22.2 (4.3)	25
	Vaccinium	22.0 (6.1)	25

[1] Standard deviation in parentheses
[2] Reference catchment used in the RAIN project

N mineralization was measured in Calluna and Vaccinium plots in the control and treatment sections of KIM and EGIL as well as in METTE. Measurements have been carried out for eleven months divided in five periods. The total N mineralization after eleven months is given in Table 4. Parameters that might cause differences in mineralization rate are soil moisture content, soil depth and temperature. The importance of the separate parameters in explaining the differences found, will be obtained by means of multiple regression analysis.

Table 4. Total N mineralization

		Control[1]	Treatment
KIM	Calluna	3.6 (0.9)	2.2 (0.5)
	Vaccinium	3.8 (1.0)	3.5 (0.7)
EGIL	Calluna	3.1 (0.4)	5.7 (0.7)
METTE	Calluna	3.1 (0.5)	
	Vaccinium	3.8 (0.8)	

[1] N mineralization in g/m^2, standard error of the mean in parentheses, n=10

In all catchments, lysimeters are installed under the litter layer, in the organic soil and in the mineral subsoil. Sampling of soil solution has been carried out 6 times. Differences in chemical composition of the runoff between the catchments as a result of the different rain treatments are also clearly visible in the soil solution. With the use of precipitation, runoff and soil moisture data, element fluxes through the soil will be calculated.

Background gas exchange measurements

D.J. Beerling & F.I. Woodward (US)

Aims The existence of a roof over Kim catchment for the past 8 years made it important to characterise its effect on the gas exchange of the vegetation. In doing this we also sought to obtain a set of background data against which measurements made under the imposed elevated CO_2 and temperature could be compared.

Methods The work focused on the two dominant tree species of the system, birch (*Betula pubescens*) and Pine (*Pinus sylvestris*), and the dwarf ground shrub bilberry (*Vaccinium myrtillus*). Daily gas exchange measurements were in July and August in Kim (roofed) and Mette (no roof) catchments on each species. We also characterised the efficiency of carbon uptake by constructing A/ci curves. All measurements were made on clear sunny days with a portable infra-red gas analyser.

Result and discussion

Microclimate

In general, plants in Mette received a greater quantity of photosynthetically active radiation(400-700 nm) than in Kim, confirming observations of established sensors. Leaf temperatures of all three species were highest in Kim, especially at around mid-day. This effect was probably the result of the large roof which, when warmed, radiated heat back towards the vegetation. At the height of the dwarf shrubs the effect was greatly diminished.

Gas exchange

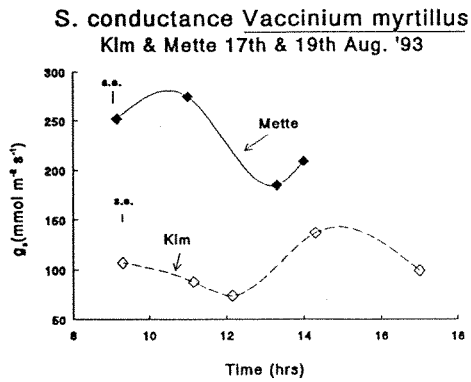
The stomatal conductances of each species were consistently lower for plants growing in Kim compared with Mette (e.g. Fig. 3a). Lower conductances in *V. myrtillus* might be attributable to lower stomatal density of leaves within Kim (abaxial values: 160mm-2 in Kim and 220mm-2 in Mette). Additional causative factors may have been the lower light levels, lower soil moisture and/or changes in wind speed. Future measurements of wind speed and soil moisture will help to determine the most likely causative agent. Daily patterns of photosynthesis in Kim and Mette did not vary in a consistent manner in any of the species, except in *V. myrtillus* (Fig. 3b). A/ci responses were also similar in Kim and Mette for the two tree species but different for *V. myrtillus*. These results suggest that *B. pubsescens* and *P. sylvestris* have acclimated to the lower light levels in Kim and that *V. myrtillus* has not yet done so.

Future work

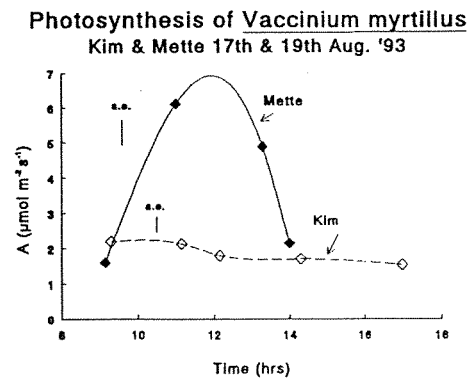
Continued measurements of gas exchange processes are required to assess the effects of the Kim elevated CO2 and temperature treatment. Vertical profiles of gas exchange will be made in Kim to characterise any heating effects from the roof on the larger individuals of *Betula* and *Pinus*. These measurements will provide an important test of model predictions made earlier in the programme.

Figure 3. Typical examples of the daily course of (a) stomatal conductance and (b) photosynthesis of *Vaccinium myrtillus* inside and outside Kim. Note that lower conductances and photosynthetic rates of leaves in Kim can be due to different environmental conditions. Both will also be influenced by differences in stomatal density of the leaves which exist in plants growing in the different catchments.

(a)



(b)



Tree Nutrient Status and growth

E.D. Schultze (UB)

No samples or measurements were taken in autumn 1993 because of the disturbance of construction and because it was decided to wait until an apparatus was available to access the crowns. Earlier data collected by NIVA staff in 1990 and 1991 and within CLIMEX in 92/93 has been evaluated.

Results

(i) Size distribution of trees

The KIM catchment and the METTE catchment show similar size distribution of trees, while the EGIL and ROLF catchments are different.

(ii) Height growth of pinus

Height growth was strongly enhanced in the KIM catchment when compared to the EGIL catchment and the ROLF catchment, but this was in part due to the fact that trees were taller in the KIM catchment and reached the warmer region directly below the roof. However, smaller trees also showed enhanced growth in KIM, despite this, we are not sure that this is a clean rain effect because the enhanced growth starts in the year after initial construction. There is no lag-period as would have been expected from soil chemistry.

(iii) Nutrition

It is important to see that the interpretation of nutrient data will depend on the type of sampling (close to ground or close to roof) but also on the underlying time-sequence. If different age classes are compared, which are collected at one time (eg in year 92) the result is different from a comparison in which the same shoot is followed over time. Magnesium contents were different between the KIM and EGIL roofs if we compare different aged needles at one time, but the difference disappears if we follow the same shoot over time. We interpret this result such that special conditions are different between years, which creates differences in needle nutrition. The main factor in this respect is water stress and it appears that the irrigation in dry summer in the KIM catchment may have caused the effects.

One-way ANOVA showed apparent significant differences for nitrogen, calcium, potassium and sodium between KIM and EGIL, but there was no significant difference between KIM nor EGIL and ROLF. From this we must conclude that the effect of clean rain was not significant, but that special conditions created an apparent difference between two roofs. This apparent difference is also to do with sample size.

Soil fauna experiments

Madelein J. Vreeken-Buijs (IB) and Lijbert Brussaard (AUW)

From June to December 1993 detailed plans and preparations were made for the three main experiments, due to start April 1994:

I. Field experiment

a. Litterbag study

Litterbags will be filled with 4 g birch litter. Half of the bags will have a mesh size of 1.5 mm and half will have a mesh size of 40 µm (top and bottom) to exclude soil meso- and macrofauna. The bags will be placed in the study catchments and sampled at half year intervals. After sampling the weight loss, loss of nutrients (N and P), C:N ratio and lignin:N ratio of the litter will be assessed and faunal groups counted.

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In April 1993 750 one-year-old *Betula pubescens* trees were potted and grown in glass-houses, one with ambient CO_2 level and two with raised CO_2 level. Temperature was the same in all three glass-houses. Half of the plants received water with the same composition as the treatment in the KIM catchment (clean precipitation) and the other half water with the same composition as in the EGIL catchment (ambient precipitation). Of the leaves, collected in July (first leaf collection), October and November (last leaf collection), samples were analyzed for C and N content and lignin content (Nov. samples only). The November results are presented in Table 5. There was a significant effect of the CO_2 level on the N content and the C/N ratio (Fprob < 5%) of the leaves collected October 4, though not on the C content. This effect was not found in the first leaves collected. No significant effect of the water composition was found on the chemical composition of the leaves nor on the total yield (dry weight). The CO_2 level also had a significant effect on the total yield of the leaves (Fprob < 5%). No interaction between the CO_2 level and the water composition was found.
In preparation of the litterbag study I paid a visit to the Risdalsheia field site in September. Undisturbed soil samples for microarthropod extraction were collected from the KIM catchment and from four different catchments with resembling vegetation in the vicinity (Fig. 4). In another area traps containing 4% formaldehyde solution were dug in for one night to capture macroarthropods. In 13 traps 21 macro-arthropods were captured, consisting of coleoptera (8), spiders (8) and ants (5). Nematodes were extracted from mixed soil samples using the wet Tullgren extraction method. On average 350 nematodes per g dry soil were counted.

II. Laboratory experiments

a. Mesocosm experiment

The aim of this experiment is to study the effect of soil mesofauna on the decomposition and nutrient release of birch litter under controlled conditions. To study the effect of a complete soil ecosystem, opposed to a soil ecosystem lacking the mesofauna, hard polyethylene boxes

are filled with a layer of washed sand, separated by a mesh screen from a layer of humus to mimic the soil at the field sites. Birch litter is packed in 6 cm diameter sieves. Six sieves ("microcosms") per box ("mesocosm") are inserted into the humus. These boxes are partially sterilized and half of the boxes are reinoculated with soil microarthropods. The boxes are incubated under eight different climate conditions (two temperature levels, two CO_2 levels and two nutrient levels). During the incubation the sieves will be taken out at regular intervals to be flushed in a mini-lysimeter and the sampled moisture will be chemically analyzed. Soil moisture in the humus layer will be sampled by soil solution samplers. Every six months boxes will be destructively sampled and weight loss of the litter, fauna content of litter and humus, KCl-extractable N and P of litter and humus, C:N and C:lignin ratio of the litter will be determined.

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In order to decide on the method for defaunation of the soil, the method to refaunate the soil and the practice of leaching of both humus and litter a pilot experiment was started in October using 400-ml plastic pots. The pots were filled with a layer of sand and 5 cm humus from the field site or a same amount of garden peat to investigate whether an alternative organic substrate could be used.
In the humus/peat one sieve per pot was inserted filled with birch litter. The prepared pots were defaunated by freezing (-40°C, 2x24 hr) or by drying (4x24 hr, 45°C). Part of these pots were refaunated with approximately equal numbers of microarthropods. At t = 0 the efficiency of the defaunation and of the refaunated pots was checked by comparison with untreated pots. The remaining pots were incubated at 20°C. All pots were leached (humus/peat and sieves with leaves separately) after 0, 2, 4, 8 and 12 weeks and NH_4^+-N and NO_3^--N of the leachates was measured. Pots were destructively sampled at weeks 0, 4 and 12, when microarthropods were extracted from both the humus/peat and the leaves and weight loss of the leaves was determined. At week 12 both leaves and humus/peat were also extracted with 1M KCl to check on remaining mineral N. Comparison of the defaunation methods showed that the freezing method was slightly more effective than the oven-drying method. We expect the defaunation to be complete if a temperature of -40°C can be reached. The leaching results were an other reason to choose for the freezing method. They showed that the oven treatment caused 7 times higher N-mineralization at t = 0 as compared to the freezer treatment and the untreated pots.

b. Plant uptake experiment

The aim of this experiment is to study the effect of the soil mesofauna on the uptake of N and P from litter by birch seedlings under controlled conditions. Plastic pots are filled with humus and a known amount of birch litter. The prepared pots are partially sterilized, after which half of the pots are reinoculated with microarthropods. Betula seedlings are planted in the pots and incubated in a glass-house under 8 different climate conditions. At half year intervals trees will be destructively sampled and dry mass and nutrient status of the plant parts, the humus and the remaining litter will be determined.

Table 5. Average leaf C, N and lignin content of glass-house grown birch trees (n=4 (700 ppm);n=2 (350 ppm))
Leaf sampling date: November 10 1993

Water	CO_2 (ppm)	%C	%N	C/N	%Lignin	Lignin/N
clean	700	37.55	0.45	85.1	15.49	34.4
clean	350	38.05	0.56	68.7	16.72	29.9
ambient	700	37.40	0.41	90.8	15.86	38.7
ambient	350	37.60	0.46	81.8	16.17	35.2

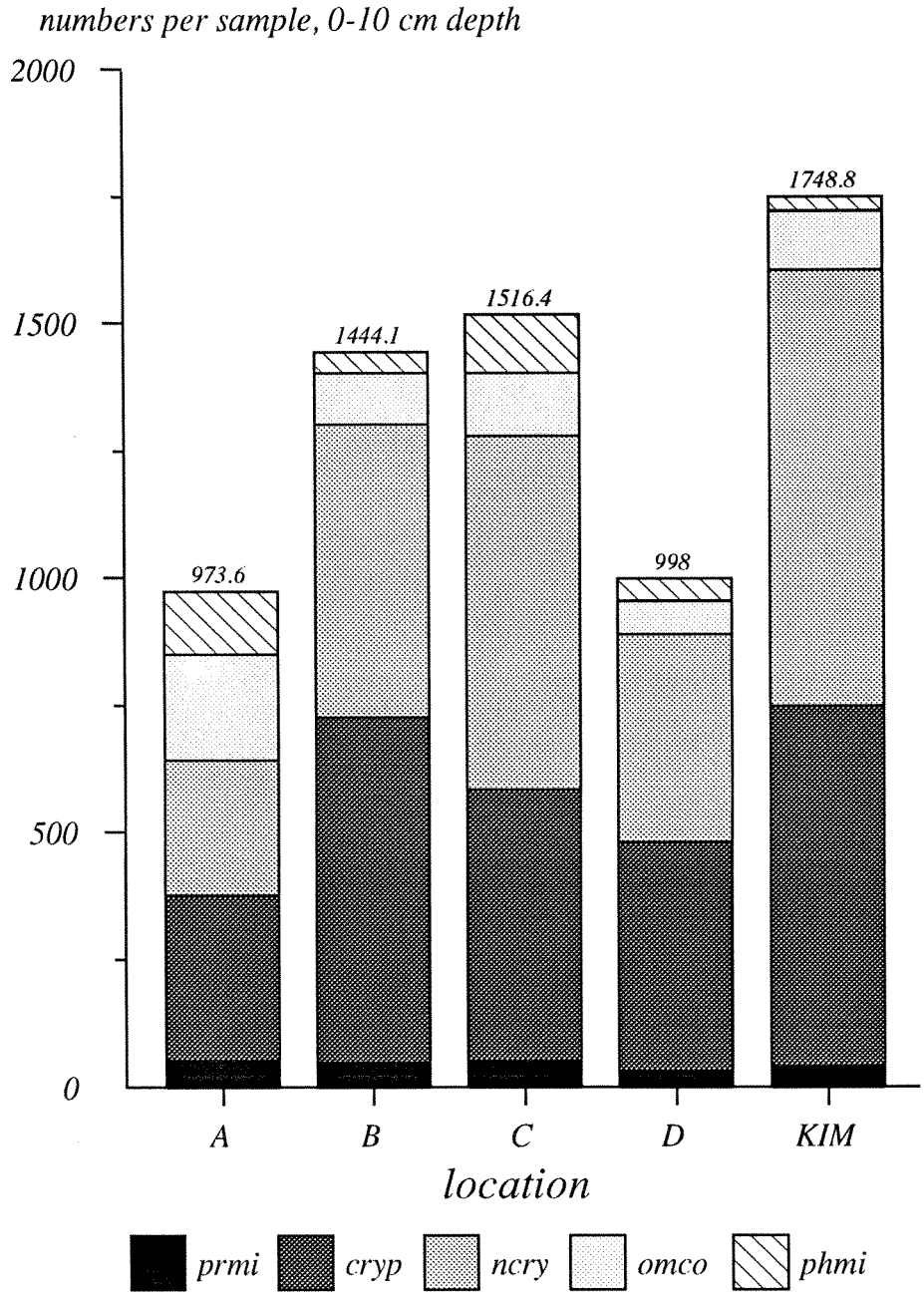


Fig. 4. Field sampling Risdalsheia September 28, 1993: microarthropod numbers
Functional groups: prmi: predatory mites
cryp: cryptostigmatic mites
ncry: non-cryptostigmatic mites
omco: omnivorous collembola
phmi: phytophagous mites
Locations: A, B, C and D: catchments in the vicinity of the study area (n = 3)
KIM: the roofed catchment, clean precipitation (n = 2)

APPENDIX

Input-output budgets for 3 catchments (KIM - roof, clean rain; EGIL - roof,acid rain: ROLF - no roof, acid rain) at Risdalsheia for the summer (18 May - 11 December 1992), winter (12 December 1992 - 14 May 1993) and year (18 May 1992 - 14 May 1993)

Figure 5. Mean soil and air temperatures for KIM , EGIL and ROLF

Climex publication list (to date)

Flux and concentrations (units meq/m2/yr and ueq/l)

KIM summer 92, 18 May 92 to 11 Dec 92

	Input					Output		concentrations		
	Wet	mar.	Dry part.	gases	subtot.	Total		Wet	In Total	Out
H2O	721.4					721	646	H2O		
H+	0.0	0.0	1.0	19.0	20.0	20.0	36	H+	0.0	27.7	55.7
Na	7.6	32.6	0.0	0.0	32.6	40.3	49	Na	10.6	55.8	75.9
K	0.2	0.7	0.0	0.0	0.7	0.9	1	K	0.2	1.2	1.5
Ca	0.3	1.4	0.0	0.0	1.4	1.7	4	Ca	0.5	2.4	6.2
Mg	3.2	7.5	0.0	0.0	7.5	10.7	7	Mg	4.4	14.8	10.8
Al	0.0	0.0	0.0	0.0	0.0	0.0	3	Al	0.0	0.0	4.6
NH4	0.0	0.0	4.0	0.0	4.0	4.0	2	NH4	0.0	5.5	3.1
NO3	0.0	0.0	0.0	11.0	11.0	11.0	2	NO3	0.0	15.2	3.1
Cl	8.9	38.1	0.0	0.0	38.1	47.0	47	Cl	12.3	65.2	72.8
SO4	0.9	3.9	5.0	8.0	16.9	17.8	14	SO4	1.3	24.7	21.7
A-	1.5	0.2	0	0	0.2	1.7	39	A-	2.1	2.3	60.4
sum+	11.32	42.18	5	19	66.2	77.5	102	sum+	15.7	107.4	157.9
sum-	11.32	42.18	5	19	66.2	77.5	102	sum-	15.7	107.4	157.9
SBC	11.32	42.18	4	0	46.2	57.5	63	SBC	15.7	79.7	97.5
SSA	9.811	42.03	5	19	66.0	75.8	63	SSA	13.6	105.1	97.5
alk	1.508	0.152	-1	-19	-19.8	-18.3	0	alk	2.1	-25.4	0.0
TOC							10.3	TOC	0.0	0.0	15.9
SiO2							1.4	SiO2	0.0	0.0	2.2
c.d.							3.79	c.d.	0.00	0.00	3.79
RAL							192	RAL			297.2
ILAL							162	ILAL			250.8
TOTN							304	TOTN			470.6

Flux and concentrations (units meq/m2/yr and ueq/l)

KIM winter 93, 12 Dec 92 to 14 May 93

	Input				Total	Output		concentrations		
	Wet	Dry						Wet	In	Out
		mar.	part.	gases	subtot.				Total	
H2O	264.1					264.1	217.7	H2O		
H+	0.0	0.0	0.0	0.0	0.0	0.0	12.2	H+	0.0	0.0	55.9
Na	12.4	10.9	0.0	0.0	10.9	23.2	21.9	Na	46.8	88.0	100.6
K	0.3	0.2	0.0	0.0	0.2	0.5	0.8	K	1.0	1.9	3.7
Ca	0.5	0.5	0.0	0.0	0.5	1.0	2.4	Ca	2.0	3.8	11.2
Mg	2.8	2.5	0.0	0.0	2.5	5.3	4.1	Mg	10.7	20.2	18.8
Al	0.0	0.0	0.0	0.0	0.0	0.0	1.4	Al	0.0	0.0	6.6
NH4	0.0	0.0	0.0	0.0	0.0	0.0	0.6	NH4	0.0	0.0	2.6
NO3	0.0	0.0	0.0	0.0	0.0	0.0	1.5	NO3	0.0	0.0	6.7
Cl	14.4	12.7	0.0	0.0	12.7	27.1	27.1	Cl	54.6	102.7	124.6
SO4	1.5	1.3	0.0	0.0	1.3	2.8	7.6	SO4	5.6	10.6	35.0
A-	0.1	0.1	0.0	0.0	0.1	0.2	7.2	A-	0.4	0.6	33.1
sum+	16.0	14.1	0.0	0.0	14.1	30.1	43.4	sum+	60.6	113.9	199.4
sum-	16.0	14.1	0.0	0.0	14.1	30.1	43.4	sum-	60.6	113.9	199.4
SBC	16.0	14.1	0.0	0.0	14.1	30.1	29.8	SBC	60.6	113.9	136.9
SSA	15.9	14.0	0.0	0.0	14.0	29.9	36.2	SSA	60.2	113.3	166.3
alk	0.1	0.1	0.0	0.0	0.1	0.2	-6.4	alk	0.4	0.6	-29.4
TOC							2.4	TOC			11.1
SiO2							0.5	SiO2			2.4
c.d.							3.0	c.d.			3.0
RAL							59.4	RAL			273.0
ILAL							45.0	ILAL			206.8
TOTN							108.1	TOTN			496.7

Flux and concentrations (units meq/m2/yr and ueq/l)

KIM year 92-93, 18 May 1992 to 14 May 1993

	Input					Output		concentrations		
	Wet	mar.	Dry part.	gases	subtot.	Total		Wet	In Total	Out
H2O	985.5					985.5	863.7	H2O	986	986	986
H+	0.0	0.0	1.0	19.0	20.0	20.0	48.2	H+	0.0	20.3	55.8
Na	20.0	43.5	0.0	0.0	43.5	63.5	70.9	Na	20.3	64.4	82.1
K	0.4	0.9	0.0	0.0	0.9	1.4	1.8	K	0.4	1.4	2.1
Ca	0.9	1.9	0.0	0.0	1.9	2.8	6.4	Ca	0.9	2.8	7.5
Mg	6.0	10.0	0.0	0.0	10.0	16.0	11.1	Mg	6.1	16.2	12.8
Al	0.0	0.0	0.0	0.0	0.0	0.0	4.4	Al	0.0	0.0	5.1
NH4	0.0	0.0	4.0	0.0	4.0	4.0	2.6	NH4	0.0	4.1	3.0
NO3	0.0	0.0	0.0	11.0	11.0	11.0	3.5	NO3	0.0	11.2	4.0
Cl	23.3	50.8	0.0	0.0	50.8	74.1	74.1	Cl	23.6	75.2	85.8
SO4	2.4	5.2	5.0	8.0	18.2	20.6	21.6	SO4	2.4	20.9	25.0
A-	1.6	0.2	0.0	0.0	0.2	1.8	46.2	A-	1.6	1.8	53.5
sum+	27.3	56.3	5.0	19.0	80.3	107.6	145.4	sum+	27.7	109.2	168.4
sum-	27.3	56.3	5.0	19.0	80.3	107.6	145.4	sum-	27.7	109.2	168.4
SBC	27.3	56.3	4.0	0.0	60.3	87.6	92.8	SBC	27.7	88.9	107.4
SSA	25.7	56.1	5.0	19.0	80.1	105.8	99.2	SSA	26.1	107.3	114.8
alk	1.6	0.2	-1.0	-19.0	-19.8	-18.2	-6.4	alk	1.6	-18.5	-7.4
TOC							12.7	TOC			14.7
SiO2							1.9	SiO2			2.2
c.d.							3.6	c.d.			3.6
RAL							251.4	RAL			291.1
ILAL							207.0	ILAL			239.7
TOTN							412.1	TOTN			477.2

Flux and concentrations (units meq/m2/yr and ueq/l)
EGIL summer 92 18 May 92 to 11 Dec 92

	Input					Output		concentrations		
	Wet	mar.	Dry part.	gases	subtot.	Total			Wet	In Total	Out
H2O	827.2					827	752	H2O			
H+	37.9	0.0	1.0	19.0	20.0	57.9	55	H+	45.8	70.0	73.1
Na	45.3	11.5	0.0	0.0	11.5	56.7	55	Na	54.7	68.6	73.1
K	2.1	0.2	0.0	0.0	0.2	2.3	2	K	2.5	2.8	2.7
Ca	7.4	0.5	0.0	0.0	0.5	7.9	8	Ca	8.9	9.5	10.6
Mg	10.3	2.6	0.0	0.0	2.6	12.9	12	Mg	12.4	15.6	16.0
Al	0.0	0.0	0.0	0.0	0.0	0.0	5	Al	0.0	0.0	6.6
NH4	19.5	0.0	4.0	0.0	4.0	23.5	2	NH4	23.5	28.4	2.7
NO3	27.7	0.0	0.0	11.0	11.0	38.7	15	NO3	33.5	46.8	19.9
Cl	49.6	13.4	0.0	0.0	13.4	63.0	63	Cl	60.0	76.2	83.8
SO4	51.7	1.4	5.0	8.0	14.4	66.0	46	SO4	62.4	79.8	61.2
A-	-6.6	0.1	0	0	0.1	-6.5	15	A-	-8.0	-7.9	19.9
sum+	122.4	14.83	5	19	38.8	161.2	139	sum+	147.9	194.9	184.8
sum-	122.4	14.83	5	19	38.8	161.2	139	sum-	147.9	194.9	184.8
SBC	84.45	14.83	4	0	18.8	103.3	79	SBC	102.1	124.9	105.1
SSA	129	14.78	5	19	38.8	167.7	124	SSA	155.9	202.8	164.9
alk	-44.5	0.054	-1	-19	-19.9	-64.5	-45	alk	-53.8	-77.9	-59.8
TOC							7.7	TOC	0.0	0.0	10.2
SiO2							1.9	SiO2	0.0	0.0	2.5
c.d.							1.95	c.d.	0.00	0.00	1.95
RAL							200	RAL			266.0
ILAL							150	ILAL			199.5
TOTN							452	TOTN			601.1

Flux and concentrations (units meq/m2/yr and ueq/l)
EGIL winter 93 12 Dec 92 to 14 May 93

	Input					Output			concentrations		
	Wet	mar.	Dry part.	gases	subtot.	Total			Wet	In Total	Out
H2O	291.5					291.5	253.9	H2O			
H+	16.4	0.0	0.0	0.0	0.0	16.4	23.2	H+	56.3	56.3	91.2
Na	34.0	9.0	0.0	0.0	9.0	43.0	40.6	Na	116.5	147.4	159.7
K	1.2	0.2	0.0	0.0	0.2	1.4	1.0	K	4.0	4.7	4.1
Ca	2.3	0.4	0.0	0.0	0.4	2.7	5.0	Ca	7.9	9.3	19.8
Mg	7.6	2.1	0.0	0.0	2.1	9.7	8.1	Mg	26.2	33.3	32.0
Al	0.0	0.0	0.0	0.0	0.0	0.0	3.7	Al	0.0	0.0	14.4
NH4	9.5	0.0	0.0	0.0	0.0	9.5	1.5	NH4	32.5	32.5	6.0
NO3	12.0	0.0	0.0	0.0	0.0	12.0	8.3	NO3	41.3	41.3	32.6
Cl	40.1	10.5	0.0	0.0	10.5	50.6	50.6	Cl	137.6	173.7	199.3
SO4	21.1	1.1	0.0	0.0	1.1	22.2	25.4	SO4	72.5	76.2	100.1
A-	-2.3	0.0	0.0	0.0	0.0	-2.3	-1.2	A-	-7.9	-7.7	-4.8
sum+	71.0	11.6	0.0	0.0	11.6	82.6	83.1	sum+	243.4	283.3	327.2
sum-	71.0	11.6	0.0	0.0	11.6	82.6	83.1	sum-	243.4	283.3	327.2
SBC	54.6	11.6	0.0	0.0	11.6	66.2	56.3	SBC	187.1	227.1	221.6
SSA	73.3	11.6	0.0	0.0	11.6	84.9	84.3	SSA	251.3	291.1	332.0
alk	-18.7	0.0	0.0	0.0	0.0	-18.7	-28.1	alk	-64.2	-64.0	-110.5
TOC							1.3	TOC			5.0
SiO2							0.9	SiO2			3.5
c.d.							-0.9	c.d.			-0.9
RAL							66.6	RAL			262.2
ILAL							29.9	ILAL			117.9
TOTN							167.0	TOTN			657.7

Flux and concentrations (units meq/m2/yr and ueq/l)
EGIL year 92-93 18 May 1992 to 14 May 1993

	Input				Total	Output		concentrations In	Out
	Wet	mar.	Dry part.	gases	subtot.			Wet	Total	
H2O	1118.7					1118.7	1005.9			
								H2O	1119	1119	1006
H+	54.3	0.0	1.0	19.0	20.0	74.3	78.2	H+	48.6	66.4	77.7
Na	79.2	20.5	0.0	0.0	20.5	99.7	95.6	Na	70.8	89.1	95.0
K	3.2	0.4	0.0	0.0	0.4	3.7	3.0	K	2.9	3.3	3.0
Ca	9.7	0.9	0.0	0.0	0.9	10.6	13.0	Ca	8.7	9.5	13.0
Mg	17.9	4.7	0.0	0.0	4.7	22.6	20.1	Mg	16.0	20.2	20.0
Al	0.0	0.0	0.0	0.0	0.0	0.0	8.7	Al	0.0	0.0	8.6
NH4	28.9	0.0	4.0	0.0	4.0	32.9	3.5	NH4	25.9	29.5	3.5
NO3	39.7	0.0	0.0	11.0	11.0	50.7	23.3	NO3	35.5	45.4	23.1
Cl	89.7	23.9	0.0	0.0	23.9	113.6	113.6	Cl	80.2	101.6	113.0
SO4	72.8	2.5	5.0	8.0	15.5	88.2	71.4	SO4	65.1	78.9	71.0
A-	-8.9	0.1	0.0	0.0	0.1	-8.8	13.8	A-	-7.9	-7.9	13.7
sum+	193.3	26.5	5.0	19.0	50.5	243.8	222.1	sum+	172.8	217.9	220.8
sum-	193.3	26.5	5.0	19.0	50.5	243.8	222.1	sum-	172.8	217.9	220.8
SBC	139.0	26.5	4.0	0.0	30.5	169.5	135.3	SBC	124.2	151.5	134.5
SSA	202.2	26.4	5.0	19.0	50.4	252.6	208.3	SSA	180.8	225.8	207.1
alk	-63.2	0.1	-1.0	-19.0	-19.9	-83.1	-73.1	alk	-56.5	-74.3	-72.6
TOC							9.0	TOC	mgC/l		8.9
SiO2							2.8	SiO2	mgSiO2/l		2.8
c.d.							1.5	c.d.			1.5
RAL							266.6	RAL	ÁgAl/l		265.0
ILAL							179.9	ILAL	ÁgAl/l		178.9
TOTN							619.0	TOTN	Ámol/l		615.4

Flux and concentrations (units meq/m2/yr and ueq/l)

ROLF summer 92, 18 May 92 to 11 Dec 92

	Input					Output		concentrations		
	Wet	mar.	Dry part.	gases	subtot.	Total		Wet	In Total	Out
H2O	896.5					897	754	H2O		
H+	41.5	0.0	1.0	19.0	20.0	61.5	56	H+	46.3	68.6	74.3
Na	47.1	29.9	0.0	0.0	29.9	76.9	81	Na	52.5	85.8	107.4
K	2.1	0.6	0.0	0.0	0.6	2.7	12	K	2.4	3.1	15.9
Ca	7.3	1.3	0.0	0.0	1.3	8.5	9	Ca	8.1	9.5	11.9
Mg	10.8	6.8	0.0	0.0	6.8	17.6	18	Mg	12.0	19.6	23.9
Al	0.0	0.0	0.0	0.0	0.0	0.0	5	Al	0.0	0.0	6.6
NH4	20.1	0.0	4.0	0.0	4.0	24.1	10	NH4	22.5	26.9	13.3
NO3	29.8	0.0	0.0	11.0	11.0	40.8	13	NO3	33.2	45.5	17.2
Cl	52.1	34.9	0.0	0.0	34.9	87.0	87	Cl	58.1	97.0	115.4
SO4	47.8	3.6	5.0	8.0	16.6	64.4	62	SO4	53.4	71.9	82.2
A-	-0.9	0.1	0	0	0.1	-0.8	29	A-	-1.0	-0.9	38.5
sum+	128.8	38.63	5	19	62.6	191.4	191	sum+	143.7	213.5	253.3
sum-	128.8	38.63	5	19	62.6	191.4	191	sum-	143.7	213.5	253.3
SBC	87.32	38.63	4	0	42.6	130.0	130	SBC	97.4	145.0	172.4
SSA	129.7	38.49	5	19	62.5	192.2	162	SSA	144.7	214.4	214.9
alk	-42.4	0.14	-1	-19	-19.9	-62.3	-32	alk	-47.3	-69.5	-42.4
TOC							10.2	TOC	0.0	0.0	13.5
SiO2							1.6	SiO2	0.0	0.0	2.1
c.d.							2.84	c.d.	0.00	0.00	2.84
RAL							199	RAL			263.9
ILAL							149	ILAL			197.6
TOTN							558	TOTN			740.1

Flux and concentrations (units meq/m2/yr and ueq/l)

ROLF winter 93 12 Dec 92 to 14 May 93

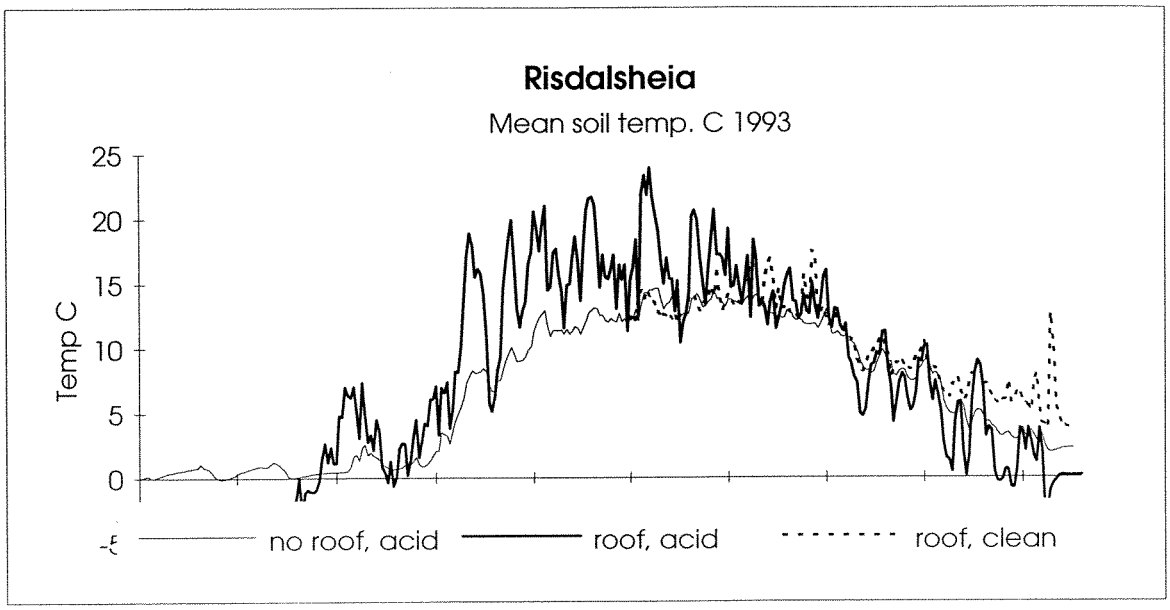
	Input				Total	Output		concentrations		
	Wet	Dry mar.	Dry part.	gases	subtot.			Wet	In Total	Out
H2O	333.1					333.1	268.4	H2O			
H+	16.5	0.0	0.0	0.0	0.0	16.5	28.0	H+	49.5	49.5	104.3
Na	74.6	11.4	0.0	0.0	11.4	86.0	77.9	Na	223.9	258.2	290.2
K	2.8	0.2	0.0	0.0	0.2	3.1	4.9	K	8.5	9.2	18.1
Ca	5.6	0.5	0.0	0.0	0.5	6.1	7.6	Ca	16.9	18.4	28.4
Mg	16.2	2.6	0.0	0.0	2.6	18.8	17.2	Mg	48.6	56.5	64.2
Al	0.0	0.0	0.0	0.0	0.0	0.0	2.9	Al	0.0	0.0	10.8
NH4	23.3	0.0	0.0	0.0	0.0	23.3	8.3	NH4	69.9	69.9	30.9
NO3	22.3	0.0	0.0	0.0	0.0	22.3	12.0	NO3	67.0	67.0	44.9
Cl	89.3	13.4	0.0	0.0	13.4	102.7	102.7	Cl	268.2	308.3	382.7
SO4	32.3	1.4	0.0	0.0	1.4	33.7	32.9	SO4	97.0	101.1	122.6
A-	-5.0	0.1	0.0	0.0	0.1	-4.9	-0.9	A-	-14.9	-14.7	-3.2
sum+	139.0	14.8	0.0	0.0	14.8	153.8	146.8	sum+	417.3	461.7	546.9
sum-	139.0	14.8	0.0	0.0	14.8	153.8	146.8	sum-	417.3	461.7	546.9
SBC	122.5	14.8	0.0	0.0	14.8	137.3	115.9	SBC	367.8	412.2	431.8
SSA	144.0	14.7	0.0	0.0	14.7	158.7	147.6	SSA	432.2	476.5	550.1
alk	-21.4	0.1	0.0	0.0	0.1	-21.4	-31.8	alk	-64.4	-64.2	-118.3
TOC							1.5	TOC			5.5
SiO2							0.3	SiO2			1.1
c.d.							-0.6	c.d.			-0.6
RAL							60.0	RAL			223.5
ILAL							30.9	ILAL			115.3
TOTN							345.6	TOTN			1287.7

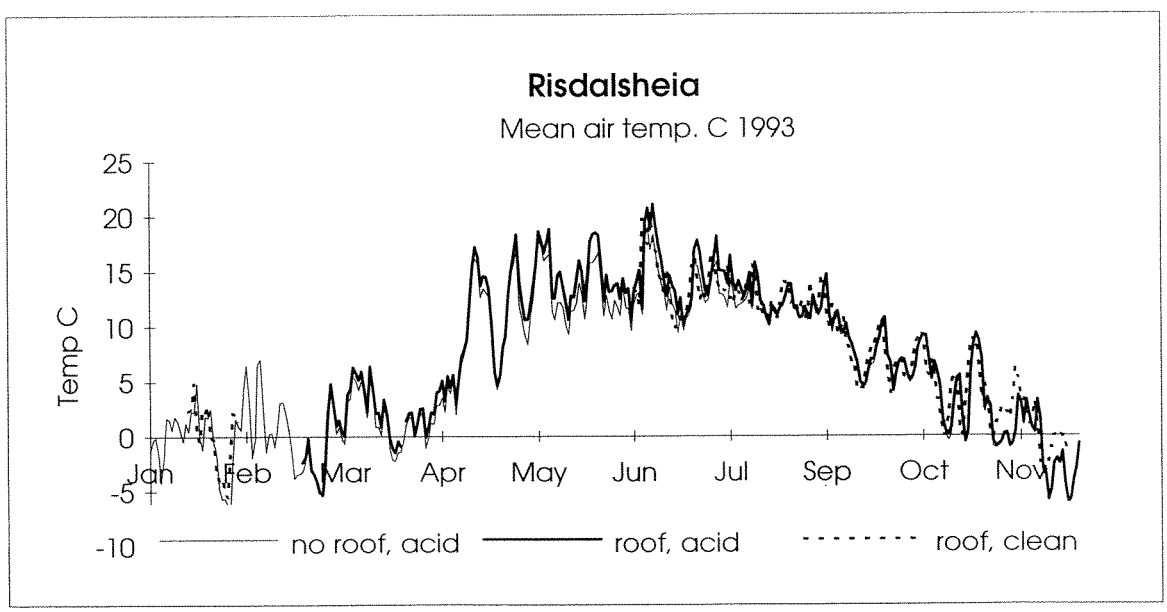
Flux and concentrations (units meq/m2/yr and ueq/l)
ROLF year 92-93 18 May 1992 to 14 May 1993

	Input					Output			concentrations		
	Wet	mar.	Dry part.	gases	subtot.	Total			Wet	In Total	Out
H2O	1229.6					1229.6	1022.4	H2O	1230	1230	1022
H+	58.0	0.0	1.0	19.0	20.0	78.0	84.0	H+	47.1	63.4	82.2
Na	121.6	41.3	0.0	0.0	41.3	162.9	158.9	Na	98.9	132.5	155.4
K	4.9	0.9	0.0	0.0	0.9	5.8	16.9	K	4.0	4.7	16.5
Ca	12.9	1.8	0.0	0.0	1.8	14.7	16.6	Ca	10.5	11.9	16.2
Mg	27.0	9.5	0.0	0.0	9.5	36.4	35.2	Mg	21.9	29.6	34.5
Al	0.0	0.0	0.0	0.0	0.0	0.0	7.9	Al	0.0	0.0	7.7
NH4	43.4	0.0	4.0	0.0	4.0	47.4	18.3	NH4	35.3	38.6	17.9
NO3	52.1	0.0	0.0	11.0	11.0	63.1	25.0	NO3	42.4	51.3	24.5
Cl	141.4	48.3	0.0	0.0	48.3	189.7	189.7	Cl	115.0	154.3	185.6
SO4	80.1	5.0	5.0	8.0	18.0	98.1	94.9	SO4	65.2	79.8	92.8
A-	-5.9	0.2	0.0	0.0	0.2	-5.7	28.1	A-	-4.8	-4.6	27.5
sum+	267.8	53.4	5.0	19.0	77.4	345.2	337.8	sum+	217.8	280.8	330.4
sum-	267.8	53.4	5.0	19.0	77.4	345.2	337.8	sum-	217.8	280.8	330.4
SBC	209.9	53.4	4.0	0.0	57.4	267.3	245.9	SBC	170.7	217.4	240.5
SSA	273.7	53.2	5.0	19.0	77.2	350.9	309.6	SSA	222.6	285.4	302.9
alk	-63.9	0.2	-1.0	-19.0	-19.8	-83.7	-63.8	alk	-51.9	-68.0	-62.4
TOC							11.7	TOC			11.4
SiO2							1.9	SiO2			1.8
c.d.							2.4	c.d.			2.4
RAL							259.0	RAL			253.3
ILAL							179.9	ILAL			176.0
TOTN							903.6	TOTN			883.8

Figure 5. Mean soil and air temperatures for KIM, EGIL and ROLF

In summer, the soil temperature in KIM (roof, fully enclosed, clean) is lower than either of the other two catchments as a result of decreased solar radiation. However, in the winter months soil temperature is highest in KIM due to a decrease in net radiative loss through the roof and walls, this is reflected in slightly higher air temperatures in Kim at this time of year.





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1) Jenkins,A., Schulze,E.D., van Breemen,N., Woodward,F.I. and Wright,R.F. 1992. CLIMEX - climate change experiment. In, Teller,A., Mathy,P. and Jeffers,J.N.R. (Eds) Responses of Forest Ecosystems To Environmental Changes. Elsevier, London.

2) Jenkins,A., Wright,R.F., Berendse,F., van Breeman,N., Brussard,L., Schulze,E.D. and Woodward, F.I. 1993. The CLIMEX project - climate change experiment. In, Experimental Manipulations of Biota and Biogeochemical Cycling in Ecosystems. EC Ecosystem Research Report (In Press)

3) Jenkins,A. and Wright,R.F. 1993. The CLIMEX project - raising CO_2 and temperature to whole catchment ecosystems. In, Schulze,E.D. and Mooney,H.A. (Eds) The design and Execution of Experiments on CO_2 Enrichment. (In Press).

4)Arp,W.and Berendse,F. 1993. Plant growth and nutrient cycling in nutrient-poor ecosystems. In, van de Geijn,S.C., Goudriaan,J. and Berendse,F. (Eds) Climate Change; crops and terrestrial ecosystems. CABO-DLO, Wageningen, 109-121

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1/1995 Jenkins, A. (ed). 1995. CLIMEX Climate Change Experiment: Progress Report December 1992 - June 1993. 12 pp.

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3/1995 Dise, N. B., and Jenkins, A. (eds). 1995. The CLIMEX project: Whole catchment Manipulation of CO_2 and Temperature. 130 pp.

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5/1995 Wright, R.F., Indrøy, A-S., Høgberget, R., Lükewille, A., Sørvåg, T., and Willbergh, M. 1995. CLIMEX Project. Climate data for first year of treatment April 1994 - March 1995. 21 pp.

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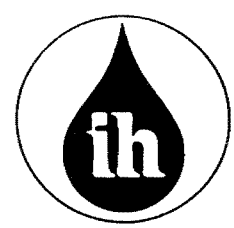

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