CLIMATE CHANGE RESEARCH

REPORT 4/1995

CLIMEX project: Final report on Phase I the first year of treatment

May 1994 - December 1994

NIVA

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NIVA - REPORT

Norwegian Institute for Water Research NIVA

Report No.:	Sub-No.:
4/1995	
Serial No.:	Limited distrib.:
3392-96	

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Report Title:	Date:	Printed:
CLIMEX Climate Change Experiment: Final report on Phase I the first year of treatment May 1994 - December 1994	Oct./95	NIVA 1996
	Topic group:	
	Climate change	
Author(s):	Geographical area:	
Alan Jenkins (Editor)	East-Agder county, Norway	
	Pages:	Edition:
	47	

Client(s):	Client ref.:
European Commission Norwegian Ministry of Environment The Research Council of Norway National Environment Research Council (UK) Hydrogas Norge A/S	

Abstract: Catchment ecosystems are expected to show a cascade of responses to increased CO_2 and temperature. The first expected step was observed in the first year of treatment: increased CO_2 changed rates of photosynthesis and stomatal densities in several of the major plant species present at Risdalsheia. An increase in biomass of Caluna in response to elevated CO_2 is also apparent. These responses are expected to cause further changes in soil and soil solution chemistry and ultimately runoff water, with time delays at each step.

4 keywords, Norwegian

1. klimaendring
2. sur nedbør
3. økosystem
4. eksperiment

4 keywords, English

1. climate change
2. acid precipitation
3. ecosystem
4. experiment

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For the Administration

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ISBN-82-577-2922-1

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Executive Summary

CLIMEX is an integrated, whole-ecosystem research project studying the response of entire forested catchments to increased CO_2 and temperature. This whole-catchment manipulation experiment is designed to allow quantification of the links between terrestrial and aquatic ecosystems and provide direct experimental evidence on the effect of climate change on natural forests, terrestrial ecosystems and water resources.

CLIMEX (Phase I, Dec 1992-Dec 1994) built on the whole catchment manipulation facilities at Risdalsheia from the RAIN project (1983-1994). Modification of the facilities for climate change experiments was carried out in 1993. Background data (pre-treatment) were collected during the period April 1993 through March 1994 (Dise and Jenkins 1995). Treatment began in April 1994. This report documents the results of the first year of treatment.

Catchment ecosystems are expected to show a cascade of responses to increased CO_2 and temperature. The first expected step was observed in the first year of treatment: increased CO_2 changed rates of photosynthesis and stomatal densities in several of the major plant species present at Risdalsheia. An increase in biomass in Calluna in response to elevated CO_2 is also apparent. These responses are expected to cause further changes in soil and soil solution chemistry and ultimately runoff water, with time delays at each step.

Acknowledgements

The CLIMEX project is maintained with funding from the Commission of the European Communities (under contract No. EVSV-CT91-0047), Norwegian Ministry of the Environment, the Norwegian Research Council (NFR-NTNF), Hydrogas Norge, the Norwegian Institute for Water Research, the Institute of Hydrology (UK) and the Dutch National Research Programme

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

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1. The CLIMEX Project

Alan Jenkins (IH)

CLIMEX (Climate change experiment) is an international, cooperative research project studying the response of entire catchments to increased CO_2 and temperature. The CLIMEX project is located at Risdalsheia, southernmost Norway. A full description of the site characteristics is given in Dise and Jenkins (1995). The project involves five catchments and employs multiple treatments and controls (Table 1.1). CLIMEX focuses on the *whole ecosystem* response to climate change, in particular plant-soil-water linkages and processes.

Table 1.1. *Overview of the 5 catchments at Risdalsheia included in the CLIMEX project.*

Catchment	Area (m^2)	Enclosure	Rain quality	Climate treatment	Start of monitoring
KIM	690	roof	clean	CO_2 + air warming	June 1983
(Control)	170	roof	clean	none	June 1993
EGIL	320	roof	acid	soil warming	June 1983
(Control)	80	roof	acid	none	June 1993
ROLF	220	no roof	acid	none	June 1983
METTE	650	no roof	acid	none	June 1993
CECILIE	380	no roof	acid	none	June 1993

The objectives and hypotheses of CLIMEX are detailed in Dise and Jenkins (1995). Briefly, they are, by enriching CO_2 and elevating temperature to boreal forest catchments:

-- to measure changes in plant CO_2 uptake, gas exchange and community phenology.
-- to measure changes in forest growth and nutrient status.
-- to measure changes in ground vegetation and nutrients.
-- to determine changes in mineralization of soil organic matter.
-- to determine changes in soil fauna and biologically-mediated processes.
-- to measure the effects on runoff water quality and quantity.
-- to develop and validate process-oriented models linking terrestrial and aquatic response.

Different parts of the ecosystem will probably respond at different rates for as long as the treatment is continued. Key responses which require quantification are the rates at which the system responds, the potential for achieving a new "equilibrium" condition, and the feedback responses which might operate to limit the ecosystem response in the longer term.

2. Site Operation.

Richard F. Wright and Anke Lükewille (NIVA)

Technical installations at KIM catchment (CO_2 and heating) were completed in late 1994. The first CO_2 tank was installed in January 1994. Treatment began with warming on 15 April and CO_2 addition on 3 May 1994. The first several weeks of treatment were characterised by various start-up problems largely connected to the computer control of the CO_2 and temperature levels. In addition there were several power failures which resulted in the loss of data for the period prior to 13 June. Many of these start-up difficulties were solved by mid-summer.

A major lightning storm on 26-27 July 1994 caused power failure and substantial damage to the electronics.

The system was modified in August to correct the problem of overdosing of CO_2. The original system reacted too slowly to opening and closing of the vents along the sides of the building. This resulted in overdosing of CO_2, especially during warm days in the summer. Since these modifications the CO_2 levels have been more closely controlled to the target level of 560 ppm (Figure 2.1). The CO_2 dosing was stopped on 4 November 1994 for the winter.

The targets for warming KIM were achieved during the entire treatment period thus far, except for days with power failures early in the experiment and in conjunction with the lightning storm in July (Figure 2.2). The heating treatment has continued without interruption.

Monitoring of relative humidity shows that RH in the heated section is somewhat higher than in the untreated control section of KIM (Figure 2.3).

At EGIL catchment (soil heating) installation of the soil heating cables and control systems was completed in May 1994. The system was then tested for several weeks before it was switched on for regular operation on 2 June 1994. The system has functioned satisfactorily with the exception of several periods during the summer due to datalogger failures and lightning strikes (Figure 2.4). In addition, the monitoring data were lost for several periods due to failure of the data logging routines. The data show that, as installed, the heating cables cannot raise the temperature to the full +5°C above ambient during the late autumn and winter months. This is due to the fact that the cables are placed on the ground rather than into the soil.

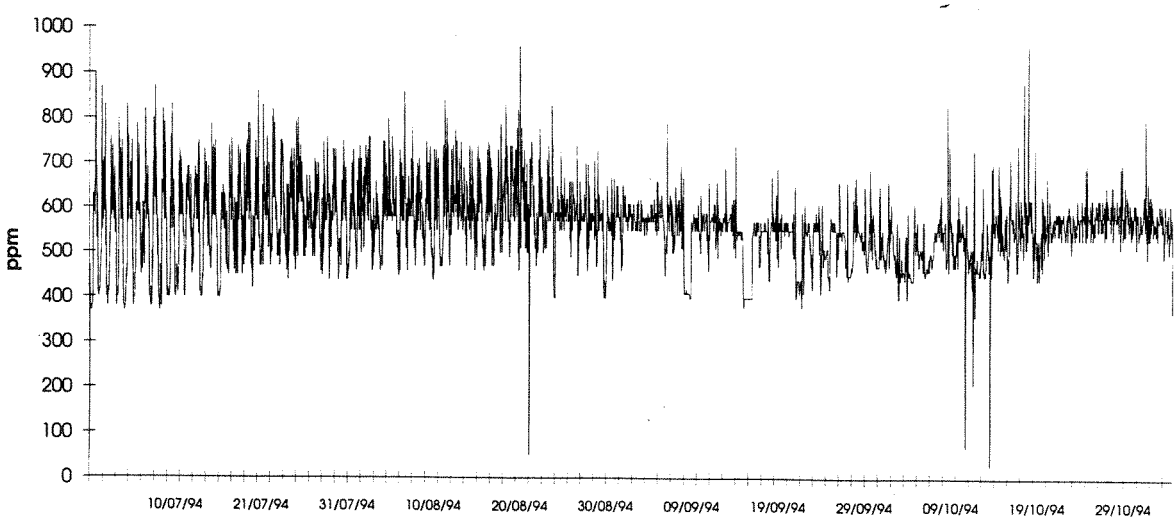

Figure 2.1. *Hourly CO_2 concentrations (ppmv) in the treatment section of KIM catchment during 1994, the first year of treatment. CO_2 was switched on 3 May 1994 and off for the winter on 4 November 1994. Data prior to 13 June were lost due to power failures.*

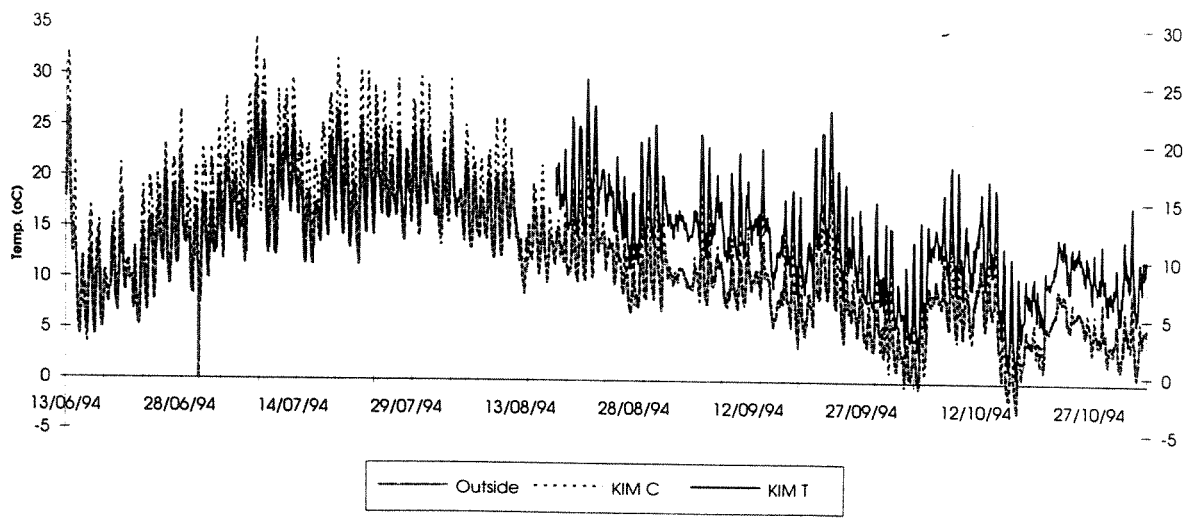

Figure 2.2. *Hourly temperature in the treatment section of KIM (KIM-t), the control section (KIM-c) and outside during 1994, the first year of treatment. Target levels for heating are +5°C in January and +3°C in July with intermediate levels in the intervening months. Data prior to 20 August at KIM-t were lost due to failure of the data logger.*

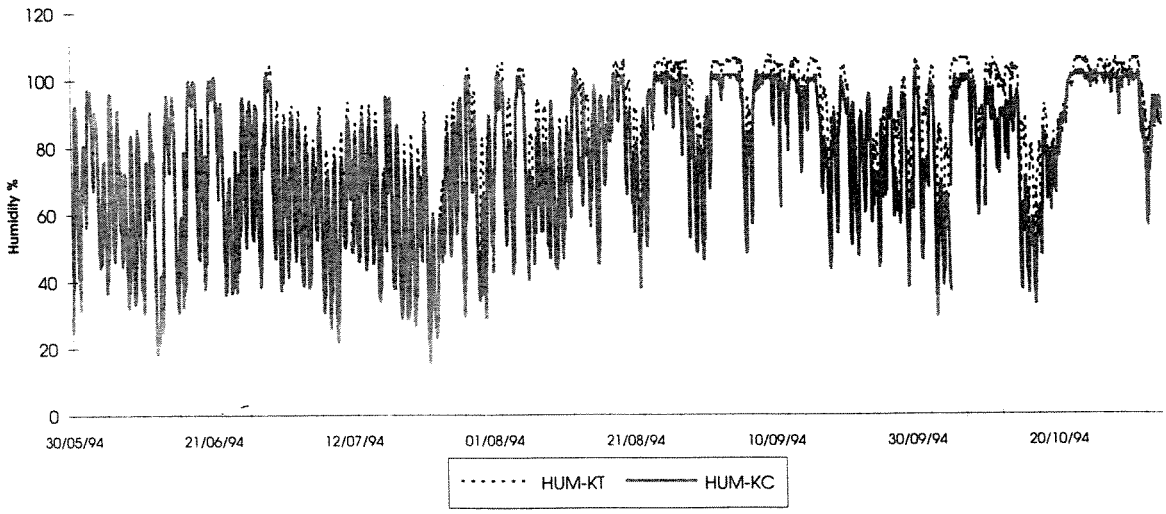

Figure 2.3. *Hourly relative humidity in the treatment section of KIM (KIM-t) and the control section (KIM-c) during 1994, the first year of treatment. Data prior to 13 June at KIM-t were lost due to power failures.*

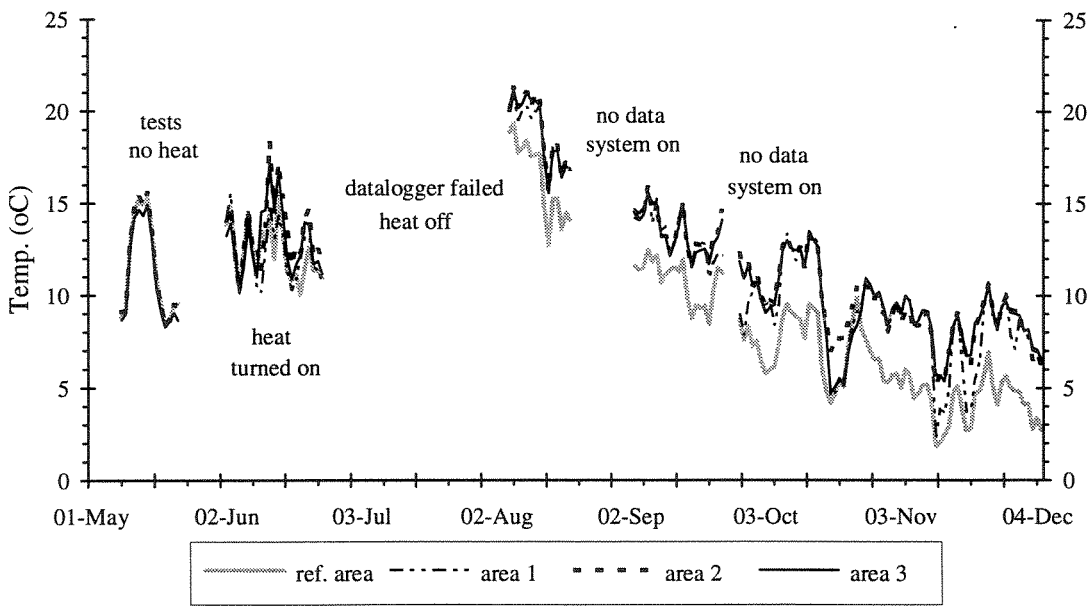

Figure 2.4. *Daily temperature (soil level: 0 cm) in the treatment section of EGIL (areas 1, 2 and 3) and the control section (ref. area) during 1994, the first year of treatment. Target levels for heating are +5°C in January and +3°C in July with intermediate levels in the intervening months.*

3. Water Chemistry and Input-Output Budgets.

Richard F. Wright and Anke Lükewille (NIVA)

Routine sampling of precipitation and runoff from the 5 CLIMEX catchments continued during 1994. Winter 1994 was characterised by low temperatures with precipitation coming mainly as snow. Under the roofs at both KIM and EGIL catchments the sprinkling systems were shut off during much of the winter due to the sub-freezing conditions, and winter precipitation was compensated in the spring by extra watering beneath the roofs. Thus although the water inputs were similar between the catchments when summed over the entire season (winter December to May and summer June to October) (Table 3.1), the distribution of precipitation differed between catchments (Figure 3.1).

At ROLF (outside, control) precipitation came as snow during much of the winter with snowmelt during April. At EGIL (roof, soil warming) there was some snow blown in during the winter (there are no walls) but the bulk of the winter precipitation was compensated buy extra watering in late April - early May. At KIM (roof, CO_2 and air warming) there was no snow in the winter and the winter precipitation was compensated by extra watering in May.

Table 3.1. *Precipitation (P), runoff (Q) and calculated evapotranspiration (ET) for winter and summer seasons in 1994 at the 5 experimental CLIMEX catchments. Units: mm*

	winter 94 (Dec 93 - May 94)		*summer 94 (May - Oct 94)*		
	P	*Q*	*P*	*Q*	*ET*
KIM	*460*	*484*	*627*	*394*	*233*
EGIL	*394*	*402*	*661*	*565*	*96*
ROLF	*581*	*542*	*608*	*358*	*250*
METTE	*581*	*541*	*608*	*377*	*231*
EGIL	*581*	*480*	*608*	*428*	*180*

Runoff chemistry during the first 6 months of treatment (May-October 1994) do not indicate any major change due to the treatment (Appendix 3.1). At EGIL catchment the soil warming was effective only during the latter half of the period. Perhaps at both catchments changes in concentrations and fluxes of key parameters such as dissolved organic carbon and dissolved organic nitrogen will be occur during the winter half year, when the vegetation is dormant and differences in rates of mineralisation between the catchments may become more apparent.

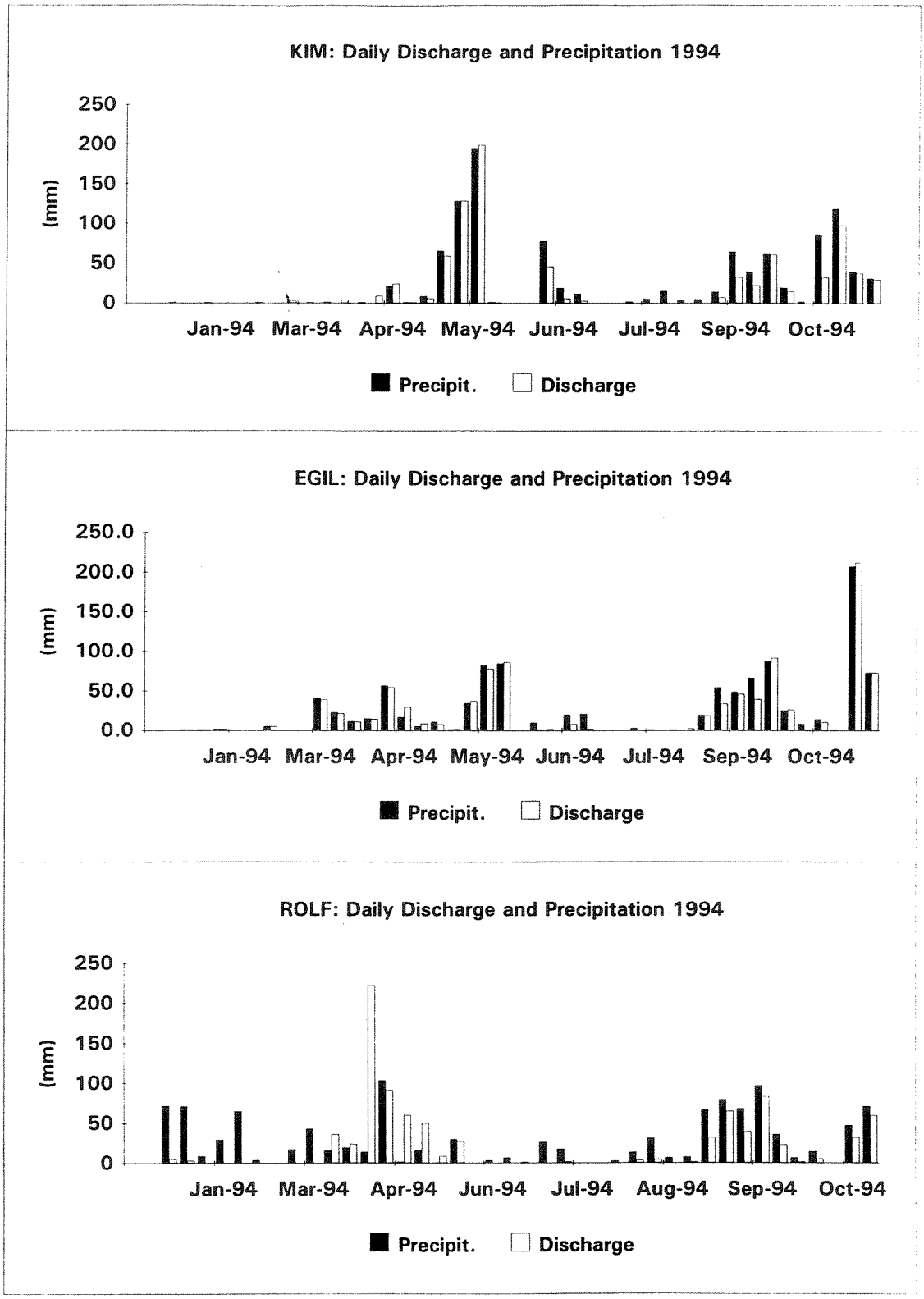

Figure 3.1. *Daily precipitation and discharge at the CLIMEX catchments during 1994.*

Appendix 3.1a. *Input-output budgets for KIM (roof, clean rain, CO_2+warming) catchment for the summer 1994 (27 May to 31 October 1994). Fluxes are to the left of the heavy double line; weighted-average concentrations to the right.*

Flux and concentrations units meq/m2/yr and ueq/l
KIM summer 94 27 May 94 to 31 Oct 94

	Input						Output		01/23 concentrations		95 In	Out
	Wet	Dry mar.	Dry part.	Dry gases	Dry subtot.	Total			Wet		Total	
H2O	627					627	394	H2O				
H+	19	0	1	19	20	39	24	H+	30		61	61
Na	38	-11	0	0	-11	26	28	Na	60		42	71
K	1	0	0	0	0	1	1	K	1		1	2
Ca	2	0	0	0	0	1	3	Ca	3		2	7
Mg	9	-3	0	0	-3	6	5	Mg	14		10	13
Al	0	0	0	0	0	0	1	Al	0		0	2
NH4	0	0	4	0	4	4	1	NH4	0		6	2
NO3	0	0	0	11	11	11	1	NO3	0		18	3
Cl	44	-13	0	0	-13	31	31	Cl	70		49	78
SO4	5	-1	5	8	12	16	6	SO4	7		26	14
A-	19	0	0	0	0	19	25	A-	30		30	63
sum+	67	-14	5	19	10	77	62	sum+	107		122	158
sum-	67	-14	5	19	10	77	62	sum-	107		122	158
SBC	49	-14	4	0	-10	38	38	SBC	77		61	95
SSA	48	-14	5	19	10	58	38	SSA	77		92	95
alk	0	0	-1	-19	-20	-20	0	alk	0		-32	0
TOC							6.6	TOC	mgC/l			16.6
SiO2							0.8	SiO2	mgSiO2/l			2.0
c.d.							3.8	c.d.				3.8
RAL							101	RAL	µgAl/l			256
ILAL							92	ILAL	µgAl/l			233
TOTN							15	TOTN	µmol/l			38

Appendix 3.1b. *Input-output budgets for EGIL (roof, acid rain, soil warming) catchment for the summer 1994 (27 May to 31 October 1994). Fluxes are to the left of the heavy double line; weighted-average concentrations to the right.*

Flux and concentrations units meq/m2/yr and ueq/l
EGIL summer 94 27 May 94 to 31 Oct 94

	Input						Output		12/12 94 concentrations		
	Wet	Dry mar.	Dry part.	gases	subtot.	Total			Wet	In Total	Out
H2O	661					661	565	H2O			
H+	32	0	0	1	19	51	46	H+	49	78	80
Na	31	-3	0	0	0	31	40	Na	46	46	71
K	1	0	0	0	0	1	4	K	2	2	7
Ca	3	0	0	0	0	3	7	Ca	5	5	12
Mg	7	-1	0	0	0	7	11	Mg	11	11	20
Al	0	0	0	0	0	0	4	Al	0	0	8
NH4	11	0	0	4	0	11	4	NH4	16	16	7
NO3	18	0	0	0	11	29	16	NO3	27	43	28
Cl	36	-3	0	0	0	36	33	Cl	55	55	58
SO4	34	0	0	5	8	42	50	SO4	52	64	88
A-	-3	0	0	0	0	-3	18	A-	-4	-4	31
sum+	85	-4	0	5	19	104	116	sum+	129	158	205
sum-	85	-4	0	5	19	104	116	sum-	129	158	205
SBC	53	-4	0	4	0	53	66	SBC	80	80	117
SSA	88	-3	0	5	19	107	98	SSA	133	162	174
alk	-35	0	0	-1	-19	-54	-32	alk	-53	-82	-57
TOC							5.8	TOC	mgC/l		10.3
SiO2							1.7	SiO2	mgSiO2/l		2.9
c.d.							3.1	c.d.			3.1
RAL							145	RAL	µgAl/l		256
ILAL							100	ILAL	µgAl/l		177
TOTN							33	TOTN	µmol/l		58

Appendix 3.1c. *Input-output budgets for ROLF (untreated reference) catchment for the summer 1994 (27 May to 31 October 1994). Fluxes are to the left of the heavy double line; weighted-average concentrations to the right.*

Flux and concentrations units meq/m2/yr and ueq/l
ROLF summer 94 27 May 94 to 31 Oct 94

	Input						Output		12/12 94 concentrations		
	Wet	mar.	Dry part.	gases	subtot.	Total			Wet	In Total	Out
H2O	608					608	358	H2O			
H+	20	0	1	19	20	40	33	H+	33	66	93
Na	20	1	0	0	1	21	31	Na	32	34	86
K	1	0	0	0	0	1	1	K	2	2	3
Ca	3	0	0	0	0	3	5	Ca	5	5	13
Mg	5	0	0	0	0	5	9	Mg	8	8	24
Al	0	0	0	0	0	0	2	Al	0	0	6
NH4	12	0	4	0	4	16	2	NH4	19	26	5
NO3	16	0	0	11	11	27	5	NO3	26	44	14
Cl	24	2	0	0	2	26	26	Cl	40	42	72
SO4	25	0	5	8	13	38	23	SO4	40	62	65
A-	-4	0	0	0	0	-4	29	A-	-7	-7	80
sum+	60	2	5	19	26	86	83	sum+	99	141	232
sum-	60	2	5	19	26	86	83	sum-	99	141	232
SBC	40	2	4	0	6	46	47	SBC	66	75	133
SSA	65	2	5	19	26	90	54	SSA	106	149	151
alk	-25	0	-1	-19	-20	-45	-7	alk	-40	-73	-19
TOC							7.5	TOC	mgC/l		20.9
SiO2							1.0	SiO2	mgSiO2/l		2.8
c.d.							3.9	c.d.			3.9
RAL							116	RAL	µgAl/l		323
ILAL							95	ILAL	µgAl/l		266
TOTN							20	TOTN	µmol/l		56

Appendix 3.1d. *Input-output budgets for METTE (untreated reference) catchment for the summer 1994 (27 May to 31 October 1994). Fluxes are to the left of the heavy double line; weighted-average concentrations to the right.*

Flux and concentrations units meq/m2/yr and ueq/l
METTE summer 94 27 May 94 to 31 Oct 94

	Input						Output		12/12 94 concentrations		
	Wet	Dry mar.	Dry part.	Dry gases	Dry subtot.	Total			Wet	In Total	Out
H2O	608					608	377	H2O			
H+	20	0	1	19	20	40	32	H+	33	66	85
Na	20	1	0	0	1	20	29	Na	32	33	78
K	1	0	0	0	0	1	1	K	2	2	2
Ca	3	0	0	0	0	3	4	Ca	5	5	10
Mg	5	0	0	0	0	5	6	Mg	8	8	15
Al	0	0	0	0	0	0	3	Al	0	0	7
NH4	12	0	4	0	4	16	1	NH4	19	26	4
NO3	16	0	0	11	11	27	4	NO3	26	44	10
Cl	24	1	0	0	1	25	25	Cl	40	41	66
SO4	25	0	5	8	13	38	23	SO4	40	62	61
A-	-4	0	0	0	0	-4	24	A-	-7	-7	64
sum+	60	1	5	19	25	85	76	sum+	99	140	202
sum-	60	1	5	19	25	85	76	sum-	99	140	202
SBC	40	1	4	0	5	45	41	SBC	66	74	109
SSA	65	1	5	19	25	89	52	SSA	106	147	137
alk	-25	0	-1	-19	-20	-45	-11	alk	-40	-73	-28
TOC							6.8	TOC	mgC/l		18.1
SiO2							1.0	SiO2	mgSiO2/l		2.6
c.d.							3.6	c.d.			3.6
RAL							143	RAL	µgAl/l		380
ILAL							116	ILAL	µgAl/l		307
TOTN							17	TOTN	µmol/l		45

Appendix 3.1e. *Input-output budgets for CECILIE (untreated reference) catchment for the summer 1994 (27 May to 31 October 1994). Fluxes are to the left of the heavy double line; weighted-average concentrations to the right.*

Flux and concentrations units meq/m2/yr and ueq/l
CECILIE summer 94 27 May 94 to 31 Oct 94

12/12 94 concentrations

	Input						Output		In	Out
	Wet	Dry mar.	Dry part.	Dry gases	Dry subtot.	Total		Wet	Total	
H2O	608					608	428			
H+	20	0	1	19	20	40	37	33	66	87
Na	20	7	0	0	7	27	38	32	44	89
K	1	0	0	0	0	1	1	2	2	2
Ca	3	0	0	0	0	3	5	5	5	12
Mg	5	2	0	0	2	6	7	8	10	17
Al	0	0	0	0	0	0	3	0	0	7
NH4	12	0	4	0	4	16	2	19	26	4
NO3	16	0	0	11	11	27	6	26	44	14
Cl	24	8	0	0	8	33	33	40	54	76
SO4	25	1	5	8	14	38	29	40	63	68
A-	-4	0	0	0	0	-4	26	-7	-7	60
sum+	60	9	5	19	33	93	94	99	154	219
sum-	60	9	5	19	33	93	94	99	154	219
SBC	40	9	4	0	13	53	53	66	88	125
SSA	65	9	5	19	33	98	68	106	161	158
alk	-25	0	-1	-19	-20	-45	-14	-40	-73	-34
TOC							6.8	mgC/l		15.9
SiO2							1.0	mgSiO2/l		2.3
c.d.							3.8			3.8
RAL							138	µgAl/l		323
ILAL							108	µgAl/l		253
TOTN							22	µmol/l		51

Appendix 3.2. *Data sources for precipitation and runoff chemistry at catchments at Risdalsheia.*

January 1983 - November 1985: Wright et al. 1986. Acid Rain Research Report 10/1986.
November 1985 - December 1986: Wright. 1987. Acid Rain Research Report 13/1987.
December 1986 - December 1987: Wright. 1988. Acid Rain Research Report 16/1988.
December 1988 - August 1990 : Wright. 1991. Acid Rain Research Report 24/1991.
June 1990 - May 1994 : Wright. 1994. Acid Rain Research Report 36/1994.

Wright, R.F., E. Gjessing, A. Semb and B. Sletaune. 1986. RAIN project. *Data report 1983-85.* Acid Rain Res. Rept. 10/86 (Norwegian Institute for Water Research, Oslo), 62 pp.

Wright, R.F., 1987. RAIN project. *Annual report for 1986.* Acid Rain Res. Rept. 13/87 (Norwegian Inst. Water Research, Oslo, Norway), 90pp.

Wright, R.F., 1988. RAIN project. *Annual report for 1987.* Acid Rain Res. Rept. 16/88 (Norwegian Inst. Water Research, Oslo, Norway), 77pp.

Wright, R.F. 1991. RAIN project. *Annual report for 1988, 1989 and 1990.* Acid Rain Research Report 24/91 (Norwegian Institute for Water Research, Oslo), 156 pp.

Wright, R.F. 1994. RAIN project: *Risdalsheia data report for June 1990-May 1994.* Acid Rain Research Report 36/94 (Norwegian Institute for Water Research, Oslo), 165pp.

4. Soil Water Responses

Rob Collins and Alan Jenkins (IH)

Routine collection of soil water content at 36 locations in KIM (treatment and control) catchment continued throughout the year. Power supply problems caused intermittent failure of equipment and loss of data throughout the year although long runs of complete data have been obtained (Figure 4.1).

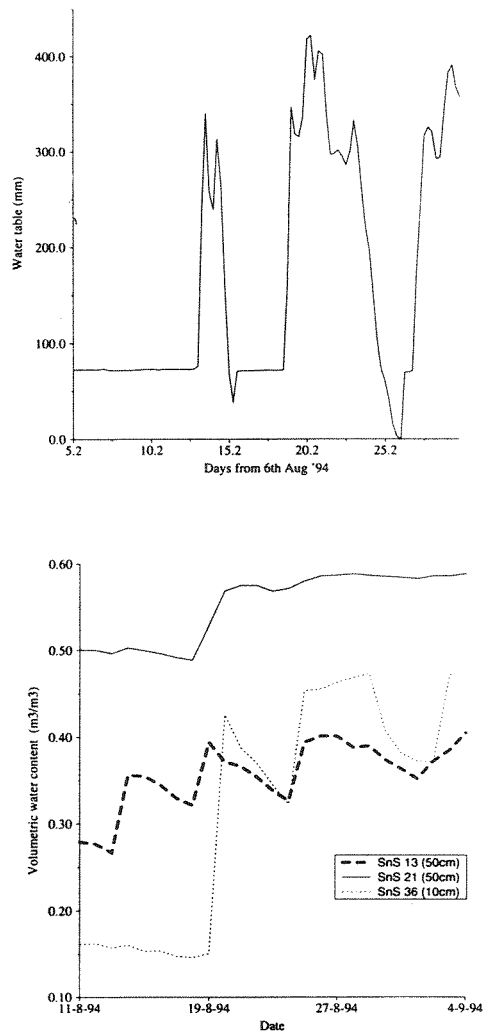

Figure 4.1. *Volumetric soil moisture content in m^3 m^{-3} (bottom) and piezometer level in mm (top) during August 1994.*

In general, the soil water response to rainfall is very dynamic although responses differ markedly over the catchment and with depth (Figure 4.1). Kriging allows the extrapolation of the point measurements across the whole catchment (Figure 4.2). Whilst soils throughout the catchment are generally wetter as the catchment input-output approaches steady-state, the central areas are the most saturated (Figure 4.2). Ground water level data collected from a piezometer situated near this area of saturation shows that the transient soil water table is also extremely dynamic and well correlated with the overall catchment soil moisture status.

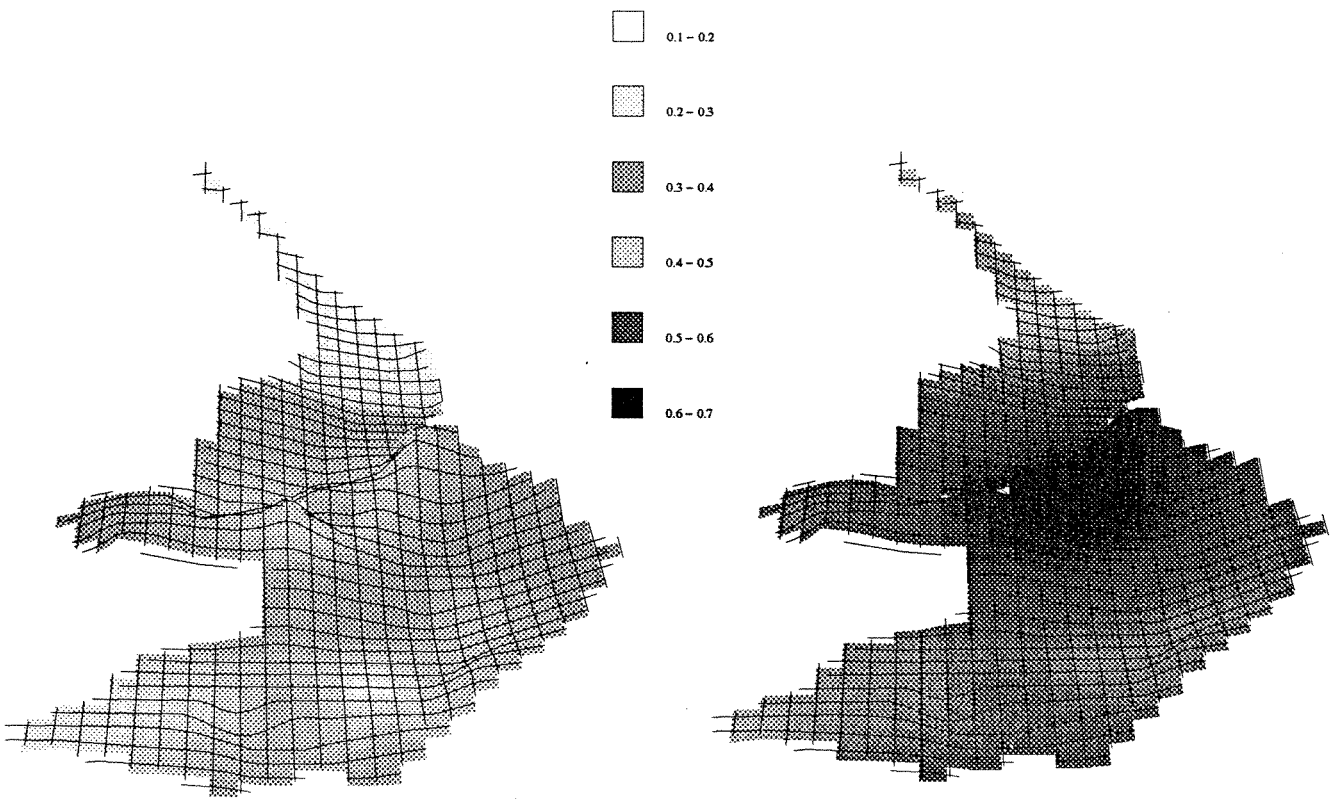

Figure 4.2. *Kriged soil moisture surfaces for KIM expressed as volumetric water content (m^3 m^{-3}) during dry conditions (left) and near saturation (right).*

Tracer studies have continued through 1994 to further identify flow pathways and transit times. The experiment undertaken in October 1994 was carried out with the catchment outflow at steady-state (Figure 4.3). Peak tracer concentration in the runoff of c.50% of the rainfall indicates substantial storage capacity in the catchment and also substantial mixing. This is probably encouraged by the bedrock topography which consists of a series of isolated

"hollows" which fill and overflow downslope. The piezometer shows a shallow water table prior to the start of the experiment rising rapidly by 35cm over 8 hours of rainfall and thereafter achieving steady-state. Soil volumetric water contents above this zone of saturation are 0.6 - 0.75 m^3 m^{-3} during steady-state.

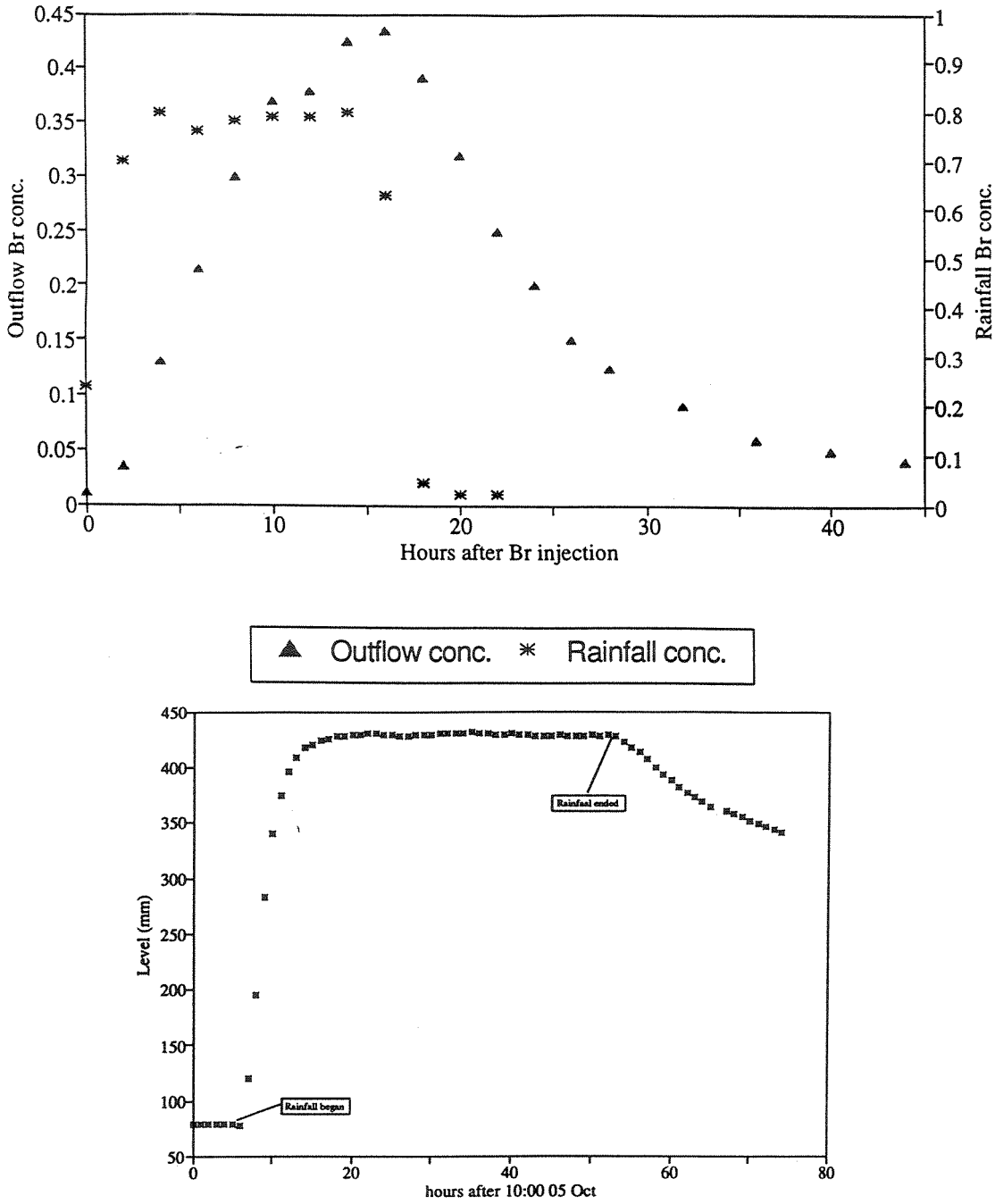

Figure 4.3. *The tracer experiment using LiBr injection carried out on 5 7 October 1994; (top) input and output Br concentrations and (bottom) piezometer level through the event.*

5. Decomposition of Soil Organic Matter

Paul Verburg and Nico van Breemen (WAU-SSG)

Decomposition of fresh litter and Nitrogen mineralisation

The influence of temperature and substrate quality on the decomposition rate of fresh litter under field conditions was investigated using litterbags. Prior to the manipulation, a pilot experiment was carried out using litter from Scots pine to detect possible site differences. Mass loss of needles incubated under heather in KIM, EGIL and ROLF after one year was 307 $\pm$53, 250 $\pm$39 and 222 $\pm$43 mg g^{-1}, respectively.

In April 1994, we incubated birch litter produced at 350 and 700 ppmv CO_2 in the treatment and control parts of KIM and EGIL. This setup allowed for separation of 'treatment-effect' from 'substrate-quality effect'. After six months of incubation, a statistically higher decomposition rate was found in KIM, as in the pilot study. Within the catchments no effect due to differences in substrate quality or climate treatment has been detected yet.

Nitrogen mineralisation is measured under field conditions by incubation of undisturbed soil cores. Comparison of the total N mineralisation from June to October in 1993 (pretreatment period) and the same period in 1994 (treatment period) shows no treatment effect. The absence of a clear treatment effect both in the decomposition and N mineralisation measurements is most likely to be due to the fact that only measurements taken in summer can be compared since the treatments started in June 1994. In general, biological processes show greater response to a change in temperature at lower temperatures. Therefore, both decomposition and N mineralisation are expected to show a clear treatment effect during the winter period.

Soil solution chemistry

Cleaning of the rain has caused a clear change in runoff chemistry over the past eight years. The percentage of the total positive charge balanced by organic anions proved to be sensitive to the rain treatments. Therefore, this parameter is used to detect whether the treatment has affected soil solution chemistry. In the control sections of the manipulated catchments, the contribution of organic anions to the charge balance increased significantly in the two consecutive years (Table 5.1). This increase was less pronounced in the high temperature sections. This observed trend cannot yet be fully explained but we speculate that increased temperature results in more complete decomposition of the dissolved organic compounds.

Table 5.1. *Fraction of total ionic charge of the soil solution due to organic anions during June-August 1993 (pre-treatment year) and 1994 (first treatment year) (%)*

		1993	1994
KIM	control	34 (10) b	56 (12) c
	treatment	32 (13) b	35 (19) b
EGIL	control	9 (8) a	27 (7) b
	treatment	9 (7) a	20 (12) d
METTE	control	25 (15) b,d	33 (16) b

Standard deviation in parentheses. Different letters show significant differences at the 95% confidence level.

Carbon mineralization in isolated soil columns

Carbon mineralization was estimated from CO_2 evolution from soil columns without vegetation. In the field, interference of CO_2 originating from root respiration makes interpretation of CO_2 emission measurements difficult. Undisturbed soil columns (16 cm wide and 60 cm long) were incubated at 5, 10 and 17°C to quantify the effect of temperature on C mineralization and chemistry of the outflow water.

Table 5.2. *Average values for selected parameters in soil column experiment after 10 weeks*

	5°C	10°C	17°C
CO_2 emission (gCO_2 $column^{-1}$ $week^{-1}$)	0.85	1.18	1.69
pH in outflow -	4.52	4.53	3.96
TOC[1] in outflow (mg l^{-1})	3.7	3.7	6.0
Al^{n+} in outflow (μeq l^{-1})	143	242	484
NO_3 in outflow (μeq l^{-1})	120	288	344

[1] Total Organic Carbon

These results show increased C loss both as CO_2 and TOC in drainage water with increasing temperature (Table 5.2). Simultaneously, more N is mineralized and nitrified, resulting in increased acidification of the drainage water. Since plants are absent, the acidification due to N mineralization and nitrification is probably more severe than in systems with vegetation. The increase in inorganic Al in the outflow with temperature reflects the increasing acidification.

Discussion

Background data obtained before the start of the treatments suggest that soil organic matter (SOM) does not behave similarly in all catchments. Some differences can be ascribed to the 'roof-effect' (litterbag studies), and others to the rain treatment (soil solution chemistry). After half a year of treatment, field data do not show a clear treatment effect except the soil solution chemistry. However, the treatments only started in June 1994. We expect changes in decomposition rate of SOM to be more pronounced in winter because at lower temperatures biological processes respond more clearly to a change in temperature than at high temperatures. One major difficulty with the interpretation of field data is that they result from an assembly of environmental conditions. Therefore, additional laboratory studies under controlled conditions are needed to separate different processes occurring simultaneously. Based on the column experiments we can expect an increase in N mineralization at increased temperature as well as higher TOC levels in runoff. Acidification of soils and surface waters will only occur if N mineralization exceeds plant uptake.

6. Productivity and Turnover of Dwarf Shrubs

Wim Arp and Frank Berendse (WAU-TENC)

Introduction

The ground vegetation at Risdalsheia is dominated by the dwarf shrubs *Calluna vulgaris* and *Vaccinium myrtillus*. The growth of these species can be directly affected by an increase in temperature or elevated CO_2 through an increased photosynthesis and higher water use efficiency. Climate change may also influence the vegetation indirectly if the availability of soil water or nitrogen is affected. This may happen when the rates of decomposition, mineralisation and evapotranspiration are different under the new environmental conditions.

Methods

To identify the effects of the different treatments on dwarf shrubs, growth parameters were measured four times during the growing season. These measurements were started in the pre-treatment year 1993 to identify existing differences between sites. Because it is essential for an ongoing experiment to keep disturbance to the system at a minimum, the measurement of plant growth rate had to be achieved without harvesting large quantities of plant material. For this reason, individual shoots of plants in the different treatments were labelled, and the growth of these plants was determined after making non-destructive measurements of the same plants on consecutive visits to the site.

In May 1993, 25 plants of each species were labelled within each treatment area. On each plant, branches varying in age from 1 to 4 years were marked. The stem diameter, length and number of branches, leaves and fruits of these branches were measured four times during the 1993 and the 1994 growing season. Whenever labelled branches died, a new plant was labelled to take its place. To correlate these non-destructive measurements with actual biomass, 10x four year old branches were harvested from each treatment site during each visit. The same non-destructive measurements were made on these harvested shoots, but on these the fresh and dry weight of stems and leaves was also measured for four branches (1 to 4 year old). These data were used to determine the relationship between the non-destructive measurements and biomass, which will make it possible to estimate the biomass of the labelled plants in the field.

Results and discussion - *Vaccinium*

The measurements made in 1993 reveal pre-treatment differences between the outside control site (METTE) and the two sites in KIM. Plants in the control site have shorter shoots, the stem diameter is less for comparable age cohorts, and there are fewer leaves per first-year

branch. No differences were found between the two sites of the KIM catchment (Table 6.1). The four measurements in 1993 (May to October) show only a slight increase in stem diameter during this period. Also, the growth during the winter (1993-1994) did not add much to the stem diameter of *Vaccinium*, resulting in stem diameters in 1994 which are less than the stem diameters of corresponding age-cohorts in 1993 (Figure 6.1). It appears that after a first rapid growth phase, *Vaccinium* continues to produce a new age cohort of branches in spring, but the size of the individual branches is less than the previous years' cohort. Because several new branches are formed on each previous years' branch, the number of first year branches is larger than the year before. Unless a large number of branches die off, the number of first year branches increases exponentially. It is likely that the ability of the plant to support all these new branches is limited, resulting in smaller branches, and a reduced growth rate. During the last phase the first year branches are very small (a few centimetres) with only a few small leaves. At this stage parts of many plants turn yellow and die. New fast growing shoots emerging from rhizomes, or sometimes from older branches, appear to take the place of these senescing shoots. For 1994, no differences were found for *Vaccinium* between the elevated and ambient CO_2 treatments in KIM for stem length, stem diameter, number of leaves and rate of leaf senescence. Differences between the outside control and KIM ambient CO_2 (chamber effect) were still present in 1994 (Table 6.1).

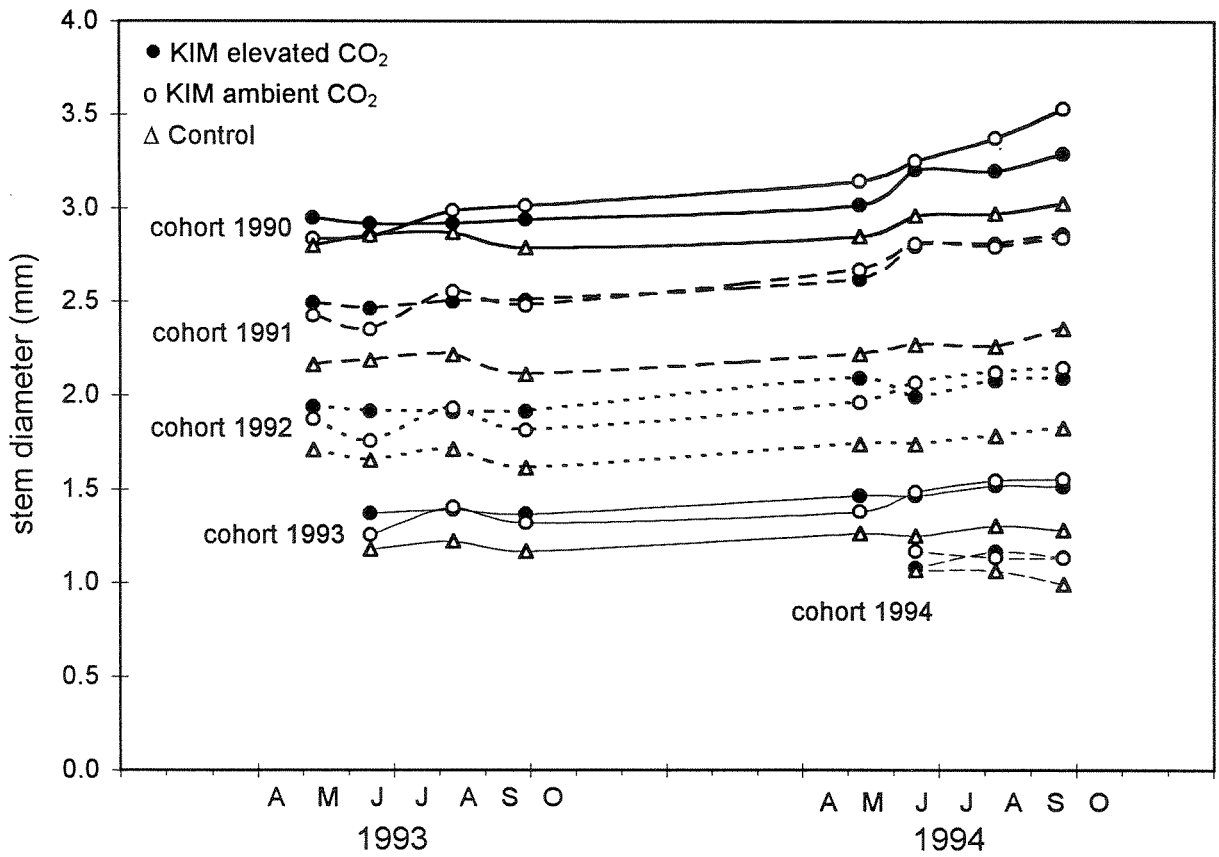

Figure 6.1. *Mean stem diameter of Vaccinium myrtillus for each cohort and each of the three treatments, for all measurements in 1993 and 1994.*

Table 6.1. *Mean stem diameter, increase in stem diameter en mean length of stem segment (mm) of Vaccinium for the periods May to October of 1993 and 1994. Statistical analysis is performed separately for treatment and chamber effect, corrected for effect of cohort (N=ca. 25 per cohort).*

Vaccinium	**1993**					**1994**				
	KIM elevated	*KIM treatment effect*	KIM ambient	*KIM chamber effect*	METTE control	KIM elevated	*KIM treatment effect*	KIM ambient	*KIM chamber effect*	METTE control
Stem diameter (mm)										
cohort 1	1.03		1.01		0.89	0.87		0.85		0.73
cohort 2	1.92		1.85		1.68	1.49		1.50		1.27
cohort 3	2.49		2.45		2.17	2.06		2.08		1.76
cohort 4	2.93		2.92		2.82	2.78		2.79		2.27
mean	2.09		2.06		1.89	1.80		1.81		1.51
p		*0.778*		*0.004*			*0.959*		*0.000*	
Stem diameter increase (mm)										
cohort 1	1.366		1.300		1.168	1.138		1.128		0.990
cohort 2	-0.026		-0.052		-0.094	0.035		0.013		0.005
cohort 3	0.016		0.058		-0.052	0.021		0.060		0.070
cohort 4	-0.020		0.165		0.000	0.267		0.193		0.114
mean	0.334		0.368		0.256	0.365		0.349		0.295
p		*0.349*		*0.002*			*0.576*		*0.100*	
Stem segment length (mm)										
cohort 1						39.6		43.5		23.2
cohort 2						56.2		55.3		36.5
cohort 3						89.2		87.3		75.7
cohort 4						78.3		76.6		69.9
cohort 5						66.2		61.6		65.3
mean						65.9		64.9		54.1
p							*0.936*		*0.007*	

Results and Discussion - *Calluna*

In 1993, there were no significant differences in stem diameter of *Calluna* plants between the five treatment areas, although the growth rate during this season (increase in stem diameter from May to October) was significantly larger in the KIM chamber and under the EGIL roof than in the outside control METTE. In 1994 this chamber and roof effect was absent. However, a treatment effect was found in KIM where the stem diameter of *Calluna* in elevated CO_2 increased faster over the course of the season (May to October) than in ambient CO_2. This growth difference is also reflected in a significantly larger stem diameter for plants in elevated CO_2 in 1994 (Table 6.2, Figure 6.2).

The harvested plants show a linear relationship between the cross section area of the stem at the base of a shoot (π* (stem diameter / 2)^2), and the total biomass of this shoot. The ratio of these two variables (amount of biomass per stem cross section area) signifies the amount of biomass that is supported by a certain stem size. The cross section of the stem is used because this relates both to strength (physical support of biomass) and to the transport function of the stem for water, nutrients, etc. This ratio could be affected by environmental factors (wind, snow) which make demands on the physical strength of the stem, and by responses of the plant to the treatments (increased carbon accumulation in elevated CO_2, reduced or increased demand for water transport in high CO_2 and higher temperatures).

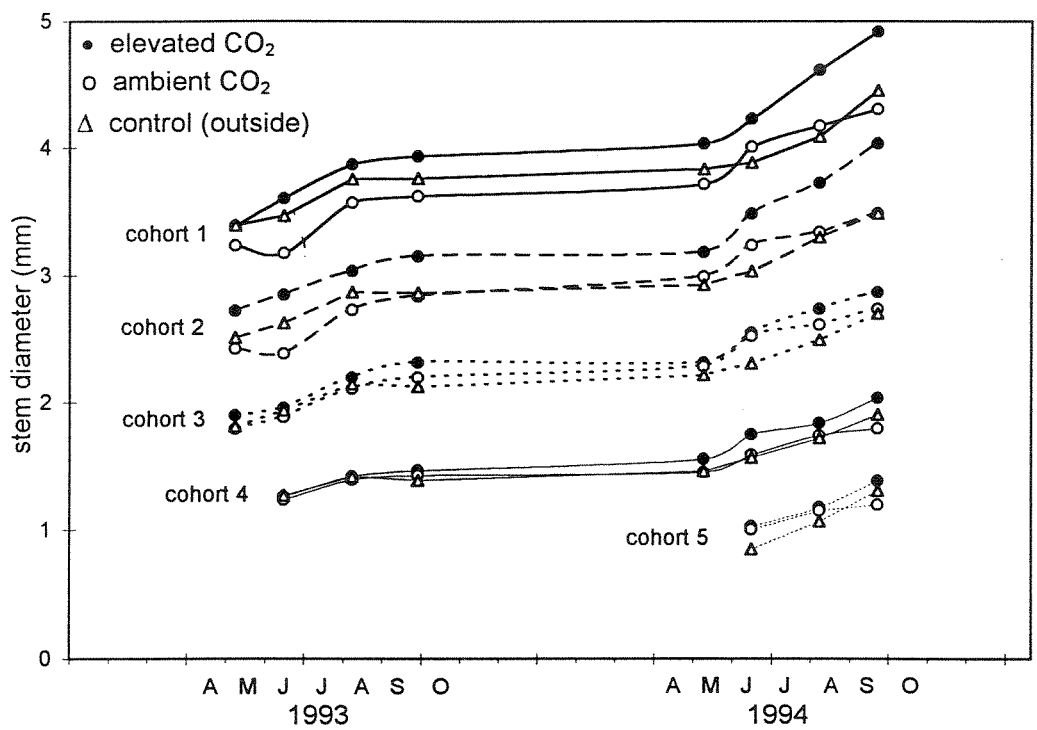

Figure 6.2. *Mean stem diameter of Calluna vulgaris for each cohort, for the treatments in KIM and METTE, for all measurements in 1993 and 1994.*

Table 6.2. Mean stem diameter (mm) and increase in stem diameter of Calluna for the periods May to October of 1993 and 1994. Statistical analysis is performed separately for each effect, corrected for the effect of cohort (N=ca. 25 per cohort).

Calluna	KIM elevated CO_2	*KIM treatment effect*	KIM ambient CO_2	*KIM chamber effect*	METTE control	*EGIL roof effect*	EGIL ambient temp.	*EGIL treatment effect*	EGIL elevated temp.
Stem diameter (mm) 1993:									
cohort 1	1.034		1.011		1.020		1.031		1.133
cohort 2	2.093		2.003		2.007		1.968		2.175
cohort 3	2.943		2.571		2.722		2.786		2.780
cohort 4	3.704		3.417		3.597		3.830		3.513
mean	2.444		2.251		2.337		2.404		2.400
p		*0.332*		*0.968*		*0.376*		*0.913*	
1994:									
cohort 1	0.784		0.775		0.712		0.707		0.637
cohort 2	1.774		1.636		1.642		1.675		1.831
cohort 3	2.598		2.550		2.424		2.419		2.628
cohort 4	3.550		3.241		3.172		3.308		3.347
mean	2.177		2.051		1.988		2.028		2.111
p		*0.037*		*0.846*		*0.682*		*0.172*	
Stem diameter increase (mm) 1993:									
cohort 1	1.466		1.426		1.388		1.481		1.592
cohort 2	0.420		0.408		0.314		0.294		0.424
cohort 3	0.430		0.368		0.352		0.400		0.470
cohort 4	0.570		0.503		0.368		0.516		0.420
mean	0.722		0.676		0.601		0.673		0.727
p		*0.857*		*0.005*		*0.042*		*0.299*	
1994:									
cohort 1	1.388		1.195		1.140		1.192		1.060
cohort 2	0.506		0.355		0.463		0.400		0.512
cohort 3	0.498		0.443		0.494		0.500		0.483
cohort 4	0.800		0.479		0.585		0.574		0.500
cohort 5	0.743		0.464		0.620		0.602		0.558
mean	0.798		0.618		0.671		0.667		0.639
p		*0.005*		*0.371*		*0.941*		*0.575*	

A comparison of this ratio between the five treatments and for the four harvests in 1994

shows that in all four harvests the plants in the control area support the lowest amount of biomass per unit stem cross section area (Figure 6.3 for KIM and METTE). This may reflect the exposure of plants outside to wind, rain and snow relative to the sheltered plants in the KIM chamber and under the EGIL roof. This difference is significant between the control and all other treatments for harvest 2 and 3 in 1994. At the last harvest of 1994 this difference is no longer significant. At this time however, a significant difference is found between the KIM elevated CO_2 and KIM ambient CO_2 treatments (Figure 6.3). This could be related to an increase in carbon accumulation in shoots in the high CO_2 treatment, or to a delay in senescence. Chemical analyses of plant material will be made to test this hypothesis.

After one growing season of high CO_2 treatment a growth response is already present in *Calluna* plants, both as a larger increase in stem diameter and as an increase in the amount of biomass per unit stem cross section area. The combination of these two responses results in a significant increase in biomass in *Calluna* in elevated CO_2. No effect of elevated CO_2 on *Vaccinium* was observed during this first period of treatment.

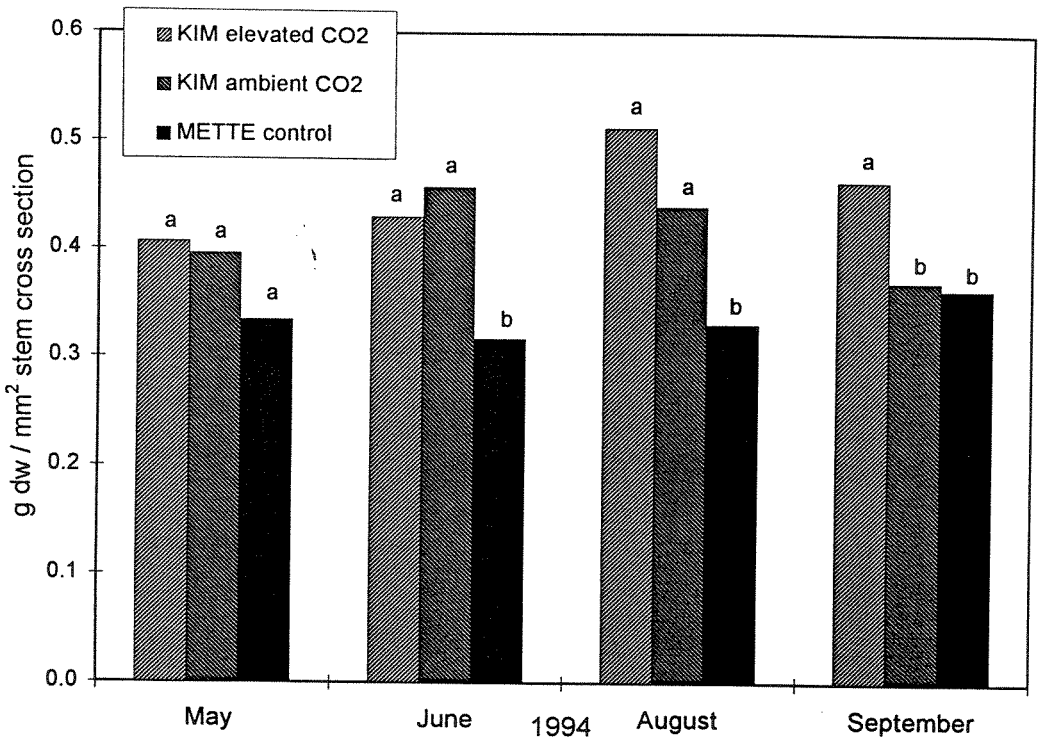

Figure 6.3. *Mean amount of biomass supported per mm^2 stem cross area for Calluna for the treatments in KIM and the control (METTE) at each of the harvests in 1994. Different characters denote significant differences between treatments ($p < 0.05$).*

7. Gas Exchange Responses

David Beerling and Ian Woodward (US)

The results represent vegetation gas exchange responses *in situ* with all of the associated soil-plant linkages intact. After the first season of treatment the two dominant tree species *Pinus sylvestris* and *Betula pubescens* and the ground shrub *Vaccinium myrtillus* showed an increase in leaf photosynthetic rate relative to the plants growing in the control areas of the experiment. As yet there is no evidence of increased leaf photosynthetic capacity. Plants growing under a naturally occurring drought in July showed a marked increase in instantaneous leaf water use efficiency (photosynthesis divided by transpiration) in elevated CO_2 and temperature relative to the controls (Figure 7.1).

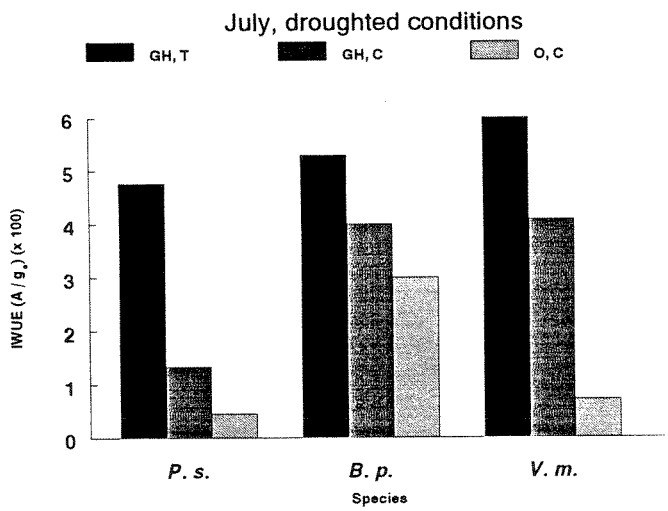

Figure 7.1. *The water use efficiency of Pinus sylvestris (P.s.), Betula pubescens (B.p.) and Vaccinium myrtillus (V.m.) in July growing in KIM under elevated CO_2 and temperature (GH,T), in the control portion (GH,C) and in the reference catchment METTE (O,C).*

Stomatal density of *P.sylvestris, B.pubescens* and *V.myrtillus* decreased under CO_2 enrichment and temperature increases relative to the controls (Figure 7.2). From these initial results it is too early to determine whether the response to boreal ecosystems to future global change will represent a source or sink for carbon. Measurements made in future growing seasons will be important for testing whether these responses are sustained or whether some acclimatory adjustments in plant metabolism occur. These are considered to be critical issues affecting the carbon balance of these ecosystems.

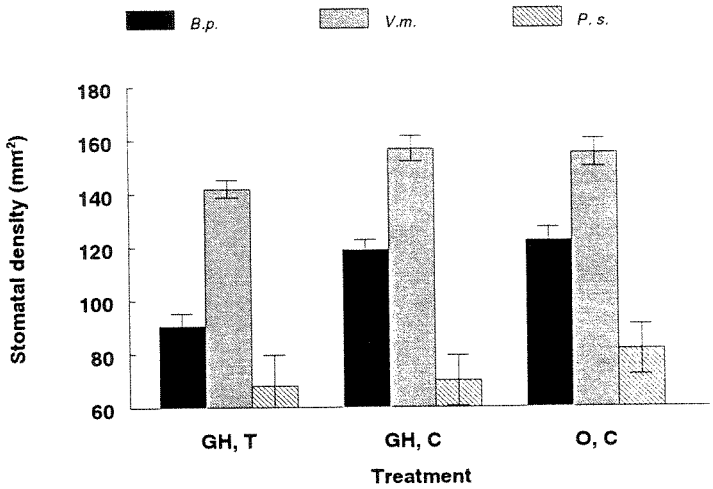

Figure 7.2. *The responses of stomatal density of leaves and needles of Pinus sylvestris (P.s.), Betula pubescens (B.p.) and Vaccinium myrtillus (V.m.) in July growing in KIM under elevated CO_2 and temperature (GH,T), in the control portion (GH,C) and in the reference catchment METTE (O,C) during the first year of treatment (1994).*

8. Tree Nutrient Status and Growth

E. Detlef Schulze and Gisela Schmidt (UB)

Growth

Growth was characterized by studying the length of sun needles which are a sensitive indicator for environmental constraints (Table 8.1).

Table 8.1. *Length of sun needles of Pinus sylvestris as related to growth conditions and time.*

	Needle Length (cm) in sun crown			
year	1994	1993	1992	1991
High CO_2	4.48^a	3.41^b	3.82^b	4.31^a
Low CO_2	4.16^a	3.34^b	3.84^b	4.28^a
open air	3.00^b	3.42^b	2.67^c	3.64^b

In 1994 there is no significant difference in needle length between the high CO_2 and temperature treatment and the glasshouse control at low CO_2 and temperature. However, both groups of plants which are part of the enclosure are significantly different from needles outside under natural conditions. The chamber effect of the enclosure caused an increase in needle length by more than 40%.

In 1993 needles were not different in the enclosure and outside, and needles of the KIM watershed were shorter than in the year before and after. This is the year when the roof was rebuilt. Thus, the comparison between 1993 and the year 1992 as well as 1994 indicates the roof effect.

In 1992 and 1991 needles of trees growing in KIM are longer than outside. Needles in 1991, before the treatment started, were not significantly different from needles in 1994. From the needle length data we cannot yet see an effect of the CO_2 and temperature treatment on growth. The extended needle length under the roof seems to be mainly a light response.

Assimilate turnover

Starch was measured as an integrtive measure of photosynthesis. The morning level of starch would indicate accumulation processes, while the difference between morning and afternoon concentration would be an indicator of photosynthetic capacity (Table 8.2). There are no significant differences for high and low CO_2. Pinus was different from Betula at 6:00 ($p=0.037$) and low CO_2 as well as at 12:00 and high CO_2 ($p=0.029$), however, since these differences are not consistent over time they may be different only by chance (low n).

Needles in high and low CO_2 did not show a difference in morning or evening starch. The concentrations were not different from inside and outside the catchment. However, only needles in the open air showed a daily increase in starch concentrations. The starch data do not indicate a significant effect of high CO_2. Both the high and low CO_2 treatment under the roof show a smaller daily starch turnover than trees outside.

Betula shows generally a higher starch turnover than Pinus, but again, there is no significant effect of high CO_2. Molinia in the open air has higher starch levels than under high CO_2. Starch was also measured in current year twigs and in wood (Figure 8.1 and 8.3). The trends are similar to that of needles, and there is no treatment effect. There was no significant difference between high and low CO_2 treatment.

Table 8.2. *Starch concentrations in 0-year needles. "open air" refers to the control catchment Mette.*

Species	treatment	starch concentration (μmol Gluc.equ. g^{-1}_{dw}) morning (6 am)			evening (19 pm)		
		av.	s.d.	n	av.	s.d.	n
Pinus	High CO_2	450[a]	62	4	487[a]	94	4
	Low CO_2	585[a]	121	4	552[a]	74	4
	open air	593[a]	125	4	599[a]	134	3
Betula	High CO_2	475[a]	102	4	584[b]	143	4
	Low CO_2	385[a]	68	4	440[ba]	94	4
	open air	414[a]	83	4	509[ba]	77	4
Molinia	High CO_2	534[a]	65	4	462[a]	36	3
	open air	504[a]	184	4	629[a]	126	4

Nitrate reductase activity (NRA)

NRA was measured in the morning, at noon and in the evening, and it showed highest at noon (Table 8.4). In Pinus, in contrast to Betula, nitrate is being reduced mainly in the bark and the wood of young twigs (Figure 8.2), but there is not significant effect of high CO_2. There is a slight tendency for higher NRA outside than under the roof, which could be related to the differences in light, but the results are very variable. This effect is most pronounced in Molinia. The rates are somewhat lower than data for Pine in N.Sweden.

Nitrogen nutrition and C/N ratios

Nitrogen concentration was measured in needles of all catchments including Egil (acid rain treatment) by end October 1994 (Table 8.5).

The data show no significant effect of the high CO_2 treatment as compared to the low CO_2 treatment on nitrogen concentrations in pine needles. Also the C/N ratio is unaffected, which is consistent with the starch data. The slight decrease in N in the year 1994 seems to be related to growth and climatic variability between the years and there is no significant difference between 1994 and 1991.

Nitrogen concentration is generally higher in the open air reference catchments and also in the acid rain catchment. This is explained by differences in growth. Consistent with the increase in N concentration in the open air is the decrease in C/N ratio. However, the high C/N ratio under the roof is not a CO_2 effect but a result of a change in light.

Cation, phosphorus and sulphur concentrations

Calcium, K, Mg, Na, P and S were measured in all catchments and age classes (Table 8.6). Calcium and K were slightly higher at high than at low CO_2, but the differences were not significant. The comparison of older age classes, which reach back before the treatment started, indicate that this difference is a site effect rather than a CO_2 effect (Figure 8.3). The deep soils of the lower part of the catchment are better supplied with Ca and K. Magnesium, Na, P and S show an opposite trend to Ca and Mg but differences are explained by site factors rather than by CO_2. Potassium and Mg are close to acute deficiency in both parts of the catchment. Ca was lower in the acid rain roof and outside. All other elements were not different inside and outside the roof and site specific variation seems to be dominating nutrition.

Conclusions

The investigated parameters of growth and nutrition do not yet identify a treatment effect of high CO_2 and temperature. Differences between the roof treatment and controls are probably explained by variation in light (most obvious for needle length) and site specific variation in nutrition.

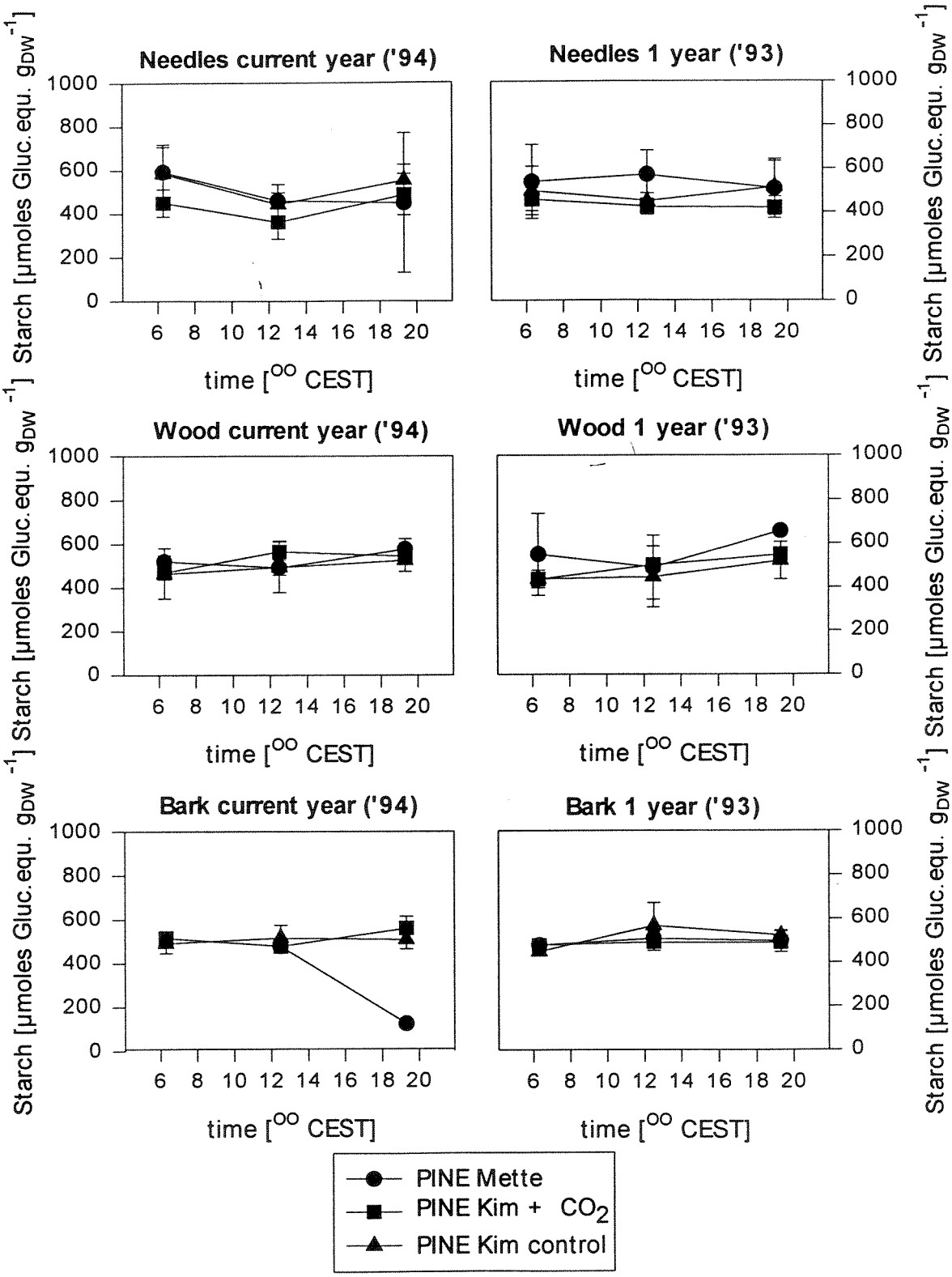

Figure 8.1a. *Starch concentrations of different compartments in Pine during the course of July 31, 1994. Means and s.d. for four replicates.*

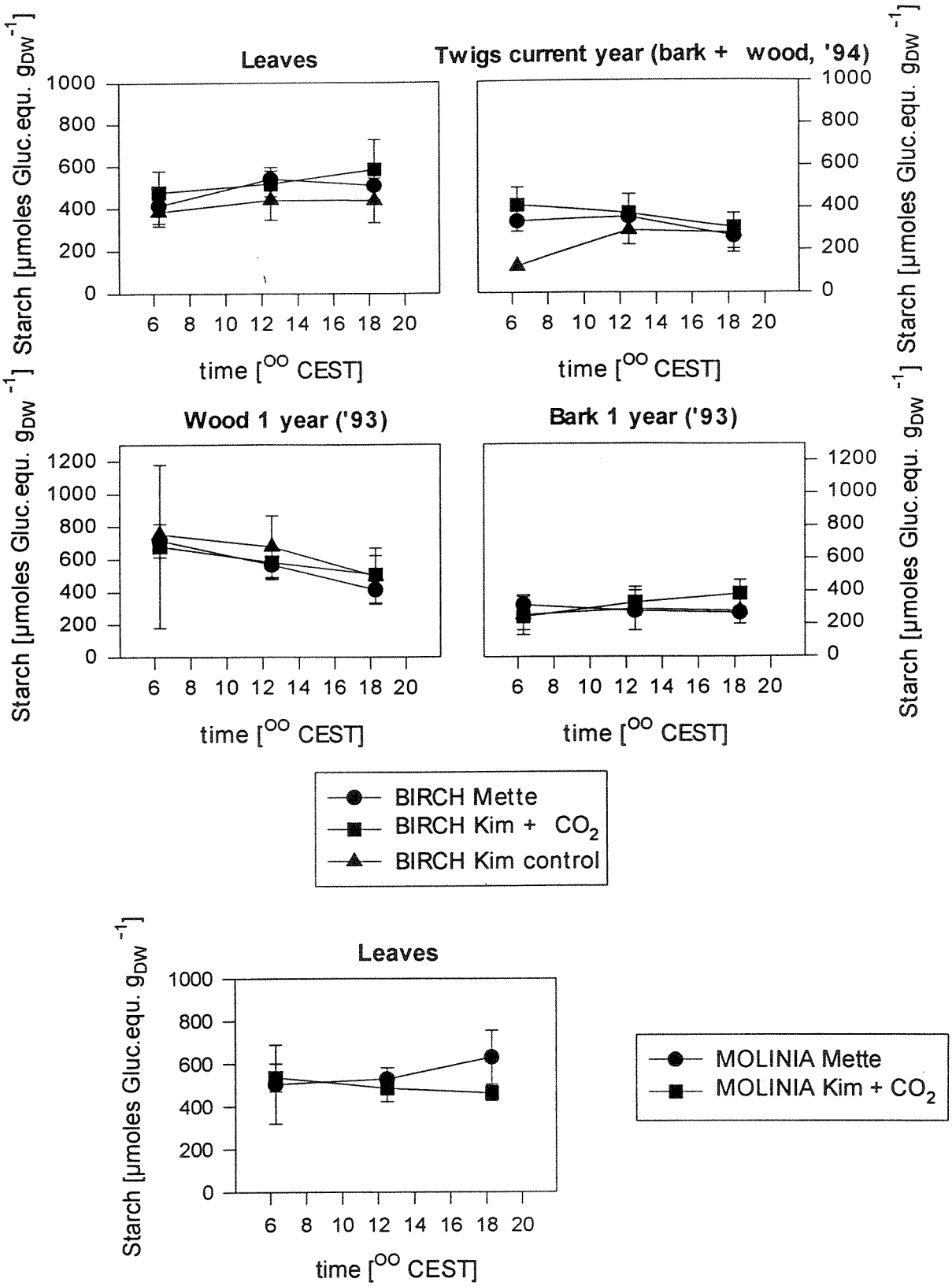

Figure 8.1b. *Starch concentrations of different compartments in Birch and Molinia during the course of July 31, 1994. Means and s.d. for four replicates.*

Table 8.3. *Starch in Needles, bark and wood at 6:00 am*

species	compartment	starch concentration (μmol Gluc.equ. g^{-1}_{dw}) High CO_2			Low CO_2			open air		
		av.	s.d.	n	av.	s.d.	n	av.	s.d.	n
Pinus	0yr needle	450[a]	62	4	585[a]	121	4	593[a]	125	4
	1yr needle	460[a]	53	4	499[a]	110	4	540[a]	169	4
	0yr wood	470[a]	31	3	465[a]	114	3	520[a]	29	4
	1yr wood	436[a]	40	4	438[b]	39	4	550[a]	187	4
	0yr bark	515[a]	19	4	491[a]	44	4	no data		
Betula	Leaves	475[a]	102	4	385[a]	68	4	414[a]	83	4
	0yr twigs	412[a]	85	3	124[a]		2	335[a]	48	3
	1yr wood	578[a]	500	4	753[a]		2	714[ab]	100	4
	1yr bark	244[a]	82	4	255[a]	122	4	318[a]	51	4

Table 8.4. *Nitrate reductase activity at midday (nmol NO_2 g^{-1}_{dw})*

species	compartment	NRA (nmol NO_2 g^{-1}_{dw} at 12:00 am) High CO_2			Low CO_2			open air		
		av.	s.d.	n	av.	s.d.	n	av.	s.d.	n
Pinus	0yr needle	86[ab]	15	4	64[a]	25	4	118[b]	14	4
	1yr needle	87[ab]	18	4	66[a]	19	4	130[b]	37	4
	0yr wood	342[a]	74	4	338[a]	116	4	205[a]	69	4
	1yr wood	198[a]	29	4	154[a]	37	4	557[b]	120	4
	0yr bark	156[a]	33	4	272[a]	200	4	no data		
	1yr bark	145[a]	14	4	120[a]	22	4	201[a]	72	4
Betula	Leaves	247[a]	79	4	223[a]	98	4	201[a]21		4
	0yr twigs	142[a]	95	4	153[a]	32	4	250[a]	120	4
	1yr wood	89[a]	38	3	31[a]	19	3	39[a]	34	4
	1yr bark	83[a]	23	3	56[a]	32	3	95[a]	49	4
Molinia	leaves	158[a]	99	4				329[a]	201	4

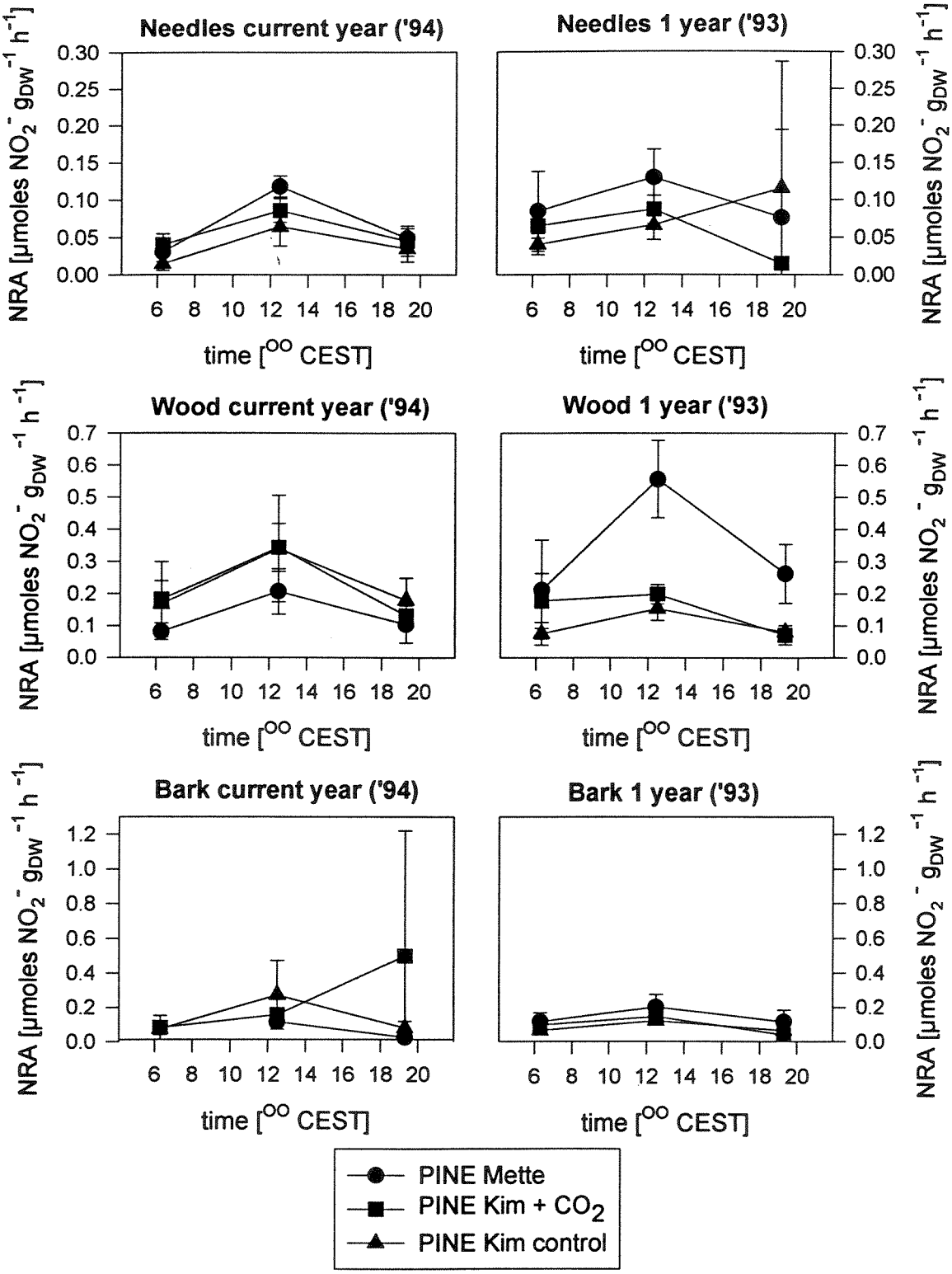

Figure 8.2a. Nitrate reductase activity in different compartments of Pine during the course of July 31, 1994. Means and s.d. for four replicates.

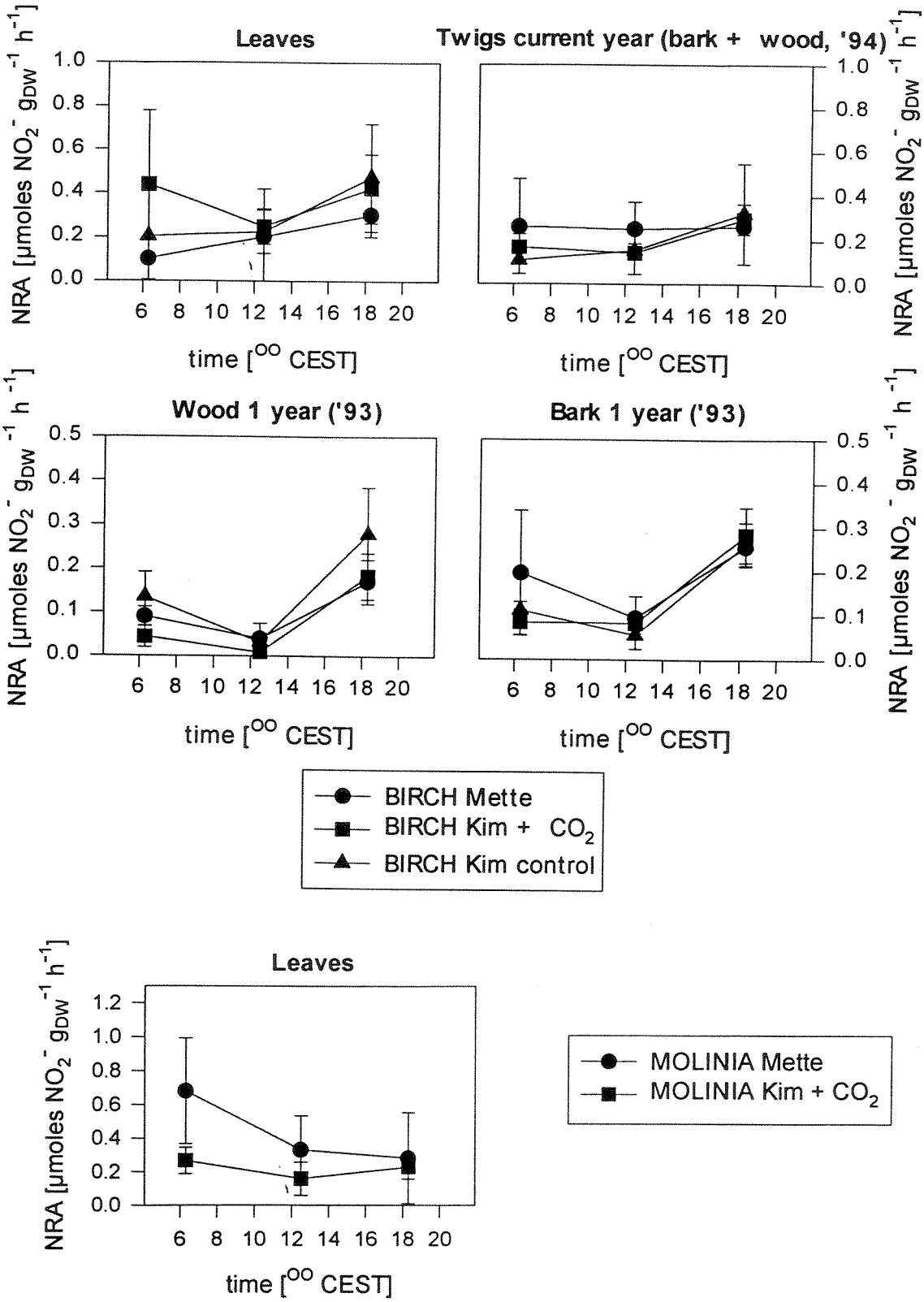

Figure 8.2b. *Nitrate reductase activity in different compartments of Birch and Molinia during the course of July 31, 1994. Means and s.d. for four replicates.*

Table 8.5. *Nitrogen concentrations (%) and C/N ratios of needles grown in different years and harvested in october 1994.*

needle year	1994		1993		1992		1991		
catchment	N	C/N	N	C/N	N	C/N	N	C/N	
High CO_2	1.55^{a}	34.0^{a}	1.59^{a}	33.6^{a}	1.71^{a}	31.5^{a}	1.68^{a}	31.9^{a}	
Low CO_2	1.56^{a}	33.0^{ac}	1.55^{a}	33.8^{ac}	1.64^{a}	32.1^{ac}	1.54^{a}	34.1^{a}	
Acid rain	2.27^{b}	23.2^{b}	2.42^{bc}	22.4^{bc}	2.63^{b}	20.2			
ROLF	1.96^{abc}	26.8^{bc}	2.44^{bc}	21.8^{bc}	2.55^{bc}	21.1^{bc}	2.56^{a}	21.3^{a}	
METTE		1.97^{bc}	26.6^{bc}	2.30^{b}	23.4^{b}	2.10^{bc}	25.4^{bc}	2.10^{a}	25.2^{a}
CECILIE	1.78^{ac}	29.8^{abc}	1.91^{ac}	28.4^{b}	1.92^{ac}	28.6^{abc}	1.91^{a}	28.2^{a}	

Table 8.6. *Element concentrations in needles ($\mu mol\ g^{-1}_{dw}$). Needles were harvested in October 1994.*

catchment	needle	Clean Rain		acid	control		
element	growth	high CO_2	low CO_2	rain	Mette	Cecilie	Rolf
Calcium	1994	46.1^{a}	40.7^{a}	34.8^{a}	35.8^{ab}	30.8^{b}	39.3^{ab}
	1993	60.7^{a}	53.0^{a}	35.7^{a}	51.5^{a}	47.8^{a}	50.3^{a}
	1992	75.6^{a}	57.6^{a}	51.8^{a}	62.6^{a}	57.4^{a}	53.7^{a}
	1991	85.9^{a}	82.6^{a}	61.8^{a}	65.8^{a}	73.4^{a}	62.5^{a}
	1990	97.3^{a}	83.9^{a}				
Potassium	1994	163.8^{a}	156.4^{a}	146.5^{a}	162.3^{a}	149.3^{a}	138.4^{a}
	1993	130.0^{a}	123.7^{a}	116.3^{a}	120.8^{a}	117.7^{a}	103.7^{a}
	1992	113.4^{a}	107.6^{a}	89.5^{a}	100.0^{a}	101.7^{a}	87.5^{a}
	1991	107.0^{a}	101.0^{a}	83.1^{a}	90.9^{a}	107.0^{a}	79.1^{a}
	1990	87.9^{a}	98.5^{a}				
Magnesium	1994	38.7^{a}	43.4^{a}	33.0^{a}	40.3^{a}	38.4^{a}	36.2^{a}
	1993	31.2^{a}	36.2^{a}	23.7^{a}	34.0^{a}	36.0^{a}	26.5^{a}
	1992	29.9^{a}	32.7^{a}	23.9^{a}	28.3^{a}	32.0^{a}	19.4^{a}
	1991	26.6^{a}	34.5^{a}	19.0^{a}	25.7a	28.5^{a}	21.5^{a}
	1990	24.3^{a}	25.7^{a}				
Sodium	1994	0.9^{a}	1.5^{ac}	4.9^{a}	2.4^{bc}	2.6^{bc}	1.8^{abc}
	1993	2.1^{a}	2.7^{ab}	5.6^{a}	4.3^{b}	4.1^{b}	4.0^{b}
	1992	4.4^{a}	5.1^{ab}	7.9^{a}	10.4^{b}	10.8^{b}	7.7^{ab}
	1991	4.5^{a}	6.8^{a}	5.4^{a}	9.2^{a}	6.3^{a}	6.9^{a}
	1990	8.9^{a}	10.8^{a}				
Phosphor	1994	36.8^{a}	40.4^{a}	36.8^{a}	40.1^{a}	36.6^{a}	38.6^{a}
	1993	32.9^{a}	35.8^{a}	31.9^{a}	34.5^{a}	30.2^{a}	34.2^{a}
	1992	33.4^{a}	34.7^{a}	32.7^{a}	35.2^{a}	32.8^{a}	33.7^{a}
	1991	32.4^{a}	32.7^{a}	27.2^{a}	33.7^{a}	35.0^{a}	30.7^{a}
	1990	31.5^{a}	30.3^{a}				
Sulfur	1994	32.6^{a}	34.7^{ab}	41.4^{a}	36.4^{b}	35.3^{ab}	35.6^{ab}
	1993	33.1^{a}	33.2^{a}	39.2^{a}	38.2^{b}	35.3^{ab}	38.1^{ab}
	1992	34.1^{a}	33.7^{a}	42.3^{a}	38.5^{b}	37.2^{ab}	36.8^{ab}
	1991	34.9^{a}	33.7^{a}	32.2^{a}	37.8^{a}	37.8^{a}	36.6^{a}
	1990	33.9^{a}	34.3^{a}				

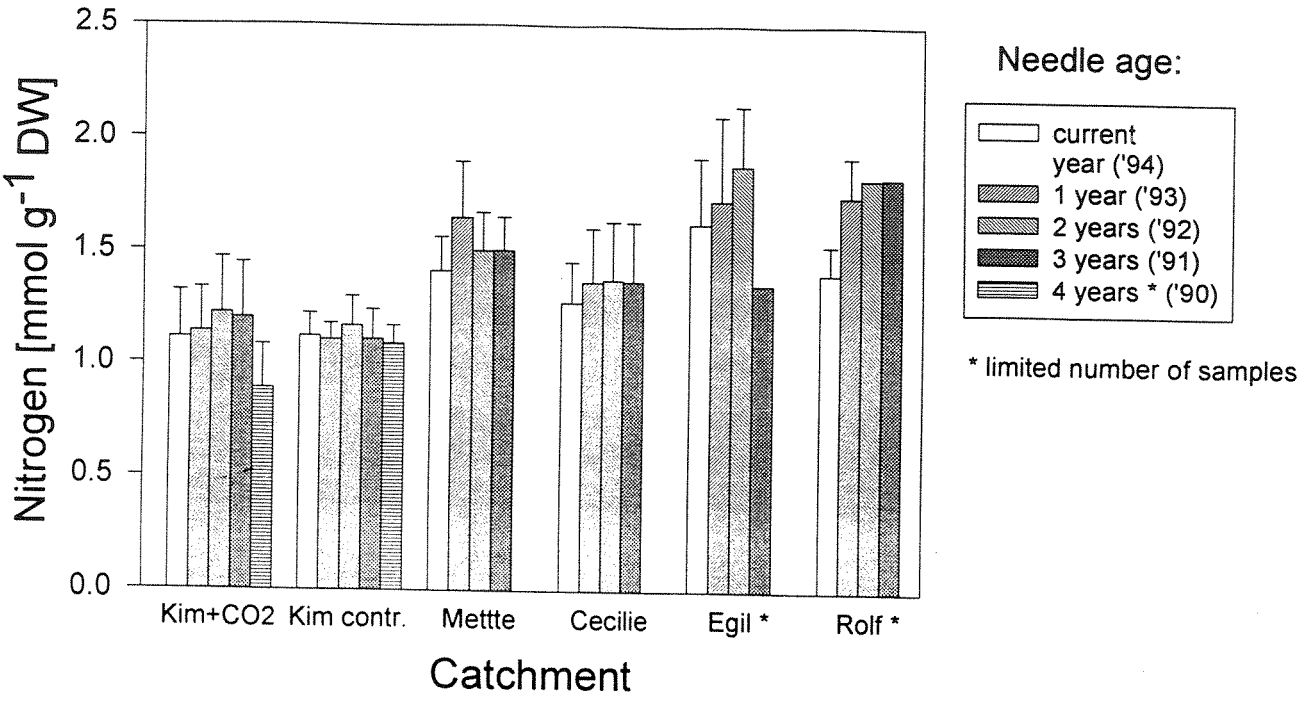

Figure 8.3a. *Nitrogen concentrations (mean and s.d.) of needles of all available age classes. All trees in each treatment were sampled. Replicates range between 3 and 36.*

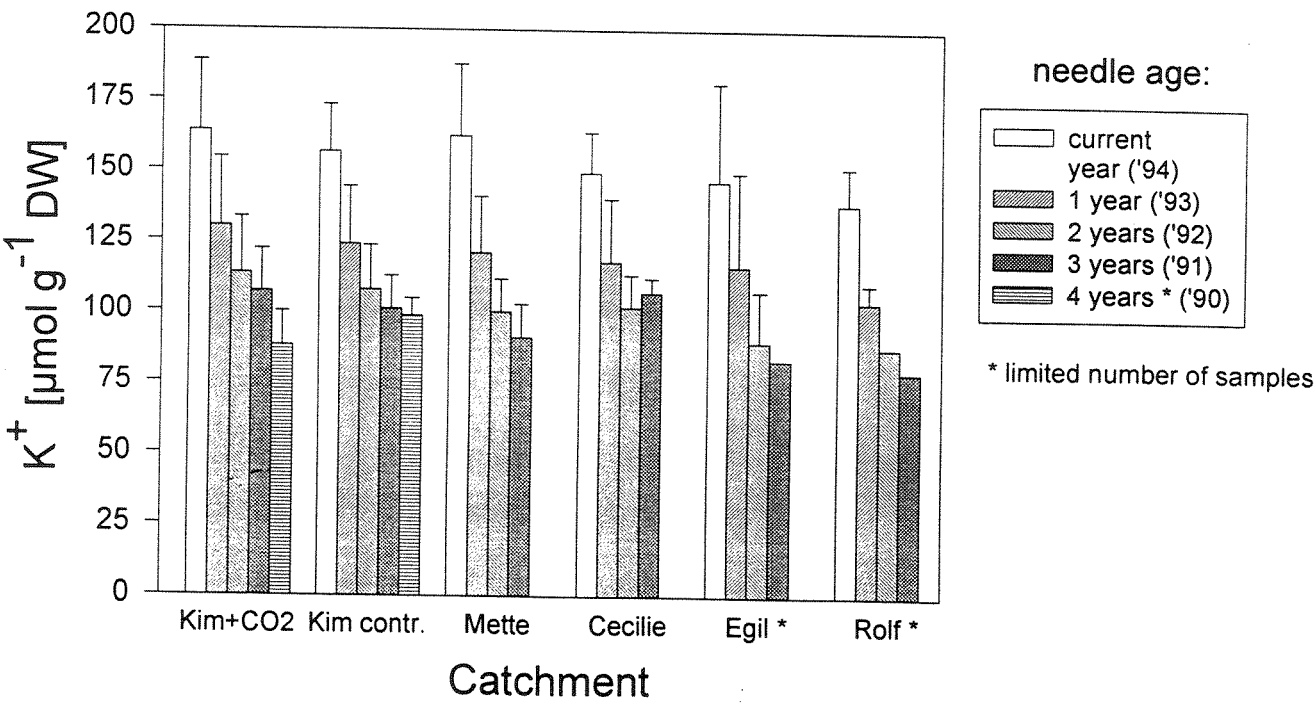

Figure 8.3b. *Potassium concentrations (mean and s.d.) of needles of all available age classes. All trees in each treatment were sampled. Replicates range between 3 and 36.*

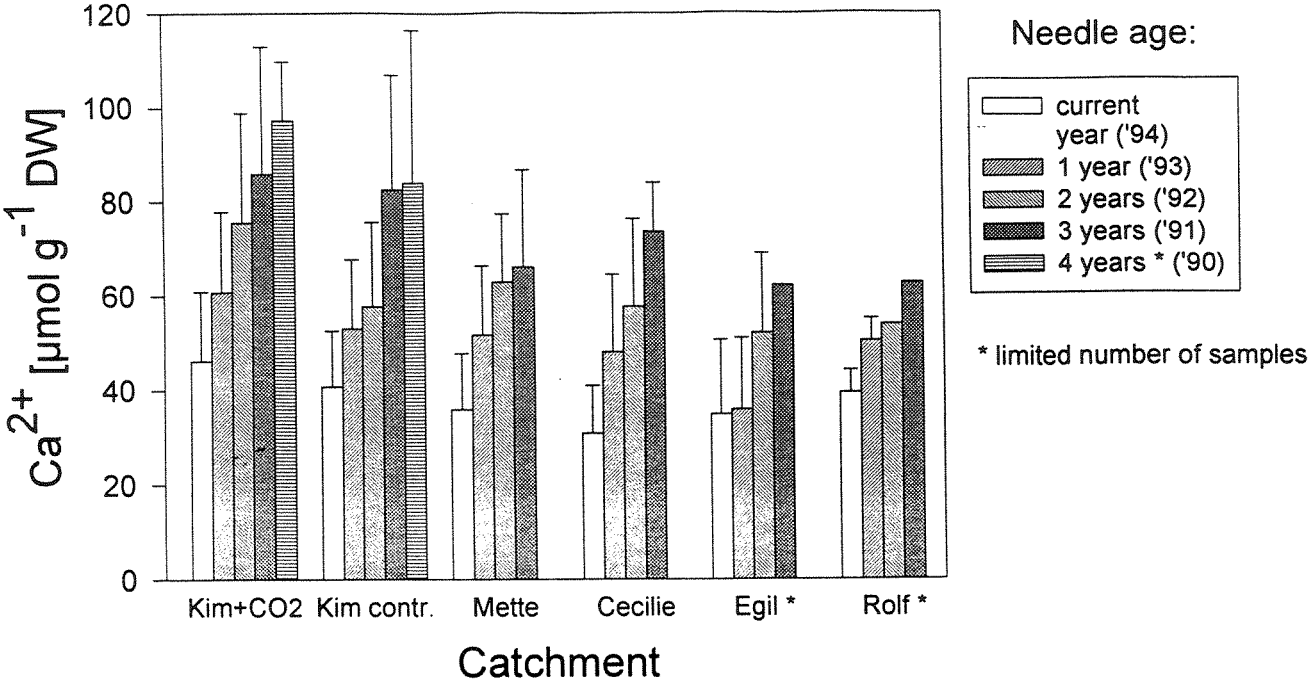

Figure 8.3c. *Calcium concentrations (mean and s.d.) of needles of all available age classes. All trees in each treatment were sampled. Replicates range between 3 and 36.*

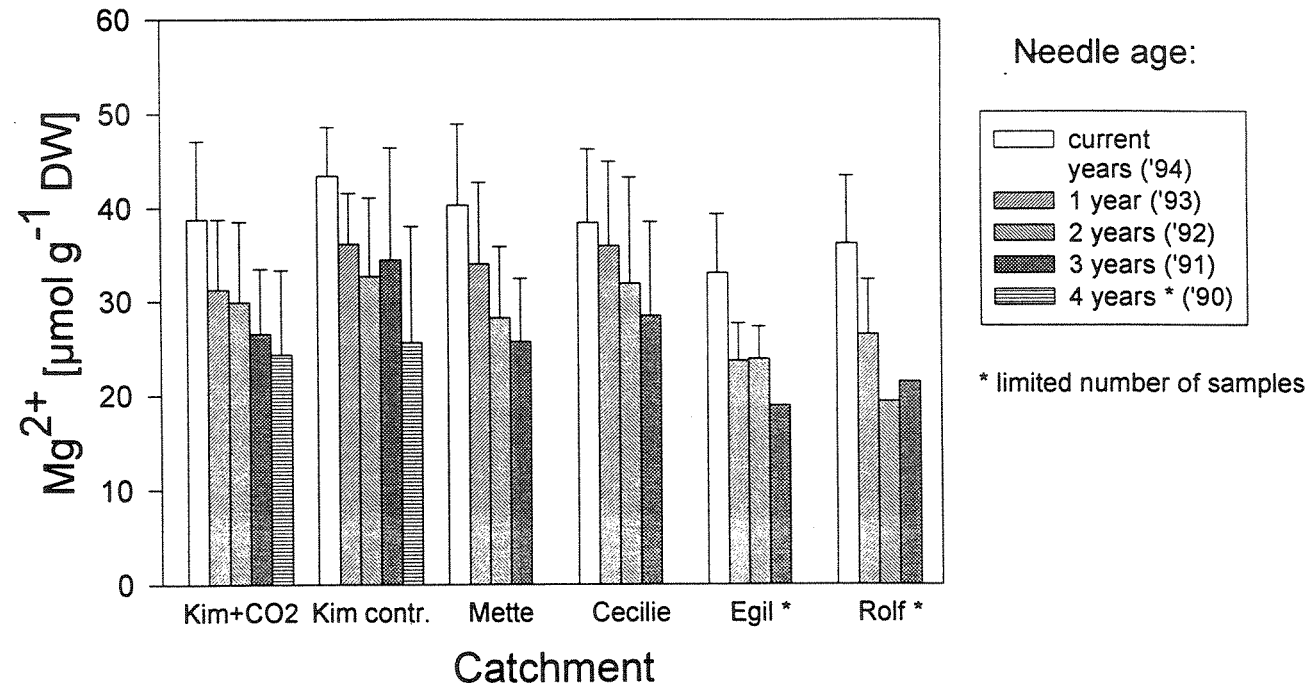

Figure 8.3d. *Magnesium concentrations (mean and s.d.) of needles of all available age classes. All trees in each treatment were sampled. Replicates range between 3 and 36.*

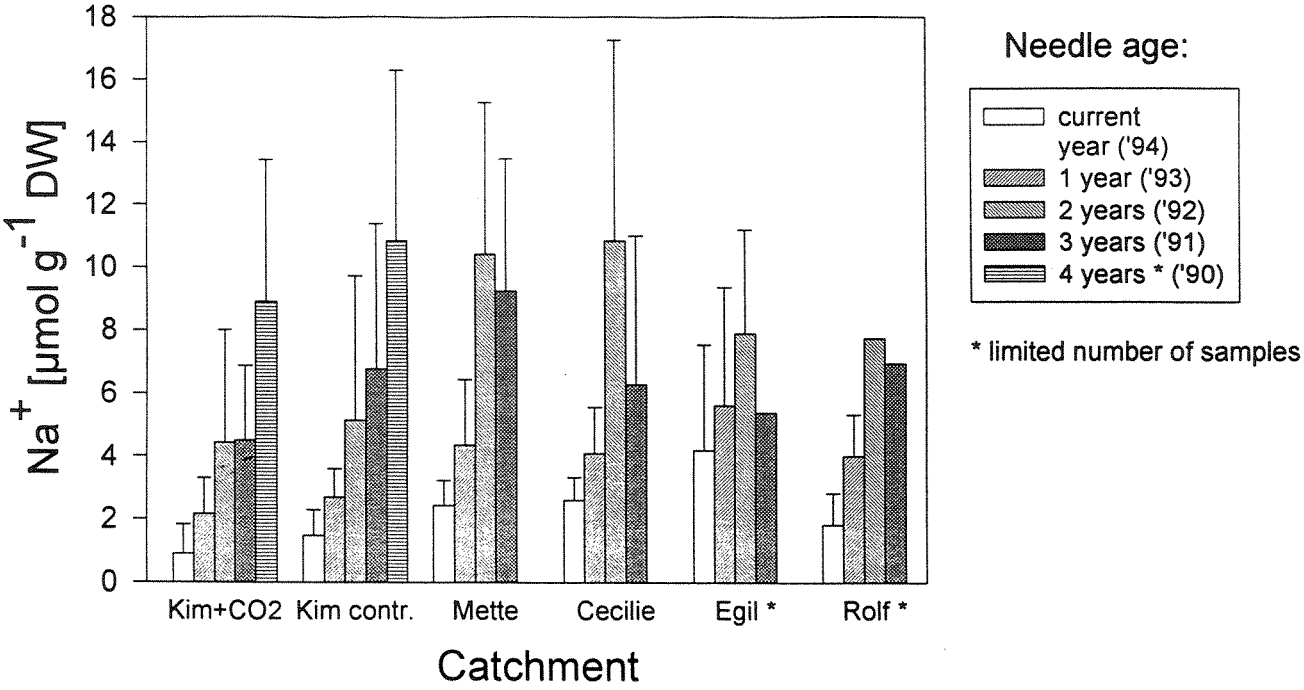

Figure 8.3e. *Sodium concentrations (mean and s.d.) of needles of all available age classes. All trees in each treatment were sampled. Replicates range between 3 and 36.*

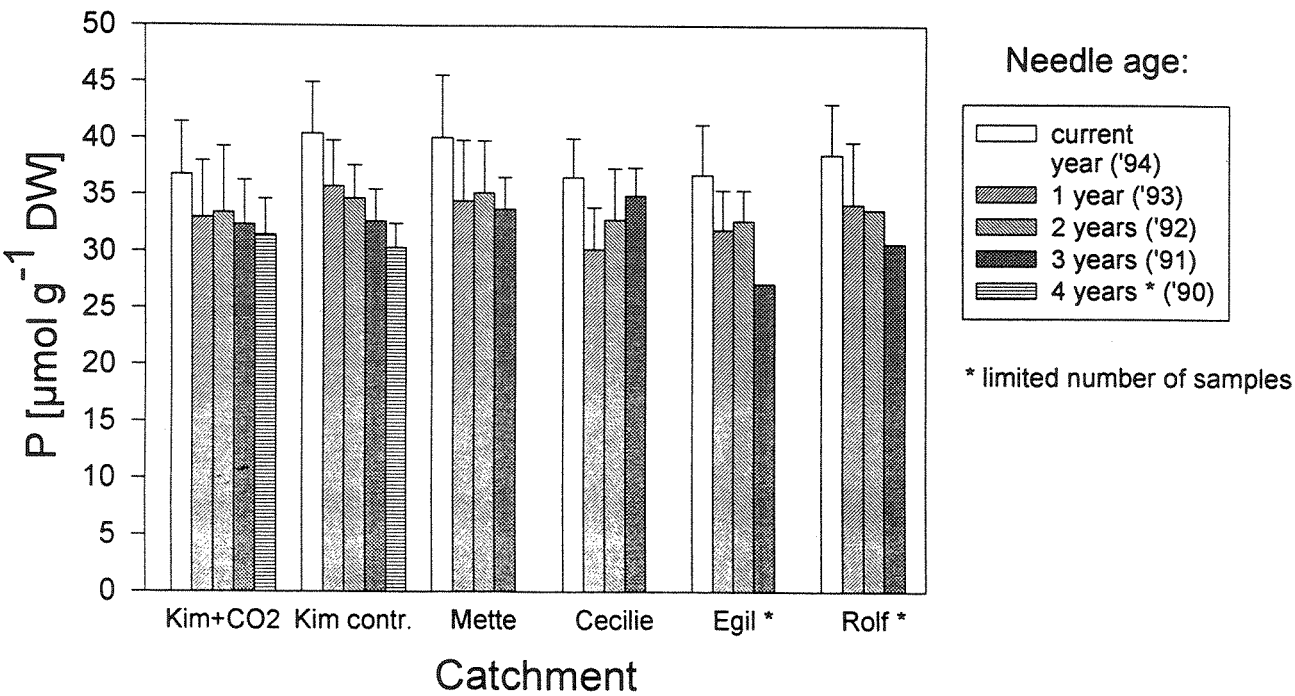

Figure 8.3f. *Phosphorus concentrations (mean and s.d.) of needles of all available age classes. All trees in each treatment were sampled. Replicates range between 3 and 36.*

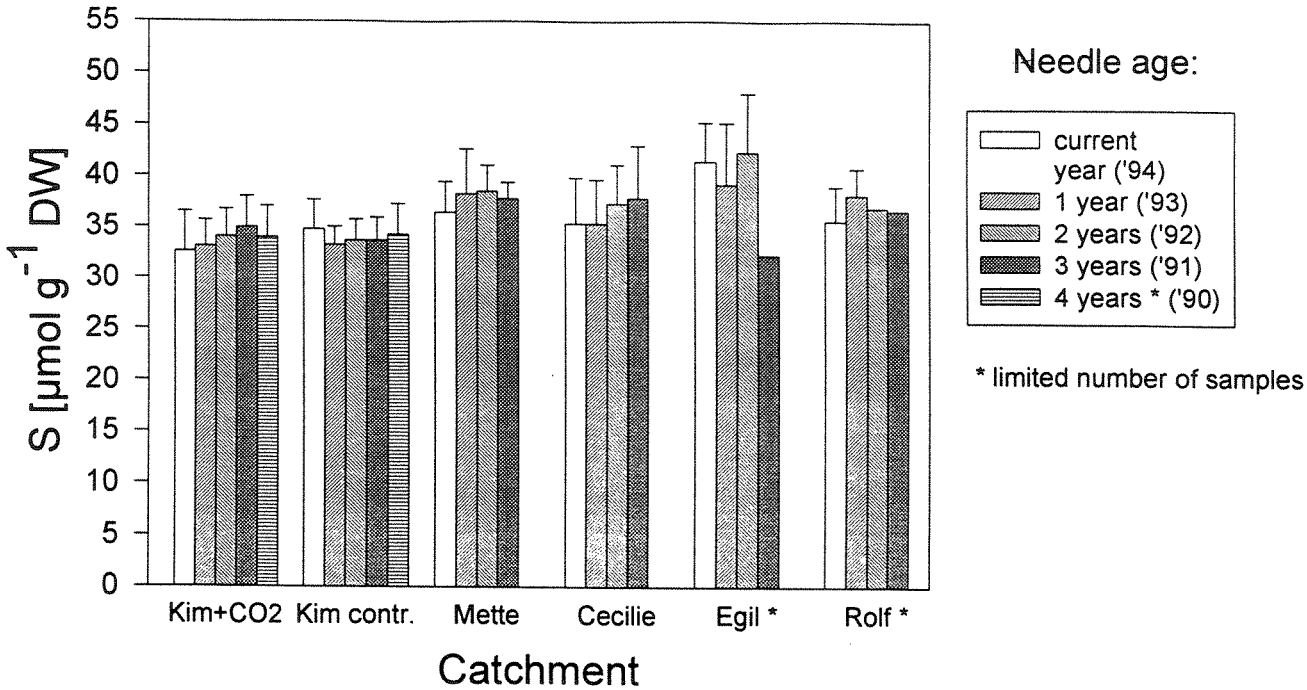

Figure 8.3g. *Sulphur concentrations (mean and s.d.) of needles of all available age classes. All trees in each treatment were sampled. Replicates range between 3 and 36.*

9. Soil Fauna Experiments

Madelein Vreeken-Buijs (IB-DLO) and Lijbert Brussaard (WAU)

Litterbag Study

480 Litterbags (15 x 15 cm) were filled with 4 g (dry matter) birch litter, grown under conditions of ambient CO_2 and clean precipitation (KIM), raised CO_2 and clean precipitation (KIM), ambient CO_2 and ambient precipitation (EGIL). Half of the bags have a 1.5mm mesh size and half a 40um mesh to exclude soil meso- and macrofauna. Ten replicates of each treatment are sampled at 6 sampling occasions. All litterbags are defaunated by freezing (-40°C, 2x48 hr) in advance of the experiment. After sampling, weight loss, loss of N and P, C/N ratio and lignin/N ratio of the litter will be assessed and microarthropods, nematodes and enchytraeids will be quantified and subdivided into functional groups.

In January 1994, all litterbags were filled and sewn closed with polyester yarn. Subsequently all litterbags were defaunated by freezing: 2 times 48 h at -60°C. Late April all litterbags were placed in different compartments of the two roofed catchments at Risdalsheia, Norway. Bags were grouped in patches of ten coarse- and ten fine-mesh bags, to facilitate retrieving. One day later the initial sapling took place, necessary to assess the mass loss due to handling and to quantify the initial C and N content of the different litter types. In September the second sampling took place. No effect of temperature, CO_2, or mesh size was found within KIM or EGIL yet, but a significant difference was found between KIM and EGIL.

This difference in decomposition rate was also reported earlier in the project. Unfortunately, the exclusion of microarthropods by the 40 um mesh-size was not complete. In KIM microarthropod numbers at the 6 months sampling reached on average higher numbers in the fine mesh litterbags than in the coarse mesh litterbags, but in EGIL numbers in the fine mesh bags remained significantly lower (Figure 9.1). The microarthropods found in the fine mesh litterbags all belonged to a single functional group, while in the coarse mesh litterbags all functional groups of microarthropods were represented. Therefore, the aims of the experiment have been adjusted as follows;

- To study the effect of different soil mesofauna compositions on litter decomposition rate under different treatments.

- To study changes in the chemical composition of decomposing litter with different soil mesofauna compositions under the different treatments.

After the second growing season leaf litter has again been sampled from greenhouse-grown birch trees under elevated and ambient CO_2 and ambient and clean precipitation. Contrary to the first year, no effect of CO_2 on the litter was found. Since C and N data are not available yet, the effect on the C/N ratio is not yet known.

Mesocosm experiment

To study effects of the complete soil fauna community, as opposed to a soil ecosystem lacking the mesofauna, hard polyethylene boxes (30 x 40 x 13 cm) 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. Betula litter (2 g dry weight) is packed in 6 cm diameter sieves, of which bottom and top are covered with 1.5 mm gauze. Six sieves ("microcosms") per box ("mesocosm") are inserted in the humus. After partial

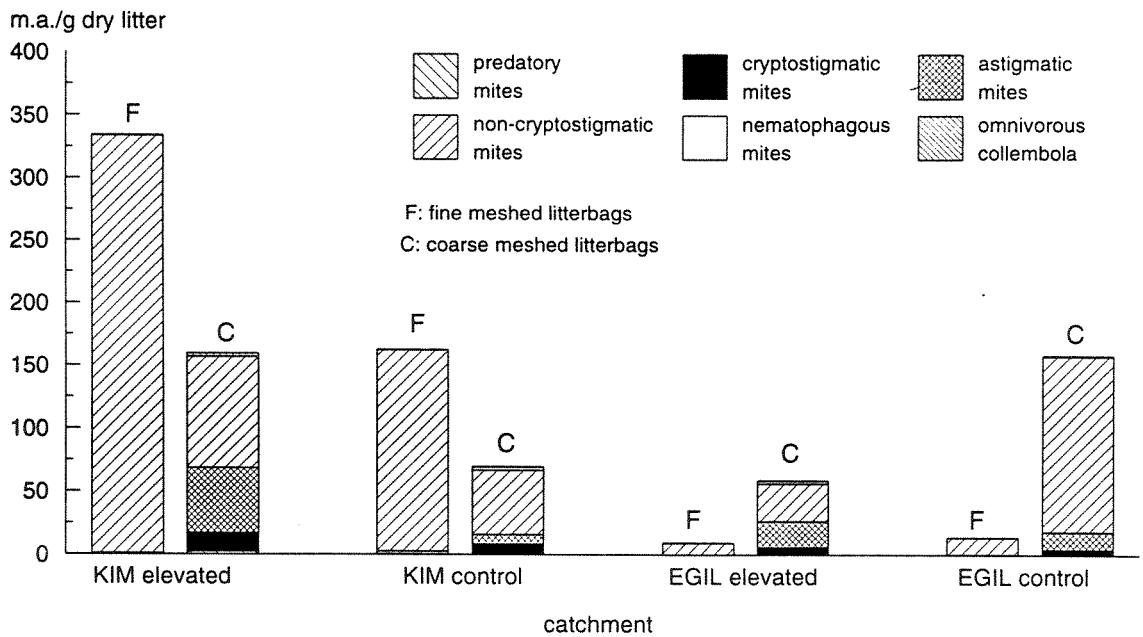

Figure 9.1. *Microarthropods, extracted from litterbags sampled from the the KIM and EGIL catchment, 6 months after placement.*

sterilisation by freezing (-40°C, 4x48 hr), half of the boxes were re-inoculated with soil microarthropods extracted from large sods collected from the field site. These sods were divided into smaller samples and extracted in a Tullgren apparatus. The collection vials were changed daily, larvae and adults of macrofauna (mainly flies, beetles, ants and spiders)removed, and microarthropods transferred to boxes.

The boxes are incubated under eight different climate conditions;

a.	350 ppm CO_2	ambient temperature	clean precipitation
b.	350 ppm CO_2	ambient temperature	ambient precipitation
c.	350 ppm CO_2	summer: +2°C; winter: +6°C	clean precipitation
d.	350 ppm CO_2	summer: +2°C; winter: +6°C	ambient precipitation
e.	700 ppm CO_2	ambient temperature	clean precipitation
f.	700 ppm CO_2	ambient temperature	ambient precipitation
g.	700 ppm CO_2	summer: +2°C; winter: +6°C	clean precipitation
h.	700 ppm CO_2	summer: +2°C; winter: +6°C	ambient precipitation

The litter used for each treatment was grown under similar conditions (except for temperature). During the incubation the sieves are taken out at regular time intervals to be flushed (40 ml demineralized water) in a mini-lysimeter and leachate is analysed for NO_3-N, NH_4-N, P and pH. Soil moisture in the humus layer is determined at the same time intervals. Afterwards moisture content of the boxes is checked by weight control and, if necessary, "clean" water is added to the a, c, e and g boxes and "ambient" water is added to the b, d, f and h boxes. The boxes are closed with a lid with ventilation holes and covered with mesh screen at the sides above the soil surface level. Every six months 3 boxes of each treatment are 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 lignin/N ratio of the litter are determined.

After an ultra-low freezing cabinet became available in February, a pilot experiment was started to asses the optimum temperature and duration of freezing necessary for defaunation of the mesocosms and the pots. The above-mentioned freezing and thawing regime proved sufficient to kill all adult microarthropods and eggs, as no microarthropods were found after extraction nor after two weeks of incubation and extraction. To minimise the amount of soil to be transported from Norway, an alternative soil to be used in this experiment and the plant uptake experiment was sought. After chemical and physical characterisation of the Risdalsheia soil we decided upon a mixture of bolster peat and cut pruning litter (2:3 weight ratio). The latter was to provide extra air filled pore volume.

Microarthropod extraction from Norwegian soil samples and re-inoculation of the mesocosms started after returning from Risdalsheia at end of April. This process took 6 weeks and in between handling all mesocosm boxes were stored at 0°C. Incubation of the mesocosm boxes in the greenhouses under the four climatic treatments started at beginning of June. Directly afterwards the first mini-lysimeter sampling and the first destructive sampling took place. Mini-lysimeter sampling also took place in September and December. NO_3-N and NH_4-N in leachate shows no effects of treatments yet (Figure 9.2).

The next destructive sampling of complete mesocosm boxes took place in December. No effect of any treatment on the litter mass loss (37% on average) has been found yet. Total soil mineral N decreased by 50% in the 6 months period, as did the soil Pw number. No effect of treatment was found. Soil pH (KCl) remained constant at 2.7.

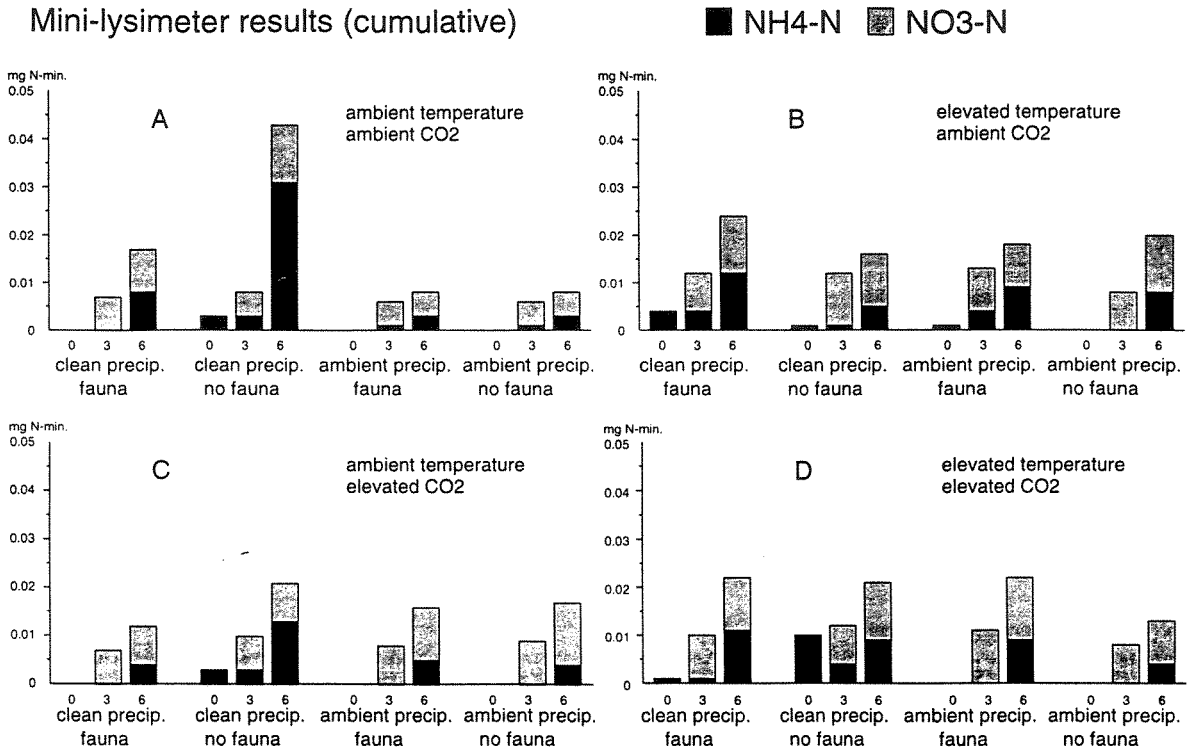

Figure 9.2. *Total N-content in mini-lysimeter leachate of litter incubated in mesocosms under; (A) ambient temperature and ambient CO_2; (B) elevated temperature and ambient CO_2; (C) ambient temperature and ambient CO_2; and, (D) elevated temperature and elevated CO_2.*

Plant uptake experiment

Plastic pots (18 cm diameter) are filled with 2 cm of washed sand, 4ℓ of bolster peat and cut pruning litter substrate and Betula litter (5 g dry weight) on top. The prepared pots are partially sterilised by freezing (see mesocosm experiment), after which half of the pots are re-inoculated with microarthropods. Approximately 10-cm high one year old Betula seedlings, defaunated by chloroform fumigation (1 hour), are planted in the pots and are incubated in four glass-house compartments. Water is applied to the dishes under the pots. At regular time intervals the N content of the soil moisture is monitored by sampling small volumes of soil water. Three replicates of each treatment are destructively sampled every six months for 2 years. Dry mass and N, P and lignin content of the leaves, stem and roots will be assessed, as well as dry mass and N and P content of remaining litter, KCl-extractable N and P from the humus and fauna content of litter and humus.

Flower pots were filled with a mixture of bolster peat and cut pruning litter (2:3 weight ratio) and defaunated by freezing -thawing-freezing (2 times 48 h at -40°C). After returning from Norway re-inoculation with microarthropods extracted from Risdalsheia soil samples started, as described in the mesocosm experiment. In the middle of May the experiment started; the birch seedlings were planted, defaunated litter and the pots placed in the four greenhouse compartments. Right after the start, the initial sampling took place. In November, the

Under ambient CO_2 and clean precipitation, as well as under elevated CO_2 and ambient precipitation a positive effect of the soil fauna on the total yield was found, while the reverse was found under elevated CO_2 and clean precipitation. However, the trees were still very small and large deviations from the mean were found, so no conclusions can be drawn from these results at this early stage.

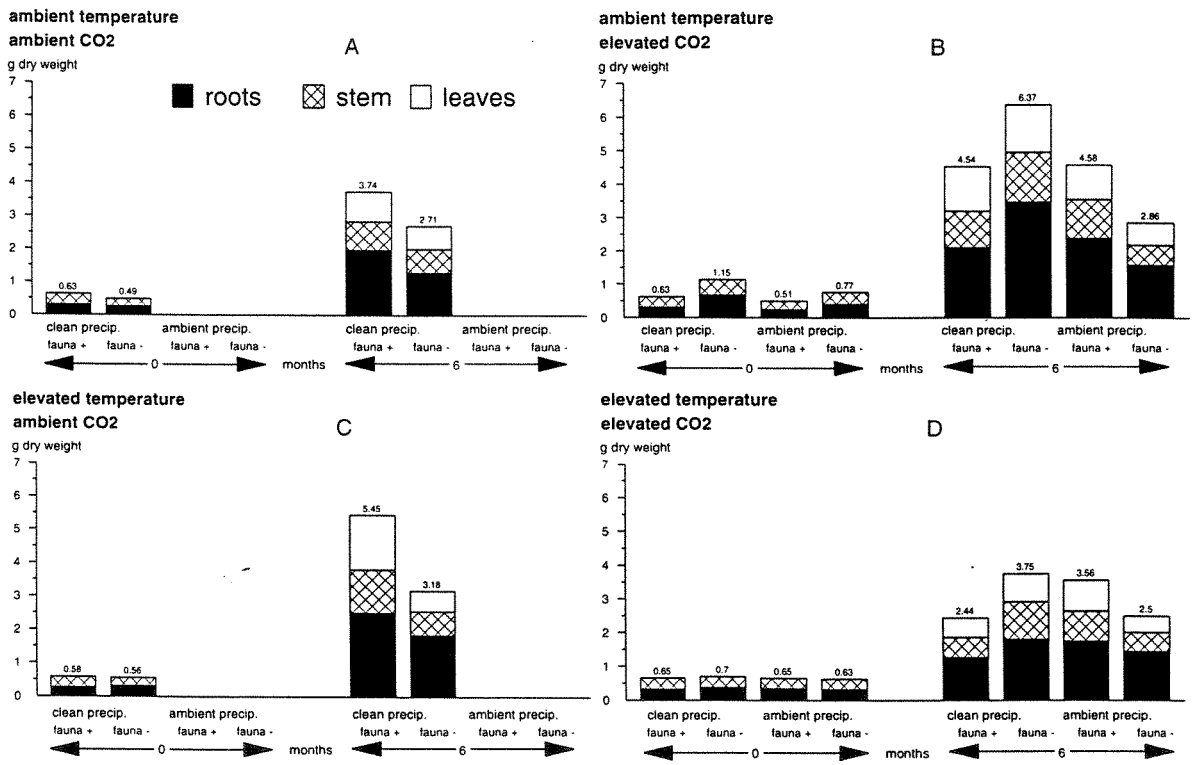

Figure 9.3. *Total dry weight yield of pot-grown birch trees, with added birch litter of different composition, grown in glasshouses with; (A) ambient temperature and ambient CO_2; (B) elevated temperature and ambient CO_2; (C) ambient temperature and CO_2; and, (D) elevated temperature and CO_2.*

10. CLIMEX Publication List

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.

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. Agrobiologische Thema's 9, CABO-DLO, Wageningen, The Netherlands.

Jenkins, A., Wright, R.F., Berendse, F., van Breemen, N., Brussaard, L., Schulze, E.D. and Woodward, F.I. 1993. The CLIMEX project - climate change experiment. In, Rasmussen, L., Brydges, T. and Mathy, P. (eds) Experimental Manipulations of Biota and Biogeochemical Cycling in Ecosystems. Ecosystems Research Report 4, CEC, Brussels.

Jenkins, A. and Wright, R.F. 1993. The CLIMEX project - raising CO2 and temperature to whole catchment ecosystems. In, Schulze, E.D. and Mooney, H.A. (Eds) Design and Execution of Experiments on CO_2 Enrichment. Ecosystems Research Report No. 6., CEC. Brussels.

Beerling, D. J. and Woodward, F.I. 1994. The climate change experiment (CLIMEX): Phenology and gas exchange responses of boreal vegetation to global change. Global Ecology and Biogeography Letters 4, 17 - 26.

Dise, N.B. and Jenkins, A. (Eds) 1995. The CLIMEX Project: Whole Catchment Manipulation of CO_2 and Temperature. CEC. Brussels.

Jenkins, A. and Wright, R.F. 1995. The CLIMEX Project: Performance of the Experimental Facility During the First Year of Treatment. In, Jenkins, A., Ferrier, R.C. and Kirby, C. (Eds) Ecosystem Manipulation Experiments. Ecosystem Research Report No. XX. CEC, Brussels.

Lukewille, A., Arp, W., Verburg, P., Jenkins, A. and Wright, R.F. 1995. The CLIMEX soil heating experiment at Risdalsheia, Southern Norway. In, Jenkins, A., Ferrier, R.C. and Kirby, C. (Eds) Ecosystem Manipulation Experiments. Ecosystem Research Report No. XX. CEC, Brussels.

CLIMATE CHANGE RESEARCH REPORTS

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

2/1995 Jenkins, A. (ed). 1995. CLIMEX Climate Change Experiment: Progress Report July 1993 - December 1993. 31 pp.

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

4/1995 Jenkins, A. (ed). 1995. CLIMEX Climate Change Experiment: Final Report on Phase I the first year of treatment May 1994 - December 1994. 47 pp.

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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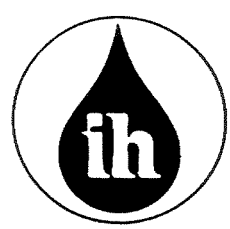

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ISBN: 82-577-2922-1