IMPACTS OF ACID PRECIPITATION ON CONIFEROUS FOREST ECOSYSTEMS[1]

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ABSTRACT

This paper summarizes the results from current studies in Norway. One main approach is the application of artificial acid "rain" and of lime to field plots and lysimeters. Application during two growth seasons of 50 mm per month of "rain water" of pH 3 to a podzol soil increased the acidity of the humus and decreased the base saturation. The reduction in base saturation was mainly due to leaching of calcium and magnesium. Laboratory experiments revealed that decomposition of pine needles was not affected by any acid "rain" treatment of the field plots. Liming slightly retarded the decomposition. No nitrification occurred in unlimed soils (pH 4.4 - 4.1). Liming increased nitrification. The soil enchytraeid (*Oligochaeta*) fauna was not much affected by the acidification. Germination of spruce seeds in acidified mineral soil was negatively affected when soil pH was 4.0 or lower. Seedling establishment was even more sensitive to increasing soil acidity. Analysis of throughfall and stemflow water in southernmost Norway reveals that the total deposition of sulphuric acid beneath spruce and pine is approximately two times the deposition in open terrain. A large part of this increase is probably due to dry deposition. Increased acidity of the rain seems to increase the leaching of cations from the tree crowns. Tree-ring analysis of spruce (*Picea abies* (L.) Karst.) and pine *Pinus sylvestris* L.) has been based on comparisons between regions differently stressed by acid precipitation and also between sites presumed to differ in sensitivity to acidification. No effect that can be related to acid precipitation has yet been detected on diameter growth.

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1. INTRODUCTION

Southern Norway receives acidic pollutants with air and precipitation far in excess of what could be expected from the emissions within the region. The monthly mean pH of the precipitation varies between 4 and 5.

The deposition of acids represents a possible threat to forest and fresh-water ecosystems. An increasing number of rivers and lakes are becoming too acidic for trout (Jensen & Snekvik 1972). Occasional mass-dying of trout has been observed. Estimates of an anticipated reduction in forest growth have been given (Dahl & Skre 1971). Lysimeter studies have indicated a dramatic increase in the leaching of calcium from soil when the percolating water pH drops below 3 (Overrein 1972).

The great concern over these problems in Norway has resulted in the establishment of a large nationwide project named "Acid Precipitation - Effects on Forest and Fish" (Overrein & Abrahamsen 1975). The aim of the forest-research portion of this project is primarily to study the effects of acid precipitation on forest growth and development, secondly to study the effects on main processes influencing forest growth and development. The present paper summarizes the main approaches, and the results obtained so far, without comprehensive discussion.

2. EFFECTS ON SOIL

The effects of acid precipitation on soil properties and processes are undoubtedly very complicated. Experiments with simplified systems in the laboratory must therefore be controlled by field experiments where the complex interaction of climate, organisms, and organic and inorganic matter are largely undisturbed. Because most field experiments have to be pursued over a long period of time, these experiments have been given priority in the starting phase of the project.

The soil studies include investigations on soil fauna, decomposition and soil chemistry.

2.1. Experimental design

The soil studies are based on the application of lime and of simulated acid rain, to field plots and lysimeters. The aim of these experiments is to obtain information on the effect of acid precipitation on soil properties, soil processes, and plant growth. At present, results from one plot experiment and one lysimeter study, both started in 1972, are available. These particular experiments were located in a semipodzolic soil (intermediate profile between podzol and brown earth), developed in a sandy, glacifluvial sediment. Soil chemical characteristics appear in Table 1. The experimental area, which is situated

Table 1. Soil chemical characteristics of the field experiments.

Soil horizon	Soil depth cm	Soil chemical properties ($\bar{x} \pm s$)				
		Loss on ignition %	$pH_{(H_2O)}$	Cation exchange capacity meq/100 g	Base saturation %	N in % of oven-dry material
A_0	0-ca. 3	28 ± 10	4.4 ± 0.1	39 ± 13	25 ± 3	1.27
A_2	3-6	7.3 ± 0.9	4.4 ± 0.1	17 ± 2	15 ± 4	0.14
B	9-12	4.3 ± 0.4	4.7 ± 0.1	11 ± 1	7 ± 2	0.06

approximately 40 km north of Oslo, was clear cut about 1960 and reforested with *Pinus contorta* Douglas, in 1965. In 1974 the trees were between 2 and 4 m high. The ground flora is completely dominated by *Deschampsia flexuosa* (L.) Trin.

Three by four meter plots were treated with lime and "rain" of various acidity (Table 2). "Rain water" quality was adjusted with sulphuric acid. The simulated rain was applied in addition to the natural precipitation, and was applied once a month in the non-frozen period of the year.

The lysimeters are 29.5 cm wide and 45 cm high fiberglass cylinders. Each is filled with an undisturbed soil monolith according to the procedure described by Overrein (1968). Treatments appear in Table 2.

The leachate from the lysimeters was collected in 5-liter plastic containers. Each week, 100 ml of the leachate was analysed for pH, conductivity and colour.

The remaining leachate was stored in the field and preserved by adding HCl (10 ml per l). At the end of each month, one liter of the preserved leachate for the month was used for chemical analysis.

Table 2. Treatment of the field plot (P) and the lysimeter (L) experiment. Lime was applied as ground limestone. Experimental design: Complete randomization with 3 replicates in the plot experiment and 2 in the lysimeter study.

Liming	No irrigation	IRRIGATION 25 mm per month pH 5.7	pH 4	pH 3	50 mm per month pH 5.7	pH 4	pH 3
No lime	P	P L	P L	P L	P	P	P
1500 kg CaO/ha				P			
3000 " "		P	P	P			
6000 " "				P			

2.2. Soil zoology

Soil samples collected from the field experiment in October 1974 were extracted for enchytraeids (*Oligochaeta*) which is one of the most abundant groups of animals in coniferous forest soils. The procedures used in sampling, extraction, etc. are described elsewhere (Abrahamsen 1972). Other groups of soil animals were not considered.

Statistical analyses did not reveal any significant influence of the various treatments on the total abundance of enchytraeids. The three main species, however, seem to respond differently to the various treatments. *Cognettia spagnetorum* (Vejdovsky, 1877) is a dominant species in acidic raw-humus habitats (e.g. Abrahamsen 1972). Populations of this organism were significantly reduced by liming, but not by the "acid rain". *Enchytronia parva* Nielsen & Christensen, 1959, is confined to more fertile soils (Abrahamsen 1972). This organism increased in numbers with increasing acidity of the rain at a high lime concentration and decreased with increasing acidity at a low lime concentration. (Significant interaction at 1% level). The abundance of the third main species, *Enchytraeus norvegicus* Abrahamsen, 1969, has not been significantly influenced by any treatment.

2.3. Soil microbiology

Studies on microbiological processes have been focused on the decomposition of organic matter, nitrification and nitrogen fixation. No results are yet available for nitrogen fixation.

Decomposition has been studied on needles of *Pinus contorta* (Ishac & Hovland 1975). The needles were collected from the field in 1973 and

1974 in the month of November. They were incubated at 15° and 25° on moistened glass-wool in conical flasks. Weight loss was measured after 90 days.

Decomposition was significantly increased by increasing temperature from 15° to 25° C, significantly decreased by liming (3000 kg CaO per ha) and not significantly influenced by the acidity (pH 5.7 and pH 3) of the "rain".

Decomposition was also examined on needles from the control plots. The needles were moistened with various dilutions of sulphuric acid. The experiment showed that the decomposition rate (weight loss) was significantly ($P<0.05$) increased when the initial pH was increased from 1.8 to 3.5 (Figure 1). No difference was found between pH 3.5 and 4.

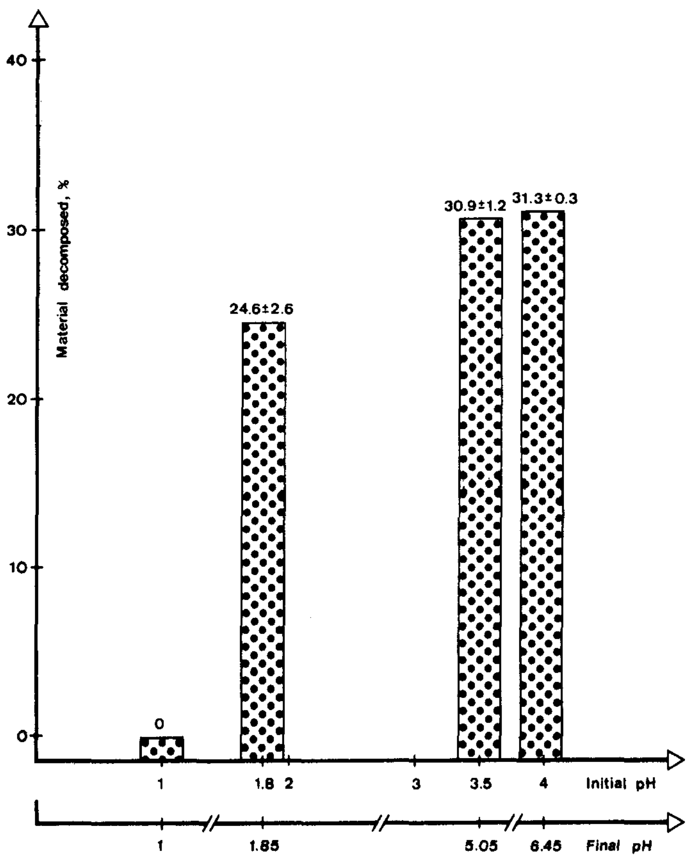

Figure 1. Effect of pH on the decomposition (weight loss after 105 days) of pine needles (*Pinus contorta*). pH of the substrate was adjusted by dilute H_2SO_4.

At pH 1 no decomposition took place.

Humus samples collected in October 1974 from the field plot experiment (Table 2) were used for nitrification experiments in the laboratory (Hovland & Ishac 1975). The experiment was carried out using a perfusion technique with the addition of $(NH_4)_2SO_4$. No nitrification occurred in humus from the unlimed plots. Liming on the other hand significantly increased the nitrification. The amount of nitrate formed was almost proportional to the quantity of lime added to the soil. No interaction was found between liming and pH. The experiment shows that in this particular soil (Table 1), the formation of nitrate is of small ecological importance probably due to the high acidity.

2.4. Soil chemistry

Soil cores sampled from the plot experiment (Table 2) in October, 1974, and the leachate of the lysimeters were analysed for chemical properties by standard methods.

Soil reaction and the amount of soluble and exchangeable nutrients in the soil of the various experimental plots are given in Tables 3 and 4. Table 3 shows the main effect of liming independently of the treatment with acid "rain". This can be given since acid "rain" had no effect on soil characteristics at the lowest rain level where lime had been applied. Liming had on the other hand highly significant effects on soil chemical properties. The decrease in potassium by increased liming must be explained by ion exchange of the two elements. The decrease in the amount of soluble and exchangable manganese is on the other hand explained by a transition to water-insoluble manganese compounds.

Effects of "rain" acidity were only observed at the highest "rain" level where no lime was applied (Table 4). Rain of pH 3 applied at a rate of 50 mm per month resulted in a significant reduction ($P < 0.01$) of the degree of base saturation. The interaction between the amount and the acidity of the "rain" was also highly significant ($P < 0.005$). The decrease in base saturation at the highest "rain" level results from the decreasing content of soluble and exchangable cations that occur in the soil when the pH of the "rain" drops from 4 to 3. The decrease in the amount of the individual cations was not, however, large enough to be statistically significant.

No effect due to the acidity of the "rain" was found on soil chemical properties in the field plots treated with 25 mm "rain" per month. However, acid "rain" applied at the same rate to the lysimeters significantly increased the leaching of calcium and magnesium (Table 5). The figures given in the table are relative, meaning that the amount of calcium or magnesium leached in 1973 at pH 5.7 is designated 1.0 and the other values are designated relative to this one. Increased leaching by increased acidity of the "rain" has not been observed for other

TABLE 3. EFFECT OF LIMING (GROUND LIMESTONE) ON SOIL CHEMICAL PROPERTIES. DATA FROM THE LOWEST "RAIN" LEVEL ONLY (25 MM PER MONTH).

Soil layer and depth cm	Kg CaO/ha 0	1500	3000	6000
			$pH_{(H_2O)}$	
Humus ca. 3 cm	4.27	5.92	6.54	6.65
Mineral soil 0-3 cm	4.31	4.75	4.85	5.14
Mineral soil 6-9 cm	4.68	4.71	4.70	4.92
		K meq/100 g		
Humus ca. 3 cm	1.15	0.87	0.73	0.85
Mineral soil 0-3 cm	0.13	0.12	0.11	0.10
Mineral soil 6-9 cm	0.06	0.06	0.06	0.05
		Ca meq/100 g		
Humus ca. 3 cm	4.8	24.1	40.6	57.6
Mineral soil 0-3 cm	1.2	4.1	5.0	7.1
Mineral soil 6-9 cm	0.4	0.8	0.6	1.1
		Mn meq/100 g		
Humus ca. 3 cm	1.07	0.58	0.50	0.53
Mineral soil 0-3 cm	0.19	0.16	0.11	0.11
Mineral soil 6-9 cm	0.04	0.05	0.04	0.03
		Base saturation %		
Humus ca. 3 cm	22	77	100	100
Mineral soil 0-3 cm	12	26	31	40
Mineral soil 6-9 cm	7	9	8	12

cations, nitrate or organic nitrogen. Nor has the acidity of the leachate been influenced by the treatment. Other lysimeter experiments in operation indicate, however, very significant increases in the leaching of most cations when the amount of rain increases and especially when it becomes more acidic than pH 3.

Table 4. The effect of the quantity and acidity of the "rain" on soil chemical properties. Data from unlimed plots only.

	25 mm/month pH 5.7	pH 4	pH 3	50 mm/month pH 5.7	pH 4	pH 3
			pH			
Humus ca. 3 cm	4.4	4.1	4.3	4.4	4.6	4.1
Mineral soil 0-3 cm	4.3	4.2	4.4	4.5	4.4	4.2
" " 6-9 cm	4.8	4.6	4.7	4.7	4.7	4.7
			Na Meq/100 g			
Humus ca. 3 cm	0.15	0.17	0.14	0.11	0.10	0.09
Mineral soil 0-3 cm	0.05	0.05	0.04	0.06	0.05	0.05
" " 6-9 cm	0.04	0.04	0.04	0.04	0.04	0.04
			K Meq/100 g			
Humus ca. 3 cm	1.14	1.32	1.00	0.99	0.85	0.87
Mineral soil 0-3 cm	0.13	0.13	0.13	0.14	0.16	0.13
" " 6-9 cm	0.06	0.07	0.07	0.06	0.07	0.06
			Ca Meq/100 g			
Humus ca. 3 cm	4.3	5.4	4.7	6.1	4.9	2.8
Mineral soil 0-3 cm	1.3	0.9	1.3	1.2	1.2	0.8
Mineral soil 6-9 cm	0.5	0.3	0.4	0.6	0.4	0.4
			Mg Meq/100 g			
Humus ca. 3 cm	1.38	1.45	1.15	1.55	1.12	0.81
Mineral soil 0-3 cm	0.39	0.30	0.30	0.39	0.34	0.23
Mineral soil 6-9 cm	0.12	0.06	0.13	0.11	0.09	0.09
			Mn Meq/100 g			
Humus ca. 3 cm	1.20	0.87	1.16	1.31	0.94	0.73
Mineral soil 0-3 cm	0.20	0.15	0.22	0.22	0.21	0.19
Mineral soil 6-9 cm	0.03	0.04	0.04	0.06	0.04	0.03
			Base saturation %			
Humus ca. 3 cm	24	19	23	25	27	18
Mineral soil 0-3 cm	14	9	13	14	11	8
Mineral soil 6-9 cm	9	5	7	7	6	6

3. EFFECTS ON TREES

3.1. Washing and leaching of tree crowns

When penetrating tree crowns, the chemical composition of the rain is altered, mainly due to the washing of absorbed deposits ("dry" deposits), and the leaching of excreted metabolites.

Table 5. The effect of acid "rain" on the relative leaching of Ca and Mg. "Rain" quantity: 25 mm per month. Leaching in 1973, pH 5.7 is designated 1.0. Differences in leaching due to different treatments are significant at the 0.1 % level.

Element	Year	pH of "rain" 5.7	4	3
Ca	1973	1.0	1.4	1.4
	1974	1.3	2.9	4.5
Mg	1973	1.0	1.2	1.4
	1974	1.2	1.9	2.4

The chemical composition of incident rainfall, throughfall and to a lesser degree, stemflow has been studied during three summer and autumn periods in Birkenes, South Norway, and one period in Målselv, North Norway.

Throughfall collectors were placed halfway between the stem and the perimeter of the crown projection. Incident rainfall was measured in open terrain. Stemflow was collected by means of a collar nailed to the tree.

The results (Table 6) show that the deposition of most chemical substances was higher in South Norway than in North Norway. Note, however, that the sampling period is shorter and the amount of precipitation less in North Norway. Further, the throughfall enrichment of sulphate, calcium, and potassium was greater in South Norway than in North Norway. In South Norway, the tree crowns seem to have absorbed nitrate and ammonium from rainwater. Throughfall beneath spruce and pine, in contrast to birch, contained more strong acid than did incident rainfall. In North Norway, the amounts of strong acid were negligible.

The concentrations of the different substances were in general negatively, but not significantly, correlated with the amount of rainfall or throughfall. In incident rainfall, chloride, sodium, and magnesium (mainly derived from sea salt) constituted one group of correlated ions, and ammonium, nitrate, calcium, sulphate, and strong acid constituted another. In throughfall, chloride, sodium, magnesium, ammonium, nitrate, calcium, sulphate, and potassium were correlated.

Table 6. Amount and chemical composition of incident rainfall and throughfall in Birkenes, ($58^{o}23'N$, $8^{o}15'E$), South Norway (average of 1973 and 1974) and Målselv, ($69^{o}03'N$, $19^{o}20'E$), North Norway (1973).

Location and Species	Period	Precip. mm	Total deposition (mg/m^2) Cl.	NO3-N	NH4-N	PO4-P	SO4-S	Ca	Mg	Na	K	Strong acid	Average pH
Birkenes													
Spruce	June-Nov.	270	2560	20	20	7	990	550	220	1210	1060	50	4.4
Pine	"	370	2900	60	40	2	950	490	470	1620	770	60	4.4
Birch	"	400	1700	80	60	15	650	340	178	880	700	14	4.7
Open	"	470	990	160	140	2	490	90	70	600	60	25	4.3
Målselv													
Spruce	July-Oct.	70	740	20	110	25	110	70	70	400	450	0	5.9
Pine	"	100	890	20	60	21	110	100	80	540	410	2	5.7
Birch	"	90	210	10	30	14	50	60	30	120	250	0	5.9
Open	"	150	170	20	20	9	90	30	20	100	60	1	5.2

The lack of correlation between strong acid and the other ions in throughfall was most consistent beneath birch.

When the net removal of chemical substances from the tree crowns (throughfall minus incident rainfall values) in North Norway and South Norway is compared to values obtained from southern Sweden and from Germany (Table 7), a certain pattern appears. The removal of chloride

Table 7. Net removal of selected elements by rain from spruce crowns in different areas of Europe.

Location	km from the coast	S	Cl	Ca kg/ha/year	Mg	Na	K	Reference
Målselv, N. Norway	60	0.6	17	1	1	9	12	Present paper. Data extrapolated to annual values
Birkenes, S. Norway	20	10	30	9	3	12	20	Do.
Scania, S. Sweden	15	34	35	11	4	17	21	NIHLGÅRD (1970)
Solling, BRD	200	174	-	49	7	5	45	ULRICH (1968)

and sodium reflects the distance from the coast to the study areas. The removal of potassium, magnesium, calcium and, most distinguishably, sulphur shows a considerable increase from north to south. The increase in sulphur and calcium is probably caused by a greater dry deposition, cf. the wet deposition pattern in Europe (Oden 1971, Royal Ministry for Foreign Affairs & Royal Ministry of Agriculture 1971).

The amount of stemflow increased in the order: spruce < pine < birch (Table 8). The concentration of strong acid, sulphate, chloride, calcium, and magnesium was roughly two times greater in stemflow than in throughfall. Sodium and potassium differed less. In birch the stem bark or epiphytes absorbed a considerable amount of nitrate and

Table 8. Amount and chemical compostion of stemflow.
Values significantly higher (h), or lower (l), than the corresponding throughfall values are indicated. Birkenes, Norway, 1974.

Species	ml/tree	Cl	NO_3	NH_4	PO_4	SO_4	Ca	Mg	Na	K	Strong acid	pH
		mg per l.										
Spruce	10-300	8.5	0.2	1.4	0.94h	11.7	3.5h	1.0h	4.7	4.0 l	0.07	4.9 h
Pine	50->3500	21.2h	0.3	0.3	0.03	20.3h	4.8h	1.7h	10.3h	3.7 h	0.42	3.8
Birch	800->3500	11.4h	0.1 l	0.1 l	0.13	15.0h	2.3h	1.2h	4.6	1.5	0.34h	3.7 l

ammonium. It is further noteworthy that while birch throughfall was less acidic than incident rainfall, stemflow was more acidic.

A conclusive interpretation of the results appears to be impossible at present. It is probable that a larger part of the throughfall enrichment in chloride, sulphate, calcium, sodium, and hydrogen ions in Birkenes is derived from dry deposits than from leached metabolites. Further, hydrogen ions from dry and/or wet deposits might replace other cations in the tree crowns.

3.2. Germination and establishment

The results presented here are based experiments carried out with seeds of spruce (*Picea abies* (L.) Karst.) and pine (*Pinus sylvestris* L.) in artificially acidified mineral soil (Teigen 1975).

Soils of different pH were obtained by percolating mineral soil with 1500 mm water of different pH values. Additional soil pH levels were obtained by liming. The soil used was derived from a podzolized morainic soil with a low content of plant nutrients (cation exchange capacity 10 meq/100 g and base saturation 2 per cent).

Seeds from one open pollinated tree of each species were transferred to the acidified soils. An adequate moisture regime was obtained by adding distilled water. The number of germinated seeds and established seedlings was recorded after 7 weeks. Seeds were defined to have germinated when the emerged embryo was at least 3 mm long. Seedlings were defined as established when the primary needles were developed.

The experiments with pine covered a soil pH range of 4.0 to 4.6. No effects upon germination or establishment were found within this range.

The experiments with spruce covered a soil pH range of 3.8 to 5.6. Significant effects of soil pH upon both germination and establishment were demonstrated (Figures 2 and 3). Germination seems to have a rather broad optimum around pH 4.8. Establishment seems to have a more narrow optimum around pH 4.9. About 80 per cent of the seeds did not develop

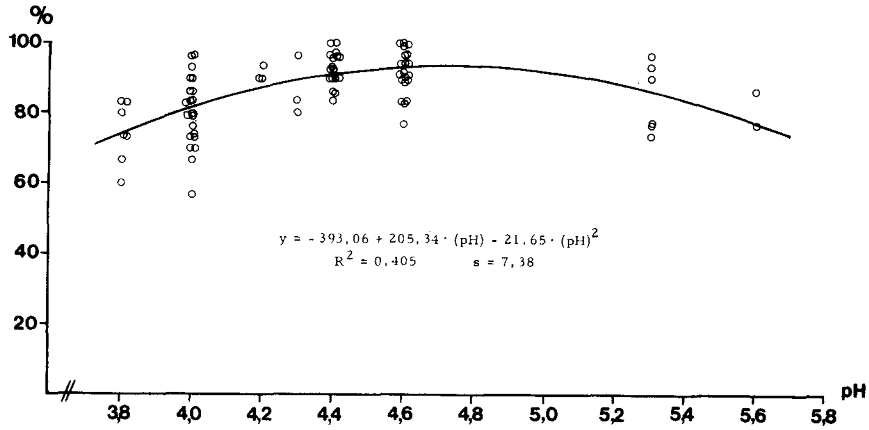

Figure 2. Relation between soil reaction and percentage of spruce seed germination.

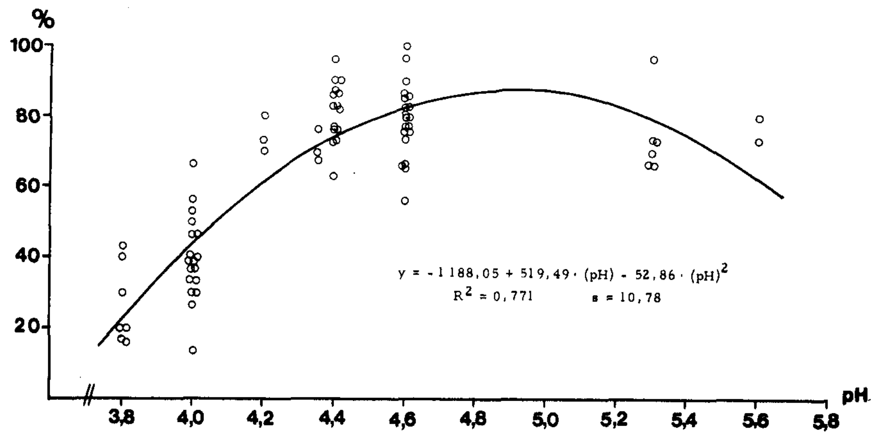

Figure 3. Relation between soil reaction and percentage of spruce seedlings established.

normal seedlings at pH 3.8. A large number of these plants had developed roots, but the roots did not penetrate into the soil. Variations in the nutrient content of the soils had no apparent effect upon germination or establishment.

3.3. Tree growth

Possible effects of acid precipitation upon tree growth are partly being studied in field experiments with simulated acid rain and partly by analysing past tree growth in different regions and on different sites. At present only preliminary results from tree ring analyses are available.

Tree ring analyses have been used in studies of air pollution effects around local emission sources (e.g. Pollanschutz 1971, Sundberg 1974). As far as we know the only attempt to use this approach in analyses of regional acidification effects has been made by Jonsson & Sundberg (1972).

Our approach and models lean heavily upon the Swedish study of Jonsson & Sundberg (1972). Tree ring development is compared: 1) between regions presumed or known to have different inputs of acid precipitation and 2) within regions between sites supposed to differ in sensitivity owing to soil properties. Increment cores of spruce (*Picea abies* (L.) Karst.) and pine (*Pinus sylvestris* L.) are obtained from the National Forest Survey which annually collects information about the Norwegian forests according to a systematic clustered sampling scheme. Sample plot information is used to stratify the material into site or regional groups.

It is necessary in the models used to have a reference period before the acidification effects started. At this stage of the study, the period from the year 1927 and onwards has mainly been investigated. Trees of the same species covering the whole investigation period are put together within sample plots to form an average-plot tree-ring series. In the models adopted, the factors influencing growth are supposed to act multiplicatively. Additive models are obtained by using logarithmic ring width as the dependent variable.

Plots within the same region or site group are combined to form average tree ring series for the separate groups. Two groups are further compared by forming a difference series which shows the relative tree ring development of the groups. The difference series are analysed for possible trend changes.

The analyses are complicated by a number of factors. Ideally there should be a negligible interaction between group and growth year. This is probably not the case in comparisons between geographically separated regions or in comparisons between regions which are extreme in ecological factors. Autocorrelation in the time series is another factor which decreases the sensitivity of the analyses. Other complicating factors are possible differences in cutting practices and intensity, stand history, and the normal time-trend between regions or site groups that are compared. The effect of these factors must be evaluated in addition to the time series analyses.

Figures 4 and 5 show the average tree ring development in pine and spruce in two geographic regions - Sørlandet and Østlandet, in South Norway and East Norway respectively - as well as the difference series between the regions. Sørlandet receives more acid precipitation and is also supposed to be more sensitive to acidification due to shallow soils.

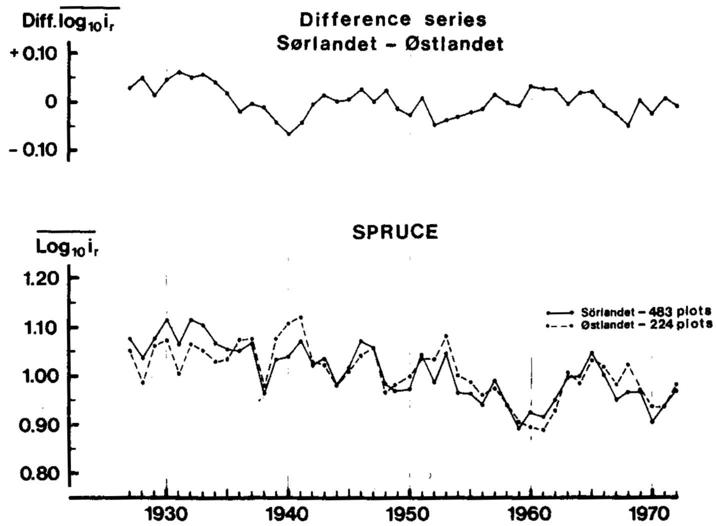

Figure 4. Tree ring development of spruce in different regions and a difference series between the regions.

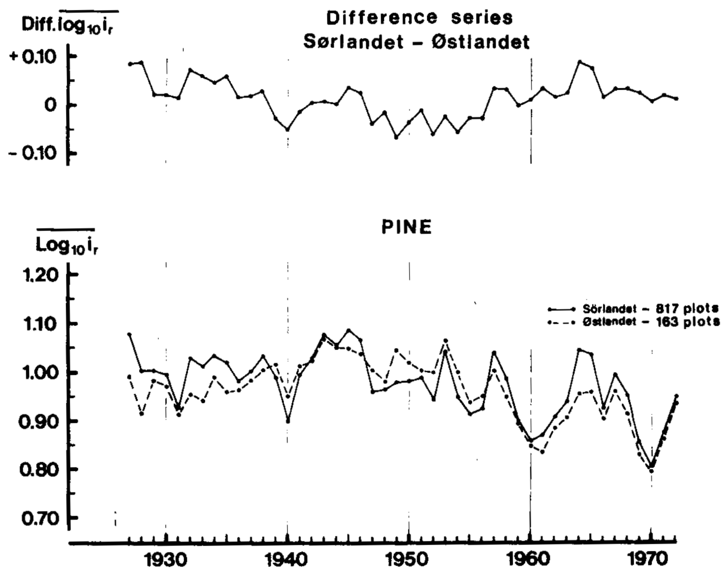

Figure 5. Tree ring development of pine in different regions and a difference series between the regions.

The main features of ring-width development are similar in the two regions pointing back to common components of climatic growth factors and time trends. The difference series reveal some fluctuations in the relative tree ring development. Interactios between region and year seem to be a main component of these fluctuations according to preliminary analyses. These interactions decrease the sensitivity of analyses of trend changes. The year 1950 has been used as a starting point for possible acidification effects in the Swedish study. There are, however, no indications of a relatively slower growth within Sørlandet after this year. The region Østlandet is, on the other hand, also influenced by acid precipitation and does not give an ideal reference.

The data from one region (Sørlandet) have been more fully analysed in an attempt to elucidate the possible effect of different productivity (the site-class concept in forest terminology), vegetation type, water regime, soil depth, and tree species in relation to the acidification problem. Although the analyses are not completed, the difference series between extreme groups do not support the hypotheses that less productive sites, poor vegetation types, ombrogen sites, or shallow soils should be more sensitive to acidification. Neither does an analysis of the development of spruce relative to pine support the hypothesis that spruce is more sensitive to acidification when growing on poor sites. Figure 6 shows as an example the tree ring development

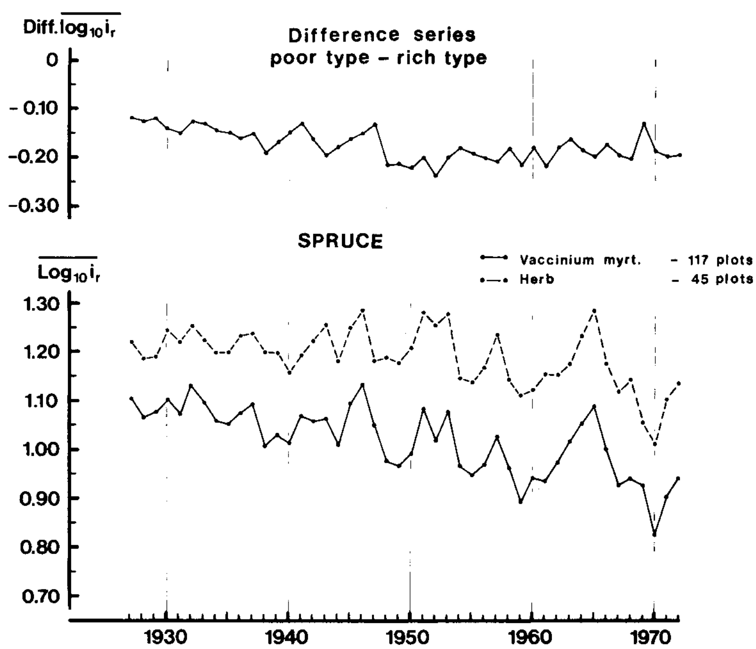

Figure 6. Tree ring development of spruce within different vegetation types and a difference series between the types. Stands from Sørlandet (South Norway) below 300 m altitude.

of spruce within two groups of vegetation types (a *Vaccinium myrtillus* type and a herb-rich type) from stands within Sørlandet and below 300 m alt. Figure 7 shows finally the development of pine on two groups of

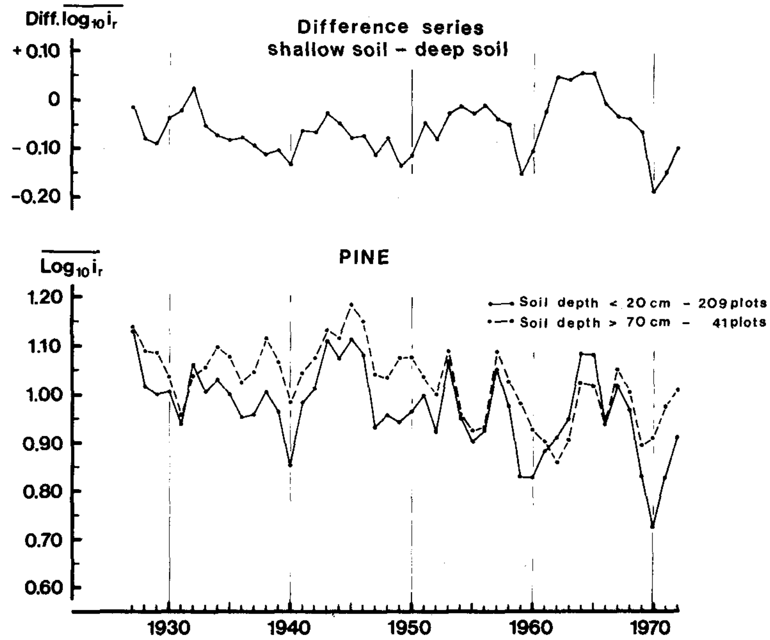

Figure 7. Tree ring development of pine on different soil depth groups and a difference series between the groups. Stands from Sørlandet (South Norway) below 300 m altitude.

soil depths (< 20 cm and > 70 cm) within the same region and height zone.

The reason for the apparent lack of relationship between tree ring development and the hypotheses about acid precipitation effects can be many-fold. The effects may be masked by other factors which are not satisfactorily isolated by the approach. The hypotheses about possible effects are based upon meagre facts and may be false. More data may be needed. It also may be that no large effects of acid precipitation upon tree growth have yet occurred.

4. SUMMARY AND CONCLUSION

The present paper summarizes the current results of ongoing studies in Norway on the impact of acid precipitation and dry deposits on coniferous forest ecosystems. These studies include investigations on soil, leaching from tree crowns, germination, establishment of seedlings and tree ring analyses.

The soil studies are entirely based on simulated acid rainfall (pH range 5.7 - 3.0) and the application of lime, in field plots and lysimeters. Results from these experiments are at present available from an experiment running since September 1972. The results concern soil fauna, decomposition of organic matter, and soil chemistry.

The abundance of one important group of the soil fauna - the Enchytraeidae has been studied. Two species had not been influenced by the acid rain. One species decreased in abundance with increasing acidity of the "rain" at a low lime level and increased in abundance at a high lime level.

Laboratory experiments with pine needles (*Pinus contorta*) from the field plots have not revealed any influence of acid "rain" (pH range 5.7 - 3.0) on decomposition. Liming on the other hand, has reduced the decomposition rate significantly.

During the period from September 1972 to October 1974 significant reduction in the degree of base saturation has occurred in the topmost layer of the soil of the plots where the highest amounts of acid have been applied. This reduction is reflected by the increased leaching of Ca and Mg in the lysimeter experiments.

Leaching from tree crowns has been studied in Birkenes, South Norway, being heavily exposed to long transported air pollutants, and in Målselv, North Norway, which is supposed to serve as a control area.

Both the amount of various chemical components in throughfall and the ratio between concentration in throughfall and in incident rainfall are significantly higher in Birkenes than in Målselv. Conclusive interpretation of these results is impossible at present. However, the high concentrations in Birkenes may derive from dry deposition, the leaching of metabolites and the exchange of ions between plant tissue and deposited pollutants.

Green-house experiments with spruce (*Picea abies*) on artificially leached (with dilute sulphuric acid) mineral soil indicate that germination and especially establishment are negatively affected when soil reaction drops below pH 4.0 - 4.2.

Regions supposed to differ in exposure to acid deposition have been compared with regard to tree ring development. So far no differences have been found that can be related to the pollution. Nor have clear effects of acid precipitation been observed on sites supposed to be most sensitive to acidification (poor vegetation types, shallow soils, etc.).

The experiments described in the present paper indicate that severe negative influences on soil and organisms are not to be expected over a period of a few years when the acidity of the rain is above ca. pH 4. Since the acidity of the precipitation in southern Norway varies greatly between pH 3.5 and 5.7 with a prevailing pH of ca. 4.5 (1974) it seems likely that possible effects on tree growth up to now have been too small to be detected by tree ring analysis. However, longer exposure time and increased acidity of the precipitation seem to be a severe threat to soil conditions, the health of vegetation, and finally to forest production.

5. LITERATURE

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