EFFECTS OF APPLICATION OF SULPHURIC ACID TO POOR PINE FORESTS

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The department of plant ecology and soils of the College of Forestry has been interested in the problem of the acid rain as an environmental factor since the discussion of this problem started in the late 1960's (Odén 1968).

FIELD EXPERIMENTS

(by C. O. Tamm)

A field experiment was started in 1969 in a young pine forest growing on a glacifluvial eskar at Lisselbo, 160 km north of Stockholm. The experiment consisted in watering out sulphuric acid in dilute solution to plots 30 × 30 m. The treatment was given in two dosages: Acid 1 corresponding to 50 kg H_2SO_4 per hectare and year and Acid 2 twice as much. The treatment Acid 1 was not started until 1970. Both treatments were tried both alone and combined with a NPK fertilizer treatment and in the same experiment also irrigation and liming were tested with and without fertilizer. There were further experiments laid out in the same site, a nitrogen dosage experiment with and without a PK treatment and a third experiment with a balanced block design to test the effect of other nutrients PK, S, Mg and a combination of micronutrients in the presence of nitrogen (Tamm et al. 1974).

The source of nitrogen in the Lisselbo experiment was amonium nitrate and this fertilizer was added every year, first in amounts corresponding to 60 (N1), 120 (N2) and 180 (N3) kg N per hectare. After two years the fertilizer amount was lowered to 40, 80 and 120 kg N per hectare and year. The other elements have been applied at somewhat larger intervals.

The Lisselbo experiments have been revised twice and the results conclusively prove that nitrogen is a factor limiting forest growth on this site. No positive effect has been established for any of the other nutrient additions. The higher nitrogen levels appear to be supra-optimum and an optimum curve for growth in relation to nitrogen percentage in the pine foliage has been established (Fig. 1). There have been some needle injuries and shoot dieback which have been attributed to

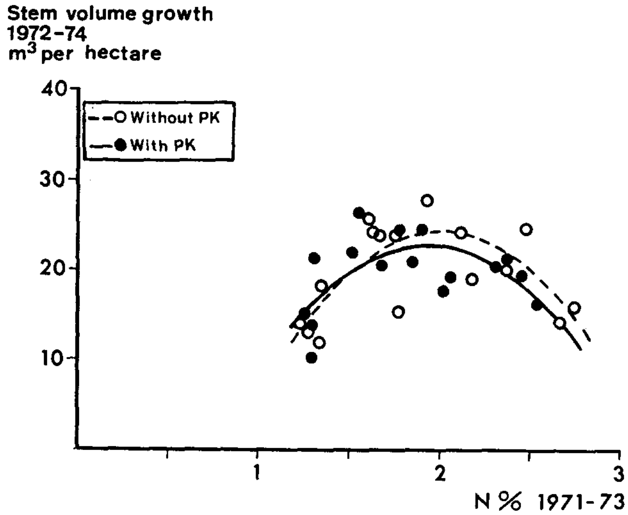


Figure 1. Stem volume growth as a function of the nitrogen concentration in current needles. Expt. E40 Lisselbo, fertilized from 1969 onwards with ammonium nitrate and in 1969, 1972 with a PK fertilizer.

frost damage (Aronsson, in preparation). These injuries have been particulary frequent on the plots receiving nitrogen. Trees on plots receiving both lime and fertilizer have been damaged particularly. Nitrogen fertilization has increased basal-area growth much more than height growth which appears to be almost unaffected by fertilization (except for the mentioned negative effect of lime). The only treatment except nitrogen application which has increased growth appears to be irrigation even if the results are not statistically significant due to the small number of replicates in the experiment (only two). Irrigation of unfertilized plots, however, had no measurable effect.

The application of sulphuric acid, particularly the treatment Acid 2, has killed much of the ground vegetation (mosses, lichens and the dwarf shrub *Calluna vulgaris*) but there is no evidence of a negative growth effect on the trees so far (Fig. 2). However, measurements of volume or basal area growth for a tree stand are relatively crude measurements so a smaller change in growth would not be detectable by the measurement method used.

Soil studies have been made within the area but the results will be briefly reported in section 3 of this paper.

The second acidification experiment started in 1971 at Norrliden 100 km northwest of Umeå in north Sweden. The site is located at about

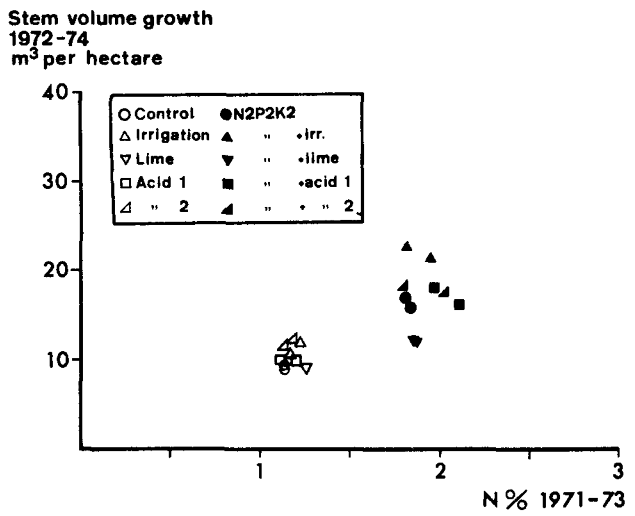


Figure 2. Stem volume growth as a function of the nitrogen concentration in current needles. Excpt. E42 Lisselbo. Treatments from 1969 onwards (cf. Fig. 1).

250 meters altitude and the soil is a glacial till. The design of the experiment is similar to that of the Lisselbo experiment although one higher level of acid was included (Acid 3, 150 kg H_2SO_4 per hectare and year). There were three replicates of each treatment in this experiment but no irrigation plots within the same experiment. However, irrigation was tested in another experiment on the same site and seemed to give a slight positive effect also here. Fertilization was also tried on the same site as in the Lisselbo experiments. The first revision of the Norrliden experiment was made in the autumn of 1974 and showed here as at Lisselbo a very clear effect of nitrogen fertilization but small effects of the other nutrient additions including the acidification (Fig. 3, 4).

LYSIMETER EXPERIMENTS

(by G Wiklander)

In the Lisselbo experimental area a lysimeter installation was made and an experiment started in May 1972. The lysimeters consisted of about 40 cm deep polyethylene buckets containing soil (medium sand) from the site. Ground vegetation and top soil were disturbed as little as possible at the installation. The buckets were drained with plastic tubes containing wicks of terylene to polyethylene flasks. The percolate was analysed at intervals. The lysimeters received the same

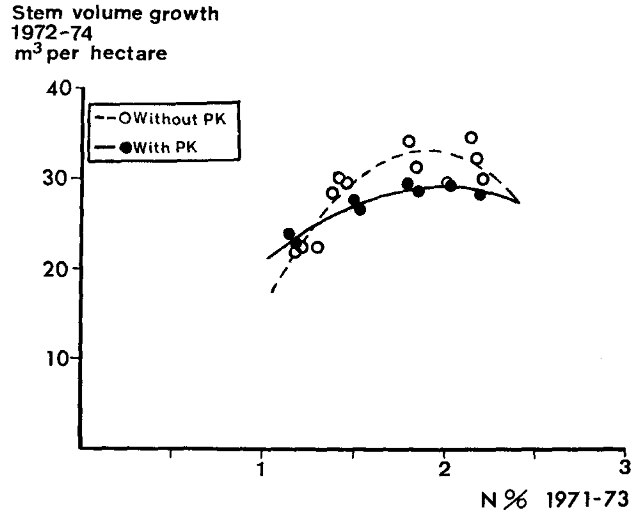


Figure 3. Stem volume growth as a function of the nitrogen concentration in current needles. Expt. E55 Norrliden, fertilized from 1971 onwards with ammonium nitrate and in 1971, 1974 with a PK fertilizer.

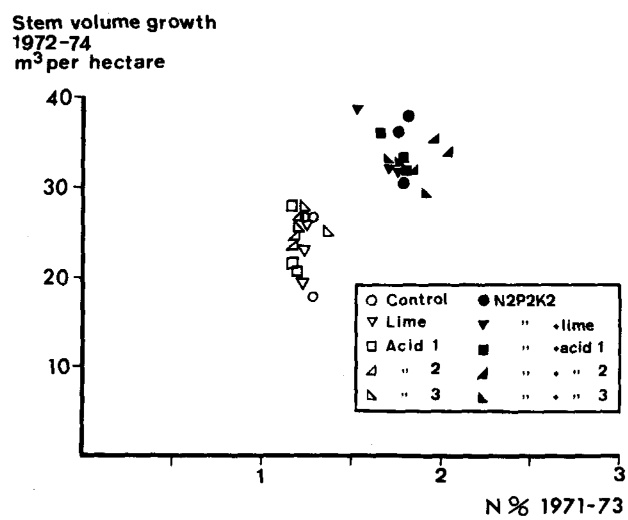


Figure 4. Stem volume growth as a function of the nitrogen concentration in current needles. Expt. E57 Norrliden. Treatments from 1971 onwards (cf. Fig. 3).

treatments as the field plots with four replicates; Control, Acid 2, N2P2K2 and the combination of these treatments. Acid 2 means 100 kg H_2SO_4 per hectare and year applied as 50 + 50 kg at an interval of one month. N2P2K2 means 120 kg N per hectare and year as ammonium nitrate and 40 kg P + 76 kg K per hectare the first year as a commercial PK fertilizer. The PK fertilizer contains also other elements, e.g. calcium (13 per cent) and sulphur (6-7 per cent).

Just after the first treatment in June 1972 there was an exceptionally heavy rain (about 90 mm) which immediately carried down a relatively large proportion of the added acid and nutrients (Fig. 5-7).

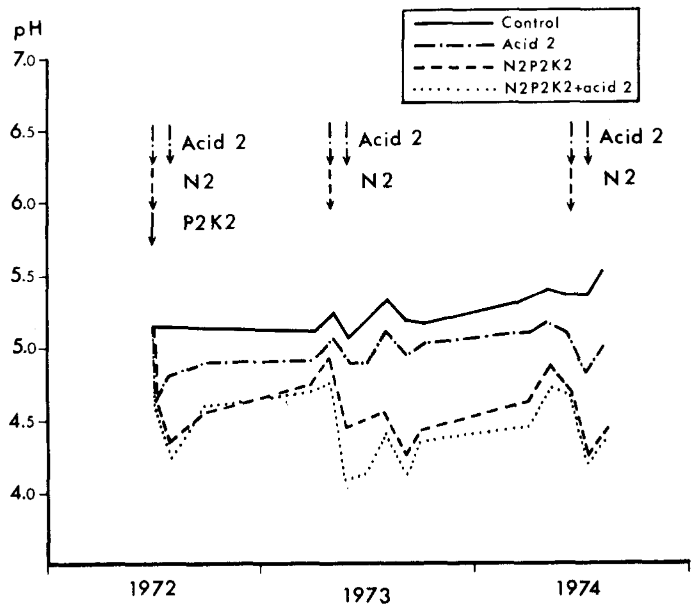


Figure 5. Lisselbo, pH of lysimeters percolates. Mean values of four repititions. Acid 2 means 50+50 kg H_2SO_4/ha, N2 means 120 kg N/ha as ammonium nitrate and P2K2 means 40 kg P/ha + 76 kg K/ha as a PK fertilizer.

However, both sulphate ions and much of the cations were retained in the soil and further leaching was rather slow. The next addition of ammonium nitrate in fertilized lysimeters led to an increased leaching of hydrogen ions and cations (Fig. 5,7). It appears as if ammonium nitrate application had a higher leaching and acidifying effect than sulphuric acid but it then has to be remembered that the number of equivalents given was considerably higher in the case of ammonium nitrate than in the case of sulphuric acid. Although sulphuric acid as well as addition of soluble salts, ammonium nitrate in particular, has an acidifying

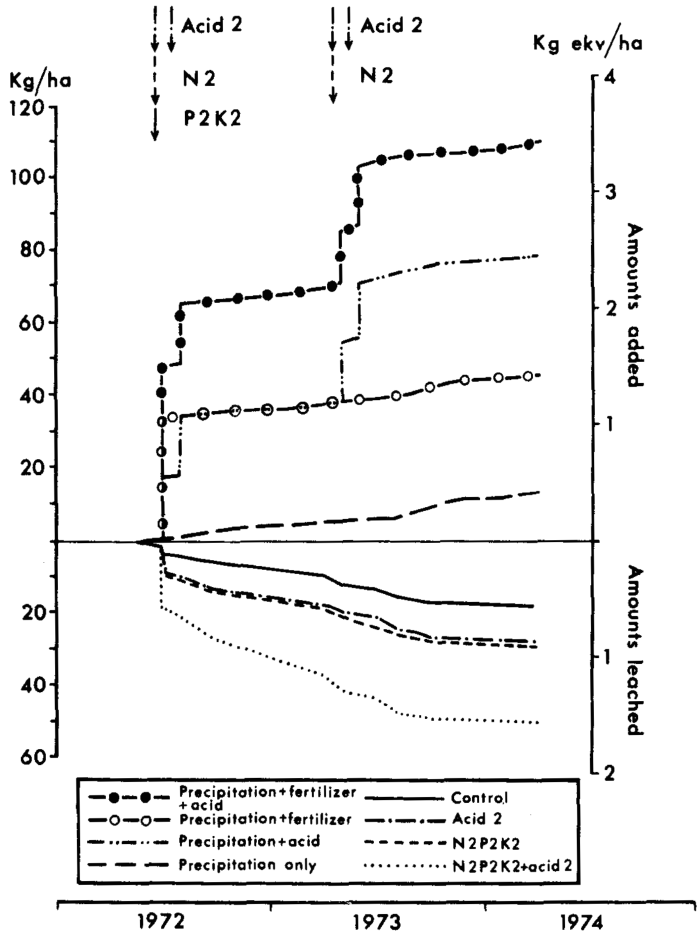


Figure 6. Lisselbo. Addition and leaching of sulphur from lysimeters (Cumulative data). Mean values of four repetitions. Amounts corresponding to Acid 2 and N2P2K2 as in Fig. 5.

effect on the leachate and also increases leaching of cations, this acid soil has an ability to retain for a considerable time a large proportion of the added ions. The leaching of cations which can be attributed to the addition of hydrogen ions as sulphuric acid is only a small proportion of the addition (Fig. 8).

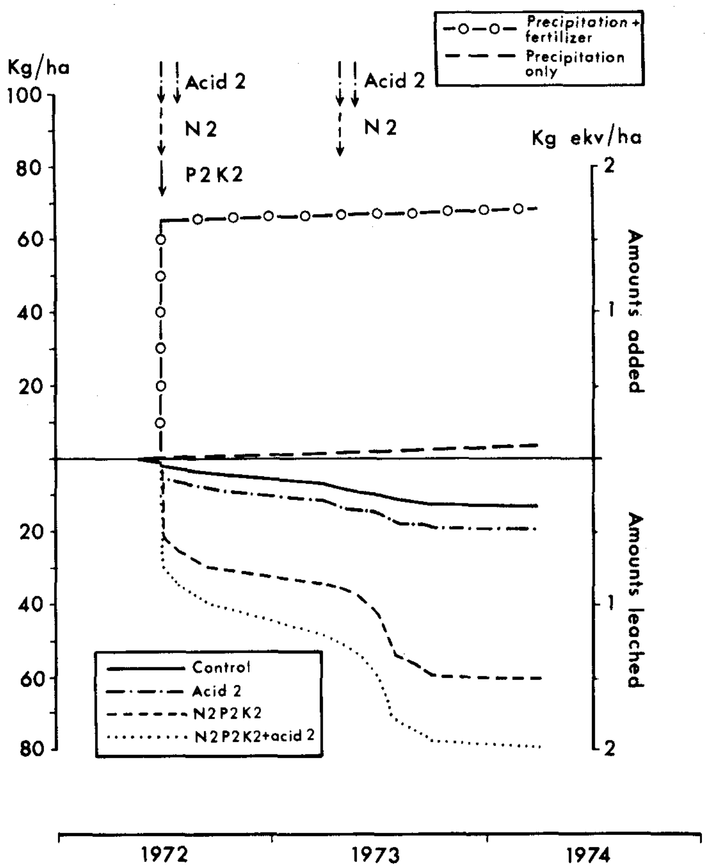


Figure 7. Lisselbo. Addition and leaching of calcium from lysimeters (Cumulative data). Mean values of four repititions. Amounts corresponding to Acid 2 and N2P2K2 as in Fig. 5.

SOIL INCUBATION EXPERIMENTS
(by B. Popović)

Soil samples (A_0 horizon) have been collected from the various plots in both the Lisselbo and the Norrliden experiments. They have then been incubated in the laboratory and the release of nitrogen has been measured after intervals of six to nine weeks. There have also been model experiments carried out with humus samples from untreated areas of the experiments (both Lisselbo, Norrliden and a new experimental area where an acidification experiment was started in 1973, Åseda, northeast of Växjö in south Sweden).

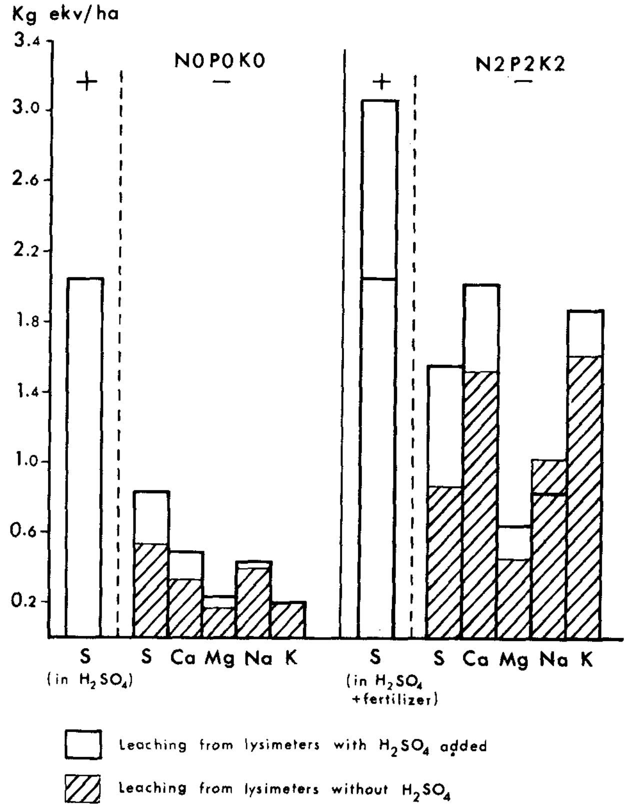
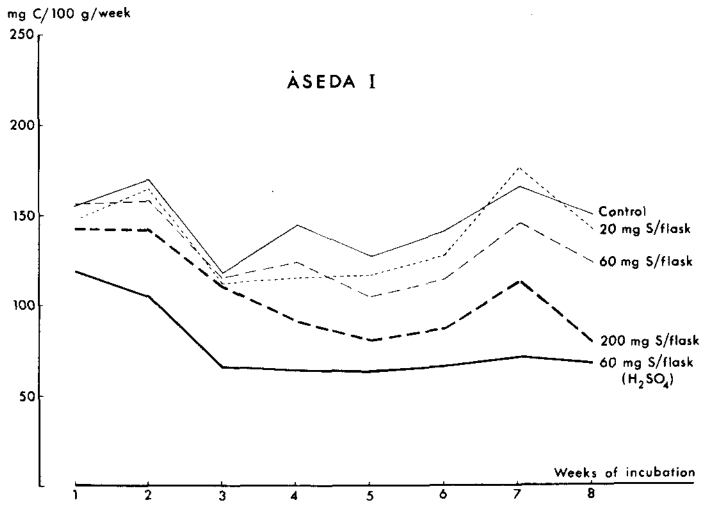
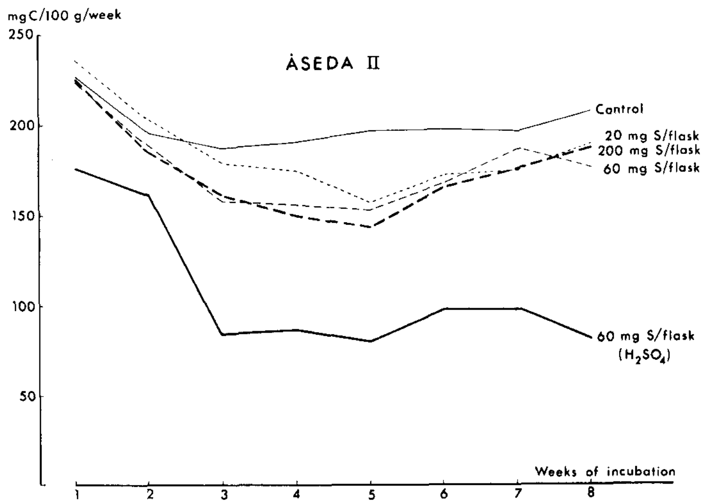


Figure 8. Lisselbo. The effect of addition of H_2SO_4 on the leaching of various elements. Mean values of four repetitions.

The incubation experiment of soil samples were carried out at a temperature of 20°C and soil moisture adjusted to 60% WHC. In some experiments the carbon evolution during the incubation experiment was measured with a technique recommended by Nömmik (1971).

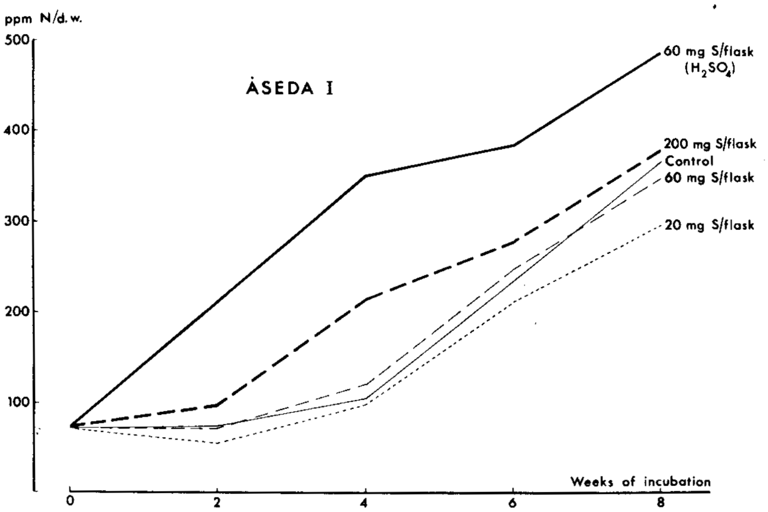
The results from the model experiments in the laboratory are more consistent than the incubation experiments with samples from field plots. There always is a local variation between plots which causes a scattering in the results. We therefore first report the results from the experiment with the Åseda samples which were from two different sites representing different experimental blocks in the field experiment. In both cases an addition of either sulphuric acid or powdered sulphur caused a distinct depression of the release of carbon dioxide during the incubation period (Fig. 9, 10). Sulphuric acid was more effective than sulphur in this respect. pH measurements showed that the lowest addition of sulphur iad no depressing effect on pH, while 60 mg S as sulphuric acid lowered pH in flask with half a pH unit. The same amount

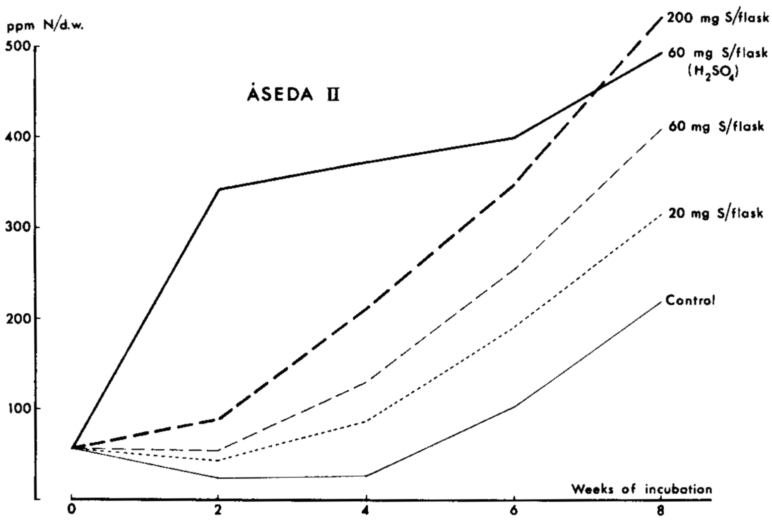




Figures 9 and 10. Respired quantity of CO_2 in mg C/100 g D. W. per week during incubation of humus samples pretreated with different doses of powdered sulphur or sulphuric acid. Experimental area Åseda I and Åseda II. Mean values of three repetitions.

as powdered sulphur had no measurable effect on pH but depressed carbon dioxide evolution, 200 mg S in powdered form depressed carbon dioxide evolution even more and lowered pH about two tenths of a unit. All these comparisons concern differences between control flasks and treated flasks; pH increased from 4.1 - 4.2 at start to 4.4 - 4.5 at end in the controls. In the case of release of mineral nitrogen the tendency was opposite (Fig. 11, 12). The additions of sulphur usually





Figures 11 and 12. Accumulation of inorganic nitrogen content in humus samples during eight weeks' incubation and pretreatment by different doses of powdered sulphur or sulphuric acid. Sampling at two weeks' interval. Experimental area Åseda I and Åseda II. Mean values of three repetitions.

increased the amount of mineral nitrogen in the samples (most pronounced for the addition as sulphuric acid), but lowered the amount of nitrate (Fig. 13-16).

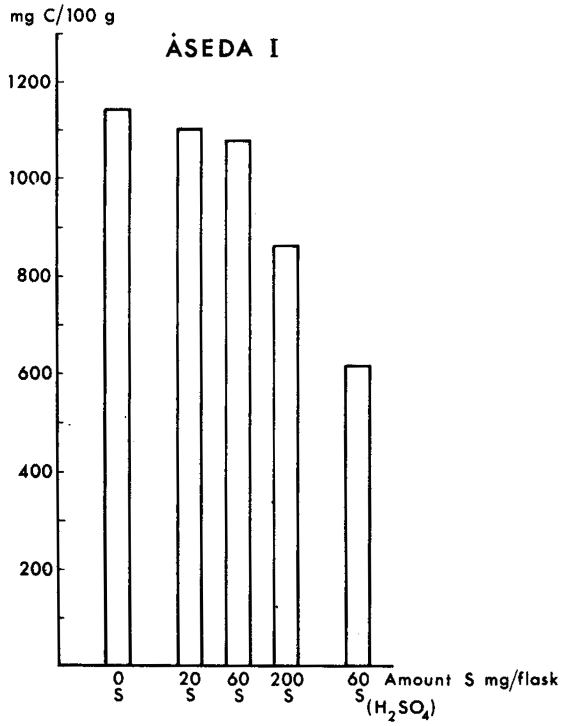


Figure 13. Total amount of CO_2 (mg C/100 g initial d.w.) respired during eight weeks incubation. Experimental area Åseda I. Mean values of three repetitions.

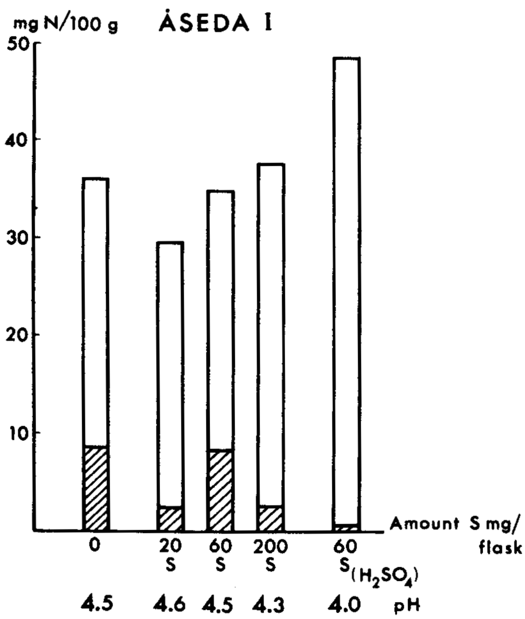


Figure 14. Total amount of inorganic nitrogen (mg N per 100 g) after eight weeks' incubation in humus samples pretreated in different ways from experimental area Åseda I. Mean values of three repetitions. Hatched area refers to nitrate nitrogen.

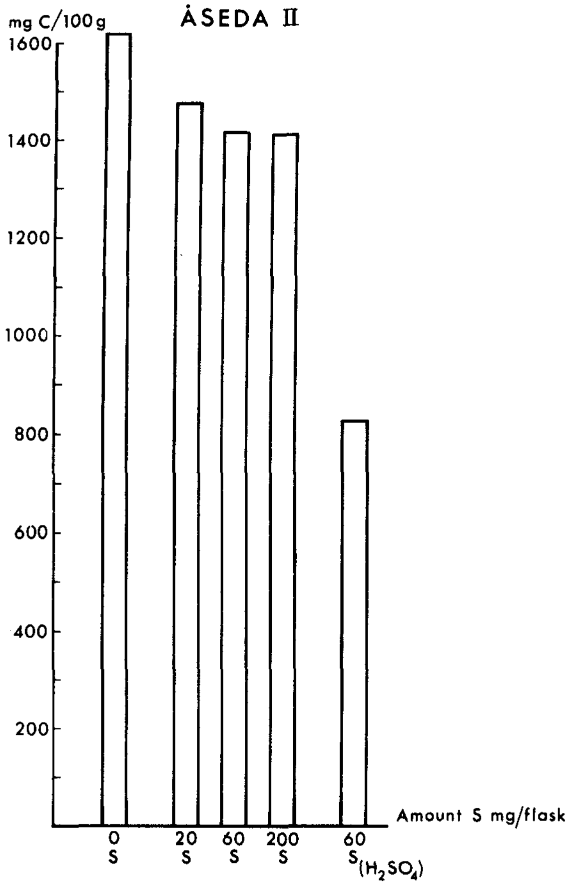


Figure 15. Total amount of CO_2 (mg C/100 g initial d.w.) respired during eight weeks' incubation. Experimental area Åseda II. Mean values of three repetitions.

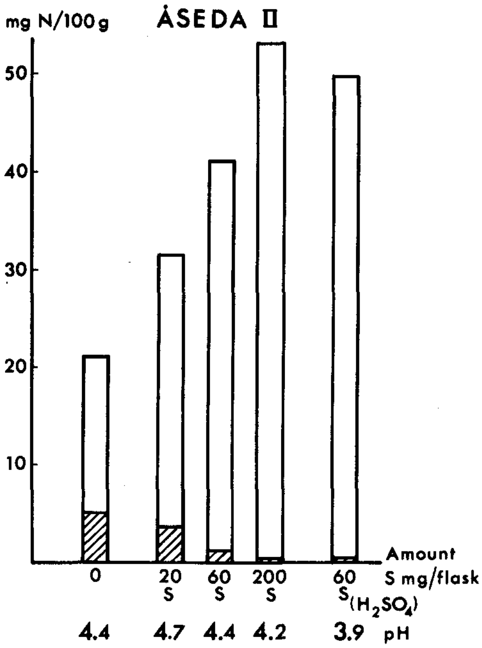


Figure 16. Total amount of inorganic nitrogen (mg N per 100 g) after eight weeks' incubation in humus samples pretreated in different ways from experimental area Åseda II. Mean values of three repetitions. Hatched area refers to nitrate nitrogen.

A similar increase in mineral nitrogen after acidification had also been established in experiments with soil from the Lisselbo experimental areas. In the absence of data on carbon dioxide evolution we had difficulties to explain the results of the earlier experiments. However, with CO_2 data available it seems safe to conclude that an acidification of the soil decreases microorganism activity in the samples and that this decrease is apparently more pronounced as regards the immobilization processes (including microbial growth) than in the case of decomposition processes. The increased availability of nitrogen in the samples should probably be looked upon as a result of a disturbance rather than as a positive effect.

As said before, rather variable results have been obtained in incubation experiments with samples from the various plots treated in the field. Table 1, where the six first lines represent composite samples from six different plots, gives an idea of the variability of the soil. In the Norrliden experimental series, which is the most extensive one, there seems to be a tendency to release of less available nitrogen in samples from acidified plots than from controls, an observation valid for both unfertilized and fertilized plots. The samples for the incubation experiment were taken after four applications of sulphuric acid. Liming also decreased mobilisation of nitrogen but probably for the opposite reason (when compared with sulphuric acid). Liming is known to favour micro-biological immobilisation of soluble nitrogen in agricultural soils and also in some forest soils.

Table 1 Norrliden. Base exchange properties of some samples

Sample and treatment	Approximate dry weight kg/ha · 10^3	Exchangeable cations (other than H_3O^+) kg e/ha	Titratable acidity (H_3O^+) kg e/ha	Cation exchange capacity kg e/ha	Degree of "base saturation" %	pH
Norrliden, Control	30	4.4	20.0	24.4	18	3.8
A_0 samples	30	9.6	16.3	25.9	37	4.7
	30	4.6	16.9	21.5	21	4.2
Norrliden, Acid 3	30	4.7	28.5	33.2	14	3.6
A_0 samples	30	7.0	17.6	24.5	28	4.3
	30	3.0	22.5	25.5	12	3.8
Norrliden, Control						
Soil profile A_0	30	5.9	16.8	22.7	26	3.8
A_2	840	16.0	57.1	73.1	22	3.5
B	1300	12.2	162.0	174.2	7	4.4
C	1400	9.8	103.6	113.4	9	4.8
	(per 10 cm)					

GENERAL CONCLUSIONS

Further acidification of already acid forest soils by air pollutants is a slow process and it probably takes a considerable time before growth effects can be established. However, there are obvious effects of even moderate additions of sulphuric acid or sulphur on soil biological processes, nitrogen turn-over in particular.

These changes may have far-reaching consequences on soil fertility in the long run, and it is imperative that these processes are studied in greater detail and over a longer range of sites before the acid rain has affected our soils much longer.

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