T. Schneider (Editor)/*Acidification and its Policy Implications*

ATMOSPHERIC DEPOSITION: IMPACT VIA SOIL BIOLOGY

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ABSTRACT

The growth of trees depends on nutrients which are released by decomposition processes in the soil. These processes are very complex and poorly understood, but they are clearly related to the biological activity of the soil. Two main groups of soil organisms cooperate in the decomposition processes: the soil animals and the soil microflora (fungi and bacteria).

Our knowledge about possible effects of soil acidification on decomposition processes and soil organisms are mainly based upon experiments with artificial acid rain. Most acidification experiments have resulted in reduced decomposition rates (for instance raw humus, birch leaves or needle litter). Important processes as N-fixation, nitrification and denitrification are also known to be pH-dependent. Field experiments with strong acidification have reduced the amounts of fungi and bacteria in the soil. Also many groups and species of soil animals were affected, some of them increasing their abundance and some decreasing in numbers. The abundance of several soil animals seems to be generally related to soil pH.

We may conclude that many processes that are important for plant growth are suppressed as the pH declines. The practical implication of this statement is, however, not easy. Several of the results referred to appeared in experiments with very strong acids (for instance pH 2.5 or pH 2). Secondly, we know very little about how much the soil pH may change due to the acid precipitation. Thirdly, different soil types react differently to acidification. It becomes a political question whether this doubt shall allow for a further spread of acid precipitation, or whether we decide not to experiment with nature.

INTRODUCTION

The growth of every forest depends on nutrients which are released by decomposition processes in the soil. These processes are regulated by living organisms, that cooperate in a very complex manner. If atmospheric deposition changes the chemical or physical condition of the soil, this may affect tree growth indirectly via, for instance, a reduced decomposition rate.

The possible effects of acid precipitation on soil biological processes are difficult to study. Firstly, our general knowledge about these processes are relatively poor. This means that we have difficulties even in formulating the correct questions. Secondly, most of the experimental approaches are of the "black box" type, which means that effects are studied without learning the relevant mechanisms. Thirdly, experiments are always "artificial" in some respect. Controlled laboratory experiments have to be simplified, and field experiments with strong acids do not necessarily mirror the long-term effects of weaker acids. A fourth point is that we have too few older soil analyses to document whether a soil acidification really has occurred.

What we can do, is to discuss some soil processes and soil organisms which we _think_ are important, and sum up the present knowledge about how these _may_ be affected by a soil acidification.

The main point will be the availability of plant nutrients, so decomposition rates are of great interest. First,however, we should have a look at the soil organisms regulating the decomposition. These can be divided into two main groups: the microflora (fungi and bacteria), and the soil animals.

SOIL MICROFLORA

Alexander (ref.1) has drawn up some major relationships between microflora and soil acidity. Generally, it is assumed that the number of bacteria are reduced by increased soil acidity (low pH), while the amount of fungi may increase. Because we know too little about the function of different groups of bacteria and fungi, it is difficult to relate changes in microflora directly to the availability of plant nutrients. However, some important processes are goverened by certain specific organisms. N-fixating _Rhizobium_-bacteria in roots of Leguminosae are sensitive to pH values below 4.6. Even N-fixating blue-green algae are acid sensitive. Bacteria transforming NH_4 to NO_3 (nitrification) rarely occur below pH 5. Also denitrification is affected by soil pH. Clearly, increased soil acidity can cause many changes in microbiological populations and processes. These changes could slow mineralization and thus reduce nutrient availability to plants (ref.2). Mykorrhiza is another important feature which might be affected by soil acidification, and which should be studied closer (ref.3).

Strong experimental acidification of coniferous forest plots have affected the microflora. By application of pH 2-water, both soil respiration, bacterial size and the number of FDA-active bacteria were reduced (ref.4). In another parallel study, application of 150 kg H_2SO_4 per ha and year over six years reduced the amount of FDA-active fungi both in the organic layer and in the bleached layer (ref.5). Different fungal species isolated from _Pinus contorta_ needles had different pH-preferences (ref.6).

The present-day information shows that soil acidification may have several negative effects on the microflora and the processes which regulate the amount of plant nutrients in the soil.

SOIL FAUNA

A rich forest soil may contain up to one thousand species of small animals. Their abundance reach many millions per m^2. Table 1 shows the approximate

TABLE 1

Body length and abundance of some soil animals in a Norwegian blueberry - spruce forest.

	Body length	Abundance per m^2
One-celled animals (Protozoa)	0.1- 0.2 mm	150 000 000
Nematodes	0.5-10 mm	10 000 000
Mites (Acari)	0.5- 1 mm	500 000
Springtails (Collembola)	0.5- 1 mm	100 000
Enchytraeids	1 - 5 mm	50 000
Earthworms	2 -30 cm	25

abundance of various soil animals in a Norwegian spruce forest with blueberry vegetation.

The role of soil animals is still poorly known, but most studies show that they speed up the decomposition rate and contribute to the release of plant nutrients (e.g. ref.7). For instance, it has been shown that the grazing of microarthropods (Collembola and Acari) on fungal colonies can stimulate the growth and activity of the fungus (e.g. ref.8). Fig. 1 shows two microarthropods (a collembole and a box mite) feeding on a fungal colony. Similarly, close relationships exist between the amount of bacteria and bacterial-feeding Nematoda or Protozoa. Soil animals also fragment the litter and humus and contribute to the spreading of fungi and bacteria. Some animals have the necessary enzymes to digest the dead plant remnants directly.

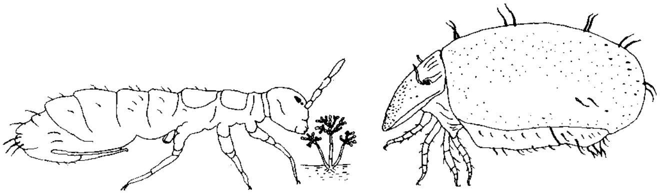

Fig. 1. A springtail (left) and a box mite (right) feeding on a fungal colony.

In Norway, a research program has been run for several years concerning possible effects of acid rain on coniferous forest. The soil zoological part of this project followed three different approaches:

1. <u>Colonisation experiment</u>. Microarthropoda and Enchytraeidae were allowed to colonise and reproduce in soil samples which had been adjusted to different pH levels (ref.9).

2. <u>Field experiments with artificial acid rain and liming</u>. In coniferous forest

with podzol soil (Typic Udipsamment), experimental plots were either limed or treated with artificial rain of pH 6 (control), 4, 3, 2.5 or 2. Effects were described on Protozoa, Rotifera and Nematoda (ref.10), on Acari (ref.11), on Enchytraeidae (ref.12) and on Collembola and Protura (ref.13). Effects of artificial acid rain on microarthropods were also studied in decomposing birch leaves, both in the field and in a greenhouse experiment (ref.14).

3. The distribution of microarthropod species in natural soils of different pH. This was considered to be an important control of the experimental results. If a general relationship exists between soil pH and the abundance of a given species, this should also be reflected under natural field conditions (ref.15, 16).

We found that soil pH is an important factor for many species and groups of soil animals. The two first approaches gave very similar results, and the main conclusions are listed in Table 2. Most effects in the field experiments were achieved at the two strongest treatments, with artificial acid rain of pH 2.5 or 2. In these treatments, the soil pH was also significantly reduced. Many groups reacted negatively on both acidification and liming, showing that they are adapted to their normal soil pH. Among Acari and Collembola, different species reacted in different ways, creating a complex picture. Acidification

TABLE 2
Effect of strong acidification and liming on different soil animals. The symbol + means increased abundance, and the symbol - means reduced abundance as a consequence of the treatment. Symbols in brachets indicate non-significant trends.

Group	Acidification	Liming
Protozoa		
Testacea	- (several species)	- (several species)
Ciliata	(-)	
Rotifera	(-)	(-)
Nematoda	(-)	(-)
Enchytraeidae (mainly one species)	-	-
Acari (mites)		
Total Acari	- +	-
Species level	- (9 species)	- (17 species)
	+ (8 species)	+ (3 species)
Collembola (springtails)		
Total Collembola	- +	-
Species level	- (7 species)	- (7 species)
	+ (6 species)	+ (5 species)

might increase or decrease the total abundance of Collembola or Acari, but in the strongest acidification, both groups were reduced in abundance. The third approach confirmed that soil pH has a general regulating effect on the soil fauna. For instance, species which were disfavoured by artificial acidification, were also rare in naturally acid soils.

Fig. 2 A-B show how the composition of the Acari and Collembola communities change from limed soil, via control soil to strongly acidified soil in the field experiments. Among Acari, an acidification induces an increased dominance of Oribatei. The Collembola community in strongly acidified soil is dominated by two species, which together make up 60% of the total.

Several of the reactions among microarthropods are confirmed by a Swedish acidification experiment (ref.5) and a Finnish liming experiment (ref.17).

There is no simple explanation to the observed effects, and different groups may probably be affected by different mechanisms. Possible hypotheses for microarthropods have been discussed (ref.18). For this group, laboratory experiments indicate that competition may be a crucial factor, and that the soil acidity affects the competition success of the various species.

Earthworms were practically absent from the soils in the referred studies. However, it is well known that earthworms are sensitive to changes in soil pH, and that very acid soils contain both few species and individuals (e.g. ref.19).

The conclusion regarding soil fauna is similar to that of soil microflora: The soil acidity is an important factor which affects the abundance both at species and group level. Our understanding is, however, small, both concerning the mechanisms and the impact on nutrient availability. The combined effect of changes in microflora and soil fauna is, on the other hand, expressed through the decomposition rate. Therefore, we shall proceed by looking at the effects of acidification on decomposition rates.

DECOMPOSITION RATES

In naturally acid soils, decomposition rates are often slow, and acidity is generally linked with decreased rates of humus decomposition (ref.1). Models have been made where increased acidification induces reduced decomposition rate and reduced availability of nitrogen (ref.20). In the following, we shall discuss a number of decomposition experiments, where the soil pH has been manipulated.

Raw humus incubated with sulphuric acid or powdered sulphur showed a reduced CO_2 production, which indicated lowered microbial acitivity and decomposition rate (ref.21). In the Swedish field studies with artificial acidification, a reduced decomposition rate of surface needle litter was noted after two years, but no effect on root litter placed in the O_f/O_h-layer after 1 year (ref.5). In a Norwegian study, application of pH 2-water reduced the decomposition rate of birch leaves in a greenhouse experiment, while corresponding trends

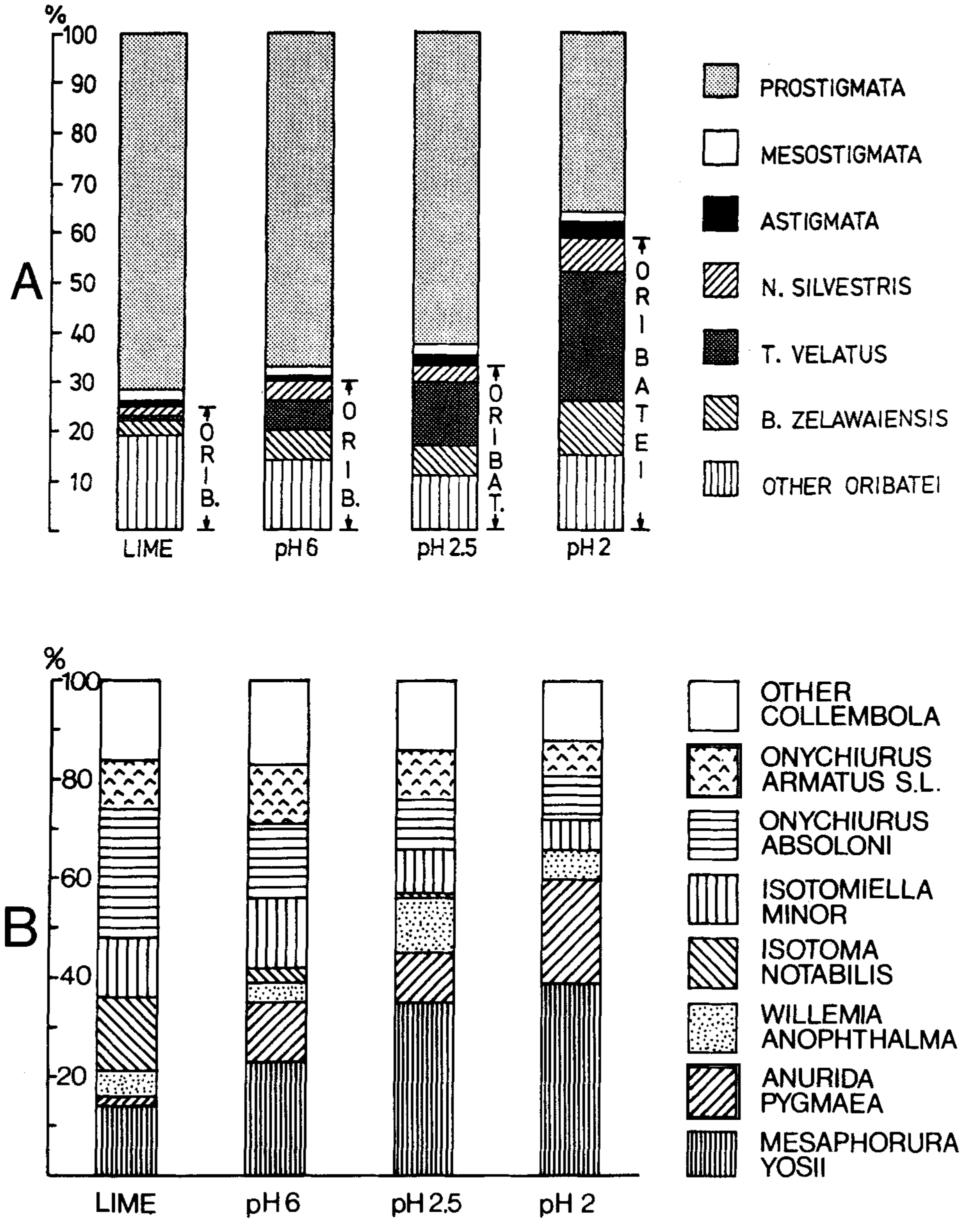

Fig. 2. Effects of liming and artificial acid rain on the composition of the Acari community (A) and the Collembola community (B). The pH 6-treatment is the control (application of ground water). Also the limed plots received the same amount of ground water. To the right: effects of the application of very acid "rain" of pH 2.5 and 2.

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were found in the field (ref.14). The same field experiment gave reduced decomposition rates of cellulose at the pH 2.5-treatment, while weight loss of aspen wood pieces were not significantly affected (ref.22). Strong acidification of spruce or pine needles (with sulphuric acid of pH between 2 and 3.1) have speeded up decomposition in the early phase, but then reduced the decomposition rate in a later phase (ref.6, 23, 24). In a greenhouse experiment, a lowering of the pH of raw humus from 4.5 to levels between 2.9 and 3.5 reduced significantly the decomposition rate (ref.9). A lowering of soil pH from 4.6 to 3.0 in a sandy loam soil from an oak-pine forest reduced the decomposition rate and the rates for ammonification, nitrification and denitrification (ref. 25). The authors feared that further acidification of acid forest soils will reduce the nutrient cycling.

CONCLUSIONS

Our general knowledge about decomposition processes, as well as experimental evidence, indicate that soil acidification, when it occurs, may slow down nutrient cycling and reduce forest growth. Many processes that are important for plant growth are clearly suppressed as the pH declines (ref.1). Data from south Sweden indicate that soil pH has been reduced in forest soil during the last decades (ref.26). Our ability to forecast trends in this field is, however, limited due to few older, comparable pH-studies of forest soil. There are also considerable local differences between soils in their ability to withstand acidification.

On the political level, the doubt about the situation may, or may not lead to any action. One view is to go on polluting, continuously waiting for more and more detailed scientific information about the effects. The other view is to decide that we shall not experiment with nature. The forest death in middle Europe showed us that we are often unable to foresee harmful effects. Nature is very complicated, and we take a large risk by waiting for explanations. Even now, scientists do not agree about the reasons for the forest death. If we don't want to experiment with nature, which is also the nature of future generations, this decision must be taken now, and taken by the politicians.

REFERENCES

1 M. Alexander, in T.C. Hutchinson and M. Havas (Eds.), Effects of Acid Precipitation on Terrestrial Ecosystems, Plenum Press, New York and London, 1980, pp. 363-374.

2 D.W. Johnson and D.S. Shriner, in T.C. Hutchinson and M. Havas (Eds.), Effects of Acid Precipitation on Terrestrial Ecosystems, Plenum Press, New York and London, 1980, pp. 601-606.

3 T.C. Hutchinson, in T.C. Hutchinson and M. Havas (Eds.), Effects of Acid Precipitation on Terrestrial Ecosystems, Plenum Press, New York and London, 1980, pp. 617-627.

4 E. Bååth, B. Lundgren and B. Söderström, Bull. Environ. Contam. Toxicol., 23 (1979) 737-740.

5 E. Bååth, B. Berg, U. Lohm, B. Lundgren, H. Lundkvist, T. Rosswall, B. Söderström and A. Wirén, Pedobiologia, 20 (1980) 85-100.

6 Y. Ishac and J. Hovland, Internal Report 24, SNSF-project, NISK-Ås, Norway, 1976, 20 pp.

7 T.R. Seastedt, Ann. Rev. Entomol., 29 (1984) 25-46.

8 R.D.G. Hanlon, Oikos, 36 (1981) 362-367.

9 S. Hågvar and G. Abrahamsen, Oikos, 34 (1980) 245-258.

10 T. Stachurska-Hagen, Internal Report 74, SNSF-project, NISK-Ås, Norway, 1980, 23 pp.

11 S. Hågvar and T. Amundsen, Oikos, 37 (1981) 7-20.

12 G. Abrahamsen, Holarct. Ecol., 6 (1983) 247-254.

13 S. Hågvar, Pedobiologia, 27 (1984) 341-354.

14 S. Hågvar and B.R. Kjöndal, Pedobiologia, 22 (1981) 409-422.

15 S. Hågvar and G. Abrahamsen, Pedobiologia, 27 (1984) 331-339.

16 S. Hågvar, Pedobiologia, 27 (1984) 355-364.

17 V. Huhta, R. Hyvönen, A. Koskenniemi and P. Vilkamaa, in P. Lebrun, H.M. André, A. De Medts, C. Grégoire-Wibo and G. Wauthy (Eds.), New Trends in Soil Biology, Proceedings of the VIII. Int. Colloq. of Soil Zoology in 1982 at Louvain-la-Neuve, Belgium, Université Catholique, 1983, pp. 61-73.

18 S. Hågvar, Ecological Studies of Microarthropods in Forest Soils, with Emphasis on Relations to Soil Acidity. Introduction to Doctoral Dissertation, University of Oslo, 1984, 35 pp.

19 J.E. Satchell, in A. Burges and F. Raw (Eds.), Soil Biology, Academic Press, London and New York, 1967, pp. 259-322.

20 F. Andersson, T. Fagerström and S.I. Nilsson, in T.C. Hutchinson and M. Havas (Eds.), Effects of Acid Precipitation on Terrestrial Ecosystems, Plenum Press, New York and London, 1980, pp. 319-334.

21 C.O. Tamm, G. Wiklander and B. Popović, Water, Air, Soil Pollution, 8 (1977) 75-87.

22 J. Hovland and G. Abrahamsen, Internal Report 27, SNSF-project, NISK-Ås, Norway, 1976, 16 pp. (In Norwegian, English summary.)

23 J. Hovland, G. Abrahamsen and G. Ogner, Plant and soil, 56 (1980) 365-378.

24 T.M. Roberts, T.A. Clarke, P. Ineson and T.R. Gray, in T.C. Hutchinson and M. Havas (Eds.), Effects of Acid Precipitation on Terrestrial Ecosystems, Plenum Press, New York and London, 1980, pp. 381-393.

25 A.J. Francis, D. Olson and R. Bernatsky, in D. Drabløs and A. Tollan (Eds.), Ecological Impact of Acid Precipitation, Proceedings of an Int. Conf. in 1980 at Sandefjord, Norway, NISK-Ås, 1980, pp. 166-167.

26 C.O. Tamm and L. Hallbäcken, Water, Air, Soil Pollution (submitted).