ACID PRECIPITATION AND FOREST SOILS

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Many soil processes and properties may be affected by a change in chemical climate such as that caused by acidification of precipitation. The effect of additions of acid precipitation depends at first on the extent to which this acid is really absorbed by the soil and on the changes in substances with actual or potential acidity leaving the soil. There is for instance the possibility that added sulphur dioxide or sulphuric acid may leave the soil either as sulphate ions or as gaseous hydrogen sulphide. In the latter case there is no net acidification. Acidity due to uptake of nitrogen oxides or ammonia later transformed into nitrate results in a net acidification only if the nitrogen ultimately leaves the soils as nitrate. Leaching of ammonium ions or organic nitrogen does not acidify the soil, nor does loss of gaseous ammonia, nitrous oxide (N_2O), or gaseous nitrogen. It must be admitted that our present possibilities are rather small to make up a complete and correct nutrient balance for a site where both leaching and gaseous inputs and outputs are considered.

Once we have established the net uptake of acidifying substances, the impact on the soil depends very much on the soil properties, particularly the total amount of exchangeable cations in the soil and the proportion of those cations which are other than hydrogen ions. A soil with a high proportion of calcium, magnesium, potassium or other basic cations among its exchangeable ions (a high base saturation) is affected differently from a soil with mainly hydrogen ions among the exchangeable cations. The degree of base saturation is well correlated with the acidity of the soil, meaning that on the average a soil with a low base saturation is acid and a soil with a high base saturation neutral to alkaline. An input of more hydrogen ions to an already acid soil means a relatively small change. In a soil with a higher base saturation the input of the same amount of hydrogen ions may seem large in comparison with the soil's own concentration of hydrogen ions, but such soils usually have high buffer capacities and often also large cation exchange capacities. Therefore the hydrogen ions are rapidly absorbed to the colloids in exchange for calcium, magnesium or other basic cations and the changes in the soil solution remain small. However, some slightly acid soils may have a low exchange capacity and a low buffer capacity. Such soils may well be sensitive to atmospheric input of acids (Malmer, 1974; Wiklander, 1974).

At commonly occurring pH-values soil colloids are usually negatively charged and surrounded by cations including hydrogen ions. Different colloids may well have different affinities for various types of ions. The affinity for hydrogen ions may be measured as the strength of the substance in question as an acid but there may also be specific bindings of certain ions in the soil for instance as chelates. The affinity of the soil colloids for different ions is pH dependent and has thus to be taken into account in a discussion of changes in soil acidity. The titration curve for various types of soil colloids, organic as well as inorganic (clay), may be rather different (Wiklander, 1974).

We also have to take into consideration that soils are differentiated vertically in horizons. This differentiation is closely connected with the movement of water in the soil profile and of substances dissolved in that water. In acid soils for instance, organic acids are produced in the humus layer and leached down to a certain depth in the soil where they may be partly destroyed by microbiological processes. Also clay particles may move vertically. Very often minerals weather more intensively in the upper more acid horizons than further down and some of the weathering products may be moved downward and either lost from the profile or precipitated in lower horizons. Strong mineral acids are not destroyed on their way down through the profile and may thereby affect both the rate of weathering and the translocation of the weathering products.

A characteristic trait for forest ecosystems as compared with agriculture ecosystems is the relatively close nutrient circulation during most of the rotation period in a managed forest. In the regeneration phase (either caused by clear felling or by natural events such as forest fire), this nutrient cycling is much less closed and leaching losses may occur. This may mean that some of the effect of changes in chemical climate may accumulate for a long period of time and then become evident in connection with a regeneration phase in the forest. In the case of acidification due to nitrogen compounds, it is quite clear that such effects do occur. In many forest ecosystems nitrogen accumulated during the life of a stand is oxidized to nitrate to a considerable extent after clear-felling. In undisturbed boreal forests there is normally very little nitrate formed and deciduous hardwood forests often have an incomplete nitrification (Ellenberg, 1971).

We also have to consider the effect of other human manipulations on soil acidity. Forest fertilization has such effects, particularly if urea or ammonium ions are supplied and then transformed to nitrate in the soil. Draining operations may also effect soil acidity, both by changing the water movement in the soil profile from very superficial and mainly horizontal in an undrained soil to vertical in a well drained soil.

The various characteristics of soils discussed so far may all be of importance for an evaluation of the effect of acid rain on the soil.

Most of the effects have not yet been quantified but there is no serious obstacle against measurement of these processes. However, we also have to consider another class of soil properties, namely the heterogenity of the soil. Soils are very seldom uniform. Very often soil aggregates occur with different physical and chemical properties on the surface of the aggregate compared with conditions inside the aggregate. The scale of variation may range from fractions of millimeters up to at least decimeters. Also other types of heterogenities may occur, for instance root channels and rock/soil interphases, which may range from centimeters to meters in extension and spacing.

Water percolation through a soil profile may be rather irregular (Tamm & Troedsson, 1957). If all or part of the percolating water follows certain channels in the soil (for instance old root channels), the chemical equilibration between the percolating water and soil particles may be very incomplete. Therefore it is possible and even likely that water percolating through the soil does not always reflect average soil properties. Instead it may be affected considerably more by its origin and thereby by the rain acidity than would be expected from the soil chemical properties as measured on standard soil samples. The rapid percolation of acid rain through certain pathways in the soil, as for example in shallow soils in Norway and Sweden, may also help to explain why lakes and streams may be acidified rapidly, although the soils around them possess a considerable buffering capacity, when studied in the laboratory.

In addition we have to consider that many soil processes, particularly those that affect plant growth do occur on the surface of soil particles or the surface of living organisms. These surface processes, especially in the top horizon of the soil, may be affected by acid rain long before we can measure changes in average properties in the soil. We know that several of these processes are very sensitive to pH, for instance nitrogen fixation and nitrogen mineralization. Also purely chemical processes such as adsorption and/or desorption of heavy metals are strongly dependent on pH conditions.

The effects of acid precipitation on surface processes--both biological and chemical--in the soil may be at least as important for site productivity as changes in "bulk properties" of the soil. We shall have to look more carefully for possible effects on processes restricted to soil particle surfaces than has been done so far, if we are to evaluate correctly the impacts of acid precipitation.

LITERATURE CITED

Ellenberg, H. 1971. NITROGEN CONTENT, MINERALIZATION AND CYCLING. PRODUCTIVITY OF FOREST ECOSYSTEM. Proc. Brussels Symp. 1969, 509-513. Unesco, Paris.

Jenny, H. 1941. FACTORS OF SOIL FORMATION. McGraw-Hill Co., New York.

Malmer, N. 1974. ON THE EFFECTS ON WATER, SOIL AND VEGETATION OF AN INCREASING ATMOSPHERIC SUPPLY OF SULPHUR. SNV PM 402E.

Tamm, C. O. & Troedsson, T. 1957. A NEW METHOD FOR THE STUDY OF WATER MOVEMENT IN SOIL. Geologiska föreningens i Stockholm förhandlingar, 79(3):581-587.

Wiklander, L. 1973/74. THE ACIDIFICATION OF SOIL BY ACID PRECIPITATION. Grundförbättring 26(4):155-164.