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Simultaneous Inhibition of Carbon and Nitrogen Mineralization in a Forest Soil by Simulated Acid Precipitation

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Acid precipitation may alter the rates of microbial processes in soil that are important for forest productivity (Evans et al. 1981). Acidification of soil can result in a depression of carbon mineralization (Tamm et al. 1977; Chang and Alexander 1983). The inhibition of CO_2 formation may be accompanied by a stimulation of nitrogen mineralization (Tamm et al. 1977) or nitrate accumulation (Francis 1982). Tamm (1976) postulated that acidification depresses the rate of nitrogen immobilization because of reduced microbial activity, leading to a net increase in the organic nitrogen available for mineralization. Though the increase in nitrogen mineralization is probably temporary (Tamm 1976; Aber et al. 1982), the duration of this effect is unknown (Bosatta 1982). A mathematical model has been developed by Bosatta (1982) to describe this phenomenon.

One method to simulate the long-term exposure of soil to acid rain involves the addition of single doses of concentrated acid. The inhibition of carbon mineralization accompanied by a stimulation of nitrogen mineralization may result from this severe, unnatural treatment.

The present study was designed to determine whether the inhibition of carbon mineralization and the accompanying enhanced nitrogen mineralization would occur when soils are treated with more dilute acid for long periods of time, as takes place in nature.

MATERIALS AND METHODS

The soil was a spodosol (coarse-loamy, mixed, frigid Typic Fragiorthod) obtained from the Panther Lake watershed of the Adirondacks region of New York. The fresh litter layer at the surface was removed, and portions of the underlying organic (02 horizon) and mineral (A2 horizon) layers were collected. The soil from each layer was passed through a 4-mm sieve and mixed separately. Polyvinyl chloride cylinders (4 cm in diameter, 7 cm high) were filled with 12.5 g of the mineral layer (pH 4.1, 2.26% organic matter, 0.09% N) at the bottom and 25 g of the organic layer (pH 3.6, 49.3% organic matter, 2.06% N) at the top. The soil was retained in the cylinders by a fiberglass screen on top of which was placed a glass fiber filter (Whatman GS/A, Laboratory Products Inc., Clifton, N.J.) to retain small soil particles.

Simulated rain was applied to the soil through two 10-µl capillary pipets placed about 5 cm from the top of the cylinder. The pipets were connected to a plexiglass reservoir that contained the liquid. The simulated rain was applied twice weekly by allowing 105 ml of the solution to drip onto the soil for 90 min. Each application was equivalent to 8.4 cm rain. The area from which the soil was taken usually receives about 100 cm of precipitation per year. The simulated rain was formulated as previously described (Strayer and Alexander 1981), but the pH of the solution was adjusted to 3.5 with 1N HCl or 5.6 with 1N KOH. The small quantities of K^+ or Cl^- used to adjust the pH of the rain probably do not affect microbial activity in soil (Sindhu and Cornfield 1967). The concentrations of nitrate and sulfate, which may influence microbial activity, were the same in all samples of simulated rain.

Each soil sample initially received 66 cm of simulated precipitation at pH 5.6. Half of the soil samples continued to receive simulated precipitation at pH 5.6 thereafter, and the other half received precipitation at pH 3.5. The temperature was 21°C.

After the soils received 58, 125, 208, or 308 cm simulated precipitation in 25, 53, 88, or 130 days, respectively, the rates of carbon and nitrogen mineralization were measured simultaneously. For this purpose, the soil moisture in 16 cylinders previously exposed to solutions at pH 5.6 or 3.5 was adjusted to field capacity, and the tops and bottoms of the cylinders were covered with polyethylene to reduce water loss. The soils were incubated at 28°C. At intervals, the organic and mineral layers from four cylinders exposed to the simulated precipitation at each pH value were extruded and separated, and each layer was well mixed. Separate 5.0-g portions of each organic and mineral layer were extracted by shaking with 25 ml of 1.5N K_2SO_4 for 60 min, and the filtrate passing through Whatman no. 42 paper was analyzed for ammonium by the phenol hypochlorite method (Weatherburn 1967) and nitrate by the chromotropic acid method (West and Ramachandran 1966).

To measure rates of CO_2 evolution, the soils in four additional cylinders were placed in 500-ml glass bottles, the moisture level being first adjusted to field capacity. A 10-ml beaker containing 5.0 ml of 0.33N KOH and a piece of filter paper to increase the rate of CO_2 absorption were placed in each bottle. The bottles were then sealed with a rubber stopper. Four cylinders of soil from each pH treatment were incubated at 28°C. Every 3 or 4 days, the contents of each beaker were transferred to 125-ml flasks, and the carbonate in the alkali was precipitated with a saturated $BaCl_2$ solution. The residual alkali was titrated with a standard HCl solution to determine the amount of CO_2 formed. The pH of the soil was determined using a 1:1 ratio of soil:distilled water by the method of Peech (1965).

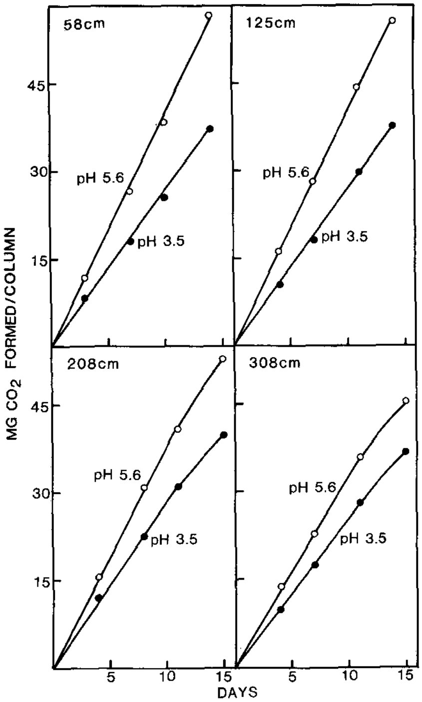

Figure 1. Carbon dioxide evolution from soil treated with 58, 125, 208, or 308 cm simulated precipitation at pH 3.5 or 5.6.

Linear regression equations were used to compare the rates of carbon and nitrogen mineralization and to determine whether differences were statistically significant (Kleinbaum and Kupper 1978).

RESULTS AND DISCUSSION

The pH of the organic layer, which was initially 3.60, increased to 3.97 during the initial treatment with 66 cm of simulated rain at pH 5.6. The pH of the organic layer was 3.72 and 4.18 following application of 308 cm of simulated rain at pH 3.5 and 5.6, respectively.

The rates of CO_2 evolution were essentially linear for at least 10 days (Figure 1). Carbon mineralization rates were significantly lower ($\underline{p} < 0.05$) in soil that had received simulated precipitation at pH 3.5. The more acid simulated rain inhibited carbon mineralization by 32, 32, 22, and 19% after application of 58, 125, 208 or 308 cm, respectively. In soil receiving simulated rain at pH 5.6, the rate of CO_2 formation was significantly less after exposure to 308 cm than 58 and 125 cm of rain. This may be a result of a decline in the amount of readily available organic carbon with time. The consistently lower rates of carbon mineralization in soil receiving the more acid solution may result from the lower levels of soluble organic carbon in these samples. Seto (1981) and Seto and Yanagiya (1983) showed that carbon mineralization is correlated with the amount of dissolved organic matter and that factors which influence the amount of this soluble carbon affect the rate of carbon dioxide evolution.

Ammonium levels in the mineral layer were less than 40 μg of N per cylinder and did not increase during incubation. The quantity of ammonium in the organic layer never accounted for more than 5% of the total inorganic N that accumulated during incubation.

Nitrate was the predominant form of inorganic nitrogen that accumulated in this highly acid soil. Nitrate formation during the 45-day incubation period was significantly slower ($\underline{p} < 0.05$) in the soil treated with the more acid rain after the application of 58, 125, or 308 cm of precipitation (Figure 2). The effect of the solution at pH 3.5 was not significant after treatment with 208 cm of precipitation for the 45-day period, although the rate of nitrate formation was significantly inhibited ($p < 0.05$) during the first 14 days of incubation.

Except for soil treated with 208 cm of precipitation, the rates of CO_2 and nitrate accumulation were inhibited by acid rain. The approach used here involved the application of 8-fold greater volumes of simulated rainfall than that which normally occurs in the Adirondacks region from which the soil was taken. However, the hydrogen ion concentration of the solution that was applied was similar to that of the rainfall that presently falls in this area. The relatively low hydrogen ion concentration of the simulated rain used in this study probably did not disrupt the microbial community to the same extent as other studies using high applications of solutions with much lower pH values (Tamm et al. 1977; Francis 1982). Hence, the changes in carbon and nitrogen mineralization noted here probably more accurately reflect what occurs in nature. Under these more mild conditions, both nitrogen and carbon mineralization are inhibited, in contrast with the reports that nitrogen mineralization is enhanced when CO_2 evolution is inhibited.

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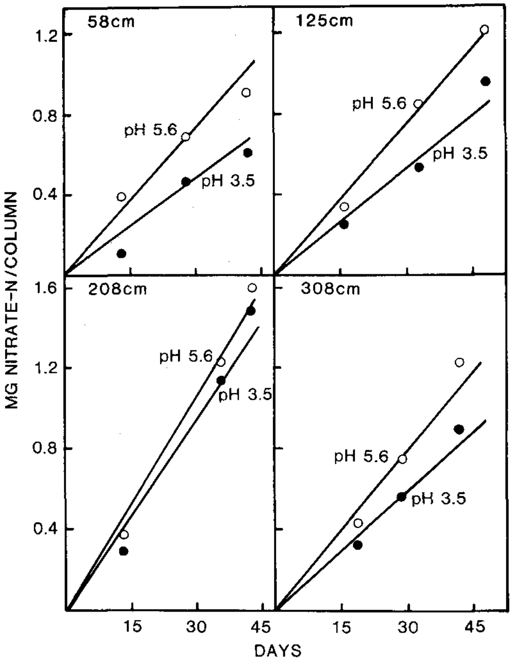

Figure 2. Nitrate accumulation in soil treated with 58, 125, 208, or 308 cm of simulated precipitation at pH 3.5 or 5.6.

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