

Long-term changes in a forested Spodosol

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Abstract

Soil formation results from the interaction of climate, relief, parent material, organisms, and time. Most soil genesis and weathering experiments are short-term and focus on addressing a single factor, with experiments to evaluate time rare. We utilized an existing long-term soil-bag experiment in central Maine, USA (Spodosols). Soil-bags containing homogeneous C horizon placed beneath the forest floor or in the middle of the B horizon for 17 years were compared with archived samples for changes in total C, N, S, and P. In addition, soil pH, exchangeable cations, and characteristics of the sorbed organic C were also examined. Soil pH in the C horizon soil-bags steadily decreased (5.2 to 3.7) as the result of organic acid leaching. Nitrogen and S accumulation beneath the O horizons was strongly related to the accumulation of C whereas P was not. Phosphorus was weathered from the C horizon material, with lower soil pH and greater organic C leading to greater P loss. The intensity of organic acid leaching was examined as a possible control on the changes that were observed. These results have important land management implications relating to forest health that can only be obtained with long-term studies.

Key Words

Organic matter, spruce-fir, ratios.

Introduction

Soil formation is a complex process that varies with climate, relief, parent material, organisms, and time. Most soil genesis and weathering experiments are short-term and focus on addressing primarily climate, relief, parent material, or organism as a single factor. Long-term soil genesis experiments are rare and are designed to evaluate the factor of time. There is a need to apply experimental designs of long-term soil studies (Richter *et al.* 2007) to different ecosystems such as forests due to their crucial role in carbon sequestration and to maintain forest productivity.

In the early 1990s, we established a long-term soil experiment to better understand the dynamics of C, N, S, and P in nutrient poor Spodosols in central Maine, USA focusing on forest floor to mineral soil transfers. Little is known about the critical organic pools of these nutrients, particularly during long time scales. We took advantage of the existing experimental design at Howland for this study. We revisited the sites during the summer of 2009 and retrieved one set of bags (others had been collected in 1993, 1994, and 1997). Newly obtained samples were compared with original, archived samples for changes in pH and organic matter. Both natural weathering processes and anthropogenic impacts such as acidic deposition were likely to lead to changes in our soil-bags. Understanding how soils change during long time periods can have important land management implications relating to forest health. Our objectives were to: 1) examine soil formation and weathering in a spruce-fir forested Spodosol; and 2) better understand organic leaching from the forest floor to mineral horizons.

Methods

A study on organic matter quantity and quality begun in 1992 was utilized for this project. The study site was a commercial spruce-fir forested plot located at Howland, Maine. Previous work on organic matter quality had been conducted, as well as dissolved organic C leaching studies (Dai *et al.* 1996abc; Christ *et al.* 1997). These soils have thick organic horizons (10 to 25 cm) and well developed E horizons 2 to 5 cm thick. As part of the initial work in 1992, a long-term soils experiment was set up. Sixty soil-bags were constructed using C horizon material (loamy sand, 83% sand, 15% silt, 2% clay) from a large soil pit in the plot, and placed directly beneath the Oa horizon in groups of five at 12 locations (sampling was planned to occur five times). The soil-bags were constructed of 250- μ m nylon mesh cloth sewn on three sides and stapled on the fourth side (David *et al.* 1990). Additional bags were placed in the center of the B horizon. Another set of bags filled with acid washed sand were also installed at that time at the same locations.

We excavated a total of 36 soil-bags from the site in June of 2009, following 17 years of incubation (Figure 1). One C horizon and one sand bag were collected from each of the 12 incubation locations, as well as B horizon bags from 4 locations. All samples were immediately frozen and then freeze-dried for further analysis, and were compared with original, archived samples as well as samples collected after 1, 2, and 5 years of field exposure.



Figure 1. Spodosol soil pit showing excavated soil-bags.

For this paper, preliminary results from soil-bags containing C horizon materials were analyzed and compared to archived soil. The methods used to analyze the samples were the same as in Christ *et al.* (1997) and Dai *et al.* (1996abc).

Results

Soil-bags placed beneath the O horizon were enriched with C, N, and S, but depleted in P compared with the original material. P is tightly cycled in this forest, and so that the dissolved organic matter (DOM) leached from the O horizons was low in P. Mineral P was likely weathered from the soil-bags. Soil-bags buried deeper in the soil profile accumulated much less C, N, and S and had less P weathering compared to the soil-bags buried directly beneath the O horizons (Table 1). Organic matter deposited on the C horizon material was enriched in N, S, and P following the 17-year leaching period as there were much lower C/N, C/S, and C/P ratios in comparison with soil profile data.

Table 1. Horizon characteristics (1992) along with C horizon soil-bags incubated for 17 years.

	pH	Total (mg/kg)			P	C/N	C/S	C/P
		C	N	S				
Oa horizon	2.54	495,000	9,200	1,100	420	54	460	1,200
E horizon	3.24	6,000	290	290	80	21	21	76
2009 soil-bag C under Oa	3.75	4,100	106	30	200	39	140	21
Bhs horizon	4.24	45,400	1,550	520	350	29	87	130
2009 soil-bag C within Bhs	4.83	1,000	100	20	240	10	46	4
C horizon	5.17	2,000	150	180	300	13	11	7

Total N and S concentrations were positively correlated with total C concentrations (Figure 2a) whereas total P had an inverse pattern (Figure 2b). Phosphorus is a limiting nutrient in this spruce-fir system. Plants and microbes take up most of the available P in the O horizons (Christ *et al.* 1997) leaving less to be leached into the soil-bags buried directly underneath the O horizon. Natural weathering of P over the past 17 years did cause substantial loss from the C horizon soil-bags from the Oa location in the soil profile.

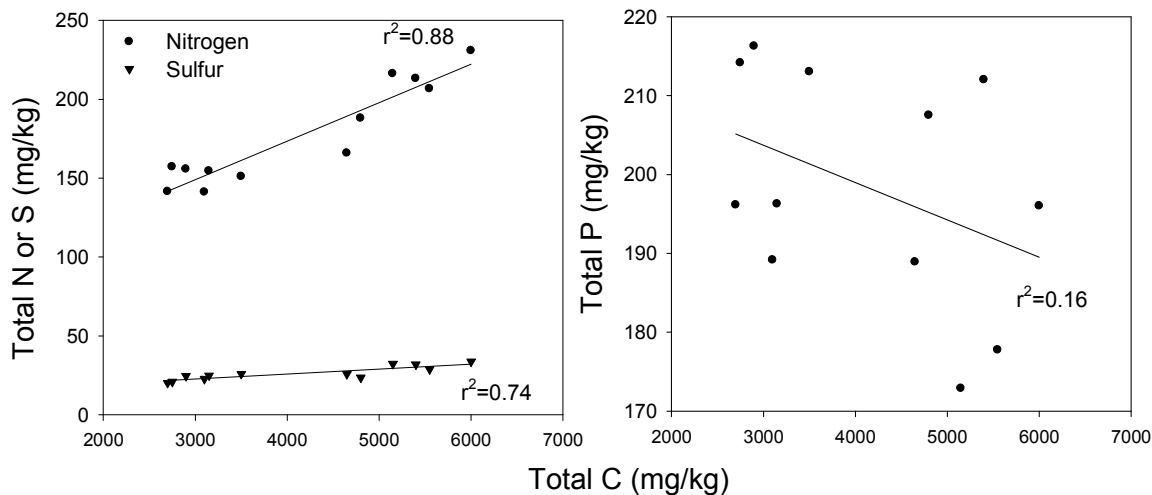


Figure 2. Relationships between total C and N or S and P of individual soil-bags collected in 2009. Linear regression r^2 values also shown.

The pH (0.01 M CaCl₂) of the soil-bags buried beneath the Oa horizon decreased from 5.30 to 3.75, with a more rapid decrease in years 1 to 5 (Figure 3a). Organic matter content (measured as loss-on-ignition) increased from an average of 0.55 to 1.2% (Figure 3b). For individual soil-bags incubated for 17 years, total C was strongly related to pH, demonstrating differential weathering and OM accumulation (Figure 4).

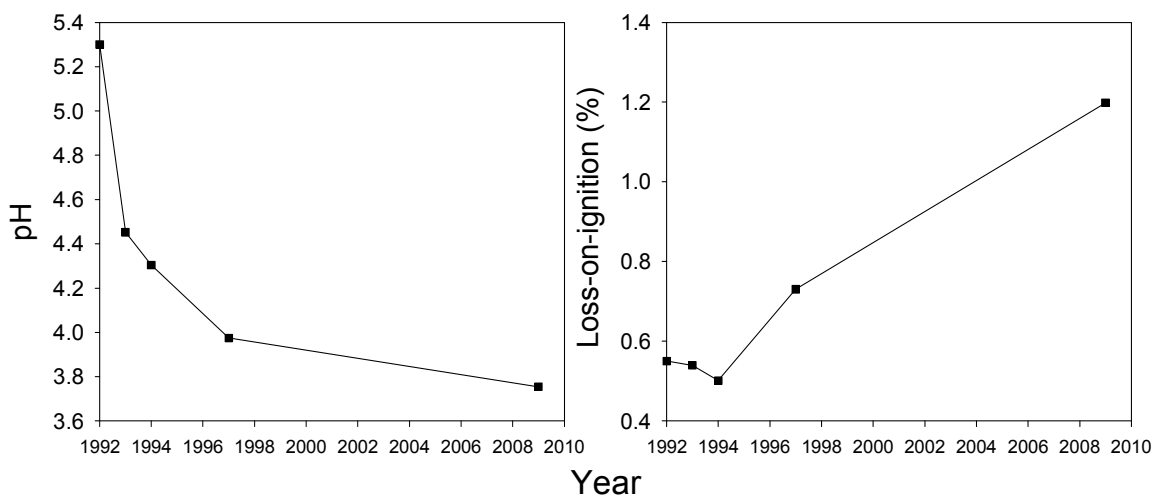


Figure 3. Changes in pH and LOI of C horizon soil-bags during 17 years beneath the Oa horizon.

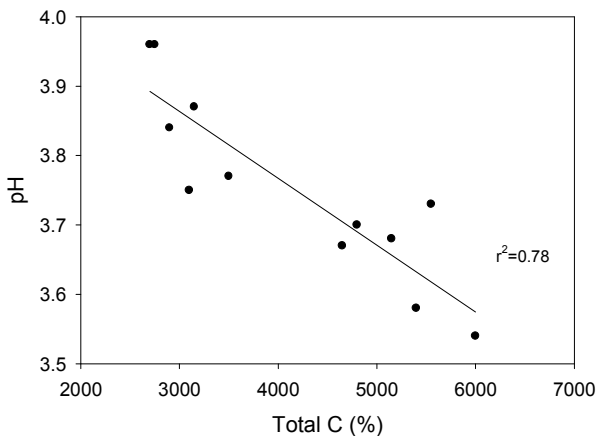


Figure 4. Relationship (linear regression r^2 shown) between total C and pH of individual soil-bags collected in 2009.

Conclusion

Soil pH in the soil-bags has steadily decreased as the result of organic acid leaching. Nitrogen and S accumulation beneath the Oa horizon was strongly related to the accumulation of C whereas P was not. Phosphorus was weathered from the C horizon material, with lower soil pH and higher total C leading to greater P loss. Further analysis from these unique soils should provide a better understanding of organic matter leaching in these soils.

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