

Water and soil chemistry of the Smith Experimental Forest, West Whately, Massachusetts

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INTRODUCTION

Understanding how water chemistry changes in the ecosystem before it enters the streams is important in understanding stream water chemistry. This study looks at the chemical changes taking place as water moves from the canopy, through the soil and into streams in an undisturbed forested ecosystem. The goal is to determine what is responsible for stream water chemistry of the Smith Experimental Forest.

The Smith Experimental Forest (SEF), located North of West Whately, MA and just east of the Northampton reservoir, is owned by Smith College. My field area was approximately a half km² just north of the southern property boarder. The land lies on a topographical high of approximately 250 m elevation. Bedrock is folded a garnetiferous quartz-mica schist. It contains beds of arenaceous and biotitic marble, interbedded with fine even-grained quartzite. Sillimanite and tourmaline are abundant near igneous contacts while biotite, muscovite and garnet are commonly found within the quartzite (Willard, 1956). The source of the soil is the thin layer of glacial till overlying the bedrock (Seegerstrom, 1955).

This forest, approximately 80 years of age, is characteristic of a northern hardwood forest. A 1997 transect showed dominant species as northern red oak (*quercus rubra*), red maple (*acer rubrum*), black birch (*betula lenta*), eastern white pine (*pinus strobus*) and eastern hemlock (*tsuga canadensis*). Percent canopy was 95 (± 2) and ground cover was 35 (± 9) (McMaster, 1998, personal communication).

FIELD WORK

Five types of water were collected. Rain (RN) and throughfall (TF) were collected using a large plastic funnel, inserted into a 1 L Nalgene® bottle and secured in place with rocks or small branches. The RN collector was placed in the largest clearing possible. One TF collector was placed under each type of canopy: mixed tree, maple and hemlock. Stem flow (SF) collectors consisted of a ring of expanding insulation foam at approximately 120 cm above the ground. A carved trough in the foam directed the water through a plastic nozzle and down a tube to the collection bottle. Soil solution (SS) was collected using two types of lysimeters; suction and zero tension. Suction lysimeters (SL) consisted of varying lengths of PVC piping with a porcelain cup attached to the bottom. The top was capped with a rubber stopper and two tubes were inserted into the pipe; a short one for drawing a vacuum and a long tube for extraction of the water sample. Six suction lysimeters were placed in pairs, two on each side of the road and a pair in a hemlock grouping. Zero tension lysimeters (ZTL) were inserted into the undisturbed face of the soil pit at various depths and then buried. Each ZTL consisted of a shallow rectangular tupperware dish filled with quartz playground sand. A plastic spout and tube connected the lysimeter to a sample bottle at the bottom of the pit. A rigid plastic tube ran to the surface allowing for sample extraction. Surface water (SW) was collected at five different sites in the SEF. The sample bottle was filled, with its mouth up stream, and emptied down stream three times before collection. Soil solution was collected from lysimeters using a side-arm 250 ml plastic flask and hand pump. Soil was sampled from a 1 m deep pit (WP) on the west side of the road. After digging a soil pit a small trowel was used to sample bands 4 cm wide from the undisturbed face at 10 cm depth increments.

LABORATORY METHODS

Water was analyzed for pH, specific conductance (SC), acid neutralizing capacity (ANC), K⁺, Na⁺, Mg⁺², Ca⁺², SO₄⁻², NO₃⁻, and Cl⁻. Soil was tested for pH, cation exchange capacity (CEC) and mineralogy. All pH measurements were taken in the lab using a portable Fisher Scientific AP62 pH/mV meter. Temperature corrected specific conductance was measured using a YSI model 34 conductance-resistance meter. ANC was analyzed using 0.02 N HCl in the gran plot method. Concentrations of base cations (K⁺, Na⁺, Ca⁺²) were measured using acetylene flame emission on a Perkin-Elmer 3030. Mg⁺² was measured using absorption. Ion chromatography was used to determine concentrations of SO₄⁻², NO₃⁻, and Cl⁻. All samples were filtered through a 45 micron Millipore filter prior to insertion in the Dionex 20001 ion chromatograph. CEC was determined using two methods. Exchangeable

bases (K^+ , Na^+ , Mg^{+2} , Ca^{+2}) were analyzed using unbuffered 1 N NH_4Cl to react with 10 g of soil. Filtered solutions were analyzed by flame emission and absorption. Exchangeable acids (Al^{+3} , H^+) were determined using 1 N KCl to react with 10 g of soil followed by a series of titrations using 0.1 N HCl , 0.1 N $NaOH$ and 1 N KF .

RESULTS

Water pH in the SEF varied greatly with an individual sample range of 4.18-6.75. Rain was the most acidic and pH averages gradually increased in this order as it moved through the forest: $RN < TF < SF < SS < SW$ (Table 1). Soil pH gradually increases at the surface from 4.14 to 5.81 at 100 cm (Fig. 3).

Mean acid neutralizing capacity (ANC) was -37 for RN and TF samples. Individual samples ranged from 353 (SW) to -71 meq/L (RN). ANC and pH showed the same increasing pattern in the forest (Table 1). In the SEF specific conductance ranged from 10.6 (RN) to 76.0 μ ohms (SF). Rain and throughfall were 18.8 and 26.4 μ ohms respectively. Stem flow, SS and SW had very similar mean values of 40.7, 42.3, and 43.6 μ ohms.

Magnesium concentrations are very low throughout the SEF. The highest sample and mean concentration were recorded respectively as 0.80 mg/L and 0.70 mg/L in SS. The concentration pattern in the system is the same for Mg^{+2} and Na^+ : $RN < TF < SF < SW < SS$. Sodium, however, had slightly higher overall concentrations in SS. The highest water sample concentration of Na^+ (1.74 mg/L) was found at 30 cm. Stem flow and TF contained such small amounts it was not traceable by the methods used. Potassium has a very different concentration pattern in the SEF. The highest concentration measured was 14.50 mg/L in SF from a red oak. Mean concentration amongst all the trees was 7.50 mg/L. Unlike other cations, K^+ values dropped to much lower values in the SS and SW after high values in the SF. Calcium showed an increase as water made more contact with the forest. The greatest concentration increase (2.40 mg/L) occurred between the SS and SW. The average SW concentration was 4.82 mg/L with a high of 5.75 mg/L. The overall Ca^{+2} concentration pattern in the SEF was $RN < TF < SF < SS < SW$.

SO_4^{-2} and NO_3^- concentrations had nearly the same mean concentrations in RN with Cl^- being only a minor anion. Cl^- doesn't change significantly in any water measured. SO_4^{-2} and NO_3^- , however, show interesting patterns. Sulfate increases to 11.48 mg/L in SF, decreases in the SS and increases again in SW. NO_3^- concentrations rise slightly in TF but then decrease to similar values as Cl^- in SF, soil and surface water (Table 1).

At and below 10 cm exchangeable cations in the west pit of SEF occur in this order: $Mg^{+2} < K^+ < Na^+ < Ca^{+2}$. Values are much higher and rank in this order at 1-4 cm depth: $Na^+ < K^+ < Mg^{+2} < Ca^{+2}$. Cation exchange capacity drops remarkably in the first 20 cm. At 1-4 cm CEC is 9.5, decreases to 5.7 at 10 cm, then to 1.2 meq/100 g at 20 cm. In the top layer base saturation is 40 % and then drops to 5% at 10 cm. Percent base saturation then gradually increases with depth to 41% at 100 cm (Fig. 3).

At 30 cm depth muscovite, biotite, quartz, calcite, plagioclase feldspar, garnet and tourmaline were identified.

DISCUSSION

The canopy and soil at the Smith Experimental Forest have a very important effect on the water chemistry. The canopy is the first buffer to the acidic rain entering the forest, absorbing H^+ and adding Ca^{+2} , K^+ , SO_4^{-2} and NO_3^- . Human addition of NO_x and SO_2 to the atmosphere causes the formation of HNO_3 and H_2SO_4 (Likens, 1995). The canopy enriches rain with cations and anions. H^+ is exchanged for other cations. Sulfate and nitrate concentrations increase in throughfall from dry deposition between precipitation events. This increases the concentration of H^+ , SO_4^{-2} and NO_3^- in the precipitation and SO_4^{-2} and NO_3^- in throughfall by dry deposition between rain events. At the SEF mean concentrations of SO_4^{-2} and NO_3^- are very similar even though concentrations vary from storm to storm. The increase in pH indicates acid rain is exchanging H^+ with passage through the system.

Stem flow increases Ca^{+2} , K^+ and SO_4^{-2} concentrations, however, SF makes up only about ~5 percent of the precipitation (Likens, 1995). Even though there are large increases in K^+ and SO_4^{-2} the same concentrations are not seen in the soil solution, which illustrates the limited effect stem flow has on SS or SW.

After chemical changes in throughfall the soil is the next major step in chemical alteration. The soil solution shows a slight average increase from throughfall in all cations, Cl^- and SO_4^{-2} . There is also an increase in Ca^{+2} , Mg^{+2} , Na^+ , SO_4^{-2} , NO_3^- and Cl^- from the SS to the SW. The decrease in NO_3^- after throughfall is most likely due to plant use because measurements were taken in the summer (Killham, 1995).

The presence of highly weathered rocks, including biotite, muscovite, feldspar and calcite, indicate that much of the Ca^{+2} , K^+ , Na^+ , and Mg^{+2} are being supplied in the forest by weathering. Weathering appears to be the major source of cations while the atmosphere is the major source of NO_3^- and Cl^- .

The highest base saturation is found in the top and bottom of the soil pit at ~40 percent. Soil with base saturation >50 is considered infertile (Tan, 1995). Low base saturation at the SEF indicates that the majority of the exchange sites are filled exchangeable acids (Al^{+3} and H^+). When this occurs it makes it increasingly difficult for plants to get the nutrients they need (Tan, 1995).

CONCLUSIONS

The precipitation at the SEF is acidic. The vegetation acts as a primary buffer and the soil continues to buffer the precipitation while H^+ is deposited. Precipitation is the primary source for NO_3^- , SO_4^- and Cl^- . Weathering is the primary source for all cations. Vegetation effects water chemistry but its source for nutrients is the soil, thus the majority of cations originate from the soil. CEC and pH increase with depth. The pH pattern suggests organic acids from the O horizon is the major contributor to soil pH.

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Figure 1. Mean cation concentrations for different waters at the Smith Experimental Forest.

Figure 2. Mean anion concentrations for different waters at the Smith Experimental Forest.

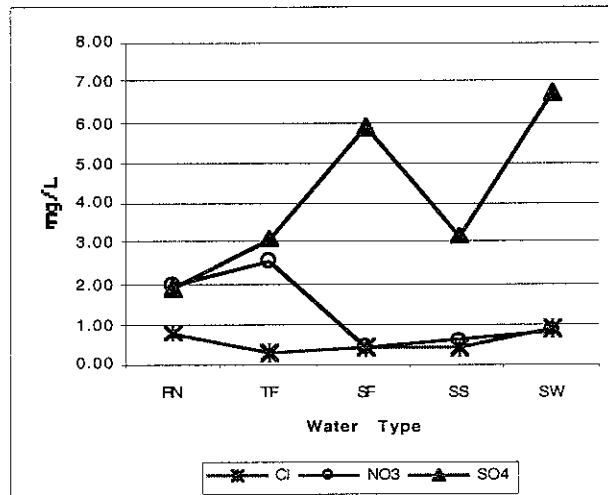
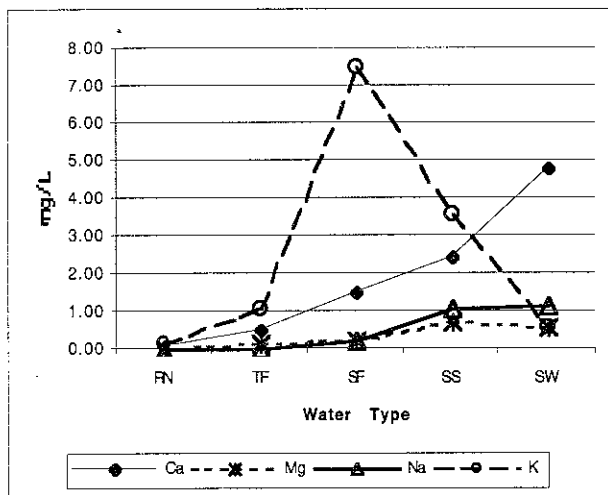


Table 1. Mean values for acid neutralizing capacity (ANC), pH and specific conductance (SC) for water in the Smith Experimental forest.

Water Type	pH	ANC (meq/L)	SC (μ ohms)
Rain	4.42	-37	19
Throughfall	4.65	-37	26
Stem flow	5.42	108	41
Soil solution	5.59	157	42
Surface water	6.33	241	44

Figure 3. Soil chemistry as a function of depth at the Smith Experimental Forest

