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Concentration and flux of solutes from snow and forest floor during snowmelt in the West-Central Adirondack region of New York

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Abstract. Decreases in pH and increases in the concentration of Al and NO_3^- have been observed in surface waters draining acid-sensitive regions in the northeastern U.S. during spring snowmelt. To assess the source of this acidity, we evaluated solute concentrations in snowpack, and in meltwater collected from snow and forest floor lysimeters in the west-central Adirondack Mountains of New York during the spring snowmelt period, 29 March through 15 April 1984.

During the initial phase of snowmelt, ions were preferentially leached from the snowpack resulting in elevated concentrations in snowmelt water (e.g. $H^+ = 140\,\mu eq.l^{-1}$; $NO_3^- = 123\,\mu eq.l^{-1}$; $SO_4^{2-} = 160\,\mu eq.l^{-1}$). Solute concentrations decreased dramatically within a few days of the initial melt ($< 50\,\mu eq.l^{-1}$). The concentrations of SO_4^{2-} and NO_3^- in snowpack and snowmelt water were similar, whereas NO_3^- in the forest floor leachate was at least two times the concentration of SO_4^{2-}.

Study results suggest that the forest floor was a sink for snowmelt inputs of alkalinity, and a net source of H^+, NO_3^-, dissolved organic carbon, K^+ and Al inputs to the mineral soil. The forest floor was relatively conservative with respect to snowmelt inputs of Ca^{2+}, SO_4^{2-} and Cl^-. These results indicate that mineralization of N, followed by nitrification in the forest floor may be an important process contributing to elevated concentrations of H^+ and NO_3^- in streams during the snowmelt period.

Introduction

Acidic deposition has been well documented in the northeastern U.S., southeastern Canada, Scandinavia and central Europe. Strong acid inputs to 'acid-sensitive' regions may contribute to chronic as well as episodic acidification of surface waters (Gherini et al. 1985; Schofield et al. 1985). In northern temperate climates, snow represents a considerable fraction of the annual precipitation loading and can have a marked influence on watershed hydrology. For example, snow accounted for 40 percent of total precipitation in the west-central Adirondack Mountains of New York during 1978–79 and 51 to 60 percent of annual runoff occurred over the months of March, April and May (Troutman and Peters 1982). Likens et al. (1977) reported that 54% of water exported from the Hubbard Brook Experimental Forest (HBEF) in New Hampshire over the same period, with 30 percent in April alone.

During the winter and spring, atmospheric inputs of solutes accumulate in the snowpack and are released over a relatively short melt period. Considerable efflux of solutes (Likens et al. 1977) and, for some elements, elevated concentrations (Johnson et al. 1969) are associated with snowmelt. Several researchers have observed short-term changes in surface water chemistry during this high discharge period. For example, Galloway et al. (1980) attributed snowmelt acidification of two Adirondack lakes to two factors: the dilution of basic cation concentrations and inputs of nitric acid. Driscoll and Schafran (1984) and Schofield et al. (1985) reported that increased NO_3^- concentrations during spring coincided in a stoichiometric increase in H^+ and Al in chronically acidic Adirondack lakes. Also, Johnson et al. (1969) observed that concentrations of NO_3^-, H^+, and Al increased with increasing discharge at the HBEF. While snowmelt acidification has generally been attributed to nitric acid inputs in the northeastern U.S., Johanessen et al. (1980) reported that pulsed inputs of SO_4^{2-} accompany snowmelt acidification in Norway.

Short-term increases in the concentrations of acidic components associated with hydrologic events have significant implications for aquatic organisms (Jenson and Snekvik 1972; Hagen and Langeland 1973; Leivstadt and Muniz 1976). For example, Henriksen et al. (1984) recently attributed fish kills in Norway to episodic increases in inorganic Al concentrations. A better understanding of the processes responsible for the short-term acidification would appear to be a prerequisite to an evaluation of the effects of acidic deposition on surface waters.

While episodic changes in surface water acidity have been generally associated with increases in NO_3^- concentrations in the northeastern United States, the source of this NO_3^- is unclear. Annual average concentrations of SO_4^{2-} exceed NO_3^- (on an equivalence basis) in precipitation in the northeastern U.S. (Galloway and Likens 1981). However during the winter months, SO_4^{2-} concentrations are greatly reduced relative to NO_3^- (Galloway and Likens 1981; Johannes et al. 1985). Consequently, NO_3^- concentrations approach (Molliter and Berg 1980) and often exceed (Johannes et al. 1980; Cadle et al. 1984) SO_4^{2-} in snowpack. During the initial phase of snowmelt, snowpack leachate is generally enriched in solutes relative to snowpack concentrations resulting in a concentrated input to the soil (Johannessen and Henriksen 1978; Cadle et al. 1984). The concentration of NO_3^- in meltwater could also be enhanced by oxidation of NH_4^+ within the snowpack or as it it percolates through the forest floor. Galloway et al. (1980) have suggested that episodic increases in NO_3^- during snowmelt could be attributed to snowpack inputs.

Biological assimilation is also an important process regulating NO_3^- efflux from the terrestrial environment. In aggrading watersheds in the Northeast, it is well established that seasonal fluctuations in surface water NO_3^- concentrations occur due to variations in biological uptake (Likens et al. 1977; Vitousek 1977). While NO_3^- inputs are strongly retained during the summer months, reduced biologcial activity during the winter and spring transforms NO_3^- from an immobile anion to a relatively mobile anion, causing elevated concentrations in surface waters (Johnson et al. 1969; Likens et al. 1977; Vitousek 1977).

Vitousek et al. (1979) have suggested that in the absence of biological control, rapid NO_3^- loss occurs from forested ecosystems in the northeastern U.S. Soils in the Adirondacks generally do not freeze due to insulation by snowpack and heating from microbial decomposition (Peters 1984). Therefore in the absence of strong biological assimilation, mineralization of organic N within the forest floor followed by nitrification could be an important source of mobile NO_3^- to surface waters during the high flow snowmelt period.

In view of the biological implications of episodic events, a better understanding of the processes regulating NO_3^- inputs to surface waters is highly relevant. The objective of this study was to evaluate the chemical transformations that occurred as water melted from the snowpack and percolated through the forest floor during the 1984 spring snowmelt in the west-central Adirondack region of New York State. Through this investigation, we hoped to obtain a better understanding of the source of mobile nitric acid inputs to mineral soil and surface waters.

Materials and methods

To evaluate the processes that contribute to episodic acidification, samples were collected from the snowpack, snowmelt water, and forest floor leachate during the spring snowmelt in 1984. The study site was located at the south end of Twitchell Lake (74°54′W, 43°51′N) in the west-central Adirondack region of New York State. This site is generally a mixed hardwood stand with *Acer saccharum*, *Fagus grandifolia*, *Betula alleghaniensis*, and *Tsuga canadensis*. Sampling was initiated on March 29 and terminated on April 15 when approximately 70 percent of the snowpack had melted. The site contained two snow-core stations, as well as primary and secondary, snow and forest-floor lysimeters.

The snowpack was sampled with Adirondack snow-coring equipment consisting of a 105-cm depth graduated fiberglass tube with a 16.7-cm diameter stainless-steel cutting head and a spring scale calibrated for water equivalents. Snow cores were collected from two stations at each plot. Snow-core stations consisted of a 2.4-m^2 sheet of 1.9-cm plywood that was covered with 0.152-mm polyethylene sheeting. The covered plywood was placed on the ground at one station. At the second station, the forest floor/organic layer of the soil was removed and placed on the plywood.

Precipitation quantity and chemistry were monitored using a wet/dry

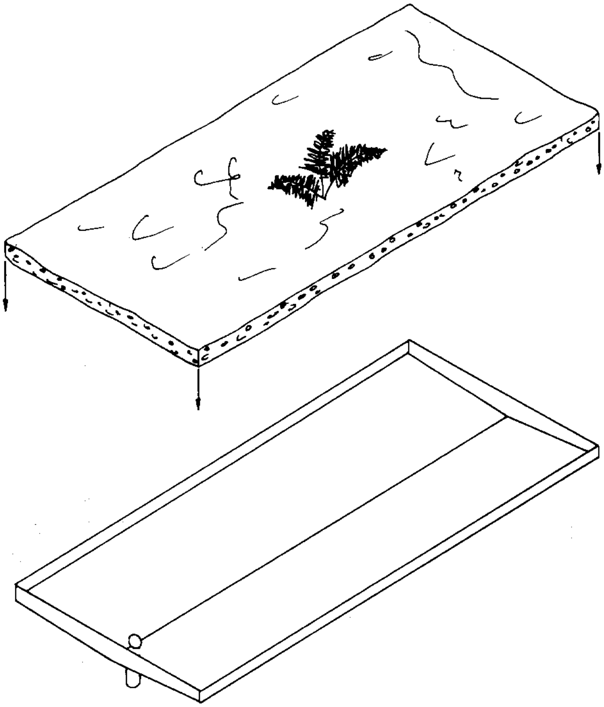

Figure 1. Conceptual diagram of stainless steel plan lysimeters (1.2 m × 2.4 m) used in this study. Pan lysimeters were placed adjacent to the soil surface for the collection of snow solutions and beneath the forest floor for the collection of forest floor leachates. Solutions were collected in a container buried beneath the soil.

collector at a nearby (~2-km) site (A.H. Johannes et al. unpub. data). Snowpack runoff and forest floor leachate were collected with stainless-steel pan lysimeters (Figure 1). Large collection areas (1.2 × 2.4 meters) were used to reduce localized channel flow and to allow for sample collection at frequent intervals. After removal of the forest floor/organic horizon, snow lysimeters were placed directly on the leveled surface of the mineral soil. The organic horizon adjacent to the lysimeter was removed to prevent contamination by the forest floor. Forest floor lysimeters were installed by excavating to the mineral soil and placing the intact forest floor/organic horizons in the lysimeter.

A second suite of snowmelt and forest floor leachate collectors, identical to those of the primary site, were installed 150 m west of the primary site, under the same forest cover. Samples were collected less frequently from these replicate collectors but on the same day as those from the primary collectors for comparison. Spatial variability in the concentra-

Table 1. Analytical methods

SO_4^{2-}, NO_3^-, Cl^-	Ion chromatography	Small et al., 1975; Tabatabai and Cook, 1983
Ca^{2+}, Mg^{2+}, K^+, Na^+	Atomic absorption spectrophotometry	Slavin, 1968
Al	Atomic absorption spectrophotometry with graphite furnace	Slavin, 1968
Dissolved Organic Carbon (DOC)	Filtration, ampulation, persulfate oxidation, syringe stripping of CO_2 and detection by chromatography	Menzel and Vaccaro, 1964
pH	Potentiometrically with glass electrode	Standard Methods, 1980
NH_4^+	Alkaline phenol	EPA, 1983
Organic N	Alkaline persulfate oxidation with detection of NO_3^- by hydrazine reduction	D'Elia et al., 1977; Kamphake et al., 1967
Acid Neutralizing Capacity	Strong acid titration with Gran plot analysis	Gran, 1952

tions of solutes in snowmelt water and forest floor leachate were assessed using a paired *t*-test (Dixon and Massey 1957). Note that lysimeters at the primary and secondary sites were unreplicated, thus temporal variability was used as an error term for comparative testing. To minimize the effects of disturbance, and allow for some equilibration prior to initial sample collection, the lysimeters were installed in October 1983, five months prior to the initiation of sample collection.

The water equivalent of the snowpack was determined by weighing snow cores of known volume. Triplicate snow cores were collected at least every second day. Selected snow cores were sectioned by visually assessing snow crystal type and thickness of ice layers. Three distinct layers were apparent in snow cores during the study period and the concentrations of chemical constituents within these individual layers were analyzed. Snow and forest-floor lysimeter solutions were collected every second day during the 18-day period of intense snowmelt. Snow, snowmelt water, and forest-floor leachates were analyzed for all major chemical solutes and dissolved organic carbon (DOC), organic nitrogen, and total aluminum using the methods summarized in Table 1.

Snowpack runoff was determined by the change in snowpack water equivalents from one time interval to the next, plus any precipitation inputs. Forest floor runoff was assumed to be equal to the volume of snowpack runoff. This approach might overestimate forest floor runoff due to changes in storage within the forest floor; however the magnitude of this potential error would not be sufficient to alter out intepretation of the results. Flux, the quantity of solute leaving or entering a compartment over a given time period, was calculated by multiplying the runoff quantity by the concentration of the solute measured over that period. Solute

Table 2. Solute influx (F_{in}), efflux (F_{out}) and retention coefficient (R) within the forest floor for the 18 day snowmelt period

Solute	F_{in} (mol. ha^{-1}. day^{-1})	F_{out} (mol. ha^{-1}. day)	R[1]
H^+	2.5	11	−0.77
ANC[2]	−2.4	−12	0.80
Ca^{2+}	0.7	0.5	0.40
Mg^{2+}	0.15	0.26	−0.47
Na^+	0.42	0.83	−0.49
K^+	0.67	3.8	−0.82
NH_4^+	0.37	1.0	−0.63
Al	0.06	0.87	−0.93
SO_4^{2-}	1.4	1.8	−0.22
NO_3^-	2.2	10	−0.78
Cl^-	0.02	0.03	−0.33
DOC	11	130	−0.92
Org.N	4.2	6.4	−0.34

[1] $R = (F_{in} - F_{out})/(|F_{out}|)$
[2] in $eq.ha^{-1}.day^{-1}$

retention coefficients within the forest floor were calculated as solute influx less solute efflux divided by the absolute value of solute efflux (Table 2).

Results

Snowpack water equivalents, precipitation inputs and snowpack runoff are tabulated for the 18-day study period from 29 March to 15 April 1984 in Figure 2. Snowmelt was most pronounced during two rainfall periods on 4–7 April and 13–15 April.

There was considerable variation in the concentration of chemical constituents in the bulk snowpack from the start to the end of the study period (Figure 3). Prior to snowmelt, concentrations were elevated within the snowpack. In particular, the upper (more recent) stratum was considerably more enriched in chemical constituents than the lower layers (Figure 4). The depletion of chemical constituents within the lower strata was undoubtedly caused by melting that occurred earlier in the winter season during late January and mid-February. An increase in density of the lower snow layers, due to these mid-winter melts, was also evident.

Hydrogen ion was the dominant cation within the snowpack although the sum of the basic cation concentrations ($C_B = Ca^{2+} + Mg^{2+} + Na^+ + K^+$ in $\mu eq.l^{-1}$) was comparable or exceeded the H^+ concentration (Figure 3). Nitrate and SO_4^{2-} were the dominant anions in the snowpack and were present at similar concentrations ($16 \mu eq.l^{-1}$ prior to the melt). During the major snowmelt, we observed substantial depletion of chemical constituents within the snowpack (Figure 3).

Considerable temporal variation in solute concentrations of snow

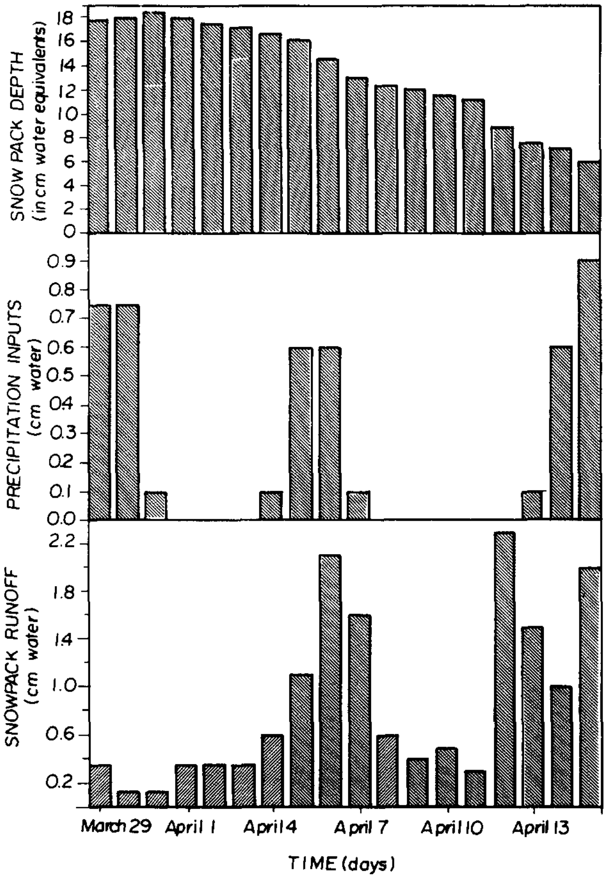

Figure 2. Snowpack water budget for the intensive melt period (3/29/1984 — 4/15/1984). Indicated are snowpack depth (2a), precipitation inputs (2b) and snowpack runoff (2c) in water equivalents. Snowpack runoff was calculated as snowpack loss plus precipitation inputs.

leachate was evident through the study period (Figure 5). At the onset of snowmelt, solutions were relatively acidic (pH = 3.83; ANC = $-146 \mu eq.l^{-1}$) and enriched in solutes. Concentrations of solutes in snowpack leachate decreased following the first few days of snowmelt. Concentrations of SO_4^{2-} in the meltwater were similar to NO_3^- concentrations.

Percolation of snowmelt through the forest floor resulted in substantial changes in water chemistry. Forest floor leachates were enriched in H^+, K^+, total Al, NO_3^- and DOC relative to snowmelt inflow (Figure 5). Modest increases in the concentrations of Mg^{2+}, Na^+, NH_4^+ and organic N were evident following transport through the organic horizon, while concentrations of Ca^{2+}, SO_4^{2-}, and Cl^- (Figure 5) were similar entering

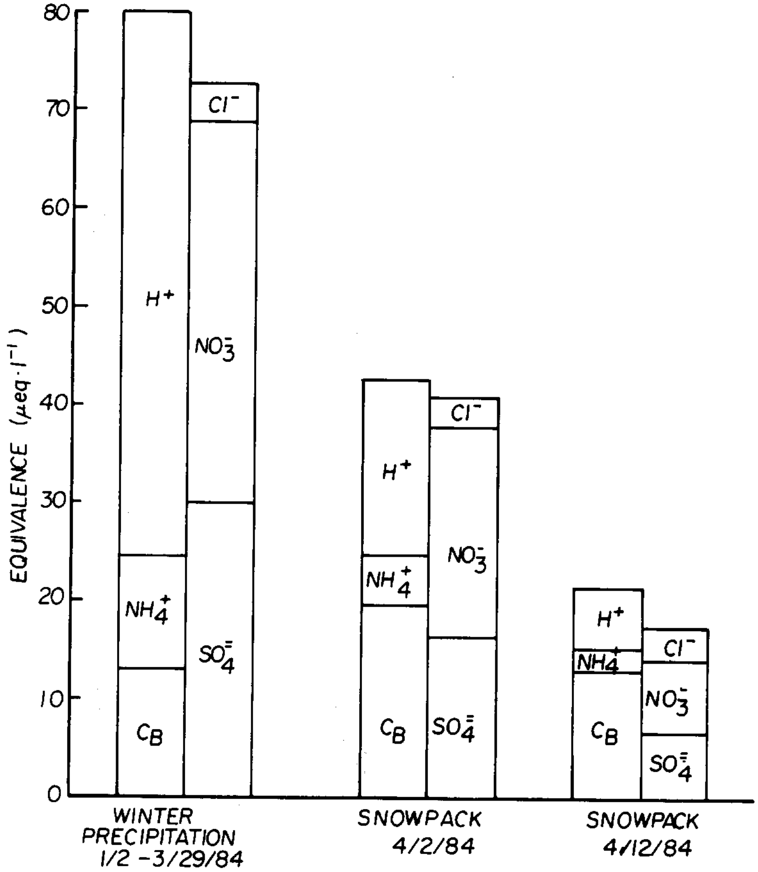

Figure 3. Equivalence diagrams of winter precipitation from (Johannes 1984) and bulk snowpack at the start (4/2/1984) and near the end (4/12/1984) of the intensive melt period. C_B is the sum of basic cation (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) equivalence.

and leaving the forest floor (Table 2). During the snowmelt, NO_3^- concentrations in the forest floor leachate were more than twice as great as SO_4^{2-} concentrations on an equivalence basis.

The concentrations of all solutes in forest floor leachate were high during the initial phase of the melt and gradually increased or remained high until a rainfall event on 4–7 April (Figure 5). The large quantity of runoff during this storm generally diluted forest floor solutes and concentrations decreased for the remainder of the study period.

Differential melting due to the positioning of trees and microtopography was evident between the primary and secondary study sites. On a given day, the water content of snowpack as well as solute concentrations

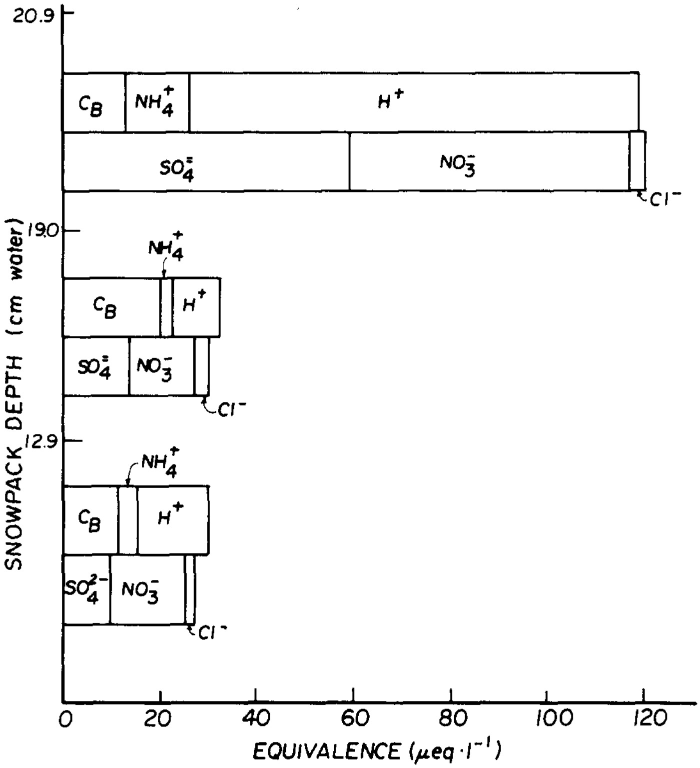

Figure 4. The solute distribution within snow strata prior to the major melt period (3/24/1985). The recent snow stratum (19.0–20.9 cm) was considerably enriched in solutes relative to the lower (0–12.9, 12.9–19 cm) layers.

in snowpack, snow leachate and forest floor leachate could be considerably different between the primary and secondary sites. Results of the paired *t*-test comparing dilute concentrations in forest floor leachates at the primary and secondary sites indicated no statistically significant differences ($p > 0.05$) over the intensive smowmelt period relative to temporal variability. Snowmelt composition was also generally similar ($p > 0.05$) at both sites; although, K^+ and Cl^- were higher in the primary site than the secondary site. While these differences in K^+ and Cl^- concentrations were statistically significant ($p < 0.05$), they were minor in magnitude ($< 2\,\mu mol.l^{-1}$ for either solute).

Discussion

Snowpack and snowmelt

With the exception of basic cation concentrations, constituents were generally lower in the bulk snowpack than in bulk precipitation for the

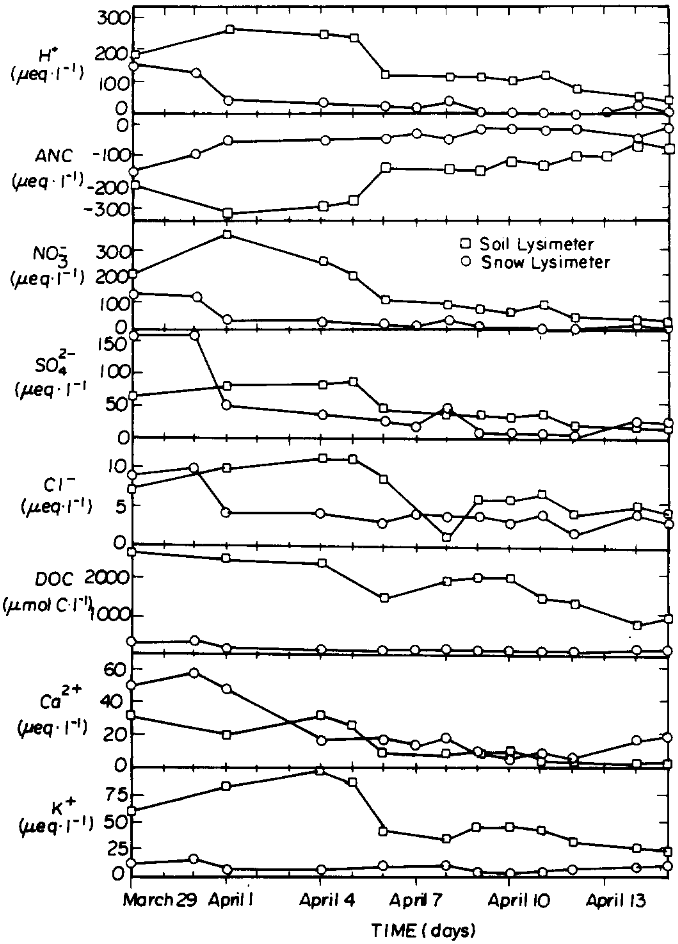

Figure 5. Solute concentration in snow and forest floor leachates over the 18 day intensive melt period.

winter 1984 period (Johannes 1984). Undoubtedly, partial melts in early January and mid-February contributed to this loss of snowpack constituents. The chemical concentrations in the upper stratum were slightly higher but proportional to values found by Johannes (1984) for bulk precipitation (Figure 8). The enrichment of basic cation concentrations in snow relative to bulk precipitation (Figure 3) may have been due to either selective retention within the snowpack during melting or an additional source of basic cations. Trends in snowmelt chemistry (discussed below) suggest that the former hypothesis may not be applicable. Organic litter was evident in the snowpack and leaching of basic cations from this material may have contributed to this enrichment.

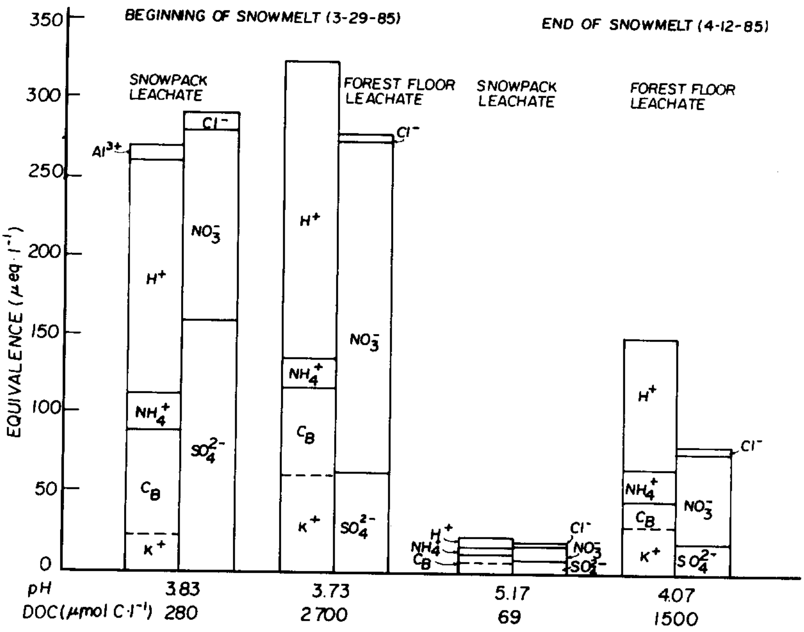

Figure 6. Solute distribution in snow and forest floor leachates near the start (3/29/1984) and end (4/12/1984) of the intensive melt period. C_B is the sum of basic cation (Ca^{2+}, Mg^{2+}, Na^+, K^+) equivalence. That fraction of C_B attributed to K^+ is indicated by a dashed line. Note that the large discrepancy in charge balance associated with the forest floor leachates is probably due to organic anions. This observation is consistent with the high concentrations of DOC.

Although concentrations in the snowpack over the 18-day intensive melt period were more dilute than bulk precipitation, the selective release of ions from the snowpack during the initial phase of snowmelt resulted in a concentrated input to the forest floor (Figures 5, 6). This initial pulse occurred for three days and coincided with a precipitation (mixed snow/rain) event (Figure 2). While snowmelt concentrations were high and substantial solute release was evident, only three percent of the snowpack-water equivalents (previous snowpack plus precipitation) was lost as runoff during this period. During this event, much of the water input from precipitation was retained in the snowpack. Cadle et al. (1984) also reported that rainfall facilitated the initial leaching of solutes from snowpack. Moreover, they demonstrated that elevated acidity during the initial phase of snowmelt was partly associated with the rainfall input.

The initial concentrated input of snowmelt water to the forest floor was followed by a relatively large quantity of more dilute meltwater, which occurred until the end of the melt. Linear regression analysis of snow lysimeter solutions indicated that individual solute concentrations were highly correlated to each other (for all pairs of solutes, $r^2 > 0.75$;

$p < 0.001$) and provides no evidence of preferential elution of ionic species from snowpack. Cadle et al. (1986) also indicated that selective loss of individual solutes did not occur from snow in northern Michigan; while Davies et al. (1982) have reported differential elution of individual solutes during the first part of snowmelt.

Forest floor processes

The relative importance of forest floor processes in regulating solution chemistry during snowmelt can be assessed through flux calculations (Table 2). The forest floor appeared to be an important source of H^+, K^+, total Al, NO_3^- and DOC to the mineral soil during this period. Moderate quantities of Mg^{2+}, Na^+, NH_4^+ and organic N were lost from the forest floor relative to inputs, while snowmelt inputs of Ca^{2+}, SO_4^{2-} and Cl^- approximately balanced the forest floor efflux. Note, however, that the forest floor was apparently a net sink for snowmelt inputs of Ca^{2+}.

We hypothesize that recent leaf-fall, forest floor decomposition and mineralization, coupled with reduced biological assimilation resulted in an accumulation of solutes within the forest floor over the winter season. The influx of water associated with the initial phase of snowmelt transported elevated concentrations of mineralization by-products to the lower (mineral) soil. As snowmelt intensified, large quantities of meltwater entered the forest floor and generally diluted forest floor leachate concentrations (Figures 5, 6). Although temporal variation in the concentrations of solutes in forest floor leachates was evident, linear regression analysis indicated that concentrations of individual ions were strongly correlated ($r^2 = 0.81; p < 0.0001$) which suggests that approximately stoichiometric release of solutes from the forest floor occurred during snowmelt.

Elevated concentrations of Al (David and Driscoll 1984; Cronan 1985) and K^+ (Cronan 1985) in forest floor leachates have previously been reported. Concentrations of K^+ were particularly high and it was the dominant basic cation in our forest floor solutions. Calcium concentrations were similar in snowmelt water and forest floor solutions (Table 2). Different patterns of Ca^{2+} and K^+ loss may reflect the fact that K^+ is not a structural component of plant tissue (Gilbert 1957) and is easily leached from organic matter relative to structural elements. Gosz et al. (1973) reported that K^+ was rapidly lost from leaf and branch litter at the HBEF. In addition, Ca^{2+} is preferentially retained on organic exchange sites relative to K^+, facilitating K^+ transport through the forest floor during biologically inactive periods. Low concentrations of K^+ in Adirondack mineral soil solutions (Mollitor and Raynal 1982; Cronan 1985) and surface waters (Cronan 1985) suggest that elevated K^+ inputs from the forest floor are efffectively retained in the mineral soil.

We also observed pronounced shifts in the composition of anionic solutes in forest floor leachates relative to the incoming meltwater (Figure

6). In snow leachate SO_4^{2-} and NO_3^- were the dominant anions, averaging approximately 30 μeq.l^{-1}. Following percolation through the forest floor, NO_3^- became the major anion, averaging 180 μeq.l^{-1}. High concentrations of DOC and a considerable discrepancy in charge balance were also evident in forest floor solutions, suggesting the presence of unmeasured organic anions (Figure 6). During the initial phase of the snowmelt, NO_3^- was clearly the dominant anion, but as snowmelt proceeded, both NO_3^- and organic anions significantly contributed to the anionic charge in forest floor leachates.

Nitric acid inputs

Hydrogen ion and NO_3^- concentrations were strongly correlated and nearly stoichiometric in forest-floor solutions ($H^+ = 44.6 + 0.72\,NO_3^-$; where H^+ and NO_3^- are in μeq.l^{-1}; $r^2 = 0.97, p < 0.0001$). This observation, coupled with relatively low concentrations of NH_4^+ (15.4 ± 6.5; mean concentration in μeq.l^{-1} and standard deviation), suggests that nitrification was occurring within the forest floor. Although NO_3^- was generally the major nitrogen form in forest floor solutions (Figure 5), concentrations of organic N were also significant (85 ± 40 μmol.l^{-1}).

The five fold increase in forest floor NO_3^- concentrations relative to snowmelt inputs strongly suggest that these inputs originated from mineralization and nitrification reactions within the forest floor. However, there is always concern over the representativeness of lysimeter data. We purposely used large lysimeters to minimize problems associated with heterogenity and edge effects. This disturbance could have induced mineralization/oxidation reactions, artificially elevating concentrations of H^+ and NO_3^- (Vitousek et al. 1979). Nevertheless, Cronan (1985) has reported similar winter NO_3^- concentrations (150 μeq.l^{-1}) in the O/E horizon leachates using ceramic porous cup lysimeters at nearby (~ 5 Km) Woods Lake watershed. Moreover, the elevated concentrations of NO_3^- (50 to 100 μeq.l^{-1}) during snowmelt reported for surface waters in the west-central Adirondacks qualitatively supports our findings (Driscoll and Schafran 1984; Schofield et al. 1985; Driscoll et al. 1987).

Elevated concentrations of nitric acid in surface waters during snowmelt demonstrate the importance of hydrologic flow paths in regulating water chemistry. Chen et al. (1984) have indicated that during low flow conditions, inputs of groundwater, reflecting the composition of the lower mineral soil solutions, largely regulate the chemistry of streams draining forested watersheds. The large influx of water associated with snowmelt exceeds the hydraulic conductivity of the mineral soil inducing short-circuiting of water through the upper soil horizons to surface waters. Under conditions of high discharge, acidic interflow containing elevated concentrations of H^+ and NO_3^- enters surface waters, diluting and acidifying groundwater inputs.

The magnitude of surface water NO_3^- concentrations during snowmelt is noteworthy. Although SO_4^{2-} is generally the dominant acidic anion in drainage waters in the west-central Adirondacks, peak concentrations of NO_3^- approach SO_4^{2-} values on an equivalence basis (Driscoll and Schafran 1984; Schofield et al. 1985; Driscoll et al. 1987). Driscoll and Schafran (1984) reported that Adirondack waters are enriched in NO_3^- relative to other surface waters in eastern North America. The reason for elevated concentrations of NO_3^- in the west-central Adirondacks during snowmelt relative to regions (e.g. Jefferies and Semkin 1983; Hemond and Eshleman 1984; Cadle et al. 1984) is not evident. Given the potential significance of elevated concentrations of nitric acid to both terrestrial (Friedland et al. 1984; Nihlgard 1985) and aquatic ecosystems, additional research elucidating the causative factors is warranted.

Conclusions

Results of this study indicate that elevated concentrations of solutes were leached from the snowpack during the initial phase of snowmelt. Although these solutions were highly acidic, acidity was further enriched following transport through the forest floor. Mineralization/nitrification reactions within the forest floor resulted in the release of elevated concentrations of H^+, NO_3^-, K^+, total Al and DOC to solution. In particular, forest floor proceses resulted in a five fold enrichment in H^+ and NO_3^- over snowpack inputs.

Our results suggest that short-term inputs of nitric acid observed in the Adirondack surface waters during snowmelt may be attributed to the flush of mineralization/nitrification by-products that accumulated in the forest floor during winter. Moreover, patterns in surface water concentration during snowmelt illustrate the importance of hydrologic flow paths in regulating the chemistry of surface waters.

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