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Soil N mineralization and nitrification in relation to nitrogen solution chemistry in a small forested watershed

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Abstract. Spatial variations in soil processes regulating mineral N losses to streams were studied in a small watershed near Toronto, Ontario. Annual net N mineralization in the 0–8 cm soil was measured in adjacent upland and riparian forest stands using in situ soil incubations from April 1985 to 1987. Mean annual rates of soil N mineralization and nitrification were higher in a maple soil (93.8 and 87.0 $kg.ha^{-1}$) than in a pine soil (23.3 and 8.2 $kg.ha^{-1}$). Very low mean rates of mineralization (3.3 $kg.ha^{-1}$) and nitrification (3.4 $kg.ha^{-1}$) were found in a riparian hemlock stand. Average NO_3-N concentrations in soil solutions were 0.3–1.0 $mg.L^{-1}$ in the maple stand and < 0.06 $mg.L^{-1}$ in the pine stand. Concentrations of NO_3-N in shallow ground water and stream water were 3–4 × greater in a maple subwatershed than in a pine subwatershed. Rapid N uptake by vegetation was an important mechanism reducing solution losses of NO_3-N in the maple stand. Low rates of nitrification were mainly responsible for negligible NO_3-N solution losses in the pine stand.

Introduction

Undisturbed forested drainage basins often exhibit small annual stream losses of nitrogen in comparison to the large amounts of nitrogen circulated annually within the forest community. In contrast, disturbing the vegetation cover can cause elevated stream nitrate exports from some forest ecosystems (Vitousek et al. 1982). A number of soil processes regulate the amount of inorganic N that enters streams, including mineralization of organic N, vegetation uptake, immobilization of N by the microbial community, volatilization of ammonia, and denitrification. Nitrogen is transferred to streams by flowing water. Consequently, the amounts and specific routes of water movement within watersheds also affect stream N concentrations.

Little research has been directed towards an understanding of how factors regulating N losses may vary spatially within small watershed ecosystems. Forest watersheds frequently contain upland and riparian vegetation communities that differ in composition, age and soil properties. Comparative regional studies across a range of forest and soil types have revealed considerable differences in rates of N mineralization, nitrate production and plant uptake (Vitousek et al. 1982; Nadelhoffer et al. 1984; Pastor et al. 1984). Successional communities which are accumulating biomass may exhibit small N losses in comparison to mature forests (Vitousek & Reiners 1975; Gorham et al. 1979). The location of riparian forests in watersheds makes them potentially important in regulating N fluxes between upland communities and the stream. Riparian forests in some agricultural watersheds remove nitrate by denitrification and vegetation uptake (Lowrance et al. 1984; Peterjohn & Correll 1984). In contrast N mineralization may increase NH_4-N concentrations in ground water within the riparian zone (Peterjohn & Correll 1984). These studies suggest that small watersheds may frequently contain considerable spatial variability in soil N transformation processes. This variability is likely to be important in regulating solution losses of N from specific areas within watersheds.

The objectives of our study were, first to examine the degree of variability in soil N mineralization and nitrification exhibited within a small forested watershed. Second, we wanted to evaluate the relationship between the spatial heterogeneity of these soil processes and N solution chemistry. Soil N mineralization and nitrification were measured in adjacent upland and riparian forest stands. The release of NO_3-N and NH_4-N from two upland forest stands was compared by monitoring mineral soil leachates, ground water and stream water. Shallow ground water emerges downslope from the upland stands and is transported through the riparian forest in spring-fed surface rivulets. Mineral N transformations in these riparian rivulets have been previously reported (Hill & Warwick 1987; Warwick & Hill 1988).

Study area

Research was conducted in a 2 km^2 headwater basin on the south slope of the Oak Ridges moraine about 50 km northeast of Toronto, Ontario (43°47′N, 79°15′W). Elevations on the watershed range from 268 m to 346 m and the topography varies from gently rolling to steeply sloping hummocky moraine. The watershed is drained by a second order stream and several perennial, spring-fed tributaries. The mean annual precipitation is 760 mm with approximately one-third as snow. Average January and July temperatures are $-5\,°C$ and $21\,°C$, respectively (Brown et al. 1968).

Soils on the moraine slopes are well-drained Ochreptic Hapludalfs formed on glacial sands and gravels (Olding et al. 1955). Organic soils (Histosols) are found along the perennial streams. The area has been settled since the mid-nineteenth century and a portion of the upland forest has been cleared, farmed and abandoned. There has been no farming in the area since about 1950. Approximately 60% of the watershed is forested with mature sugar maple-beech (*Acer saccharum-Fagus grandifolia*) on sites that were never cleared and younger stands of white pine (*Pinus strobus*) and paper birch (*Betula papyrifera*) on areas of abandoned farm land. The riparian area adjacent to the streams is dominated by a mature stand of eastern hemlock (*Tsuga canadensis*) and white cedar (*Thuja occidentalis*). An old-field community of grasses and forbs with scattered hawthorn (*Crataegus* spp.) and white pine occurs on the western portion of the basin where perennial streams are absent.

A ground water discharge zone produces a riparian wetland area 20–100 m wide along the streams. The water table intersects the ground surface at the upland margin of this riparian zone and then slopes towards the stream at a depth of 10–30 cm. Springs at the base of the moraine slopes produce numerous small rivulets which cross the riparian zone and contribute approximately 50% of the ground water entering the second order stream (Hill & Warwick 1987). Ground water also flows upward to the water table beneath the riparian zone and reaches the stream as bank and bed seepage.

Table 1. Vegetation and soil (0–8 cm) characteristics of the three forest stands.

	Maple	Pine	Hemlock
Forest age (yr)	80–100	20–40	80–120
Tree density (stems.ha^{-1})	488	1348	510
Phytosociology	SM 45	WP 54	H 48
	B 34	A 17	YB 15
	OV 8	WA 11	C 15
	RO 4	PB 11	SM 9
	WA 3	O 8	WA 4
	O 6		O 8
Soil properties (0–8 cm)			
Organic matter %	8.2	6.2	49.2
Total N%	0.25	0.14	1.48
Soil N (Mg.ha^{-1})	1.86	0.98	2.37
Soil pH	5.8	5.7	5.9
Bulk density (g.cm^{-3})	0.93	0.88	0.20

Data are relative importance values. Abbreviations:
A = *Populus tremuloides* Michx.
B = *Fagus grandifolia* Ehrh.
C = *Thuja occidentalis* L.
H = *Tsuga canadensis* Carr.
OV = *Ostrya virginiana* (Mill) K. Koch
PB = *Betula papyrifera* Marsh,
RO = *Quercus rubra* L.
SM = *Acer saccharum* Marsh
WA = *Fraxinus americana* L.
WP = *Pinus strobus* L.
YB = *Betula lutea* Michx.
O = Other

Three stands were selected to represent the main forest communities and soil characteristics of the watershed (Table 1). The stands were located within 300 m of one another. Forest floors in the maple and pine stands are mulls with an O_1 horizon less than 2 cm thick and a minimally developed O_2 horizon. Soils (0–8 cm) in the two upland stands have a loamy-sand texture. The A_1 horizon in the maple stand is approximately 8 cm in depth. In the pine stand the Ap horizon is 20 cm thick and has an incipient A_1 horizon in the upper 5–7 cm. In the hemlock stand a thin < 2 cm forest floor rests on peat which ranges in thickness from 10–20 cm at the upland boundary of the riparian zone to about 160 cm near the second order stream. Fine roots in all three stands occur mainly in the upper 8 cm of the soil profile.

Methods

Mineralization, nitrification and pool sizes

Two 100 m transects were established within each stand. Samples used in measuring N mineralization, nitrification and other soil properties were taken at 5 randomly selected sites along each transect in the two upland stands. Six sites were similarly located along each transect in the riparian hemlock stand. Net N mineralization and nitrification in the 0–8 cm soil horizon was estimated from mid-April 1985 to mid-April 1987 by the buried polyethylene bag technique (Eno 1960; Ellenberg 1977; Westermann & Crothers 1980). This method determines net, not gross, mineralization because microbial immobilization of NH_4-N and NO_3-N over the incubation period is not determined.

At each site within the three stands a 6 cm diameter × 8 cm deep soil core was placed undisturbed in a 0.04 mm thick plastic bag, buried in the same hole and covered with litter. Non-incubated soil cores were collected adjacent to each incubation in order to determine initial NH_4-N and NO_3-N levels. Incubation intervals were 28–34 days except for an overwinter incubation from 4 December 1985 to 8 April 1986 and from 7 December 1986 to 13 April 1987. Additional 0–8 cm soil samples were collected from each site at the mid-point of each monthly incubation period between April–December and on 3–4 occasions during the winter to monitor changes in soil NH_4-N and NO_3-N pools. Soil temperature at 3 cm and 7 cm depths was measured by thermistors installed at three sites in each forest stand. Measurements of temperature were recorded on each sampling date between 12.00 and 14.00 h.

Soil samples were returned to the lab in a styrofoam cooler and stored at

4 °C until processed, usually within 24–48 h. Fresh subsamples of each initial and incubated soil core were extracted with 2 N KCl. Extracts were analyzed for NH_4-N and NO_3-N with a Technicon Autoanalyzer (Technicon 1977, 1978). Another subsample was dried at 105 °C for 24 h to estimate dry mass of extracted soil and per cent moisture. Net N mineralization estimates were obtained by subtracting initial values of NH_4-N + NO_3-N from the final incubation values. Net nitrification rates were measured in a similar manner. The terms mineralization and nitrification are used henceforth to refer to net mineralization and net nitrification. Rates were converted from a per gram basis to an areal basis using soil bulk density and depth of incubation as conversion factors. Bulk density was determined by taking six 226 cm^3 cores from each site within the three stands. Soils were dried at 105 °C for 24 h to obtain the mean dry mass per unit volume.

Volumetric soil water content was obtained as the product of gravimetric moisture and bulk density. The use of volumetric moisture allowed a better comparison of upland and riparian soils that differed widely in bulk density. All other soil analyses (Table 1) were done on 10 samples (maple and pine stands) or 12 samples (hemlock stand). Soil organic matter was measured by ashing oven dry soil at 550 °C for 4 h (Broadbent 1965). Soil pH was measured with a glass electrode on a 1:5 soil to water mixture. Total nitrogen was analyzed using a Technicon block digester followed by determination of the resulting ammonia on the Autoanalyzer (Schuman et al. 1973).

Water chemistry profiles

Water chemistry profiles were examined by monitoring mineral N concentrations at various stages during the passage of water through the drainage basin. Estimates of relative N leaching losses in the two upland stands were obtained by comparing mineral N concentrations of soil water near the base of the rooting zone. Soil leachates at 60–70 cm depth were sampled with porous-cup tube lysimeters. Four lysimeters were placed at randomly selected sites along the transects in each stand in mid-June 1985. In April 1986 the number of lysimeters was increased to 6 in each stand. Lysimeter samples were collected bi-weekly with the exception of the January–March period. After each collection suction of 12 centibars was applied with a hand vacuum pump. Tests showed that inorganic N concentrations did not change signficantly during the period that the samples remained in the cups.

Shallow ground water was monitored by two well transects located along the upland margin of the riparian hemlock forest downslope from the maple and pine stands. Each transect consisted of 5 wells about 20 m apart which were positioned at depths of 1–1.5 m below the ground surface. The ground water wells consisted of plastic pipe perforated for the bottom 30 cm and covered with nylon mesh screening. Monthly ground water samples were taken by pumping the wells free of water and collecting fresh samples a few hours later. Sampling of the well transect downslope from the maple stand was discontinued in April 1986. Stream water samples were collected biweekly from the second order stream at the watershed outlet and from two small tributaries about 100 m downstream from their source in subwatersheds containing maple and pine stands respectively. The sampling sites on the two tributaries were upstream from the main zone of riparian hemlock forest. Samples of soil leachate, ground water and stream water were analyzed for NH_4-N and NO_3-N using automated methods (Technicon 1977, 1978).

Results

Temperature and moisture

Soil temperatures increased to a peak in August or early September in the three stands (Fig. 1). Winter temperatures were slightly below freezing in the maple and pine stands. However, the 0–8 cm soil in the hemlock stand remained unfrozen at sites where the water table was at depths of < 10–15 cm. During the growing season soils in the two upland stands exhibited similar temperatures, whereas soils in the hemlock stand were usually 2–3 °C cooler.

Volumetric soil moisture was slightly lower in the pine stand in comparison to the maple stand during the growing season (Fig. 1). Precipitation in the June–September 1985 was similar to the 30 year normal of 282 mm for the area (A.E.S. 1982). Soil moisture in the upland stands declined from about 30% in mid-April 1985 to only 10–14% in early August after a two week drought. In 1986 June–September rainfall was 535 mm mainly as a result of above normal rains in June, August and September. The unusually wet summer was reflected in higher soil moisture levels in the upland stands in 1986 (Fig. 1). High late winter moisture levels in soils of the pine and maple stands are probably a result of meltwater produced during winter thaws that is refrozen in the upper few cm of the soil. Average volumetric soil moisture levels in the hemlock stand generally ranged between 60–70% and seasonal variations were less evident than in the upland soils.

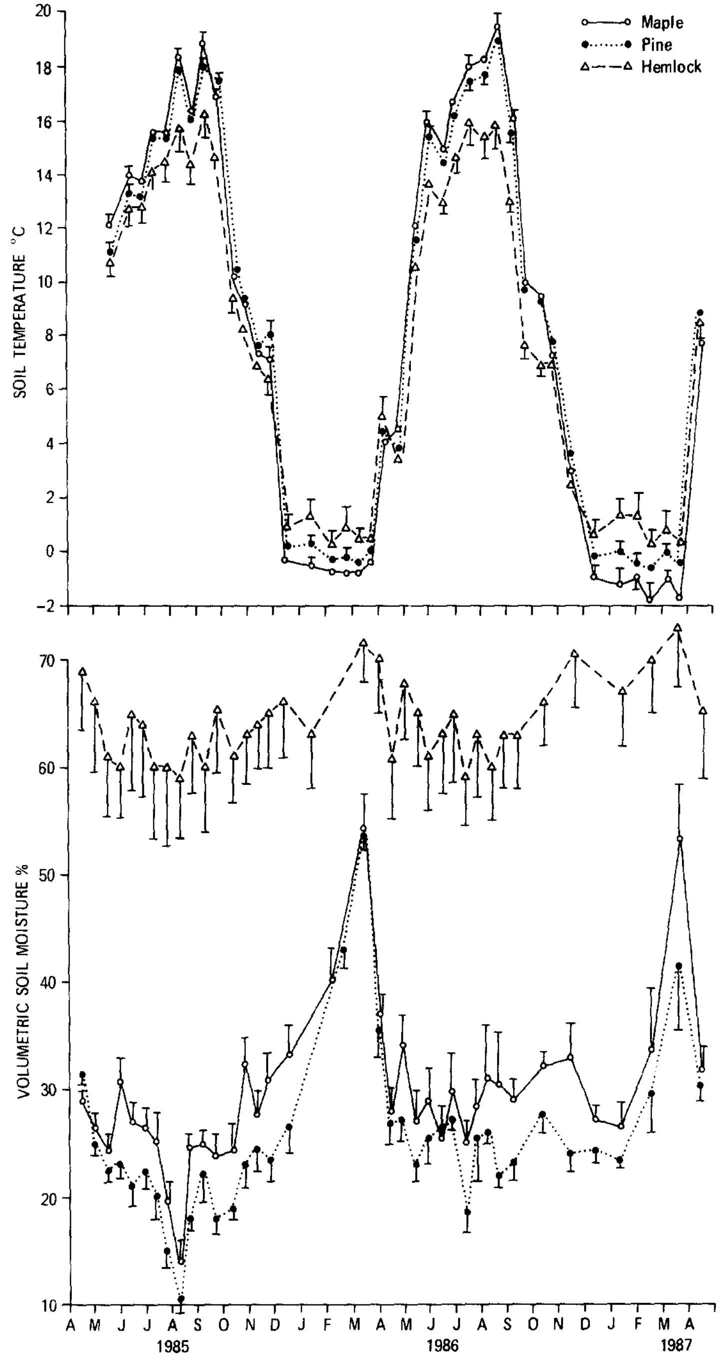

Fig. 1. Patterns of mean (± 1 SE) soil temperature and moisture in the 0–8 cm soil. Error bars are not shown where they are too small to be visible.

Net mineralization and nitrification

Similar seasonal trends in mineralization and nitrification were observed in the three forest stands (Fig. 2). N mineralization and nitrification increased rapidly between April and June or July. In 1985 a pronounced decline in N mineralization and nitrification in August was followed by a secondary peak

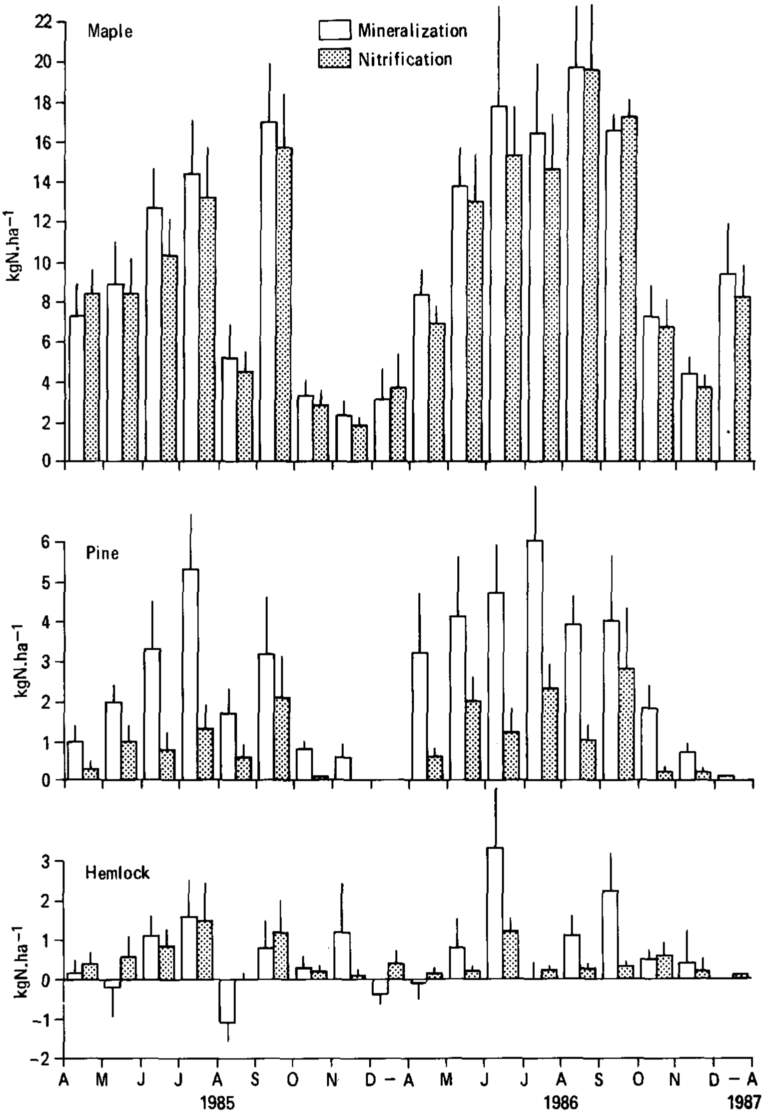

Fig. 2. Seasonal patterns of net N mineralization and nitrification in three forest stands Vertical lines are ± 1 SE.

in September. Rates were low from December to April in the three stands. During some months N mineralization and nitrification were not significantly different from 0 ($P < 0.05$). The negative N mineralization estimates recorded during some months in the hemlock stand may result from immobilization of soil NH_4-N.

During the May–October period volumetric soil moisture in incubated samples exhibited a significant positive correlation of $r = 0.71$ and 0.81 ($P < 0.01$) with mean monthly mineralization and nitrification in the maple stand. However, neither mineralization nor nitrification were correlated with soil moisture in the pine and hemlock stands. Soil temperatures showed no significant trends with average monthly soil N transformation rates in the three stands during the growing season.

Although seasonal patterns were similar, N mineralization and nitrification rates for each incubation period differed considerably between the three stands (Fig. 2). Mean annual rates of N mineralization and nitrification for 1985–87 in the maple stand were 4–11 times higher than in the pine stand and 25–28 times higher than in the hemlock stand (Table 2). The proportion of mineralized N that was nitrified during each incubation period also differed between stands (Fig. 2). Per cent nitrification was >90% in the maple stand in contrast to approximately 35% in the pine stand (Table 2). The highest percentage of N was mineralized annually in maple stand, whereas the hemlock stand exhibited a very low rate of annual mineralization in relation to a large total N soil pool (Table 2).

Although N mineralization and nitrification rates were very low in the hemlock stand, large standard errors (often 50–100% of the mean rate for each incubation period) indicate the extreme variability of these soils. Significant differences in N mineralization and nitrification between sites in the hemlock stand were related to topographic position and depth to the water table (Table 3). Sites located at the upland margin of the riparian zone showed moderate rates of N mineralization and nitrification. Sites in wet

Table 2. Annual soil N mineralization, and nitrification from 0–8 cm soil in the three forest stands.

	Maple		Pine		Hemlock	
	1985–86	86–87	85–86	86–87	85–86	86–87
N mineralization (kg.ha^{-1})	74.2	113.5	17.9	28.8	1.2	5.5
Nitrification (kg.ha^{-1})	68.8	105.3	6.3	10.1	4.2	2.7
% Nitrification	92.7	92.8	35.2	35.1	350.0	49.0
% Soil N mineralized	4.0	6.1	1.8	2.9	0.05	0.2

Table 3. Mean annual soil N mineralization ($kg.ha^{-1}$) and nitrification ($kg.ha^{-1}$) in relation to location and water table depth in the hemlock stand. H = Kruskal-Wallis statistic.

	Perimeter sites	Water table < 10 cm sites	Water table > 20 cm sites	H	P
N mineralization	22.8	−4.1	3.3	8.21	<0.01
Nitrification	11.3	0.3	2.7	7.25	<0.05
n	3	4	5		

depressions with water tables within 10 cm of the surface had negative rates of N mineralization (net immobilization) and negligible nitrification, whereas drier sites showed low rates of both N mineralization and nitrification.

Ammonium and nitrate pools

Seasonal trends in soil pools of exchangeable NH_4-N and NO_3-N were similar in the three stands (Fig. 3). For example, a decline in NH_4-N pools from mid-April 1985 to early June was followed by an increase from late June to mid-August during the period of rapidly increasing soil N mineralization. A second decline in NH_4-N pools occurred between mid-August and early October. Large NH_4-N pools were observed during the winter months in the maple and pine stands. Soil NH_4-N pools were always larger than NO_3-N pools in the three stands. In the maple stand NO_3-N pools showed a definite seasonal pattern with low levels during the growing season and high levels in late winter. In contrast, NO_3-N pools in the pine and hemlock stands were very small and NO_3-N was frequently not detected during the growing season in the pine stand (Fig. 3).

Water chemistry profiles

During the summer months soils were too dry to permit the extraction of water samples (Fig. 4). The wetter late summer conditions of 1986 allowed leachate collections to begin in mid-September in comparison to mid-October in 1985. Large differences were found in the average concentration of NO_3-N in subsoil water which ranged from 0.3–1.0 $mg.L^{-1}$ in the maple stand to $<0.06\,mg.L^{-1}$ in the pine stand.

Shallow ground water at the upland perimeter of the riparian hemlock forest exhibited higher NO_3-N levels downslope from the maple stand than from the pine stand (Fig. 4). Ground water in both locations showed distinct seasonal variations with low levels in late summer and higher levels in late

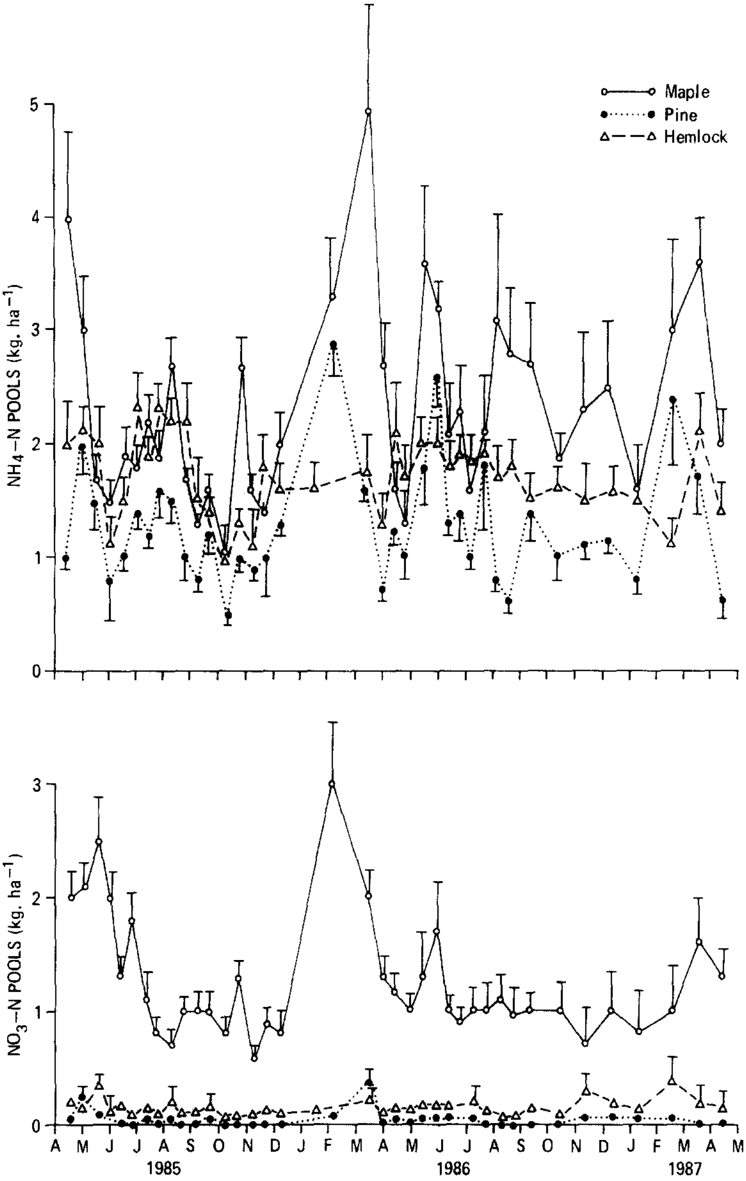

Fig. 3. Seasonal variations in mean soil pools (0–8 cm) of ammonium and nitrate-N in three forest stands. Vertical lines are ± 1 SE.

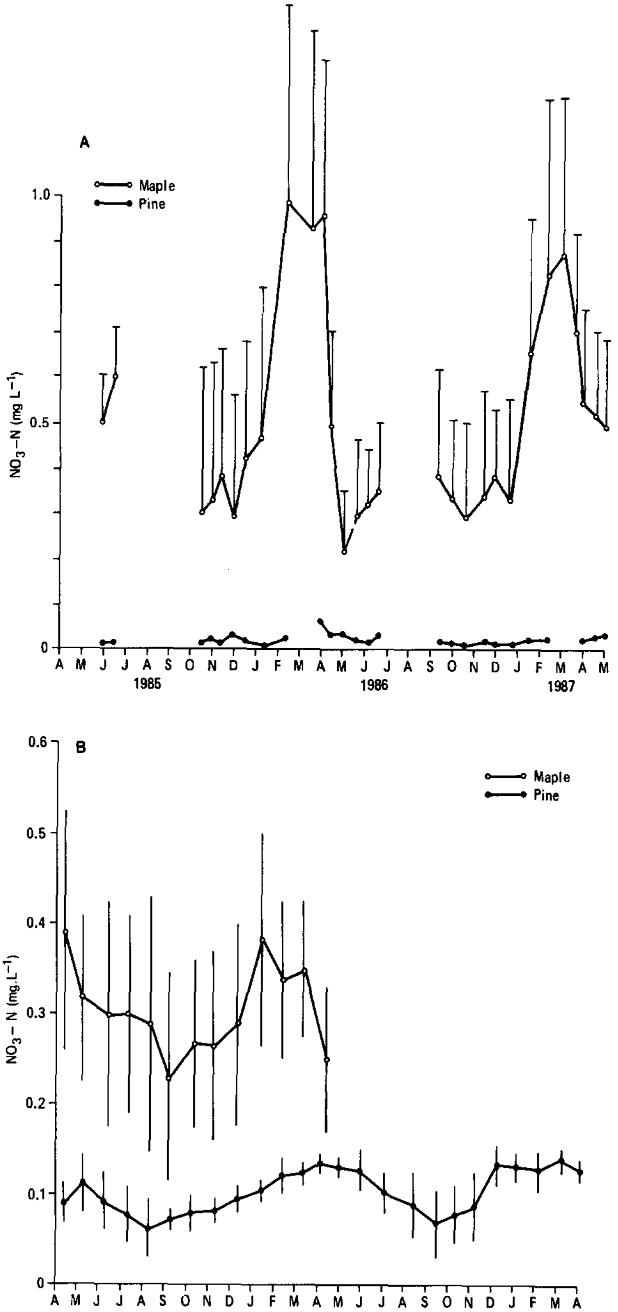

Fig. 4. (A) Mean nitrate-N concentrations in subsoil water sampled at 60–75 cm. Vertical lines are ± 1 SE. Error bars are not shown where they are too small to be visible; (B) Mean (± 1 SE) nitrate-N concentrations in shallow ground water.

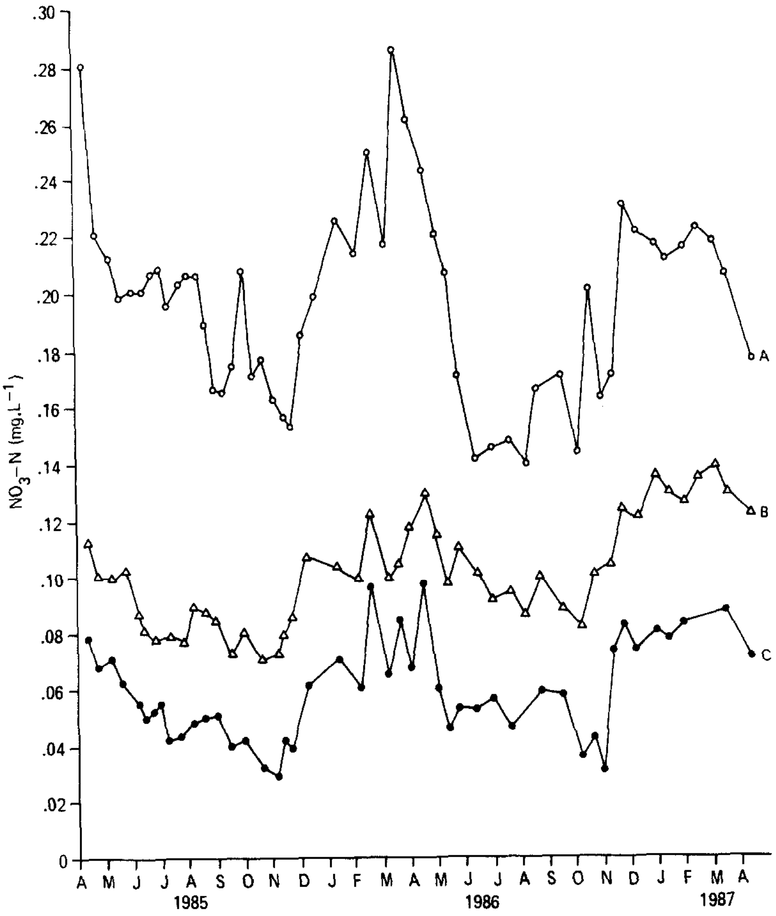

Fig. 5. Seasonal variations in nitrate-N concentrations in streams. A = Maple subwatershed, B = Pine subwatershed, C = Stream at watershed outlet.

winter and early spring. Results for NH_4-N are not reported in Fig. 4 because concentrations were always very low (< 0.06 mg.L^{-1}) in soil leachate and shallow ground water and did not differ between the two upland stands.

Nitrate levels in the tributary draining the maple subwatershed were 3–4 times greater than those in the pine tributary (Fig. 5). The second order stream at the watershed outlet exhibited NO_3-N concentrations which were higher than the pine tributary but considerably lower than the maple tributary. Ammonium levels in all streams were always < 0.01 mg.L^{-1} and did not vary seasonally.

Discussion

Soil N mineralization and nitrification vary seasonally in ways that are similar to variations reported in other studies of temperate forests (Ellis 1974; Nadelhoffer et al. 1983; Pastor et al. 1984). Ellenberg (1977) has suggested that these nitrogen transformation patterns are related to seasonal differences in soil temperature and moisture. During the summer soil moisture was more highly related than temperature to mineralization and nitrification in the maple stand. Although growing season N transformation rates were not correlated with soil moisture in the pine stand a pronounced decline in mineralization and nitrification occurred during a drought in August 1985 during which average volumetric soil moisture declined to 10.5%. Standford & Epstein (1974) suggested that soil moisture levels of 10–20% inhibited N mineralization in sandy loam soils. In the hemlock stand the August 1985 drought period was associated with negative soil N mineralization rates that may indicate immobilization of soil NH_4-N. Surface drying and high soil temperatures may stimulate immobilization in organic soils (Guthrie & Dusbury 1978).

Seasonal variations in N mineralization and nitrification rates and soil N pools can be compared with inorganic N concentrations in water chemistry profiles to identify mechanisms regulating nitrogen loss to streams. In the maple stand pool sizes of NO_3-N declined throughout the growing season to minimum levels in November despite high rates of nitrification. The small NO_3-N pool coupled with an absence of measurable summer NO_3-N losses in soil leachate suggests rapid NO_3-N uptake by the forest community. In contrast, the pine stand showed very low rates of nitrification and soil NO_3-N pools were negligible throughout the year. Although plant uptake occurred in the pine stand, the release of NO_3-N to streams is probably prohibited mainly by low nitrate production. N mineralization rates in the pine stand were one-quarter of that of the maple soil. Nevertheless, nitrification does not appear to be limited by these low mineralization rates since annual nitrification was only about 35% of annual mineralization. Soils in which nitrification utilizes a small proportion of annual N mineralization have also been reported elsewhere (Vitousek et al. 1982; Pastor et al. 1984). Several mechanisms such as allelochemic inhibition of nitrifying bacteria, phosphorus deficiency, and competition for ammonium between roots, mycorrhizae and nitrifiers leading to low initial populations of nitrifying bacteria can inhibit nitrification in forest stands (Rice & Pancholy 1972; Purchase 1974; Johnson & Edwards 1979; Robertson 1982).

Negligible leaching beyond the rooting zone occured during the July–September period in the two upland stands because of summer transpiration which dries the soil raising the water storage capacity. Soil N mineralization and nitrification decreased rapidly after September in the maple and pine stands. Low nitrification rates during the late fall and winter served to minimize N leaching losses. However, some of the soil NO_3-N in addition to precipitation NO_3-N entering the soil was leached in the October to May period. This seasonal pattern of leaching is reflected in higher NO_3-N concentrations in shallow ground water and in the perennial streams from November to April. The relatively large NH_4-N and NO_3-N pools present in February and March particularly in the maple stand coincides with a period of high soil moisture content and probably represents precipitation N and forest floor leachate that is transferred into the 0–8 cm soil in snow meltwater during brief winter thaws. A sharp decline in the maple stand NO_3-N pool in late winter may indicate leaching however, a similar decline in NH_4-N pools in the upland stands suggests that plant N uptake may also occur. Active growth of maple roots has been observed to begin in February (Morrow 1950).

The contrast between the low nitrification rates of the pine soils and the much greater rates in the maple soils is reflected in the higher NO_3-N concentrations in maple soil leachate. Higher NO_3-N levels also occurred in shallow ground water and in the tributary draining the maple subwatershed. Very low NO_3-N losses to streams were evident in areas of the watershed occupied by pine stands. Despite differences in rates of N mineralization and % nitrification between the two upland stands, water chemistry profiles showed similar low NH_4-N concentrations indicating efficient soil retention of NH_4-N.

The generally very low rates of N mineralization in the hemlock stand may be related to two factors, low rates of gross N mineralization and high rates of NH_4-N immobilization that are often associated with moist organic soils (Patrick 1982). The relative importance of these two factors cannot be separated because we only measured net N mineralization. However, negative rates of N mineralization in wet depressions suggest that immobilization is partly responsible for low N mineralization. Low rates of nitrification in the hemlock stand are probably a result of low N mineralization and restriction in O_2 supply in these wet soils. The absence of NO_3-N accumulation in incubated soils could also be caused by denitrification. However, N_2O fluxes from the hemlock soils were often near zero (Warwick & Hill 1987).

Patterns of N mineralization and nitrification in the hemlock stand have several implications for the role of the riparian zone in regulating mineral N losses to streams. Low annual N mineralization rates in the 0–8 cm hemlock soil indicate that NH_4-N levels are unlikely to increase in the surface rivulets. Although NH_4-N concentrations were frequently 0.03 to 0.06 $mg.L^{-1}$ in shallow ground water entering the riparian zone from the upland stands, NH_4-N levels were always < 0.01 $mg.L^{-1}$ in the spring-fed riparian rivulets (Hill & Warwick 1987). Previous research involving NH_4-N enrichment of rivulets and lab experiments with riparian substrates revealed rapid NH_4-N depletion as a result of microbial immobilization (Hill & Warwick 1987). The occurrence of negative rates of N mineralization in wet depressions that are frequently sites of diffuse surface rivulet flow provides additional evidence that microbial immobilization is an important mechanism of NH_4-N retention in the riparian zone.

Rates of N mineralization from soil pools determine the availability of N for uptake by plants. The very slow turnover of N in the hemlock stand suggests that N uptake by vegetation is probably a minor factor in N retention. Low rates of nitrification in the hemlock soil may also influence denitrification activity. Warwick & Hill (1988) observed generally low denitrification rates in riparian substrates and an absence of NO_3-N depletion during nitrate enrichment of rivulets. Moreover, short-term N_2O evolution rates were highly correlated with initial NO_3-N content of substrate samples implying that denitrification is limited by nitrate availability.

Our results indicate that significant contrasts in soil N mineralization and nitrification occur among adjacent upland and riparian forest communities within this small watershed. Inorganic N concentrations in soil leachate, shallow ground water and streams exhibit spatial variations that are related to these soil transformation processes. Small watersheds containing upland mineral soils and organic soils adjacent to streams are widespread in the Great Lakes area (Verry & Timmons 1982; Pierson & Taylor 1985). These small watershed ecosystems contain variability in soil nitrogen transformation processes which is critical to understanding their ability to regulate losses of inorganic nitrogen.

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