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Nitrogen cycling processes and soil characteristics in an urban versus rural forest

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Abstract. Different soils of an urban forest in New York City showed relatively low, yet similar rates of N mineralization and nitrification in laboratory potential measurements. This consistent pattern occurred even though a number of factors known to influence these processes (including overstory vegetation, soil type, and heavy metal levels) differed between the urban samples. Net N mineralization rates in forest floor and A horizon samples from a hemlock stand within the urban forest were 81% and 53% lower than respective samples from a comparable rural stand. In addition, all forest floor and A horizon samples from the urban forest were extremely hydrophobic. The low mineralization rates and hydrophobic nature of the urban samples suggested that factors associated with the 'urban grime' hydrocarbons may be limiting the activity of soil microbes and invertebrates. Trampling and high concentrations of heavy metals may have synergistic effects that would act to reduce net N mineralization and nitrification within the urban forest.

Introduction

Urban environments significantly differ from rural environments in many aspects. Pollution from transportation and industry contributes oxides of carbon, nitrogen and sulfur (NAS 1983), heavy metals (Volchok et al. 1974; Tyler 1975; Johnson et al. 1982), particulate matter (Matsumoto & Hanya 1980), and an array of aliphatic and aromatic hydrocarbons (Broddin et al. 1980) to urban environments. Not only do these pollutants pose an obvious threat to the health of urban inhabitants (Stern et al. 1984), but urban pollutants may alter ecosystem processes and threaten vital resources, including soil fertility in surrounding areas. Research pertaining to the effects of urban air pollutants had addressed questions relating to the effects of acid rain and associated inorganic constituents on terrestrial and aquatic systems (NAS 1983 and 1984), or changes in plant community structure within urban environments (Gill & Bonnett 1973; Numata 1977; Bornkamm et al.

1982, Grodzinski et al. 1984; Roundtree 1984). Little is known about the chronic effects of urbanization and associated air pollutants on nutrient cycling processes including decomposition, nitrogen mineralization, and nitrification.

The objectives of this study were:

1. to determine spatial variation in nitrification and N mineralization potentials within a mixed hardwood-hemlock forest in New York City;
2. to correlate the rates of these soil processes with soil type, heavy metal content, and other soil characteristics to determine possible factors controlling these nutrient cycling processes in this urban ecosystem; and
3. to compare rates of these soil processes in urban and rural forest stands.

Study sites

NYBG Forest

The New York Botanical Garden Forest (NYBG Forest), located in the Bronx, New York (40° 50′ N, 73° 51′ W) provides a unique opportunity to study the long-term effects of urbanization on a natural forest ecosystem. This 16 ha (40 acre) forest (Fig. 1) has never been cleared of timber or actively developed, and is one of the last remnants of the original forest which once covered the New York City area (Britton 1906).

The climate of the NYBG Forest is characterized by warm humid summers and cold winters. At Central Park Observatory, which is approximately 16 km (10 miles) south of the NYBG Forest, average annual air temperature is 12.5 °C with 0.6° and 25 °C the average for January and July, respectively (Pack 1974). Average annual precipitation is 108 cm, which is evenly distributed throughout the year (Pack 1974).

The bedrock of the NYBG Forest consists of metamorphic rock of three major formations; Fordham gneiss, Inwood marble, and Manhattan schist (Schuberth 1968). The Wisconsin Ice Sheet retreated from the area around 17,000 years ago (Schuberth 1968). Soils in the forest are predominantly fine sandy loams derived from glacial till (Thornes 1974). Five major soil types within the forest include: Hollis; Chatfield; Limerick; Wallington; and Charlton soil series (Thornes 1974, Fig. 1). The New York Botanical Garden Forest is representative of a mixed hardwood-hemlock forest, dominated by oak (*Quercus borealis* Michx.), hemlock (*Tsuga canadensis* (L.) Carr.), cherry (*Prunus serotina* Ehrh.), hickory (*Carya* spp.), maple (*Acer rubrum* L.), and beech (*Fagus grandifolia* Ehrh.). The NYBG Forest has a well

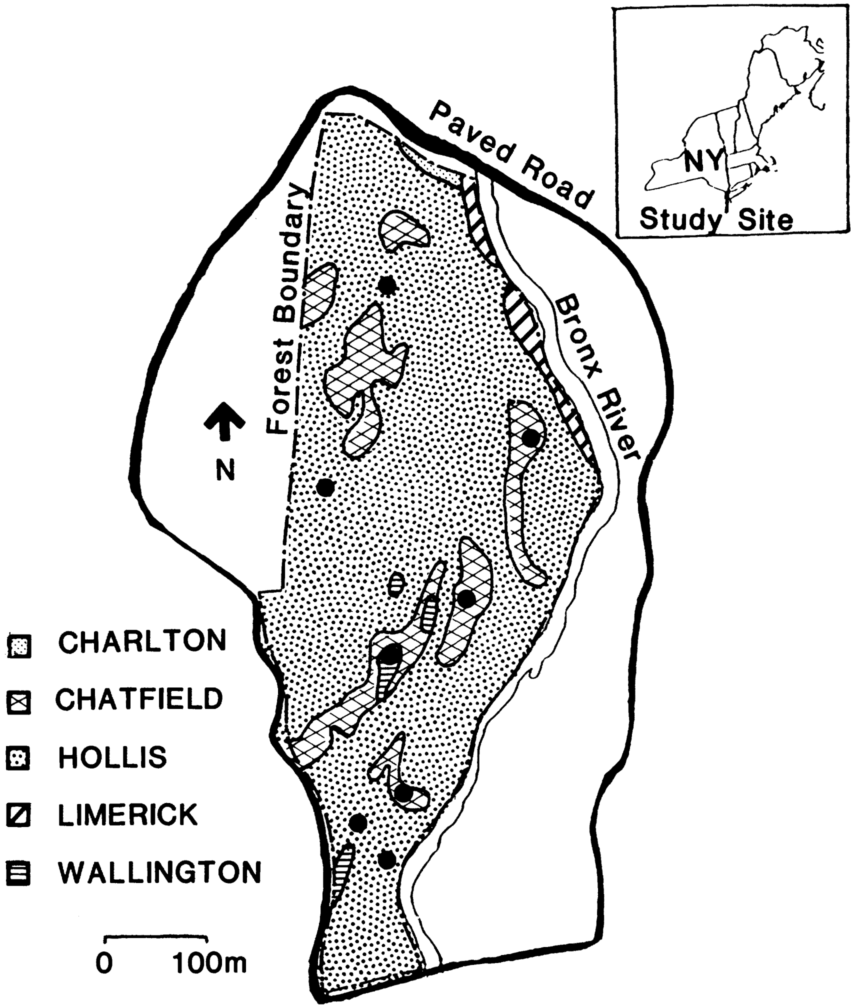

Fig. 1. Map of the New York Botanical Garden Forest located in the Bronx, New York indicating the five major soil series as mapped by Thornes 1974. The black circles indicate locations of the 8 soil pits where the A horizon samples were collected. Insert is a map of the New England states showing the location of the NYBG Forest.

developed understory composed of such shrubs and subcanopy trees as witch-hazel (*Hamamelis virginiana* L.), spicebush (*Lindera benzoin* (L.) Blume), dogwood (*Cornus florida* L.), and arrow-wood (*Viburnum dentatum* L.). The forest floor is populated by a diversity of herbs and wildflowers, including solomon's-seal (*Polygonatum biflorum* (Walt) Ell.), may-apple (*Podophyllum peltatum* L.), and wild lily-of-the-valley (*Maianthemum canadense* Desf.). Using standard ordination techniques, the canopy trees have been grouped into four major cover types: Hemlock; Oak; Cherry-Birch; and Beech (Rudnicky & McDonnell, in prep.).

Cary Forest

The rural study site was located at the Mary Flagler Cary Arboretum (41° 48′ N, 73° 45′ W), which is 117 km (70 mi.) north of New York City. The Arboretum covers 778 ha (1924 acre) and provides a variety of habitats including deciduous and coniferous forests.

The Cary Forest is slightly cooler than the NYBG Forest, with an average annual air temperature of 8.5 °C and monthly averages of −4.8 °C and 20.9 °C for January and July, respectively (Climatography of the United States No. 20). Average annual precipitation is 103 cm, which is evenly distributed throughout the year.

The bedrock of the Cary Forest consists primarily of late Cambrian-early Ordovician slates of the ancient Taconic Mountains (Knopf 1927; Broughton et al. 1966). Similar to the NYBG Forest, this area was glaciated during the last ice age. The portion of the Cary Forest used in this study was underlain by Nassau slaty loams derived from the slate bedrock (Secor et al. 1955). This rural hemlock stand was dominated by hemlock with a very sparse understory of shrubs and herbs.

Methods

NYBG forest soils

In November 1985, the three major soil types in the NYBG Forest were sampled proportional to their area to determine soil properties. Thus, 4 pits were dug in the Hollis soil series, 3 in the Chatfield, and 1 in the Wallington series. Soil pits were located randomly within each soil series and were dug to bedrock or to a 2-m depth, whichever came first. Vegetation types traversed soil series, and the pits in the Hollis soil series were in Cherry-Birch and Hemlock vegetation types, the Chatfield pits were in Hemlock and Beech, and the Wallington pit was in Beech.

Four replicate samples of the entire A horizon (which varied from 4 to 20 cm in depth), one from each side of the soil pit after cleaning of the profile, were taken with a 10 cm long by 4.8 cm diameter aluminum cylinder. Separate replicates were collected in a similar fashion for bulk density analyses using 5-cm long by 4.8-cm diameter aluminum cylinders. Samples used for chemical analysis were taken to the lab, air dried, sieved to remove material larger than 2.0 mm, and subsamples were analyzed by the Cornell University Soil Laboratory for analysis. Routine chemical methods for the Soil Laboratory were used for all samples with samples run in replicate and the mean values displayed in Table 1 (replication was acceptable according to the soils report). It should be noted that elemental composition is total for each element (particularly important for C which includes organic and inorganic sources).

On 4 June 1986, additional samples were taken for laboratory incubations. Fresh A horizon samples were collected from areas immediately adjacent to the eight soil pits as well as 5 replicate forest floor and A horizon samples taken at 1-m intervals along a line transect in a representative hemlock stand within the NYBG Forest. Forest floor samples included all organic horizons (Oi, Oe, and Oa) beneath a 225 cm^2 template. All samples were placed in coolers, transported to the Institute of Ecosystem Studies, and kept refrigerated until prepared for analysis. All A horizon samples used to determine mineralization potentials were sieved to remove material greater than 6.4 mm (1/4″). Later analyses determined that the amount of material between 2 and 6.4 mm dia. ranged from 3% to 7% by weight and was not significantly different between urban and rural sites.

Organic matter was determined by loss upon ignition at 500 °C.

Cary forest soils

On 8 June 1986, 5 replicate forest floor and A horizon samples were taken at 1-m intervals along a line transect for laboratory incubations. In August 1986, a single soil pit was dug to characterize the soil profile and collect samples for soil properties and chemical analysis. All samples were collected and analyzed in the same manner as previously described for the NYBG Forest.

Nitrogen mineralization and nitrification potential

Nitrogen mineralization and nitrification potentials are determined under standard moisture and temperature conditions. An aerobic incubation at 20 °C and 50% of water-holding capacity (White 1986) was used for this study. Water-holding capacity was determined by placing subsamples into stoppered funnels fitted with a glass-wool plug and adding water until the subsample was completely covered with water. The subsamples were allowed to remain in contact with the water for 30 min, then drained by gravity for 30 min, and water content determined by loss upon heating at 105 °C to

Table 1. NYBG and Cary Forest A horizon soil characteristics. Chemical analyses performed by Cornell University Soil Laboratory.[1]

Characteristic or Elemental composition	NYBG Forest soil series									Cary Forest soil series
	Hollis				Chatfield			Wallington		Nassau
	1	2	3	4	1	2	3	1	$\bar{X}$	1
C (%)	7.95	12.22	8.21	9.84	19.41	11.47	9.86	6.86	10.73	7.92
N (%)	0.38	0.56	0.40	0.40	1.03	0.50	0.44	0.28	0.499	0.44
S (%)	0.0802	0.1668	0.1061	0.1049	0.2688	0.0784	0.0777	0.0666	0.119	0.0540
P (%)	0.0928	0.0761	0.0515	0.0477	0.0648	0.0476	0.0528	0.0326	0.0582	0.0840
Ca (%)	3.005	0.68	0.518	0.47	0.423	0.544	0.43	1.429	0.94	0.11
Mg (%)	0.893	0.549	0.401	0.563	0.333	0.366	0.401	0.888	0.549	0.622
K (%)	0.94	0.9	1.02	1.06	0.66	0.91	0.96	0.72	0.896	1.78
Na (%)	0.891	0.83	0.934	0.841	0.84	0.845	0.824	0.975	0.873	0.68
Fe (%)	3.37	3.3	2.83	3.39	2.75	2.83	2.4	3.84	3.09	2.84
Mn (μg/g)	926	318	220	240	215	193	206	642	370	2466
Cu (μg/g)	129	120	55.3	98.2	97.8	107	105.5	68.8	97.7	22.8
Pb (μg/g)	558	426	200	274	522	309	265	221	347	75.0
Zn (μg/g)	161	96.6	71.4	90.7	107	60.9	58.4	99.8	93.2	142.0
Ni (μg/g)	45.8	34.4	19.7	25.7	52.2	29.5	22.4	51.5	35.2	21.0

Table 1. (contd).

Characteristic or Elemental composition	NYBG Forest soil series									Cary Forest soil series
	Hollis				Chatfield			Wallington		Nassau
	1	2	3	4	1	2	3	1	$\bar{X}$	1
Extractable Al (μg/g)	0.01	265	253	335	167	495	472	298	286	355
Cation exc. cap. (meq/100 g)	26	35.5	25.5	33	46.5	40	35	25.5	33.4	31.8
Exchangeable elements										
Ca (meq/100 g)	34.4	0.19	0.44	0.17	0.95	0.068	0.073	0.34	4.58	2.6
Mg (meq/100 g)	0.37	0.16	0.31	0.16	0.48	0.102	0.021	0.22	0.228	0.272
K (meq/100 g)	0.124	0.115	0.114	0.14	0.403	0.081	0.041	0.131	0.156	0.227
Na (meq/100 g)	0.066	0.021	0.029	0.077	0.053	0.035	0.057	0.03	0.046	0.034
Organic matter (%)	16.3	33.9	15.9	16.0	7.7	22.0	17.7	11.8	17.7	8.8
pH										
H_2O	5.4	3.7	3.9	3.9	3.4	3.6	3.6	3.7	3.9	4.3
KCl	4.9	3.2	3.4	3.2	2.8	3.0	2.9	3.1	3.3	3.6

[1] CEC by NH_4OAc extraction pH 7.0; Total C, N by Perkin Elmer 240-C Elemental Analyzer; Total S determined turbidimetrically on $Mg(NO_3)_2$ ashing; Total P determined by vanadomolybdophosphoric acid method on $Mg(NO_3)_2$ ashing; Total cations on HF digestion.

constant weight. The water-holding capacity equaled the amount of retained water. Separate subsamples were adjusted to 50% of their determined water-holding capacity prior to incubation. However, all the NYBG Forest samples were extremely hydrophobic and would not absorb water during contact with water for up to 2 h. We felt the water content of the NYBG samples at field moisture condition was below 50% of water-holding capacity and was not equivalent to the available water content of the rural samples; thus, subsamples of all NYBG Forest samples were first mixed with water by a folding action until evenly moistened. These mixed samples were then placed in a funnel and their 'apparent water-holding capacity' was determined by the above procedure. Thus, we do not know the true water-holding capacity of the NYBG samples. This wetting procedure appeared to be adequate with 50% of water-holding capacity being nearly proportional to soil organic matter content, and was similar to water-holding capacity measurements on the rural (Cary) hemlock samples.

After adjusting other portions of each sample to 50% of determined water-holding capacity, subsamples were apportioned into plastic cups, each cup containing approximately 10 g dry-weight (DW) mineral soil or 2 g DW forest floor. Two subsamples (cups) of each sample were extracted immediately with 100 ml of 2 *N* KCl. The remainder of the subsamples were covered with plastic wrap (to minimize water loss but allow CO_2 and O_2 exchange; Bremner & Douglas 1971), weighed, and incubated at 20 °C. Moisture was replenished as necessary during incubation. Approximately weekly, two cups of each sample were removed and extracted with 100 ml KCl with the last set of NYBG Forest samples extracted after 48 days of incubation and the Cary samples extracted after 46 days of incubation. The two subsamples of each sample were composited prior to analysis. After settling for 24 h, the KCl extracts and appropriate standards were filtered to remove floating material. The filtrate was analyzed for ammonium by an automated phenolate method (Technicon AutoAnalyzer Industrial Method # 19-69W) and for nitrate by an automated nitroprusside method (Technicon AutoAnalyzer Industrial Method # 33-69W).

Available inorganic nitrogen pools were assumed to be equal to the initial (day 0) extractable NH_4-N and NO_3-N levels. Potential nitrification rates were calculated as the change in nitrate levels during incubation. Net N mineralization was the change in the sum of nitrate and ammonium levels during incubation. Since all samples were at or below pH 5.4, ammonium volatilization would be minimal. Although denitrification was not measured, other investigations with these incubation conditions have shown no significant loss from denitrification (Gosz & White 1986), and denitrification was assumed to be negligible during the incubation period.

Linear regression analysis was used to determine mean rates of net N mineralization and nitrate production (mean rate equaled the slope of the regression). Correlation analyses were used to identify the relationship between each soil characteristic and the mean production rates (n = 8). Differences between urban and rural hemlock stands were tested by comparing rates of the 5 replicate samples of forest floor or A horizon soil from each stand by t-test. Plant nomenclature follows Gleason & Cronquist (1963).

Results

Soil properties

Soils in the NYBG Forest are loams and sandy loams with high organic matter content (Table 1). The soil mean bulk densities of the A horizons ranged from 0.63 to 0.79 $g\,cm^{-3}$. Most soil characteristics showed a 2 to 4 fold difference between the lowest and highest value within all the NYBG Forest samples (Table 1). Extractable Al and Ca concentrations showed the greatest range between NYBG samples (49500 and 505 fold differences between samples, respectively). The range in soil characteristics was nearly as wide between replicates of each soil series as the range in all soil samples in the NYBG Forest.

The A horizon of the rural hemlock stand in the Cary Forest was a sandy loam with a high gravel content (23%). The mean bulk density of the Cary soil was 0.68 $g\,cm^{-3}$. Soil characteristics of the Cary soil were within the range shown in the NYBG Forest soils (Table 1) except for lower levels of total Ca, S, Cu, and Pb, and higher levels of total K and total Mn. The pH of the Cary soil was higher than all but one sample (Hollis-1) from the NYBG Forest when measured in water or KCl (Table 1).

Nitrogen mineralization and nitrification

In all A horizon samples from the 8 randomly selected sites within the NYBG Forest, rates of net N mineralization per g dry weight ($N\,g^{-1}\,DW$), and net N mineralization per g ash-free weight ($N\,g^{-1}\,AFW$, or per g of organic matter), and nitrification rates were constant with time throughout the incubation period. Linear regressions of inorganic N accumulation vs. time were significant ($p < 0.05$) for all analyses (r^2 ranged from 0.67 to 0.98), although non-linear regressions may have explained more of the variation in either nitrate production or net N mineralization in some

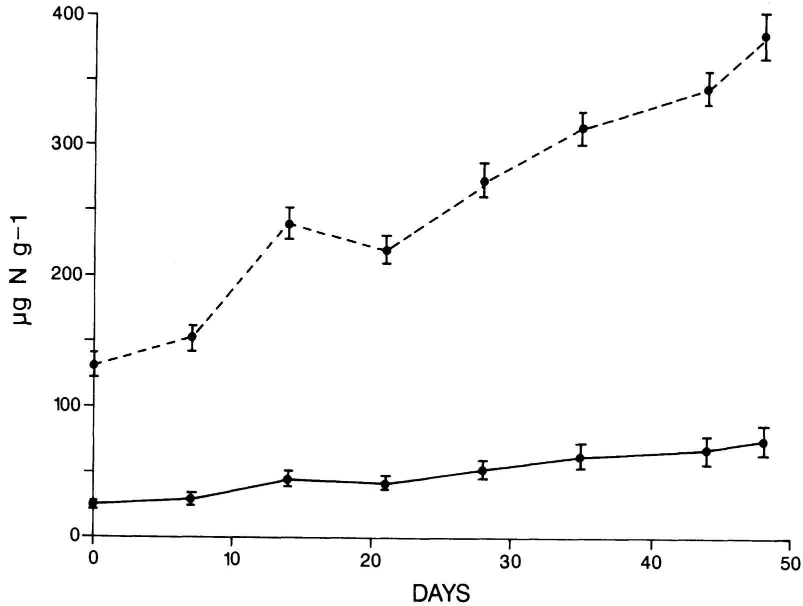

Fig. 2. Net inorganic nitrogen levels (NH_4 + NO_3, mean + S.E.) during nitrogen mineralization potential incubations of A horizon soils from the NYBG Forest (n = 8) expressed on a dry weight (——) and organic matter (ash-free weight, ---) basis.

samples. Regression slopes were correlated with all other soil characteristics in Table 1. Out of 72 correlations (24 soil characteristics correlated with rates of nitrification, net N mineralization as $N g^{-1} day^{-1} DW$ and $N g^{-1} day^{-1} AFW$), only one correlation was significant ($p < 0.05$): Cu levels and net N mineralization as $N g^{-1} day^{-1} DW$ ($r = 0.732$, d.f. = 6). At least 3 significant correlations would have been expected by random chance alone.

Mean concentrations of nitrate plus ammonium in the 8 A horizon NYBG Forest samples (expressed on a DW and AFW basis) for each extraction are shown in Fig. 2. The range in net N mineralization rates between all NYBG Forest samples was less when rates were expressed as $N g^{-1} day^{-1} AFW$ rather than $N g^{-1} day^{-1} DW$ (a 2.5 fold difference vs. nearly 6 fold difference). The range within a soil type for net N mineralization and nitrification rates was nearly as large as the range in all 8 samples (Table 2). In all samples, nitrate levels were in near constant proportion to ammonium levels throughout the incubation averaging 26% of total inorganic N levels.

The 5 replicate A horizon samples in the NYBG Forest hemlock stand were nearly equal to the other 8 randomly located A horizon samples in the Forest for initial inorganic nitrogen levels and net N mineralization rates

Table 2. Nitrification and net N mineralization rates for forest floor and A horizon in an urban and rural hemlock stand and for A horizons at 8 randomly located sites in the NYBG Forest (identified by soil type). Values are mean rate (slope) determined by regression of nitrate and ammonium levels in 8 extractions with incubation time (r value).

Sample type	Nitrification (N μg/g day DW)	Net N mineralization	
		(N μg/g day DW)	(N μg/g day AFW)
NYBG Forest			
A Horizon (soil type-rep.)			
Hollis-1	0.19(0.896)	2.08(0.978)	5.58(0.978)
Hollis-2	0.62(0.985)	1.35(0.976)	5.97(0.976)
Hollis-3	0.18(0.907)	0.55(0.935)	4.17(0.935)
Hollis-4	0.11(0.823)	0.52(0.874)	2.59(0.875)
Chatfield-1	0.29(0.990)	0.35(0.929)	3.66(0.928)
Chatfield-2	0.17(0.919)	1.75(0.987)	6.14(0.988)
Chatfield-3	0.51(0.966)	1.22(0.994)	6.10(0.994)
Wallington-1	0.13(0.882)	0.57(0.965)	6.57(0.966)
Hemlock stands			
Forest floor			
Urban (NYBG)	1.10(0.718)	5.44(0.828)	7.60(0.864)
Rural (Cary)	6.1 (0.772)	22.1 (0.833)	40.6 (0.865)
A Horizon			
Urban (NYBG)	0.41(0.792)	0.96(0.755)	4.37(0.929)
Rural (Cary)	0.96(0.736)	1.11(0.594)	9.25(0.677)

(Fig. 3). Throughout the incubation, the 5 replicate hemlock samples had standard errors of the extraction means similar to the other 8 randomly located samples in the NYBG Forest (Fig. 3).

Forest floor of the urban hemlock stand had significantly lower rates of net N mineralization expressed as $N g^{-1} day^{-1} DW$ ($p < 0.001$) and as $N g^{-1} day^{-1} AFW$ ($p < 0.001$), and has significantly lower rates of nitrification ($p < 0.001$) than the forest floor of the rural stand. The A horizon of the urban stand had significantly lower rates of net N mineralization expressed as $N g^{-1} day^{-1} AFW$ ($p < 0.05$) and significantly lower rates of nitrification ($p < 0.001$) than the rural stand. Between-sample variation was less in the urban stand than in the rural stand. Standard errors of the means ranged between 3.3% and 8.5% for the urban samples and between 7.8% and 17.9% for the rural samples (Fig. 4, 5). Initial levels of nitrate-N and ammonium-N in the mineral soil were higher ($p < 0.05$) in the urban stand than in the rural stand. The pattern of net N mineralization exhibited in all urban samples was nearly linear with respect to time throughout the incubation (Fig. 4, 5). Net N mineralization in the rural A horizon samples appeared to have reached an asymptote after about 35 days of incubation (Fig. 5).

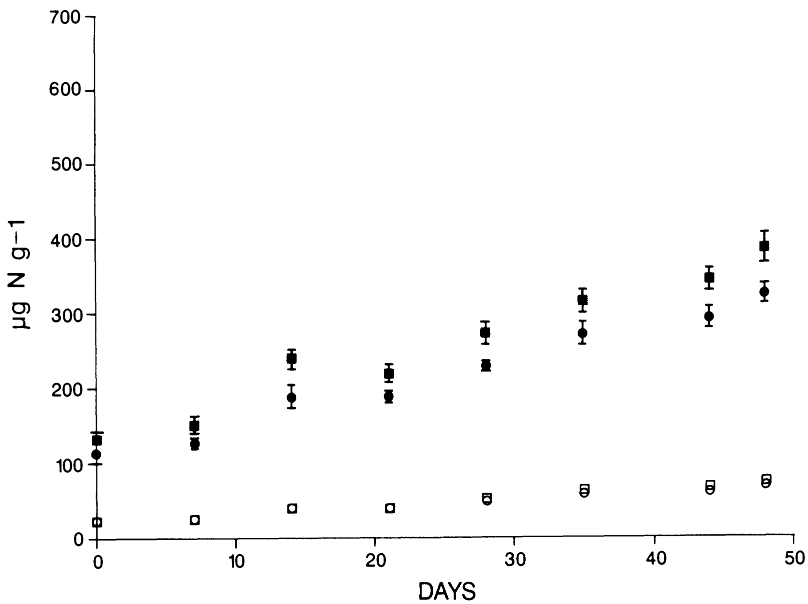

Fig. 3. Net inorganic nitrogen levels (NH_4 + NO_3, mean + S.E.) during nitrogen mineralization potential incubations of A horizon soil samples from a hemlock stand (n = 5) within the NYBG Forest (circles) and from randomly located sites (n = 8) within the NYBG Forest (squares). Open symbols (standard error bars were omitted) are $N g^{-1}$ dry weight soil, and closed symbols are $N g^{-1}$ organic matter (or ash-free dry weight).

Discussion

Nitrogen mineralization potentials are known to vary with vegetation type (Vitousek et al. 1982; Nadelhoffer et al. 1983; Binkley et al. 1986; Carlyle & Malcolm 1986; Gosz & White 1986), season (Nadelhoffer et al. 1983; Gosz & White 1986; Carlyle & Malcolm 1986), pH (Klein & Alexander 1986; White & Gosz, in press), available carbon (Flanagan & Van Cleve 1984), levels of other essential nutrients (White & Gosz, in press), heavy metal content (Ruhling & Tyler 1973; Tyler 1975; Doelman & Haanstra 1984), and presence of allelopathic inhibitors (White 1986). Nitrification potentials can be affected by many of the same factors (Robertson 1982; Olson & Reiners 1983; Vitousek & Matson 1985), and can be limited by low ammonium levels (Robertson 1982). Vegetation type plays a major role in determining both N mineralization and nitrification rates in forest ecosystems. Vitousek et al. (1982) reported that net N mineralization rates for oak-maple, red pine, northern hardwoods, and balsam fir forest sites in New England differed by 10-fold or more, ranging from 0.2 to 2.7 $\mu g N g^{-1} day^{-1}$ expressed on a DW basis. Nitrification potentials of these New England sites differed by nearly

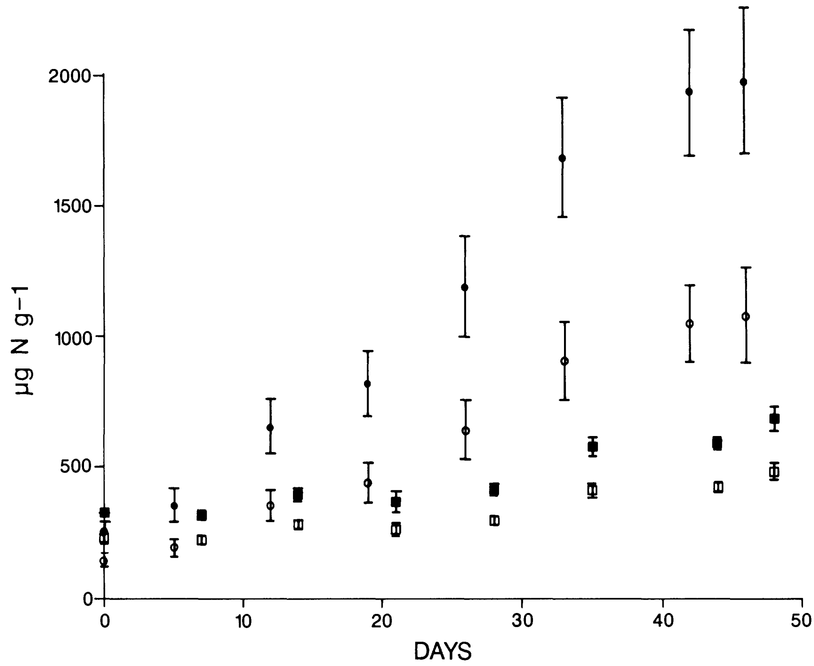

Fig. 4. Net inorganic nitrogen levels (NH_4 + NO_3, mean + S.E.) during nitrogen mineralization potential incubations of forest floor samples (n = 5) from hemlock stands within the NYBG Forest (squares) and on the grounds of the Cary Arboretum (circles). Open symbols are $N\,g^{-1}$ dry weight forest floor, and closed symbols are $N\,g^{-1}$ organic matter (or ash-free dry weight).

two orders of magnitude, ranging from 0.04 to 2.80 $\mu g\,N\,g^{-1}\,day^{-1}$. Carlyle & Malcolm (1986) reported that net N mineralization rates were 4 to 10 times higher when larch was present in spruce stands than in stands of pure spruce.

Net N mineralization and nitrification rates were expected to vary between the 8A horizon samples within the NYBG Forest by an order of magnitude or more because samples varied with respect to overstory vegetation, soil type, heavy metal content, extractable cations (including Al), or levels of other essential nutrients (S and P). In fact, the actual variation in the NYBG Forest samples was lower than expected. Net N mineralization rates and nitrification rates in the 8 randomly located A horizon samples were similar to the 5 A horizon samples within a 4-m area in the hemlock stand in the NYBG Forest. For all 13 A horizon samples collected from the NYBG Forest, nitrification rates differed by a maximum of 5.6 times and net N mineralization differed by 5.9 times and 2.5 times expressed on a dry weight and ash-free weight basis, respectively.

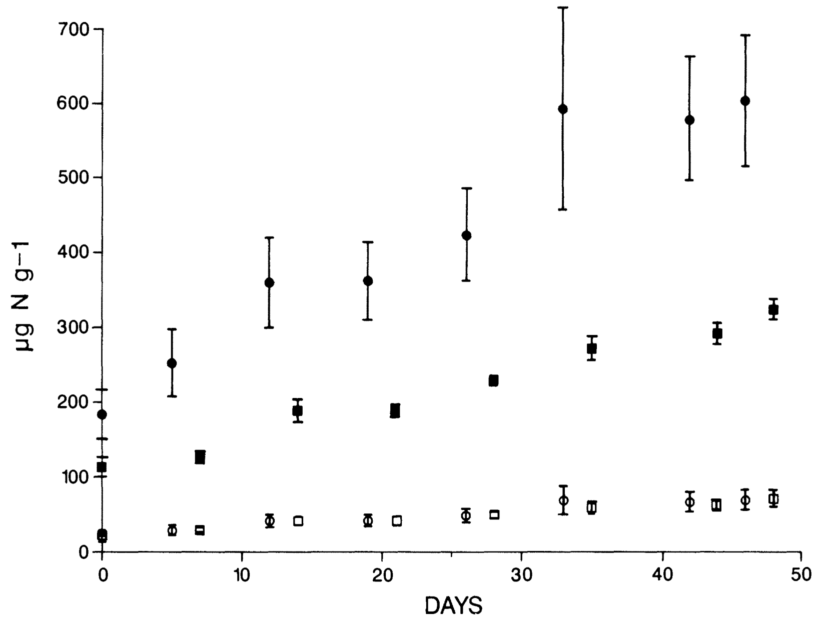

Fig. 5. Net inorganic nitrogen levels (NH_4 + NO_3, mean + S.E.) during nitrogen mineralization potential incubations of A horizon soil samples (n = 5) from hemlock stands within the NYBG Forest (squares) and on the grounds of the Cary Arboretum (circles). Open symbols are $N g^{-1}$ dry weight soil, and closed symbols are $N g^{-1}$ organic matter (or ash-free dry weight).

Net N mineralization rates in the NYBG Forest and the Cary Forest were within the range reported for other New England forest sites reported by Vitousek et al. (1982, values reported above). However, the Cary hemlock A horizons (Table 2) were on the upper end of the range, while all the NYBG Forest samples (including the urban hemlock stand) were on the lower end of the range for the New England sites. The low net N mineralization rates in the NYBG Forest occurred even though inorganic nitrogen levels at the beginning of incubation (week-0) were 2 times higher in the NYBG Forest samples than the maximum week-0 levels reported for the New England sites (Vitousek et al. 1982). It should be noted that Vitousek et al. (1982) used similar incubation techniques, but sampled the 0–15 cm depth while only the A horizon (which varied from 4 to 10 cm depth) was sampled in this study. The rates for the NYBG Forest samples probably would have been even lower if we had sampled to the 15-cm depth, which would have included part of the B horizon.

Since vegetation type, season, sampling methods, and analytical methods were standardized in the comparison of rural and urban hemlock stands, the main variables contributing to variation in these soil processes were location and soil type. The significantly lower rates of N mineralization and nitrification in the urban stand suggests that factors associated with either location, soil type, or their interaction were controlling these processes. Chemical characteristics of the rural hemlock soil were within the range shown in the NYBG Forest soils, except for lower levels of Ca, S, Cu, and Pb and higher levels of Mn and K. The high Pb and Cu content of the urban soils can be attributed to anthropogenic sources (Friedland et al. 1986), which indicates that some of the apparent differences in soil properties may be the direct result of location (urban versus rural) rather than differences in soil types. Thus, location (representing the effect of the urban environment) may be the primary factor resulting in the low N mineralization and nitrification rates in the NYBG Forest.

The combination of low rates of net N mineralization, the degree of similarity in these rates between all samples within the NYBG Forest, and the lack of correlation with major soil characteristics suggests that a single factor (or a combination of factors) associated with the urban environment is controlling these processes. A universal characteristic of all NYBG Forest samples was the hydrophobic phenomenon. According to the water drop penetration time test (Savage et al. 1972), all NYBG Forest samples would be considered nonwettable with penetration times in excess of 120 min, while the Cary samples never retained a drop on the surface for a measurable time (< 1 s). Characterization of the hydrophobic properties and the cause of this phenomenon in the NYBG Forest soils was not the purpose of this study; however, the extreme hydrophobic nature of all forest floor and mineral soil samples from the NYBG Forest suggested that the factors producing this phenomenon may exert control over nitrogen mineralization processes.

Hydrophobic soils have been reported to occur in a variety of natural ecosystems and in agroecosystems (Jamison 1946; Adams et al. 1970; DeBano et al. 1970; DeBano 1971; Richardson & Hale 1978; Reeder & Jurgensen 1979; McGhie & Posner 1981; Giovannini & Lucchesi 1984). The hydrophobic condition results from natural plant products or their associated decomposition products coating soil particles (Savage et al. 1972). Hydrophobic soils are known to occur after natural and prescribed fires when volatilized hydrophobic substances (aliphatic hydrocarbons and long-chained amines) condense on cool soil particles in lower soil horizons (DeBano et al. 1970). The hydrophobic nature of the NYBG Forest soils may be due to natural plant compounds or their breakdown products; however, the lack of hydrophobic soils in the Cary samples and the universal nature of this phenomenon within the NYBG Forest suggests that the organics responsible for this phenomenon may be from other sources.

An alternative explanation is that the hydrophobic substances were generated by anthropogenic sources and contributed to the soils via the atmosphere. Urban atmospheres contain an array of aliphatic and aromatic hydrocarbons (Broddin et al. 1980; Matsumoto & Hanya 1980) including volatile organics, gasoline, soot, grease and oils; components of 'urban grime' (term suggested by White & McDonnell). Matsumoto & Hanya (1980) and Broddin et al. (1980) reported that anthropogenic emissions contain aliphatic hydrocarbons that are continuously distributed between compounds containing 15 carbon atoms (15 C) and 40 C with a maximum around 24 to 26 C. Aliphatic compounds in this range would be hydrophobic and could account for the hydrophobic nature of the urban soils.

The entire NYBG Forest would be exposed to anthropogenic hydrocarbons contained in the urban atmosphere. Deposition of atmospheric hydrocarbons in urban areas has been reported to vary from 186 to 203 $\mu g\,m^{-2}\,day^{-1}$ for total hydrocarbons in Norfolk, Virginia (Wade 1983; Farmer & Wade 1986), and from 23 to 375 $\mu g\,m^{-2}\,day^{-1}$ for dry deposition alone in Tokyo (Matsumoto & Hanya 1980). Based on these rates, urban hydrocarbon deposition could approach 0.2 $g\,m^{-2}$ on an annual basis. These deposition studies measured deposition in and on open collectors, which may underestimate actual atmospheric deposition rates in forest ecosystems (Schlesinger & Reiners 1974; Gosz et al. 1983; Graustein & Armstrong 1983).

We propose that the low, yet similar, rates of net N mineralization between all samples within the NYBG Forest results from the interaction of 3 primary factors. The first factor is associated with the universal hydrophobic nature of the NYBG Forest soils. 'Urban grime' hydrocarbons may be coating surfaces of soil particles throughout the NYBG Forest, which may restrict the surface area available for microbial growth. Hydrophobic hydrocarbons also may have direct toxic effects on soil organisms. Both mechanisms would lower general microbial activity and slow microbial-mediated processes. The high organic matter content of the NYBG Forest soils may be evidence to support the hypothesis of reduced rates of microbial processes.

The second possible factor is the effect of heavy metals. Concentrations of Pb, Ni and Cu in the NYBG Forest soils are some of the highest levels reported in the northeastern United States (Johnson et al. 1982; Friedland et al. 1986). Many, if not all, of these heavy metals can be traced to atmospheric deposition of urban pollutants in New York City (Volchok et al. 1974). Ruhling & Tyler (1973) reported a 40% reduction in microbial activity in soils with the sum of Pb, Ni and Cd between 7 to 20 $\mu M\,g^{-1}$ when compared to soils with 0.1 to 2 $\mu M\,g^{-1}$. The sum of Cu, Pb, Ni, and Zn in the NYBG Forest was between 3.3 to 7.9 $\mu M\ g^{-1}$, slightly below the inhibitory levels reported by Ruhling & Tyler (1973). Also, the urban hemlock A horizons show a similar reduction in rates of nitrification and net N mineralization when compared to the rural hemlock samples. It is possible that the total heavy metal content of the soils in the NYBG Forest may be above a critical threshold level, or other metals that were not measured could be at toxic levels.

The third possible factor is that the NYBG Forest has a high human visitation rate and suffers from the resulting effects of trampling. Among other effects, trampling has been reported to reduce the numbers and diversity of microbes and micro-invertebrates in forest systems (Smeltzer et al. 1986). Soil invertebrates play important roles in regulating rates of soil microbial processes, including N mineralization (Seastead 1984). The numbers and diversity of soil microbes and invertebrates may be further reduced by the heavy metal content of the soil. Earthworms appear to be particularly sensitive to heavy metals (Neuhauser et al. 1985). Although populations were not directly measured, a number of observations indicated lower invertebrate populations in the NYBG Forest samples than in the Cary Forest samples. Earthworms and other large invertebrates would have been removed from the soil during the sieving process to reduce the between-cup variation. However, no earthworms and few other macro-invertebrates were observed during collection or sieving of the NYBG Forest samples while these organisms were observed during collection and sieving of the rural hemlock samples.

Other factors associated with location (particularly ozone) may contribute to or ultimately control nutrient cycling processes in this urban area. Also, these data represent a one-time collection and may not reflect long-term rates in these measurements. The hydrophobic nature of the NYBG Forest soils would act to lower actual field moisture conditions, which would act to further depress in situ nitrogen cycling processes.

To summarize, the rates of N mineralization and nitrification in laboratory potentials were lower in the NYBG Forest than in a comparable rural forest. Rates of these processes did not vary much between samples within the NYBG Forest. The low rates of N mineralization and nitrification in the NYBG Forest may have resulted from the synergistic effects of hydrophobic hydrocarbons and their impact on soil organisms, high levels of heavy metals, and trampling. Studies are currently in progress to determine the importance of each factor in the control of N mineralization and nitrification processes and to determine the cause and persistence of the hydrophobic characteristics of soils in the NYBG Forest.

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