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Short communication

Soil microbial biomass and nitrogen transformations among five tree species of the Catskill Mountains, New York, USA

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Abstract

We measured soil microbial biomass nitrogen (MBN), microbial uptake of ^{15}N , potential net mineralization and net nitrification in the laboratory to determine the influence of tree species on nitrogen (N) transformations in soils of the Catskills Mountains, New York, USA. Organic horizon soils were taken from single species plots of beech (*Fagus grandifolia*), hemlock (*Tsuga canadensis*), red oak (*Quercus rubra*), sugar maple (*Acer saccharum*) and yellow birch (*Betula alleghaniensis*). $^{15}\text{NH}_4\text{Cl}$ was added to the soils and N pools were sampled at 1, 3, 10 and 28 days to examine microbial uptake of ^{15}N over time. Soil MBN was about 60% lower in red oak and sugar maple soils than in the other three species. Soil pools of NO_3^- and rates of net nitrification were significantly greater in soils associated with sugar maple than hemlock, red oak and yellow birch. With the exception of sugar maple soils, microbial recovery of ^{15}N was significantly greater after 10 and 28 days compared to 60 min and 1 day following ^{15}N tracer addition. Microbial ^{15}N recovery declined significantly within sugar maple stands within the first 3 days of incubation. Soil carbon to nitrogen ratio (C:N) was lowest in sugar maple soils and highest in red oak soils. However, correlations between soil C:N and MBN or rates of net mineralization and nitrification were not significant. Soil moisture could account for 22% of the variation in MBN and 36% of the variation in net mineralization. Soil microbial transformations of N vary among tree species stands and may have consequences for forest N retention and loss.

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Microbial biomass (MB) represents a relatively small standing stock of nutrients compared to soil organic matter (SOM) and aboveground biomass of trees, but it can act as a labile source of nutrients for plants, a pathway for incorporation of organic matter into the soil, and a temporary sink for nutrients (Groffman et al., 1993; Seely and Lajtha, 1997; Vitousek and Matson, 1984; Zak et al., 1990a,b; Zogg et al., 2000). Because soil MB can act as a significant source or sink for soil nutrients and potentially influence how much N is retained within SOM, it is important to understand the controls on microbial abundance, turnover, and nutrient sequestration.

Soil MB is related to other factors such as climate (Dyer et al., 1990), soil moisture (Taylor et al., 1999), soil texture (Bauhus et al., 1998; Hassink, 1994; Wardle, 1992), plant productivity (Zak et al., 1990a,b; Zak et al., 1994), soil

cation availability (Diaz-Ravina et al., 1993) and organic matter quality (Taylor et al., 1989; Zak et al., 1990a). Microbial biomass and the rate of leaf litter decomposition can decrease with increasing C:N or lignin:N ratios in organic tissue (Prescott, 1996; Taylor et al., 1989; Zak et al., 1990a). Tree species differ in quality of leaf litter (e.g. C:N), so microbes receive organic matter of varying quality across stands of different tree species (Pastor and Post, 1986). Soil microbes associated with different tree species often have variable amounts of MB (Bauhus et al., 1998) and rates of decomposition of organic matter (Melillo et al., 1982), N mineralization (Vitousek et al., 1982; Zak and Pregitzer, 1990; Zak et al., 1986), and nitrification (Finzi et al., 1998; Lovett and Rueth, 1999; Robertson, 1982; Zak et al., 1986).

The objectives of this research were to examine the effect of tree species on the amount of soil microbial biomass N (MBN) and to determine if MBN is correlated with microbial N-cycling processes. We conducted a laboratory

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Table 1
Organic horizon properties across tree species with standard error ($n = 4$ for each tree species)

Tree species	Moisture	Organic matter	%C	%N	C:N	$\mu\text{g NH}_4\text{-N/g soil}$	$\mu\text{g NO}_3\text{-N/g soil}$	$\mu\text{g DON/g soil}$	$\mu\text{g TDN/g soil}$
Beech	0.47 ± 0.15	0.79 ± 0.07	34.31 ± 7.63	1.88 ± 0.41	18.36 ^{ac} ± 0.91	69.4 ± 15.6	11.0 ^a ± 2.5	67.7 ± 8.4	146.6 ± 18.3
Hemlock	0.33 ± 0.12	0.88 ± 0.03	46.55 ± 1.26	2.33 ± 0.08	20.04 ^{ab} ± 0.40	61.5 ± 11.2	6.3 ^a ± 1.6	54.7 ± 7.5	110.3 ± 7.9
Red Oak	0.18 ± 0.06	0.78 ± 0.05	35.86 ± 3.46	1.74 ± 0.20	20.74 ^b ± 0.69	56.4 ± 11.1	1.3 ^a ± 0.3	59.1 ± 9.4	112.8 ± 14.9
Sugar Maple	0.32 ± 0.09	0.84 ± 0.02	42.71 ± 1.45	2.49 ± 0.09	17.29 ^c ± 1.03	51.2 ± 14.0	53.6 ^b ± 19.1	62.4 ± 27.6	147.7 ± 36.8
Yellow Birch	0.48 ± 0.08	0.86 ± 0.05	43.47 ± 3.77	2.23 ± 0.19	19.54 ^{abc} ± 0.11	81.0 ± 13.4	8.0 ^a ± 2.3	71.2 ± 8.3	156.5 ± 12.5

Moisture was determined by the following calculation: (wet–dry mass)/dry mass. Organic matter was determined by the following calculation: (dry mass – ash free dry mass)/dry mass. NH_4^+ , NO_3^- , dissolved organic N (DON) and total dissolved N (TDN) were averaged across days 0, 1, 3, 10, and 28 for each tree species. Different letters above values represent statistically significant differences at $p < 0.05$.

study with soils collected in August 1997 to examine MBN, potential net mineralization, potential net nitrification, and microbial uptake of added $^{15}\text{NH}_4$ in soils collected from plots of five dominant tree species of the Catskill Mountains in New York (NY). These mountains have inceptisol soils (Murdoch and Stoddard, 1992) are well drained, moderately steep, and have moderate to high acidity (Stoddard and Murdoch, 1991). Vegetation between 500 and 1100 m elevations is dominated by northern hardwood forest species common throughout the northeastern United States, including American beech (*Fagus grandifolia* Ehrh.), eastern hemlock (*Tsuga canadensis* L.), red oak (*Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh.), and yellow birch (*Betula alleghaniensis*; Kudish, 1971). These mountains receive among the highest rates of N deposition (11.2 kg N/ha/yr) in the northeastern United States (Lovett and Rueth, 1999; Ollinger et al., 1993).

We chose two 12 m diameter plots that were dominated by mature individuals of each of the five target species, were of similar age, had no recent disturbance, and were surrounded by mixed species stands. Litter of the target tree species represented 66–92% of the total litter at each plot (unpublished data). Beech, hemlock, sugar maple and yellow birch soils were collected from the upper Rondout watershed and red oak soils were collected from the Kanape Brook watershed (see Lovett et al., 2000 for watershed characteristics). Mineral soil texture did not vary among tree species' plots (Lovett et al., In Review). After brushing aside the litter layer, we collected four samples of the organic horizon (two samples from each plot). Each sample was bulked from four soil cores (6 cm diameter; 12 cm depth maximum). Once in the laboratory, each soil core was sieved (8 mm sieve) to remove larger roots, woody fragments and stones. We dried (65 °C), ground (0.4 mm mesh) and analyzed a sub-sample of each of the four soil core replicates on a Carlo-Erba NA-1500 Autoanalyzer for total C and N with acetanilide as a reference standard. We also determined soil moisture (>48 h at 65 °C) and SOM content (loss on ignition at 450 °C for 4 h).

We had four paired replicates (10 g fresh soil incubated at room temperature) for each of the five tree species for each of the five incubation periods (0 (1 h), 1, 3, 10 or 28 days; total = 200 sub-samples). Prior to the incubation, we added 6 μg 99 atom% enriched ^{15}N (as NH_4Cl dissolved in 1 ml H_2O) to each soil sample to determine microbial ^{15}N uptake. We did not standardize moisture content across soils because there was no significant difference among tree species' stands (Table 1). We considered any variation in dilution of the added $^{15}\text{NH}_4$ among the soil samples to be negligible because the tracer solution was probably in solution for a very small amount of time. At the end of each incubation period, one-half of each paired replicate was extracted with 60 ml 2N KCl, shaken for 1 h and filtered through a Whatman 42 filter. The other half was placed in a desiccator and fumigated with chloroform for 24 h (Vance et al., 1987), extracted, shaken and filtered as above. A 2 ml

sub-sample of each KCl extraction was digested with 4 ml persulfate to determine total dissolved N (TDN; [Cabrera and Beare, 1993](#)). Dissolved organic N (DON) was calculated from the difference between TDN and inorganic nitrogen (NH_4^+ plus NO_3^-). MBN was determined from the N released during fumigation ([Vance et al., 1987](#); no correction factor used). Nitrogen concentrations in soil solutions were determined on an Alpkem Autoanalyzer. The ^{15}N within soil extractions was determined after concentrating ^{15}N with a diffusion technique ([Stark and Hart, 1996](#)) and analyzing on a Europa Integra, a combined sample combustion unit and isotope ratio mass spectrometer.

The amount of ^{15}N in MB at the end of each incubation period was determined by the following equation

$$\text{Mic Bio}^{15}\text{N} = (\text{TDN}_{\text{fum}} \times \text{Atom}\%^{15}\text{N}_{\text{fum}}/100) - (\text{TDN}_{\text{con}} \times \text{Atom}\%^{15}\text{N}_{\text{con}}/100)$$

where Mic Bio ^{15}N is microbial biomass ^{15}N ; Atom% $^{15}\text{N}_{\text{fum}}$ is the atom% ^{15}N of the TDN of fumigated soils; Atom% $^{15}\text{N}_{\text{con}}$ is the atom% ^{15}N of the TDN of the non-fumigated control soils.

Net mineralization was calculated from the difference in NH_4^+ plus NO_3^- concentration between two incubation times (non-fumigated soils), while net nitrification was calculated from the difference in NO_3^- concentration.

We conducted two-way analyses of variance (ANOVA) for MBN, soil NO_3^- and NH_4^+ using SAS JMP software

(Version 3.2.5, 1999) with tree species and incubation length as the main effects. For all other variables, we conducted one-way ANOVAs with tree species as the main effect. We also conducted correlations between soil C, N, C:N, field condition soil moisture and microbial properties and processes to examine potential relationships among factors. We treated the four samples as independent because the variance was often as high among samples taken within a plot as it was among plot means.

Our study indicates that tree species influence MBN and N transformations within our soils but not in a parallel fashion. Soil MBN ranged two-fold, with lower values in stands of red oak and sugar maple than beech and yellow birch ([Fig. 1\(a\)](#); $p < 0.05$). Sugar maple soils consistently had larger soil NO_3^- pools ([Table 1](#)) and greater rates of potential net nitrification ([Fig. 2](#)) than red oak soils despite similarity in MBN. This can have consequences for forest N retention as higher nitrification rates can potentially lead to greater leaching losses and reduced forest N retention ([Templer, 2001b](#)). The lower MBN content of sugar maple stands is surprising given the apparent better quality (low C:N) of their SOM ([Table 1](#)). The high quality, low molecular weight sugars that are released by sugar maple roots ([Smith, 1976](#)) could fuel rapid microbial processing. This could lead to a fast turnover, but a small standing stock of MB ([Fisk and Fahey, 2001](#)).

Recovery of ^{15}N within MB was always less than 7% of the ^{15}N applied ($p < 0.05$; [Fig. 3](#)). The small amount is not

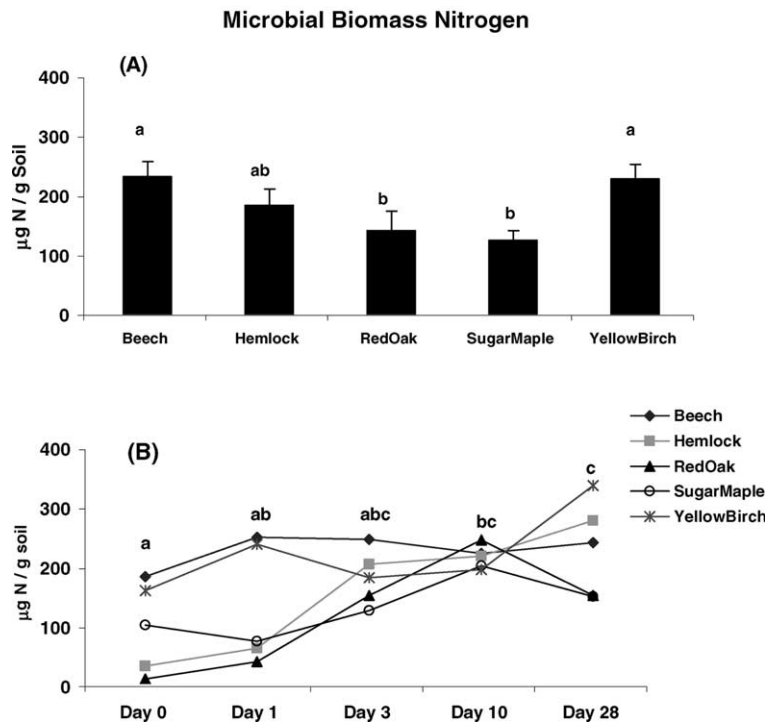


Fig. 1. (A) Microbial biomass N among tree species (error bars represent standard error; $n = 4$ for each tree species; each bar represents the mean of four sample replicates averaged across the following five sampling periods: 0, 1, 3, 10, 28 days). (B) Microbial biomass N over time ($n = 4$ for each tree species at each sampling time). Different letters above bars represent statistically significant differences across time at $p < 0.05$. The least significant difference for all pairwise comparisons among dates range between 30.8 and 45.02.

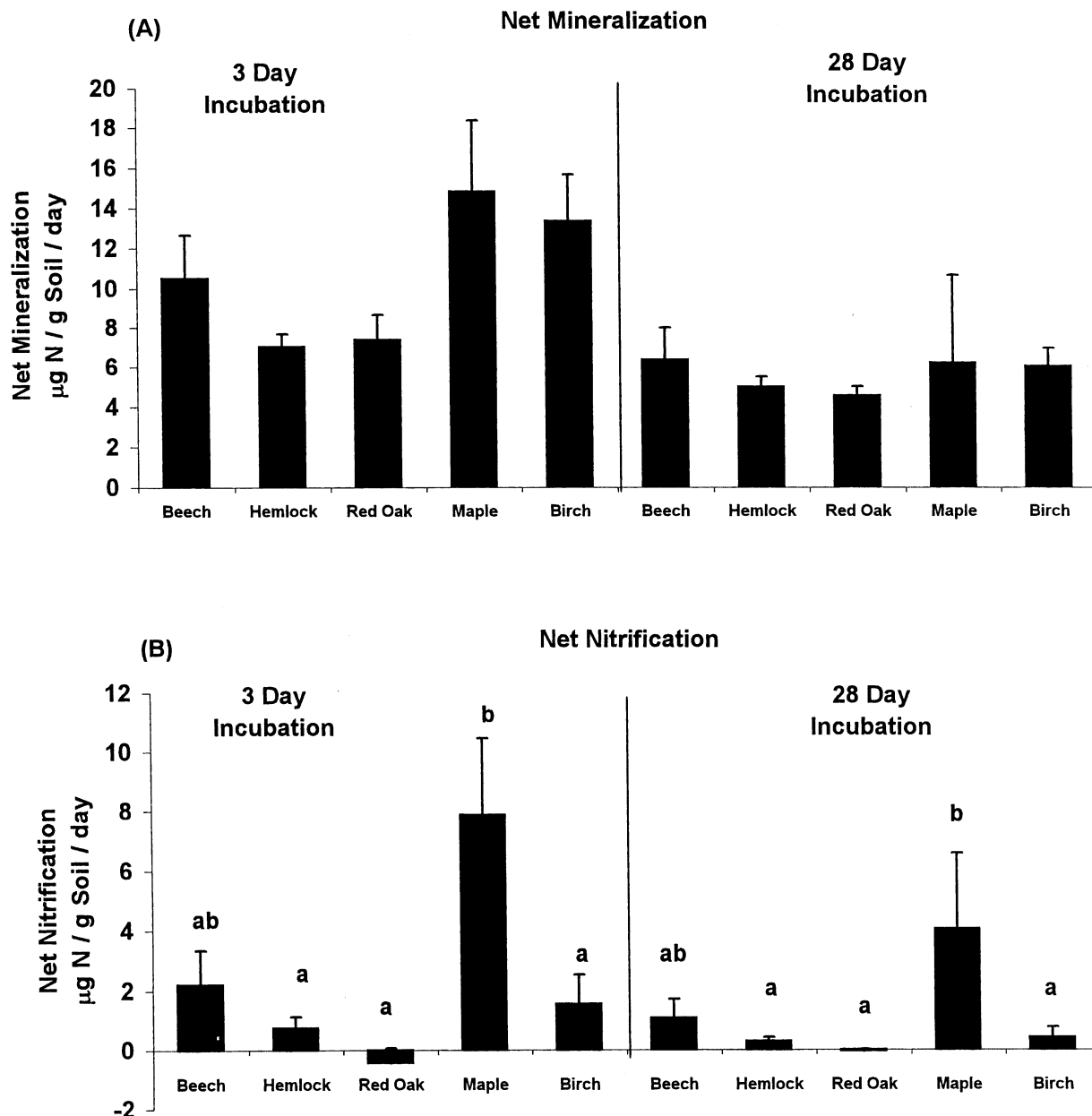


Fig. 2. (A) Potential net mineralization and (B) potential net nitrification measured after 3 and 28 day laboratory incubations (error bars represent standard error; $n = 4$ for each tree species). Different letters above bars represent statistically significant differences at $p < 0.05$.

surprising given that MBN is a significantly smaller pool than the surrounding SOM (Templer, 2001b). Short-term (day 3 minus day 0) % ^{15}N recovery per unit MBN varied among tree species with greater values in soils of red oak (0.023 ± 0.012) and hemlock (0.03 ± 0.007) stands compared to sugar maple stands (-0.024 ± 0.018 ; $p = 0.049$). 28-Day uptake of ^{15}N per unit MBN was similar to the 3-day trend, but the differences among tree species were not significant ($p = 0.5940$). We observed a pattern of short-term ^{15}N (3-day) uptake and release in sugar maple soils, which was similar to a field study of Zogg et al. (2000), suggesting that microbes within sugar maple stands are

significant immediate sinks of added N and may help to retain episodic inputs of N within the forest. However, microbes within sugar maple stands had relatively lower retention after 1 day compared to yellow birch and beech soils, suggesting that tree species composition can influence the magnitude and duration of soil N retention.

Soil moisture could account for 22% of the variation in MBN ($p = 0.039$) and 36% of the variation in net mineralization ($p = 0.006$; Table 2). The C:N ratio of the soil samples varied significantly across tree species, with lowest values in sugar maple soils and the greatest values in red oak soils ($p < 0.05$; Table 1). Despite this variation,

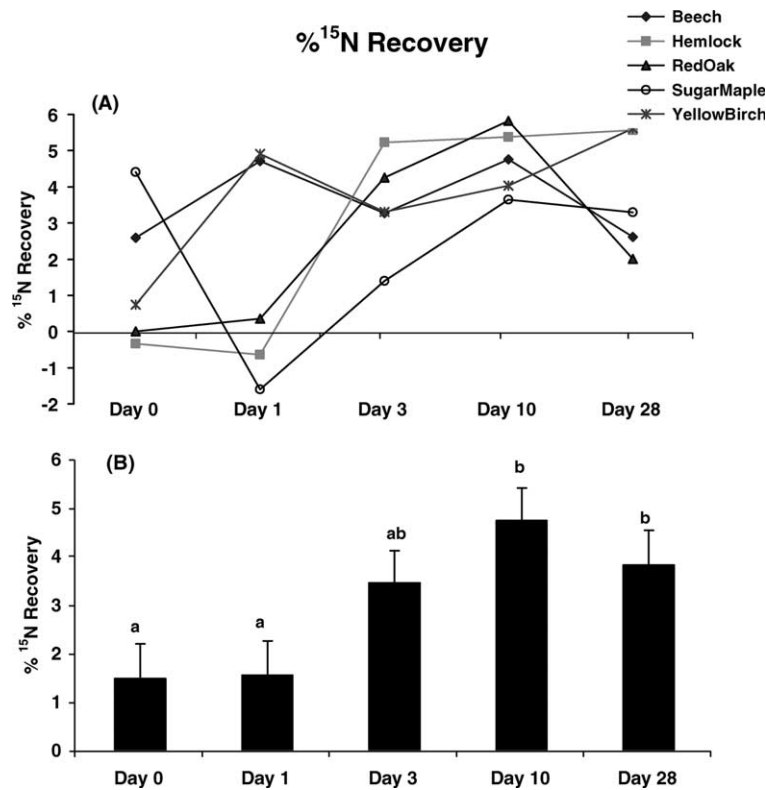


Fig. 3. (A) ¹⁵N recovered within microbial biomass at five sampling times with each tree species shown separately ($n = 4$) and (B) mean and standard error of five tree species at each sampling time ($n = 20$). Day 0 samples were examined 60 min following ¹⁵N addition. Different letters above points or bars represent statistically significant temporal differences at $p < 0.05$. The least significant difference for all pairwise comparisons among dates range between 0.95 and 1.02.

C:N was not correlated with mineralization and nitrification rates or MBN (Table 2). The lack of significant positive relationships between soil C:N and net mineralization and nitrification rates or MBN in this study could be due to the smaller range of organic horizon C and N found in these soils compared to other studies which found positive relationships (Lovett et al., In Review; Zak et al., 1990a, 1994).

Although we did not standardize the moisture content of our samples across tree species' stands prior to our experiment and we sampled red oak plots in a different watershed than the other tree species, our nitrification results are similar to a separate laboratory experiment (Lovett et al., In Review) carried out with soils collected

from a broader set of sites and which standardized soil moisture to 60% field holding capacity. Their study found consistently high rates of net nitrification within all sugar maple plots examined compared to consistently low rates in red oak plots, regardless of the watershed from which they were sampled (Lovett et al., In Review). The similarity in N cycling rates found between our study and Lovett et al. (In Review) suggests that our results are not due to differences in soil moisture alone, nor watershed location, but at least partly due to the relationship between tree species and soil MBN and activity.

The variation among tree species stands in N transformations and 3-day vs 28-day dynamics of microbial ¹⁵N uptake has implications for forest N retention. Microbial

Table 2
Coefficients of determination (r^2) and p -values in parentheses for correlations between organic horizon characteristics and microbial biomass N and activity ($n = 20$ for each analysis)

	Soil %C	Soil %N	Soil C:N	Soil moisture
Microbial biomass N	0.09 (0.1970)	0.07 (0.2603)	0.003 (0.8145)	0.22 (0.0390)
Net mineralization measured at 28 days	0.04 (0.4213)	0.03 (0.4503)	0.003 (0.8202)	0.36 (0.0056)
Net nitrification measured at 28 days	0.007 (0.7271)	0.06 (0.3184)	0.03 (0.1034)	0.09 (0.2038)

uptake of N within sugar maple soils immediately following N addition may be especially important during short periods of high N release such as snowmelt or disturbances to the soil. This could lead to sporadic periods of N retention followed by longer periods of N loss caused by fast rates of net nitrification and lack of significant microbial or plant uptake of NO_3^- (Templer, 2001a). If soil microbes associated with beech, hemlock, red oak and yellow birch stands behave similarly over longer periods of time as they did in this 28-day experiment, they may be more important for chronic, long-term additions of N (e.g. N deposition) because of their slower turnover and greater long-term retention of ^{15}N . The results of this study suggest that while MBN and N transformations can vary widely among tree species, the patterns we observed cannot be explained by differences in organic matter C:N or soil moisture alone. Similarly, differences among tree species in MBN do not appear to explain the variation in N transformations such as potential net mineralization and nitrification. It is important to understand the mechanisms that control soil MBN and N transformations because of potential increases in N availability in the future.

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