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NUTRIENTS IN FOREST LITTER TREATED WITH NAPHTHALENE AND SIMULATED THROUGHFALL: A FIELD MICROCOSM STUDY

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Summary—The effects of naphthalene (arthropod exclusion) and simulated throughfall (N, P, K, Ca and Mg) additions on the decomposition and mineralization of dogwood (*Cornus florida* L.) litter were studied by using a field microcosm approach in a southeastern United States deciduous forest. Treatments without microarthropods decayed more slowly than litter with microarthropods. Simulated throughfall additions alone had no effect on litter decay rates. Fauna, simulated throughfall, and fauna plus simulated throughfall treatments increased the nutrient concentrations of decomposing litter; the treatment with both microarthropods and simulated throughfall generally exhibited the highest nutrient concentrations. Simulated throughfall also significantly increased microarthropod densities in litter. Litter immobilization of elements in throughfall was insignificant in litter with microarthropods; naphthalene-treated litter immobilized up to 8% of the elements contained in simulated throughfall.

INTRODUCTION

Mineralization of elements in decaying organic matter represents a large, available source of nutrients for plants (e.g. Clarke 1977; Jorgensen *et al.*, 1980). Bulk precipitation and canopy leachates (throughfall) represent other sources of nutrients for plant uptake. The actual availability of these nutrients to plant roots and mycorrhizae is determined by mineralization and immobilization processes of forest floor biota. We have hypothesized (Seastedt and Crossley, 1980), that microarthropod interactions with microflora enhance the nutrient retention capacity of forest floor litter. Hanlon and Anderson (1979, 1980) demonstrated that certain densities of arthropods stimulate microbial respiration. We therefore speculated that litter with both microflora and microarthropods would be capable of temporarily immobilizing greater quantities of nutrients from bulk precipitation and throughfall inputs than with litter with microflora alone. In support of this hypothesis we reported absolute increases in amounts of Ca, Mg and K in older litter containing microarthropods, but did not find this response in older litter without microarthropods (Seastedt and Crossley, 1980). The amounts of elemental inputs to the litter were not measured; hence, quantitative effects of microarthropods on the flux of elements through litter could not be estimated from measurements of the standing crops of elements in litter.

We have used a field microcosm approach to control nutrient inputs to litter. Litter with and without microarthropods was treated with distilled water or distilled water plus nutrients (Ca, K, Mg, P and N). Thus, the hypothesis that microarthropods speed nutrient loss from litter but enhance the retention of throughfall and bulk precipitation elements by litter microflora could be tested in a quantitative manner.

STUDY SITE AND METHODS

The study was made at Coweeta Hydrologic Laboratory, in the southern Appalachians of North Carolina. Coweeta has been the site of nutrient cycling studies since 1968, and extensive data were available on litter decomposition rates, mineralization rates and nutrient content of bulk precipitation and throughfall (Johnson and Swank, 1973; Cromack and Monk, 1975; Swank and Henderson, 1976).

Our study site was located in a small (*ca* 50 m^2) portion of an oak–hickory forest (Watershed 2), a watershed previously used for other litter decomposition studies (Seastedt and Crossley, 1980; Whitford *et al.*, 1981; Seastedt *et al.*, 1983).

Four, 2.3 m^2 box-like shelters were constructed to prevent rainfall and throughfall from reaching the forest floor. The sides of the boxes were covered with window screen which allowed gas exchange but prevented lateral movement of macroparticulates into or out of the plots. Metal troughs were installed on the uphill side of the plots to prevent surface or litter percolates from entering the shelters. The systems were therefore largely closed to nutrient inputs; only microparticulates, forest floor invertebrates and colonization by fungal hyphae could potentially add nutrients to the system. Coweeta has low densities of annelids (Crossley and Seastedt, unpublished results); hence mixing of litter and soil by annelid activities is not common. No small mammal activity was observed on the plots.

Dogwood (*Cornus florida* L.) is a common successional and understory tree species at Coweeta (Day

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and Monk, 1974; Boring *et al.*, 1981). Senescent dogwood leaves were gathered from trees on 20 October 1979. These were placed in preweighed, 10 × 10 cm nylon bags (1 mm mesh), air-dried for 10 days, and weighed. Sixty bags containing an average of 3 g leaves were placed in each of the shelters on 3 November 1979. An additional 10 bags of litter were dried at 60°C, reweighed to measure the ratio of air-dried to oven-dried weight, and then ground and analyzed for Ca, K, Mg, P and N to measure initial nutrient concentrations. Plasma emission spectroscopy was used to measure cation and P concentrations while the micro-Kjeldahl method was used to measure N content of litter.

Each plot was watered weekly with 19 l of distilled water. This volume, delivered to the bags centered within 1 m^2 of the shelters, was equivalent to about 100 cm yr^{-1} precipitation. Average rainfall at Coweeta is higher (170 cm yr^{-1}), but much less regular. Two of the four plots were treated once a month with 100 g naphthalene to repel arthropods. Naphthalene is known to stimulate microbial respiration (Witkamp and Crossley, 1966). Microflora may use the chemical as an energy source and immobilize additional nutrients from throughfall or litter to supplement metabolic requirements during naphthalene breakdown. Hence, the use of this chemical could obscure faunal effects on immobilization processes. However, the chemical is volatile, insoluble in water, and generally preferred over insecticides that would add nutrients to the litter. Arthropod exclusion was obtained by applying most of the naphthalene crystals around the litter bags; direct contact did occur but was not excessive.

Nutrient solutions were added to one naphthalene-treated and one untreated plot. $CaCl_2$, KCl, $MgCl_2$, KH_2PO_4 and later in the study, KNO_3 were mixed with deionized water to produce a solution of 1 g Ca or K l^{-1}, 0.5 g Mg l^{-1} and 50 mg P l^{-1}. The pH of the solution was 4.8, well within the range of pH of rainfall at Coweeta. Nitrogen was not added to the system until June 1980. The delay was, in part, to add some seasonality to the input regime, but also to observe the effects of N additions on the concentrations of other elements in litter. In June 1 g N l^{-1} was added to the solution, and the K concentration was increased to 3 g l^{-1} at that time. Five ml of the solution was dispensed per month on each litter bags in the two plots. Thus, 5 mg Ca, 2.5 mg Mg and 0.25 mg P were added once a month to each bag. Potassium was initially added at the rate of 5 mg $month^{-1}$, then increased to 15 mg $month^{-1}$ for the last 5 months of the study. Nitrogen was added at the rate of 5 mg $month^{-1}$ for the last 5 months of the study. A total of 60 mg Ca, 110 mg K, 30 mg Mg, 3 mg P and 25 mg N was added to the litter bags that remained in the field for 1 yr. Bulk precipitation and throughfall are much more dilute in terms of elemental concentrations than the solution applied here. However, on an annual basis throughfall inputs to 100 cm^2 of forest litter (i.e. the area of the litter bags) are estimated at 80 mg Ca, 300 mg K, 30 mg inorganic P and 35 mg inorganic N (Best and Monk, 1975; Swank and Henderson, 1976). Our knowledge of organic N and P inputs to litter remains fragmentary; hence, no organic inputs were used in our study.

Four litter bags were harvested from each plot every month. An additional 11 bags were harvested on the last collection date to obtain a precise estimate of weight loss after 364 days in the field. Microarthropods were extracted from the litter bags by refrigerated Tullgren funnels, counted and identified into broad taxonomic categories following the procedure of Seastedt and Crossley (1981). Only total numbers g^{-1} litter are reported. Litter was then dried, weighed and analyzed for nutrients.

RESULTS

Decomposition rates

Plots receiving naphthalene had lower decomposition rates (Table 1). An analysis of variance indicated that, after all other sources of variation were removed (i.e. Type IV SS), nutrient additions did not influence mass loss ($F_{1,158} = 0.08$, $P > 0.05$). In contrast, the presence or absence of naphthalene had a highly significant effect on the amount of litter mass ($F_{1,158} = 74.00$, $P < 0.001$). The average percentage of initial mass for the treatments over the 12 collection dates is shown in Fig. 1. While some unexplainable "noise" exists in results (attributable, perhaps, to the small sample size on all but the last collection date), naphthalene-treated litter retained more mass on all but one collection date. The addition of nutrients, including the addition of N beginning in June, 215 days into the study, showed no consistent effect on either the pattern of decomposition or the amount of mass remaining at a particular time of sampling.

The climatic regime within the shelters probably affected these results. Decomposition rates reported here are somewhat lower than previously reported. Cromack and Monk (1975) reported a decay constant (k-value) of −1.35 for dogwood litter, while in an earlier study (Seastedt and Crossley, 1980) we reported a decay constant of −0.64. Rates reported

Table 1. Decomposition rates and percentage of initial mass of litter remaining after 1 yr

Treatment	Annual decomposition rate (k)*	r ($N = 48$)	% of initial mass after 1 yr: Calculated	% of initial mass after 1 yr: Observed ($N = 15$)
H_2O	−0.60	0.91	54.9%	55.5%
H_2O + nutrients	−0.64	0.90	52.7%	52.9%
H_2O + naphthalene	−0.40	0.76	64.0%	65.4%
H_2O + naphthalene + nutrients	−0.41	0.84	64.4%	62.2%

*Calculated from the formula Log_e (collected mass/initial mass) = kt (Olson, 1963).

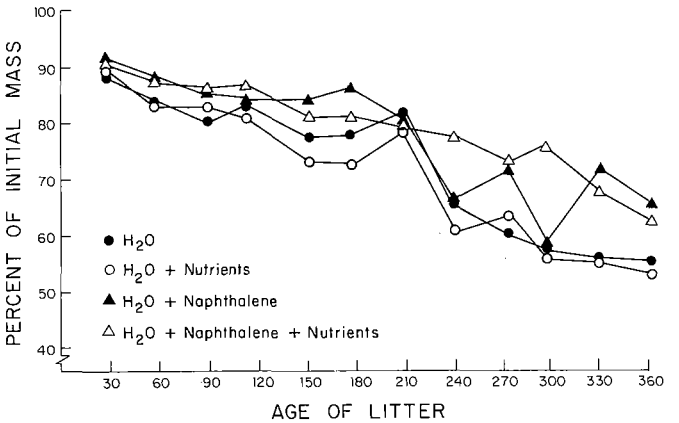

Fig. 1. Retention of mass by dogwood litter. The study was initiated on 3 November 1979, and the age of the litter refers to days since the litter was placed on the forest floor.

here (Table 1) may be attributed to a dry environment within the shelters. Potential evapotranspiration from this litter was calculated from ambient temperature data and known amounts of water inputs. Moisture deficits (potential evapotranspiration > actual evapotranspiration) would have occurred in May through August during our study. Moisture deficits in open litter are usually less frequent (Seastedt *et al.*, 1983). However, naphthalene effects on litter decomposition rates appear within the range of values previously reported (e.g. Witkamp and Crossley, 1966).

Microarthropods in litter

Densities and species composition of microarthropods in litter have been extensively documented at Coweeta (Abbott *et al.*, 1980; Seastedt and Crossley, 1980, 1981; Seastedt *et al.*, 1983). While all samples were extracted for microarthropods, counts were made only once every three months to compare results with earlier studies (Table 2). Naphthalene-treated litter contained few microarthropods, averaging less than 5% of those observed in the distilled water treatment. Seasonal trends in plots not treated with naphthalene exhibited a pattern previously observed. Moderate numbers of microarthropods initially colonize the fresh litter, followed by equal or lower counts in spring, followed by increases in populations in summer and autumn.

Numbers of microarthropods in summer and autumn in the plot receiving simulated throughfall were twice those observed in the distilled water plot. These densities were also greater than those observed in earlier studies. These higher populations did not enhance the decomposition rate of this litter (Fig. 1). Thus, while arthropod exclusion may reduce decomposition rates, an increase of microarthropod numbers does not increase the decomposition rate of dogwood litter.

Nutrient concentrations

An analysis of variance indicated that nutrient concentrations of litter were affected by naphthalene and simulated throughfall (Table 3). The treatment receiving water + nutrients consistently exhibited the highest nutrient concentrations and was significantly greater than the nutrient + naphthalene treatment for the elements Ca, Mg and N. The water treatment was similar to the water + naphthalene + nutrient treatment for all elements except Mg. Except for K, the water treatment exhibited higher elemental concentrations than the water + naphthalene treatment.

Nutrient concentration data were pooled into quarter-year estimates to remove some of the

Table 2. Densities of microarthropods in dogwood litter

	Individuals g^{-1} litter (95% confidence limits of geometric means)			
Treatment	89 days	175 days	276 days	364 days
H_2O	10.2 (5.9–62.5)	4.3 (1.4–14.6)	18.7 (7.2–48.3)	73.3 (44.0–122.0)
H_2O + nutrients	27.4 (21.1–35.5)	3.5 (1.3–9.4)	65.6 (57.5–74.7)	180.4 (146.0–223.0)
H_2O + naphthalene	0.3 (0.0–0.6)	0.1 (0.0–0.8)	2.6 (0.5–6.6)	0.9 (0.0–4.9)
H_2O + naphthalene + nutrients	0.2 (0.0–0.6)	0.0 (0.0–0.8)	1.9 (0.5–6.6)	1.0 (0.3–4.5)
Dogwood 1975–1976*	15.5 (9.3–26.0)	7.5 (4.3–12.9)	47.5 (23.7–95.3)	60.4 (37.6–97.1)
Dogwood 1977–1978*	10.8 (11.0–60.8)	36.7 (21.8–61.8)	36.8 (19.0–71.4)	25.2 (11.0–57.9)

*Results from Seastedt and Waide (unpublished results).

Table 3. Effects of simulated throughfall and naphthalene on the nutrient concentrations of dogwood litter

Element	Treatment*	Mean concentration† (mg g^{-1})	ANOVA F-value (Type IV SS) Age df = 11	Treatment df = 3	Age × treatment df = 33
P	Pooled	1.01	5.63¶	9.00¶	0.91
	1	1.00^{B}			
	2	1.08^{A}			
	3	0.93^{C}			
	4	1.03^{AB}			
K	Pooled	6.84	9.48¶	3.92‡	1.40
	1	6.43^{B}			
	2	7.50^{A}			
	3	6.55^{B}			
	4	6.90^{AB}			
MG	Pooled	3.20	11.21¶	25.02¶	2.35¶
	1	3.07^{C}			
	2	3.67^{A}			
	3	2.83^{D}			
	4	3.26^{B}			
Ca	Pooled	27.02	14.88¶	8.99¶	1.74‡
	1	27.12^{B}			
	2	28.65^{A}			
	3	25.53^{C}			
	4	26.84^{B}			
N	Pooled	14.56	6.66¶	5.89¶	0.34
	1	14.72^{AB}			
	2	15.58^{A}			
	3	13.50^{C}			
	4	14.45^{BC}			

*Pooled = all treatments, $N = 192$. Trt 1 = distilled water, Trt 2 = water + nutrients, Trt 3 = water + naphthalene, Trt 4 = water + naphthalene + nutrients.
†Means followed by different letters are significantly different (Duncan's multiple range test, $P < 0.05$).
‡$P < 0.05$; §$P < 0.01$; ¶$P < 0.001$.

monthly variation within treatments and to observe seasonal trends (Fig. 2). Mass loss was also treated in this manner for comparison. Each point in Fig. 2 represents an average for 12 samples collected during a three-month periods corresponding to winter (December–February), spring (March–May), summer (June–August) and autumn (September–November). Significant interactions between treat-

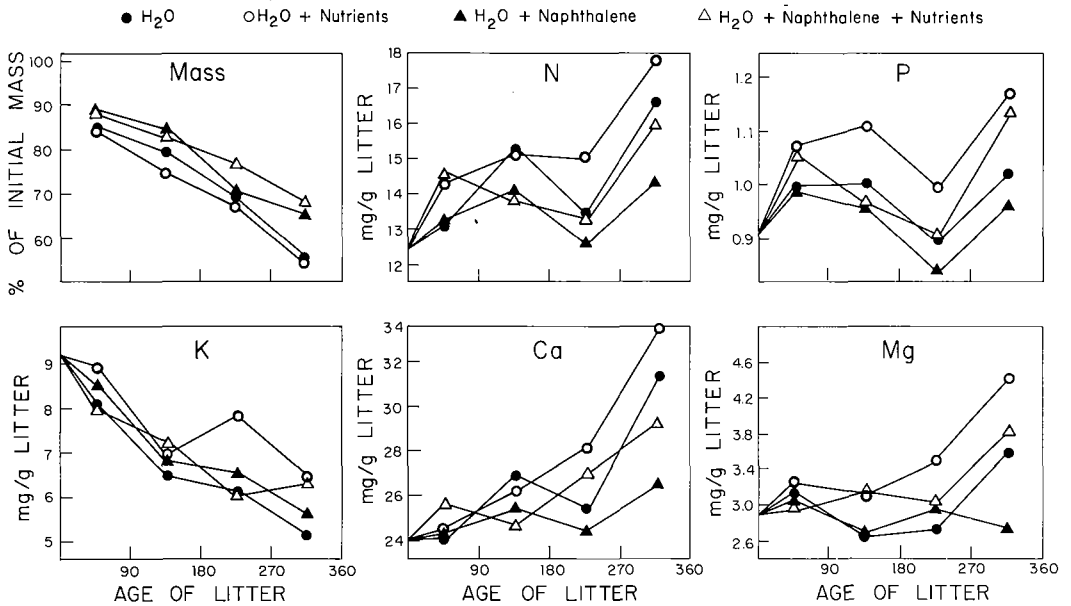

Fig. 2. Concentrations of nutrients in dogwood litter under four different treatment regimes. Values represent quarterly averages (winter–autumn). Retention of mass based on quarterly averages is shown for comparison.

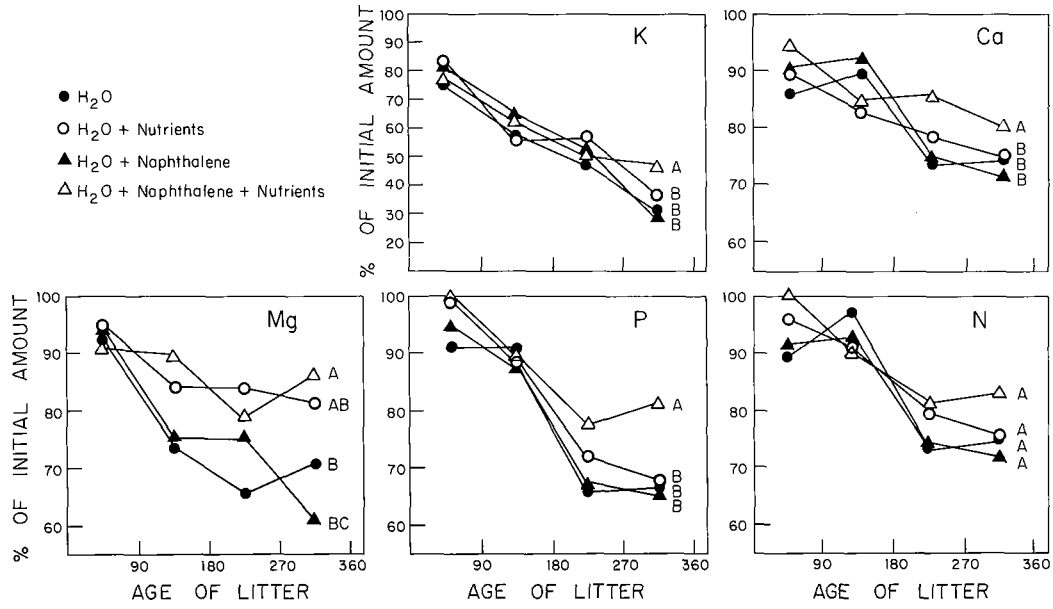

Fig. 3. Retention of nutrients by dogwood litter under four different treatment regimes. Values are products of % of mass remaining times nutrient concentration (Figs 1 and 2), and are expressed as % of initial amounts in litter. Symbols followed by different letters indicate that values for 10–12-month old litter are statistically different (Duncan's multiple range test, $P < 0.05$).

ment and date occurred for Ca and Mg (Table 3); changes in nutrient concentrations of these elements were not parallel for all treatments. Each element exhibited a different pattern; however, seasonal trends for N and P were similar, as were the patterns for Ca and Mg. Potassium, the only element to decrease significantly in concentration, exhibited a pattern similar to mass loss. No effects of the delayed N additions or the increased K additions are evident in these patterns. With the exception of Mg in the naphthalene plot, those plots receiving distilled water showed responses which paralleled those of plots receiving nutrients. Had N additions stimulated microbial immobilization or mineralization of other elements, we would not have expected parallel behaviors between fertilized and unfertilized plots.

Nutrient flux

Net mineralization of litter was calculated by multiplying nutrient concentrations by the percentage of initial mass remaining. Seasonal averages were then calculated as in Fig. 2. In the absence of simulated throughfall, naphthalene had no effect on the amount of elements remaining in 10–12 month-old litter (Fig. 3). Increased nutrient concentrations in litter without naphthalene compensated for enhanced mass loss of this litter. With the addition of simulated throughfall, litter with naphthalene exhibited consistently higher mean amounts of elements in 10–12 month litter, and significant differences between the two plots receiving throughfall were observed for K, Ca and P.

The amount of elements in simulated throughfall that were retained in litter after 1 yr in the field was estimated by subtracting amounts of elements remaining in plots receiving only distilled water from estimates of amounts of elements in plots receiving throughfall. This analysis assumed that elemental inputs from fungal hyphae were equal in all treatments, and that N fixation by litter microbes was also equal in all plots. Since the amount of mass differed between naphthalene-treated and untreated plots, comparisons are limited to treatments with equal amounts of mass remaining. The analysis of variance illustrated in Fig. 3 indicated that final amounts of elements were not different between the two plots not receiving naphthalene. Thus, the small amount of throughfall immobilized by the plot receiving nutrients (Table 4) is not statistically significant. Naphthalene-treated litter immobilized statistically significant amounts of all elements except N. The relative amounts of elements immobilized was small, never exceeding 10% of amounts added in simulated throughfall.

DISCUSSION

We have commented on the limitations of litter bag experiments and on the potential problems with the synonymous use of the terms "naphthalene-treated" and "arthropod-excluded" (Seastedt and Crossley, 1980). St John (1980) had added to these warnings regarding the limitations of litter bag studies. We maintain that comparisons among litter bag treatments are valid, but caution must be used in extrapolating results to unconfined and untreated litter.

Microarthropods often stimulate immobilization of elements contained in litter bags or in soil microcosms (Seastedt and Crossley, 1980; Bååth *et al.*, 1981; Douce and Crossley, 1982), but often concurrently stimulate mass loss (e.g. Witkamp and Crossley, 1966; Douce and Crossley, 1982). Both effects were seen in our study. The flux of elements from litter is determined by these opposing effects. In our study the naphthalene plot lost less mass and had lower nutrient concentrations than the distilled water plot. Thus, while both elemental concentrations and

Table 4. Estimates of simulated throughfall immobilized by 1-yr old dogwood litter

Treatment	Measurement	Nutrient (mg) Ca	K	Mg	P	N
All treatments	Initial amount*	72.0	27.6	8.7	2.7	37.2
Water	Final amount	52.5	8.5	6.0	1.8	27.8
Water + nutrients	Final amount	54.2	10.0	7.1	1.9	28.4
	Difference (water + nutrients) minus (water)	1.7	1.5	1.1	0.1	0.6
	% throughfall immobilized†	2.9%	1.4%	3.7%	3.3%	2.4%
Water + naphthalene	Final amount	52.3	9.0	5.4	1.9	27.9
Water + naphthalene + nutrients	Final amount	55.3	11.9	7.2	2.1	29.9
	Difference (water + naphthalene + nutrients) minus (water + naphthalene)	3.0	2.9	1.8	0.2	2.0
	% throughfall immobilized†	5.0%	2.6%	6.0%	6.8%	8.0%

*Average amount of element in the initial mass (3 g) of dogwood leaves in each litter bag.
†% of throughfall immobilized on litter is estimated as the additional amount retained by those treatments receiving simulated throughfall, divided by the total amount of element added in throughfall to each bag.

amounts of mass differed between plots not receiving simulated throughfall, the annual flux of elements from the litter in these two plots was equal. We therefore rejected our hypothesis that microarthropods enhance the release of elements initially contained in litter. The plot receiving water and simulated throughfall exhibited the highest nutrient concentrations, but mass loss from this plot was sufficiently greater than the naphthalene + nutrients plot to result in greater elemental outputs. Thus, we rejected our second hypothesis that microarthropods enhance retention of elements in throughfall by the litter–microflora system.

Litter with microarthropods did not immobilize a significant amount of simulated throughfall while naphthalene-treated litter immobilized less than 10% of throughfall inputs. These findings imply that elements in bulk precipitation and throughfall are rapidly transferred to lower litter and soil horizons. Other studies (e.g. Gosz *et al.*, 1973; Seastedt and Crossley, 1980) have shown increases in the absolute amounts of elements in 10–12-month old litter, indicating that immobilization of elements from sources outside of those initially contained in litter may be substantial. These differences among studies are not believed to be methodological artifacts, but suggest that nutrient flux varies depending upon litter substrate composition, microfloral and microfaunal characteristics, and microclimate (e.g. Witkamp and Frank, 1970). Thus, while microarthropods consistently increase the concentrations of most elements in litter up to 1 yr in age, the nutrient flux from this litter cannot be predicted without knowledge of other properties of the forest floor milieu.

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