LITTER DECOMPOSITION IN LOW AND HIGH MORTALITY NORTHERN RED OAK STANDS ON EXTREMELY ACIDIC SOUTHWESTERN PENNSYLVANIA SOILS

Michael C. Demchik and William E. Sharpe[1]

Abstract—Previous research has shown that decomposition of organic matter is slower in soils with high levels of soil acidity and available aluminum (Al). The objective of this experiment was to determine if differences in decomposition rates of northern red oak leaves occurred between extremely acidic and less acidic sites that also differed in oak mortality. Leaf litter from red oaks on high and low acidity soils was reciprocally transplanted into both high and low acidity sites. After one growing season, neither site of decomposition or leaf origin had a significant effect on the rate of decomposition. Litter that decomposed in low acidity stands tended to lose more calcium (Ca) and sodium (Na) and gain more phosphorus (P) than litter that decomposed in high acidity stands. Litter with origins in the low mortality stands tended to lose more potassium (K) and gain more P and zinc (Zn) than litter with origins in the high mortality stands. The stand with the highest oak mortality did not have the highest rate of decomposition indicating that soil acidity (low Ca/Al ratio) may have operated to reduce decomposition at that site.

INTRODUCTION

In southwestern Pennsylvania, mortality of northern red oak has occurred that is related to low levels of available Ca and high levels of available Al (Demchik 1998). In a review of the literature, Cronan and Grigal (1995) suggested that at molar ratios of Ca/Al of 1 or less a 50 percent chance of growth reduction of forest trees exists. Ca/Al ratios of less than 1 were found for all B-horizons in high mortality stands. Soil conditions such as these reportedly reduce litter decomposition rates (Tamm 1976, Wolters 1991). Reduced decomposition rates slow nutrient cycling.

On sites that have experienced a large thinning (as experienced with increased rates of mortality), decomposition rates may increase. Increased exposure of forest soil to sunlight can increase rates of nutrient cycling from litter (Zhang 1995). For this reason, if all other factors were equal, the rates of decomposition on a site that has undergone substantial mortality would be expected to increase. However, low Ca/Al ratios (soil acidity) may serve to reduce decomposition rates, thus potentially canceling out such increases.

Litter quality is also important to the rate of decomposition. Lamb (1976) found Monterey pine (*Pinus radiata*) decomposition rates to be most influenced by soil nutrients at the site of litter origin. The difference in soil nutrients at the site of origin was potentially an index of litter quality. Foliar samples taken from the canopy of high mortality stands on the Laurel Hill were found to be lower in Ca and K than foliar samples from low mortality stands (Demchik 1998). Soils in these high mortality stands had lower Ca/Al ratios (Demchik 1998).

In additional to physical breakdown, minerals released from the litter are an important component of decomposition. In general, leaf matter contains the highest ash content of litter fall and is approximately 70 percent of total litter fall (Bray and Gorham 1964). Laskowski and others (1995) reported that litter turnover of Ca, magnesium (Mg) and manganese (Mn) was governed by biological processes, litter turnover of K and Na was controlled by physical processes (leaching) and litter turnover of Zn was controlled by both fixing to humic materials and leaching. In general, base nutrients in organic matter decrease with time (O'Connell 1988) while iron (Fe), Zn, copper (Cu) (Laskowski and others 1995) and Al (McBrayer and Cromack 1980) may increase with time. Bases decrease with decomposition and leaching but proposed causes for increases in the absolute quantity of metals have not been firmly defined. Laskowski and others (1995) suggested a natural process but they proposed no mechanisms to explain how it occurred.

Because base nutrient availability on acidic soils is governed in large part by organic matter decomposition, changes in rates of decomposition could drastically alter nutrient cycling. Assessing the effect of both litter origin and site of decomposition on changes in nutrient release from litter is useful in assessing the impact of soil acidification on forests.

The objectives of this study were to determine if differences occurred between high and low mortality oak stands for decomposition rates, element concentrations and absolute level of elements in northern red oak leaves between high and low mortality oak stands on the Laurel Hill.

METHODS

The Site

Three blocks of land on the Forbes State Forest (Hickory Flats, Linn Run and Jones Mill) were selected that contained stands with high mortality (40 to 60 percent standing dead oak timber) and low mortality (0 to 10 percent standing dead oak timber) of northern red oak in the Laurel Hill region of southwestern Pennsylvania. The overstory trees were 85-90 years old. The geology of the area is dominated by parent material from the Pottsville, Mauch Chunk and

[1] Agroforestry Management Extension Educator, University of Minnesota, Central Lakes Agricultural Center, Staples, MN 56479; and Professor of Forest Hydrology, Environmental Resources Research Institute and School of Forest Resources, The Pennsylvania State University, University Park, PA, 16802, respectively.

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Table 1—$SrCl_2$ extractable Ca/Al ratios and soil pH from low mortality and high mortality plots of northern red oak on Hickory Flats, Linn Run, and Jones Mill[a]

	Hickory Flats		Linn Run		Jones Mills	
Parameter	Low	High	Low	High	Low	High
			0.01M $SrCl_2$ extractable Ca/Al ratios and soil pH[b]			
O-horizon	37.9 ± 7.6	9.1 ± 1.2	12.6 ± 4.1	7.9 ± 1.2	6.4 ± 0.8	27.8 ± 7.9
	3.74 ± 0.04	3.77 ± 0.04	3.99 ± 0.02	3.95 ± 0.04	4.4 ± 0.03	4.0 ± 0.04
A-horizon	2.3 ± 0.4[c]	1.2 ± 0.6[c]	2.2 ± 1.0[c]	1.1 ± 0.4[c]	1.6 ± 0.5	1.2 ± 0.3
	3.65 ± 0.04	3.60 ± 0.02	4.01 ± 0.04	3.65 ± 0.03	4.26 ± 0.03	4.09 ± 0.04
B-horizon	1.3 ± 0.5[d]	0.7 ± 0.4[d]	1.2 ± 0.4[c]	0.40 ± 0.3[c]	1.1 ± 0.2[c]	0.66 ± 0.3[c]
	3.78 ± 0.04[c]	3.68 ± 0.03[c]	4.12 ± 0.03[c]	3.82 ± 0.02[c]	4.26 ± 0.02[d]	4.2 ± 0.03[d]

[a] n = 8-20 for each cell.
[b] Data presented as means±SE.
[c] Denotes significant difference between low and high mortality stands of decomposition within each block at 5 percent.
[d] Denotes significant difference between low and high mortality stands of origin within each block at 10 percent.

Burgoon formations. The soils were Typic Dystrochrepts of the Hazelton very stony sandy loam, Calvin very stony silt loam, and Dekalb very stony loam series, Aquic Fragiudults of the Ernest very stony silt loam series and Typic Hapludults of the Gilpin very stony silt loam series. All soils were extremely acidic (table 1). Soils on the high mortality stands had Ca/Al ratios in the A and B horizon that would indicate high probability of expression of aluminum toxicity in plants. Ca/Al ratios in the A and B horizon of low mortality stands were higher and would have a low probability of expression of aluminum toxicity (table 1; Data summarized from Demchik 1998). High mortality stands for Hickory Flats and Linn Run had lower overall leaf mass production compared to the low mortality stands. No difference in leaf mass production was found between high and low mortality stands in the Jones Mill block (Demchik 1998). For a more complete description see Demchik (1998).

Litter Collection

Approximately 500 grams of northern red oak leaf litter was collected in April 1996 from all six stands. The leaf litter was oven-dried at 90 °C until a consistent mass was reached and then two weeks more in order to limit resident microflora. Thus a total of 6 bulk samples, one from each stand was available for use.

In order to assess decomposition, litter bags were used. Bags made of 0.2 mm nylon mesh with dimensions of 20X10 cm were filled with 3 grams of the dried northern red oak leaves. The mesh bags were closed with standard size carbon steel staples. Twenty litter bags were filled with litter from each stand. A total of 120 bags were prepared (20 samples for each of six litter sources).

A reciprocal transplant within blocks was the design used for placing the litter bags in the field (fig. 1). Within each stand, 10 litter bags with litter of "origin" in that stand and 10 litter bags with litter of "origin" in the other stand in that

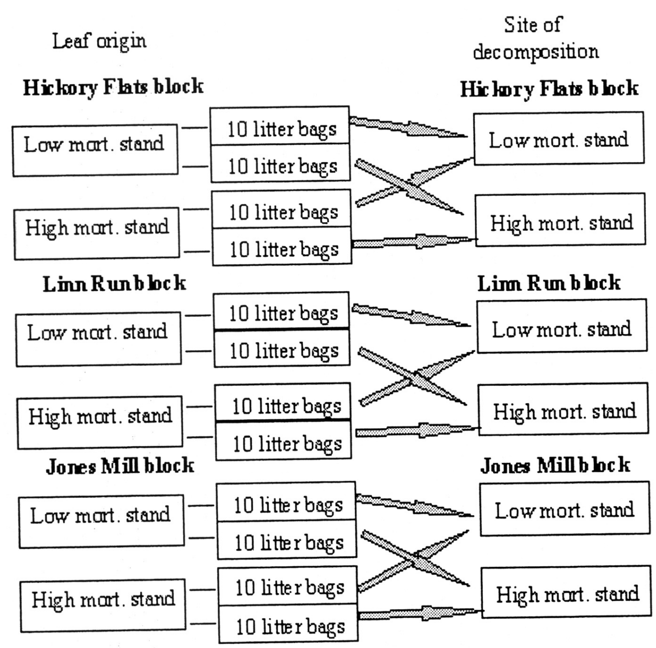

Figure 1—The reciprocal transplant design for decomposition of northern red oak leaf litter from low and high mortality stands (leaf origin) that was allowed to decompose on low and high mortality stands.

block were buried. The litter bags were buried between the organic layer and the A-horizon under 5 cm of leaf litter in early May 1996. The litter bags were collected in mid-October after 167 days in the field. The leaves were removed from the bags and washed with deionized water over a 0.01 mm sieve to remove clinging soil mineral fraction and root material that had grown into the bag. All visible leaf material was salvaged. The washed leaves were oven dried at 90 °C until a consistent mass was reached. Results were analyzed using nested ANOVA with blocks.

Mineral content analysis was conducted on randomly selected samples using Inductively Coupled Plasma Emission Spectroscopy at the Pennsylvania State University Agricultural Analytical Services Laboratory following procedures of Dahlquist and Knoll (1978). Three randomly chosen replicates of each of the 12 possible combinations of litter by origin and site of decomposition were selected for a total of 36 samples. Three replicates of fresh 1995 oak litter from each of the 6 stands were also analyzed to determine mineral content prior to decomposition. Data were analyzed using ANOVA. In addition to physical decomposition and concentration of minerals in the sample before and after decomposition, changes in total quantity of a mineral in the sample were determined. Due to high variance in sample nutrient levels both prior to decomposition and after decomposition, mean total quantity of a nutrient prior to decomposition was determined by summing the estimates for each litter origin. This gave a single estimate of total quantity of the nutrient in a sample bag for each litter origin (i.e. low and high mortality stands for each block). Variance was determined for each pooled estimate from differences between samples. Total nutrient level was determined after decomposition by essentially the same procedure. This resulted in 12 estimates of total nutrient level (i.e. leaf litter from low and high mortality origin that decomposed in low and high mortality sites of decomposition in each block). Percent of absolute gain or loss was determined by the formula:

$$\text{percent change} = \frac{(C_a M_a) - (C_b M_b)100}{(C_b M_b)} \tag{1}$$

where

C_a= concentration of nutrient after decomposition

M_a= mass of sample after decomposition

C_b= concentration of nutrient before decomposition

M_b= mass of sample before decomposition

Results were compared using computed standard errors.

RESULTS

Decomposition Rate

Significant decomposition occurred on all blocks. However, the only block where a difference in rate of decomposition was found between high and low mortality stands (site of decomposition) was the Hickory Flats block (table 2). The low mortality stand lost less mass (30 percent ± 3 percent) than the high mortality stand (47 percent ± 3 percent; $P < 0.01$).

The only block where litter origin had an effect on rate of decomposition was also the Hickory Flats block (table 3). The litter that came from the low mortality stand lost less mass (35 percent ± 3 percent) than the litter that came from the high mortality stand (42 percent ± 3 percent; $P < 0.05$).

A significant litter origin by site of decomposition interaction was found ($P < 0.009$). Litter from the low mortality stands of all blocks decomposed more slowly when in the low mortality stands than when in the high mortality stands (table 4) and rates of physical decomposition were not related to soil Ca/Al ratio.

Chemical Changes

Effect of site of decomposition—After decomposition, litter originating from the low mortality stands tended to have greater concentrations of P, Mn and lower concentrations of Mg and Ca than litter originating from the high mortality stands (table 2).

Table 2—Percent of physical decomposition[a] (n = 20 per cell) and concentration of minerals[a] (n = 6 for each cell) in remaining sample of northern red oak leaf litter that decomposed in low mortality and high mortality stands (site of decomposition) of northern red oak in block established on Hickory Flats, Linn Run, and Jones Mill

	Hickory Flats		Linn Run		Jones Mills	
Parameter	Low	High	Low	High	Low	High
Decomp.(%)	30 ± 3[b]	47 ± 3[b]	43 ± 1	43 ± 2	23 ± 3	26 ± 5
Mass lost(g)	0.9 ± 0.09[b]	1.41 ± 0.09[b]	1.29 ± 0.03	1.29 ± 0.06	0.69 ± 0.09	0.78 ± 0.15
Ca(%)	0.56 ± 0.05[b]	0.75 ± 0.05[b]	0.58 ± 0.06[b]	0.93 ± 0.05[b]	0.67 ± 0.04[b]	0.74 ± 0.04[b]
Mg(%)	0.021 ± 0.001[b]	0.024 ± 0.001[b]	0.037 ± 0.001	0.038 ± 0.001	0.031 ± 0.001[b]	0.035 ± 0.001[b]
K(%)	0.071 ± 0.012	0.085 ± 0.008	0.094 ± 0.006	0.10 ± 0.011	0.129 ± 0.016	0.095 ± 0.011
P(%)	0.058 ± 0.01[b]	0.054 ± 0.003[b]	0.065 ± 0.006[b]	0.061 ± 0.001[b]	0.073 ± 0.005[b]	0.059 ± 0.005[b]
Mn(ug/g)	882 ± 46[b]	820 ± 50[b]	922 ± 34[b]	624 ± 65[b]	583 ± 30	647 ± 78
Fe(ug/g)	419 ± 87	312 ± 62	313 ± 58	349 ± 48	228 ± 67	248 ± 87
Cu(ug/g)	10.0 ± 2.6	9.8 ± 0.4	8.5 ± 0.75	8.4 ± 0.63	8.6 ± 0.75	8.2 ± 0.75
B(ug/g)	14.9 ± 2.1	16.8 ± 1.0	18.4 ± 2.7	17.7 ± 3.3	16.8 ± 2.3	17.8 ± 1.9
Al(ug/g)	998 ± 293	1014 ± 200	437 ± 31	356 ± 20	322 ± 36	321 ± 88
Na(ug/g)	82 ± 7.4	92 ± 6.5	38 ± 24	33 ± 11	54 ± 11	55 ± 10
Zn(ug/g)	115 ± 40	127 ± 20	155 ± 21	154 ± 18	157 ± 12	224 ± 10

[a] Data presented as means ± SE.

[b] Denotes significant difference between low and high mortality stands of decomposition within each block at 5 percent.

Table 3—Percent of physical decomposition[a] (n = 20 per cell) and concentration of minerals[a] (n = 6 for each cell) in remaining sample of northern red oak leaf litter that originated in low mortality and high mortality stands (litter origin) of northern red oak in blocks established on Hickory Flats, Linn Run, and Jones Mill

	Hickory Flats		Linn Run		Jones Mills	
Parameter	Low	High	Low	High	Low	High
Decomp.(%)	35 ± 3[b]	42 ± 3[b]	41 ± 2	43 ± 4	23 ± 3	24 ± 3
Mass lost(g)	1.05 ± 0.09[b]	1.26 ± 0.09[b]	1.23 ± 0.06	1.29 ± 0.12	0.75 ± 0.09	0.72 ± 0.09
Ca(%)	0.67 ± 0.06	0.65 ± 0.06	0.66 ± 0.08[b]	0.84 ± 0.06[b]	0.75 ± 0.07[b]	0.66 ± 0.08[b]
Mg(%)	0.021 ± 0.001[b]	0.024 ± 0.001[b]	0.034 ± 0.002[b]	0.040 ± 0.003[b]	0.032 ± 0.004	0.034 ± 0.004
K(%)	0.084 ± 0.01[b]	0.072 ± 0.006[b]	0.112 ± 0.008[b]	0.083 ± 0.006[b]	0.138 ± 0.005[b]	0.086 ± 0.004[b]
P(%)	0.056 ± 0.01	0.056 ± 0.008	0.074 ± 0.006[b]	0.052 ± 0.01[b]	0.071 ± 0.005[b]	0.061 ± 0.005[b]
Mn(ug/g)	918 ± 116[b]	784 ± 84[b]	915 ± 185[b]	631 ± 128[b]	625 ± 105	605 ± 87
Fe(ug/g)	239 ± 61[b]	491 ± 57[b]	379 ± 41[b]	282 ± 27[b]	280 ± 111[b]	196 ± 45[b]
Cu(ug/g)	10.0 ± 1.2	8.8 ± 1.0	8.8 ± 0.5[b]	8.2 ± 0.4[b]	8.8 ± 0.2[b]	8.0 ± 0.3[b]
B(ug/g)	15.0 ± 1.0[c]	13.8 ± 0.8[c]	16.3 ± 0.8[b]	19.7 ± 0.8[b]	15.3 ± 0.9[b]	19.3 ± 1.0[b]
Al(ug/g)	510 ± 293[b]	1,501 ± 636[b]	422 ± 31[b]	371 ± 20[b]	377 ± 36[b]	265 ± 88[b]
Na(ug/g)	97 ± 7	62 ± 65	37 ± 25	34 ± 11	57 ± 17	52 ± 6
Zn(ug/g)	123 ± 46	119 ± 7	205 ± 65[b]	104 ± 30[b]	195 ± 25	186 ± 77

[a] Data presented as means ± SE.
[b] Denotes significant difference between low and high mortality stands of decomposition within each block at 5 percent.
[c] Denotes significant difference between low and high mortality stands of origin within each block at 10 percent.

Table 4—Percent decomposition and mass loss of leaf litter from low mortality and high mortality stands (origin) that decomposed in low and high mortality stands (site of decomposition) of northern red oak in blocks established on Hickory Flats, Linn Run, and Jones Mill

Leaf origin[a b]	Hickory Flats		Linn Run		Jones Mills	
Site of decomposition	Low	High	Low	High	Low	High
Low mortality	21 ± 3%	38 ± 3%	33 ± 2%	53 ± 2%	18 ± 3%	24 ± 3%
	0.63 ± 0.09g	1.14 ± 0.09g	0.99 ± 0.06g	1.59 ± 0.06g	0.54 ± 0.09g	0.72 ± 0.09g
High mortality	43 ± 4%	62 ± 4%	45 ± 1%	43 ± 4%	23 ± 4%	20 ± 5%
	1.29 ± 0.12g	1.86 ± 0.12g	1.35 ± 0.03g	1.29 ± 0.12g	0.69 ± 0.12g	0.60 ± 0.15g

[a] n = 10 for each cell.
[b] Data presented as means ± SE.

Litter that decomposed in the low mortality stands tended to lose more Ca and Na and gain less Zn than litter that decomposed in the high mortality stands (fig. 2). Litter that decomposed in the low mortality stands tended to gain P while litter that decomposed in the high mortality stands lost P (fig. 2).

Prior to decomposition, litter from the low mortality stands had significantly greater concentrations of Ca than litter from the high mortality stands. This difference was significant for the Hickory Flats and Linn Run blocks ($P < 0.01$). Boron was greater for the low mortality stand on Jones Mill than the high mortality stand ($P < 0.01$).

After decomposition, no effect of litter origin was found in concentration of Ca (except in Hickory Flats block); however, since the litter from the low mortality stands started the experiment with greater concentrations of Ca, the portion that was lost was calculated. A tendency to lose more Ca from the litter from the healthy sites was found ($P < 0.07$). After decomposition, the litter from the low mortality stands had greater concentrations of K, P, Mn, Zn and Cu than the litter from the high mortality stands (table 3). In absolute terms, litter with origin in the low mortality stands lost more K than litter with origin in the high mortality stands (fig. 3). Litter with origin in the low mortality stands gained more Zn and less Al than litter from the high mortality stands (fig. 3). Litter from the low mortality stands tended to gain Na and P while litter from the high mortality stands tended to lose both elements (fig. 3). Across all samples, total amounts of B, Mn, K, Mg and Ca after decomposition were lower and Al and Zn were higher (figs. 2 and 3).

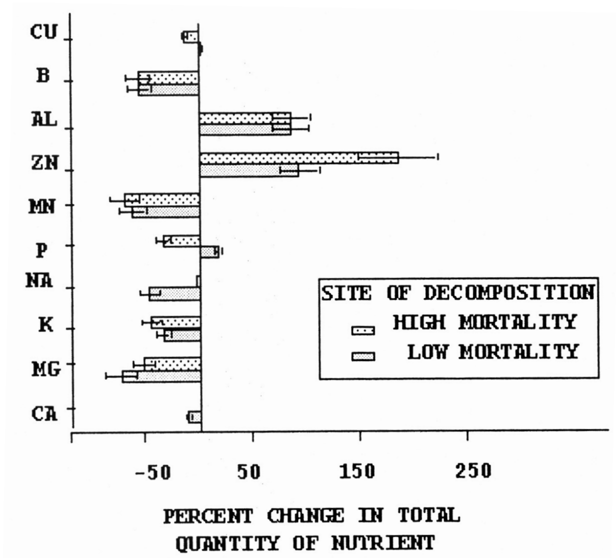

Figure 2—The change in total mineral content of northern red oak leaf litter after decomposition for 167 days during the growing season of 1996 for the leaf litter allowed to decompose in low and high mortality stands (n=6 bags per bar).

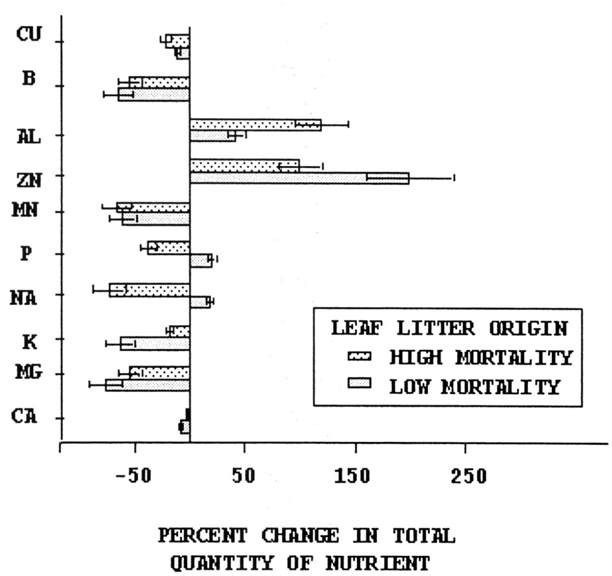

Figure 3—The change in total mineral content of northern red oak leaf litter after decomposition for 167 days during the growing season of 1996 for the leaf litter from low and high mortality stands (n=6 bags per bar).

DISCUSSION

The high mortality stands selected for this study had a considerable amount of standing dead timber and lower Ca/Al ratios in the A and B-horizons (Demchik 1998). These two factors could have quite opposite effects on decomposition. Increases in canopy gap size can increase decomposition (Zhang 1995), but sites with low Ca/Al ratios may have reduced rates of decomposition (Tamm 1976, Wolters 1991). Of the blocks, only Hickory Flats showed significantly higher decomposition rates in the high mortality stand. The more open canopy may have resulted in greater decomposition rates. This indicates that the difference in soil chemistry between the sites, specifically the low Ca/Al ratios in the soils of the high mortality site, did not reduce the decomposition rates.

The overall lack of significant difference in rates of decomposition between high and low mortality sites may be related to the position of the litter bags in the soil column. The litter bags were buried at the interface of the O-layer and A-horizon. The O-layer was not different in Ca/Al ratio between stands (Demchik 1998). Even with differences in Ca/Al ratio observed in the A-horizon, the actual effect of the Ca/Al ratio may have been limited by bag placement.

While only limited differences occurred in rates of decomposition, the litter that decomposed in the low mortality stands lost more Ca and Na and gained more P than litter that decomposed in the high mortality stands. Transport of Ca is controlled primarily by biological action (Laskowski and others 1995). More favorable soil conditions on the low mortality sites and greater site occupation by trees and other vegetation may have resulted in greater Ca uptake and processing by soil organisms. Ca that was not taken up by vegetation may be more susceptible to leaching. The gain of P is documented to occur in the early stages of decomposition for Scots pine (*Pinus silvestris*) (Berg and Staaf 1980). Leaf litter from the low mortality stands lost more K and gained more P and Zn than leaf litter from the high mortality stands. Potassium loss is primarily controlled by leaching (Laskowski and others 1995). More K was leached from the litter from the low mortality stands probably because the amount tended to be a function of the amount present. The greater accumulation of Zn and P in the litter originating in the low mortality stands is probably caused by either strictly chemical transport or by fixation with humic compounds (Laskowski and others 1995) that are produced in the earlier stages of decomposition (Edwards and others 1970). More research is required to elucidate the reason for these differences.

While much variation was evident, some general observations can be made about the nutrient transport observed. Of the soil bases, total level of Ca seemed to be the most stable. Magnesium, K and Na had much higher rates of loss. Laskowski and others (1995) found K and Mg to be more mobile than Ca; however, Na was found to be less mobile than all other soil bases (although this varied with litter origin). Locally, the mobility of Na was of less importance than the other soil bases. For most forests of the east, Na is only a major soil cation near the coast or adjacent to roadways, where NaCl is used to de-ice surfaces.

While Mn and B leached from the sample at rates roughly similar to rates of decomposition, Zn and Al increased in absolute mass. Laskowski and others (1995) found increases in total level of Zn in litter and McBrayer and Cromack (1980) found increases in Al. While Laskowski and others (1995) suggested this as a natural process, they offered no explanatory mechanism. Possible explanations may include fecal deposition of soil mineral fraction by soil invertebrates, adhesion of soil particles by leaching foliar polysaccharides and root exudates. Additionally, since plant available Al was problematic on these soils (Demchik 1998), possible formation of complexes of Al with P could explain these increases.

SUMMARY AND CONCLUSIONS

Collectively, more Ca and Na were lost from samples decomposing on sites with low mortality of northern red oak, even though the overall rates of physical decomposition were similar. Potentially, Ca was being actively transported from this litter by plants and processed by soil biota. Ca remaining in litter may be more likely to leach with subsequent inputs of hydrogen ions.

Origin of litter affected the loss and gain of nutrients. Litter originating in the low mortality stands tended to lose more K and gain more P and Zn than litter originating in the high mortality stands. This litter had higher concentrations of these minerals to begin with; consequently, more could be expected to be lost as a consequence of mobile anion driven leaching. The greater accumulation of Zn and P in the litter originating in the low mortality stands was probably caused by either chemical transport or by fixation with humic compounds and Al. More research is required to elucidate the reasons for these differences.

In general, of the soil bases, total level of calcium seemed to be the most stable. Magnesium, K and Na had much higher rates of loss. Manganese and B leached from the samples at rates roughly similar to rates of decomposition. Zinc and Al increased in absolute mass.

Overall, while several potentially important differences were seen in the quantity of nutrients remaining after decomposition, no important differences in decomposition were found. The more acidic soils of the high mortality stands may have balanced the increased decomposition rates expected in these more open stands.

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