ORGANIC MATTER AND NUTRIENT CONTENT OF THE FOREST FLOOR OF OAK-HICKORY FORESTS IN SOUTHWESTERN ILLINOIS[1]

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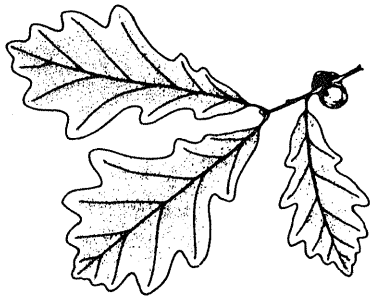

ABSTRACT.--The distribution patterns of forest floor detritus and nutrients were studied to determine their relationship to site (aspect and slope position) and forest structure in southwestern Illinois oak-hickory forests. In these forests the forest floor (32.8-38.7 mt/ha) was equivalent to 16 to 19% of the total aboveground tree biomass. It also accounted for a significant amount of the aboveground nutrient pools of Ca (26-32%), Mg (55-61%), K (21-24%), Mn (27-29%), Cu (17-27%), and Zn (35%). The wood component in the forest floor accounted for substantial amounts of the total nutrients found there with 36-58% Ca, 31-38% Cu, 42-47% K, 29-35% Mg, 15% Mn, 19-37% P, and 36-40% Zn. Slight structural differences (species composition, basal area, and density) observed within these oak-hickory forests reflected differences in forest floor Mn concentrations. Differences in species composition more accurately reflected forest floor nutrient concentrations than did differences in total species basal areas.

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INTRODUCTION

The forest floor composed of organic detritus is an important component of forest ecosystems. The magnitude and chemical contents of this compartment often represent a significant proportion of the total organic matter and nutrients in temperate forests (Rodin and Basilevich 1967) and may affect plant regeneration, hydrologic processes, nutrient cycling and forest productivity (Westman 1975 and Youngberg 1966). Forest floor characteristics may be dependent on climate, soil fertility, successional stage, and species composition (Ovington 1968, Lang and Forman 1978). Many studies have shown (summarized by Lang and Forman 1978) that forest floor detritus, nutrient standing crops and distribution patterns vary with major changes in species composition among forest communities. However, the importance of slight intracommunity changes in species composition which may result in differences within the forest floor nutrient concentrations and detritus have not been examined.

In this study the detritus and nutrient contents of the forest floor in late successional and mature forests of oaks, hickories and other hardwoods were measured in a region of southwestern Illinois. This region

of Illinois is characterized by complex topography and loessial soils. Also, the relationships of species composition and local physiography to forest floor detritus nutrient contentrations and nutrient standing crops were examined. This is the first in a series of studies designed to illustrate the functional attributes of these forests for which only phytosociological information has been available (Miller and Fuller 1921, Telford 1926, Sanders 1953, Ashby and Kelting 1963, Voight and Mohlenbrock 1964).

Study Areas

The study was conducted in two watersheds in southwestern Illinois (Fig. 1). One site was in the Trail of Tears State Forest, Union County (UC) and the other in the Shawnee National Forest, Alexander County (AC). These areas are approximately 80 ha each in size, have not been glaciated, and the topography is exceedingly dissected with maximum relief of about 60 meters.

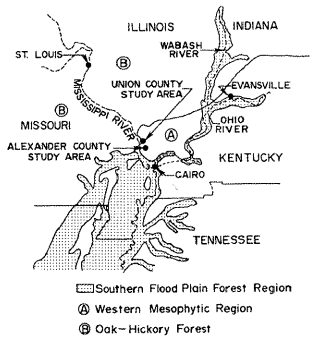

FIGURE 1.--Location of the Alexander County and Union County study areas in relation to the three major forest types which occur in southern Illinois and principal geographic features adapted from Braun (1950) and Kuchler (1964).

The climate of these areas is warm temperate with the average annual temperature of 14.9 degrees C and average precipitation of 108 cm, based on data from Cairo, Illinois, about 40 km south of Alexander County study area. The average frost free period is over 200 days (NOAA 1975).

The region is part of the Salem Plateaus Section of the Ozark Plateaus Province (Leighton et al. 1948). Both study areas are underlain by Clear Creek chert of Devonian age at least 90 m thick. Clear Creek chert is somewhat calcareous, with alternating chert and limestone layers 7.6 to 20.0 cm thick. Toward the south silification and subsequent weathering become more pronounced leaving a well bedded siliceous clay forming between the chert layers (Savage 1920, Weller and Ekblaw 1940).

The soils of these areas were developed primarily from Peorian loess greater than 6 m thick. The Peorian loess when deposited was calcareous and well supplied with all plant nutrients except nitrogen (Fehrenbacher et al. 1967). In both study areas, major soils are Typic Hapludalfs (7th Approximation) occurring on the upper part of steep slopes and Typic Dystrochrepts occurring on lower slopes. Typic Udifluvents are found along overflow channels where the surface layer is a cherty silt loam (Parks and Fehrenbacher 1968). The basic difference between the two study areas is that the soils of the AC area are loamy skeletal and older, whereas the soils in the UC area are clayey skeletal and younger, thus having a higher base saturation (Miles, personal communication, 1976).

The potential natural vegetation of these areas has been classified by Kuchler (1965) as Broadleaf, Oak-Hickory. Braun (1950) included this region in the Western Mesophytic Forest Region of the Eastern Deciduous Forest Formation. Miller and Fuller (1921) classified the vegetation in the AC area then as Upland Oaks, which they stratified into three communities; upland oaks, beech-maple, and bottom forests. The upland oaks found on hilltops and exposed slopes were dominated by Quercus velutina Lam., Q. alba L., with Q. muhlenbergii engelm, and Q. rubra L. as co-dominates. Other associated species included Sassafras albidum Nuttl, Carya ovata Mill, and Diospyros virginiana L. Communities found on sheltered slopes and narrow valleys were dominated by Fagus grandifolia Ehrh. and Acer saccharum Marsh., with Liriodendron tulipifera L. and Q. rubra as co-dominates. The understory consisted of Cercis canadensis L., Asimina triloba L., and Ostrya virginiana Mill. In the larger stream terraces, Juglans nigra L., Ulmus americana L., U. fulva Michx. (= U. rubra Muhl.), Plantanus occidentalis L., Nyssa sylvatica Marsh., Liquidambar styraciflua L., and Fraxinus americana L. predominate.

The AC area has been heavily cut, starting with the removal of L. tulipifera from 1880 to 1890 followed by removal of Q. alba and other oaks, then finally the removal of F. grandifolia for railroad ties (Miller and Fuller 1921). The remaining stands were referred to as a "culled forest" in 1920 in which small Q. alba, Q. velutina, and Carya glabra Mill. occurring in many areas and pioneer species such as sumacs, S. albidum, and D. virginiana dominated the remaining areas (Miller and Fuller 1921). Miller and Fuller observed in 1920 that species composition was being changed from an upland oak and beech-maple forest to a black oak-hickory forest type due to logging activities, grazing and brush fires. Results of a 1975 study (Rosson 1981) indicate that dominant vegetation in the AC area now is black oak-hickory forest-type with very little F. grandifolia and A. saccharum in the overstory.

In the UC area, Sander (1953) recognized five distinct forest communities. Ulmus americana L., characterized the floodplain.

Fagus grandifolia, Acer nigrum Michx. (probably Acer saccharum Marsh.) and Liriodendron tulipifera L. dominate on north and lower south slopes. Quercus velutina and Quercus alba forests occupy upper and middle south slopes. The most common community in the watershed occupies remaining mid-slopes and ridges and is dominated by Q. velutina, Q. alba, C. glabra and Co ovata (Mill.) K. Koch., with F. grandifolia, Magnolia acuminata L., and L. tulipifera as associates.

Generally the stands are well stocked, appear to be uneven-age (Rosson 1981), relatively free from recent anthropogenic disturbance, and in late secondary succession (50-60 years old). The basal area (BA) of the forest on the AC study area in 1975 ranged from 6.4 - 39.4 m^2/ha with a mean of 21.9 m^2/ha. The density (>2.6 cm. dhb) ranged from 400-1780 stems/ha with a mean of 748 stems/ha. In the UC forest the BA ranged from 11.7 - 41.6 m^2/ha with a mean of 24.0 m^2/ha. The density ranged from 419-1335 st/ha with a mean of 857 stems/ha (Rosson 1981).

METHODS

Plot Location

A topopgraphic map of each study area was enlarged so that a grid with lines spaced 7.5 mm apart would correspond to a ground distance of 23 m. At each line intersection the point was classified by physiographic features. The following 14 site-types were used: ridge (N,S,E,W), slope (N,S,E,W), lead (N,S,E,W), bottom and cove. Approximately 2,000 points were classified within each study area, and four plots in each site-type were randomly selected for a total of 56 plots per study area. Each point represented the center of a circular plot, 0.04 ha in area. The plots were located on the ground by measuring from base points which could be recognized in each study area.

When sampling the forest floor many studies (Bourn and Brown, 1971, McFee and Stone 1965, Grier and McColl 1971 and Wooldridge 1968) have indicated that the spatial distribution of forest floor detritus is highly variable and that the sampling intensities required to achieve a given level of sampling error and precision may vary among forest types. A previous study by Luvall and Weaver (1978) established sampling intensites that were required to sample 0_1 and 0_2 horizons in these forest types to attain levels of precision. On the basis of their findings, six 0.25 m^2 samples per plot were required to provide estimates of the nutrient and detritus characteristics (0_1 horizon) of these areas $\pm$ 30% of mean with a probability of 80%.

In November and December 1975 and January 1976, the 0_1 and 0_2 horizons were collected from six randomly selected 0.25 m^2 quadrats using the following criteria to identify the detritus: 0_1 consisting of all dead organic material the source of which could still be recognized, including parts of branches $\leq$ 2.5 cm diameter; 0_1 consisting of small woody (SW) material > 2.5 cm diameter, < 10 cm dia. was collected from each 0.04 ha plot in the fall of 1974 from a randomly selected rectangular plot 1 m wide x 11.6 m in length. Large woody (LW) material $\geq$ 10 cm diameter was inventoried in all plots by measuring the length and diameter of each end of each log included within the plot. The material was divided into three decay classes by visual observation: Class I - wood with the bark still attached, Class II - wood without bark and less than 50% decayed, and Class III - wood greater than 50% decayed.

For the determination of mass and nutrient concentration discs were collected from the three classes of logs from ten randomly selected plots in each study area, for a total of 30 samples per study area. Specific gravity was determined for each disc by volume of H_2O displaced (USDA, SCS 1967).

Volume was calculated by using the equation for the volume of the frustum of a cone (Selby 1965). Mass of woody material was determined as the product of volume and specific gravity. The mass of Class III wood was multiplied by 0.5 because the diameter measured in the field was based on a complete cylinder and by definition Class III wood had < 50% of the original diameter remaining.

The 0_2 horizon consisted of all dead organic material of which the source could not be recognized. Also included in the 0_2 were fungal hyphae, micro-organisms, and fine roots which could not be separated. Difficulty was encountered in separating the 0_2 from the lower 0_1 because the 0_2 tended to adhere to leaves; consequently, some 0_2 was included with the 0_1. A more serious problem was encountered in separating the 0_2 from the mineral A_1 horizon. This was corrected by removal of as much as possible of the mineral soil in the laboratory.

Laboratory Methods

All samples were oven-dried at 70°C to constant weight. The 0_1 horizon samples from each plot were homogenized by mixing all six samples in a large plastic bag and taking a random grab sample of about 200 g in preparation for nutrient analyses. Because there was so little 0_2 material, the total from all six samples per plot was used for mineral analysis. All samples were ground to pass a 2 mm mesh seive in a Wiley Mill equipped with stainless steel knives to minimize contamination (Grier 1966).

Samples were prepared for nutrient analyses by using a nitric perchloric acid digestion procedure with sodium chromate added as a catalyst and as a safety indicator (Smith 1953).

The samples were stored at 3°C in polyethylene bottles until all analyses were completed. Total elemental analyses were performed for Ca, Cu, K, Mg, Mn, and Zn with a Perkin-Elmer Model 360 atomic absorption spectrophotometer. Chemical interferences caused by the presence of aluminum, phosphate, and sulfate in the determintion of Ca and Mg were corrected through the use of nitrous oxide - acetylene flame with the addition of 2% lanthanum to the samples (Perkin-Elmer 1973). Total phosphorus was determined colorimetrically as ($PO_4^{\equiv}$) by using the vanadomolybdophosphoric-yellow method as described by Jackson (1958).

Statistical Methods

The subprogram Oneway (Nie et al. 1975) was used for one-way analysis of variance. A significant level of 0.05 was used for all tests. When significant differences were found, Tukey's HSD test (α = 0.05) was used for group mean separation (Nie et al. 1975 and Roscoe 1975).

Multivariate analysis was performed using MANOVA (SAS 1976) to examine groups of variables which may be important in determining the quantities and distribution of detritus and nutrients in the forest floor. Roy's maximum root criterion (Harris 1975) was used to determine significance (α = 0.05). Factor loadings into discriminant functions were determined from the characteristic vector matrix using only characteristic roots which were significant and discriminant scores were correlated with original variables to evaluate the relative importance of variables in determining factor scores. This procedure allowed for the partitioning out of the variance accounted for by each factor.

The relation of species variables used was based on the tree species that Pearson (1978) used to delineate litterfall communities and by examination of Rosson's (1981) vegetation data. Nutrient variables were obtained from the group of nutrients (Mn, Mg, Zn) which were significantly different among site-types.

RESULTS

Detritus

Both areas had similar mean forest floor standing crop detritus although the UC area had considerably larger standard deviation than did AC area (Table 1). The relative distribution of detritus among horizons also was identical at the sites with the large wood (LW) $\geq O_1$ > small wood (SW) > O_2 (Fig. 2). The absolute amounts of each component differed with the UC area having slightly more organic matter in the large wood component and less in the O_2 horizon.

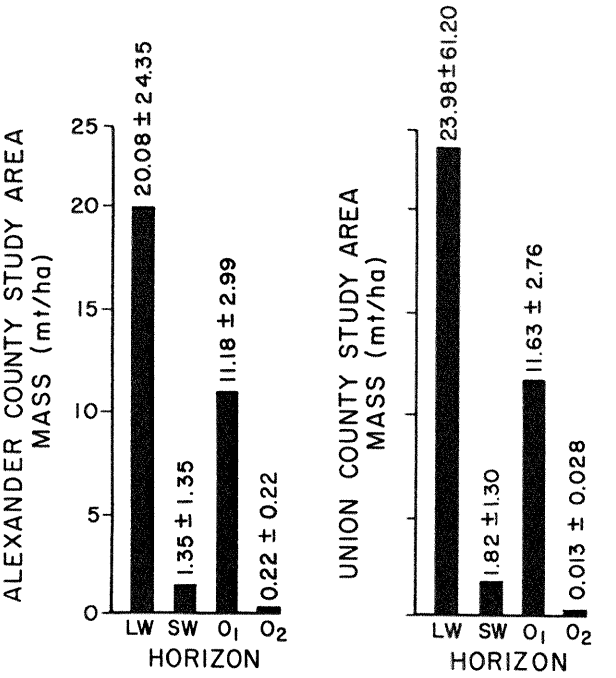

FIGURE 2.--Distribution of mass among forest floor horizons on southwestern Illinois.

Mineral Nutrient Concentrations

Several distribution patterns in concentrations (mg/kg) of mineral nutrients among horizons were evident (Table 2). In both study areas the patterns of P, Mg, Mn, Cu, and Zn followed the pattern O_2 > O_1 > SW ≈ LW, except for Mg where there was little difference between the O_1 and O_2; for K, the pattern was O_1 > O_2 > LW ≅ SW. Woody components usually had the lowest concentration of all elements except for Ca. Ca concentrations in the AC area were LW > O_1 > O_2 > SW and in the UC area O_1 ≥ LW > O_2 > SW.

The concentrations of mineral nutrients in the forest floor (Table 2) varied among horizons for each study area. Except for Ca, the nutrient concentrations in the wood compartments were lower than in the O_1 and O_2 horizons. Concentrations of Ca were an order of magnitude or more greater than those of other nutrients. Cu and Zn concentrations were lowest of all nutrients. Concentrations of many nutrients were highly variable and in many cases the standard deviation was greater than the mean.

Only Mn, K, Mg and Zn showed significant differences in means among site-types (Table 3). The bottom site-type had the lowest mean nutrient concentrations for Mn (O_1 and O_2), K (O_2), and Mg (O_2) and was the only site-type that was consistently and significantly different from the other site-types. Of the site-types that were significantly different from the bottom, only one, a lead east was consistent for Mn, K, and Mg. The only

TABLE 1.--Total forest floor standing crop mass (mt/ha) in southwestern Illinois forest floor horizons.

Study Area	Mean[1]	Standard Deviation	Minimum	Maximum	Difference Among Site-types[2]
Alexander County	32.8	24.4	7.8	147.1	NS
Union County	38.7	62.2	5.7	405.4	NS

[1] n = 56

[2] NS = no significant differences (P = 0.05) in mean standing crop biomass among site-types.

TABLE 2.--Mineral nutrients mg/kg in southwestern Illinois forest floor horizons.

Mineral Nutrient	O_1 Horizon[1]	O_2 Horizon	Small Wood (2.5 ≥ 10 cm diameter)	Large Wood[2] (> 10 cm diameter)
		Alexander Study Area		
P	1055 ± 374	1458 ± 466	262 ± 141	312 ± 600
K	2087 ± 470	1663 ± 408*	740 ± 300	855 ± 557
Ca	21223 ± 3761	16815 ± 6487	11035 ± 5379	23320 ± 23639
Mg	2071 ± 346	2102 ± 483*	750 ± 203	439 ± 504
Mn	1687 ± 456*	3159 ± 1296*	319 ± 123	131 ± 144
Cu	11 ± 19	19 ± 25	3 ± 3	4 ± 5
Zn	53 ± 45	105 ± 46	15 ± 14*	14 ± 6
		Union Study Area		
P	1092 ± 1336	1093 ± 633	206 ± 384	312 ± 588
K	2014 ± 559	1686 ± 857	800 ± 517	910 ± 642
Ca	23953 ± 3031	16431 ± 10292	13036 ± 5146	16478 ± 13480
Mg	1532 ± 620	1487 ± 800	410 ± 199	405 ± 530
Mn	1661 ± 397	3409 ± 1970*	325 ± 150*	131 ± 115
Cu	7 ± 10	16 ± 12	7 ± 27	3 ± 2
Zn	44 ± 12	96 ± 55	21 ± 15	14 ± 19

[1] * Indicates significant differences (P = 0.05) in mean mineral nutrient concentrations (± standard deviation). n = 56.

[2] n = 30

TABLE 3.--Tukey's HSD test (α = 0.05) for significant differences in mean mineral nutrient concentrations mg/kg in the forest floor among site-types for southwestern Illinois upland oak-hickory forests.

Manganese O_1 Mean[1]	Manganese O_1 Site-Type[2]	Manganese O_2 Mean	Manganese O_2 Site-Type	Potassium O_2 Mean	Potassium O_2 Site-Type	Magnesium O_2 Mean	Magnesium O_2 Site-Type	Zinc Small Wood Mean	Zinc Small Wood Site-Type
885	bottom	1216	bottom	739	bottom	1107	bottom	3	lead east
1320	ridge south	2353	ridge south	1572	ridge east	1974	slope west	4	ridge east
1490	slope south	2466	lead south	1592	lead north	2019	ridge east	4	slope west
1506	slope west	2545	slope west	1627	lead east	2033	lead north	5	lead west
1567	lead west	2828	slope south	1664	lead west	2034	slope north	9	bottom
1590	lead north	2964	cove	1667	ridge south	2110	slope south	12	lead south
1734	lead south	2992	slope north	1700	cove	2125	slope east	13	slope north
1753	cove	3197	lead west	1709	slope east	2132	cove	14	cove
1761	ridge east	3584	lead north	1725	slope west	2151	lead south	16	ridge north
1857	slope north	3856	ridge north	1735	lead south	2180	lead west	17	lead north
1891	ridge west	3874	slope east	1754	slope south	2287	ridge north	19	slope south
1932	slope east	3882	ridge west	1843	slope north	2291	lead east	20	ridge south
2141	lead east	3904	ridge east	1921	ridge north	2386	ridge south	30	slope east
2202	ridge north	4563	lead east	2028	ridge west	2603	ridge west	36	ridge west

[1] No significant difference between pairs of means included within the same line.

[2] Sample sizes were unequal for some cases.

exception if Zn (SW) for which only a ridge west showed significant difference.

Standing Crops of Mineral Nutrients

The standing of crops of mineral nutrients for both study areas were generally similar (Table 4). The standard deviations of several nutrients (Ca, Cu, K, Mg, and Mn) were larger than or equal to the mean. The standing crop of Mn in the UC area was the only elemental quantity which showed significant differences among site-types; and only one site-type mean, a ridge south, was significantly different from the other site-type (Table 5).

Several distribution patterns emerge for the AC area (Fig. 3). Standing crop of Ca, K, Mg, and P follow the pattern: O_1 > LW > SW > O_2; Mn and Zn: O_1 > LW > O_2 > SW and Ca: LW > O_1 > SW > O_2. Only one pattern was evident in the UC area where the distribution of all nutrients was O_1 > LW > SW > O_2 (Fig. 4). The relative quantities of standing crop of mineral nutrients were similar for both study areas and among horizons. Generally Ca, Mn, K, Mg, and P were present in the greatest quantities, and Zn and Cu were present in the smallest quantities.

Both structural and functional variables were used to determine differences among site-types (Table 6). In the AC area the first characteristic root only accounted for 51% of the variance compared to 89% for the UC area (Table 7). These differences were reflected in the individual R^2 values for the AC area variables where only *carya* BA seemed important in delineating the site-types. However, in the UC area the variables Quve (*Q. velutina*) BA and TD (tree density) were much stronger in predicting differences among site-types.

DISCUSSION

In this study the forest floor detritus was 16 to 19% of the total above ground tree biomass of 198 to 205 mt/ha estimated for these forests by Jones (1980). The quantities of forest floor detritus (32.8 to 38.7 mt/ha)

TABLE 4.--Total mineral nutrient standing crop (kg/ha) in southwestern Illinois upland oak-hickory forest floor horizons.

MINERAL NUTRIENT	ALEXANDER COUNTY AREA[1]	UNION COUNTY AREA[1]
P	14.95 ± 6.75	21.04 ± 28.24
K	41.00 ± 85.38	49.95 ± 61.24
Ca	579.25 ± 817.03	491.17 ± 474.47
Mg	33.70 ± 13.43	30.21 ± 30.95
Mn	23.32 ± 11.25	26.77 ± 31.02*
Cu	0.21 ± 0.21	0.13 ± 0.15
Zn	0.91 ± 0.53	0.94 ± 1.07

[1] *Indicates significant difference (P = 0.05) in mean mineral nutrient standing crop among site-types (± standard deviation). n = 56

TABLE 5.--Tukey's HSD test (α = 0.05) for significant differences in mean mineral nutrient standing crop (kg/ha) among site-types for Union County study area.

MANGANESE	
MEAN[1]	SITE-TYPE
1.5	slope west
1.8	slope east
1.9	slope north
2.0	lead north
2.2	lead south
2.2	slope south
2.4	lead east
2.5	ridge north
2.6	cove
2.6	ridge east
2.7	lead west
2.9	bottom
3.1	ridge west
12.9	ridge south

[1] No significant difference between pairs of means included within the same line.

found in this study are similar to those reported in several other studies in the oak-hickory forest type (Bourn and Brown 1971, Henderson 1972, Johnson and Risser 1974, Rodin and Bazilevich 1967, and Loomis 1975). However, the distribution of material between the O_1 and O_2 horizons was conspicuously different from an oak-hickory forest studied by Henderson (1972). He found that the O_2 horizon had about twice as much material than the O_1 horizon, whereas in this study the O_1 horizon contained about 50 times more material than the O_2 horizon. These differences may be due to: (1) the faster decay rates of the calcareous litter in this study, (2) differences in relative maturity, or (3) differences in harvest history, especially in the UC area where there has been little or no removal of larger mature trees in the past 75 years. Witkamp (1961) showed that the decomposition of calcareous litter in a *Quercus robur* L. forest in Europe was almost complete in a half year because of a favorable C/N ratio. The large proportion of detritus (61-64% of the total) in the large wood component was comparable to Henderson's (1972) 61% and emphasizes the magnitude of error in forest floor mass estimates when this component is not inventoried.

TABLE 6.--Variables used in discriminant function analysis to predict differences in forest floor (O_1 horizon) nutrient concentrations and detritus among site-types.

FOREST FLOOR VARIABLES	
Mass of O_1 horizon	Magnesium ppm, standing crop
Zinc ppm,[1] standing crop	Manganese ppm, standing crop
Copper ppm	Calcium ppm, standing crop

TREE SPECIES VARIABLES	
Total plot density (stems/ha)	*Nyssa sylvatica* BA, TD
Total plot basal area (m^2/ha)	*Quercus alba* BA,TD
1*Carya* BA2, TD3	*Quercus rubra* BA, TD
Cornus florida BA, TD	*Quercus stellata* BA, TD
Liriodendron tulipifera BA, TD	*Quercus velutia* BA, TD
Liquidambar styraciflua BA, TD	*Sassafras albidum* BA

[1] *Carya* = *Carya glabra* + *Carya ovalis* + *Carya ovata*.
[2] Basal area m^2/ha.
[3] Tree density stems/ha.

TABLE 7.--Major variables in discriminant function analysis which determine differences in forest floor (O_1 horizon) nutrient concentrations and biomass among site-types in southwestern Illinois upland forest.

ALEXANDER STUDY AREA

Variable	R^2	Variable	R^2
[a]Carya [b]BA	.19	Total plot BA	.05
[d]Carya [c]TD	.10	Total plot TD	.03
[d]Qual TD	.09	Qual BA	.03
Qust TD	.06	Mn ppm	.02
Ca ppm	.05	Quve TD	.02

*Characteristic Root 51%

UNION STUDY AREA

Quve TD	.69	Total plot TD	.06
Quve BA	.46	Qust TD	.06
Total plot BA	.18	Weight (O_1 horizon)	.06
Qust BA	.14	Mn ppm	.04
Qual TD	.12	Quru BS	.04
Mn SC[f]	.09	List BA	.03
Carya TD	.08	List TD	.03
Ca SC	.06	Litu TD	.02

**Characteristic Root 89%

[a] Carya = *Carya glabra* + *Carya ovalis* + *Carya ovata*
[b] Basal area m^2/ha
[c] Tree density stems/ha
[d] Species are coded using the first 2 letters of the generic name and the first 2 of the specific epithet from Table 6.
[e] Significant differences among site-types are indicated *95% and **99%.
[f] Standing crop (kg/ha).

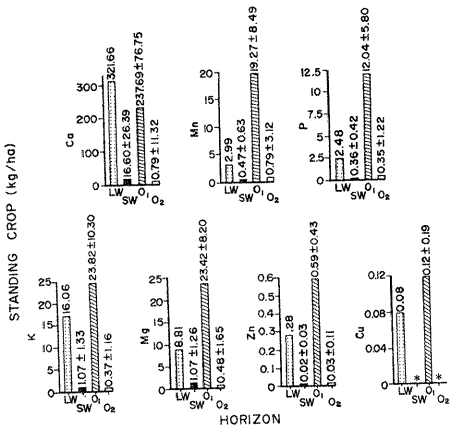

FIGURE 3.--Distribution of standing crop mineral nutrients in forest floor horizons for Alexander County study area. *indicates quantity less than 0.01 kg/ha.

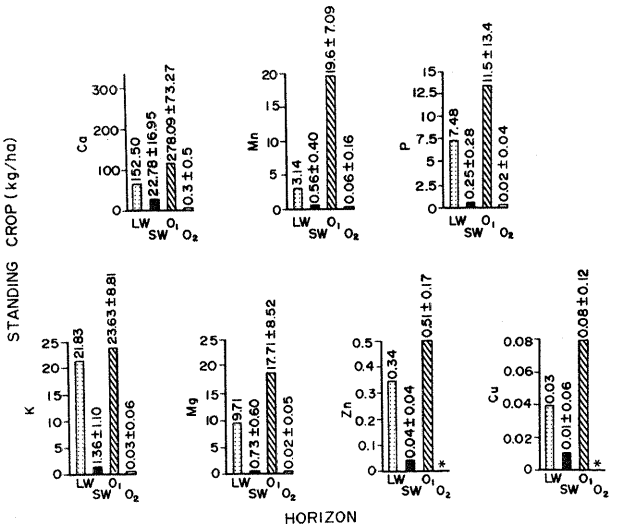

FIGURE 4.--Distribution of standing crop mineral nutrients in forest floor horizons for Union County study area. *indicates quantity less than 0.01 kg/ha.

The large amount of variability expressed in both study areas is a result of the variable distribution of all horizons, but especially the large wood component. In the UC area many plots had no large wood present and in others large fallen trees were present. In the AC area most of the plots had some large wood, but none had fallen trees due to differences in relative maturity (see above), thus giving a more uniform distribution and less variation. Many factors may have contributed to the variability within the O_1 horizon. These include changes in distribution by movement caused by wind, water, and gravity and differences in the species composition, basal area, and density of overstory vegetation.

For the O_2 horizon, difficulty in collection caused by adherence to the lower portion of the O_1 horizon and the contamination of mineral soil contributed to the variability. The O_2 horizon tended to be found in small pockets or was not present giving it a clumped distribution. The large variability in the forest floor mass and nutrient concentration appears to be an inherent characteristic of these oak-hickory forests (Luvall and Weaver 1978).

The concentrations of the macronutrients in both study areas were comparable to the values reported for oak-hickory forest types (Johnson and Risser 1974, and Rodin and Bazilevich 1967).

The distribution pattern for nutrients within the horizons were similar to those found in several other studies (Lang and Forman 1978, Reiners and Reiners 1970, Duvigneaud and Denaeyer-DeSmet 1970, Rodin and Bazilevich 1967). This pattern of nutrient distribution seems to be related to the stage of decay with the most decayed (O_2) horizon generally having the greatest concentrations. In woody components, the patterns appear not to be related to size of material because the initial nutrient concentrations may be extremely variable due to species differences and may be further modified by the decay process (Gosz et al. 1973). The exception is K concentration which is lower in the O_2 horizon because it is easily leached (Gosz et al. 1973). The large concentration of Ca in the O_1 horizon and leaf material relative to the other horizons has been shown by several studies (Duvigneaud and Denaeyer-DeSmet 1970, Rodin and Bazilevich 1967). Also, Ca tends to accumulate in leaf tissue until abscission (Gosz et al. 1972) and high Ca concentrations seems to be an attribute of these oak forests (Jones 1980).

The increase in Mn concentration from the O_1 to the O_2 horizon may be caused by the concentrating and immobilization of Mn by micro-organisms as shown by Witkamp and Ausmus (1975).

With the exception of Zn, the nutrients which showed significant differences among site-types (K, Mn, Mg, and Zn), appear to be among the more mobile nutrients in the forest ecosystem. Separation of site-type means in AC area indicated that only a bottom site-type which also had the smallest mean concentration of K, Mn, and Mg, was significantly different from the other site-type means. Gosz et al. (1972) showed that Mn concentrations in leaf litterfall were greatly dependent on the site. This corresponds to the significant differences in Mn concentrations among site-type means for the O_1 and O_2 horizons. Also the environment of a bottom site would tend to promote rapid removal of these nutrients through leaching and rapid decay rates. The only other significant site-type difference for Alexander County area, Zn (SW) slope west was larger than the other

site-type means. This may be due to a species difference (Gosz et al. 1973) or to the availability of Zn to the plants.

The large variability in the concentrations of the mineral nutrients within horizons is due to several factors. Initial differences may be present before the leaves reach the forest floor. Gosz et al. (1972) found that senecesent leaves falling early in the autumn have larger concentrations of the more mobile nutrients (K, Mg, and Mn) and lower concentrations of the immobile ones (Ca, Cu, and Zn), than those falling later in the autumn. Also species composition, availability of nutrients in the soil, and the effect of rainfall (amount and intensity; Edwards and Shanks 1972) may affect initial concentrations. After the leaves reach the forest floor, such factors as stage of decay, presence or absence of fungal hypae and small roots, and contamination from soil material may affect the concentrations. The localized effect of stemflow around the bases of trees and shrubs, especially for Ca, K, Mg, and Mn, would tend to increase those concentrations. (Edwards et al. 1971, Edwards and Shanks 1972, Johnson and Risser 1974). The variability within the wood component may be due to species differences, length of time on the forest floor, and initial age and size of material (Gosz et al. 1973). Sampling error in the large wood component caused by not taking the discs from different relative positions in the tree for each disc could also be a factor (Rodin and Bazilevich 1967).

The mean standing crops of mineral nutrients were almost identical for both study areas and were comparable to those reported by several other studies (Henderson 1972, Rodin and Bazilevich 1967). Mean standing crops of Ca (579 kg/ha and 491 kg/ha) were almost identical to those Henderson (1972) found for oak-hickory (573 kg/ha) forests. The agreement (within sampling error) of the standing crop nutrient values to Henderson's (1972) study is striking because there are large differences in the distribution of detritus among horizons. However the absolute quantities of nutrients in this study and Henderson's were fairly consistent for two similar forest physiognomic types developed on dissimilar geology and soils. The standing crop of nutrients in the forest floor in this study was a considerable portion of the total aboveground tree nutrient standing crop found by Jones (1980): Ca (26-32%), Mg (55-61%), K (21-24%), Mn (27-29%), Cu (17-27%) and Zn (35%).

The distribution patterns of the standing crop nutrients among horizons for both study areas varied according to the nutrient. Several studies have shown that Ca tends to be accumulated by oak-dominated forest (Duvigneaud and Denaeyer-DeSmet 1970, Jones 1980, Johnson and Risser 1974, and Rodin and Bazilevich 1967). The interaction of the quantity of detritus and the nutrient concentrations in determining the relative nutrient standing crop among horizons is demonstrated by Ca. In the Alexander County area the greater mass in the large wood component than in the O_1 horizon resulted in the larger standing crop of Ca in the former. Although the O_1 horizon did not have the maximum quantity of organic matter or concentrations of most nutrients, it generally had the greatest standing crop nutrients. The O_1 horizon appears to decay rapidly and it may control a large portion of the nutrient flow in this ecosystem. In these forests Pearson (1978) estimated the O_1 turnover rate at 2.1 years.

The wood component of the forest floor still contained a large amount of the forest floor nutrient standing crop: Ca (36-58%), Cu (31-38%), K (42-47%), Mg (29-35%), Mn (14-15%), P (19-37%), and Zn (36-40%). The woody component tends to act as a nutrient storage pool which is not readily available due to the slow decay rates (Harris et al. 1972). In contrast, the O_2 horizon, which has large concentrations but is present in small quantities, may not be a significant nutrient pool in these forests.

The relative position of each nutrient's standing crop within the horizons is similar to the worldwide patterns for oak-mixed hardwood forests described by Rodin and Bazilevich (1967). The relative positions of K, Mg, and Mn varied among horizons. This variation may be due to the relative mobility of these nutrients.

Robertson et al. (1978) suggested that multiple regression interpretation could be used to identify and measure environmental factors relating to species distribution. In the present study, the interpretation of the significant Mn differences was coupled to multiple analysis of variance to determine which factors are controlling the differences among site-types and plots. Pearson (1978) concluded that in the AC area, environment (aspect) and community structure were significant predictors of annual nutrient mass in leaf litterfall.

The large and significantly different mean concentration of Mn in the O_1 horizon (Union County area) for the south ridge site is related to the large amount of Q. alba, Q. velutina and Carya spp. present there. Jones (1980) demonstrated that the Mn foliage concentrations of Q. alba, Q. velutina and Carya spp. were up to six times greater than in the more mesic species, L. tulipifera, A. saccharum, and L. styraciflua. Also Q. alba, Q. velutina and Carya spp. contained about 88% of the total foliage standing crop of Mn (Jones 1980). These differences are maintained in the litter. Scott (1955) observed a wide range in litter Mn concentrations among species and that the oaks tended to have larger Mn concentrations, particularly when there were large amounts of available Mn.

CONCLUSIONS

Significant differences in quantities and composition of forest floor detritus do not occur either among broad topographic site-types or between watersheds. Large variability in the spatial distributions of detritus, controlled by highly localized processes such as species composition, stand structure, mortality rates and water action, is an inherent characteristic of these forests.

Large woody material comprises a major component of the forest floor mass, emphasizing the need to include this component in estimates of the detritus and nutrient pools of the forest floor in these and other mature forests.

Significant differences in nutrient concentrations in the forest floor among site-types for these forests occurred for only a few nutrients (K, Mg, Mn, and Zn). With the exception of Zn, these nutrients are highly mobile in these forests, but patterns are not consistent for horizon or for study areas.

The inherent variability of these forests may be the reason that the standing crop of only one nutrient, Mn (Union County area), showed significant differences among site-types. This variability must be considered when sampling the forest floor. In addition, the heterogeneity of plots within the same site-type emphasizes the difficulty of stratifying a possible continuum in these forests into artificial segments.

The forest floor in these oak-hickory forests contains a substantial portion of nutrient pools. However, they are in a constant state of flux due to the rapid decay of O_1 and O_2 horizons. The large woody material may act as a nutrient storage pool because of its slow decay and storage of large quantities of nutrients. Thus the total forest floor detritus may be controlling a large portion of the energy flow, both spatially and temporally, between biotic and abiotic compartments.

Slight structural differences observed within these oak-hickory forests do affect nutrient concentration differences, especially for forest floor Mn. Nutrient differences in the forest floor are more closely related to species composition than to total stand density and basal area.

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