Investigation of Mineral Nutrient Cycling in Upland Piedmont Forest[1]

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Abstract

Nutrient cycling was investigated in a mixed hardwood and a natural loblolly pine stand. Measurements were made of the mineral element content of precipitation alone, throughfall, stemflow, and litterfall. Total litterfall was 25 per cent greater in the hardwood than in the pine. Nitrogen and Ca in the litterfall were respectively 70 and 250 per cent greater in the hardwood than in the pine. Hardwood litter contained about twice as much K, Mg, Mn, Cu, Na, and Al as did the pine stand. More N, K, Ca, and Mg was washed from the hardwood canopy trees than from the pine. A greater amount of K was contributed by throughfall than by litterfall.

Introduction

Among the important environmental factors that control the function of any ecoystem are the levels of essential mineral nutrients available to the primary producers. It is known from many earlier papers that the forests maintain nutrient levels for the photosynthetic portion of their biomass by cycling the nutrients stored in the litter and freed while the litter is slowly decaying. Many recent investigations have revealed that nutrients are washed out of leaves and bark by rainwater, e.g., Carlisle et al., 1966, 1967; Cole et al., 1968; Duvigneaud and Denaeyer-De Smet, 1968; Kaul and Billings 1965; Tamm, 1951; Tarrant et al., 1968; and Voight, 1966. Other research indicates that portions of minerals involved in nutrient cycling are provided by rainwater (Eriksson, 1952, 1957; Junge and Wearby, 1958; Fisher et al., 1968; Likens et al., 1967; and Woodwell and Whittaker, 1968; Wolaver, 1972).

Compilation of the mineral nutrient budget for a forest must therefore include measurements of the nutrient content of (1) rainwater alone, (2) water dripping through the crown (throughfall), (3) water running down the trunks (stemflow), and (4) the minerals reaching the forest floor with the litter (litterfall). Also necessary are measurements of (5) mineral nutrient levels present in soil water solution, (6) amounts provided by the weathering processes, and (7) yearly uptake of elements by the vegetation.

Since mineral nutrients are so vital in the functioning of ecosystems, complete studies of nutrient cycling and budgets were designated as an integral part of the International Biological Program. This report is part of a study conducted to investigate nutrient cycles in the southeastern forests of the United States. The general succession pattern in this region extends from evergreen pine forests to broadleaf deciduous forests. Our study therefore included both pine and hardwood stands. This study was a joint effort of the Southeastern Forest Experiment Station, U.S. Forest Service, located in the Research Triangle Park, North Carolina, and members of the Botany Department, University of North Carolina at Chapel Hill. The investigations were carried out through the calendar year 1969 for litterfall and throughfall, and from November 1969 through October 1970 for precipitation and stemflow. In addition to the nutrient studies, other characteristics of this forest have been studied in the same general area—the Blackwood Division of the Duke Forest, one of the Triangle Sites of the Eastern Deciduous Forest Biome, US-IBP. The present study is intended to provide data for ecosystem modeling in the Deciduous Forest

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Biome and to compare briefly the levels of individual nutrients in the eastern Piedmont area of North Carolina with values from other regions of the temperate deciduous forests of the world in order to increase knowledge about ecosystem functions.

The Site

The geographical location of the research site has been measured as 35° 58′ N and 76° 06′ W, with elevations ranging from 154–236 m above mean sea level. Figure 1 shows the site in relation to the State of North Carolina.

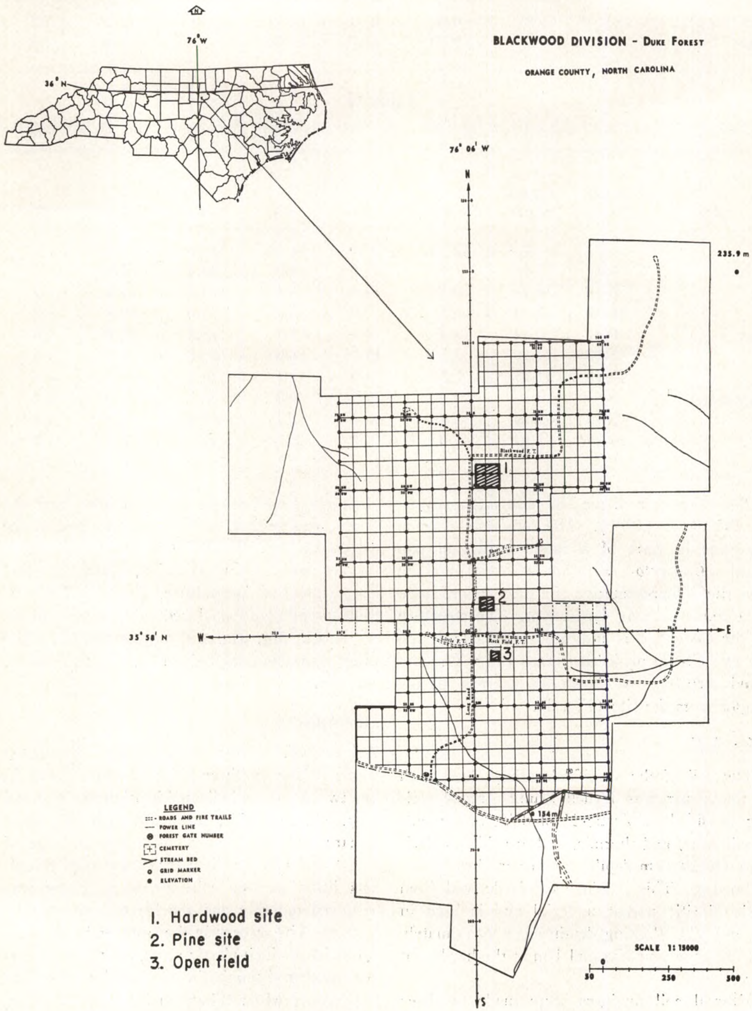

Figure I.

FIG. 1. Location of the IBP research site in the Blackwood Division of the Duke Forest.

Table I

Basal area, height, and number of trees in overstory and basal area and number of stems larger than 2.5 cm in diameter in understory

	OVERSTORY				UNDERSTORY		
	Age (yrs)	Trees/ha	Ht (m)	B.A. m^2/ha	Age (yrs)	Stems/ha	B.A. m^2/ha
Hardwood	85	605	25.1	26.21	50	1173	5.9
Pine	62	390	27.8	21.99	15	750	2.6

Table II

Chemical properties of the soils in the field, pine, and hardwood plots (soil type, Iredell loam)

Site	Sample Depth	Organic Matter	P	K	Ca	Mg	Mn	pH
	(cm)	%	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	
Field	0–5	3.8	1.9	17.9	199	36.4	51.6	4.9
	5–10	1.89	0.8	9.9	151	26.7	54.8	5.1
	10–15	1.41	0.8	7.9	151	30.0	50.4	5.2
Pine	0–5	3.24	3.6	8.5	342	43.3	49.6	5.0
	5–10	1.70	2.1	13.9	226	39.0	58.8	4.8
	10–15	1.27	1.3	9.6	184	36.4	56.8	4.8
Hardwood	0–5	4.49	2.2	29.9	332	58.7	49.6	5.6
	5–10	2.59	1.4	16.5	154	40.8	32.4	5.4
	10–15	1.93	1.0	12.0	157	44.7	36.1	5.4

The vegetation of the IBP site was analyzed by Whigham (1971). The hardwood site is classified as part of a mesic hardwood oak woods (*Querceto-Caretosum-mesicum*), and the pine site is representative of a successional stage of a similar climax forest type. The structure of the two sites is indicated by Table I and the two Crown projection maps (Fig. 2). The stand structure is shown in fish-eye photographs from the site (Fig. 3).

The Soil

The soil of the specific locations dealt with in this paper was Iredell loam.[4] Iredell soils are classified as Vertic Hapludalf; fine, montmorillonitic, and thermic, and are thin A horizons (to 20.8 cm depth) and a very heavy clay B horizon. This residual soil is derived from basic dioritic parent material and is high in Ca and Mg. Rooting depth was approximately 70 cm at the pine site and 1 m at the hardwood site.

Mineral soil analyses were made at three different locations—in an open area near the main weather hut, at the pine site, and at the hardwood site. Results of these analyses, made by the Soil Testing Division, North Carolina Department of Agriculture, appear in Table II. Soil samples were analyzed only for pH and for P, K, Ca, Mg, Mn, and organic matter, while litter was also analyzed for N, Cu, Fe, Na, Al, and Zn.

Methods

• *Litterfall.* Litter traps were distributed along a line on three sides of square plots in the two stands as indicated in Figures 2(a) and (b). On each side, two traps each one meter square and five plastic cans with an area of 1,000 cm^2 (36 cm diameter) were used to collect litter for one calendar year. Litter was removed monthly and the leaves separated by species. The screens in the traps and cans were 16 × 18-per-inch plastic mesh. Particulate matter passing through the screens into the cans was recovered on Whatman No. 40 filter paper, weighed, and analyzed separately.

• *Throughfall.* The fifteen litterfall cans in

[4] A soils map by Jenkins is included in Whigham (1971).

Table III

Diameter breast height (D.B.H.), height, and crown area of trees sampled for stemflow

Tree	D.B.H. (cm)	Height (m)	Crown Area (m^2)
Pine site			
Pinus taeda—C	21.34	16.6	14.4[1]
Pinus taeda—C	20.83	19.0	12.5[1]
Pinus taeda—C	21.34	17.0	18.7
Liquidambar styraciflua—U	7.87	6.8	9 9
Liriodendron tulipifera—U	6.20	6.6	5.9[1]
Hardwood site			
Liquidambar styraciflua—C	28.38	22.5	35.6[1]
Quercus falcata—C	54.10	23.0	153.4[1]
Fraxinus americana—C	26.72	22.8	43.7[1]
Carya tomentosa—U	11.62	14.3	16.2
Quercus alba—U	10.92	13.0	27.8

C = canopy tree
U = understory tree
[1]Shown in Figures 3 P and 3 H.

each stand and three cans in the open were also used to collect precipitation. The cans were emptied after periods of heavy rainfall, but evaporation losses prevented estimation of canopy interception. The latter was measured by using five Forester rain gauges and five Taylor see-thru rain gauges from August 1969 through October 1970. Measurements were made after each precipitation period. Three gauges each were placed in the field and in the pine forest, and four were used at the hardwood site. The positions of the gauges in the two forested sites were altered after each precipitation measurement. The cans, which collected throughfall water, were not cleaned at each collection; we later found that cleaning them with a brush was essential to obtain quantitative removal of elements. As a result, throughfall data are valid on the annual basis, but storm and seasonal nutrient variations were not determined.

• *Stemflow.* Five trees in both the pine and hardwood sites were fitted with stemflow water catchments. At the pine site, three canopy trees (*Pinus taeda* L.) and two understory trees (*Liriodendron tulipifera* L. and *Liquidambar styraciflua* L.) were studied. At the hardwood site the three canopy trees were *Liquidambar styraciflua* L., *Fraxinus americana* L., and *Quercus falcata* Michaux. Understory species studied were *Carya tomentosa* (Poiret) Nuttall and *Quercus alba* L. Diameter, height, and canopy area data for each tree are shown in Table III.

The stemflow attachments consisted of aluminum foil gutters placed around the boles of the trees. After the rough bark was removed, the gutters were attached to the trees with rubber tubing and a commercial sealant (Permagum). Stemflow water was filtered and drained into covered 20-gal plastic buckets. The entire array is shown in Figure 3. The buckets were checked

Table IV

One year of litterfall and its nutrient content by species of leaves for the hardwood plot (kg/ha)

Species[1]	Litter	N	P	K	Ca	Mg	Mn	Cu	Fe	Na	Al	Zn	pH
Hickory	526.7	4.39	.270	1.389	12.69	2.545	1.593	.0108	.0576	.0736	1.5391	.0445	4.8
Sweetgum	306.6	1.64	.129	.737	3.76	1.337	.333	.0088	.0336	.0212	.0759	.0133	4.5
Elm	27.8	.13	.009	.050	.66	.067	.031	.0003	.0024	.0026	.0130	.0009	4.9
Blue beech	75.2	.81	.117	.251	1.63	.329	.163	.0011	.0125	.0106	.0685	.0036	4.5
Tulip Poplar	811.8	4.65	.305	1.725	19.36	5.202	.854	.0106	.1231	.0788	.2270	.0189	5.3
Dogwood	159.7	1.19	.092	.687	3.24	.729	.047	.0082	.0278	.0170	.1100	.0040	5.7
Ash	34.5	.27	.002	.123	.90	.109	.007	.0036	.0057	.0012	.0074	.0007	5.2
Red oak	369.2	2.61	.166	.698	4.68	.934	1.066	.0054	.0476	.0554	.0239	.0125	4.6
White oak	823.7	5.85	.298	1.753	11.73	1.575	1.514	.0069	.0773	.0845	.0611	.0130	4.3
Willow oak	3.3	.02	.002	.010	.03	.009	.011	.0001	.0004	.0005	.0004	.0001	4.8
Mics. leaves	248.4	2.34	.173	.798	4.76	.873	.371	.0211	.0521	.0222	.2387	.0103	4.7
Misc.[2]	1218.1	9.35	.671	3.914	16.20	2.277	.776	.0322	.6487	.1571	.4726	.0454	4.9
Maple	287.1	1.48	.097	.655	3.79	.926	.347	.0034	.0528	.0261	.0360	.0089	4.3
Twigs	830.8	3.24	.181	.758	9.67	.658	.217	.0079	.0733	.0736	.0729	.0219	4.8
Blackgum	2.5	.16	.001	.006	.03	.014	.003	.0005	.0004	.0001	.0007	.0001	4.4
TOTALS	5725.4	38.13	2.513	13.554	93.13	17.583	7.333	.1209	1.2153	.6245	2.9472	.1981	

[1]Scientific names are shown in Table Va.
[2]Mainly bark, fruits, and seeds.

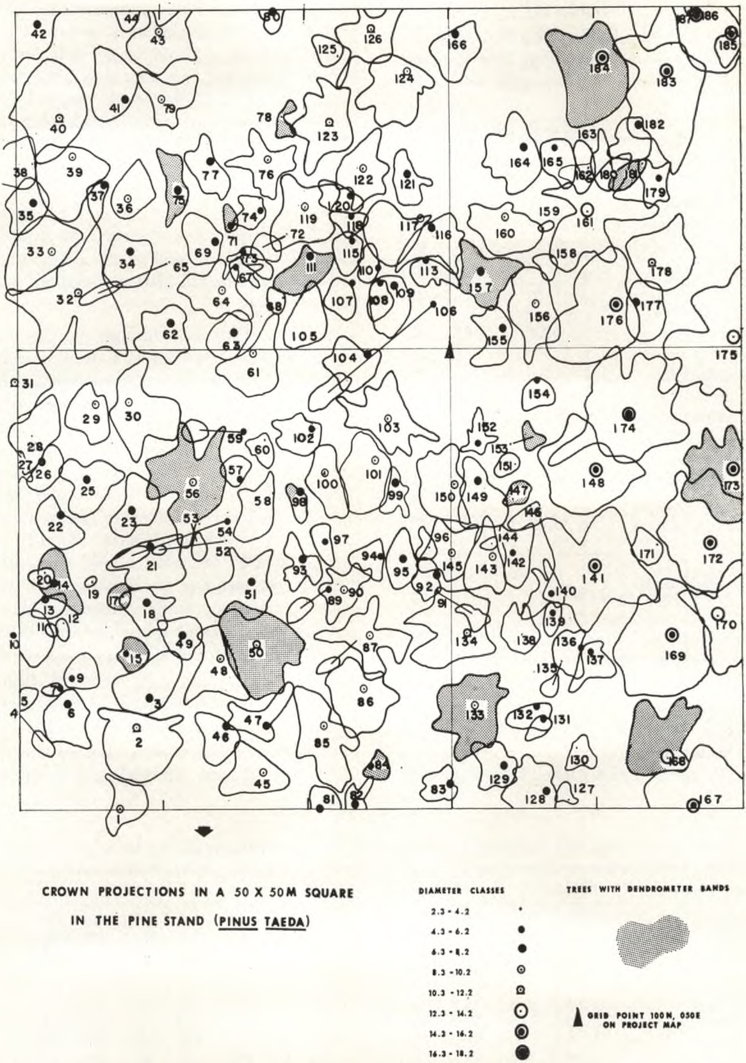

FIG. 2a. Crown projection map for the pine site, site #2 in Fig. 1.

after each precipitation period, and water was measured and collected only after those precipitations during which a sufficient amount of stemflow water (500 ml) was collected. During each collection period, the amount of stemflow water was measured, and a filtered 500-ml sample was collected for chemical analysis. The 500-ml water samples were stored in a refrigerator in a cold room until the analyses were performed. Nitrogen (organic, NH_4, NO_3), Ca, P, K, and Mg analyses were made. Repeated analysis showed that NH_4 and NO_3

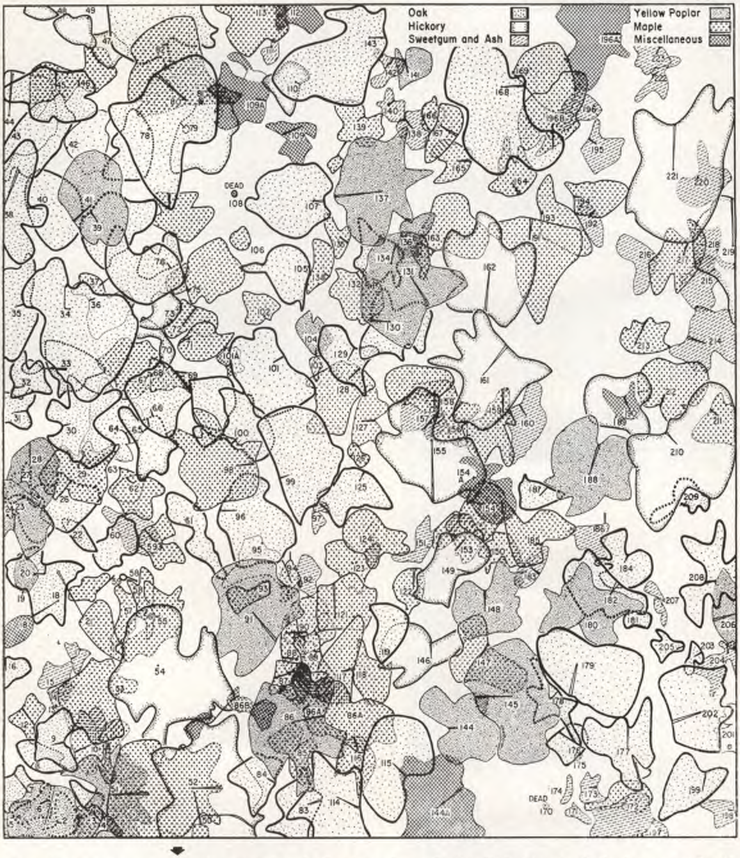

FIG. 2. (b) Crown projection map for the hardwood stand, site #1 in Fig. 1. In both maps only dominant and subdominant crown layers are included. The sampling areas were at the northern, eastern, and southern (bottom line in each figure) portions of each plot. ↓ indicates approximate location of camera for fisheye photographs (Fig. 3).

concentrations were stable in the samples that were stored for one month at near freezing temperature, as indicated by ice formation in some bottles.

• *Chemical Analysis.* Nitrogen was determined by macro-Kjeldahl for both plant and water samples according to the procedures in Jackson (1958). For mineral elements in water, an 80-ml sample was evaporated to near dryness, 2 ml of 30% hydrogen peroxide were added, and the sample was then evaporated to complete dryness. The residue was dissolved in 16 ml of 0.4*N* HCl with 0.2% lanthanum. Phosphorus was determined by the molybdenum blue method with stannous chloride as reducing agent (Jackson, 1958). Other mineral elements in the solution were determined by atomic absorption spectrophotometry. The evaporation, oxidation, and concentration procedure was essential to phosphorus analysis because less than 50 per cent of the phosphorus constituent was recovered without oxidation.

Plant samples were analyzed for mineral elements by ashing in a muffle furnace at 450°C for 6 hours. The ash residue from the furnace was dissolved in 2 ml of concentrated HCl, evap-

FIG. 3. Fish-eye photographs from the bottom of each sampling area. H = hardwood, P = pine, and O = old field. The pictures demonstrate the similarity of stand structure as indicated in Table I. The understory, which cannot be shown in crown projections, can be seen in these photographs. Stemflow sampling devices are seen in the lower right corner of H and P.

orated to near dryness, and then dissolved in 20 ml of 0.4*N* HCl with 0.2% lanthanum. Phosphorus was determined by the vanadomolybdophosphoric yellow color method (Jackson 1958), and other mineral elements by AASP.

Results

• *Litterfall.* The total litterfall was 25 per cent greater in the hardwood stand than in the pine stand (Tables IV and V). Nitrogen and calcium content in the litterfall was respectively 70 and 250 per cent greater in the hardwood than in the pine. Phosporus, Zn, and Fe content was about the same for the two stands. Hardwood litter contained about twice as much K, Mg, Mn, Cu, Na, and Al as did the pine stand. The larger amounts of Mn and Al, the solubility of which increases with acidity, were not expected in the hardwood stand, where the soil pH was higher than in the pine.

For the pine stand, approximately 70 per cent of the total litterfall collected on the screens was pine needles. Twigs, trash (mostly bark), and miscellaneous unidentified leaves accounted for a larger portion of the hardwood litterfall. Relative seasonal litter and nutrient fall were nearly the same for the two stands (Table VI). Of the total litterfall, 76 per cent of the pine and 71 per cent of the hardwood fell in October through December.

Metz (1954) analyzed leaf fall for nitrogen and calcium in pine and hardwood stands of the South Carolina Piedmont. His litterfall values were lower for hardwood than those found in this study. The values for pines were similar. When nitrogen and calcium in leaf fall are compared, results for both pine and hardwood are nearly the same for the two studies. Acidity of the litter was greater in the pine stands, even though the hardwood understories contributed to the basic element content. Pine needles constituted the most acid

Table V

One year of litterfall and its nutrient content by species of leaves for the pine plot (kg/ha)

Species[1]	Litter	N	P	K	Ca	Mg	Mn	Cu	Fe	Na	Al	Zn	pH
Hickory	8.1	.06	.068	.027	.16	.032	.024	.0001	.0011	.0015	.0263	.0004	4.7
Sweetgum	325.7	1.83	.253	.995	4.69	1.190	.709	.0029	.0544	.0339	.1035	.0187	4.3
Elm	43.6	.29	.044	.098	.89	.073	.053	.0006	.0074	.0032	.0048	.0009	4.8
Catkins	4.2	.03	.005	.038	.01	.003	.001	.0005	.0004	.0008	.0008	.0002	4.8
Tulip poplar	96.0	.59	.062	.422	2.39	.495	.099	.0008	.0126	.0216	.0295	.0021	5.4
Dogwood	52.4	.47	.066	.308	1.05	.219	.009	.0010	.0105	.0072	.0524	.0018	5.3
Willow oak	14.9	.12	.006	.028	.15	.035	.025	.0003	.0009	.0024	.0019	.0005	
Misc. leaves	88.8	.60	.098	.302	1.90	.325	.138	.0044	.0156	.0093	.0364	.0032	4.8
Pine	3240.9	13.99	1.760	3.793	11.85	3.680	2.393	.0348	.6005	.2691	.7480	.1335	3.9
Misc.[2]	498.4	3.14	.251	.581	3.07	.535	.164	.0057	.2395	.0341	.2476	.0214	4.1
Maple	14.6	.01	.001	.001	.02	.005	.002	.0000	.0002	.0001	.0127	.0000	
Twigs	195.9	.83	.054	.121	.52	.060	.030	.0012	.0299	.0134	.0446	.0052	3.7
Redbud	3.5	.03	.006	.027	.11	.014	.000	.0000	.0005	.0007	.0004	.0001	4.4
TOTALS	4587.0	21.99	2.674	6.741	26.81	6.666	3.647	.0524	.9735	.3973	1.3099	.1880	

[1]Scientific names are shown in TableVa.
[2]Mainly bark, fruits, and seeds.

Table Va

Scientific names of species included in Tables IV and V

Common name	Scientific name
Hickory	*Carya tomentosa* (Poiret) Nuttall.
	Carya glabra (Miller) Sweet.
Sweetgum	*Liquidambar styraciflua* L.
Elm	*Ulmus alata* Michaux
	Ulmus americana L.
Bluebeech	*Carpinus caroliniana* Walter
Tulip poplar	*Liriodendron tı lipifera* L.
Dogwood	*Cornus florida* L.
Ash	*Fraxinus americana* L.
Red oak	*Quercus rubra* L.
White oak	*Quercus phellos* L.
Maple	*Acer rubrum* L.
Pine	*Pinus virginiana* Miller
	Pinus taeda L.
Redbud	*Cercis canadensis* L.

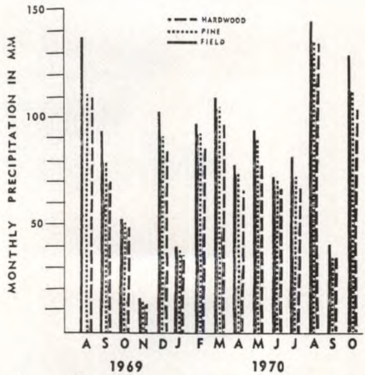

FIG. 4. Mean monthly precipitation measured at ground level in the three locations shown in Figs. 1 and 3.

material collected, while dogwood leaves had the highest pH.

Particulate material passing through the litter trap screens (Table VII) adds to the measured litterfall shown in Tables IV and V. Nitrogen content of this material was greater than 2 per cent. The sum of this fine and other miscellaneous materials—mostly bark, fruits, and seeds collected on the screens—amounted to about 30 per cent of the total nitrogen in the litterfall. Carlisle et al. (1967) mentioned this fraction as of considerable importance in nutrient cycling.

• *Precipitation and Throughfall.* For the general area of the study, the mean annual precipitation for 68 years was 1168 mm. Precipitation recorded at the field site from August 1969 until November 1970 was 1300.8 mm (Fig. 4). During the same period, 1195.8 mm of throughfall precipitation was recorded under the pine and 1156.7 mm under the hardwood areas. Maximum rainfall (146.2 mm) occurred during August and the minimum (15.8 mm) during November.

The mineral content of rain water in the eastern United States is shown in Figure 5, Maps 1–4. Only those elements are shown that were included in the set of minerals observed by the National Precipitation Chemistry Sampling Network (Lodge et al., 1968). The SYMAP display was made by Wolaver and

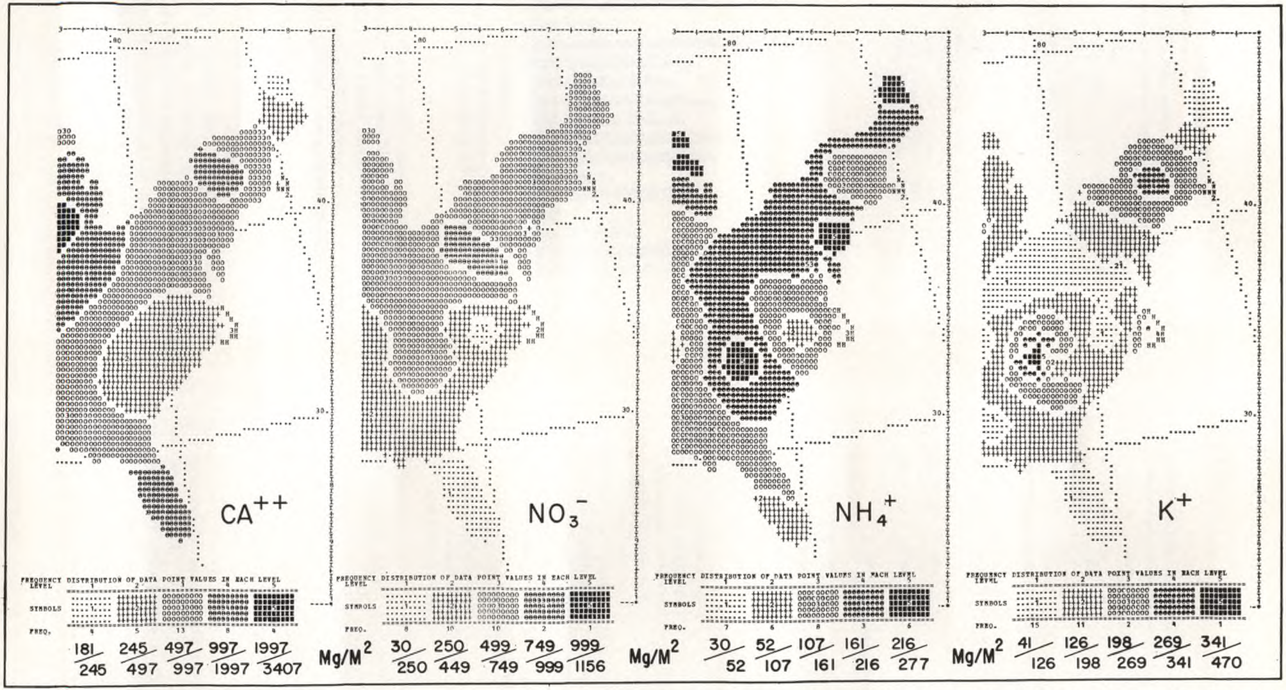

FIG. 5. Precipitation chemistry of the eastern United States. The four maps show the fallout of Ca, K, NH_4, and NO_3 in mg/m^2 surface ground area. The data from our open field station are included in the map. The value for Ca is the same as in the surrounding area. The values for K and the two N components, however, are significantly lower in our area.

Table VI

Nutrient content of litterfall by month (kg/ha)

Element	Jan-Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
						Hardwood						
	754	40	154	298	114	45	66	225	1608	2229	191	5725
N	2.82	.24	2.40	2.42	1.15	.44	.57	2.15	10.45	14.42	1.07	38.13
P	.119	.039	.158	.189	.063	.031	.057	.136	.740	.901	.078	2.511
K	.502	.063	1.004	1.347	.313	.087	.197	.597	4.732	4.539	.173	13.553
Ca	8.29	.55	1.44	2.68	1.25	.89	1.05	5.34	31.39	37.64	2.66	93.18
Mg	.478	.037	.272	.586	.223	.102	.206	1.069	7.637	6.716	.257	17.584
Mn	.197	.031	.110	.131	.064	.044	.069	.250	2.148	4.105	.192	7.334
Cu	.0053	.0004	.0020	.0012	.0014	.0006	.0008	.0591	.0237	.0237	.0027	.1208
Fe	.078	.010	.021	.078	.103	.027	.094	.168	.268	.263	.105	1.216
Na	.0230	.0037	.0322	.0674	.0189	.0031	.0081	.0125	.1671	.2726	.0162	.6248
Al	.085	.014	.028	.046	.063	.058	.075	.191	1.001	1.254	.131	2.947
Zn	.0160	.0044	.0052	.0093	.0034	.0018	.0026	.0145	.0484	.0839	.0083	.1978
						Pine						
	234	82	104	163	121	102	140	230	992	1815	604	4587
N	1.32	.45	.78	1.12	.71	.57	.76	1.14	4.73	7.25	3.16	21.99
P	.096	.037	.078	.101	.064	.056	.077	.130	.675	1.019	.339	2.672
K	.193	.097	.262	.268	.187	.160	.187	.318	1.961	2.329	.781	6.742
Ca	.85	.28	.57	.55	.49	.47	.72	1.81	8.47	10.12	2.51	26.83
Mg	1.38	.052	.106	.272	.139	.120	.164	.371	2.181	2.525	.596	6.666
Mn	.083	.027	.051	.076	.067	.065	.097	.194	1.011	1.601	.379	3.651
Cu	.0014	.0004	.0009	.0008	.0007	.0006	.0054	.0175	.0082	.0112	.0053	.0524
Fe	.043	.019	.015	.021	.044	.053	.043	.037	.185	.412	.109	.981
Na	.0116	.0038	.0090	.0108	.0082	.0066	.0096	.0152	.1085	.1633	.0506	.3972
Al	.085	.029	.034	.041	.040	.044	.046	.073	.293	.463	.157	1.305
Zn	.0083	.0077	.0042	.0059	.0049	.0041	.0063	.0095	.0409	.0722	.0242	.1880

Table VII

Particulate matter—N, P, K, Ca, and Mg—passing through litter-trap screens (16 × 18-per-inch mesh) and collected by filtering (kg/ha)

Location	Organic Matter	N	P	K	Ca	Mg
Hardwood	330	7.85	0.75	0.71	1.86	0.53
Pine	268	6.39	0.57	0.46	0.89	0.32
Open	93	2.71	0.26	0.23	0.17	.013

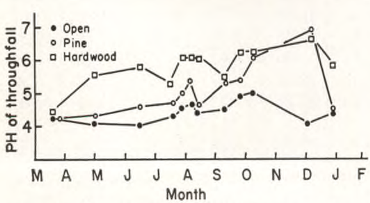

FIG. 6. The pH of throughfall in the hardwood and pine stands and of the rain in the old field.

Lieth (in preparation).[5] The comparison of Table VIII (open-field rain-collection station) with Figure 5 shows that the Ca content of the rain collected in this study compares very well with that shown at neighboring stations of the National Network. However, K, NH_4, and NO_3 are significantly lower for our station than for the surrounding precipitation chemistry stations. The reason for this should be found with further study.

On an annual basis, N, P, K, Ca, and Mg concentration in rainfall increased as it passed through the forest canopy (Table VIII). The gain in K, Ca, and Mg was greater for hardwood than for pine.

The pH of throughfall water corresponded to chemical composition of the leaf tissue and was highest in hardwood, followed by pine and the open area (Fig. 6). The greatest differ-

[5] Wolaver, T. and H. Lieth, in preparation: Distribution of natural and anthropogenic elements in precipitation across the United States: Theory and quantitative models.

Table VIII

N, P, K, Ca, and Mg in hardwood and in throughfall and open-field rainfall (kg/ha)

Location	Nitrogen				P	K	Ca	Mg
	NH_4	NO_3	Organic	Total				
Hardwood	1.15	1.43	2.32	4.86	0.61	17.48	12.47	3.75
Pine	0.74	2.03	1.59	4.38	0.74	9.28	8.94	2.25
Open	0.74	1.46	1.33	3.53	0.28	0.88	3.42	0.72

Table IX

Nutrients measured in stemflow water (kg/ha)

	Nitrogen				P	K	Ca	Mg
	NH_4	NO_3	Organic	Total				
Yearly Total Pine Site	.019	.046	.091	.156	.004	.321	.853	.120
Hardwood Site	.014	.034	.185	.233	.003	.647	2.024	.242
Winter Months Pine Site	.005	.014	.020	.039	.001	.075	.163	.017
Hardwood Site	.003	.007	.064	.074	.001	.177	.760	.066
Growing Season[1] Pine Site	.014	.032	.071	.117	.003	.246	.690	.103
Hardwood Site	.011	.027	.121	.159	.002	.470	1.264	.176

[1]Growing season was considered to be from third week of April through last week of October.

Table X

Quantity and relative contribution of nutrients in rainfall, throughfall, stemflow, and litterfall of hardwood and pine stands (kg/ha/yr)

	HARDWOOD					PINE				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
(a) Rainfall	3.52	0.28	0.88	3.42	0.62	3.52	0.28	0.88	3.42	0.62
% Total	.89	7.26	2.72	3.12	2.80	10.70	7.04	5.24	9.12	6.63
(b) Throughfall	4.86	0.61	17.48	12.47	3.75	4.38	0.74	9.28	8.94	2.25
% Total	9.51	15.76	54.13	11.41	16.97	13.31	18.60	55.24	23.85	24.04
(c) Stemflow	0.23	0.00	0.65	2.02	0.24	0.15	0.00	0.32	0.85	0.12
% Total	0.45	0.01	2.01	1.79	1.08	.46	0.01	1.90	2.27	1.29
(d) Litterfall	45.98	3.26	14.16	94.99	18.11	28.38	3.24	7.20	27.70	6.99
% Total	90.03	84.23	43.86	86.87	81.95	86.24	81.74	42.87	73.90	74.69
TOTALS (b+c+d)	51.07	3.87	32.29	109.48	22.10	32.91	3.98	16.18	37.48	9.36

ence in pH of pine and hardwood throughfall was in the spring and summer; during fall and early winter the pine and hardwood were nearly the same.

• *Stemflow.* Table IX shows the nutrient contribution from stemflow. The data show, for several elements, seasonal and yearly differences between the hardwood area and pine stands. There were no definite trends when comparisons were made between overstory and understory for the two sites.

The hierarchical order of the elements in stemflow was Ca, K, Mg, N, P. Duvigneaud et al. (1970) reported the same relationship for a mixed oak forest in Belgium, and Cole et al. (1968) reported similar results for a Douglas fir stand in the State of Washington. Nitrate nitrogen, NH_4, and P were approximately equal for both stands. In the hardwood stand, approximately twice the amount of K, Ca, Mg, and organic N was measured during the year than at the pine site. Approximately 80 per cent of the precipitation fell during the growing season and contained a proportional amount of each element, thus indicating no seasonal differences in the nutrient content of stemflow water.

• *Relative Contribution of Rainfall, Throughfall, Stemflow, and Litterfall to Nutrients Reaching the Soil Surface.* Rainfall (Table X) contributed about 75 per cent of the N in throughfall, slightly less than 50 per cent of the P, about 30 per cent of the Ca and Mg, and a very small portion of the K. Except for P, more of each measured element was washed from the hardwood canopy trees than from the pine canopy. A greater amount of K was contributed by throughfall than by litterfall. The amount of all other elements was much greater in litterfall than in throughfall (Table X).

The least amounts of all elements were contributed by stemflow. Duvigneaud et al. (1970), measuring in the "mixed oakwood" ecosystem at Verelles, Belgium, found similar results. Carlisle et al. (1967) and Cole et al. (1968) also obtained similar results.

The hardwood understory of the pine was quantitatively important to nutrient cycling. Actually, the needlefall of pine contributed 63, 59, 56, 44, and 54 per cent of N, P, K, Ca, and Mg, respectively, in the total litterfall. Most of the other elements came from hardwood understory. Hardwood understory would probably also contribute proportionally more to the throughfall and stemflow components.

Several nutrients measured in the precipitation at the Research Triangle site were compared with nutrient levels reported from other stations within the Southeast (Fig. 5). The maps were produced by the SYMAP program (Reader et al., 1972). The displays are contours of yearly fallout of four constituents (K, Ca, NH_4, NO_3) in mg/m^2.[6] The data, except for those from the Triangle site, were collected in conjunction with the National Air Sampling Network (1959–64). Yearly fallout of K at the Triangle Site seems to represent a rural low, higher values occurring along coastal and specific urban areas. Yearly Ca fallout has a fairly even distribution throughout the Southeast, with slight increases inland of the Triangle Site and southward into Florida. Ammonium, like Ca, is low in certain rural areas and higher in coastal and urban areas. Ammonium has a fairly continuous fallout distribution throughout the Southeast, with lows occurring at the Triangle site and the Florida panhandle. Better definition of these relationships will be obtained when more collecting stations become established throughout the Southeast.

Rainfall adds elements in quantities considered important for maintaining the function of the ecosystem. Total nutrient and cycling models, when completed, will indicate the importance of variations in element content of rainfall as shown for the eastern United States.

In the cycling of elements between forest trees and soil, litterfall, throughfall water, and stemflow water, in that order, are the important means of element return to the soil. In this study of adjoining hardwood and pine forests, the effect of species shows the greater cycling rate of hardwood in comparison with pine.

[6] $mg/m^2 \times 10^{-2} = kg/ha$.

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