NUTRIENT INPUTS AND POOLS IN UPLAND AND BOTTOMLAND FORESTS OF ALLERTON PARK, ILLINOIS[1]

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Abstract.--Inputs of base cations (Ca^{2+}, Mg^{2+}, K^+, Na^+), NO_3^-, NH_4^+, SO_4^{2-}, Cl^-, dissolved organic carbon (DOC) and H^+ were examined in upland and bottomland sites in east-central Illinois. Soil pools of base cations and exchangeable Al^{3+} and H^+ were also determined. Litterfall added large amounts of N, S, and organic materials (e.g. 11.2 and 7.1 kg S/ha/yr in bottomland and upland sites, respectively). Inputs of sulfate by throughfall were 14.8 and 15.2 kg S/ha/yr in bottomland and upland sites, respectively, corresponding to 27 and 11% of the 0-60 cm soil sulfate pool. Throughfall was dominated by base cations (primarily Ca^{2+} and K^+), sulfate, and nitrate. Upland soils had low levels of Ca^{2+} and Mg^{2+} and similar levels of K^+ compared to the bottomland soil (e.g. 1-5 and 19-26 meq Ca^{2+}/100 g in upland and bottomland soils, respectively). Exchangeable H^+ and Al^{3+} levels were also greater in the more acid upland soils, in comparison to the bottomland (1-5 and 0.05-0.1 meq total acidity/100 g soil in upland and bottomland soils, respectively). Each forest requires different management with respect to nutrient availability and possible fertilization requirements.

INTRODUCTION

Nutrients are added to forest soils through several mechanisms including: litterfall, root litter, throughfall, stemflow, root exudates, and periodic flooding. All can add to the pool available for plant uptake, although some inputs require subsequent mineralization (e.g. litterfall).

Peterson and Rolfe (1982a, 1982b) examined inputs of nitrogen, potassium, calcium, magnesium, and phosphorus via litterfall, stemflow, and throughfall in upland and bottomland forests of central Illinois. Although bottomland and upland litterfall were similar in terms of dry mass and most nutrients, both were greater than comparable temperate forests (Peterson and Rolfe 1982a). They did find greater litter decomposition in the bottomland site compared to the upland. Their examination of solution inputs indicated that for the elements studied the contribution to the forest floor was small compared to organic inputs via litterfall, with the exception of potassium (Peterson and Rolfe 1982b). This work also pointed out that differences in species characteristics and variability in the physical environment produced contrasting patterns of nutrient transfer (Peterson and Rolfe 1982a).

The purpose of the present work was to expand on results obtained earlier at upland and bottomland forests in Illinois by examining similar processes and including additional nutrients, primarily sulfur. The objectives of this project were to: 1) quantify inputs of dry mass, sulfur, and nitrogen through litterfall; 2) determine inputs of anions and cations in throughfall; and 3) relate these inputs to soil pools of nutrients.

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STUDY SITES

Bottomland and upland sites previously studied at Robert Allerton Park were utilized in this study. The park is located along the Sangamon River in east-central Illinois. A detailed description can be found in Peterson and Rolfe (1982a) and Bartel-Ortiz and David (1988).

Silver maple (Acer saccharinum L.) dominates the floodplain site, whereas black and northern red oak (Quercus velutina Lam. and Q. rubra L.) dominate upland sites. Basal areas were 52.0 and 31.8 m^2 ha^{-1} for the bottomland and upland sites, respectively in 1986 (Bartel-Ortiz and David 1988). Peterson and Rolfe (1982a) classified upland soils in this area as Russell silt loam (fine-silty, mixed, mesic Typic Hapludalfs) and Martinsville silt loam (fine-loamy, mixed, mesic Typic Hapludalfs). Bottomland soils primarily consisted of Sawmill silty clay loam (fine-silty, mixed mesic Cumulic Haplaquolls).

METHODS

Field Sampling

After a 0.1 ha circular plot was established on each upland and bottomland site, a 20m x 20m area was centered and divided into 2m x 2m subplots. Soil samples were collected at four depths in the summer of 1986 (0-10, 10-30, 30-60, and 60^+ cm) from pits excavated at five randomly selected points in each plot. Twelve and six funnel (15.5 cm diameter) throughfall collectors were randomly located in the upland and bottomland sites, respectively. Upland collectors were 0.3 m from the ground, whereas the bottomland were 2 m so that they were above flood waters. Collectors were sampled every 2-3 weeks, depending on rainfall. During the winter 8.5 cm diameter plastic cups were used as snow collectors, with samples collected monthly. Bulk precipitation was also collected in an open area of the Park using two collectors. Collections were made from October 1986 through September 1987. River water samples from the Sangamon were obtained whenever throughfall was collected.

Litterfall was collected in twelve and six 0.5 x 0.5 m traps that were randomly located in the upland and bottomland sites, respectively. Traps were constructed from wood frames and fiberglass window screening. Samples were collected periodically from October, 1986 to December, 1987. This included two fall periods which were averaged for yearly flux calculations.

Analytical Techniques

Soil samples were air-dried and sieved (2 mm) before analysis. Litterfall was sorted into leaves, reproductive parts, and wood (only leaf data reported here), dried for 48 hours at 65°C, and ground to pass a 20 mesh sieve in a Wiley Mill. Volume of the throughfall and precipitation was determined by weighing or volume, and all solutions were filtered through GF/C glass fiber filters.

Exchangeable cations were determined using unbuffered NH_4-Cl, with cations in extracts determined by atomic absorption (Robarge and Fernandez 1986). Exchangeable acidity was measured by titrating unbuffered 1N KCl extracts to a phenolphthalein endpoint (Robarge and Fernandez 1986). Base saturation was calculated by summing base cations and dividing by this sum plus exchangeable H^+ and Al^{3+}. Soil content of cations was determined using bulk densities from Bartel-Ortiz and David (1988).

Total S in litter was determined using a LECO SC-132 S analyzer (David et al. 1988). Litter total N was determined by Kjeldahl digestion with ammonium in digests measured using a Wescan Ammonia Analyzer. Solution anions (sulfate, nitrate, and chloride) were determined by ion chromatography, cations by atomic absorption, dissolved organic carbon using a Dohrmann DC-80 analyzer, pH potentiometrically, and ammonium using a Wescan Ammonia Analyzer. Volume weighted averages were used for all solution summaries of precipitation and throughfall.

RESULTS AND DISCUSSION

Litterfall

During the 14 months litterfall was collected, leaf litter averaged 3828 and 5284 kg/ha/yr in the bottomland and upland sites, respectively (table 1). Peterson and Rolfe (1982a) found similar levels of litterfall at both sites during 1978 and 1979 (2-year means of 3846 and 5213 kg/ha/yr for bottomland and upland sites, respectively).

Although dry mass deposition of leaves was less in the bottomland site, S concentrations were much greater leading to greater S inputs (table 1). Total S ranged from 0.161 to 0.532% and 0.097 to 0.224% in bottomland and upland sites, respectively. Annual inputs of leaf S were 11.2 and 7.1 kg S/ha/yr, indicating the large difference in leaf S inputs to the forest floor. Litterfall S inputs for a chestnut oak forest in Tennessee and a northern hardwood forest in the Adirondack Mountains of New York were 10 and 4.7 kg S/ha/yr, respectively (Johnson et al. 1982; David et al. 1987).

Nitrogen inputs were 56 kg N/ha/yr in the bottomland site, and 54 in the upland. Peterson and Rolfe (1982a) observed similar or greater inputs of P, K, Ca, Mg, and Na and smaller inputs of N in litter in the upland versus the bottomland site. Their values for N were 54 and 49 kg N/ha/yr for bottomland and upland sites, respectively.

Table 1.--Leaf litterfall dry mass (kg/ha) and total S and N concentrations and mass at bottomland and upland sites.

Collection Date	Dry Mass	%S	kg S/ha	%N	kg N/ha
Bottomland					
4 Nov	2031	0.262	5.3	1.51	30.7
18 Nov	852	0.223	1.9	1.36	11.6
10 Mar	164	0.188	0.3	1.94	3.2
20 May	17	0.532	0.1	4.07	0.7
28 Jul	140	0.328	0.5	2.49	3.5
30 Sep	486	0.388	1.9	1.37	6.7
2 Nov	2914	0.318	9.3	1.30	37.8
9 Dec	247	0.161	0.4	1.66	4.1
Upland					
4 Nov	2768	0.153	4.2	1.02	28.1
18 Nov	1230	0.115	1.4	0.76	9.5
10 Mar	437	0.126	0.6	0.98	4.3
20 May	33	0.224	0.1	2.32	0.8
28 Jul	114	0.192	0.2	2.23	2.5
30 Sep	502	0.154	0.8	1.43	7.2
2 Nov	2867	0.136	3.9	0.95	27.2
9 Dec	1531	0.097	1.5	0.86	13.2

The higher concentration of S and N in bottomland leaf litter probably reflects the large pools of total S and N found in this soil (Peterson and Rolfe 1982b; Bartel-Ortiz and David 1988). Because of inputs of organic matter from flood events, the bottomland site is richer in both of these elements. Peterson and Rolfe (1982b) measured total N contents of 16540 and 6530 kg N/ha for the 0-60 cm soil depth in bottomland and upland sites, respectively, whereas Bartel-Ortiz and David (1988) measured corresponding total S contents of 3072 and 1353 kg S/ha. Inasmuch as S and N cycling is closely coupled, increased N uptake by the bottomland forest in comparison to the upland would also increase S uptake.

Precipitation and Throughfall

Wet only precipitation chemistry is available from a nearby (30 km) NADP station at Bondville, Illinois. Volume weighted mean chemistry for the period 1980-1984 is shown in figure 1. Wet deposition is dominated by sulfate and H^+, with smaller concentrations of nitrate and ammonium. Because of exposure to dust and other dry components and gases, bulk precipitation collected at Allerton Park shows increased concentrations of most elements, particularly base cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) and sulfate (fig. 1).

After passage of precipitation through the bottomland and upland canopies, large increases in base cations and sulfate were found (fig. 1). Hydrogen ion was also neutralized, with little change in chloride, ammonium, or nitrate concentrations. This increase in cations and sulfate may be from two processes: 1) washoff of dust deposited on foliage; and 2) leaching of foliage. For K^+, leaching is known to be an important process. Little difference in throughfall chemistry was observed between sites, a similar finding to that of Peterson and Rolfe (1982b). Calcium was the dominate base cation, followed by K^+, Mg^{2+}, and Na^+.

The imbalance between anions and cations in throughfall suggests that other anions are present in the solutions. Both organic anions and bicarbonate are probably present. Dissolved organic carbon concentrations averaged 756 and 735 µmol C/L in the bottomland and upland throughfall, and could contribute large amounts of organic anions (table 2).

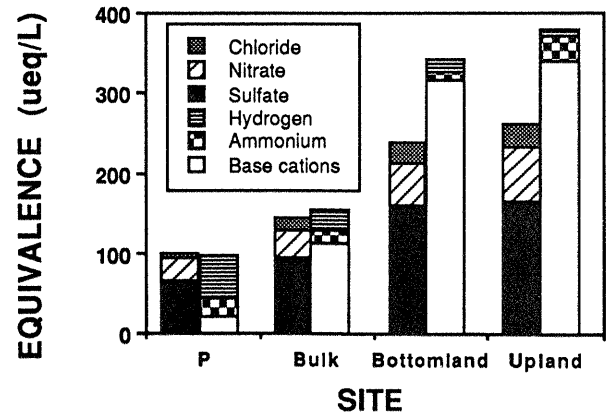

Figure 1.--Charge distribution in precipitation collected at Bondville, IL, bulk precipitation, and bottomland and upland throughfall at Allerton Park. Base cations are the sum of Ca^{2+}, Mg^{2+}, K^+, and Na^+ equivalence.

Table 2.--Volume weighted concentrations of dissolved organic carbon (μmol/L) in throughfall at bottomland and upland sites.

Sample	Mean	Range
Bottomland Throughfall	756	237 - 1460
Upland Throughfall	735	274 - 2022

Deposition of ions follows the same pattern as concentration, and illustrates the amounts of ionic inputs to the forest floor (fig. 2). Sulfate inputs were 617, 925, 948 eq/ha/yr in bulk precipitation and bottomland and upland throughfall, respectively. On a kg S/ha/yr basis corresponding values are 9.9, 14.8, and 15.2, respectively. These data suggest a large increase in S as a result of canopy washing and leaching.

Sangamon River

Another input to the bottomland site is the Sangamon River, which usually floods the site for several months each year. Peterson and Rolfe (1982c) measured sedimentation inputs for several elements, and showed this was an important input. Water chemistry suggests that for many elements flooding and diffusion of elements into the soil solution may also be a significant input (table 3). Very high concentrations of all elements except K^+ and ammonium are found in river water. It is not possible to calculate inputs from this source, but the potential is there for substantial additions.

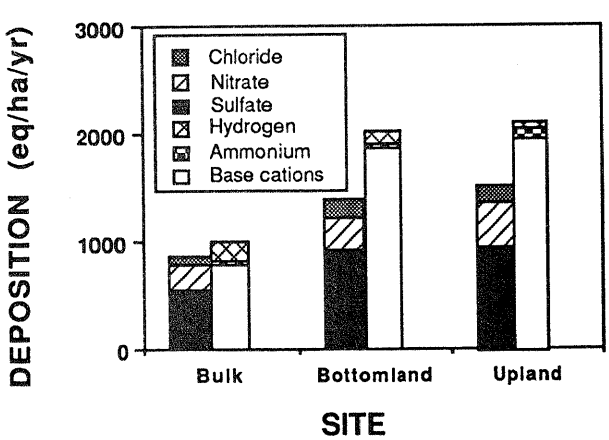

Figure 2.--Charge distribution in bulk deposition and bottomland and upland throughfall at Allerton Park. Base cations are the sum of Ca^{2+}, Mg^{2+}, K^+, and Na^+ equivalence.

Table 3.--Concentrations of anions and cations in the Sangamon River sampled at Allerton Park, Illinois (units are μeq/L).

	Mean	Range
pH	8.2	7.6 - 8.5
Ca^{2+}	3346	1344 - 3969
Mg^{2+}	2347	1041 - 3076
K^+	49	22 - 102
Na^+	594	150 - 1481
NH_4^+	6	1 - 15
SO_4^{2-}	830	485 - 1088
NO_3^-	429	74 - 928
Cl^-	856	483 - 1514

Soil Pools

Cation levels are strikingly different between the sites (table 4). The upland site is an acidic Alfisol, with low concentrations of cations and large amounts of exchangeable Al^{3+}. Base saturations range from 33.5 to 91.5% however, indicating that although the cation pool is small, base cations still dominate. In the bottomland soil, levels of Ca^{2+} and Mg^{2+} are much greater, K^+ about the same, and exchangeable Al^{3+} and H^+ lower. Base saturations are all greater than 99%. This difference between the sites can be attributed to annual flooding of the bottomland site with Ca^{2+} and Mg^{2+} rich river water along with particle sedimentation. Soil pH (0.01 M $CaCl_2$) reflects the cation levels and base saturation ranging from 6.3 - 6.8 and 3.7 - 4.5 in bottomland and upland soils, respectively (Bartel-Ortiz and David 1988).

Table 4.--Soil exchangeable cations at bottomland and upland sites.

Depth (cm)	Mg^{2+}	Ca^{2+}	K^{+}	Al^{3+}	H^{+}	% Base Sat
	meq/100 g					
Bottomland						
0-10	9.7	25.6	0.3	0.04	0.06	99.7
10-30	9.1	23.2	0.3	0.04	0.03	99.8
30-60	8.1	20.0	0.2	0.03	0.02	99.8
60-90	7.6	18.8	0.2	0.06	0.00	99.8
Upland						
0-10	1.1	3.8	0.2	0.41	0.05	91.5
10-30	0.4	1.1	0.1	2.54	0.62	33.5
30-60	2.3	2.4	0.2	4.16	0.55	50.9
60-100	4.2	5.3	0.2	2.48	0.64	75.7

The content of exchangeable cations illustrates the large pool size of Ca^{2+} and Mg^{2+} in the bottomland soils (table 5). For the top 0-60 cm of mineral soil Ca^{2+} and Mg^{2+} pools are 1736 and 687 versus 207 and 143 keq/ha for the bottomland and upland soils, respectively. Potassium is remarkably similar between the sites (16 - 18 keq/ha), suggesting little input from river water or sediments. Concentrations of K^{+} were similar at both sites to levels determined by Peterson and Rolfe (1982c). Bottomland concentrations also were similar for Ca^{2+} and Mg^{2+}. However, these latter two cations were only about half the values they reported. This could be attributed to seasonal variation in cation concentrations illustrated by Peterson and Rolfe (1982c, 1985) for these sites.

Elemental Cycling of S

Inputs of S by litterfall and throughfall add large amounts of this element to the soil (26.0 and 22.3 kg S/ha/yr for bottomland and upland sites, respectively). Total S pools in the soil (0-60 cm) were estimated at 3072 and 1353 kg S ha^{-1} in the bottomland and upland, respectively, with sulfate pools of 54 and 71 kg S/ha (Bartel-Ortiz and David 1988). Throughfall is an important source of sulfate, adding 27 and 11% of the soil sulfate annually for the bottomland and upland sites, respectively. Additional sulfate is probably made available through mineralization of organic S as well (Bartel-Ortiz and David 1988).

Table 5.--Content of soil exchangeable cations at bottomland and upland sites.

Depth (cm)	Mg^{2+}	Ca^{2+}	K^{+}	Al^{3+}	H^{+}
	keq/ha				
Bottomland					
0-10	112	296	4	0.4	0.7
10-30	247	630	7	1.0	0.9
30-60	327	809	7	1.1	0.7
60-90	282	697	6	2.2	0.0
Sum					
(0-60)	687	1736	18	2.5	2.3
Upland					
0-10	14	52	2	5.6	0.7
10-30	13	34	4	81	20
30-60	116	122	10	211	28
60-100	246	307	14	145	38
Sum					
(0-60)	143	207	16	298	48

CONCLUSIONS

Inputs of elements to bottomland and upland soils are similar for throughfall but different for leaf litter S. Bottomland soils are strongly influenced by inputs from the Sangamon River, which annually floods the site. This increases soil pH, and exchangeable Ca^{2+} and Mg^{2+}, compared to the upland soil. Large amounts of sulfate are added to the soil by throughfall in comparison to soil pools. For other elements, proportions are much smaller. Because of large differences in soil pools and inputs, each forest requires different management with respect to nutrient availability and possible fertilization requirements.

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