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# Mineral cycling and productivity in an upland deciduous forest: soils and methods

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## MINERAL CYCLING & PRODUCTIVITY IN AN UPLAND DECIDUOUS FOREST: SOILS & METHODS

### INTRODUCTION

This study was designed to improve our understanding of the dynamics of the upland forest and of the productivity of Wisconsin forest communities. Data were collected to quantify the biological cycling of nutrients, nutrient availability and water availability, the principal factors supporting production of organic matter in forest ecosystems (Duvineaud and Denaeyer-De Smet, 1970). Using the data from this study we can then examine the stability of the upland deciduous forest and its response to the environment, for example recovery from a catastrophic event such as the March ice storm. Once this ecosystem's structure and functioning are known, we can compare it to other ecosystems on the basis of production efficiency and potential. Knowledge of mineral cycling and productivity should help land planners to more efficiently manage the forest resource. This study extends work done previously on primary production in Wisconsin and complements nutrient flux studies at Oak Ridge National Laboratory.

### METHODS

Work on this study began on June 1, 1974 and the installation and instrumentation were completed in December. Mineral fluxes between the dominant tree layer and the abiotic (soil and atmosphere) compartments in the upland deciduous forest were sampled from January 1 to December 31, 1975.

The study plot (80 x 100 ft) (*Fig. 1*), located on a ridge crest in the northwestern portion of the upland deciduous forest of the UWM Field Station, included the dominant tree species: sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), white ash (*Fraxinus americana*), and shagbark hickory (*Carya ovata*) (Dunnum, 1972). The study plot was relatively level. The soil profile, a Hocheim-Sisson-Casco Complex, was described qualitatively and quantitatively. The major rooting zone was determined to be 15 inches deep. Sampling was designed to examine the effects of stemflow on nutrient accumulation in the organic layer.

Precipitation was collected to determine the water and nutrient input to the system. Measurements included direct rainfall, throughfall (that penetrating the canopy) and stemflow (water flowing down the tree trunk). Nutrient content and amounts of percolating groundwater were also determined. One rain gauge, located in a nearby field, collected precipitation unaffected by vegetation, two gauges on the test plot collected throughfall (*Fig. 1*) and one gauge on the UWM campus was used to determine urban effects. Snow samples and dust samples (atmospheric fallout between precipitation events) were obtained in a similar manner. Collars to collect stemflow were placed around the trunk, on a sugar

maple, beech trees of two sizes, an ash, a shagbark hickory and a dead elm. Zero-tension lysimeters, designed by Jordan (1968), were placed under the O1, O2, A2, and B2t soil layers. Each layer was monitored by two lysimeters. The B2t layer was the lowest layer of the major rooting zone, and the lysimeters under this layer monitored those nutrients leaving the system. Lysimeters were housed in a protected pit, 7 feet deep. The Wisconsin Department of Natural Resources provided water analyses which included  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$ ,  $\text{NH}_3\text{-N}$ , organic matter, total N,  $\text{PO}_4\text{-P}$ , total P, Ca, Mg, Fe, Mn, Na, K, conductivity,  $\text{SO}_4$ , Cl, pH, alkalinity and turbidity. One hundred ten samples were tested.

A sugar maple (5.5 in. dbh) and an American beech (7.1 in. dbh) were cut, measured and dissected to obtain data on biomass (Whittaker, 1961, 1965, and 1966, and Whittaker and Woodwell, 1968) above and below ground annual production, and nutrient content (total N, total P, K, Ca and Mg) of all plant structures. The maple was approximately 76 years old and the beech approximately 74 years old.

Data were obtained in a manner compatible with systems analysis techniques to permit modeling the nutrient budget. Timing and rate of mineral transfer, potential nutrient loss from the system, nutrient sources, storage and relation of nutrient availability to annual productivity are involved in the model.

## SOIL CLASSIFICATION

Quantitative soil measurements were made to precisely identify soil horizons and determine mineral storage. Knowledge of soil horizons was necessary for placement of ground water lysimeters.

As the lysimeter pit was dug, five soil horizons were tentatively identified by color and texture. Soil samples were obtained from these horizons on both sides of the five foot long pit. Ten soil samples were sent to the Wisconsin Soil and Plant Analysis Laboratory for analysis (*Table 1*). Soil testing procedures are outlined in their pamphlet (Schulte and Olsen, 1970).

Soil samples were analyzed to determine available phosphorus and potassium, and exchangeable calcium and magnesium. Available nutrients are those which can be readily absorbed or assimilated by growing plants (Soil Science Society of America, 1970). Ca and Mg are cations which are held by the negatively charged clays and organic matter (Buol, Hole and McCracken, 1973). These cations can be replaced by other cations (exchanged), thus becoming available for absorption or assimilation by growing plants.

The O1 layer (litter layer) varied in thickness, it was often absent around tree trunks and as thick as half an inch in shallow depressions. The O2 layer (decomposed organic matter) appeared black and averaged 3 inches in thickness. This layer was high in organic matter, available phosphorus, exchange bases (Ca and Mg), and total nitrogen (*Table 1*). The A2 layer (mineral layer leached of

clay) was light colored and averaged 8 inches in thickness. This layer was characterized by some accumulation of organic matter, probably due to earthworm and soil fauna mixing of humus and mineral soil (Buol, et al, 1973), a concentration of sand and silt, and loss of clay (*Table 1*). The B2t layer (mineral layer with accumulation of clay) was 4 inches thick and darker than the A2 layer and had a red tint, indicating illuvial iron. Analyses indicated an accumulation of clay, available potassium and exchangeable magnesium (*Table 1*). The B3t layer, or transitional layer between the B2t and C layers, was lighter than the B2t layer but darker than the C. This layer averaged 4 inches in thickness and was characterized by illuvial clay (*Table 1*). The C layer (underlying glacial till) at the 5 ft. level was light in color and was characterized by a high level of exchangeable calcium and considerable sand (*Table 1*). The B3t and C layers were extremely rocky, inhibiting root penetration. The major rooting zone occurred in the O2, A2 and B2t layers.

These soils data substantiated the tentative selection of soil horizons made as the pit was dug. Two lysimeters were placed under each of the top four horizons (O1, O2, A2 and B2t), collecting the groundwater leaving each layer. Nutrient flow between layers could thus be monitored.

The upland deciduous forest soils of the UWM Field Station, about 90 percent Hocheim-Sisson-Caseo Complex and about 10 percent Casco Loam, are classified (using the 7th Approximation soil classification system), as Typic Hapludalfs (USDA-SCS, 1970). Typic Hapludalfs, formerly called grey-brown podzolics, are well-drained, high-base status forest soils (Buol, Hole and McCracken, 1973). The major soil series, and that found on the experimental plot, Hocheim-Sisson-Casco Complex, is further defined as a fine loamy, mesic soil (USDA-SCS, 1970).

Loamy soils are those with 7 to 27 percent clay, 28 to 50 percent silt and less than 52 percent sand (SSSA, 1970). In the experimental plot, the active soil forming layers (O, A and B) contain loamy soils, and except for the O layer, the percent clay is in the upper range for loam soils (*Table 1*), indicating a fine loamy soil.

Where litter was present, the O2 horizon remained moist throughout the year. Although moist, the soils were never waterlogged, even during or after the most severe rains. No evidence of gleization, indicating standing water, could be found within the seven foot soil profile observed while digging the lysimeter pit.

The trees, especially beech and maple, bring up large quantities of nutrients from the soil. Accumulation of nutrients in the surface layers, especially N, P, K, Ca and Mg, occurs during succession as a stand develops towards climax (Duvigneaud and Denaeyer-DeSmet, 1970). This enrichment of nutrients in the surface layers probably helps to buffer or stabilize the ecosystem against human or natural perturbations.

The O2 layer has a high concentration of Ca and Mg (*Table 1*); these cations were absorbed by the roots, largely in the B3t or upper C layer, translocated and incorporated into leaf tissue, and after leaf fall and the subsequent decay of leaf tissue, accumulated in the O2 layer. Accumulation occurs because Ca and Mg are not readily leached through the soil, since they are absorbed by clay particles and organic matter.

Calcium to magnesium ratios ranging from 1:1 to 8:1 are common and these ratios support normal plant growth (Walsh, 1973). Soil analyses (*Table 1*) indicate a 4.5:1 ratio for the O2 layer, 2.8:1 for the A2 layer, 2.1:1 for the B2t layer, 2.3:1 for the B3t layer and 11.3:1 for the C layer; thus suitable Ca/Mg ratios for normal plant growth are present in the experimental plot.

Available Ca is estimated by measuring exchangeable calcium (Walsh, 1973). The optimum range of available Ca in loamy soils is 2000 to 4000 lbs/acre (Walsh, 1973). Soils in the plot ranged from 2675 (A layer) to 7875 (C layer) lbs/acre (*Table 1*), indicating abundant calcium available for plant growth, consistent with high base status forest soils.

#### EFFECTS OF STEMFLOW ON NUTRIENT ACCUMULATION IN THE O2 LAYER

A beech (13 in. DBH) and maple (14.5 in. DBH) just outside the experimental plot were chosen to determine the effects of stemflow on nutrient accumulation in the O2 layer. These trees were isolated with the trunk at least 20 ft. to the nearest tree, thus stemflow from surrounding trees should have little effect on the data (*Table 2*). Soil samples were taken in a line north and south of the tree trunk at 0, 8, 16, 28, and 68 inches distant from the trunk. In sampling, a can 2 inches in diameter was inserted approximately 3 inches into the O2 layer.

Sixty eight inches from the tree base, the phosphorus level was 27 percent lower than at the trunk for the beech and 41 percent lower for the maple. Potassium levels dropped over the same distance 23 percent in the case of the beech and 47 percent for the maple. Presumably these differences result because the nutrients from stemflow remain near the trunk since P and K are relatively immobile in the soil. Preliminary data suggest that P and K are accumulated by the rainwater as it flows down the stem. Both water extractable pH and reserve pH (SMP) also decrease with distance from trunk base (*Table 2*). Stemflow from the beech and maple trees had a pH of approximately 5.0.

These nutrient and pH differences may influence habitat selection by plants and animals inhabiting the forest floor. Further research is needed to explore these relationships. Studies in Europe suggest that floristic composition, especially ground flora, is indicative of the degree of nutrient accumulation in the soil surface (Duvigneaud and Denaeayer-DeSmet, 1970).

## MODELING

Data on the nutrient content of rainfall, throughfall, stemflow, ground-water and plant tissue, and productivity and biomass values are being organized and analyzed to formulate an annual nutrient budget and model.

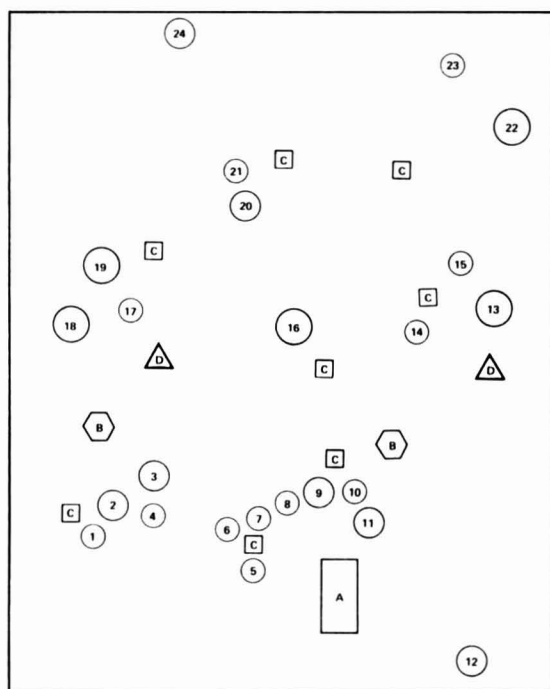


Fig. 1. Experimental Plot

- A. Ground lysimeter pit housing lysimeters for the O<sub>2</sub>, A<sub>2</sub> and B<sub>2t</sub> soil layers.
- B. Ground lysimeter pit housing lysimeters for the O<sub>1</sub>, or litter layer.
- C. Litter trap.
- D. Rain collector.

Species	DBH (inches)	Species	DBH (inches)
1. American Beech	5.05	18. Sugar Maple	16.00
2. Sugar Maple	14.10	19. Shagbark Hickory	15.70
3. Sugar Maple	12.10	Used to monitor stem flow.	
4. Sugar Maple	8.70	20. American Beech	10.10
5. American Beech	4.10	Used to monitor stem flow.	
6. American Beech	6.50	21. American Beech	5.60
7. White Ash	4.15	Used to monitor stem flow.	
8. American Beech	8.30	22. American Beech	18.40
9. Sugar Maple	9.20	23. American Beech	3.80
10. American Beech	8.05	24. Dead Elm	13.25
11. Shagbark Hickory	12.50	Used to monitor stem flow,	
12. Black Cherry	9.90	12 ft. stump.	
13. White Ash	15.20		
Used to monitor stem flow.			
14. Northern Red Oak	5.05		
15. Sugar Maple	3.00		
16. Sugar Maple	17.80		
Used to monitor stem flow.			
17. Sugar Maple	6.50		
Lightning hit tree, only one main branch remains.			

Table 1. Soil of experimental plot.

Analyses <sup>1</sup>	Soil Horizons				
	O2	A2	B2t	B3t	C
pH	6.6	6.9	7.0	7.4	7.8
Organic matter (tons/acre)	73	23	15	18	6
Available phosphorus (lbs/acre)	32	19	13	9	5
Available potassium (lbs/acre)	143	150	178	175	75
Exchangeable calcium (lbs/acre)	4750	2625	3700	4075	7875
Exchangeable magnesium (lbs/acre)	1050	900	1750	1750	700
NO <sub>3</sub> -N (lbs/acre)	4	1	1	1	1
Total nitrogen (%)	0.32	0.08	0.07	0.08	0.02
Soluble salts (mhos x 10 <sup>-5</sup> /cm)	28	10	25	25	15
Sand (%)	51	50	47	49	68
Silt (%)	42	35	24	31	27
Clay (%)	8	16	29	20	6

<sup>1</sup> All values represent an average of two samples, each taken from opposite ends of the lysimeter pit.

Table 2. Effects of stemflow on nutrient accumulation in the O2 layer.

Sample	pH	SMP <sup>1</sup>	Organic Matter tons/acre	Available Phosphorus lbs/acre	Available Potassium lbs/acre
Base of beech to south	3.7	5.0	125	35	185
8" from base	4.5	5.6	125	37	210
16" from base	5.7	6.4	120	30	165
28" from base	6.3	6.8	100	27	170
68" from base	6.1	6.7	100	30	120
Base of beech to north	5.5	6.4	125	45	135
8" from base	5.8	6.5	100	35	125
16" from base	6.0	6.6	100	37	125
28" from base	5.6	6.4	100	35	110
68" from base	6.2	6.8	100	27	120
Base of maple to south	5.1	5.3	125	65	415
8" from base	4.0	5.2	125	45	315
16" from base	5.0	6.1	125	50	225
28" from base	5.8	6.5	100	45	160
68" from base	6.3	6.8	125	35	150
Base of maple to north	5.0	6.0	115	55	210
8" from base	6.6	7.0	125	35	170
16" from base	6.9	—	125	35	145
28" from base	6.4	6.8	125	45	140
68" from base	6.7	7.0	125	35	150

<sup>1</sup>SMP — buffer solution, used to measure reserve pH or saturation pH

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