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Forest Lysimeter Studies Under Hardwoods

HERBERT A. LUNT

Connecticut
Agricultural Experiment Station
New Haven

CONTENTS

FIGURE 1. Location of tank lysimeters. Tank No. 1 at near end of pit; tank No. 6 at far end.

FIGURE 2. Location of the second set of pan lysimeters (Nos. 13 - 18). No. 13 in foreground, not visible, but location marked by two stakes.

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IN the spring of 1932 a forest lysimeter study was started with the installation of a set of six shallow tanks under red pine (*Pinus resinosa*). A year later two sets of six pan-type lysimeters [a modification of the Ebermayer type (1)] were added and the whole eighteen carried on for two years. The findings of this work were reported in two publications (2) (3). Then, in the spring of 1938, the equipment was moved to a hardwood stand where the study was continued for two more years. The results of this portion of the work are presented herewith.

DESCRIPTION AND INSTALLATION

The place selected for installation was an uneven-aged stand of mixed hardwoods in Block 2, Maltby Division, Eli Whitney Forest, belonging to the New Haven Water Company and situated in the town of West Haven about three miles due west of the New Haven Green.

The stand in the vicinity of the lysimeters consisted of black birch (*Betula lenta*) and red oak (*Quercus borealis* Michx. f.) up to 15 inches D. B. H., and 55 to 60 years old; and smaller stems of sugar maple (*Acer saccharum*, Marshall), dogwood (*Cornus* spp., mostly *florida*), red maple (*Acer rubrum*) and white oak (*Quercus alba*). The lesser vegetation consisted of maple-leaf viburnum (*Viburnum acerifolium*), chestnut sprouts (*Castanea dentata*), pinxter flower (*Rhododendron nudiflorum*), blueberry (*Vaccinium vacillans* or *pennsylvanicum*) and sarsaparilla (*Aralia nudicaulis*).

The topography was nearly level to gently sloping west. The soil was classified as Woodbridge fine sandy loam. The profile in the immediate vicinity of the tank lysimeters (see Figure 1) may be described as follows:

F ½ inch. Normal decomposition; variable in amount.

H ½ inch. Black, felty, slightly fibrous mor.

A_1 0 - 1 inch (±½"). Very dark brown f. s. l., finely granular, friable.

A_3 1 - 4 inches (±1½"). Brown f. s. l., finely granular, friable; gradually changing to

B_1 4 - 12½ inches (±½"). Yellow brown loam, somewhat granular, firm.

B_2 12½ - 31 inches (±2"). Reddish yellow brown loam, somewhat granular, firm.

C_1 31 inches+. Mixed red and yellow brown loam, moderately compact. Occasional zones of iron accumulation in root channels and cracks. Some stone (granite gneiss) was present in the B and C horizons.

In the vicinity of the two pan-lysimeter units (Figure 2) there was less H material present, and the type of humus layer varied from a granular mor to a firm mull.

The amount of duff as measured in four one-foot squares was found to be equivalent to the following quantities of oven-dry material per acre: F — 6,800 pounds, H — 17,440 pounds. Most of the roots close to the trees were found to occupy the soil between the two- or three-inch level and the 26-inch level, with a few going 30

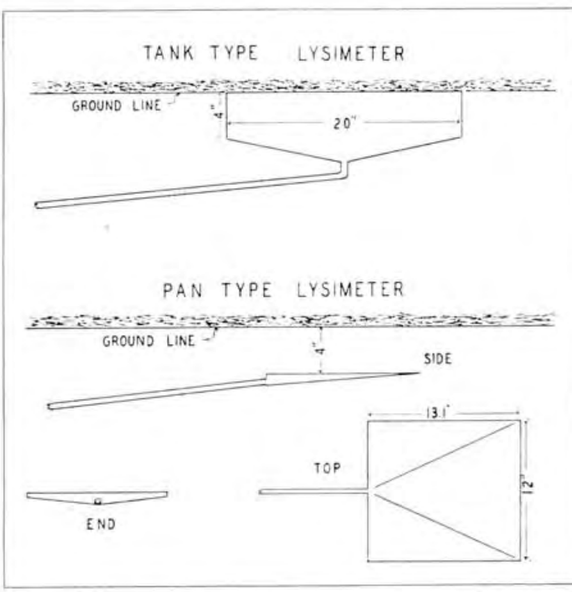

FIGURE 3. Sketch showing the two types of lysimeters used in these studies.

inches or more. At greater distances from the tree the roots did not, for the most part, go deeper than 7 to 10 inches.

The equipment consisted of a set of six tank-type lysimeters and two sets of six pan-type lysimeters (Figures 3 and 4) installed April 6 to 11, 1938. The relative position of each lysimeter around the central pit was governed by the position of the trees and shrubs, the presence or absence of rocks and tree roots and the suitability of the surface soil.

As in the previous experiment, the primary object was to study the movement of water and nutrients through the forest floor, alone or together with 3 to 4 inches of the upper mineral soil. Two tanks were filled with pure quartz sand and then covered with the natural F and H material with as little disturbance as possible. Two more were filled with the natural mineral soil which had been removed in the form of a round block of the same size as the tanks and then put into the tanks in quarter sections with as little disturbance as possible (Figures 5 and 6). This pair was kept free of leaves and other debris.

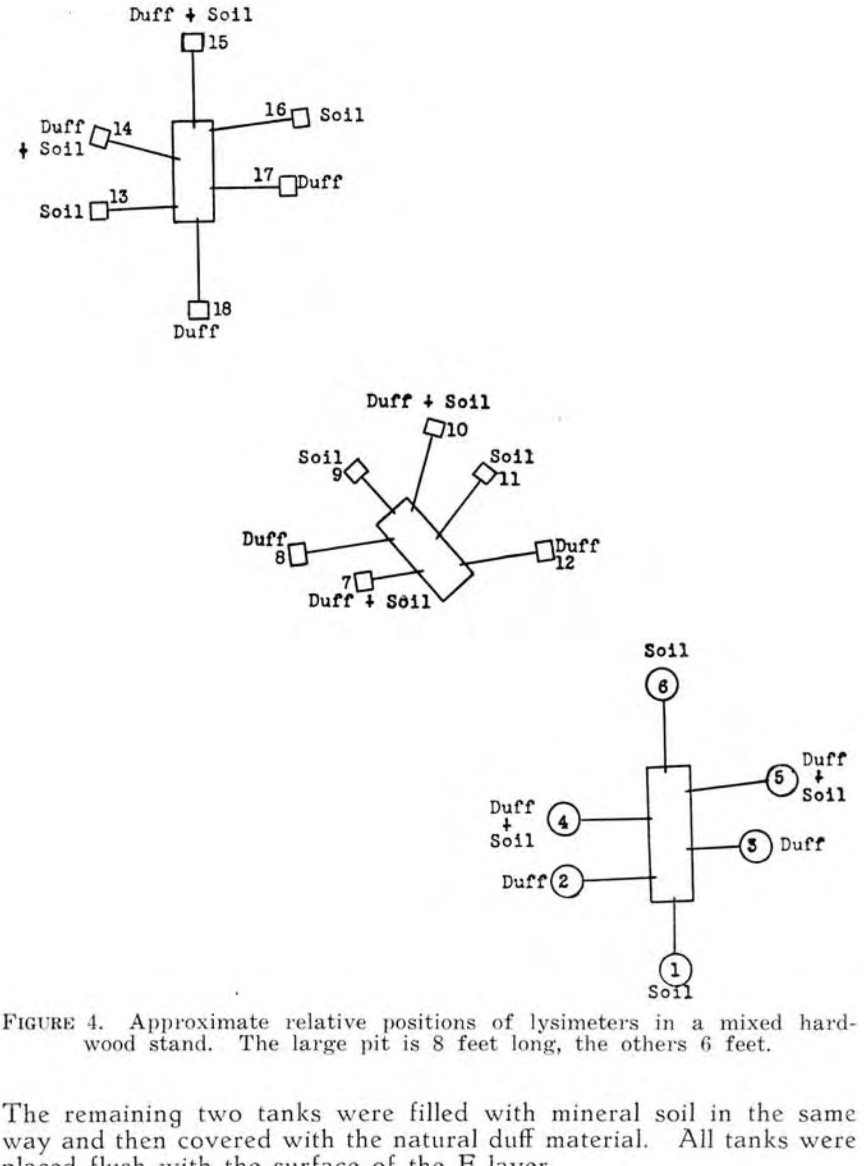

FIGURE 4. Approximate relative positions of lysimeters in a mixed hardwood stand. The large pit is 8 feet long, the others 6 feet.

The remaining two tanks were filled with mineral soil in the same way and then covered with the natural duff material. All tanks were placed flush with the surface of the F layer.

In the case of the pan lysimeters, two in each set were placed just under the H layer, two under 4 inches of soil kept bare of debris, and two under 4 inches of soil with the natural undisturbed F and H layers on top. As in the red pine study, the pans were shoved horizontally into place with a minimum of disturbance of the soil.

FIGURE 5. Installation of tank lysimeters. Tank No. 6 at the far end of pit; No. 3 on extreme right.

FIGURE 6. Showing method of putting soil into tanks.

COLLECTION AND ANALYSIS

At irregular intervals, usually after every rain of any consequence, the leachate was measured and a definite aliquot was placed in glass jugs for subsequent analysis. Another portion was taken to the laboratory and tested immediately for nitrates, ammonia, conductivity and reaction.

The year was divided into three periods: *spring* (April 11 to July 14), *summer and fall* (July 15 to November 20), and *winter* (November 21 to April 10). During the second year, however, the paucity of leachate made it necessary to combine the fourth and fifth periods into one. At the end of each period, a filtered composite of the aliquots saved was analyzed for nitrate, ammonia and organic nitrogen, total solids, ash and loss-on-ignition, calcium, magnesium, potassium, sulfur, phosphorus, iron and silica.

The full soil profile was sampled at the time of installation. At the conclusion of the experiment the soil within the lysimeters and also corresponding horizons in the vicinity were sampled and subjected to certain physical and chemical tests.

Methods Used in Analyzing Leachates

Reaction: Determined by means of a pH meter equipped with a glass electrode.

Conductivity: Kolrausch method using a four-dial decade Wheatstone bridge in place of the Kohlrausch slide.

Nitrate nitrogen: Phenoldisulfonic acid method. Discolored leachates were clarified by the use of copper sulfate, boneblack, calcium hydroxide and magnesium carbonate.

Ammonia nitrogen: Distillation of 400 cc. of leachate and nesslerization of the distillate.

Organic nitrogen: Determined on the residue remaining after distilling off the ammonia nitrogen.

Total solids, loss-on-ignition, calcium, potassium and sulfur: By the customary methods.

Soluble silica: By the colorimetric method of Nemec, Lavik and Koppova, as described by Wright (4).

Iron: Colorimetrically by the method of Griffin, Technical Methods of Analysis, 2d. Ed., p. 691, 1927.

Phosphorus: By a modification of Truog's colorimetric method.

Methods Used in Soil Analysis

Quick tests: Universal Soil Testing System.

Total nitrogen: Gunning method modified to include NO_3-N.

Exchangeable hydrogen: Displacement of H ions by leaching with 0.5 N barium acetate solution, and electrometric titration of the leachate to pH 7.0 with 0.1 N NaOH.

Exchangeable calcium and *base capacity:* Calcium displaced with 0.5 N acetic acid; after washing out excess acid with alcohol, the absorbed H ions were displaced with 0.5 N barium acetate and the leachate titrated as above.

Volume weight and *water-holding capacity:* Obtained on a 250 cc. soil sample collected by means of a cylinder of that capacity forced into the undisturbed soil.

Aggregate analysis: By the sieving method in which water rises and falls in a nest of stationary sieves.

The apparatus[1] consisted of a nest of five brass sieves with round holes whose diameters are 5, 3, 2, 1 and 0.5 mm., respectively, from top to bottom. The base of the nest was equipped with a one-fourth inch inlet tube and a 1-inch outlet, the latter connected by pipe and rubber tubing to a siphon made of three-fourths inch glass tubing. Wide rubber bands cut from an old inner tube of an automobile

[1]The apparatus herein described is a modification of one used by G. Torstensson at the Ultuna Agr. Expt. Sta., Sweden. A somewhat similar one is described and illustrated by Heinrich Dittrich in *Bodenkunde und Pflanzenernahrung*, 16 (1-2): 36-37, 1939.

tire served to prevent leakage at the junctions between sieves. With proper adjustment of the rate of inflow, the water rises almost to the top of the top sieve and then automatically runs out very rapidly through the siphon. This process is repeated about three times a minute.

A sample of fresh soil equivalent to 50 grams dry weight is placed in a beaker of water and allowed to slack about two hours. With the apparatus in operation and properly adjusted, the sample is transferred to the top sieve and subjected to the action of the water until the outflowing water is free of suspended matter—usually a period of four to eight minutes. A gentle stream of water is used to prevent material from remaining on the solid part of the sieve between holes.

When finished, the sieves are taken off one at a time and the material on each is dried and weighed, and then passed through the 0.5 mm. sieve using the fingers or a rubber pestle to crush all aggregates. Any stones or coarse sand present is then subtracted from the gross weight of the aggregates of each size class.

CONDITIONS OBTAINING DURING THE EXPERIMENT

Temperature and Precipitation

The first year of the experiment was characterized by mean monthly temperatures appreciably higher than normal in April, July, August, October, November, December and February, and lower than normal in September; and precipitation above normal in May, June, July, September, November, February and March. It was below normal in April, August and October. The second year temperatures were, on the whole, lower than the first year, the reverse being true only for the months of May and September. Precipitation was considerably lower for the second year than it was the first, although in April, August and October more rain fell than in the corresponding months of the first year. The data represented by Figure 7 were obtained from the Weather Station in New Haven. As rainfall records are obtained by the Water Company at Wepawaug Reservoir, six miles west of New Haven, the precipitation data contained in Table 6 are averages of the amounts recorded at Wepawaug and New Haven, the lysimeters being situated just midway between the two stations.

Disturbances

Several unforeseen events occurred during this experiment which interfered with the reliability of the results and hastened the termination of the study. The first was the hurricane of September 21, 1938, which blew down or broke off trees and branches in the vicinity of the pan lysimeters and considerably reduced the canopy over some of them. No damage was done to the vegetation where the tanks were located. The second event was the disturbance of the soil in tank No. 1 about November 1, 1939, and the complete ruining of tank No. 6 about a week later by vandals. Some glass jugs were broken at the same time. Later in the winter, during an unusual cold snap, some of the glass jugs were broken by frost and the contents lost.

In spite of these disturbances, however, much valuable information was obtained.

CONDITION OF LYSIMETERS AT CONCLUSION OF THE EXPERIMENT

When the equipment was dismantled in June, 1940, observations on the soil and equipment showed the following conditions:

No. 1 (tank, bare soil). The tank had become slightly tipped but was otherwise undisturbed. Growing in the soil were some scattered bits of grass and a few small herbs, none over 2 to 3 inches tall. Some moss was present.

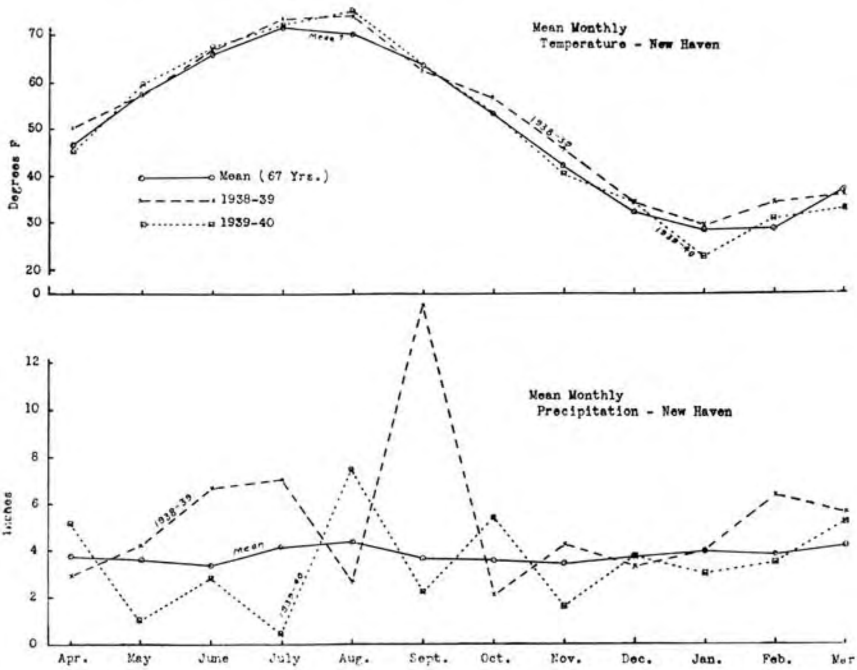

FIGURE 7. Mean monthly temperature and precipitation at New Haven for 1938-39 and 1939-40, in comparison with the 67 year average.

No. 2 (tank, duff on sand). The amount of F material present was equivalent to 4,490 pounds per acre, dry basis. The H layer was three-fourths to seven-eighths inches thick. Two small seedlings, red oak and witchhazel, were growing in the lysimeter, and a single root from the outside reached over the edge into the tank. Numerous small roots were present in the H layer and extended into the sand to some extent. The sand in the bottom center was saturated, and was quite wet around the sides. Throughout the sand were little pockets or splotches of rust-covered sand grains resulting from precipitation of some of the iron leached out of the duff.

No. 3 (tank, duff on sand). F layer equalled 8,180 pounds per

TABLE 1. VOLUME WEIGHT, MOISTURE AND AGGREGATE ANALYSIS OF FIELD SOIL, JUNE, 1938

	Depth inches	Volume Weight (Water = 1.0)	Field Moist-ure %	Water-holding cap. %	Field moisture in % of cap.	Aggregates mm. >5 %	5 - 3 %	3 - 2 %	2 - 1 %	Total >1 %	1 - .5 %	Grand total %
A_1	0 - 2	0.67	32.2	80.8	39.8	2.6	4.2	5.9	8.8	21.5	14.7	36.2
		0.86	32.5	62.1	52.3	23.6	6.8	5.4	8.9	44.7	9.8	54.5
		0.78	29.5	66.4	44.4	28.4	7.2	6.6	11.3	53.5	8.6	62.1
	Av.	0.77	31.4	69.8	45.5	18.2	6.1	6.0	9.7	39.9	11.0	50.9
A_2	2.5 - 4.5	0.99	23.2	47.1	49.2	23.7	6.8	4.0	7.6	42.1	8.7	50.8
		0.92	28.6	53.0	53.9	—	—	—	—	—	—	—
		1.01	22.9	44.0	52.0	—	—	—	—	—	—	—
	Av.	0.97	24.9	48.0	51.7	—	—	—	—	—	—	—

acre; H about the same as No. 2, although wetter, more decomposed and less felty. Three small birches with small root systems were present. Fewer roots than in No. 2. Rust-covered sand grains present as in No. 2.

No. 4 (tank, duff plus soil). F layer — 5,940 pounds per acre. H layer rather well decomposed, black mull-like. Whole mass of soil was very wet. Plants growing in lysimeter: 1 sassafras (8 inches), 6 birch trees (2 - 11 inches), 1 raspberry (20 inches), 1 herb (6 inches).

No. 5 (tank, duff plus soil). F layer — 6,670 pounds per acre. Vegetation: 1 black cherry (24 inches), 1 ash (30 inches), 2 low bush blueberry (5 and 8 inches), 1 dogwood (6 inches), 6 birch (2 - 6 inches), 3 unidentified herbs (4 - 12 inches), 1 witchhazel (10 inches).

No. 6 (tank, bare soil). Disturbed by vandals and removed November 20, 1939. No comments on soil.

No. 12 (pan, duff only). H layer much wetter and much more decomposed than adjoining field sample.

Nos. 17 and 18 (pans, duff only). Some mineral soil was included with the H layer.

It is believed that the presence of the above mentioned vegetation growing on some of the lysimeters did not have much influence upon moisture and nutrients in the soil inasmuch as most of the growth occurred in May and June of 1940, after the termination of the experiment in April.

SOIL STUDIES

Physical Properties of the Soil

Samples of the A horizon in the vicinity of the lysimeters were collected in June, 1938, and subjected to the physical tests indicated in Table 1. These are referred to as field soil. Two years later samples of the soil in the lysimeters and additional field samples were taken and given the same tests. These data are shown in Tables 2 and 3.

The data in Table 1 serve to show the general physical properties of the A_1 and A_2 horizons. The second depth had a somewhat higher volume weight and lower water-holding capacity, and the field moisture at the time of sampling was lower in percent but higher relatively than the uppermost 2 inches. The percentage of aggregates varied considerably, but the data show that this soil compares favorably with other forest soils in this respect.

At the end of the experiment, there were no consistent differences in *volume weight* except that the bare soil in tank No. 1 appeared to have a somewhat higher volume weight than the others. *Field moisture* at time of sampling is indicative of the differences in moisture content which prevailed more or less throughout the experiment.

The soil in the tank lysimeters under duff averaged 72 percent moisture, water-free basis, that in the bare soil tanks 44 percent and the field soil 33 percent. The soil over the pans appeared to average slightly less than the field samples but the differences are hardly significant. It is quite possible, however, that there should be a difference, owing to the fact that the soil over the pans was cut off from all vertical capillary movement, but at the same time was subject to

TABLE 2. VOLUME WEIGHT AND MOISTURE OF FIELD SOIL AND LYSIMETER SOIL, JUNE, 1940

Depth of Sample Approximately 0.5 to 2.5 Inches

	Volume weight (Water=1)	Field moisture %	Water-holding capacity %	Field Moisture in % of water-holding capacity
		Field Soil		
Near tank No. 4	0.75	36.1	61.1	59.0
" " " 4	0.95	28.0	43.7	64.1
" " " 5	0.81	36.0	55.4	64.9
Av.	0.84	33.4	53.4	62.7
	Tank Lysimeter Soil		**Duff + Soil**	
Tank No. 4	0.76	80.8	75.8	106.5
" " 4	0.68	80.5	74.8	107.6
" " 5	0.82	68.4	65.2	104.9
" " 5	0.88	59.4	56.7	104.7
Av.	0.78	72.3	68.1	105.9
	Tank Lysimeter Soil		**Bare Soil**	
Tank No. 1	0.92	44.2	47.1	93.8
" " 1	0.94	42.9	47.8	89.7
Av.	0.93	43.6	47.5	91.8
	Pan Lysimeter Soil		**Duff + Soil**	
Pan No. 7	0.90	29.3	42.6	68.7
" " 10	0.84	25.4	41.6	61.0
" " 14	0.84	30.7	46.3	66.3
" " 15	0.79	34.9	70.1	49.7*
Av.	0.84	30.1	50.2	65.3
	Pan Lysimeter Soil		**Bare Soil**	
Pan No. 9	0.71	33.8	55.1	61.3
" " 11	0.72	32.6	55.0	59.2
" " 13	0.90	30.7	44.4	69.1
" " 16	0.96	24.9	23.4*	106.4*
Av.	0.82	30.5	51.5	63.2

*Omitted from average.

the same root competition and evaporation as was the adjacent field soil.

The data in Table 2 would indicate a lower *water-holding capacity* for the field soil than for the tank soil under duff. Field soil samples collected in 1938 (Table 1), however, showed a higher water-holding capacity than did those in 1940. Therefore, the evidence is not sufficiently clear to permit any conclusions one way or the other. That the bare soil would have a lower capacity is not improbable due to the poorer structure which develops in the absence of a protecting duff layer (5).

The last column in Table 2, "Field moisture in percentage of water-holding capacity", shows clearly the differences in degree of saturation of the soil at the time of sampling.

Aggregate analysis was made on the samples from two depths, 0 to 1 inch and 1 to 4 inches (Table 3). There was relatively little difference between field soil and lysimeter soil under duff in either horizon. The variations are greater between duplicate samples than they are between treatments. The bare soil, however, was markedly lower in all sizes of aggregates than either of the other two treatments, especially in the 0 - 1-inch horizon. This is in agreement with the findings obtained in the red pine study (5).

TABLE 3. AGGREGATE ANALYSES, JUNE, 1940

	Depth inches	Aggregates, percent Size class, mm. > 5	5 - 3	3 - 2	2 - 1	Total > 1	1 - .5	Grand total
		Field Soil						
	0 - 1	11.9	13.0	5.8	11.6	42.3	3.5	45.8
	"	9.6	5.4	4.7	8.2	27.9	3.1	31.0
	Av.	10.8	9.2	5.3	9.9	35.1	3.3	38.4
	1 - 4	7.3	7.4	5.9	15.4	36.0	4.9	40.9
	"	3.8	3.9	3.6	10.6	21.9	7.0	28.9
	Av.	5.6	5.7	4.8	13.0	29.0	5.95	34.9
		Lysimeter Soil		**Duff + Soil**				
Tank 4	0 - 1	4.7	6.5	5.4	8.8	25.4	5.7	31.1
" 5	"	7.6	3.8	4.8	16.1	32.3	6.9	39.2
	Av.	6.2	5.2	5.1	12.5	28.9	6.3	35.2
" 4	1 - 4	3.3	4.5	4.5	20.3	32.6	9.6	42.2
" 5	"	4.0	3.8	7.6	17.6	33.0	3.6	36.6
	Av.	3.7	4.2	6.1	19.0	32.8	6.6	39.4
		Lysimeter Soil		**Bare Soil**				
Tank 1	0 - 1	2.7	2.4	1.0	6.5	12.6	7.1	19.7
"	"	3.6	2.6	1.6	6.4	14.2	—	—
	Av.	3.2	2.5	1.3	6.45	13.4	—	—
"	1 - 4	2.2	2.5	2.7	10.2	17.6	8.2	25.8
"	"	2.0	2.1	3.4	7.6	15.0	—	—
	Av.	2.1	2.3	3.1	8.9	16.3	—	—

Soil Tests

Was there any difference at the end of the two-year period in the acidity and the soluble constituents of the soils inside and outside of the lysimeters? To answer this question, samples collected June

18, 1940 (two months after termination of leachate measurements), were tested by the Universal quick test method, with the results shown in Table 4. Part A gives the data for all of the tests on the field samples which are more or less representative of the area, while part B gives the figures for nitrates, ammonia nitrogen and potassium in soil within the tanks in comparison with the field samples. It appears

TABLE 4. QUICK SOIL TESTS (Pounds per Acre)
Samples Collected June 18, 1940

A. Field Samples, representative of the area

Horizon	pH*	NO_3-N	NH_3-N	P	K	Ca	Mg	Al	Mn	Fe
H	4.40	2	3	15	75	300	25	20	5	55
H	4.85	1	5	55	125	400	30	75	13	250
H	4.80	2	3	50	100	300	25	100	5	175
H	4.77	15	8	18	75	300	10	75	10	440
Av.	4.72	5	6	35	94	325	23	68	8	230
0 - 1"	4.44	2	3	10	75	300	15	300	T	100
0 - 1	4.67	4	8	35	75	300	10	600	T	250
Av.	4.56	3	6	23	75	300	13	450	T	175
1 - 4"	5.13	2	6	23	75	300	10	500	T	50
1 - 4	4.88	1	5	35	75	300	15	600	T	50
Av.	5.00	2	6	29	75	300	13	550	T	50

B. Comparison of Soil in Tanks with Field Soil

Horizon		NO_3-N H	NO_3-N 0 - 1"	NO_3-N 1 - 4"	NH_3-N H	NH_3-N 0 - 1"	NH_3-N 1 - 4"	K H	K 0 - 1"	K 1 - 4"
Field Sample		5	3	2	6	6	6	94	75	75
Tank Lys.	Duff	2	—	—	3	—	—	75	—	—
		2	—	—	5	—	—	75	—	—
	Av.	2	—	—	4	—	—	75	—	—
	Soil	—	2	15	—	15	20	—	150	150
		—	3	2	—	5	6	—	200	100
	Av.	—	3	8	—	10	13	—	175	175
	Duff + Soil	2	3	13	7	35	18	75	200	100
		15	20	18	8	13	10	75	75	75
	Av.	9	12	16	8	24	14	75	138	84

*Determined with glass electrode pH meter.

that all three constituents were somewhat higher in the mineral soil in the tanks than in the corresponding portion of the field soil profile. This can be ascribed to the higher moisture content favoring microbiological action and to the lack of root competition. In the case of the H layers, differences are absent or inconclusive. Inasmuch as neither pH nor any of the constituents other than nitrogen and potassium show any significant differences, the data are omitted.

Base Exchange Properties, Organic Matter and Nitrogen Content

Analyses of samples from the field, from all horizons in the tanks and from the H layer of the pans are reported in Table 5. The organic layers in the tank lysimeters were lower in exchangeable H, generally lower in base capacity and higher in percent saturation than the field soil. It would appear that this condition may be due to an increase in concentration of soluble bases as the result of higher moisture content and absence of absorption by roots, although no such increase is observed in exchangeable calcium, except in one instance. No consistent difference was observed in the case of the A horizons.

TABLE 5. DATA PERTAINING TO BASE EXCHANGE, ORGANIC MATTER AND NITROGEN

Samples Collected June 18, 1940

Horizon	Field Sample	Tank lysimeters Duff	Tank lysimeters Soil	Tank lysimeters Duff +Soil	Pan lys. Duff	Field Sample	Tank lysimeters Duff	Tank lysimeters Soil	Tank lysimeters Duff +Soil	Pan lys. Duff
	Exchangeable Hydrogen mgm. eq.					**Base Capacity mgm. eq.**				
F	46.7	39.2	—	40.8	—	65.5	59.0	—	60.9	—
H	36.1	23.6	—	30.1	17.1	44.8	32.9	—	43.4	25.0
A 0-1″	15.0	—	13.5	14.4	—	18.6	—	14.9	18.4	—
A 1-4″	7.4	—	9.9	9.7	—	9.0	—	11.7	11.7	—
	% Saturation					**Exchangeable Calcium p.p.m.**				
F	28.8	33.6	—	33.0	—	3200	2940	—	2800	—
H	19.4	28.5	—	31.1	31.3	1180	1005	—	1586	743
A 0-1″	20.0	—	9.4	21.7	—	100	—	100	162	—
A 1-4″	17.8	—	15.4	17.1	—	55	—	65	73	—
	Loss-on-ignition %					**Total Nitrogen %**				
F	91.4	91.1	—	93.1	—	1.56	1.27	—	1.43	—
H	45.8	27.3	—	43.3	20.6	1.04	.78	—	1.02	.51
A 0-1″	14.0	—	11.1	12.1	—	0.28	—	0.23	0.27	—
A 1-4″	7.5	—	8.6	9.1	—	0.14	—	0.21	0.19	—
	Loss-on-ignition: Nitrogen									
F	58.2	71.7	—	65.2	—					
H	44.0	35.0	—	42.5	40.3					
A 0-1″	50.0	—	48.2	44.8	—					
A 1-4″	53.5	—	41.0	47.8	—					

Organic matter as determined by loss-on-ignition and the total nitrogen content were considerably lower for the H layer of the duff-only tanks and slightly lower for the top layer of mineral soil. The low values for the H layer in the pans were probably due to the presence of mineral soil in the sample. With respect to the ratio of organic matter to nitrogen, the chief differences are: (1) the wider ratio for duff **F**, and (2) the narrower ratio for duff **H** than for the corresponding horizons of the field samples.

Discussion of Soil Changes Occuring within the Lysimeters

Since conditions surrounding the soil in the *pan* lysimeters were not greatly different from those surroundings the adjoining field soil, one would expect very little change within the soil itself. This was borne out by the physical and chemical tests and by observation in the field. The accidental inclusion of considerable mineral soil in pans 17 and 18, which were meant to contain only the organic horizons, more or less vitiated the exchangeable base, loss-on-ignition, and total nitrogen data on the pan soils as reported in Table 5.

In the tank lysimeters, on the other hand, the absence of root competition resulted in a very moist condition of the soil practically the year around. There was some indication that the F layer was slightly thinner and the H layer somewhat more completely decomposed than in the adjoining area outside of the lysimeters. Significant physical changes in the mineral soil were not found except in the case of the bare soil which was definitely in poorer condition. Chemically, the mineral soil in the tanks contained somewhat larger amounts of nitrates, ammonia and available potassium. The organic layers were slightly more saturated with bases than were the same layers in the adjoining field.

AMOUNT OF LEACHATE

The complete data, by periods, are given in Table 6. The rainfall during the first year amounted to 65.9 inches, which is equivalent to 338.73 liters of water falling on each tank (in the open) and half that amount on each pan lysimeter. The second year the corresponding figures were 43.9 inches, equivalent to 225.65 and 112.83 liters, respectively.

In almost every case the largest amount of leachate came from the duff lysimeters. The bare soil delivered the least amount in the tanks, although the pans showed considerable variation in that respect. Presumably this was due to run-off from the bare soil, especially during heavy storms and when the soil was frozen. The percentage of rainfall collected from the tanks tended to increase with each period during the first year but not during the second. There was no such tendency in the pans. Variations between duplicate tanks were fairly small the first year but quite large the second. It was observed that individual measurements frequently showed remarkably good agreement between duplicates, particularly during the winter months.

In the case of the pans, No. 7 (duff plus soil) yielded much less leachate than any of its mates. Pan 15 yielded three to five times more during the third period of the first year than any of the others of that group. Comparing set 1 (pans 7 - 12) with set 2 (pans 13 - 18) it is seen that with duff alone, set 1 gave more than set 2, and with duff-plus-soil, set 2 gave more than set 1. With bare soil there was no definite relationship either way.

The analysis of variance of the data on leachate collected in percentage of rainfall is given in the Appendix Table I. It shows that in the tanks the all-over effect of humus was significant in comparison with the mineral soil but the differences between bare soil and duff-plus-soil were not significant. There were no significant differences

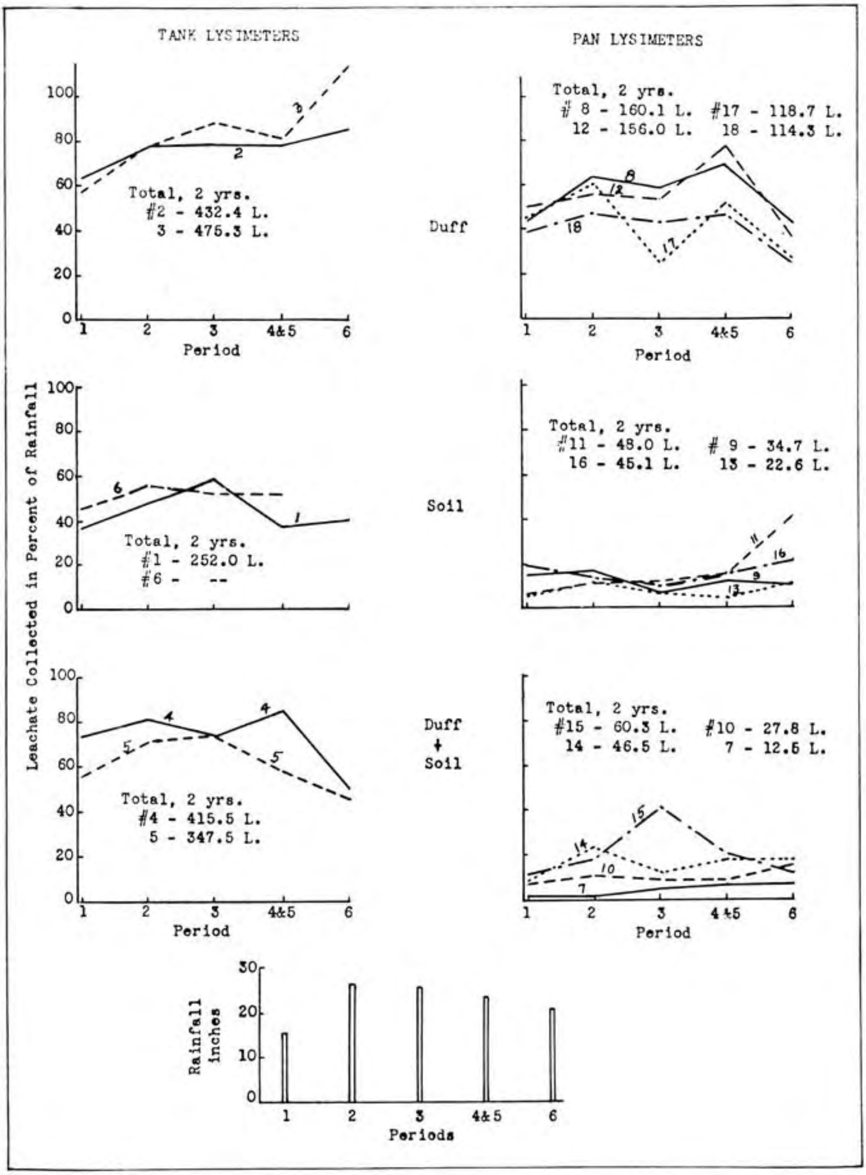

FIGURE 8. Leachate collected, in percent of rainfall, and total rainfall for each period.

TABLE 6. RAINFALL, AND AMOUNT OF LEACHATE COLLECTED

		First Year (1938-39)								Second Year (1939-40)					
		1st Period Apr. 11-July 14		2nd Period July 15-Nov. 20		3rd Period Nov. 21-Apr. 10		Total for Year		4th & 5th Periods Apr. 11-Nov. 20		6th Period Nov. 21-Apr. 13		Total for Year	
Rainfall, inches		15.43		26.15		24.32		65.90		23.48		20.42		43.90	
		Liters	% of Rain-fall	Liters	% of Rain-fall	Liters	% of Rain-fall	Liters	% of Rain-fall	Liters	% of Rain-fall	Liters	% of Rain-fall	Liters	% of Rain-fall
TANK LYSIMETERS															
Rain over tanks		79.31	23.4	134.4	39.7	125.0	36.9	338.7	100.0	120.7	53.5	105.0	46.5	225.7	100.0
Leachate collected:															
Duff	2	50.08	63.14	102.76	76.45	98.00	78.40	250.84	74.05	91.96	76.20	89.61	85.38	181.57	80.47
	3	45.20	56.99	103.39	76.92	110.43	88.34	259.02	76.47	97.62	80.88	118.64	113.03	216.26	95.84
	Av.	47.64	60.07	103.08	76.69	104.22	83.38	254.93	75.26	94.79	78.54	104.13	99.21	198.92	88.15
	%[1]	18.7		40.5		40.8		100.0		47.6		52.4		100.0	
Soil	1	28.74	36.24	64.68	48.12	71.69	57.35	165.11	48.74	44.54	36.90	42.37	40.37	86.91	38.52
	6	35.72	45.04	73.65	54.80	65.04	52.03	174.41	51.49	61.30	50.79	—	—	—	—
	Av.	32.23	40.64	69.17	51.46	68.37	54.70	169.76	50.12	52.92	43.85	—	—	—	—
	%	19.0		40.8		40.2		100.0		51.3		48.7		100.0	
Duff plus Soil	4	58.20	73.38	109.68	81.60	92.39	73.91	260.27	76.84	102.79	85.17	52.41	49.93	155.20	68.78
	5	43.38	54.70	94.94	70.63	91.56	73.25	229.88	67.87	69.94	57.95	47.72	45.46	117.66	52.14
	Av.	50.79	64.04	102.31	76.12	91.98	73.58	245.08	72.35	86.37	71.56	50.07	47.70	136.43	60.46
	%	20.7		41.8		37.5		100.0		63.3		36.7		100.0	

PAN LYSIMETERS

Rain over pans		39.66	23.4	67.21	39.7	62.50	36.9	169.4	100.0	60.35	53.5	52.48	46.5	112.8	100.0
Leachate collected:															
Duff	8	17.13	43.20	42.70	63.54	36.15	57.83	95.98	56.67	41.89	69.41	22.26	42.42	64.15	56.86
	12	19.74	49.78	37.30	55.50	33.56	53.03	90.60	53.49	46.65	77.30	18.77	35.77	65.42	57.98
	17	17.72	44.69	40.13	59.71	15.84	25.34	73.69	43.51	31.04	51.43	13.99	26.66	45.03	39.91
	18	15.09	38.05	31.55	46.95	26.95	43.11	73.59	43.45	27.95	46.31	12.78	24.35	40.73	36.10
	Av[1]	17.42	43.93	37.92	56.42	28.13	44.83	83.47	49.28	36.88	61.11	16.95	32.30	53.83	47.71
	%	20.9		45.4		33.7		100.0		68.5		31.5		100.0	
Soil	9	5.82	14.68	11.45	17.04	4.48	7.16	21.75	12.84	7.45	12.34	5.51	10.50	12.96	11.49
	11	2.47	6.23	7.18	10.68	7.29	11.66	16.94	10.00	9.35	15.49	21.69	41.33[2]	31.04	27.51
	13	1.85	4.67	7.37	10.97	4.28	6.84	13.50	7.97	3.33	5.52	5.80	11.05	9.13	8.09
	16	7.62	19.22	9.71	14.45	6.27	10.03	23.60	13.93	9.85	16.32	11.67	22.24	21.52	19.07
	Av.	4.44	11.20	8.93	13.29	5.58	8.92	18.95	11.19	7.50	12.43	11.17	21.28	18.66	16.54
	%	23.4		47.2		29.4		100.0		40.2		49.8		100.0	
Duff plus Soil	7	0.40	1.01[2]	1.05	1.56[2]	3.27	5.22	4.72	2.79	3.74	6.20	4.01	7.64	7.75	6.87
	10	2.51	6.33	7.07	10.52	5.19	8.30	14.77	8.72	5.15	8.53	7.90	15.05	13.05	11.57
	14	3.20	8.07	15.66	23.30	7.41	11.85	26.27	15.51	10.71	17.75	9.52	18.14	20.23	17.93
	15	4.56	11.50	11.98	17.83	25.55	40.87[2]	42.09	24.85	11.91	19.73	6.27	11.95	18.18	16.11
	Av.	2.67	6.73	8.94	13.30	10.35	16.56	21.96	12.97	7.88	13.06	6.92	13.19	14.80	13.12
	%	12.2		40.7		47.1		100.0		53.3		46.7		100.0	

[1] Percent of yearly total. [2] Not used in analysis of variance; calculated for missing values instead.

in the amount of leachate between summer and winter nor from one year to another. All of the interactions between duff, soil and duff-plus-soil in relation to season and year were significant, but in every case the effect of duff *vs.* soil contributed more to the correlation than did the between-soil effect. Finally, the difference between the first two periods of the first year were highly significant.

In the case of the pan lysimeters, all of the differences reported above as significant were highly significant except where the effect

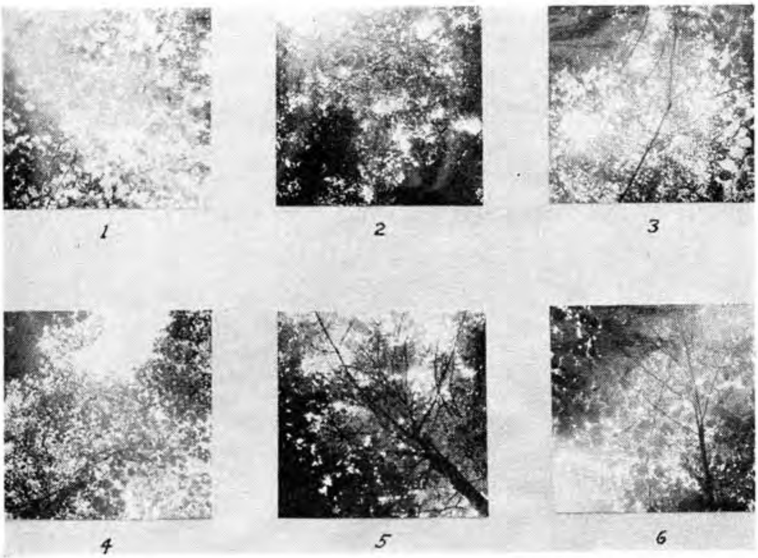

FIGURE 9. Photographs of the canopy over each tank lysimeter, taken about a week before the hurricane.

of soil was correlated with the year, in which case the difference was not significant. In the pans the seasonal differences were highly significant.

In considering the foregoing data, it is necessary to take into account differences in canopy over the individual lysimeters, and changes in canopy as a result of the hurricane. The leachate in percentage of rainfall for each pan, by periods, is shown graphically in Figure 8; and photographs of the canopy over each lysimeter are shown in Figures 9, 10 and 11. Considering first the tank lysimeters, Figures 8 and 9, there appears to be relatively little difference both in canopy and in leachate collected over tanks 1 and 6 (in this case only the first year is available for comparison). Practically the same can be said for tanks 2 and 3, although No. 3 did deliver about 10 percent more leachate than No. 2. The canopy over tank 4 appeared to be less than that over 5, and the amount of leachate is correspondingly greater in 4 than in 5. As previously stated, the canopy over this set was not damaged by the hurricane.

With respect to the pan lysimeters, duff only, Nos. 8 and 12 yielded almost the same amount of leachate although No. 12 would appear to have less canopy (Figure 10). Nos. 17 and 18 (Figure 11) were about alike in canopy and performance, but were considerably below 8 and 12 in leachate recovered. None of these was influenced to any great extent by the hurricane.

The bare-soil lysimeter 9 appeared to have more canopy and, for the first two periods, more leachate than No. 11. The hurricane reduced the canopy somewhat over No. 11 and, from the third period on, No. 11 contributed more leachate than 9. Although the hurricane markedly reduced the canopy over No. 13, it had no appreciable

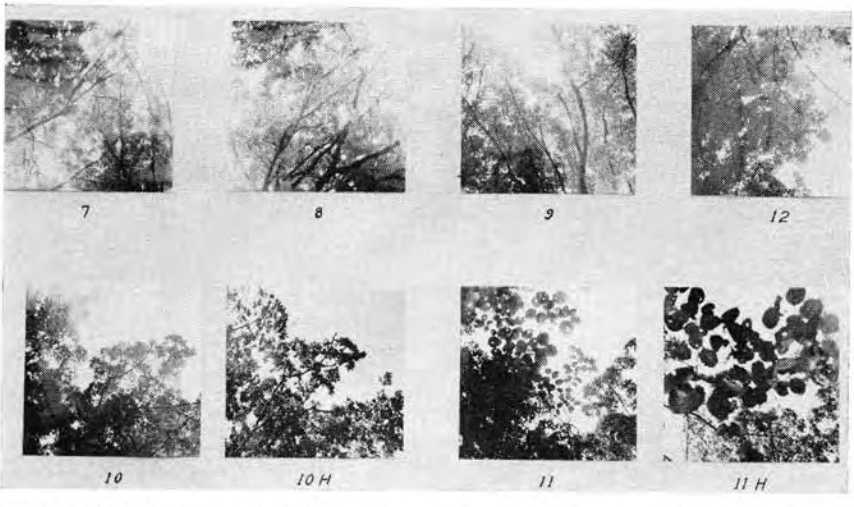

FIGURE 10. Photographs of canopy over each pan lysimeter, Nos. 7 - 12, taken about a week before the hurricane; 10H and 11H taken the day after the hurricane.

effect upon the amount of leachate collected, which was the least of the four bare-soil lysimeters.

In the case of duff-plus-soil lysimeters, No. 7 had more canopy and less leachate than No. 10. The canopy of the latter was thinned out to some extent by the hurricane, but this did not seem to affect the relative differences between the two lysimeters. Nos. 14 and 15 were reasonably close together in leachate delivered during the first and second periods but, for some unaccountable reason, No. 15 went very high and No. 14 dropped during the third period. They were together again at the end of the fourth and fifth periods, and No. 14 was ahead during the sixth period. Both lysimeters delivered a great deal more leachate over the two-year period than did Nos. 7 and 10.

The canopies over both Nos. 14 and 15 were very markedly opened up by the hurricane, but this does not appear to be reflected in the leachate collected, with the possible exception of No. 15 in the third period.

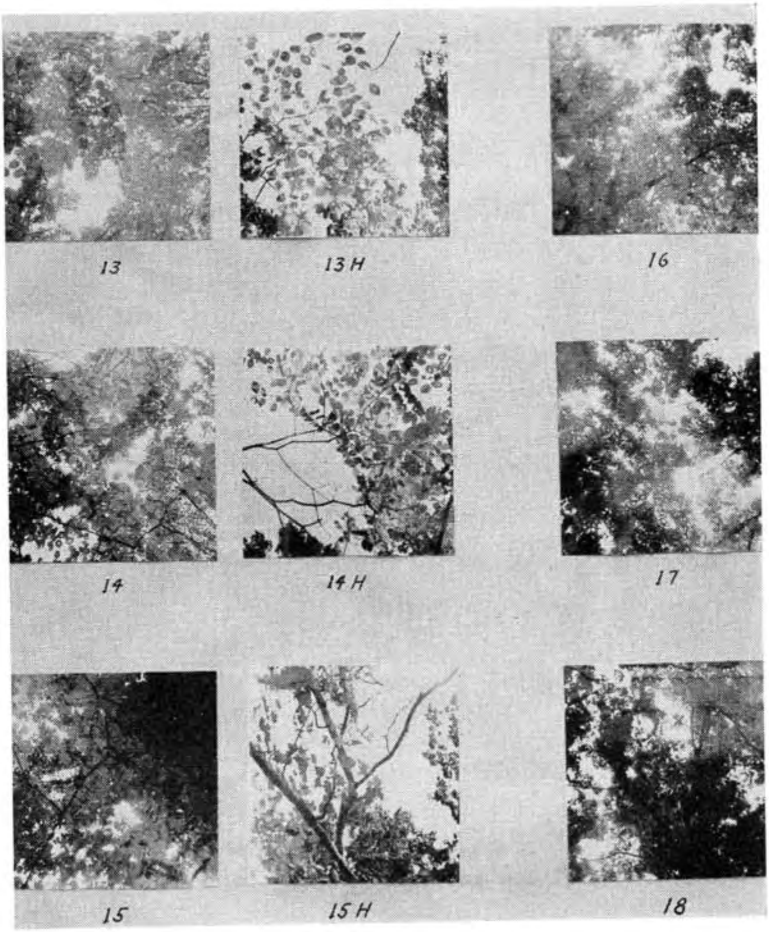

FIGURE 11. Photographs of canopy over each pan lysimeter, Nos. 13 - 18 taken about a week before the hurricane; 13H, 14H and 15H taken the day after the hurricane.

It is apparent from the preceding discussion that canopy alone in terms of amount of sky hidden from view is a rather poor criterion of the performance of lysimeters, particularly those of the pan type. In the first place, the amount of interception by foliage varies tremendously with the shape of the tree and its position with respect to the lysimeter. It is practically impossible in any particular situation to predict what proportion of the rainfall will reach the ground immediately beneath. This varies, too, with the direction and velocity of the wind and rate of precipitation. In the second place, minor variations in the position of the pan or in relief may have important bearing on the efficiency of the lysimeter; and thirdly, the presence and direction of root channels and rodent burrows, and the presence of live roots can likewise interfere with the proper functioning of the lysimeter. Examinations of the pans at the conclusion of the experiment did not show any untoward condition that would seriously interfere with the proper operation of the lysimeters.

COMPOSITION OF LEACHATE

Soluble Nitrogen, Conductivity and Reaction

As previously stated, nitrate and ammonia nitrogen, conductivity and reaction were determined each time the leachate was collected. These data, together with the amount of leachate, are shown graphically in Figures 12 to 15.

In the tank lysimeters the concentration of nitrates in the *duff* leachate was prevailingly low except for a slight rise in the fall months of the first year and midsummer of the second year. Leachate from *bare soil* tank No. 1, for some unaccountable reason (probably nitrification of urine from a deer or other animal) reached a maximum of 150 p. p. m. on November 21 of the first year, although its mate, No. 6, contained only 12 p. p. m. on the same date. There were considerable differences between the two all through the third period but not in the fourth and fifth. The erratic portion of the data from tank 1 has been omitted in Figure 12. As previously mentioned, No. 6 dropped out of the picture during the last period. It will be seen that the period of high concentration of nitrates occurred through September, October and November the first year and from June to October during the second year. *Duff-plus-soil* leachate was high in nitrates from September through December the first year, with a maximum of 22 p.p.m., and from May through September the second year with a maximum of 51 p. p. m.

In general, ammonia nitrogen followed the nitrates although the maximum concentrations were considerably lower than in the case of nitrates. The conductivity curves follow the nitrate curves rather closely for the most part. The high concentrations reached during the second year in the soil and duff-plus-soil leachate made necessary a change in the scale for the higher values of conductivity and NO_3-N in Figure 13, a fact which should be noted when studying the graphs.

The reason for the maximum nitrate content occurring earlier in the season the second year than it did in the first year is not entirely clear. It was probably due mostly to an adjustment effect following the installation of the lysimeters. The good moisture conditions and absence of root competition favored the breakdown of or-

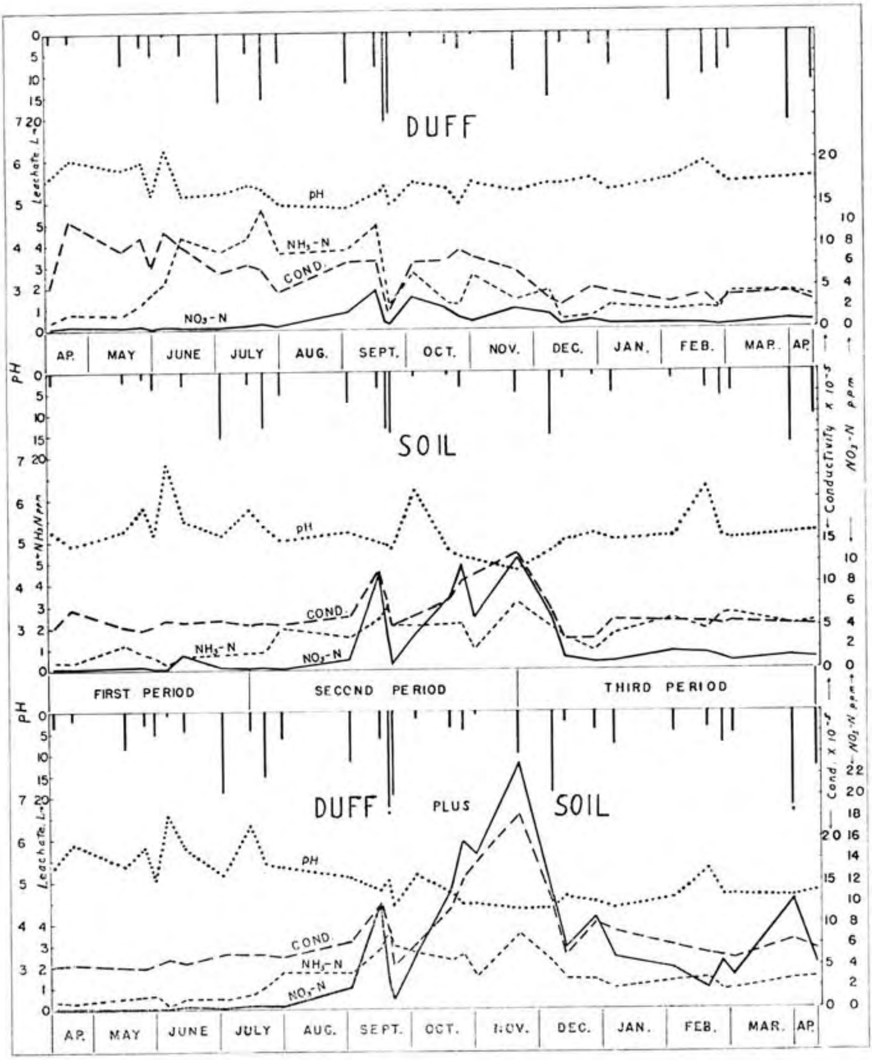

FIGURE 12. Current amount of leachate collected the first year from the tank lysimeters, and its pH, conductivity, and nitrate and ammonia nitrogen content in parts per million.

ganic compounds, and these became available for nitrification earlier in the second year than in the first. A second factor which may have had some influence was the lower rainfall during the spring months of the second year, thus permitting a greater accumulation of nitrates. It will be noted that high nitrate values usually followed periods of relatively low rainfall as indicated by the amounts of leachate collected.

On the whole, the duff leachate had the highest pH, and the duff-plus-soil the lowest. The former was remarkably steady, showing only a slight drop during the late summer and fall of the first year. Both bare soil and duff-plus-soil showed a general trend towards a lower pH during the first year, but during the second year there was a definite upward trend in January, February and March.

In the case of the *pan* lysimeters we have a different situation. Natural root competition kept the soil moisture and soluble plant food content to a relatively low level. This made it necessary to use a different scale for NO_3-N in Figures 14 and 15 than was used in Figures 12 and 13. Of particular interest is the fact that ammonia greatly exceeded nitrates in concentration (note difference in scale used for ammonia and for nitrates). This would indicate one of two things: either the roots absorbed nitrates in preference to ammonia, or the lower moisture content did not permit the conversion of ammonia to nitrates.

Variations in the soluble nitrogen concentration are relatively small and hardly significant. While conductivity tends to follow nitrates or ammonia, there are several instances, notably in May, June and October of the first year and October of the second year, in which conductivity was high without a corresponding increase in soluble nitrogen. Usually high conductivity was inversely correlated with amount of leachate collected.

The pH values showed a slight trend upward during the first year except in the duff-plus-soil pans. In the second year the trend was slightly downward in all three cases.

Total Nitrogen

In Tables 7 and 8 will be found the data pertaining to the different forms of nitrogen, by periods. Considering the tank lysimeters first, the total amount of nitrogen ranged from 54 pounds in the duff to 75 pounds in the duff-plus-soil the first year, and 32 (duff) to 91 (duff-plus-soil) the second. Of the total, nitrates accounted for only 14 percent to 19 percent in the duff, but 52 percent to 86 percent in the soil and duff-plus-soil. By periods the first period contributed the least amount of nitrogen, particularly in bare soil and duff-plus-soil. In the latter two soils there was not much difference between the second and third periods; but on the basis of pounds per acre per month, Table 9, the second period contributed the largest amount of nitrogen. As previously mentioned, the small amount of leachate in the fourth period made it necessary to combine the fourth and fifth per-

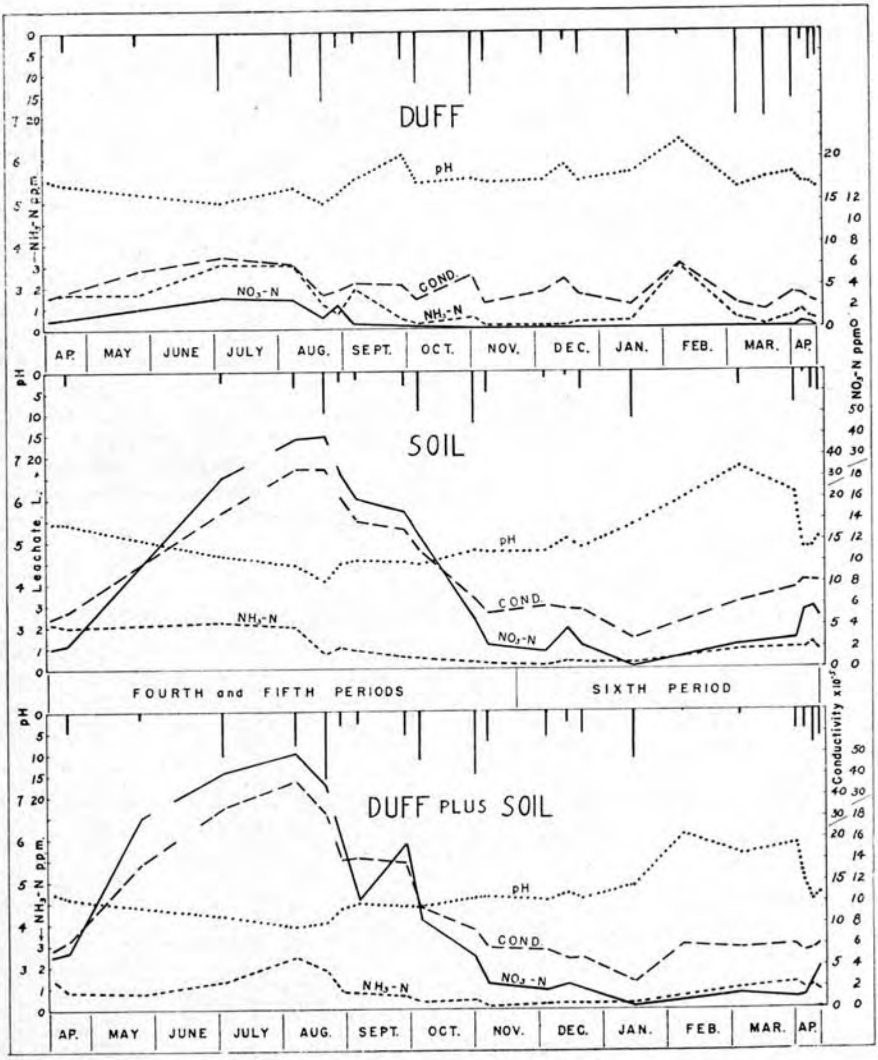

FIGURE 13. Current amount of leachate collected the second year from the tank lysimeters, and its pH, conductivity, and nitrate and ammonia nitrogen content. (Conductivity and nitrate scales changed on account of high values for soil and duff-plus-soil.)

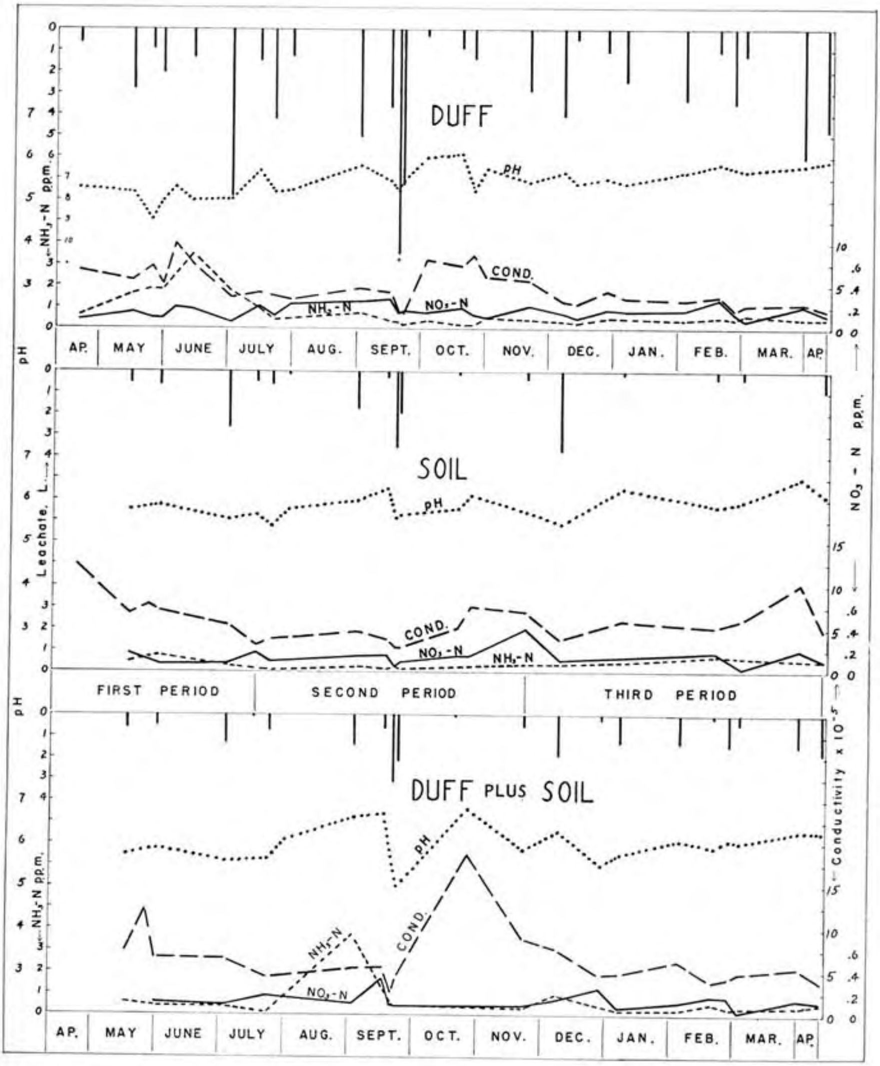

FIGURE 14. Current amount of leachate collected the first year from the pan lysimeters, and its pH, conductivity, and nitrate and ammonia nitrogen content. (Note that the scale for leachate is one-fifth and for NO_3-N one-tenth of corresponding scales in Figures 12 and 13.

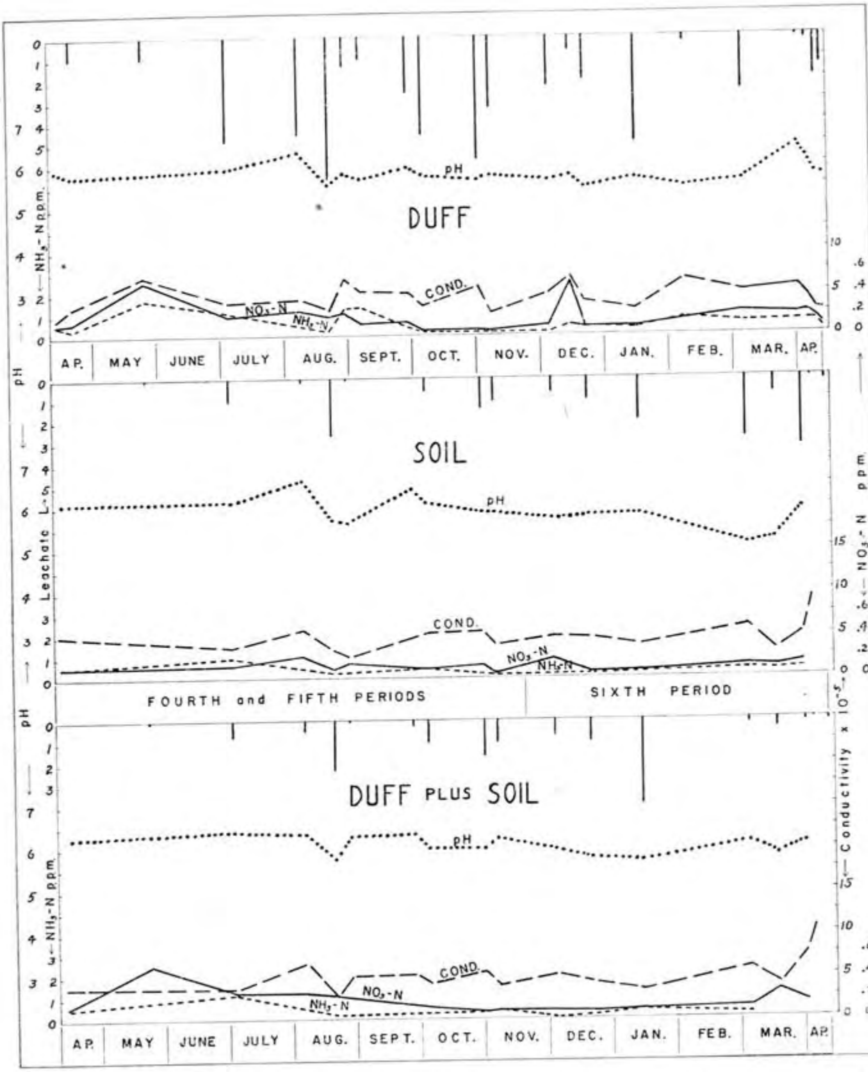

FIGURE 15. Current amount of leachate collected the second year from the pan lysimeters, and its pH, conductivity, and nitrate and ammonia nitrogen content. (Scale same as in Figure 14.)

TABLE 7. NITROGEN IN LEACHATE FROM TANK LYSIMETERS

A. First Year (1938-39)

	1st Period Apr. 11-July 14		2nd Period July 15-Nov. 20		3rd Period Nov. 21-Apr. 10		Total lbs. per acre (Av. of ea.pair)	% of total
DUFF								
No.	2	3	2	3	2	3	—	—
NH_3-N mgs.	107	153	309	288	141	97	24.07	44.2
NO_3-N "	11	15	96	93	83	59	7.88	14.4
Org. N "	101	156	226	227	137	177	22.53	41.4
Total lbs. per A.	9.64	14.25	27.76	26.75	15.88	14.65	54.50	—
Av. " " "	11.99		27.26		15.27		—	—
Av. %	22.0		50.0		28.0		—	100.0
SOIL								
No.	1	6	1	6	1	6	—	—
NH_3-N mgs.	22	23	(723)[1]	162	(552)[1]	139	14.23	37.3
NO_3-N "	11	8	(1421)	192	(1615)	248	19.78	51.8
Org. N "	9	16	(18)	24	(47)	58	4.16	10.9
Total lbs. per A.	1.81	2.07	(95.13)	16.63	(97.42)	19.58	38.17	—
Av. " " "	1.96		16.63		19.58		—	—
Av. %	5.1		43.6		51.3		—	100.0
DUFF AND SOIL								
No.	4	5	4	5	4	5	—	—
NH_3-N mgs.	15	24	244	288	76	156	17.69	23.5
NO_3-N "	5	3	536	518	644	600	50.73	67.6
Org. N "	22	16	71	63	77	63	6.86	8.9
Total lbs. per A.	1.85	1.89	37.44	38.24	35.07	36.04	75.28	—
Av. " " "	1.87		37.84		35.56		—	—
Av. %	2.5		50.3		47.2		—	100.0

B. Second Year (1939-40)

	4th & 5th Periods Apr. 11-Nov. 15		6th Period Nov. 21-Apr. 13		Total lbs. per acre (Av. of each pair)	% of total
DUFF						
No.	2	3	2	3	—	—
NH_3-N mgs.	168	78	34	64	7.57	23.8
NO_3-N "	96	132	19	26	6.03	19.0
Org. N "	258	203	141	222	18.13	57.2
Total lbs. per A.	22.97	18.17	8.54	13.73	31.73	—
Av. " " "	20.57		11.14		—	—
Av. %	64.8		35.2		—	100.0
SOIL						
No.	1	6	1	6	—	—
NH_3-N mgs.	29	55	32	—	3.26	6.3
NO_3-N "	769	1025	118	—	44.66	86.2
Org. N "	26	33	58	—	3.87	7.5
Total lbs. per A.	36.26	48.97	9.15	—	51.79	—
Av. " " "	42.61		—		—	—
Av. %	82.3		17.7		—	100.0
DUFF AND SOIL						
No.	4	5	4	5	—	—
NH_3N mgs.	116	62	40	23	5.32	5.8
NO_3-N "	1764	1619	133	60	78.66	86.4
Org. N "	126	22	109	67	7.13	7.8
Total lbs. per A.	88.26	74.93	12.41	6.60	91.11	—
Av. " " "	81.59		9.50		—	—
Av. %	89.5		10.5		—	100.0

[1]Figures in parenthesis not used in calculating averages nor in the analysis of variance.

TABLE 8. NITROGEN IN LEACHATE FROM PAN LYSIMETERS
Average of Four Pans

A. First Year (1938-39)

	1st Period Apr. 11-July 14	2nd Period July 15-Nov. 20	3rd Period Nov. 21-April 10	Total lbs. per acre	% of total
		DUFF			
NH_3-N mgs.	29.81	12.06	9.91	4.56	38.5
NO_3-N "	2.96	5.60	4.02	1.11	9.4
Org. N "	30.22	22.16	17.79	6.17	52.1
Total lbs. per A.	5.54	3.50	2.79	11.84	——
% of total	46.7	29.6	23.7	——	100.0
		SOIL			
NH_3-N mgs.	1.39	1.92	1.57	0.43	40.2
NO_3-N "	0.44	0.76	0.52	0.15	14.0
Org. N "	1.57	1.89	2.14	0.49	45.8
Total lbs. per A.	0.30	0.40	0.37	1.07	——
% of total	28.0	37.4	34.6	——	100.0
		DUFF AND SOIL			
NH_3-N mgs.	0.86	3.18	2.08	0.54	33.0
NO_3-N "	0.21	0.94	1.09	0.20	12.5
Org. N "	1.42	3.83	4.60	0.87	54.5
Total lbs. per A	0.22	0.69	0.68	1.60	——
% of total	13.8	43.4	42.8	——	100.0

B. Second Year (1939-40)

	4th and 5th Periods April 11-Nov. 20	6th Period Nov. 21-April 13	Total lbs. per acre	% of total
		DUFF		
NH_3-N mgs.	15.13	5.68	1.83	20.2
NO_3-N "	4.50	2.55	.62	6.9
Org. N "	53.37	21.46	6.59	72.9
Total lbs. per A	6.42	2.61	9.04	——
% of total	71.1	28.9	——	100.0
		SOIL		
NH_3-N mgs.	1.93	3.25	0.46	21.6
NO_3-N "	.46	1.09	.14	6.6
Org. N "	5.44	12.00	1.53	71.8
Total lbs. per A.	0.69	1.44	2.13	——
% of total	32.4	67.6	——	100.0
		DUFF AND SOIL		
NH_3-N mgs.	2.06	1.70	0.33	15.6
NO_3-N "	.63	.65	0.11	5.2
Org. N "	9.41	9.66	1.68	79.2
Total lbs. per A.	1.06	1.06	2.12	——
% of total	50.0	50.0	——	100.0

iods. Less nitrogen, both actually and relatively, was obtained in the sixth period than in the third.

With respect to the pan lysimeters, Table 8, the amount of nitrogen was, of course, only a fraction of that from the tanks. In every case organic nitrogen constituted the largest percentage of the total, and nitrates the smallest. There seemed to be little consistency with respect to proportion obtained in the different periods.

In Table 9 data pertaining to the sum total of all forms of nitrogen are presented three ways: parts per million of leachate, pounds per acre, and pounds per acre per month, the latter being necessitated by the fact that the periods were not of equal length. The results

TABLE 9. TOTAL NITROGEN IN LEACHATE

Parts per Million, Pounds per Acre and Pound per Inch per Month.

Year		1938-39				1939-40		
Period		1st	2nd	3rd	Total	4th & 5th	6th	Total
TANK LYSIMETERS (Av. of two)								
Duff	p.p.m.	5.71	6.01	3.31	4.86	4.93	2.43	3.62
	lbs./A.	11.99	27.26	15.27	54.50	20.57	11.14	31.73
	lbs./A./mo.	3.99	6.82	3.05	—	2.94	2.23	—
Soil	p.p.m.	1.38	5.46	6.51	15.57	18.30	4.91	13.54
	lbs./A.	1.96	16.63	19.58	38.17	42.61	9.15	51.79
	lbs./A./mo.	0.66	4.16	3.92	—	6.08	1.83	—
Duff and Soil	p.p.m.	0.83	8.37	8.78	6.98	21.47	4.31	15.17
	lbs./A.	1.87	37.84	35.56	75.28	81.59	9.50	91.11
	lbs./A./mo.	0.62	9.45	7.11	—	11.67	1.90	—
PAN LYSIMETERS (Av. of four)								
Duff	p.p.m.	3.62	1.05	1.13	1.61	1.98	1.75	1.91
	lbs./A.	5.54	3.50	2.79	11.84	6.42	2.61	9.04
	lbs./A./mo.	1.85	0.88	0.56	—	0.92	0.52	—
Soil	p.p.m.	0.76	0.51	0.76	0.64	1.04	1.46	1.30
	lbs./A.	0.30	0.40	0.37	1.07	0.69	1.44	2.13
	lbs./A./mo.	0.10	0.10	0.07	—	0.10	0.29	—
Duff and Soil	p.p.m.	0.93	0.89	0.75	0.83	1.54	1.74	1.63
	lbs./A.	0.22	0.69	0.68	1.60	1.06	1.06	2.12
	lbs./A./mo.	0.07	0.17	0.14	—	0.15	0.21	—

of statistical analyses, based on pounds per acre per month, are shown in Appendix Table 2. Differences between soils (*i.e.*, duff, bare soil and duff-plus-soil) were significant, particularly between the latter two. In both tanks and pans the winter period yielded less nitrogen than the summer period, and the first year yielded more than the second. Interactions between season and year were very low in the tanks but highly significant in the pans. In all but one instance significant interactions of soils with season and year were due primarily to the duff vs. soil relationship rather than the between-soils relationship.

TABLE 10. CHEMICAL CONSTITUENTS IN LEACHATE

Parts per Million, Pounds per Acre and Pounds per Acre per Month.

		Tank Lysimeters (Av. of two)							Pan Lysimeters (Av. of four)						
		1938-39				1939-40			1938-39				1939-40		
		Period			Av. & total	Period		Av. & total	Period			Av. & total	Period		Av. & total
		1st	2d	3d		4th &5th	6th		1st	2d	3d		4th & 5th	6th	
TOTAL SOLIDS															
Duff	p.p.m.	191.7	145.1	71.0	135.9	94.6	67.8	81.2	116.6	84.0	49.4	83.3	78.4	69.4	73.9
"	lbs./A.	402.0	658.2	324.5	1384.7	394.3	316.9	711.2	178.7	284.7	124.8	588.2	255.8	109.4	365.2
	lbs./A./mo.	134.0	164.5	64.9	—	56.3	63.4	—	59.6	71.2	24.9	—	36.5	21.9	—
Soil	p.p.m.	51.2	140.8	117.0	103.0	113.4	71.4	92.4	50.8	44.1	37.2	44.0	42.3	51.2	46.8
"	lbs./A.	72.6	412.9	362.4	847.9	257.2	133.1	390.3	19.8	33.4	18.3	71.5	25.8	62.7	88.5
	lbs./A./mo.	24.2	103.2	72.5	—	36.8	26.6	—	6.6	8.4	3.7	—	3.7	12.5	—
Duff and Soil	p.p.m.	57.1	95.1	82.4	78.2	132.5	73.4	103.0	47.2	65.3	42.8	51.8	54.2	97.4	75.8
" " "	lbs./A.	127.6	427.4	333.4	888.4	492.4	162.1	654.5	11.9	48.6	34.3	94.8	35.6	55.0	90.6
	lbs./A./mo.	42.5	106.9	66.7	—	70.3	32.4	—	4.0	12.2	6.9	—	5.1	11.0	—
ASH															
Duff	p.p.m.	47.7	35.5	29.6	37.6	34.3	20.6	27.5	22.2	26.6	19.7	22.8	31.2	23.5	27.4
"	lbs./A.	100.0	161.0	135.4	396.4	143.0	95.5	238.5	34.0	89.1	51.1	174.2	101.2	36.0	137.2
	lbs./A./mo.	33.3	40.3	27.1	—	20.4	19.1	—	11.3	22.3	10.2	—	14.5	7.2	—
Soil	p.p.m.	28.4	66.6	56.2	50.4	62.9	37.9	50.4	25.6	24.9	21.8	24.1	25.1	24.7	24.9
"	lbs./A.	40.3	196.4	173.8	410.5	142.2	70.7	212.9	10.0	18.4	10.8	39.2	15.3	28.9	44.2
	lbs./A./mo.	13.4	49.1	34.8	—	20.3	14.1	—	3.3	4.6	2.2	—	2.2	5.8	—
Duff and Soil	p.p.m.	34.7	38.9	37.4	37.0	66.4	28.4	47.5	25.8	29.7	24.1	26.5	25.6	21.5	23.6
" " "	lbs./A.	77.6	174.8	151.4	403.8	158.8	62.5	221.3	6.1	20.9	18.4	45.4	16.8	11.6	28.4
	lbs./A./mo.	25.9	43.7	30.3	—	22.7	12.5	—	2.0	5.2	3.7	—	2.4	2.3	—

LOSS-ON-IGNITION																
Duff	p.p.m.	144.1	109.6	41.4	98.4	60.4	47.3	53.9	94.3	57.4	29.8	60.5	47.2	45.8	46.5
"	lbs./A.	302.0	497.1	189.1	988.2	251.3	221.4	472.7	144.5	195.5	74.0	414.0	154.6	73.3	227.9
	lbs./A./mo.	100.7	124.3	37.8	—	35.9	44.3	—	48.2	48.9	14.8	—	22.1	14.7	—
Soil	p.p.m.	22.9	74.2	60.8	52.6	50.5	33.5	42.0	25.3	19.3	15.4	20.0	17.2	26.5	21.9
"	lbs./A.	32.5	216.5	188.5	437.5	115.0	62.4	177.4	9.9	15.1	7.5	32.5	10.6	33.7	44.3
	lbs./A./mo.	10.8	54.1	37.7	—	16.4	12.5	—	3.3	3.8	1.5	—	1.5	6.7	—
Duff and Soil	p.p.m.	22.4	56.2	45.0	41.2	64.3	45.0	54.7	21.4	35.5	18.7	25.2	28.6	75.9	52.3
" " "	lbs./A.	50.1	252.5	182.1	484.7	237.5	99.5	337.0	5.3	27.7	15.9	48.9	18.8	43.3	62.1
	lbs./A./mo.	16.7	63.1	36.4	—	33.9	19.9	—	1.8	6.9	3.2	—	2.7	8.7	—
LOSS-ON-IGNITION IN PERCENT OF TOTAL SOLIDS															
Duff		74.8	75.6	58.3	69.6	63.8	69.5	66.7	80.6	67.9	60.6	69.7	60.1	64.7	62.4
Soil		44.6	49.5	50.7	48.3	44.7	46.9	45.8	51.8	45.3	41.8	46.3	40.4	51.4	45.9
Duff and Soil		39.3	59.1	54.6	51.0	48.3	61.2	54.8	46.0	53.1	43.7	47.6	52.0	76.6	64.3

Strangely enough, differences between the first and second periods of the first year were highly significant in the tanks but not significant in the pans.

Total Solids, Ash and Loss-On-Ignition

Data pertaining to these constituents are shown in Table 10, with a statistical analysis of solids and organic matter in Appendix Table III. The concentration of solids, ash and loss-on-ignition in the duff leachate decreased from spring to winter periods each year, but the total amount and the average per month were highest in the second period. In the case of bare soil and duff-plus-soil, there was a tendency for the highest concentration and highest amount, total and average per month, to occur in the second period.

In all cases except one the total solids from the duff contained a higher percentage of organic matter than did that from either soil or duff-plus-soil. It is rather significant that the amount of organic matter recovered from the duff the first year totaled nearly 1,000 pounds in the tank lysimeters and over 400 pounds in the pans; and that the amount from the duff-plus-soil did not, in most cases, greatly exceed that from the bare soil.

The analysis of variance of solids and organic matter data, Appendix Table III, shows that differences between soils were significant and highly significant, respectively, and differences between soil and duff-without-soil were highly significant in all cases; but the effect of duff on the soil was significant in only one instance.

Calcium, Magnesium and Potassium

(Table 11, and Appendix Tables IV and V)

The *calcium* recovered from the tanks varied from 14 to 33 pounds and, from the pans, 1.6 to 19.5 pounds per acre per year. Of the three materials bare soil furnished the least calcium in all but one instance. Table IV indicates that differences between soils were not significant except in the case of duff versus soil in the pans. More calcium was obtained in summer than in winter and more the first year than the second. Interactions between soils and season and year, separately and together, were all highly significant. The higher yields of calcium the second period over the first period were significant.

In the tanks, duff-plus-soil gave the most *magnesium* and bare soil the least; in the pans, duff gave the most. The ratio of calcium to magnesium varied from 1 : 1 to 18 : 1. Peculiarly enough, the variation the first year for tanks and pans alike was from 1 : 1 to 6.6 : 1, with an average of about 3 : 1; but the second year the variation was from 2.1 : 1 to 18.0 : 1, with an average of 8.9:1. It is quite possible that the hurricane had something to do with this. The data in Table 11 show a tendency toward a higher concentration of magnesium the second period which could well have been the result of magnesium in the salt water spray that blew inland many miles during the storm.

The amount of *potassium* recovered per acre in a year ranged from 28 to 56 pounds in the tank leachate, and 2.5 to 24 in the pans. In the former case the bare soil gave the highest concentration and duff the lowest, but in the pan lysimeters the duff leachate had the highest concentration in every case.

The higher amount per month of all three constituents generally obtained during the second period might be said to have resulted from the leaching out of material from the freshly fallen leaves in the autumn. However, this does not explain the situation in the case of the bare soil lysimeters on which leaves were not allowed to accumulate. Since removal of leaves and other debris took place only when the lysimeters were visited and collections made, it is possible, though hardly probable, that during the intervals between collections, light rains might have leached some material into the soil although the precipitation was insufficient to produce much, if any, leachate. The analysis of variance (Table V) indicates that the differences found are significant in practically the same pattern as was the case with calcium.

Sulfur, Phosphorus, Iron and Silica

(Table 11 and Appendix Table III)

Sulfur was found in amounts ranging from 16 to 48 pounds per acre per year in the tanks, and 4 to 18 in the pans. In the former the amount was generally highest in duff-plus-soil and lowest in bare soil, but the concentration of sulfur in the leachate was generally lowest in the duff. In the pans, the duff delivered the largest amount but not the highest concentration. With respect to periods, the second appeared to furnish more sulfur than either the first or the third in the tanks. In the pans the data are not consistent in this respect.

Statistical analysis of the data, Table III, indicates a significant relationship between soils in the tanks and a highly significant relationship in the pans. Soil versus no soil was not significant in the tanks but highly significant in the pans. Humus effect was significant in the tanks but not in the pans.

As would be expected the amount of *phosphorus* in the leachate was very small, seldom reaching a pound to the acre in a year's time. In all cases the largest amounts came from the duff alone and the least from the bare soil. Neither the concentration nor the total amount differed significantly in the tanks and pans, nor was there any consistent correlation with period of the year.

With respect to *iron*, the largest amounts and, generally, the highest concentrations were found in the duff leachate, and least in the bare-soil leachate. No other significant relationships are apparent.

Silica shows a tendency to be present in larger amounts in the

TABLE 11. CHEMICAL CONSTITUENTS IN LEACHATE

Parts per Million, Pounds per Acre and Pounds per Acre per Month.

		Tank Lysimeters (Av. of two)							**Pan Lysimeters (Av. of four)**						
		1938-39				1939-40			1938-39				1939-40		
		Period			Av. & total	Period		Av. & total	Period			Av. & total	Period		Av. & total
		1st	2d	3d		4th & 5th	6th		1st	2d	3d		4th & 5th	6th	
CALCIUM (Ca)															
Duff	p.p.m.	2.54	1.87	1.99	2.13	4.48	1.59	3.04	2.87	2.90	2.02	2.60	2.69	2.52	2.61
"	lbs./A.	5.32	8.47	9.25	23.04	18.82	7.58	26.40	4.40	10.06	4.99	19.45	9.07	3.89	12.96
	lbs./A./mo.	1.77	2.12	1.85	—	2.69	1.52	—	1.47	2.51	1.00	—	1.29	0.78	—
Soil	p.p.m.	1.64	2.33	1.44	1.80	4.50	1.82	3.16	1.59	1.10	1.09	1.26	0.70	1.50	1.10
"	lbs./A.	2.32	7.04	4.40	13.76	10.38	3.39	13.77	0.62	0.85	0.53	2.00	0.50	1.80	2.30
	lbs./A./mo.	0.77	1.76	0.88	—	1.48	0.68	—	0.21	0.21	0.11	—	0.07	0.36	—
Duff and Soil	p.p.m.	1.83	1.35	1.57	1.58	7.87	2.06	4.97	1.71	2.38	1.05	1.71	1.08	1.82	1.45
" " "	lbs./A.	4.09	6.05	6.36	16.50	28.49	4.51	33.00	0.40	1.28	1.06	2.74	0.63	0.95	1.58
	lbs./A./mo.	1.36	1.51	1.27	—	4.07	0.90	—	0.13	0.32	0.21	—	0.09	0.19	—

MAGNESIUM (Mg)															
Duff	p.p.m.	0.48	0.71	0.44	0.54	0.45	0.20	0.33	0.55	0.71	0.69	0.65	0.34	0.14	0.24
" " "	lbs./A.	1.01	3.20	2.02	6.23	1.90	0.92	2.82	0.84	2.40	1.52	4.76	1.19	0.21	1.40
	lbs./A./mo.	0.33	0.80	0.40	—	0.27	0.18	—	0.28	0.60	0.30	—	0.17	0.04	—
Soil	p.p.m.	0.25	1.24	0.56	0.68	0.67	0.13	0.40	0.65	0.72	0.48	0.62	0.33	0.20	0.27
"	lbs./A.	0.35	3.72	1.67	5.74	1.63	0.24	1.87	0.25	0.58	0.22	1.05	0.23	0.22	0.45
	lbs./A./mo.	0.12	0.93	0.33	—	0.23	0.05	—	0.08	0.15	0.04	—	0.03	0.04	—
Duff and Soil	p.p.m.	0.88	0.69	1.25	0.94	0.95	0.20	0.58	0.75	1.02	0.99	0.92	0.39	0.18	0.29
" " "	lbs./A.	1.97	3.09	5.06	10.12	3.61	0.43	4.04	0.18	0.63	0.66	1.47	0.25	0.11	0.36
	lbs./A./mo.	0.66	0.77	1.01	—	0.52	0.09	—	0.06	0.16	0.13	—	0.04	0.02	—
POTASSIUM (K)															
Duff	p.p.m.	6.98	3.76	2.09	4.28	2.77	3.38	3.08	4.11	2.70	3.31	3.37	2.88	3.53	3.21
"	lbs./A.	14.63	17.03	9.63	41.29	11.54	17.63	29.17	6.30	9.12	8.35	23.77	9.55	5.62	15.17
	lbs./A./mo.	4.88	4.26	1.93	—	1.65	3.53	—	2.10	2.28	1.67	—	1.36	1.12	—
Soil	p.p.m.	4.83	8.76	6.81	6.80	9.44	3.97	6.71	4.05	1.59	1.46	2.37	1.42	2.01	1.72
"	lbs./A.	6.85	25.82	21.07	53.74	20.83	7.40	28.23	1.58	1.29	0.67	3.54	0.90	2.01	2.91
	lbs./A./mo.	2.28	6.45	4.21	—	2.98	1.48	—	0.53	0.32	0.13	—	0.13	0.40	—
Duff and Soil	p.p.m.	5.76	5.66	4.31	5.24	7.50	1.97	4.74	3.13	2.00	2.22	2.45	2.69	1.67	2.18
" " "	lbs./A.	12.87	25.33	17.44	55.64	27.94	4.38	32.32	0.73	2.21	2.00	4.94	1.54	0.92	2.46
	lbs./A./mo.	4.29	6.33	3.49	—	3.99	0.88	—	0.24	0.55	0.40	—	0.22	0.18	—

TABLE 11. CHEMICAL CONSTITUENTS IN LEACHATE—*Continued*

		Tank Lysimeters							Pan Lysimeters						
		1938-39				1939-40			1938-39				1939-40		
		Period			Av. & total	Period		Av. & total	Period			Av. & total	Period		Av. & total
		1st	2nd	3rd		4th & 5th	6th		1st	2nd	3d		4th & 5th	6th	
SULFUR (S)															
Duff	p.p.m.	3.57	2.81	2.19	2.86	4.40	2.34	3.37	3.65	2.15	2.35	2.72	2.79	2.55	2.67
"	lbs./A.	7.48	12.61	9.84	29.93	18.35	10.96	29.31	5.60	7.25	5.45	18.30	9.32	3.88	13.20
	lbs./A./mo.	2.49	3.15	1.97	—	2.62	2.19	—	1.87	1.81	1.09	—	1.33	0.78	—
Soil	p.p.m.	2.89	5.07	2.96	3.64	3.46	4.58	4.02	5.19	2.97	1.82	3.33	3.49	4.08	3.79
"	lbs./A.	4.10	15.40	8.93	28.43	7.92	8.54	16.46	2.03	2.32	0.93	5.28	2.24	4.57	6.81
	lbs./A./mo.	1.37	3.85	1.79	—	1.13	1.71	—	0.68	0.58	0.19	—	0.32	0.91	—
Duff and Soil	p.p.m.	4.89	4.52	4.15	4.52	4.77	4.50	4.64	5.61	2.51	3.46	3.86	3.17	3.64	3.41
" " "	lbs./A.	10.93	20.05	16.78	47.76	17.72	9.91	27.63	1.48	2.46	2.92	6.86	2.29	1.89	4.18
	lbs./A./mo.	3.64	5.01	3.36	—	2.53	1.98	—	0.49	0.62	0.58	—	0.33	0.38	—
PHOSPHORUS (P)															
Duff	p.p.m.	tr.	.140	.080	.110	.007	.060	.034	.025	.079	.089	.064	.130	.068	.099
"	lbs./A.	—	.635	.372	1.007	.028	.276	.304	.038	.269	.228	.535	.396	.098	.494
	lbs./A./mo.	—	.159	.074	—	.004	.055	—	.013	.067	.046	—	.057	.020	—
Soil	p.p.m.	.025	.028	.023	.025	.014	.017	.016	.025	.031	.025	.027	.028	.052	.040
"	lbs./A.	.035	.084	.067	.186	.035	.032	.067	.010	.023	.012	.045	.018	.041	.059
	lbs./A./mo.	.012	.021	.013	—	.005	.006	—	.003	.006	.002	—	.003	.008	—
Duff and Soil	p.p.m.	.044	.033	.025	.034	.012	.042	.027	.025	.054	.028	.036	.077	.046	.062
" " "	lbs./A.	.098	.144	.101	.343	.042	.092	.134	.006	.038	.021	.065	.055	.026	.081
	lbs./A./mo.	.033	.036	.020	—	.006	.018	—	.002	.009	.004	—	.008	.005	—

IRON (Fe)															
Duff	p.p.m.	2.27	2.38	0.75	1.80	0.45	0.27	0.36	0.86	1.65	0.36	0.96	0.10	0.20	0.15
"	lbs./A.	4.76	10.78	3.44	18.98	1.85	1.25	3.10	1.32	0.53	0.87	2.72	0.33	0.33	0.66
	lbs./A./mo.	1.59	2.69	0.69	—	0.26	0.25	—	0.44	0.13	0.17	—	0.05	0.07	—
Soil	p.p.m.	0.10	0.16	0.31	0.19	0.05	0.15	0.10	0.47	0.55	0.29	0.44	0.10	0.19	0.15
"	lbs./A.	0.14	0.47	0.91	1.52	0.14	0.28	0.42	0.18	0.43	0.14	0.75	0.07	0.25	0.32
	lbs./A./mo.	0.04	0.12	0.18	—	0.02	0.06	—	0.06	0.11	0.03	—	0.01	0.05	—
Duff and Soil	p.p.m.	0.07	0.65	0.24	0.32	0.05	0.13	0.09	1.00	0.73	0.32	0.68	0.08	0.46	0.27
" " "	lbs./A.	0.16	2.94	0.97	4.07	0.23	0.28	0.51	0.23	0.61	0.31	1.15	0.05	0.27	0.32
	lbs./A./mo.	0.05	0.74	0.19	—	0.03	0.06	—	0.08	0.15	0.06	—	0.01	0.05	—
SILICA (Si)															
Duff	p.p.m.	3.00	2.50	1.18	2.23	2.08	0.59	1.34	1.20	1.38	0.73	1.10	1.14	0.90	1.02
"	lbs./A.	6.29	11.33	5.30	22.92	8.62	2.74	11.36	1.84	4.63	1.73	8.20	3.66	1.29	4.95
	lbs./A./mo.	2.10	2.83	1.06	—	1.23	0.55	—	0.61	1.16	0.35	—	0.52	0.26	—
Soil	p.p.m.	2.50	2.44	1.33	2.09	2.71	1.32	2.02	1.07	1.50	1.13	1.23	1.17	0.97	1.07
"	lbs./A.	3.55	7.44	4.01	15.00	6.36	2.46	8.82	0.42	1.17	0.54	2.13	0.75	0.99	1.74
	lbs./A./mo.	1.18	1.86	0.80	—	0.91	0.49	—	0.14	0.29	0.11	—	0.11	0.20	—
Duff and Soil	p.p.m.	2.50	2.25	1.86	2.20	3.57	1.63	2.60	1.12	1.47	1.17	1.25	0.76	0.83	0.80
" " "	lbs./A.	5.59	10.13	7.53	23.25	13.70	3.59	17.29	0.26	0.95	0.99	2.20	0.53	0.44	0.97
	lbs./A./mo.	1.86	2.53	1.51	—	1.96	0.72	—	0.09	0.24	0.20	—	0.08	0.09	—

duff-plus-soil leachate in the tanks although the concentration in parts per million varied relatively little. In the pans the duff yielded more silica than either of the other two soils but the concentration in parts per million was remarkably uniform. In practically all cases, in both types of lysimeters, the average amount of silica per month was greatest in the second period of the year.

ARTIFICIAL LEACHING IN THE LABORATORY

To obtain additional data on the effect of leaching, samples of the F, H and A (0-4-inch) layers collected in June, 1940, from the immediate vicinity of the lysimeter pits were used for study in the laboratory. The F material was cut up in a food cutter; the H layer was passed through a coarse screen, and the A through a 2 mm. sieve.

In the first experiment, 30 grams of F, 60 grams of H and 80 grams of A were placed on filter paper in separate Buchner funnels and leached with about 300, 275 and 250 cc. portions, respectively, of distilled water once each day for nine days, omitting leaching on the fifth day. Suction was used during leaching; and between leachings the Buchners were covered to prevent the soil from drying out. The leachate was tested for pH, conductivity and color, the latter being merely the percent extinction as read in a Lange photometer used without filters. The results, Figure 16, show a progressive increase in pH for all three materials up to the fourth day, after which there was either no change (H and A_1) or a gradual decrease (F). Conductivity increased the second day (F and H), then dropped off. In the A material it decreased right from the start. The biggest change in color occurred in the leachate from the F layer.

In the second experiment, litter (L) from Pachaug State Forest was included. There were four successive leachings the first day and two successive leachings daily thereafter on the second, third, fourth, fifth, eighth and fifteenth days. The total amount of water applied was equivalent to approximately 22 inches of rain. In this experiment the filtering medium was a layer of medium sand over a layer of coarse sand. During leachinq, suction was used continuously on the A sample but only intermittently on the other horizons. At the conclusion of the experiment the leached material in the Buchners and identical unleached material were tested for exchangeable hydrogen, base capacity, exchangeable calcium, and loss-on-ignition. The data are given in Figure 17 and Table 12.

Successive leachings resulted in an increase in pH and a decrease in conductivity and color, but during the 22-hour interval between the second leaching of one day and the first leaching of the next day the pH dropped and the conductivity and color increased. Even the two-hour interval which occurred between the second and third leachings on the first day was long enough to have some influence on the results. On the other hand the two-day interval following the fifth day, and the seven-day interval following the eighth day, caused only a moderate recovery. These results are similar in most respects to those obtained in a like experiment on material taken from the vicinity of the red pine lysimeter study, and the reasons are, presumably, the same, namely, that during the interval between leachings some basic material became soluble, and most of this was removed in the first leaching.

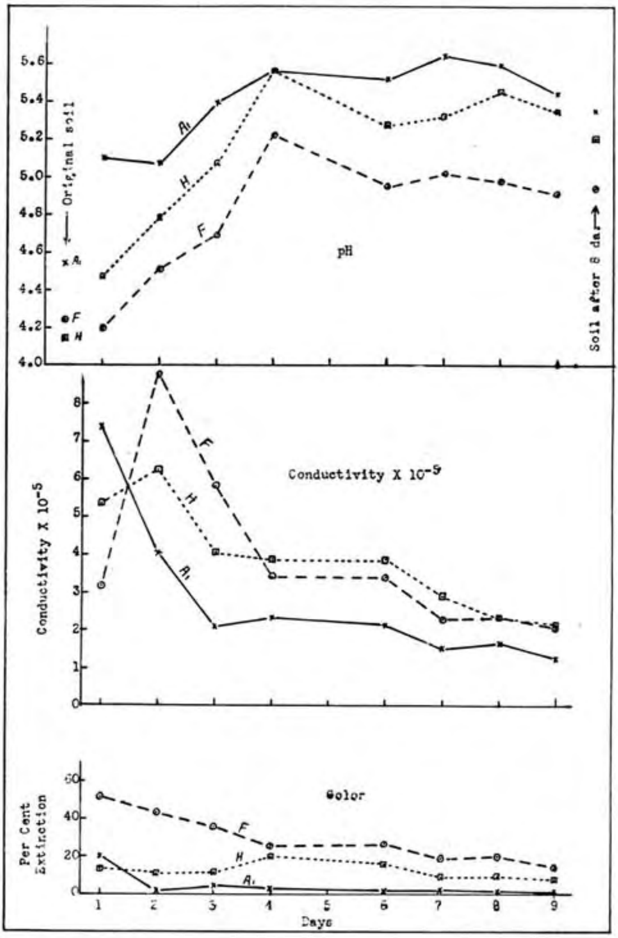

FIGURE 16. pH, conductivity and relative color of leachate obtained in the *first* artificial leaching experiment in the laboratory.

The chemical studies on the soil indicate that the leaching process tends to reduce the exchangeable H content of all horizons and reduce the base capacity of the organic horizons. The relative saturation is increased in three cases out of four. There was an increase in concentration of exchangeable calcium in the L and F layers but a decrease in the H and A. The organic matter content was slightly reduced.

The foregoing results serve to confirm, in general, the findings relative to changes that occurred in the lysimeter soils, Table 5.

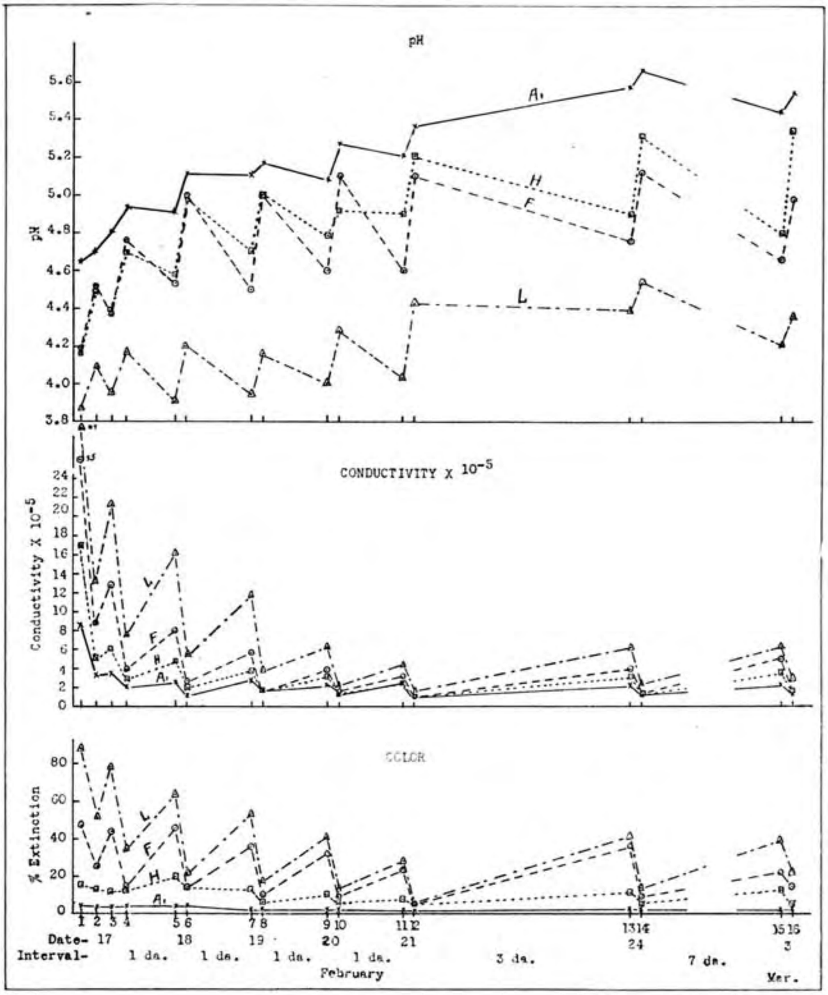

FIGURE 17. pH, conductivity and relative color of the leachate obtained in the *second* artificial leaching experiment in the laboratory.

DISCUSSION

In spite of the fact that the red pine and hardwood lysimeter studies were carried on at different times and under different conditions, the agreement in amount of leachate collected, both actual and percentage of rainfall (Table 13), is surprisingly close, except for the duff-plus-soil pan lysimeters. The total amount of *nitrogen* obtained under hardwoods in the two-year period was, for the tanks, 86 pounds from the duff, and practically twice that much from the bare soil and duff-plus-soil. These values are considerably in excess of those for red pine, both total and pounds per inch of leachate, and are the result, no doubt, of the greater amount of nitrogen in the hardwood duff (Table 14). In the pans, on the other hand, the hardwood soil delivered less nitrogen in two cases out of three, and less per inch of leachate in all cases. The proportion of nitrogen in the form of nitrates was lower in the hardwoods in every instance. It is probable that this condition was due to a greater utilization of nitrogen, particularly in the nitrate form, by the hardwoods. It is generally conceded that hardwoods have a higher nitrogen requirement than do pines.

TABLE 12. EFFECT OF ARTIFICIAL LEACHING ON BASE EXCHANGE PROPERTIES AND ORGANIC MATTER CONTENT OF THE SOIL

Samples Leached in Laboratory Sixteen Times Over a Period of Two Weeks. Leaching Equivalent to about 22 inches of Rain.

	Before	After	% Change	Before	After	% Change	Before	After	% Change
	Exch. H mg.eq.			**Base Capacity mg.eq.**			**% Saturation**		
L	49.5	35.0	−29	66.5	53.5	−20	25.6	34.6	+35
F	45.6	34.1	−25	66.4	41.8	−37	31.3	18.4	−41
H	24.7	22.5	− 9	31.4	31.3	−0.3	21.3	28.1	+32
A (0-4″)	9.8	8.6	−12	12.0	12.0	0	18.3	28.3	+55
	Exch. Ca p.p.m.			**Loss-on-ignition %**					
L	2000	2825	+41	97.0	95.9	−1.1			
F	3080	4200	+36	88.0	84.2	−4.3			
H	691	600	−13	27.2	26.0	−4.4			
A (0-4″)	94	45	−52	—	—	—			

Calcium was invariably less in amount in the hardwood leachate, a fact that can be explained primarily by the lower calcium content, both total and replaceable, of the litter and top soil under the hardwoods, and secondarily by the higher calcium requirements of hardwoods. The situation with respect to *potassium* is exactly the reverse, the largest amount being obtained in the hardwood stand. Analyses of the litter from these and other stands indicate that hardwood leaves usually contain more potash than pine needles, but the upper 4 inches of *mineral* soil in this particular case proved to be richer in potash under the pine stand than did that under the hardwoods. This latter fact seemed to have no bearing on the relative amount of potassium in the bare soil leachate.

The findings with respect to sulfur were inconclusive, being higher in the hardwood leachate in some cases and lower in others.

Direct comparisons of the other constituents are not possible because of incomplete data from the pine study.

Examination of the pan lysimeter data reveals that in the hardwood study the total amount of constituents leached from the duff-plus-soil was, in 13 cases out of 20, somewhat more than that from the bare soil, the difference representing the amount of material from the duff which was not taken up by roots or absorbed by the 4 inches of soil. In the red pine study, on the other hand, the material from litter-plus-soil exceeded that from the bare soil in only one instance out of the 13 for which data are available. This situation would seem

TABLE 13. COMPARISON OF RED PINE AND HARDWOODS WITH RESPECT TO TOTAL AMOUNT OF MATERIAL OBTAINED DURING TWO-YEAR PERIOD[1]

	Stand	Leachate Collected			Total N		NO_3-N in % of total	Ca		K		S	
		liters	inches	% of rainfall	lbs./Acre	lbs./In.[2]		lbs./Acre	lbs./In.	lbs./Acre	lbs./In.	lbs./Acre	lbs./In.
TANK LYSIMETERS													
Duff	RP	458.4	89.2	92	55.7	0.62	33	95.5	1.07	52.2	0.58	62.2	0.70
	Hdws.	453.9	88.3	82	86.2	0.98	16	49.4	0.56	70.5	0.80	59.2	0.67
Soil	RP	186.7	36.3	34	76.9	2.12	88	86.8	2.39	30.7	0.84	30.2	0.83
	Hdws.	256.7	50.0	44	168.1	3.37	76	27.5	0.55	82.0	1.64	44.9	0.90
Duff + Soil	RP	400.2	77.9	81	110.8	1.43	82	101.0	1.30	52.5	0.68	65.0	0.83
	Hdws.	381.5	74.2	66	166.4	2.24	77	49.5	0.67	88.0	1.18	75.4	1.02
PAN LYSIMETERS													
Duff	RP	116.6	45.4	48	33.3	0.73	38	60.0	1.32	29.4	0.65	36.2	0.80
	Hdws.	137.3	53.4	45	20.9	0.39	8	32.4	0.61	38.9	0.73	31.5	0.59
Soil	RP	38.6	15.0	16	6.81	0.45	40	19.2	1.28	6.5	0.43	17.1	1.14
	Hdws.	37.6	14.3	14	3.20	0.22	11	4.3	0.29	6.4	0.44	12.1	0.83
Duff + Soil	RP	13.2	5.1	5.4	2.2	0.44	38	6.0	1.17	2.0	0.39	4.0	0.78
	Hdws.	36.8	14.3	13	3.7	0.26	9	4.3	0.30	7.4	0.52	11.0	0.77

[1] Total precipitation April, 1931, to April, 1936 (R.P. expt.) 95.3 inches
Total precipitation April, 1933, to April, 1940 (Hdw. expt.) 109.8 inches
[2] Pounds per inch of leachate collected.

to indicate a higher degree of absorption by the pine roots in the soil with the normal litter cover than in the bare soil. It has been observed that fine feeding roots of pine are found in the litter to a greater extent than are those of hardwoods. When we examine the tank lysimeter data, we find in most cases more material from the duff-plus-soil than from the bare soil, and this is true in both pines and hardwoods.

It is interesting to note that the leachate from under the hardwoods was generally a little more acid and, in the case of the bare-soil tank lysimeters, considerably more acid than was the leachate from under red pine, although there was little difference in the pH of the soils. Undoubtedly the higher calcium content of the red pine soil was responsible for this situation.

Comparison with Joffe's lysimeter study (6) is possible only in the case of our duff-plus pan lysimeters (10 cm. deep) and his A_1 horizon (18 cm. depth) for the first two years. This has been made and the data recorded in Table 15. Our results are characterized by less leachate per inch of rainfall, especially under pine; and the leachate was less acid, lower in total soluble salt content, as indicated by the conductivity test, and definitely lower in all constituents analyzed. While the lysimeter leachate under hardwoods contained more of everything except nitrogen than did that obtained under pine, the amounts were still far below these reported by Joffe. This may be due in part to the difference in stand composition and partly to

TABLE 14. COMPARISON OF SOIL IN THE RED PINE STAND WITH THAT UNDER THE HARDWOODS

		Red Pine Soil		Hardwood Soil	
		Litter	Mineral Soil (0-4″)	Duff	Mineral Soil[2] (0-4″)
pH		4.70	4.58	4.68	4.75
Loss-on-ignition	%	90.70	10.60	71.00	9.70
Volume weight		—	0.88	—	0.84
Total nitrogen	%	.972	.300	1.300	.185
" phosphorus	%	.080	.030	.037	.018
" calcium	%	.811	.382	.585	.221
" magnesium	%	.154	.258	.218	.253
" potassium	%	.627	1.760	.533	.938
Replaceable calcium	p.p.m.	2920	562	3100	41
" potassium	p.p.m.	702	55	980	27
Base capacity	mgm. equiv.[3]	38.0	15.8	53.2	13.0
Percentage saturation		34.7	35.4	26.6	23.3

[1] Data based on separate analyses of F and H layers.
[2] Data based on separate analyses of 0-1 inch and 1-4 inch depths.
[3] Milligram equivalents per 100 g. soil.

differences in level of soil fertility. What other factors, if any, are involved is not known.

It will be recalled that Joffe (7) found a definite increase in pH, conductivity, calcium and magnesium in the fall, as the result of the increase in bases released from the freshly fallen leaves. In a later publication (10) he found that, over a period of nine years, the greatest movement of Ca and Mg took place in the early fall and again in March, while K appeared in greatest amount in August. In our study, the pH and conductivity increased in the fall in some cases but to a much lesser degree than Joffe reported. Calcium, magnesium and potassium, in terms of pounds per acre per month, were generally highest in the late summer and fall period.

The artificial leaching experiments in the laboratory serve to indicate the kind of changes that take place in the field but which are indiscernible because of insufficient control. The percolate obtained as the result of any one rain storm is not a homogenous solution in any sense of the word but is rather a composite of solutions that vary in composition and reaction with the progress of the percolation. In other words, the first 100 cc. of leachate is vastly different in composition than the last 100 cc., but the greatest difference occurs during the first part of the percolation and is greater the longer the period since the preceding percolation. During heavy storms, when large amounts of percolate are obtained, and during long-drawn-out rainy spells, the leachate becomes relatively homogenous. This is shown by the yellowish-brown color of the leachate from the duff lysimeters which gradually disappears with the progress of percolation. Also the amount of color is less in winter, indicating a diminished activity of biological decomposition processes.

TABLE 15. COMPARISON OF RESULTS OBTAINED BY JOFFE AND LUNT

JOFFE (A_0 & A_1 horizon (18 cm.))			LUNT (Duff + 4″ soil, pan lysimeters)			
	Hardwoods		Red Pine		Hardwoods	
Year	1929-30	1930-31	1934-35	1935-36	1938-39	1939-40
Precipitation, inches	37.26	34.14	50.85	44.45	65.90	43.90
Total leachate, liters	21.0	29.2	4.9	8.3	22.0	14.8
Leachate per inch of rainfall, cc.	564	855	97	187	334	337
pH	4.6-6.4	4.6-6.4	6.0-6.5	5.8-6.5	5.0-6.5	5.7-6.4
Conductivity X 10^{5}	8-26	8-35	5-12	4-8	2-19	2-11
Nitrates lbs./A.	10.0	11.3	0.9	0.1	0.2	0.1
Total N "	13.4	19.4	1.6	0.6	1.6	2.1
Total solids "	362	564	36	53	94	91
Loss-on-ignition "	140	258	14	30	49	62
Sulfur "	33.8	47.6	1.7	—	6.9	4.2
Calcium "	19.4	23.8	1.9	4.1	2.7	1.6
Magnesium "	6.9	11.2	0.5	—	1.5	0.4
Potassium "	—	—	0.7	1.4 ±	4.9	2.5

SUMMARY

A set of six tank (fill-in type) lysimeters and two sets of six pan (Ebermayer type) lysimeters were installed in a mixed hardwood stand, for the purpose of determining the kind and amount of materials leached out of: (1) the forest floor, referred to in this bulletin as duff; (2) the surface four inches of soil kept free of duff; and (3) the same depth of soil with the normal duff cover. Reaction, conductivity, ammonia and nitrates were determined in the leachate usually after every significant rainfall, and other constituents were determined on composite aliquots in April, July and November. In addition, certain soil tests and analyses were made at the beginning and at the end of the investigation. During the two-year period the study was disturbed somewhat by the hurricane of September 21, 1938, by vandalism and by loss of some leachate through freezing and breakage.

Soil Changes

The mineral soil in the tanks contained considerably more moisture and somewhat higher amounts of nitrates, ammonia and available potassium and the bare soil in the tanks exhibited a higher volume weight, lower water-holding capacity and lower aggregate content than did the soil in any of the other lysimeters or in the field. The organic layers in the tanks were lower in exchangeable hydrogen and base capacity and higher in percent saturation, and the H layer of the duff tanks contained less organic matter and total N than the corresponding layers in the field soil.

Amount of Leachate

The amount of leachate collected was much lower in the pan lysimeters in which there was root competition than it was in the root-free tanks. In each set the largest amount came from the duff-only lysimeters. In all cases the differences between soils (*i.e.*, duff, bare soil and duff-plus-soil), between soil and no soil, between periods, and the interaction between soils and periods, were either significant or highly significant. The kind and amount of canopy over each lysimeter, in its original state and as altered by the hurricane, had a bearing on the amount of leachate obtained but was not the controlling factor in all cases.

Composition of Leachate

Analyses of the leachate indicated that, without root competition, the amount of nitrogen collected in a year ranged from 32 to 75 pounds per acre. The duff-only lysimeters yielded the lowest amount, of which 24 to 44 percent was ammonia-N, and 14 to 19 percent was nitrate-N, the remainder being in the organic form. In the lysimeters containing soil, nitrates constituted 52 to 86 percent of the total, and ammonia 6 to 31 percent. Where root competition was present (pan lysimeters), from one to 12 pounds of nitrogen was recovered, of which ammonia N made up 15 to 40 percent and nitrates only 5 to 14 percent. In all cases the duff-only leachate contained the most nitrogen. The average amount of nitrogen per month was generally highest in the summer-fall period (July 15 - November 20), and the concentration in p. p. m. was, in most cases, as high in winter as in the other two periods of the year.

The amount of total solids in the tank leachate ranged from 390 to 1,385 pounds per acre per year, of which 46 to 70 percent was organic matter (loss-on-ignition). Usually the duff alone yielded the most solids and organic matter; and of the three periods, the second had the highest average per month.

Calcium in the tank leachate varied from 14 to 33 pounds per acre per year, and in the pans, 2 to 20; and magnesium 2 to 10 and 0.4 to 5, respectively. In both cases bare soil furnished the smallest amount.

Potassium ranged from 28 to 56 pounds in tanks, with the highest concentration in the bare soil and the lowest in the duff leachate. In the pans the amounts were 2.5 to 24 pounds, with the duff leachate having the highest concentration. In most cases the monthly average was highest in the summer-fall period.

Artificial leaching of identical materials in the laboratory confirmed the findings in the field experiment.

In comparison with the previous red pine lysimeter study, the lysimeters under hardwoods yielded, roughly, about the same amount of leachate which contained more nitrogen from the tanks but less from the pans, and a smaller percentage of NO_3-N than did the red pine leachate. Also the hardwood leachate contained more calcium but less potassium. Under hardwoods the total removal of constituents from duff-plus-soil generally exceeded that from the bare soil, but in the pan lysimeters under pine the reverse condition existed. The hardwood leachate was somewhat more acid, particularly that from the bare soil, than the pine leachate, although differences in acidity of the *soil* were slight.

The fact that the two studies were carried on at different periods, with some variation in technique, lessens the value of the comparison and makes it difficult to explain the reason for the differences obtained. It is not believed that such differences are necessarily characteristic for pine and hardwoods, but rather are due, in part at least, to differences in age of the stand, soil and previous history of the land.

CONCLUSIONS

From the results of this study under hardwoods and the previous study under pine, it is evident that, under the conditions of the investigation, the amount of nitrogen which is leached into the soil from the forest floor of a normal, fully stocked stand may vary from 4 or 5 up to 25 or 30 pounds per acre per year. Of this, from 5 to 40 percent may be in the nitrate form, 12 to 40, ammonia nitrogen, and 40 to 75 organic nitrogen. Other materials washed out of the A_0 horizon in a year's time are: total solids 300-700 pounds, of which about 45 to 70 precent was organic matter; calcium 12 to 32 pounds; magnesium 1 to 10; potassium 12 to 25; sulfur 12 to 20; iron 0.5 to 5; silica 2 to 10, and phosphorus 0.5. The bulk of this material is either taken up by roots or fixed in the soil so that only a very small portion of it goes deeper than 4 inches.

Nitrogen transformation may continue into the early winter, and the concentration of nitrogen and other constituents is frequently as high in winter as it is the rest of the year.

Comparison of the hardwood findings with those obtained previously in a red pine plantation indicate some differences in acidity and composition of the leachate. However, since the two studies were not carried on simultaneously and, since the two stands were dissimilar as to age, soil types and previous history of the land, it is not advisable to stress differences obtained in the two investigations.

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APPENDIX TABLE I. ANALYSIS OF VARIANCE — LEACHATE COLLECTED

In Percent of Rainfall

	Tank Lysimeters				Pan Lysimeters			
	DF	Sum of Squares	Mean Square	F	DF	Sum of Squares	Mean Square	F
Effect duff vs. soil	1	3543.20	3543.20	19.08*	1	13256.35	13256.35	83.20**
Effect duff on soil	1	1332.25	1332.25	7.18	1	0.53	0.53	0.003
Error for lysimeters	3	557.03	185.68	—	9	1434.07	159.34	—
Between lysimeters, total	5	5432.48	—	—	11	14690.95	—	—
Total	22	8010.08	—	—	44	17157.97	—	—
Error	8	566.77	70.85	—	24	651.31	27.14	—
(1) Winter vs. summer	1	106.68	106.68	1.51	1	461.90	461.90	17.02**
(2) 1st year vs. 2nd year	1	16.33	16.33	0.23	1	31.20	31.20	1.15
(3) W vs. S X 1st vs. 2nd year	1	139.20	139.20	1.97	1	86.67	86.67	3.19
Duff vs. soil X (1)	1	553.52			1	709.05		
Between soils X (1)	1	232.56	393.04	5.55*	1	0.11	354.81	13.07**
Duff vs. soil X (3)	1	176.33			1	487.35		
Between soils X (3)	1	102.01	291.44	4.11*	1	5.20	205.99	7.59**
Duff vs. soil X (2)	1	643.87			1	34.20		
Between soils X (2)	1	40.32	342.10	4.83*	1	.03	17.12	0.63
Between 1st & 2nd periods, 1st year	1	520.08	520.08	76.73**	1	326.34	326.34	21.19**
Duff vs. soil X 1st year	1	17.68	17.68	2.61	1	78.80	78.80	5.12*
Between soils X 1st year	1	7.20	7.20	1.06	1	29.98	29.98	1.95
Error	3	20.33	6.78	—	9	138.62	15.40	—
Total	6	565.30	—	—	12	573.74	—	—

* Significant. **Highly significant.

Appendix Table II. Analysis of Variance — Total Nitrogen in Leachate

Based on Average Amount per Month

	Tank Lysimeters				Pan Lysimeters			
	DF	Sum of Squares	Mean Square	F	DF	Sum of Squares	Mean Square	F
Effect duff vs. soil	1	8.70		23.38*	1	11.00		35.91**
Effect duff on soil	1	43.73		117.57**	1	.027		.088
Error for lysimeters	3	1.12			9	2.76	.306	
Between lysimeters, total	5	53.54	.37		11	13.78		
Total	20	292.11			45	29.98		
Error	6	6.53	1.09		25	3.04	.122	
(1) Winter vs. summer	1	125.26	125.26	115.13**	1	2.42	2.42	19.91**
(2) 1st year vs. 2nd year	1	32.32	32.32	29.70**	1	1.20	1.20	9.83**
(3) W vs. S X 1st vs. 2nd year	1	.62	.62	.57	1	1.56	1.56	12.84**
Duff vs. soil X (1)	1	.35			1	4.15		
Between soils X (1)	1	10.51	5.43	4.99	1	.0003	2.07	17.06**
Duff vs. soil X (3)	1	44.29			1	1.65		
Between soils X (3)	1	5.30	12.31	11.31**	1	.000	1.33	10.95**
Duff vs. soil X (2)	1	12.35	6.69	6.15*	1	2.19	1.09	9.00**
Between soils X (2)	1	1.04			1	.0009		
Between 1st & 2nd periods, 1st year	1	87.26		139.71**	1	.488		2.25
Duff vs. soil X 1st year	1	9.74		15.60*	1	.283		1.30
Between soils X 1st year	1	9.40		15.04*	1	.013		0.061
Error	3	1.87	.63		9	1.96	.218	
Total	6	108.28			12	2.74		

* Significant. ** Highly significant.

Appendix Table III. Analysis of Variance — Total Solids, Loss-on-Ignition and Sulfur

Based on Average Amount per Month

	Degrees of Freedom	Total Solids		Loss-on-ignition		Sulfur	
		Mean Square	Observed F	Mean Square	Observed F	Mean Square	Observed F
I. Tank Lysimeters							
Between soils	2	4666169	26.80*	3444344	43.39**	2411.20	16.30*
Error for lysimeters	3	174090		79390		147.97	
Total for lysimeters	5						
Soil vs. no soil	1	7399784	42.51**	6212671	78.26**	54.53	0.37
Duff effect on soil	1	1932554	11.10*	676016	8.52	4767.87	32.22*
Between periods	4						
Soils X periods	8						
Error	12						
Total	29						
II. Pan Lysimeters							
Between soils	2	1116848	18.37**	585567	17.32**	724.34	18.03**
Error for lysimeters	9	60792		33818		40.18	
Total for lysimeters	11						
Soil vs. no soil	1	2227960	36.65**	1166458	34.49**	1447.06	36.01**
Duff effect on soil	1	5736	0.09	4676	0.14	1.61	0.04
Between periods	4						
Soils X periods	8						
Error	36						
Total	59						

* Significant. ** Highly significant.

NOTE: Owing to the lesser importance of the data for solids, loss-on-ignition and sulfur, the breakdown for statistical analysis was not carried as far as was done in Tables I, II, IV and V.

Appendix Table IV. Analysis of Variance — Total Calcium in Leachate

Based on Average Amount per Month

	Tank Lysimeters				Pan Lysimeters			
	DF	Sum of Squares	Mean Square	F	DF	Sum of Squares	Mean Square	F
Effect duff vs. soil	1	1,140.75		1.62	1	3,266.55		22.01**
Effect duff on soil	1	1,560.25		2.21	1	2.27		0.015
Error for lysimeters	3	2,118.37	706.12		9	1,335.90	148.43	
Between lysimeters, total	5	4,819.37			11	4,604.69		
Total	22	17,297.85			43	8,907.39		
Error	8	274.31	34.29		23	830.25	36.10	
(1) Winter vs. summer	1	9,274.80	9,274.80	270.49**	1	599.54	599.54	16.61**
(2) 1st year vs. 2nd year	1	311.04	311.04	9.07*	1	506.22	506.22	14.02**
(3) W vs. S X 1st vs. 2nd year	1	1.50	1.50	0.04	1	444.33	444.33	12.31**
Duff vs. soil X (1)	1	29.14	351.27	10.24**	1	968.95	484.52	13.42**
Between soils X (1)	1	673.40			1	0.10		
Duff vs. soil X (3)	1	248.43	436.14	12.72**	1	364.69	320.39	8.88**
Between soils X (3)	1	795.24			1	0.12		
Duff vs. soil X (2)	1	297.01	435.31	12.70**	1	587.02	293.57	8.13**
Between soils X (2)	1	573.60			1	1.48		
Between 1st & 2nd periods, 1st year	1	399.05		30.17*	1	146.42		7.90*
Duff vs. soil X 1st year	1	14.26		1.08	1	154.77		8.35*
Between soils X 1st year	1	161.10		12.18*	1	3.11		0.17
Error	3	39.68	13.23		9	166.72	18.53	
Total	6	614.09			12	471.02		

* Significant. ** Highly significant.

APPENDIX TABLE V. ANALYSIS OF VARIANCE — TOTAL POTASSIUM IN LEACHATE

Based on Average Amount per Month

	Tank Lysimeters				Pan Lysimeters			
	DF	Sum of Squares	Mean Square	F	DF	Sum of Squares	Mean Square	F
Effect duff vs. soil	1	1.41		0.006	1	4,363.88		34.23**
Effect duff on soil	1	5,005.56		20.50*	1	9.36		0.073
Error for lysimeters	3	732.57	244.19		9	1,147.42	127.49	
Between lysimeters, total	5	5,739.54			11	5,520.67		
Total	20	113,325.71			43	9,628.24		
Error	6	1,391.20	231.87		23	335.87	14.60	
(1) Winter vs. summer	1	41,044.01	41,044.01	177.02**	1	595.87	595.87	40.80**
(2) 1st year vs. 2nd year	1	31,068.01	31,068.01	133.99**	1	952.48	952.48	65.23**
(3) W vs. S X 1st vs. 2nd year	1	21,834.53	21,834.53	94.17**	1	544.05	544.05	37.26**
Duff vs. soil X (1)	1	901.33			1	569.74		
Between soils X (1)	1	2,520.04	1,710.69	7.38*	1	0.11	284.93	19.51**
Duff vs. soil X (3)	1	4,412.17			1	322.19		
Between soils X (3)	1	81.90	2,041.40	8.80**	1	7.21	279.88	19.17**
Duff vs. soil X (2)	1	3.33	2,166.49	9.34*	1	773.90	390.03	26.71**
Between soils X (2)	1	4,329.64			1	6.15		
Between 1st & 2nd periods, 1st year	1	1,805.65		16.18*	1	11.76		0.929
Duff vs. soil X 1st year	1	2,262.04		20.27*	1	1.65		0.131
Between soils X 1st year	1	12.01		0.108	1	9.32		0.736
Error	3	334.82	111.61		9	113.93	12.66	
Total	6	4,414.52			12	136.66		

* Significant. ** Highly significant.