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(I. N. É. A. C.)

MINERAL NUTRIENT IMMOBILIZATION

UNDER FOREST AND GRASS FALLOW IN THE YANGAMBI (BELGIAN CONGO) REGION

WITH SOME PRELIMINARY RESULTS ON THE DECOMPOSITION OF PLANT MATERIAL ON THE FOREST FLOOR

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THIS WORK IS THE RESULT OF COOPERATIVE INVESTIGATIONS CONDUCTED AT YANGAMBI IN 1951 WHILE THE SENIOR AUTHOR WAS A MEMBER OF TECHNICAL AGRICULTURAL MISSION (MUTUAL SECURITY AGENCY) TO THE BELGIAN CONGO.

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This work is the result
of cooperative investigations conducted at Yangambi in 1951
while the senior author was a member
of technical agricultural mission (Mutual Security Agency)
to the Belgian Congo.

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INTRODUCTION

The use and conservation of the supply of plant nutrients indigenous to soils of the tropical rain forest present many perplexing problems in land use. The problems arise in designing land use practices which do not permit excessive losses of plant nutrient or a marked decline in productivity during the cropping interval.

Plant nutrient cycles.

In the native rain forest a large proportion of the available plant nutrients is immobilized in living organisms — mostly forest trees and vines. Annually large quantities of plant tissue (mostly leaves and branches) die, are decomposed on the forest floor and return their supply of nutrients to the soil to be readsorbed by other members of the forest flora and fauna. The readsorption of nutrients is so rapid in the rain forest that, in the case of the acid sandy soils studied here, the available supply in the soil is continually kept at an exceptionally low level. Under a plant cover with such high nutrient demands it is unlikely that many nutrients are lost by fixation or leaching.

The agricultural use of the forest soils requires removal of the forest species and substitution of crop plants. The transition interval between forest and cropping often results in the temporary liberation of large quantities of mineral nutrients to the soil and in an accelerated loss of nitrogen, particularly if the area is burned over as is the most frequent current practice. There is, therefore, a possibility of high plant nutrient loss before the cultivated crop is sufficiently large to reimmobilize most of the nutrients. In conventional cultivation practices, however, often the new crop is planted and grown concurrently with the disintegration and decomposition of the forest residues, but even then reimmobilization of all nutrients does not keep pace with mineralization and there exists the possibility of excessive nutrient losses.

Experience has shown that if the land is occupied by cultivated crops too long the productivity markedly declines and the forest species cannot be readily reestablished. The fundamental causes for the decline in productivity have not yet been established but depletion of available nutrients may well be among the most important. Deterioration of tilth may also be a contributing factor.

Fallow systems.

The cropping practices most frequently employed in the Central Congo Basin permit the return of forest species within 2 to 3 years after the forest is cut, initiating a forest fallow or regeneration period which may continue for about 15 years under government supervision to erratic, indefinite fallow periods where operated entirely by native farmers. This type of soil management is expensive in terms of both soil and labor, but appears to be a practical solution to the soil management problems where land is in good supply, demand is not great for agricultural products, transportation to market and supply is long and costly, and where local fertilizer resources are either non-existent or not developed.

Fallow systems of land regeneration are widely used for diverse specific purposes. In areas of low rainfall clean fallow is used for water conservation and storage. In some areas the production and accumulation of available nitrogen are important aspects of the fallow period.

In forest or grass fallow two factors appear most important in enhancing soil productivity. One is an accumulation of plant nutrients in organic combinations and prevention of nutrient losses by virtue of plant immobilization. The second factor is the improvement of soil structure by virtue of both rest from cultivation and biological activity. In the sandy soils of the Central Congo it seems likely that the former is of much greater importance than the latter.

In forest or grass fallow systems the rapidly growing vegetation immobilizes and accumulates quantities of plant nutrients. When the fallow area is again cleared and prepared for cropping, the fallow plant residues are decomposed or burned and in the process the nutrients are liberated. The relatively rapid release of nutrients permits the new crops to be nourished. If the nutrient release from the fallow crop is too slow the new crop will suffer. If, on the other hand, the release of nutrients is too rapid part of them may be lost before reimmobilization can take place by the crop plants. After the area has been cropped for one or two years the liberation of nutrients from the organic residues becomes slow; nutrients already liberated are used up, are fixed by the colloids, or are lost by leaching; and the crop may suffer because the supplying capacity of the soil is not sufficiently large. The operator then must either supply plant nutrients by fertilization or return the land to fallow if maximum crop yields are to be obtained.

Fallow systems neither create plant nutrients nor markedly accelerate their liberation from primary sources in the soil. Their chief function is to conserve nutrients and effect immobilization of sufficient quantities in organic combination so that a crop can be well nourished by the plant food biologically or chemically liberated at the conclusion of the fallow period. Plants are good for fallow inasmuch as they perform this function or as they influence soil physical properties.

In the current systems of agriculture in the rain forest area, the conservation and proper utilization of the indigenous supply of plant nutrients is an ever pressing problem. Management practices need be evolved which will maximize the use of the limited supply of plant nutrients in the soil or immobilized in the plant cover. In this respect a knowledge of the magnitude and importance of the several factors which influence or control the nutrient transformations both under native forest and in the fallow systems of soil regeneration might be most helpful in evaluating current practices and in evolving better soil management programs.

Following cropping of latosolic soils in the Congo Basin, regeneration by forest fallow is presumed to be slow. Agricultural supervisors recommend 15 to 20 years for the forest to become firmly re-established and for the soil to have regained its fertility and productivity. This long period is expensive in terms of land use. If it could be shortened the land could be used more advantageously.

Grass fallow has been considered as an alternative for short rotations but little practical information is available upon its probable usefulness for native agriculture. Grasses perhaps approach their maximum usefulness as fallow crops within a very few years. After two to four years the rate of root elaboration reaches a maximum and decomposition of grass residues proceeds as rapidly as the new growth is formed. At this stage a maximum of plant nutrients has been immobilized in organic form and further extension of the fallow period could enhance soil productivity chiefly through improvement of tilth.

Mineral nutrient immobilization may well be the most important factor in evaluating the usefulness of fallow systems. The study reported in part one was made to ascertain the order of magnitude of nutrients immobilized in several forest fallow plots of varying ages and to compare grass with forest as a fallow system.

PART ONE

Mineral nutrient immobilization under forest and grass fallow.

Plant associations.

Numerous species make up the plant cover in the forest fallow of the Central Congo Basin. Moreover, the plant associations change with age of the fallow and are also influenced by management and by the nature of the soil. Since the general objective was the estimation of immobilized plant nutrients, samples were generally taken by compositing many species. Selected areas were cut and weighed green at the sample site and small samples retained for moisture and for chemical analysis.

The establishment of a forest fallow is accomplished by merely permitting the natural forest species to establish themselves during the latter part of the cropping period. When the forest areas are put under cultivation the trees are cut and most of the litter and small branches are burned. Only the large stumps and resistant large trunks remain during the cropping period that follows. In the corridor system the areas are cropped intensively for about two years after which the forest is permitted to re-establish. A typical rotation may begin with maize which is followed by upland rice and then planted to cassava and bananas. The whole operation from cutting the forest to planting to bananas and cassava transpires within a year's time. During the growth and harvest of the latter crop which takes about 2 years the new forest families are permitted to establish.

During the first period of fallow while the native species are establishing themselves cassava and bananas dominate. These plants become intergrown with annual weeds and short fast growing perennials. As the fallow progresses Umbrella (*Musanga cecropioides*) trees tend to dominate the area. The single generation of umbrella trees grows up together and usually forms the upper strata or leaf canopy over the forest fallow areas. At Yangambi, the umbrella trees still remain the dominant species on the area after 15 years of fallow. At some later period, however, the umbrella trees die and other plant associations become dominant.

Sampling sites and procedures.

The sample sites in the more mature forest fallow areas were approximately 10 meters wide and 30 meters long. Approximate boundaries were established by measuring off an area of the above dimensions. Exact boundaries were established by projecting to the ground surface the area occupied by the tops of the umbrella trees confined in the measured area.

For convenience in harvest the plots were subdivided. The vegetation in each subplot was harvested by height strata. Initially, dominant species were separated but owing to extreme local heterogeneity in specie distribution, in subsequent plots, with the exception of Musanga, only composite samples were taken.

All living material was harvested and weighed at the sample site. Leaves were separated from the woody parts and dried and weighed separately. Samples of the several plant materials were retained for moisture determinations and prepared for chemical analysis.

Litter was estimated by determining the quantity of leaf and limb residue on each of five 2 square meter areas chosen at random within the plot. Litter samples were dried, weighed and subsamples retained for chemical analyses.

Estimations of the quantity of roots in the plot soils were made by sampling at random pie shaped areas adjacent to tree locations. The main roots of the umbrella tree branch above the ground and radiate into the soil as far as 1,5 meters from the entry of the main tap root.

When the trees were cut the locations of the main tap roots were noted. Root sample areas were delineated by rotating a radius of 2 to 2,5 meters through an angle of 60°. The inscribed areas were calculated and the root yields for the several soil horizons reported as kilograms per hectare. Samples of roots were also retained for chemical analyses.

Grass samples were taken from small replicated plots established by the Division of Botany and chosen from among the numerous species available in pure stands. *Panicum maximum*, *Setaria sphacelata* and *Cynodon dactylon* (1) were selected because they appeared to represent those species best adapted for fallow uses. At the time of harvest the grass plots had been established for three years.

Samples from the grass plots were taken by harvesting the total tops and roots from 1 sq. meter areas chosen to represent the mean of the sampled area. The above ground parts were arbitrarily divided into green tops, undecomposed litter and decomposed litter.

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(1) *C. plectostachyum* Auct.

The green tops represent all living plant parts above about 10 cm from the soil. Undecomposed litter constituted those non-living plant parts which make up the loose mat on the grass areas. The well decomposed residues still retaining their physical identity were separated and constitute the decomposed litter. These latter residues form a rather thin but somewhat compact mat on the soil surface and are often partly admixed with soil.

Root samples were taken by appropriate soil horizons and were separated from the soil by hand. Because many roots had invaded the surface litter the separation of roots and litter was difficult and often not sharp. Samples of all the harvested material were dried, and prepared for chemical analysis.

Analytical procedures.

In preparation for analyses the samples were dried, ground in a hammer mill and stored in moisture tight jars. For the cations and phosphorus 10 or 20 gram samples, depending upon the expected ash content, were ashed with nitric and perchloric acids and the silica separated by filtration. Samples of the filtrate were used in subsequent analyses. Phosphorus was determined colorimetrically following the method of DICKMAN and BRAY (1). Potassium was determined for the first samples colorimetrically according to the method of KOLTHOFF and BENDIX (3) and then with a PERKIN-ELMER Flame Photometer. Calcium was precipitated as the oxalate at pH 5 after the removal of iron, aluminium and phosphorus. The washed oxalate salt was titrated with standard permanganate. Sulphur was determined gravimetrically as baryum sulphate.

Determinations for magnesium were made on the filtrate from the calcium precipitation after destruction of the excess oxalate with nitric acid. Magnesium was precipitated as the ammonium phosphate and after drying the precipitate the magnesium was determined by titration.

Nitrogen was determined on a separate sample of the plant materials by a standard KJELDAHL procedure. The mineral elements are reported as a percentage of the dry plant material.

RESULTS AND DISCUSSION.

Fallow growth and nutrient immobilization.

The gross dry weigths of organic materials and the nutrient uptake are summarized in tables 1 and 2.

A comparison between the several fallow plots and between the fallow and grass plots provides a partial measure of the relative value of the systems.

Nutrient immobilization in the forest fallow is rapid at the onset. In 5 years of forest fallow the quantity of total nutrients immobilized was more then ½ as great as in 18 years. Little difference in total immobilization of nutrients was found between the 5 and 8 years plots. The normal heterogeneity of the area and the error of sampling would easily account for the failure of the results to show significant differences.

In forest fallow the leaf growth rapidly approaches a maximum. Later increases in total growth occur chiefly in the woody parts, particularly the above ground parts.

Roots also approach a maximum at a rather rapid rate. The data show at 5 years 75 % as much growth as at 18 years.

Litter accumulation builds up from leaf and stem residues and closely approaches a maximum some time between 8 and 12 years.

Among the grasses, Cynodon made the greater total growth and had the highest nutrient immobilization. The differences among grass species, however, are small and, owing to the small number and size of the samples, may not be significant.

In the grasses a large part of the total harvested material consisted of litter in various stages of decomposition. This is in sharp contrast to either the quantity or proportion of litter in the forest fallow plots.

Total root weigth among the grasses was considerably less than in the forest fallow. Grass roots, however, were generally small and fibrous, whereas the major part of the roots from the forest fallow were large and woody.

The total nutrient composition as well as the relative proportion of the several nutrient elements differed among the plant parts. Leaves comprise a small proportion of the total weight of plant parts except at the early stages of establishment of the forest fallow. This is shown by the data in table 3. Living woody tissue, both above ground and roots, account for most of the total weight. In nutrient immobilization, on the other hand, leaves are considerably more important, particulary in uptake and release of nitrogen.

The woody tissues, trunks, limbs and roots, contain the major proportion of all nutrients, except in very early periods of fallow. Woody tissues are particularly important in the immobilization of the cations and phosphorus.

On the grass plots, litter contained the large proportion of the plant nutrients. Grass roots were relatively low in nutrients and accounted for only 10-20 percent of the immobilized plant food elements.

The relative nutrient concentration in the several plant parts are compared to nitrogen in table 4. Leaves and litter in forest fallow contain relatively more nitrogen than the woody parts. Grass is relatively higher in phosphorus and potassium and lower in calcium and magnesium than forest fallow.

A comparison of the relative extent of nutrient immobilization among the several fallow plots is shown in table 5. Nutrient immobilization like total growth in leaves rapidly reaches a maximum and appears to increase very slowly if at all thereafter.

Roots likewise approach maximum immobilization early in the forest fallow systems. In the woody tissues, on the other hand, maximum immobilization is approached slowly, although the rate of nutrient uptake is most rapid in the early stages of fallow development.

Nutrient immobilization in the grass plots compared favorably with that in the forest fallow (table 6). Grass fallow appears to absorb nitrogen and phosphorus at a more rapid rate in the early stages of development than does forest fallow. Grass, on the other hand, could not be expected to immobilize the large total quantity of nutrients which are found in forest fallow at the later or mature stages of growth. For short fallow systems, grass appears to be equal or superior to forest in nutrient immobilization.

TABLE 1. — **Nutrient immobilization in forest fallow.**

	Total dry wt. Kg/ha	N Kg/ha	P Kg/ha	S Kg/ha	K Kg/ha	Ca + Mg Kg/ha
17-18 years forest fallow						
Leaves	6,442	143	7.5	17.1	80	76
Wood	114,637	301	62.2	85.8	305	378
Roots	31,240	146	34.2	78.1	200	266
Litter	5,520	75	2.7	9.9	8	66
Dead wood	17,290	36	1.4	5.2	8	36
	175,109	701	108.0	196.1	601	822
8 years forest fallow						
Leaves	5,379	120	6.6	9.0	79	87
Wood	116,313	206	15.3	47.0	579	344
Roots	22,682	152	9.1	35.4	100	127
Litter	7,983	101	4.1	9.2	81	110
	152,515	579	35.1	100.6	839	668

TABLE 1 (*sequel*).

	Total dry wt. Kg/ha	N Kg/ha	P Kg/ha	S Kg/ha	K Kg/ha	Ca + Mg Kg/ha
5 years forest fallow						
Leaves	5,627	125	7.1	15.1	79	78
Wood	71,067	181	13.9	39.1	243	138
Roots	25,753	178	7.7	40.0	113	129
Litter	7,320	79	2.9	9.1	15	70
Dead wood	2,522	4	0.3	—	6	6
	112,289	567	31.9	103.3	456	421
2 years forest fallow						
Leaves and annuals	5,560	80	10.7	11.0	80	63
Wood	5,360	18	6.2	3.9	37	34
Roots and stems	6,939	76	4.9	19.0	65	42
Dead annuals	1,853	15	0.4	3.6	4	21
	19,712	189	22.2	37.5	186	160

TABLE 2. — **Nutrient immobilization in grass** (1).

	Yield Kg/ha	N Kg/ha	P Kg/ha	S Kg/ha	K Kg/ha	Ca + Mg Kg/ha
Panicum maximum :						
Green tops	8,260	61	10.8	18.9	150	38
Litter	21,700	234	19.2	31.1	165	114
Roots	9,877	79	6.6	11.1	36	17
Total	39,837	374	36.6	61.1	351	169

(1) Chemical analyses were made only on the first set of grass samples. Weighted means of the mineral composition of the first samples were employed to estimate nutrient immobilization in the second set of samples.

TABLE 2 (*sequel*).

	Yield Kg/ha	N Kg/ha	P Kg/ha	S Kg/ha	K Kg/ha	Ca + Mg Kg/ha
Setaria sphacelata :						
Green tops	6,910	46	14.1	6.3	95	28
Litter	25,785	261	32.3	47.3	149	111
Roots	7,726	71	8.8	9.4	29	12
Total	40,421	378	55.2	63.0	273	151
Cynodon dactylon :						
Green tops	8,430	68	14.9	21.0	165	46
Litter	25,775	299	27.0	26.7	200	178
Roots	12,093	96	10.4	12.6	58	26
Total	46,298	463	52.3	60.3	423	250

TABLE 3. — **Relative dry weights and nutrients quantities in the several plant parts.**

	Total dry wt. %	N %	P %	S %	K %	Ca+Mg %
17-18 year forest fallow						
Leaves	3.7	20.4	6.9	8.7	13.4	9.2
Wood	65.5	42.9	57.6	43.8	50.7	46.0
Roots	17.8	20.8	31.7	40.0	33.3	32.4
Litter	3.2	10.7	2.5	5.1	1.3	8.0
Dead wood	9.9	5.1	1.3	2.4	1.3	4.4
8 year forest fallow						
Leaves	3.5	20.7	18.8	9.0	9.4	13.0
Wood	76.3	35.6	43.6	47.0	69.0	51.5
Roots	14.9	26.3	25.9	35.0	11.9	19.0
Litter	5.2	17.4	11.7	9.0	9.7	16.5

TABLE 3 (*sequel*).

	Total dry wt. %	N %	P %	S %	K %	Ca+Mg %
5 year forest fallow						
Leaves	5.0	22.1	22.3	14.7	17.3	18.5
Wood	63.3	31.9	43.6	38.2	53.3	32.8
Roots	22.9	31.4	24.1	39.0	24.8	30.6
Litter	6.5	13.9	9.1	8.1	3.3	16.6
Dead wood.	2.2	0.7	0.9	—	1.3	1.4
2 year forest fallow						
Leaves and annuals	28.2	42.3	48.2	29.3	43.0	39.4
Wood and stems	27.2	9.5	27.9	10.4	19.9	21.3
Roots	35.2	40.2	22.1	50.0	34.9	26.3
Dead annuals	9.4	7.9	1.8	9.5	2.2	13.1
Panicum maximum						
Green tops	20.7	16.2	29.5	30.9	42.7	22.4
Litter	54.4	62.7	52.5	60.9	47.0	67.6
Roots	24.8	21.0	18.0	18.2	10.3	10.0
Setaria sphacelata						
Green tops	17.1	12.2	25.5	10.0	34.7	18.6
Litter	63.8	69.1	58.5	75.0	54.7	67.4
Roots	19.1	18.7	15.9	15.0	10.6	8.0
Cynodon dactylon						
Green tops	18.2	14.7	28.5	34.8	39.0	18.4
Litter	55.7	64.6	51.6	44.2	47.4	71.2
Roots	26.1	20.6	19.9	21.0	13.6	10.3

TABLE 4. — **Relative amount of nutrients in the plant parts compared to nitrogen as 100.**

	N	P	K	Ca + Mg
Forest fallow				
Leaves	100	6	73	65
Wood	100	11	160	125
Roots	100	7	70	80
Litter	100	3	32	100
Grass				
Green tops	100	22	234	63
Roots	100	10	65	51
Litter	100	11	50	22

TABLE 5. — **Proportion of plant nutrients immobilized at various intervals compared to the 18 year forest fallow plot.**

	Length of forest fallow			
	18 years	8 years	5 years	2 years
Nutrient uptake				
Leaves	100	95	94	94
Wood	100	61	45	9
Roots	100	59	64	27
Litter	100	100	80	19
Mean	100	79	71	37
Total nutrient immobilization				
Nitrogen	100	83	81	28
Phosphorus	100	32	30	21
Calcium + magnesium	100	81	59	19
Mean	100	65	57	24

TABLE 6. — **A comparison of total nutrient immobilization among the forest and grass fallow plots.**

Fallow plots	N Kg/ha	P Kg/ha	S Kg/ha	K Kg/ha	Ca+Mg Kg/ha
		Forest fallow			
18-19 year forest	701	108	196	601	822
8 year forest	579	35	101	839	668
5 year forest	567	32	103	456	421
2 year forest	189	22	37	186	160
		Grass fallow (3 years old)			
Panicum maximum	374	37	51	351	169
Setaria sphacelata	378	35	63	273	151
Cynodon dactylon	463	52	60	423	250

Plant nutrient supply in the soil.

A consideration of the total supply of plant nutrients indigenous to soils of the rain forest area must include those elements which are associated with soils. Table 7 contains an estimation of the quantities per hectare of plant food content where data were available.

The total supply of nitrogen and phosphorus in the soil is very large in comparison to the quantity immobilized in fallow vegetation. This supply must make some contribution to the available supply and contribute to the growth of plants. Nitrogen in soil is largely tied up in organic combinations and becomes available through biological decomposition of soil organic matter. Nitrogen may also be added to the soil through biological fixation of atmospheric sources.

Some phosphorus is associated with nitrogen in soil organic matter. Estimations using the carbon-phosphorus relationship found in soil organic matter by PEARSON and SIMONSON (5) and the carbon content of Congo soils as reported by LAUDELOUT and D'HOORE (4) indicate the quantity may range between 300 and 700 kg/ha. Soil organic phosphorus is biologically mineralized along with nitrogen and thus becomes available for crop use.

TABLE 7. — **Estimations of total phosphorus and of available calcium, magnesium, potassium and phosphorus in two soils near Yangambi compared to nutrients immobilized in the 8 and 18 year forest fallow.**

	Forest soil		Cropped soil		Forest fallow vegetation	
	0-15 cm. depth Kg/ha	15-100 cm. depth Kg/ha	0-15 cm. depth Kg/ha	15-100 cm. depth Kg/ha	8 years Kg/ha	18 years Kg/ha
Nitrogen (1) (total)	1,500–2,500	3,000–5,000	1,000–1,500	2,000–350	(total) 579	701
Phosphorus (2) (total).	920	4,300	780	3,500	(total) 35	108
Phosphorus (available)	12	40	13	70	—	—
Calcium (exchangeable)	45	250	175	250	(total) 404	578
Magnesium (exchangeable)	27	150	44	150	(total) 264	244
Potassium (exchangeable)	180	1,000	780	1,000	(total) 839	601

(1) Nitrogen was estimated from data by Laudelout and D'Hoore (4).

(2) Phosphorus, calcium, magnesium and potassium data were taken from Kellogg and Davol (2).

The exchangeable cations are somewhat comparable in quantity to the amounts immobilized in fallow vegetation. The existence in the Congo soils of a supply of these elements in unavailable form has not been demonstrated. It seems safe to assume, however, that the soils must contain cations in forms other than exchangeable, particularly in the case of potassium. The extent of such unavailable forms and their influence on the available supplies need further investigation.

The rate and conditions of revision of plant foods in the soil from unavailable to available forms have not been clearly elucidated. It seems certain, however, that these so-called « unavailable » supplies are quite important as a source of plant nutrients for fallow crops.

PART TWO

Decomposition and mineralization of plant material on the forest floor.

It was interesting to obtain a partial evaluation of the rate of nutrient release during decomposition in connection with the estimation of total immobilization in plant material described in Part One.

The decomposition processes on the floor of the equatorial rain forest proceed rather rapidly. Leaf residues, even though added continuously throughout the season and in substantial amounts (1), do not result in litter accumulations comparable to those found in temperate zone forests.

The rapid rates of residue decomposition are the result of a number of factors. Moisture conditions on the forest floor are generally near the optimum for decomposition. Rainfall in the rain forest area is generally high and quite well distributed. Evaporation from the forest floor is slow and the relative humidity of the air near the soil remains near saturation.

Temperature conditions on the forest floor are also favorable for rapid decomposition. The dense vegetation cover serves as a heat buffer preventing the soil from absorbing the intense radiation on bright, hot days and from excessive heat lose during cool weather.

Insect life has a very important function in the disintegration and decomposition of organic residues in the tropical forests. Termites and other insects which attack organic matter are very numerous in and on rain forest soils.

The decomposition of woody tissues is markedly accelerated by the action of insects. Separation of the influence of insects apart from the action of microbes is, of course, impossible. Presumably, insects and microbes compete with one another for certain plant parts and plant constituents but complement each other in the

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(1) Observations of the leaf fall during one year indicates that the total amount of plant material returned yearly to the forest floor is :

Forest : 12,300 Kg/Ha.
8 year Forest fallow : 14,200 Kg/Ha.

decomposition of other constituents. The presence of a large insect population in the forest soils and on the forest floor indicates, in part, their importance in the general decomposition process in forest soils.

The rapid initial attack on large woody residues is made by insects. In the utilization of the wood for food or for nests the insects form numerous cavities and interlocking holes and channels. These cavities serve as additional surface areas for attack by microorganisms. Termites, in particular, not only produce large cavities in wood but have the habit of replacing part of the removed woody tissue by soil.

Chemical composition of plant residues also has an influence upon the rate of decomposition under a particular set of environmental conditions. Since there is little litter accumulation in the rain forest it is presumed that all materials are quite readily attacked and decomposed by microorganisms and that none are exceptionally resistant. The experiment reported herein was initiated to provide information on the general rate of decomposition in the forest and to see if there were any wide differences in decomposition rate among a few of the common types of forest leaves.

EXPERIMENTAL.

Plant materials.

Leaf samples were used for experimental substrates because they are the chief plant residue materials deposited on the forest floor. Numerous tree species make up the forest flora. Since only a few leaf species could be utilized in the experiment, selections were made which would include representatives of dominant genera and leaf morphology.

Included with the leaf samples was one sample of grass to provide a comparison between the two types of plant material. The species chosen were :

1. *Gilbertiodendron* (*Macrolobium*) *dewevrei.*
2. *Panicum maximum.*
3. *Scorodophloeus zenkeri.*
4. *Anonidium mannii.*
5. *Musanga cecropioides.*
6. Composite sample of mixed leaves from forest.

The samples were collected and partly dried. Since climatic conditions prevented air drying sufficiently rapid to impede measureable decomposition, the samples were cut into small pieces and individual samples weighed while the material was yet moist. A total of 74 individually weighed samples were prepared from each plant material. Of these, 8 were dried and weighed as a measure of initial weight and 64 were used in the decomposition experiment.

Experimental design.

The experimental design consisted of 6 plant material species located at random in 4 replications. Each plant species consisted of 16 individual samples separated by wire mesh in a large wooden frame. At each of 4 time intervals 4 samples from each plant material in each replication were selected at random for determination of dry weight and for chemical analysis.

Frames one meter square with a bronze mesh bottom were used as containers for each sample. These frames were divided into 16 compartments by the use of coarse wire mesh. Each compartment was about 25 cm square and 10 cm in height. The separating wire mesh was of such a size as to minimize interchange or mixing of plant materials but permit the free passage of insects.

The experiment was located in a typical forest area and each frame was placed in a typical undisturbed forest site. Care was taken to minimize the disturbance of either forest undergrowth or the surface litter. After the frames were set and the leaf samples placed in the compartments, leaf litter from adjacent areas was brought in and placed around the frame exterior to provide good insect contact between the forest litter and the decomposition samples. To initiate equal and rapid decomposition the samples were wetted by sprinkling each with about 20 litters of water.

Sample recovery and analysis.

At the following predetermined time intervals samples were removed for determination of dry weigh and for chemical analysis :

Sample No.	Time interval in weeks	Date of Sampling
—	—	—
1st	0	August 21-24
2nd	4	September 17-21
3rd	10	October 30-November 3
4th	20	January 8-11
5th	35	April 22-25

It should be noted that the first, second and third time intervals were during a very rainy season. The weather during the fourth interval, on the other hand, was exceptionally dry, and during the fifth interval the rains were scanty at first and normal at the end.

Because position variation within the frames was suspected the samples at each sampling date were selected at random according to a latin square design. This design permitted some evaluation of position variation if the latter seemed important.

Samples were individually recovered by hand from the compartments in the frames. Each sample was individually dried and weighed. For chemical analysis the individual plant material samples were composited. At the initiation of the experiment 4 sample composites were used for chemical analysis making 2 chemical analysis for each plant material. At the end of 4 weeks decomposition 8 sample composites selected at random were used for chemical analysis again making 2 chemical analyses for each type of plant material. The third sampling at the end of 10 weeks was complicated by the excessive quantities of soil material carried in by termites and admixed with the decomposing plant residues. This contamination by soil was particularly critical in the case of the grass, *Panicum maximum.* In the third sampling two 8-sample composites were used for chemical analysis, but the compositing was not done at random but rather by combining those high in soil into one composite and those low in soil into another. This scheme provided some measure of the influence of soil on the determination of plant nutrients.

After the samples had been composited, subsamples were taken, ground in a hammer mill and set aside for chemical analysis. Chemical procedures outlined in part one were followed.

RESULTS AND DISCUSSION.

The loss of organic matter and the nutrients remaining at the conclusion of the several periods of incubation are shown in table 8.

In order to avoid errors due to contamination of all samples with soil brought in by termites, organic matter losses are expressed on an ash-free basis.

Since the soil of the forest in the Yangambi region is very low in mineral nutrients, the contamination by termites did not greatly influence the results of the chemical analysis of the plant material.

Organic matter losses varied among the plant samples. Macrolobium leaves decomposed slowly. The resistance to decomposition may be related to the leathery texture of these leaves and their waxy cuticle which do not allow them to become easily soaked with moisture.

Scorodophlœus leaves and the grass *Panicum maximum* decomposed rather rapidly. Scorodophlœus leaves are small, soft and rich in nitrogen and behave during decomposition very much as a leafy forage legume. The rapid rate of decomposition of Panicum is very likely due in part to the strong termite action on this material.

TABLE 8. — **Organic matter loss and liberation of nutrients during decomposition.**

Material	Time in weeks	Change in organic matter Ash-free	Nutrients remaining in sample (g per Kg of original material)					
			N	P	S	Ca	Mg	K
Macrolobium	0	1,000	17.5	0.95	1.33	7.9	3.7	10.0
	4	903	19.1	0.72	0.70	7.5	3.7	2.8
	10	720	14.4	0.60	0.63	6.1	2.8	2.0
	20	706	18.7	0.61	1.44	4.9	3.2	0.8
	35	638	19.5	0.42	0.76	5.0	1.6	0.7
Panicum	0	1,000	13.5	1.30	1.50	1.9	2.7	29.3
	4	505	4.5	0.50	0.45	1.4	1.2	2.1
	10	428	6.6	0.54	0.54	1.0	0.7	0.5
	20	362	6.8	0.60	0.82	1.0	2.7	0.5
	35	294	8.2	0.49	0.74	1.1	1.2	0.4
Scorodophlœus	0	1,000	40.0	1.70	12.3	6.0	7.9	14.1
	4	647	20.6	1.05	5.9	5.8	5.2	4.0
	10	465	14.9	0.57	3.7	4.3	2.2	1.4
	20	459	17.0	0.57	4.2	3.3	1.5	0.5
	35	359	14.4	0.49	2.6	1.6	1.6	0.5
Anonidium	0	1,000	28.6	1.27	3.7	7.2	8.5	9.5
	4	621	20.2	0.77	1.5	4.7	4.0	3.2
	10	613	20.4	0.48	1.3	3.3	1.9	0.5
	20	560	23.8	0.57	1.8	3.4	1.2	0.5
	35	550	23.3	0.49	1.0	2.0	0.4	0.4
Musanga	0	1,000	18.9	1.40	2.0	9.5	5.5	13.0
	4	804	16.0	0.82	1.2	9.1	4.2	5.3
	10	552	15.8	0.83	0.8	7.2	2.6	1.0
	20	538	19.7	0.67	1.0	5.2	1.4	0.7
	35	545	20.1	0.59	1.4	6.0	3.9	0.4
Forest leaves	0	1,000	28.6	1.46	5.2	7.0	8.8	14.0
	4	593	17.8	0.60	1.8	4.9	3.8	2.5
	10	436	14.0	0.57	0.4	3.5	1.6	1.0
	20	481	16.2	0.50	2.0	2.0	1.4	0.6
	35	433	17.1	0.54	1.3	2.0	1.1	0.4

Nitrogen losses varied among the leaf samples. The highest losses occurred in samples which were initially high in nitrogen. Musanga and Macrolobium wich were lowest in initial nitrogen lost little or no nitrogen during the 35 weeks of decomposition although both materials were extensively decomposed. Among the leaf samples, nitrogen remained in the material at the end of 35 weeks of decomposition to the extent of about 3-4 % of the dry weight of the residues.

The grass, *Panicum maximum*, retained less nitrogen during decomposition than did the leaf samples although it was most extensively decomposed.

Potassium losses were very rapid and included almost all of the initial content. Loss of phosphorus was less rapid than that of potassium but somewhat more rapid than that of nitrogen. The pattern of sulfur loss was similar to that of phosphorus.

Losses of calcium and magnesium were similar in all cases but lower than that of potassium.

The number of fungi and bacteria found in the residues at the several stages of decomposition are shown in table 9.

TABLE 9. — **Number of fungi and bacteria in the residues after the several periods of decomposition.**

(Fungi in thousands and bacteria in millions per gram of residue.)

Time (weeks)	4		10		20		35	
Plant material	Fungi.	Bact.	Fungi.	Bact.	Fungi.	Bact.	Fungi.	Bact.
Macrolobium	690	35	280	110	337	85	443	132
Panicum	1,290	80	866	604	794	194	2,050	187
Scorodophloeus	291	77	1,300	320	962	157	3,280	236
Anonidium	3,659	773	1,136	297	575	197	565	138
Musanga	2,736	658	607	162	310	100	400	55
Mixed leaves	2,649	672	1,603	295	527	134	936	296

There appears no relationship between the rate and extent of decomposition and the numbers of microorganisms. The rather general decrease in numbers of microorganisms found after 20 and 35 weeks may be due more to the drier conditions prevailing at these times rather than to decomposition of the food materials available for microbes.

Nutrient release from fallow vegetation.

The rate of nutrient release or mineralization from forest residues when the fallow lands are cleared for cropping is an important characteristics of fallow systems. Although this aspect of the fallow plots was not specifically studied, some estimations may be made from data obtained in the decomposition experiment and from a general understanding of mineralization processes in plant constituents. Burning of forest fallow or grass fallow releases the immobilized nutrients immediately. The large part of the bases (potassium, calcium, magnesium, and etc.) and phosphorus are deposited as the oxides on the surface of the ground. Nitrogen, on the other hand, is almost totally lost into the atmosphere as free nitrogen, N_2, or as the volatile oxides.

When the fallow vegetation is burned an estimation of the nutrients liberated by the above ground parts is simple and direct. An evaluation of the influence of burning on the total availability of nutrients is more complex. Phosphorus, for exemple, when deposited on the soil may be partly fixed in relatively unavailable form before the cultivated crops have a chance to absorb it. Potassium, likewise, may be fixed or it may be lost in the drainage water. Conversely, available nitrogen, because of the elimination of tie-up or immobilization by decomposition of woody tissues, may be higher immediately after burning than where the vegetation is not burned.

Where the fallow vegetation cover is not burned the nutrients would be largely held in organic combination until liberated by microorganisms during the processes of decomposition. An estimation of the rate of release of the various nutrient element is difficult because of the general lack of specific data. Analogous data from temperate climates is likely to be misleading. Data from the decomposition experiments under tropical rain forest conditions permit a partial evaluation of nutrient release during decomposition.

When microbes invade plant tissue and initiate decomposition the easily accessible and available constituents are attacked and decomposed first. Among these plant constituents are the soluble carbohydrates, the proteins and the agents of intermediate metabolism. As a result, the major part of the nitrogen, phosphorus and other plant food elements which were immobilized in plant tissue are rapidly liberated in mineral form. Simultaneously, however, nitrogen, phosphorus and other plant food elements are immobilized in the synthesis of new microbial cell tissue by the invading and decomposing organisms. The net difference between mineralization on the one hand and immobilization on the other represents a measure of the plant nutrients available for use by crop plants.

The size of the microflora initially developing in most common crop residues decomposing under optimum conditions of moisture and temperature requires nitrogen to the extent of about 1,2-1,5 percent of the dry weight of the residue. Less nitrogen is required in the decomposition of woody tissue because of the slower rate of decomposition and development of fewer numbers of microbes per unit of plant substrate. Except where initially high in nitrogen, as decomposition of plant materials progresses the residues tend to become richer in nitrogen. This can be seen by analysis of the data in table 8. The factors responsible for the stabilization of nitrogen are not clearly understood.

Phosphorus is usually required in microbial cell tissue in amounts equal to 6-10 percent of the nitrogen. Potassium, calcium, magnesium and the other essential plant food elements are also necessary for the growth of microbes but they are required in much lower quantities than either nitrogen or phosphorus. Table 10 shows the approximate mineral composition of plant materials compared to that of microorganisms.

TABLE 10. — **A comparison of the mineral composition of plant materials and microorganisms.**

	Percentage composition				Relative composition			
	N	P	K	Ca+Mg	N	P	K	Ca+Mg
Cereal straw	0.60	0.08	0.90	0.50	100	13	150	83
Corn stalks	0.90	0.10	1.10	0.60	100	11	122	67
Alfalfa	2.20	0.30	1.80	2.20	100	14	82	100
Mixed tree leaves (1) ..	2.45	0.12	1.92	1.67	100	5	78	68
Trunks, branches (1) ..	0.59	0.08	0.70	0.70	100	13	119	119
Musanga	0.16	0.01	0.36	0.24	100	6	225	150
Bacteria (2)	10.00	1.50	0.40	0.80	100	15	4	8
Fungi	5.00	0.80	0.30	0.50	100	16	6	10

(1) Mean composition of forest fallow leaves and woody tissue.

(2) Estimated from data in *Bacterial Chemistry and Physiology* by J. R. PORTER, John Wiley and Sons, New York, 1946.

As decomposition progresses in ordinary plant residues, potassium and phosphorus are lost more rapidly than nitrogen. In plant residues and in microorganisms the ratio of nitrogen to phosphorus approaches 7-8 : 1. In soil organic matter PEARSON and SIMONSON (5) found ratios ranging from 7,0 : 1 to 15,7 : 1 with a mean of about 9,3 : 1. The litter from the forest fallow plots and litter gathered from the native forest had a nitrogen to phosphorus ratio of about 25 : 1. In the residue from the decomposition of the mixed forest leaves, table 8, the ratio was 32 : 1 and in the decomposed litter from the grass plots, table 2, the ratio was 12 : 1.

Considering the foregoing principles it seems quite unlikely that nitrogen would be rapidly liberated during the initial stages of decomposition of forest or fallow vegetation. Indeed, in consequence of the large quantity of woody tissues on some fallow areas, the decomposing organisms may be expected to initially readsorb a part of the nitrogen mineralized from the surface soil. Burning the fallow vegetation, therefore, may actually result in a better nitrogen supply during the early stages of cropping forest or fallow land than leaving the vegetation to decompose biologically.

The release of phosphorus from decomposing fallow vegetation would be expected to be more rapid than that of nitrogen. Considering the low content in microbial tissue, potassium, calcium and magnesium should be rapidly released during the decomposition process. In the case of potassium this rapid loss has been demonstrated experimentally (see table 8). Calcium and magnesium, however, even though they are liberated and made available, form insoluble salts (carbonates, sulfates and phosphates), and are not removed from the system by leaching and remain as a part of the decomposed residue. This property makes difficult the measurement of mineralization.

Mineralization of nitrogen and phosphorus from grass fallow in general would be more rapid than from forest fallow. Release of potassium from grass fallow would be expected to be similar to that from forest fallow but in each case the rate of release would be related to the total quantity immobilized. Calcium and magnesium, on the other hand, were low in the grass samples examined and therefore could not be supplied rapidly from such fallow systems.

The process of decay of forest or fallow vegetation may not provide a balanced nutrient supply for crop plants. Moreover, it appears most likely that the relative concentration of available nutrients would undergo marked changes during the course of decomposition.

The processes of natural decomposition tend to tie up nitrogen extensively and the other plant nutrients to a lesser extent. The liberation process of any of the elements through biological decomposition is likely to be slow. It is doubtful that 4-6 months of decomposition of forest fallow residues would result in more than 30 to 50 percent liberation of the potassium or calcium and magnesium and 15-30 percent of the phosphorus. In that same period of time the percentage release of nitrogen may be even smaller than that of the cations or phosphorus.

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