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CHANGES IN THE SOIL AFTER CLEARING TROPICAL FOREST

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INTRODUCTION

An article published in this Journal [1] has described the content of nutrients in the soil and vegetation on an area under high tropical rain forest, and a further article [3] has considered the rate of the nutrient cycle in this system. This article describes some of the changes in the soil that follow the cutting and burning of the forest cover, and its subsequent cultivation by various methods.

In the local practice of shifting cultivation for production of subsistence food crops the forest is always cut and burned and the crops are planted by making a small hole with a stick or hoe in the friable surface soil, which is not otherwise disturbed. Maize is planted first, and semi-perennials such as cassava (*Manihot utilissima*), cocoyam (*Colocasia antiquorum*), and plantain (*Musa* sp.) are added later, a continuous cover over the soil being maintained. Farmers abandon the land to forest regrowth some two to four years after clearing; among the possible reasons are decline in fertility, weeds, and the need to clear fresh land to plant maize. It was hoped that our experiment would yield information about the changes in the organic matter content, pH, and exchangeable cations, which largely determine the decline in fertility.

From time to time it is suggested that these soils should be cropped by mechanised methods. These involve stumping and root lifting after clearing in order to free the land for implements. Subsequent cropping under a system of monoculture bares the surface of the soil after each harvest. Such methods may be expected to lead to a rapid loss of organic matter by mineralisation and erosion, and of plant nutrients by leaching and erosion.

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The experiment was designed to study the following questions:

1. Effect of burning
   (a) Do the gains in soil nutrients estimated by analysing the soil before and after burning agree with estimates obtained by weighing and analysing the forest vegetation?
   (b) Does the burning lead to destruction of soil humus?
   (c) How are the gains in nutrients distributed in the immediate top soil? It has been suggested that large amounts of alkaline ash in the top soil may induce micronutrient deficiencies.
2. Effect of cultivation
   (a) Does clear felling and stumping followed by deep cultivation or by shallow cultivation cause greater loss of organic matter and nutrients than cultivation by local practice?
   (b) What is the influence of cropping compared with bare fallow on nutrient losses?

Previous work bearing on these questions has been fully discussed by Nye and Greenland [4] in a review of the effects of shifting cultivation on the soil. No comparison of nutrient gains following burning with analyses of vegetation on the same site has been made before. Vine [6] found that burning secondary forest about 30 years old had little effect on the C- and N-level in the soil. Other studies on this point have given no estimate of errors involved or of sampling methods. No reliable data is available showing changes in the nutrients in forest soils following cultivation by methods of shifting cultivation, though Kowal and Tinker [2] found surprisingly small losses of K, Ca, and Mg between one and eleven years after clearing a forest soil and cropping it to exhaustion between interplanted oil palms. This experiment suggests most of the nutrients released on clearing may have been lost during the first year. There are several trials summarized in Table 10 of the review mentioned in which changes in organic matter levels with cultivation are reported. Losses range from 9.0% of the humus present per annum to an actual increase according to conditions.

In devising our experiments, previous work indicated we should pay particular attention to the following points:

1. The soil is very heterogeneous, especially because of decay of old fallen timber, termite mounds and irregular distribution of ash following burning. It is particularly difficult to obtain reliable estimates of changes in organic C and N, which will amount each year to only a few per cent of the amount present.

2. Samples should be taken to at least 12 inches since in some previous work losses from the top 6 inches have been found to be compensated by gains in the second 6 inches.

3. Soil density may be changed by cultivation, and if the usual practice of sampling to a fixed depth is adopted, this means that the same mass of soil is not sampled on each occasion. This effect occurred in Popenoe's [5] study of changes following clearing in the Polochic valley, Guatemala, where the density at 2 to 4 inches before clearing was 0.56 and after clearing was 0.71. In estimating changes in soil nutrients and organic matter over a period of time it is essential that comparisons should be based on the same soil mass, or the possible error involved in sampling to a fixed depth clearly recognised.

METHODS

Design of the experiment

The cultivation treatments involving clear felling and disturbance of the soil were carried out on a rectangular central block of 1.2 acres divided into 24 plots of 0.05 acres. On each plot the soil was first sampled and then the vegetation was cleared, weighed, sampled, and finally burnt, as described by Greenland and Kowal [1]. The local-practice treatment was studied on 0.05 acre plots arranged in two smaller blocks each 0.2 acres on either side of the central block. Because large trees are left in the local-practice plots it was not possible to mingle them with the cultivated plots in the random lay-out customary for crop trials.

Treatments

On the central block the treatments were:

MF – Minimum cultivation	;	bare fallow
MC – ,, ,,	;	maize–cassava rotation
DF – Deep cultivation	;	bare fallow
DC – ,, ,,	;	maize–cassava rotation

Deep cultivation consisted in clearing all stumps and large roots and digging with a fork to 12 inches.

Cropping was as follows:

March 1958	– site cleared and burned
March–July 1958	– Maize
August 1959–August 1959	– Maize and cassava
September 1959–January 1960	– Maize

In the local-practice plots maize was planted with a dibble stick at wide spacing – about 4 feet – and interplanted with cassava, cocoyam and plantain or banana. The maize was harvested in July, and the other crops at frequent intervals in the following year as they matured.

Sampling

For each plot, a composite sample was formed from 50 cores taken with a cylindrical auger 1.5 inches in diameter at 0–2, 2–6, and 6–12 inches depth, except for some plots sampled for 0–2 and 2–12 inches in the initial sampling. Samples were taken before clearing, immediately after burning, after one year of cropping, and after two years of cropping. Surface litter was scraped aside before taking samples. Samples were air dried, put through the 2-mm sieve and the fine earth reserved for analysis. The small proportions of gravel have been allowed for in estimating the total amount of nutrients.

The composite samples for each treatment were bulked for laboratory analysis. Thus each determination reported for each treatment represents a mean of 300 cores (200 cores for local practice). The sampling procedure immediately after burning was duplicated, and affords an estimate of the sampling error.

Analyses

To minimize systematic errors all samples taken over the two years were analysed together at the end of the experimental period. So far as possible samples for a given treatment taken at successive intervals were analysed in the same batch.

The analytical methods used have been described by Greenland and Kowal [1].

RESULTS AND DISCUSSION

(1) *pH and exchangeable cations*

Changes in the pH and exchangeable cations in the top 12 inches of soil over the experimental period are shown in Table 1, The distribution of these nutrients within the top 12 inches, for plots other than those where the top 12 inches was mixed by deep cultivation is shown in Table 2.

Effect of burning. Burning causes a dramatic change in the quantities of exchangeable Ca, K, and Mg, and in the pH. In the plots with minimum cultivation the effects are mainly in the 0–2 inch layer. Small changes in the 6–12 inch layer are probably due to disturbance during clearing and contamination during sampling by small portions of top soil falling in. In the local practice plots the pH rose by nearly 3 units in the 0–2 inch layer. Even so it did not exceed 8.1 and it is therefore unlikely that any serious micronutrient deficiency would be induced.

It is particularly interesting to compare the amounts of calcium, magnesium, and potassium in the vegetation on the central block

TABLE 1

Nutrients in soils (2-mm fraction; 0–12 inch depth) before clearing and at yearly intervals after clearing and burning

Sampling times	*Treatments*
(1) Before clearing	MB Minimum cultivation – bare
(2) After burning	MC ,, ,, – cropped
(3) ,, one year	DB Deep ,, – bare
(4) ,, two years	DC ,, ,, – cropped
	LP Local practice

Treatments	pH (1 : 5 water)				Ca (milliequiv. per 100 g)			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
MB	4.6	6.0	5.2	5.2	1.4	4.4	3.1	3.0
MC	4.8	6.6	5.4	5.5	1.5	4.5	2.8	2.8
DB	4.7	6.5	5.4	5.3	1.6	4.8	3.1	2.8
DC	4.8	6.7	5.6	5.6	1.8	5.5	3.7	3.5
LP	5.0	6.5	5.6	5.8	2.5	6.1	5.7	5.8
Coeff. of *variation*	2.2%				3.6%			
Means								
Bare	4.7	6.2	5.3	5.2	1.5	4.6	3.1	2.9
Cropped	4.8	6.6	5.5	5.5	1.6	5.0	3.2	3.1
Min. Cult.	4.7	6.3	5.3	5.3	1.5	4.4	2.9	2.9
Deep ,,	4.7	6.6	5.5	5.4	1.7	5.1	3.4	3.1
Treatments	K (milliequiv. per 100 g)				Mg (milliequiv. per 100 g)			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
MB	.25	.59	.38	.29	.95	1.50	1.12	.93
MC	.23	.70	.30	.20	1.05	1.43	1.05	.93
DB	.29	.64	.40	.27	1.02	1.60	1.15	.95
DC	.23	.72	.31	.20	1.12	1.60	1.38	1.12
LP	.38	.90	.35	.21	1.40	1.75	1.40	1.25
Coeff. of *variation*	5.0%				3.7%			
Means								
Bare	.27	.61	.39	.28	.99	1.55	1.13	.94
Cropped	.23	.71	.30	.20	1.09	1.51	1.21	1.02
Min. Cult.	.24	.65	.34	.24	1.00	1.46	1.08	.93
Deep ,,	.26	.68	.35	.23	1.07	1.60	1.26	1.03

with the increases in the amounts of these ions present on the exchange complex in the soil on which it was standing. These are shown in Table 3. The figures for the vegetation are taken from Greenland and Kowal[1] and include all except the roots. The figures for the soil have been calculated on the basis of weights of soil in the surface 12 inches as reported in Table 6 of Greenland

TABLE 2

Distribution of K, Ca, and Mg between successive layers of top soil

Sampling time		(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Treatment	Depth (inches)	pH (1 : 5 water)				Ca (milliequiv. per 100 g)			
MB	0–2	5.2	7.6	6.6	6.5	4.3	11.2	8.2	7.8
	2–6		5.7	5.2	5.2		4.5	3.0	3.0
		4.5				1.0			
	6–12		5.7	4.7	4.8		3.0	1.2	1.5
MC	0–2	5.2	8.0	6.8	6.6	4.0	12.7	7.2	6.8
	2–6		7.4	5.5	5.5		5.0	3.0	3.0
		4.7				1.2			
	6–12		5.5	4.8	4.9		2.5	1.2	1.5
LP	0–2	5.2	8.1	7.5	7.0	7.2	21.2	20.5	14.5
	2–6	4.9	6.2	5.4	6.0	2.0	5.0	3.2	5.2
	6–12	4.9	6.2	5.0	5.2	1.7	3.8	2.5	3.2
		K (milliequiv. per 100 g)				Mg (milliequiv. per 100 g)			
MB	0–2	0.4	1.2	0.6	0.3	2.2	2.8	2.3	1.4
	2–6		0.6	0.4	0.3		1.5	1.1	0.9
		0.2				0.8			
	6–12		0.4	0.3	0.3		1.2	0.8	0.7
MC	0–2	0.4	1.5	0.4	0.2	1.9	2.9	1.7	1.3
	2–6		0.8	0.4	0.2		1.5	1.2	1.0
		0.2				0.9			
	6–12		0.5	0.2	0.2		1.1	0.7	0.8
LP	0–2	0.5	2.5	0.6	0.3	2.6	3.9	2.4	2.0
	2–6	0.3	0.9	0.4	0.2	1.2	1.6	1.2	1.1
	6–12	0.4	0.5	0.3	0.2	1.2	1.4	1.1	1.1

and Kowal. These were determined by direct weighing of soil in six pits each 1 sq. yard. The errors reported take account of those for sampling, as recorded in this paper, and those for the weights of soil, as recorded by Greenland and Kowal. The agreement between the two measurements is satisfactory, and indicates that the calcium, magnesium, and potassium can be retained in the top foot of soil by the exchange complex. It should be noted that only one light rain fell between the burning and the sampling of soil.

It was hoped to follow changes in the isotopically exchangeable phosphorus, but this was not possible, and arbitrary extractions were thought to mean little. It may however be recorded that a large increase in 'available' phosphorus determined by extraction with 0.002 N sulphuric acid was observed after the burn.

Effect of cultivation. Figures in Table 1 indicate there is a

TABLE 3

Comparison of exchangeable K, Ca, and Mg gains in soil with amounts in cleared vegetation on the central block, (pounds per acre)

Element.	Ca	Mg	K
Gains in soil (lbs/acre/foot. . . .	2460 ± 196	232 ± 19	615 ± 56
Nutrients in aerial parts (lbs/acre)	2250 ± 187	309 ± 35	731 ± 62

TABLE 4

Losses of nutrients (pounds per acre) from top soil (0–12 in.) in 2 years of cultivation

Treatment	Ca	K	Mg
MB	1070	450	260
MC	1300	740	230
DB	1530	550	300
DC	1530	770	220
LP	230	1040	230
Nutrients in crop harvest over 2 years (estimated).	90	350	40

striking loss of all nutrients from the whole of the top 12 inches. during the first year. Table 2 shows the loss to occur in all the layers sampled; evidently the lower layers did not gain at the expense of the upper one.

In the second year little more calcium was lost, though under local practice some was leached from the 0–2 inch layer to those below. Changes in pH ran parallel to the changes in calcium. At the end of the second year both Ca and pH were at a higher level than they were in the soil before the site was cleared. On the other hand, the levels of Mg and K continued to fall and at the end of the second year they were below the level in the soil before clearing.

As shown by the figures in Table 4, in the central block the main losses of exchangeable Ca and Mg must be due to leaching and erosion, for the amounts removed in the crops are relatively small. The removal of potassium in the harvested crops is estimated to be about half the total loss. This may explain why on the average losses are less on the bare than on the cropped plots.

In the local-practice plots the loss of calcium is markedly reduced. The continuous cover protected the surface soil, in which the calcium was concentrated, very effectively from erosion, and the continuous transpiration would reduce leaching. Loss of potassium was however, high. This may in part be explained by the fact that more potassium was added when the forest was burnt on the local-practice plots than on the central block. Also, banana and plantains are known to have a very high content of potassium, which was immobilised in the standing crop at the latest time of soil sampling.

There is little difference between the effects of deep and minimum cultivation.

(2) *Organic matter*

Changes in the levels of C and N for the 0–12 inch layer are shown in Table 5.

Effect of burning. In the clear-felled central block the mean C-content rose from 0.94 to 1.24 per cent and the mean N-content from 0.108 to 0.125 per cent. The samples evidently include some partially burnt unhumified material. The increase represents 5 tons per acre of C, while the amount of C in the burned vegetation was about 60 tons per acre. In the local-practice plots where there was no disturbance of the surface by stumping and rooting, samples were not mixed with incompletely burned material for it was possible to brush this aside before sampling. The burning caused little change in the level of C and N.

TABLE 5

Organic matter content of soils (2-mm fraction; 0–12 inch depth) before clearing and at yearly intervals after clearing and burning

Sampling time . . .	C (per cent)				N (per cent)			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Treatment								
MB	.98	1.30	.96	.94	.112	.125	.093	.088
MC	.96	1.17	.94	.89	.101	.115	.089	.085
DB	.89	1.23	.93	.88	.108	.127	.090	.082
DC	.93	1.28	1.02	1.03	.112	.133	.100	.091
LP	1.15	1.13	1.10	1.07	.118	.122	.110	.103
Coeff. of variation	2.6%				1.9%			
Means								
Bare.	.94	1.27	.95	.91	.110	.126	.092	.085
Cropped.	.95	1.23	.98	.96	.107	.124	.095	.088
Min. cult.	.97	1.24	.95	.92	.107	.120	.091	.087
Deep cult.	.91	1.26	.98	.96	.110	.130	.095	.087

TABLE 6

Distribution of organic matter between successive layers of topsoil

Sampling times		C (per cent)				N (per cent)			
		(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Treatment	Depth (in.)								
MB	0–2	2.48	2.19	1.94	1.71	.228	.205	.170	.150
	2–6		1.34	0.99	1.00		.129	.096	.094
		0.78				.096			
	6–12		1.09	0.62	0.64		.105	.065	.064
MC	0–2	2.26	2.06	1.64	1.60	.241	.187	.148	.145
	2–6		1.17	1.07	0.97		.127	.101	.094
		0.78				.082			
	6–12		0.98	0.61	0.59		.093	.061	.059
LP	0–2	2.86	2.34	2.67	2.19	.259	.250	.242	.194
	2–6	1.06	1.18	1.01	1.06	.110	.129	.101	.107
	6–12	0.84	0.85	0.63	0.71	.092	.092	.072	.070

It has not proved possible by this method to resolve the question of whether the burning of the forest actually causes decomposition of humus formerly present in the soil, but it can be said with certainty that there is no net decline in humus as a result of firing. The combustion achieved in the present experiment, though incomplete, was probably more complete than normally attained in agricultural practice, primitive or otherwise.

Effect of cultivation. On the central block, after one year of cropping levels of C were much lower than the initial levels on all plots. Much of this decline could be attributed to decomposition of unhumified material. Erosion of the surface soil also played a part, since in spite of low contour bunds built across the plots some soil wash was evident. No special differences were noted between the treatments. In the second year the rate of decline was reduced, the annual decomposition constant, calculated from the simple approximation $k = 1/t \ln No/N$, averaging .07 for N and rather less for C. These figures are probably a truer reflection of the mean rate of decomposition of humified material, though they may also reflect some loss by erosion and be influenced by the presence of unhumified material.

In the local practice plots, where samples were less mixed with unhumified material, and the soil was not disturbed, the annual decomposition constant for C was .03 in the first and the second year, and for N it was .10 in the first year and .06 in the second. Since the uncertainty in any one of the values for the annual decomposition constant for C or N is at least .02, they are not very precise. To some extent humus levels in the local practice plots may be maintained by decay of roots in the top 12 inches. Losses must be due to mineralisation, since erosion was observed to be very slight.

The changes in organic matter levels in successive layers for the plots where they have not been mixed by cultivation are shown in Table 6. It will be seen that the greatest losses occur in the surface 2 inches. The losses from the 2–6 inch layer are far lower and suggest that some of the organic matter in the 0–2 inch layer has been leached or mixed into the 2–6 inch layer. It is, however, interesting that significant losses were observed in the 6–12 inch layer on all plots.

(3) *Changes in soil density on clearing and cultivation*

In its original state under forest the surface 2 inches is much more porous than the lower layers, due to the intense activity of termites, ants, worms and other fauna in the surface stimulated by the forest litter. This horizon rapidly becomes more compact when the forest cover is removed and the surface is exposed to rain. The other notable change was promoted by deep cultivation which left the soil in a more porous condition than minimum cultivation.

Determinatons of relative densities, with a cylindrical sample of 1½ inches internal diameter, on all plots at the end of the experiment indicated that density changes in the course of the experiment were smaller than had been expected. The difference in the calculated nutrient losses shown in Table 4 caused by sampling to a fixed depth of 12 inches instead of sampling always the same amount of original forest soil are less than 2 per cent. The differences would of course have been much larger if the depth of sampling was say 6 inches or less.

(4) *Crop yields*

The yields from the different treatments are shown in Table 7. Local practice yielded considerably less over two years than the row planted plots, though it should be noted that the well established plantains and bananas were continuing to produce fruit when the

TABLE 7

Crop yields (lb/acre)				
Harvest	Crop	Minimum cultivation	Deep cultivation	Local practice
June 1958	Maize (oven-dry grain)	2,880	3,020	1,010
Jan. 1959	Maize (oven-dry grain)	1,140	1,270	
Aug. 1959	Cassava (fresh roots)	16,600	21,400	
Feb. 1960	Maize	2,420	2,710	
July 1959 to	Plantain and Banana (fresh) .			13,855
Jan. 1960 (weekly harvest)	Cassava and Cocoyam (fresh roots)			1,020

experiment had to be closed. The yield of maize was lower because of the traditional wide spacing, and the cassava and cocoyam were largely destroyed by cane rats.

Deep cultivation induced consistently better yields than shallow cultivation. For the first two maize crops the differences are not significant, but for the cassava and last crop of maize they are nearly significant at $P = .05$.

These experiments show that a much greater return per acre could be achieved by row cultivation for two years without significantly greater loss to the soil than is entailed in local practice. Row cultivation is, however, very much more costly because of the need for stumping, levelling of termite mounds, and weeding. In addition, it is not possible to combine the advantages of row cultivation with the local practice of restoring fertility by the regenerating natural-bush fallow, since clean weeding destroys the roots from which the fallow regenerates, and grasses will come in. Any mechanised system of cropping involves a complete revolution in methods, and it has yet to be shown that the consequences in terms of erosion, maintenance of fertility, labour and costs can be satisfactorily met.

SUMMARY

About one-and-a-half acres of tropical forest, of known mass and chemical composition, was cleared and burned. Soil changes during clearing and two years' cropping were studied.

Following burning, approximately all the K, Ca, and Mg in the vegetation were accounted for by the rise in exchangeable K, Ca, and Mg in the soil. There was a marked rise in soil pH. A small but significant increase in C and N was attributed to admixture of parts of the vegetation with the soil.

Following cultivation, there was a rapid loss of nutrients by leaching and erosion during the first year and a substantial loss of K and Mg, but smaller loss of Ca in the second year. Losses of calcium were less and of potassium more under the local practice of shifting cultivation than under cultivation treatments involving clearing of roots followed by bare fallow or a maize–cassava rotation. Depths of cultivation had little effect on nutrient losses. Losses of organic matter in the first year were rapid due to oxidation of unhumified material. They were much reduced in the second year. Greater production of food was obtained from the maize–cassava rotation than by local practice.

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