Reprinted from the 1955 COCOA CONFERENCE REPORT.

THE NUTRIENT STATUS OF GOLD COAST FOREST SOILS

WITH SPECIAL REFERENCE TO THE MANURING OF COCOA

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Gold Coast Forest Soils

The forest region of the Gold Coast in which climatic conditions suitable for cocoa production occur comprises upland soils belonging, in the main, to two great soil groups: the ochrosols* and the oxysols†.

The ochrosols consist of red to yellowish-brown kaolinitic earths with characteristic reaction profiles: the surface horizons vary from moderately acid to mildly alkaline and lower horizons become increasingly acid. The surface 2-3 inches are frequently slightly calcareous due to concretions weathered from odum (*Chlorophora excelsa*) trees, to mollusc shells (*Achatina fullica* etc.), to arthropod exo-skeletons and to vertebrate endo-skeletons. These soils are developed over a variety of parent materials, including the weathering products of granodiorites, biotite schists, phyllites, epidiorites etc. both accumulated in place (residual soils) and transported as terrestrial deposits (peneplane drift soils). Under forest, ochrosols occur under rainfalls varying from 40-50 inches to 70-80 inches. It is on soils of this great soil group that the vast majority of cocoa is produced.

The oxysols typically consist of pale orange-coloured kaolinitic earths, though red examples also occur. This great soil group also displays a characteristic reaction profile: the surface horizon is highly to very highly acid and the horizons below are only slightly less acid. Oxysols are developed in similar parent materials to the ochrosols but typically under rainfalls exceeding 70-80 inches and, outside the Gold Coast, up to as much as 200 inches or more; where they occur under lower rainfalls they have been derived from the weathering products of highly siliceous rocks, i.e. quartzites, or from those of pyritiferous sediments which set free sulphuric acid during decomposition. The soils of this great soil group produce very little cocoa. Fortunately they are not extensive in the Gold Coast but elsewhere in the very humid, forest regions of the tropics they are extremely widespread.

Apart from colour differences in some cases, the ochrosols differ very little from the oxysols as far as visual characteristics are concerned. Distinct floral and faunal differences, however, can be employed to distinguish them in the field, the oxysols being characterised by indicator plants such as *Lycopodium* spp, *Gleichenia* spp, abundance of *Melastomaceae* and blue-fruited rubiaceous plants. The reaction profile has been taken as the main distinguishing feature, as this is readily determined in the field by colorimetric means but chemically they differ in many other ways as well. Organic matter tends to be higher in quantity in the oxysols, has a higher carbon/nitrogen ratio, is more dispersible and shows greater penetration down the profile and has a far smaller capacity for holding

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* Once termed reddish-brown, yellowish-brown laterite and laterite soils and, later, red, earthy red, yellow and reddish-brown latosols by U.S. workers.

† Approximately comprise those soils once termed reddish-yellow latosols by U.S. workers. U.S. soil workers are revising their classification of tropical soils.

TABLE I

A REPRESENTATIVE OXYSOL

Altitude 650 ft.
Rainfall 70 in.
Vegetation: Forest

Sample No. B262 — Series: Dompim

Lower Depth of Horizon in inches	Colour Wet		Organic Matter %	C/N	*p*H	Cation Exchange Capacity m.e./100g Soil	Exchangeable Cations m.e./100g Soil			Ratios			$CaCO_3$ %
	Munsell Notation	Description					Ca	Mg	K	Ca/Mg	Mg/K	Ca+Mg/K	
1½	10YR 3/2	Very Dark Grey Brown	15·10	22·00	4·1	34·42	3·27	1·22	0·68	2·68	1·79	6·60	Nil
6	10YR 4/2	Dark Grey Brown	7·00	11·87	4·2	23·96	1·51	0·28	0·42	5·39	0·67	4·26	—
16	10YR 4/4	Dk. Yellow Brown	3·42	9·95	4·6	17·75	1·08	0·08	0·38	13·50	0·21	3·05	—
28	10YR 4/4	Dk. Yellow Brown	2·06	8·57	4·6	12·88	0·82	0·09	0·26	9·11	0·35	3·50	—
52	10YR 5/4	Yellow Brown	2·06	8·45	4·8	12·20	0·75	0·11	0·36	6·82	0·31	2·39	—
58	5YR 4/8	Yellow Red	0·71	6·61	5·1	7·65	0·96	0·12	0·27	8·00	0·44	4·00	—

TABLE II

A REPRESENTATIVE OCHROSOL

Altitude 450 ft.
Rainfall 55-60 in.
Vegetation: Cocoa

Sample No. B257 — Series: Swedru

Lower Depth of Horizon in inches	Colour Wet		Organic Matter %	C/N	*p*H	Cation Exchange Capacity m.e./100g Soil	Exchangeable Cations m.e./100g Soil			Ratios			$CaCO_3$ %
	Munsell Notation	Description					Ca	Mg	K	Ca/Mg	Mg/K	Ca+Mg/K	
2	7·5YR 4/2	Dark Brown	9·37	10·38	7·4	30·08	23·44	10·98	1·44	2·13	7·63	23·90	0·275
5	7·5YR 4/2	Dark Brown	3·84	9·53	7·3	14·82	11·24	4·36	0·56	2·58	7·78	27·86	0·071
12	5YR 4/4	Reddish Brown	1·39	8·35	6·4	8·25	4·95	1·53	0·48	3·24	3·19	13·50	0·013
29	5YR 5/6	Yellowish Red	1·00	8·06	6·1	7·12	4·03	1·15	0·43	3·50	2·67	12·05	—
59	2·5YR 4/6	Red	0·62	6·21	5·2	6·63	3·55	0·71	0·45	5·00	1·58	9·47	—
78	2·5YR 4/6	Red	0·55	6·40	5·4	6·06	2·76	1·42	0·36	1·94	3·94	11·61	—
115	5YR 5/6	Yellowish Red	0·43	6·41	5·3	5·75	2·50	1·13	0·39	2·21	2·90	9·31	—
128	5YR 5/6	Yellowish Red	0·26	5·36	5·2	4·63	2·08	1·25	0·40	1·66	3·12	8·32	—

bases than is the case with the organic matter of the ochrosols. The latter, as may be surmised from the reaction profiles, are far more abundantly supplied with divalent bases, calcium and magnesium, than are the oxysols; potassium, however, occurs in similar quantities in both great soil groups. No very significant differences have so far been noted, either, in their contents of total or dilute-acid-soluble phosphorus, excepting that the latter is far more abundant in the ochrosols with calcium carbonate present in the topsoils[1]. Analytical data for a representative oxysol and a representative ochrosol are given in Tables I and II.

It is considered that modal oxysols have surface reactions of *pH* 4–5 and modal ochrosols surface reactions of *pH* 6–7. Intergrades between these great soil groups occur with surface reactions between *pH* 5 and 6. Such intergrades are abundant amongst the soils of the Gold Coast forest zone and observation suggests that they are far less productive for cocoa than are the ochrosols proper. Analytical data for a representative intergrade between the oxysols and ochrosols are given in Table III.

Ochrosols with reactions above *pH* 7 intergrade with calcimorphic soils, derived from basic or calcareous rocks, which are abundantly supplied with divalent bases and approach neutrality throughout the profile. Calcimorphic soils are excellent producers of cocoa but are very inextensive in the Gold Coast and only locally of importance elsewhere.

The Base Status of Gold Coast Cocoa Soils

Attention is particularly directed towards the base status of the ochrosols, the oxysols and the intergrades between them. Study of the data in Tables I, II and III will show that, as one passes from the slightly calcareous ochrosols, through the non-calcareous ochrosols and intergrade soils to the oxysols, the divalent bases, calcium and magnesium, diminish in amount and there is a tendency for magnesium to be lost to a greater extent than calcium. On the other hand the proportions of potassium diminish far less, or hardly at all.

The examination in the laboratory of the upper horizons of a number of oxysols, ochrosols and intergrades between them shows tendencies of the same nature. Tables IV and V give the results of such examinations. The irregularities in the general trends can be accounted for by the varying numbers of samples forming the composite means and the fact that the soils employed in the computation had their origin, as was inevitable, from parent materials of varying composition. Additional determinations when employed in the computation of the means may be expected to smooth out such irregularities. However, attention is drawn to the very marked

TABLE III

A REPRESENTATIVE INTERGRADE OCHROSOL-OXYSOL

Sample No. B481 — Series: Akroso — Altitude 1,300 ft. Rainfall 60+ in. Vegetation: Forest

Lower Depth of Horizon in inches	Colour Wet		Organic Matter %	C/N	*p*H	Cation Exchange Capacity m.e./100g Soil	Exchangeable Cations m.e./100g Soil			Ratios			$CaCO_3$ %
	Munsell Notation	Description					Ca	Mg	K	Ca/Mg	Mg/K	Ca+Mg/K	
2	7·5YR 3/2	Dk. Brown	10·18	12·23	5·5	24·32	9·34	4·82	0·81	1·94	5·95	17·48	Nil
5	10YR 4/4	Dk. Yellow Brown	2·55	9·61	5·0	9·94	1·86	0·99	0·34	1·88	2·91	8·38	—
13	10YR 6/8	Brn. Yellow	1·27	9·74	4·9	9·01	1·13	0·03	0·25	37·7	0·12	4·64	—
26	10YR 6/8	Brn. Yellow	0·83	8·14	4·7	12·50	2·28	0·05	0·15	45·6	0·33	15·53	—
50	10YR 6/8	Brn. Yellow	0·77	6·72	4·6	—	—	—	—	—	—	—	—
72	5YR 6/8	Reddish Yellow	0·67	6·96	4·9	—	—	—	—	—	—	—	—

TABLE IV

BASE STATUS OF OXYSOLS, INTERGRADES AND OCHROSOLS
in Milligram Equivalents per cent. Fine Earth

	Ca					Mg					K				
*p*H Range	4·0–5·0	5·0–5·5	5·5–6·0	6·0–7·0	7·0+	4·0–5·0	5·0–5·5	5·5–6·0	6·0–7·0	7·0+	4·0–5·0	5·0–5·5	5·5–6·0	6·0–7·0	7·0+
No. of Samples	5	7	8	23	12	5	7	8	23	12	5	7	8	23	12
TS1	5·73	9·38	7·94	15·68	23·77	1·04	2·76	1·86	4·57	6·44	0·62	0·60	0·43	0·61	0·85
TS2	1·59	2·19	2·43	5·68	11·60	0·12	0·60	0·33	1·64	2·54	0·27	0·28	0·26	0·31	0·40
SS1	1·41	1·12	1·80	2·73	5·01	0·10	0·37	0·21	1·02	1·53	0·21	0·20	0·25	0·24	0·40
SS2	1·03	1·48	1·67	2·47	3·90	0·10	0·62	0·26	0·97	1·77	0·17	0·20	0·26	0·28	0·39

TS1 = Upper humus horizon, average lower depth 2–3 in.
TS2 = Lower humus horizon, average lower depth 8–9 in.
SS1 = Upper subsoil, average lower depth 19–20 in.
SS2 = Lower subsoil, average lower depth 35–36 in.

TABLE V

BASE RATIOS OF OXYSOLS, INTERGRADES AND OCHROSOLS

	Ca/Mg					Mg/K					Ca+Mg/K				
*p*H Range	4·0–5·0	5·0–5·5	5·5–6·0	6·0–7·0	7·0+	4·0–5·0	5·0–5·5	5·5–6·0	6·0–7·0	7·0+	4·0–5·0	5·0–5·5	5·5–6·0	6·0–7·0	7·0+
No. of Samples	5	7	8	23	12	5	7	8	23	12	5	7	8	23	12
TS1	5·51	3·40	4·27	3·43	3·69	1·68	4·60	4·33	7·49	7·58	10·92	20·23	22·79	33·20	35·54
TS2	13·25	3·65	7·36	3·46	4·57	0·44	2·14	1·27	5·29	6·35	6·33	9·96	10·62	23·61	35·35
SS1	14·10	3·03	8·57	2·68	3·27	0·48	1·85	0·84	4·25	3·82	7·19	5·32	8·04	15·63	16·35
SS2	10·30	2·39	6·42	2·55	2·20	0·59	3·10	1·00	3·46	4·54	6·65	10·50	7·42	12·29	14·54

TS1 = Upper humus horizon, average lower depth 2–3 in.
TS2 = Lower humus horizon, average lower depth 8–9 in.
SS1 = Upper subsoil, average lower depth 19–20 in.
SS2 = Lower subsoil, average lower depth 35–36 in.

widening of the ratios of the divalent bases, calcium and magnesium, to potassium in soils included in the reaction group *pH* 6-7 and in that exceeding *pH* 7. These results should be kept in mind when the distribution of cocoa with respect to reaction groups is discussed later.

It has already been stated that some of the ochrosols are slightly calcareous. Of 157 ochrosols having a surface reaction exceeding *pH* 6·0 and analysed for $CaCO_3$, 100 had contents of $CaCO_3$ greater than 0·025 per cent.; of these 56 were under cocoa and had an average reaction of *pH* 7·14 at the surface and an average content of 0·312 per cent. $CaCO_3$.

The content of exchangeable bases and of calcium carbonate is reflected in the soil reaction. Table VI shows the distribution of cocoa on soils with varying reaction in the surface horizon, the data being obtained from profiles examined colorimetrically by survey staffs and electrometrically by the laboratory staff.

I first draw your attention to the number of soil profiles examined for reaction colorimetrically: 1,846. These profiles were sampled in the course of surveys

THE REACTION OF THE SURFACE HORIZON OF GOLD COAST FOREST SOILS AND THE DISTRIBUTION OF COCOA

(See Table VI A p. 5)

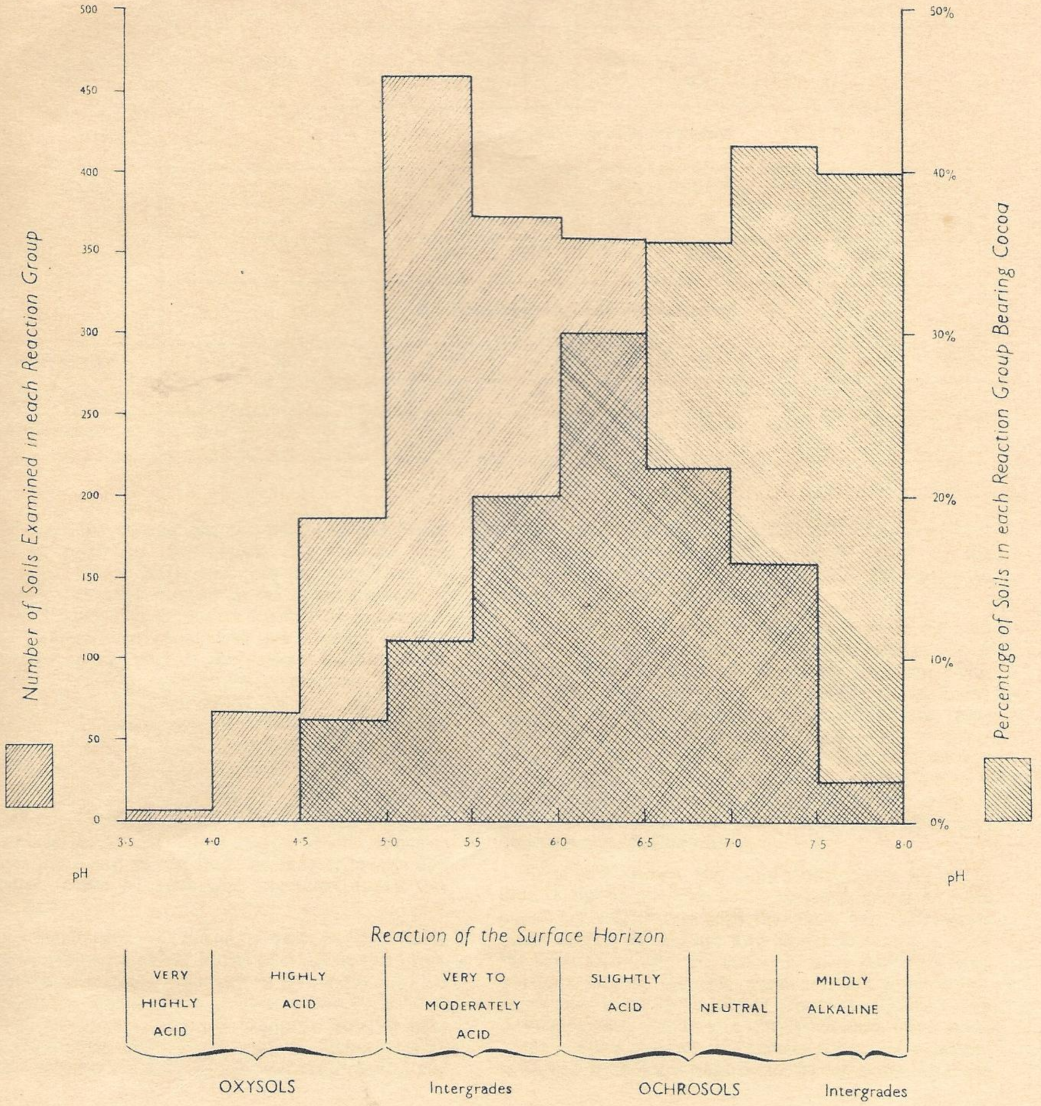

TABLE VI

DISTRIBUTION OF COCOA ON SOILS WITH VARYING SURFACE REACTIONS

	OXYSOLS			Intergrades		OCHROSOLS			Inter-grades	(Total)
Reaction of surface soil (*p*H)	< 4·0	4·0–4·4	4·5–4·9	5·0–5·4	5·5–5·9	6·0–6·4	6·5–6·9	7·0–7·4	> 7·4	
	A. Reaction colorimetrically determined									
Total soils examined	6	68	186	459	370	357	216	159	25	(1846)
No. supporting cocoa	0	0	12	52	74	107	77	66	10	(398)
% Supporting cocoa	0	0	6·5	11·3	20·0	30·0	35·6	41·5	40·0	
	B. Reaction electrometrically determined									
Total soils examined	6	20	37	36	47	67	55	50	35	(353)
No. supporting cocoa	0	0	1	3	10	22	18	25	21	(100)
% supporting cocoa	0	0	2·7	8·3	21·3	32·8	32·7	50·0	60·0	

widely scattered throughout the whole of the forest region in order to characterize the various soils encountered (Plate XIII) and may be considered to have been selected at random as far as the land-use of the soils from which they were taken was concerned. Cocoa having been planted in the absence of any knowledge on the part of the peasant farmer of the significance of soil reaction, it is assumed that its production has been attempted on most of the soil included in the Table but that it has survived after planting to a greater extent where the soils approached neutrality or slight alkalinity than on those which were more acid or highly acid.

It should be noted from the Table that the most frequent soils in the forest region have reactions between *pH* 5 and 6, but that the greater proportion of cocoa occurs on soils with reactions above this (Plate XIV).

The distribution of cocoa shown in the Table represents the survival of farms planted to this crop. Without much doubt, however, it also represents an approximate picture of the yield of cocoa on soils of different reaction. I do not suppose anyone here imagines that the 6 or so per cent. of cocoa growing on soils between *pH* 4·5 and 5 is yielding as well as the 20 per cent. growing on soils of *pH* 5·5 to 6 or that this cocoa, even, is contributing as much to the Colony's production as the 35 per cent. on soils with reactions between *pH* 6·5 and 7.

Manuring with suitable fertilizer to improve the base status and raise the reaction of the acid soils would, if properly carried out, result in greatly increased yields and permit many areas not now capable of supporting cocoa to produce profitably. Of this I believe there should be no doubt whatsoever. Experiments to determine what materials should be used and the time and method of application are, of course, essential and so is the provision of sufficiently uniform cocoa over areas of sufficient extent so that such experiments can yield accurate and reliable results.

As is well known, the Gold Coast cocoa farmer is unable, by the methods he at present employs, to raise cocoa successfully on soils that have had their forest cover destroyed and are now under thicket and used for food farming[2]. He can only raise cocoa on land partially cleared for this purpose from high forest. Since the forest in the Gold Coast is rapidly being destroyed and the time is not far distant when none outside forest reserves will remain for cocoa planting, it is a matter of some importance to determine what are the changes that occur following destruction of the forest which render the soils unsuitable for cocoa growing.

Some of the difficulty is explicable by the fact that immature cocoa growing up in thinned forest has to compete only with other shade-enduring shrubs and small trees; on the other hand, young cocoa attempting to attain maturity on land cleared from thicket has to compete with far more vigorous sun-loving vegetation. Thus land on which the forest has been destroyed by farming may not be suitable for cocoa growing until sufficient time has elapsed for trees to grow and for a shade-enduring under-storey to develop with which young cocoa can successfully compete during its establishment. In this connection a statement by a Nigerian forester is of interest[3]. He is recounting the vegetation changes that take place on reversion of farms to forest and is describing the secondary forest that develops after 20 years from bush: " The bush is now no longer called *Ewu* 'old farm' but *Igbo dudu* 'black bush', which refers to the darker coloured foliage of the dominant species, as distinct from the paler green foliage of the *Ewu* or old farm. . . . Ajua farmers said that land supporting such vegetation would be suitable for cocoa growing." Earlier stages in the succession from farmland to forest were, from experience, not considered capable of supporting cocoa.

However, this is considered not to be the sole explanation by any means. Destruction of the forest means loss of organic matter and consequent loss of the bases and other plant nutrients combined with it. Not only is there this absolute loss in nutrients but it would appear probable that there would be changes in the proportions in which the nutrients, particularly the bases, are present. It is not improbable that the species of which the high forest is composed would maintain in circulation bases and other nutrients in different proportions than would be done by the very different plants that make up thicket. An investigation was, therefore, commenced in the autumn of last year to determine whether such changes occurred and, if so, what they were. This investigation, which is by no means easy on account of the very heterogeneous composition of the secondary vegetation following forest, which naturally affects soil base status, is still continuing but some preliminary results are given in Tables VII and VIII.

These results indicate a somewhat similar trend in passing from forest to farmland as was evidenced in going from the neutral ochrosols to the acid oxysols; that is, the divalent bases, calcium and magnesium, tend to be depleted and potassium to increase in amount. Similar findings have resulted from a recent investigation in the Belgian Congo[4]. This trend is not very clearly shown, but when more analytical results are available it is expected that it will become apparent in a more regular manner. It is important to note, however, that in farmland, the ratio of calcium and magnesium to potassium is considerably narrowed, indicating an increase of potassium in proportion to calcium and magnesium. It is in this environment that young cocoa would be planted were attempts made to establish it on land cleared from thicket.

TABLE VII

ANALYTICAL DATA FOR 9-INCH SURFACE SAMPLES OF OCHROSOLS UNDER FIVE VEGETATION TYPES

Vegetation	No. of Samples	Organic Matter %	C/N	*p*H	Cation Exchange Capacity m.e. % Soil	Exchangeable Cations m.e. % Soil			Ratios			
						Ca	Mg	K	Ca/Mg	Mg/K	Ca/K	Ca+Mg/K
Forest ..	23	3·59	9·74	6·27	14·01	9·49	2·40	0·36	3·95	6·67	26·36	33·03
Cocoa	53	3·22	10·07	6·73	14·38	10·52	2·21	0·41	4·76	5·39	25·66	31·05
Thicket	14	2·56	9·61	6·37	10·14	7·08	1·45	0·30	4·88	4·83	23·60	28·43
Forb Regrowth	21	2·78	9·47	6·63	11·15	8·73	1·72	0·34	5·08	5·06	25·68	30·74
Farmland ..	16	2·37	10·63	6·25	10·53	6·58	1·73	0·39	3·80	4·44	16·87	21·31

Forest: Includes recent secondary forest as well as primary forest.
Thicket: Closed formation of shrubs 20-30 ft. high that occupies abandoned farmland after a few years.
Forb Regrowth: The growth of suffrutescent herbs and grasses that takes over abandoned farmland in the first couple of years.
Farmland: Subsistence farming following the cutting and burning of bush; no tillage of the soil is involved.

TABLE VIII

ANALYTICAL DATA FOR 9-INCH SURFACE SAMPLES OF OCHROSOL-OXYSOL INTERGRADES UNDER FIVE VEGETATION TYPES

Vegetation	No. of Samples	Organic Matter %	C/N	*p*H	Cation Exchange Capacity m.e. % Soil	Exchangeable Cations m.e. % Soil			Ratios			
						Ca	Mg	K	Ca/Mg	Mg/K	Ca/K	Ca+Mg/K
Forest	14	3·05	10·22	5·28	11·15	4·18	1·42	0·25	2·94	5·68	16·72	22·40
Cocoa	7	2·40	10·55	5·34	7·59	4·68	0·88	0·29	5·32	3·03	16·14	19·17
Thicket	4	2·69	10·59	5·25	9·17	4·01	0·78	0·21	5·14	3·71	19·09	22·81
Forb Regrowth	6	2·68	10·74	5·37	9·84	3·57	0·96	0·24	3·72	4·00	14·88	18·88
Farmland ..	5	2·76	10·99	5·33	9·68	3·69	0·96	0·30	3·84	3·20	13·30	15·50

Forest: Includes recent secondary forest as well as primary forest.
Thicket: Closed formation of shrubs 20-30 ft. high that occupies abandoned farmland after a few years.
Forb Regrowth: The growth of suffrutescent herbs and grasses that takes over abandoned farmland in the first couple of years.
Farmland: Subsistence farming following the cutting and burning of bush; no tillage of the soil is involved.

Divalent Bases, Particularly Magnesium, Needed for Optimum Cocoa Production

The evidence to hand suggests that the divalent bases, calcium and magnesium, and particularly the latter, play a highly significant role in the nutrition of cocoa, and for soils to produce cocoa satisfactorily these bases must be present in adequate amounts. These findings based on soil analyses receive great support by the conclusions reached by Homès and his collaborators[6] with pot experiments conducted at I.N.E.A.C. in the Belgian Congo which the writer had the privilege of examining during his visit to the Institute in 1948. The treatments which promoted the best growth of young cocoa were those containing increased proportions of calcium and magnesium, particularly the latter, and Homès recommends a mixed fertilizer containing notable proportions of magnesium.

It is also evident from observation that the best cocoa soils in the Gold Coast are those developed from rocks rich in ferromagnesian minerals such as hornblende (the hornblende granodiorite of W.A.C.R.I. and the epidiorites of the upper Tano basin) and biotite, magnesium, mica (the biotite schists of the Ayensu basin and the biotite granodiorite of the Upper Densu basin).

Sickle-Leaf of Cocoa and Magnesium Deficiency

Relatively few observations have been made in the field regarding leaf symptoms of nutrient deficiencies in cocoa, but one foliar condition, sickle-leaf, has been of sufficiently frequent occurrence in the Gold Coast to attract attention[6, 7, 8]; latterly it has been observed in Ceylon as well[9]. In the Gold Coast sickle-leaf has been attributed to excess potash in the soil due to heaps of split cocoa pods being left in the neighbourhood of cocoa trees, cocoa pods being particularly rich in potassium[8]. However, this evidence of nutritional disorder occurs apart from such contamination. Sickle-leaf has been proved to be brought about by zinc deficiency[7, 10] and the condition can be remedied by spraying with zinc solutions[11]. Such a deficiency, however, may be an induced one rather than an actual one. Thus Camp[12], discussing magnesium deficiency on the sandy citrus soils of Florida, states that this can affect the health of roots and result in an inadequate uptake of zinc and copper from soils with a satisfactory supply of these elements; zinc deficiency symptoms disappear, however, after applications of magnesium. In this connection it is of considerable interest to note that sickle-leaf, under the name of magnesium deficiency, has been cured in Ceylon[9] by applications of dolomitic, i.e. magnesian, limestone, it having been observed that cocoa did not exhibit sickle-leaf on soils developed over dolomite.

The observation in the Gold Coast that sickle-leaf can develop in the presence of excess potash may also be explicable as a result of inadequate magnesium. Potassium and magnesium exhibit what is known as ionic antagonism, excess of the former depressing uptake of the latter by the plant. Numerous instances of this could be quoted from the literature of plant nutrition and manurial trials. This matter of ionic antagonism is likely to be of considerable importance in cocoa soils: it has already been pointed out that magnesium is increasingly lost as soils become increasingly acid whilst the content of potassium remains much the same. A similar trend occurs when forest is cleared and replaced by bush. It is probable, therefore, that unfavourable ratios of magnesium to potassium may occur under both conditions.

Magnesium in Plants and Soils

As magnesium is not an element in plant manuring that has received as much attention as others such as nitrogen, phosphorus and potassium, it may not be out of place here to recapitulate briefly what its functions in the plant are. *Firstly*, magnesium is an essential component of chlorophyll, the green colouring matter of plants essential in the synthesis of carbohydrates and hence in the production of fats. It may well be that shade plants, of which cocoa is one, may frequently possess higher amounts of chlorophyll in their leaves than do plants accustomed to growing in full sunlight. Such leaves would be a deeper green. Earlier in this paper reference[3] was made to the succession, after 20 years, from bush in which cocoa could not be successfully grown to secondary forest, the latter being characterized by its dark green undershrubs. On land carrying this vegetative growth cocoa could be established satisfactorily. It is not improbable that land once farmed does not become suitable for cocoa again without manuring until the vegetation has gradually built up the magnesium content of the topsoil and shade-enduring shrubs have sufficient of this nutrient available for their metabolism. *Secondly*, magnesium is concerned in fat production and is always characteristically high in oil seeds, cocoa being no exception. *Thirdly*, it is concerned in the transport of phosphorus into and within the plant, magnesian materials often being mixed with phosphorus fertilizers with this end in view. *Fourthly*, it is most abundant, until the fruiting stage, in the growing points of plants and must therefore play an important role in early growth and establishment.

Magnesium is most frequently deficient in sandy soils, in fact the first major case of magnesium deficiency investigated was in tobacco and was known as ' sand drown.' Many soils in the forest region of the Gold Coast are highly sandy throughout the profile whilst others are sandy in the topsoil, the main feeding zone of cocoa roots[13, 14]. Such soils are prone to magnesium deficiency and are widespread in the tropics apart from the Gold Coast; the notorious acid Benin sands on which cocoa has failed so signally are a good example.

The characteristic aluminosilicate clay mineral of the tropical red and yellow earths is kaolinite and the available calcium, magnesium and potassium are associated with it in exchangeable form. The ease with which these bases can take up exchange positions on kaolin particles is in the order potassium, calcium and magnesium, and this, of course, affects the ability of the soil to retain these bases for the use of plants. In the moist temperate zones other clay minerals occur in upland soils and not only do these have a greater capacity for absorbing bases but the divalent bases, calcium and magnesium, can enter their exchange positions more readily. These are important differences between tropical and temperate soils and need to be kept in mind when manuring is being considered.

Humified organic matter can absorb bases in exchangeable form as do the clay colloids but in larger amounts, and the divalent bases can more readily assume exchange positions on its surface than is the case with kaolin. These are two of the valuable characteristics of humus and help in explaining why depletion of the organic matter content of the soil following destruction of the forest results in a lower content of bases with a less favourable ratio of calcium and magnesium to potassium.

Both exchangeable magnesium and exchangeable potassium are more readily removed by leaching than is exchangeable calcium. However, calcium and magnesium minerals are more readily decomposable than potassium minerals, and when a soil has been highly weathered, as have the oxysols, there are few or no unweatherable minerals left to replace losses of the exchangeable divalent bases; but this is not the case with minerals such as potash mica and potash feldspar, which weather slowly and thus go on supplying exchangeable potassium to very acid soils. The consequence is, then, that in highly leached soils magnesium tends to disappear from the exchange complex at a greater rate than calcium and both of them at a greater rate than potassium.

Manurial Experiments with Cocoa

In studying manurial experiments on cocoa, with the exception of those carried out at I.N.E.A.C., it is very noticeable that the fertilizer elements experimented with have been confined in the main to nitrogen, phosphorus and potassium; admittedly, however, where ammonium or potassium sulphate have been employed, sulphur has been included, though its effects have never been directly studied; similarly, where superphosphate has been the source of phosphorus, calcium has been included in the dressings but has rarely been studied as a nutrient. Even when liming experiments have been carried out, the calcium added has perhaps invariably been applied with the intention of its acting as a soil ameliorant rather than as a plant nutrient. As fertilizer and nutrient investigations continue, it is becoming increasingly obvious that reliance cannot be wholly placed on the old favourites N, P and K and that the other elements necessary for optimum crop growth must be considered also. Recent work on the necessity for sulphur manuring illustrates this very well. Besides five or more trace elements needed in minute proportions, there are six primary elements obtained from the soil that are essential for plant growth in relatively large quantities: these are nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. Fertilizer investigations have to take *all* the primary elements into consideration, as was done in the I.N.E.A.C. experiments, and not limit inquiries to only half of them. It is very noticeable that up to date very little success has been achieved with manurial work on cocoa compared with what has been attained with other crops, and the supposition is put forward that this may be due to the neglect of the divalent bases, calcium and magnesium, particularly the latter. Liebig's Law of the Minimum could very well be in operation here.

Summary and Conclusions

In this paper I have given particulars of the main soil groups occurring in the Gold Coast forest region and discussed the changes that take place when forest is destroyed and replaced by secondary bush. Special attention has been paid to the distribution and behaviour of the bases calcium, magnesium and potassium, especially magnesium. Evidence is brought forward to show that the divalent bases, particularly magnesium, are of very considerable importance in cocoa production, and some account of the part played by the latter element in plant nutrition and of its behaviour in tropical soils is given. It is pointed out that, with one exception, the divalent bases, and again magnesium in particular, have been disregarded in fertilizer trials. It is suggested that the relative failure that has attended such investigations may very likely be due to this neglect, and it is emphasized that future manurial experiments should include treatments with the divalent bases if they are to produce profitable results.

Finally, I have to thank the soil survey staff of the Department for the colorimetric data contained in Table VI and the laboratory staff, particularly Dr. A. S. de Endredy and Mr. C. W. Montgomery, for the other analytical data quoted in this paper.

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