GHANA DIVISION OF AGRICULTURE
SOIL AND LAND-USE SURVEY BRANCH
formerly
GHANA DEPARTMENT OF AGRICULTURE
DIVISION OF SOIL AND LAND-USE SURVEY

DIVISIONAL PAPER NO. 6

NOT FOR PUBLICATION

S O I L S O F G H A N A

By
H. Brammer
Principal Agricultural Officer

KUMASI
1959

GP 312739/10.000/5-59

GHANA DIVISION OF AGRICULTURE
SOIL AND LAND-USE SURVEY BRANCH

Soils of Ghana

H. Brammer

P R E F A C E

This work has been prepared for inclusion in the forth-coming Ministry of Food and Agriculture publication 'Agriculture and Land Use in Ghana' as Chapter 6, Soils, and is issued in this present form, without diagrams and map, for the information of the Division's staff and bona fide associates.

Since the issue of the first edition in May 1958, the text has been revised and this second edition has been brought out in a limited number of copies for reference purposes while the book is being printed. Publication, by Oxford University Press on behalf of the Ministry, is expected in 1960.

Chapter 6

SOILS

By H. Brammer, M.A.
Principal Agricultural Officer,
(Soil and Land-Use Surveys)

"The soil comes first. It is the basis, the foundation of farming. Without it nothing; with poor soil, poor farming, poor living; with good soil, good farming and living. An understanding of good farming begins with an understanding of the soil"

Henry L. Ahlgren,
Grass: Yearbook of Agriculture, 1948.
U.S. Department of Agriculture: p. 425.

Introduction

Soil knowledge is fundamental to good agriculture. For the soil is the home of the plant root, and, with the exception of carbon and oxygen which are obtained from the air, it is from or by way of the soil that plants obtain all the materials they require for their growth.

Soil is not one single object. There are many soils. These vary in their ability to supply food and water to plants. It is the object of a soil survey, fundamentally, to recognize soils with different nutrient and moisture properties and to map them separately so that the properties of each soil can be used to their best advantage.

Different crops, too, require different soil conditions if they are to grow satisfactorily. The needs of rice, for example, are quite different from those of groundnuts; and, expressed from a different angle, coconuts will give satisfactory yields from soils on which cocoa would not thrive. Having recognized that different soils exist, therefore, their suitability for different crops must be assessed.

The agricultural value of a soil does not depend only on its intrinsic properties, however. Other factors are involved, such as amount and seasonal distribution of rainfall, ~~technical skill and mental~~ inclinations of the cultivators, crop — and human — pests and diseases, access to markets, etc. But, other things being equal, 'the soil comes first .....'.

What, then, is soil? The term is not easy to define satisfactorily for there are two ways of looking at the question. Physically, soil is the surface part of the earth's crust which has been affected by physical and chemical weathering and the action of various plant and animal organisms. Functionally, soil is that part of the earth's crust which gives physical support to plants and supplies them with food and water. Whichever way it is looked at, soil cannot be separated from plant life. It is not merely broken-up rock or a collection of mineral particles with particular chemical and physical properties. Such materials do not become soil until they are acted upon by plant and animal life. Enriched by plant and animal remains, supporting living plants and inhabited by millions of micro-organisms, all these changing with the seasons, the soil might itself almost be regarded as a living organism.

The factors influencing soil development are complex and by no means fully understood yet, particularly in the tropics. In broad terms, however, any particular soil can be regarded as the outcome of the local climate and vegetation acting on the local surface geology under particular drainage conditions for a particular period of time. This can be summed up in a formula: soil = climate, vegetation, parent material, relief and drainage, and age. A study of the soil, therefore, necessarily involves some understanding of climatology, plant ecology, geology and geomorphology as well as of chemistry.

Inspection of a sufficiently deep soil exposure, as in a freshly-excavated road cutting, borrow-pit or drain, will show that the soil is made up of a number of different layers occurring more or less horizontally one on top of another. These layers — in so far as they are true soil features and not different bands of rock or alluvium — are known as <u>soil horizons.</u> In soils that are alike, the component layers always occur in the same order. This regular succession of soil horizons is known as a <u>soil profile</u> (by analogy with the human profile in which particular features such as eyes, nose, mouth and chin occur in a definite order).

The main differences between soils can be observed in the colour, thickness, texture (size of mineral particles), structure (size and shape of units contained by natural cracks in the soil), consistency (feel) and content of visible chemical deposits (lime, ironstone) of the horizons they contain. There are further differences which can only be discovered by laboratory analysis, such as reaction (acidity or alkalinity), content of particular chemicals known to be useful or harmful to plants and moisture-retaining capacity.

Soils with similar profile features from the ground-surface down to recognizable rock, i.e. soils with a similar number of horizons respectively similar in appearance and composition, form what is known as a soil series. Each series is given a name after the locality in which it is first recognized. This does not imply that the soil only occurs in the vicinity of the locality name given: Kumasi series, for instance, was first identified during the soil survey of the site for the Central Agricultural Station, Kumasi, in 1946, but has subsequently been recognized in several other parts of the forest zone of Ashanti and Southern Ghana. Nor does the name imply that the soil covers the whole of the neighbourhood of the locality named: Kumasi series, although one of the most extensive, is only one of nine soils identified on the Central Agricultural Station, Kumasi, and Kumasi municipality itself is underlain by many other soils besides Kumasi series. The name is given for ease of reference and to ensure that like soils are known by like names wherever they are found.

In Ghana, soil series rarely cover a sufficient area in individual expanses to make it practical to map them on any but very large-scale maps (see Figure 1). It would be impossible — as well as unnecessary — to map soils in this detail over the country as a whole under present circumstances, although soil series maps are prepared for special development projects covering only a few square miles or less. For surveys of larger areas, carried out on a drainage-basin basis, soil series are combined into larger assemblages for mapping purposes. Such assemblages, known as soil associations[1], make use of the fact that, over any particular parent rock, soils occur in a regular pattern according to changes in drainage conditions occurring between hill top and valley bottom.

In the commonest type of soil association in the forest zone, a red[2], well drained soil and a brown, rather

---

[1]This general term is equivalent to soil catena as used originally by Milne in East Africa.

[2]The colour referred to in describing soils as red earths, brown earths, etc., is that of the subsoil. Almost regardless of the subsoil colour, topsoils are generally stained grey or black with organic matter so that the colour of this horizon cannot be used as a differentiating feature. Termite mounds give a useful indication of the colour of the soil since they are generally constructed of subsoil material.

less well drained soil, both developed directly in the parent rock, occur on the summits and middle slopes of the topography; they are succeeded downslope by yellowish, seasonally poorly drained soils developed in colluvial material washed down from the upper slopes, and eventually by grey, poorly drained soils developed in valley-bottom alluvium derived from the same local rock. Such a pattern normally repeats itself up-hill and down-dale so long as the underlying geology remains the same. The whole of such an area can therefore be mapped as a single unit. A person requiring information on a particular piece of land within an association mapped in this manner should be able to identify the soils he is on from the descriptions of the soils and their pattern of distribution given in the report on the survey of the area, if this has been completed. In areas of complicated geology or topography, more complex soil patterns occur, necessitating the use of more inclusive mapping units[3].

On the scale of the map used in this book, it has not been possible to make use even of soil associations as mapping units. The units used show the most widespread soils of the area, usually the upland soils, grouped according to their mode of formation. This allows their comparison with soils occurring in other parts of the world. The terminology used will be explained in a later section.

The soils having been described and mapped, and representative samples analysed, their value can then be assessed. This can best be done by observing the growth and yield of different crops on individual soils both under traditional farming practice and on agricultural stations where various forms of cultivation and manuring are practised. Crops and practices giving the best economic returns can then be recommended for all similar soils. More often, however, such direct extrapolation of results is impossible because of lack of suitable agronomic studies. Resort can then be made to correlation of soils and environmental conditions with those of other parts of the country or the tropics where improved forms of agriculture are known to be practised so that recommendations can be made locally in the light of experience obtained elsewhere with various crops and methods of cultivation. This principle of geographical correlation requires expert knowledge and needs to be applied with caution. It is essential that all environmental factors should be taken into account. It would not be sufficient,

---

[3] These units have been defined in an appendix to the Report on the Department of Soil and Land-Use Survey, 1951-55.

for instance, to recommend groundnut production for certain soils physically resembling others known to support a profitable groundnut industry if climatic or marketing conditions were not closely comparable in the two areas.

There have, none-the-less, been some striking successes achieved by the expert use of this principle, one of the more renowned being the development of the Hevea rubber industry in Malaya where Sir Joseph Hooker recognized that environmental conditions closely resembled those in the homeland of this crop, Brazil. In Ghana, this principle has been employed in recommending the development of certain soils, the Black Clays, on the Accra plains. These soils are uncultivated locally, but similar soils under somewhat similar environmental conditions are known to support successful agriculture in India (the regur) and South Africa (Springbok Flats)[4]. Crops and techniques employed in the latter areas, therefore, indicate those likely to succeed on the Accra plains and there would seem no reason from the technical point of view why these soils should not one day be made productive in this country, too.

Where no instance can be found of similar soils occurring or being utilized elsewhere, less precise recommendations can be made. A study of the physical and nutrient properties of the soils may indicate that conditions lie within the range of those known from experience elsewhere in the country or abroad to be required by particular crops or methods of farming. These can then be tried, but it is wiser that they should first be confirmed by suitable agronomic studies on the soils concerned.

Classification of Ghanaian soils

In the introductory section, soil formation was described as a function of climate, vegetation, parent material, relief and drainage, and age. This formula was made the basis of an interim system of classification for tropical soils worked out by the late C.F. Charter (Brammer, in prep.) This classification is briefly outlined below.

---

[4]Samples of the Indian and South African soils were in fact obtained by the Department of Soil and Land-Use Survey for visual comparison and laboratory analysis to confirm their similarity to the Black Clays of the Accra plains.

At the highest classificatory level — soil order — soils are grouped together according to whichever one, or more usually two, of these factors has (or have) predominently influenced their development, viz:-

I. Climatophytic earths: soil formation primarily determined by climate and vegetation.

II. Topoclimatic earths: soil formation primarily determined by relief (high mountain) and climate.

III. Topohydric earths: soil formation primarily determined by relief and drainage.

IV. Lithochronic earths: soil formation primarily determined by parent material and/or age.

At the next lower classificatory level — soil suborder — different grouping factors are used within each soil order, viz:-

I. Climatophytic earths: These are normally developed, well drained soils. Suborders are differentiated according to whether rainfall penetrates to groundwater or not, viz:

A. Hygropods - soil profile through-leached.

B. Xeropods - soil profile not through-leached.

II. Topoclimatic earths: These are not found in Ghana and not subdivided into suborders at present.

III. Topohydric earths: These are soils with impeded drainage. Five suborders are recognized: four of these are differentiated according to nature of the topographic site with which the poor drainage conditions are associated; the fifth comprises soils in which poor drainage has led to the accumulation of a superficial layer of incompletely decomposed organic matter. Viz:

A. Planopeds - soils with poor drainage due to flat or very gentle topography (e.g. on peneplains, river terraces, etc.).

B. Clinopeds - soils affected by water seeping from upslope and precipitating chemical substances from solution.

C. Depressiopeds - soils developed in poorly drained depressions receiving run-off or seepage waters from adjoining areas.

D. Hydropeds - soils developed under open water in shallow lagoons, rice paddies, etc.

E. Cumulopeds - soils developed in depressions where peat has accumulated.

IV. Lithochronic earths: These are soils with restricted profile development. Suborders are differentiated according to the particular factor retarding development.

A. Lithopeds - profile development retarded by resistant rock or erosion on steep slopes.

B. Regopeds - profile development retarded by the inert nature of loose sandy parent material.

C. Alluviopeds - profile development retarded by constant accretions of fresh alluvium on the surface.

Suborders are subdivided into great soil groups. The latter comprise soils with common profile characteristics developed in response to similar environmental conditions. (Soil series, into which great soil groups can be further subdivided, are differentiated mainly on the nature of the parent material in which individual soils are developed.)

There are large numbers of great soil groups within some suborders, and it is convenient to group some of them together according to certain common characteristics. These groupings are tentatively named great soil group families. The differentiating criterion is usually the reaction of the profile.

I. Climatophytic earths

A. Hygropeds. These are subdivided according to the ability or otherwise of the parent material to supply mineral bases at a sufficient rate to counteract those lost by leaching. Under humid tropical conditions the soils produced are:

1. Latosols - soils over highly weathered parent materials in which the clay fraction consists mainly of kaolinite and iron and aluminium sesquioxides.

2. Basisols - soils over incompletely weathered parent materials relatively rich in bases in which, apparently, montmorillonitic clay is present in some proportion together with kaolinite and iron and aluminium sesquioxides.

B. Xeropeds. These soils are doubtfully represented in Ghana and are not further discussed below.

II. Topoclimatic earths

These are not represented in Ghana and are not further discussed below.

III. Topohydric earths

Suborders are subdivided according to the nature and reaction of the groundwater influencing the soils. Very acid, acid, neutral, calcium and sodium group families are generally recognizable. The suffix 'sol' is normally substituted for 'ped' used in the suborder name. In the case of Depressiopeds, the very acid, acid and neutral group families are together termed Gleisols, and the calcium and sodium group families are termed Vleisols.

IV. Lithochronic earths

Suborders are not further subdivided.

Within each group family, great soil groups are differentiated, if at all, according to whether they are developed under forest or savanna, their colour and differences in the trend of reaction changes in the profile. Differences in colour and reaction trends are used as criteria because of their convenience; they are, however, manifestations of more fundamental differences in soil properties between different groups.

Great soil groups so far known to occur in Ghana are listed in the accompanying table. They are too numerous to be discussed here individually, but the more important are described in the next section.

TABLE 1 PROVISIONAL CLASSIFICATION OF SOILS SO FAR DISCOVERED IN GHANA

ORDER	SUB-ORDER	SOIL GROUP FAMILY	GREAT SOIL GROUP	GREAT SOIL SUB-GROUP
CLIMATOPHYTIC EARTHS	HYGROPEDS	Latosols	Forest Ochrosol	Red Forest Ochrosol
				Yellow Forest Ochrosol
			Savannah Ochrosol	Red Savannah Ochrosol
				Yellow Savannah Ochrosol
			Forest Rubrisol	Red Forest Oxysol
				Yellow Forest Oxysol
		?Basisol		
	XEROPEDS		Forest Rubrisol	Red Forest Rubrisol
				Yellow Forest Rubrisol
			Savannah Rubrisol	Red Savannah Rubrisol
				Yellow Savannah Rubrisol
			Forest Brunosol	
			Savannah Brunosol	
			(Reddish Prairie?)	
TOPOHYSDRIC EARTHS	PLANOPEDS	Very Acid Planosol?	Groundwater Podsol	
		Acid Panosol?	Groundwater Laterite	
		Calcium Planosol	Tropical Black Earth	
			Tropical Brown Earth	
		Sodium Planosol?	(Tropical Grey Earth)	
		Very Acid Gleisol	(Savannah Grey Very Acid Gleisol)	
	DEPRESSIOPEDS	Acid Gleisol	(Savannah Black Acid Gleisol)	
			(Savannah Brown Acid Gleisol)	
			(Forest Grey Acid Gleisol)	
			(Savannah Grey Acid Gleisol)	
		Neutral Gleisol	(Forest Black Neutral Gleisol)	
			(Forest Brown Neutral Gleisol)	
			(Forest Grey Neutral Gleisol)	
			(Savannah Grey Neutral Gleisol)	
		Calcium Vleisol	(Black Vleisol)	
			(Brown Vleisol)	
			(Grey Vleisol)	
		Sodium Vleisol	Solonetz?	
			Solonchak	
	CUMULOPEDS	Cumulosol	Very Acid Bog?	
			Acid Bog	
			Saline Bog?	
	HYROPEDS	Hydrosol	Neutral Hydrosol?	
			Saline Hydrosol	
LITHOCHROMIC EARTHS	LITHOPEDS	Basimorphic Lithosol	(Black Basimorphic Lithosol)	
			(Brown Basimorphic Lithosol)	(Yellow Basimorphic Lithosol)
			(Red Basimorphic Lithosol)	
		Non-Basimorphic Lithosol	(Non- Basimorphic Lithosol)	
	REGOPEDS	Regosol	(Dune-sand Regosol – with calcareous pan – without calcareous pan)	
			(Other Regosols)	
	ALLUVIOPEDS	Alluviosol	(Black, Brown and Grey Alluviosols)	

N.B. (I) The use of brackets around a term indicates that the nomenclature is still provisional

(II) ? before a term indicates that there is some doubt as to the exact place in the soil group or group family in the classification

(III) ? after a term indicates that there is some doubt as to the classification of the soils contained within the group indicated or of the soil in the group family indicated

Description of the major soils of Ghana

The soil map in this book shows the distribution of the more extensive great soil groups occurring in Ghana. On the scale used, much generalization has been necessary and the units used merely indicate the more important, usually upland, soil group occurring. The whole of the coastal savanna zone, rather over half the forest zone but only a small fraction of the interior savanna zone have been surveyed at the time of compilation of this map. In areas not yet surveyed, boundaries have had to be drawn in by extrapolation from known areas, usually using geological boundaries and isohyets as a guide. Soil changes due to climatic factors take place over a broad zone, and boundaries drawn in such cases are necessarily ill-defined.

There are considerable differences between the soils of the forest, interior savanna and coastal savanna zones, and the soils of these zones will be treated separately below. Within each zone, the units described will be those shown on the soil map.

Forest zone

The soils of this zone are at once distinguishable from those of the other zones by the greater accumulation of organic matter in the surface horizon resulting from the more abundant leaf-fall under forest vegetation and the slower rate at which humus is oxidized in the forest environment. The soils are developed over a variety of crystalline, metamorphic and sedimentary rocks under an annual rainfall of c.35-80+ inches falling in two rainy seasons.

The major soils are Climatophytic Earths, Latosols, subdivided into Ochrosols and Oxysols. Lesser amounts of Lithosols, Regosols and Rubrisols occur, and there are topographically associated Gleisols. Ochrosols, Oxysols, Lithosols and Regosols have been mapped separately. Fully developed Rubrisols are not usually extensively developed, but it has been possible to show some areas where soils transitional between Ochrosols and Rubrisols occur. Similarly, a belt of soils intermediate between Ochrosols and Oxysols has been mapped. Gleisols are not separately mapped, but are discussed briefly in the text below where appropriate.

Forest Ochrosols

These are red, brown and yellow-brown, relatively well drained soils developed in the weathering products of intermediate or moderately acidic rocks, in peneplain drifts covering the intermediate erosion surface (cf. Chapter 5) and in terrace alluvia on upland portions of gently undulating to strongly rolling topography in that part of the forest zone receiving approximately 35-65 inches' annual rainfall. They are the most extensive and most important soils of the forest zone.

Generally, the colour of the soils (below the humous topsoil) changes from red or reddish brown on the summits and upper slopes, through orange-brown or brown on the middle slopes to yellow-brown on the lower slopes; associated valley bottom Gleisols vary from yellow to grey or white. These colour changes reflect changes in the degree of hydration of the iron present in the profile consequent upon changes in internal drainage conditions of different parts of the topography. On the well drained upper slopes, the iron is well oxidized and the soils are reddish in colour. As drainage conditions deteriorate downslope, the iron becomes increasingly hydrated and the soils increasingly yellow. In the ill-drained valley bottom, reducing conditions obtain throughout much of the year and iron is either washed out of the soils or is present in the ferrous form giving a bluish grey colour to the soil. Where the soils are subject to alternate waterlogging and drying out, the iron is subject to alternate reduction and oxidation resulting in the development of mottles (patches of yellow, orange or red in an otherwise grey soil) or rusty stains along root-channels.

Texture varies according to the nature of the parent material, soils derived from sandstone, granites and gneisses being more sandy than those derived from shales, phyllites and schists. Soils associated with peneplain remnants may contain massive ironpan or abundant ironstone concretions in the subsoil and those over rocks containing numerous quartz veins are gravelly or stony to varying degrees. The clay mineral is kaolinitic; in few Ghanaian soils is the clay fraction likely to consist predominantly of iron or aluminium hydroxides.

The texture of the parent material varies not only with the underlying rock but also with the topographical site. This can only be understood by reference to the geomorphology of this part of the country. An ideal topographical association (over lower Birrimian phyllite) is illustrated in section and in map form in Figure 1. The names given below relate to the soil series shown on this and the accompanying Figure 2.

Drift soils (Akumadan) occupy remnants of the intermediate erosion surface on the almost flat hilltop; sheet ironpan (Wenchi) and brown concretionary soils over ironpan (Nsuta) may occur locally on these remnants, but they more typically occur as a collar around the edge; on the slightly concave valley slopes below the ironpan outcrop occur drift (Dominase) and sedentary soils (Bekwai, Nzima) containing in their upper parts varying proportions of material derived from the break-up of the ironpan collar; colluvial fine earth, probably accumulated in slightly earlier geomorphological phases than the present, mantles the lower slopes or occupies drainage grooves on the middle slopes (Kokofu); alluvial silty clays occupy the valley bottom (Oda). Such sections are common in the northern part of the forest zone in Ashanti. Further south, where the intermediate erosion surface has been more dissected, sedentary soils predominate and all that remain of the former peneplain mantle are accumulations of ironstone concretions, sometimes with relict ironpan boulders, in the summit soils (Dominaso). Upper slopes are then convex in section.

Over biotite granite (Figure 3), peneplain drift soils (Boamang) again sometimes cap the ridges. The major soils are sedentary, red, gritty clays (Kumasi) with brown gritty clays (Asuansi) occurring downslope. Textural differentiation takes place within the yellow-brown lower-slope colluvium (Akroso, Nta), the clay being washed through leaving the coarser sand behind; grey alluvial sands (Ofin) and clays (Densu) occupy the bottoms; yellow, loose, levee sands (Chichiwere) are developed along the larger streams and rivers.

Despite differences of parent material over different parent rocks and on different topographical sites, mature upland soils are pedologically similar. Organic matter from the forest vegetation has a blanketing effect, and most series have porous, loamy topsoils about 8 inches thick, dark grey-brown with organic matter and near-neutral in reaction in the surface 2-3 inches, becoming paler-coloured, less humous and slightly to moderately acid in reaction in the lower part. Lower horizons generally have higher clay contents than the topsoil; regardless of colour, texture and drainage, they are moderately to highly acid in reaction and have low plant-nutrient contents. In upland soils, a thick layer of whitish and red (or orange) mottled, loamy, thoroughly decomposed rock usually overlies the zone of rock-weathering: the latter zone may often be 150-200 feet below the ground surface, but is less deep under middle- and lower-slope soils and fresh rock frequently outcrops in stream beds along the valley bottoms.

Typical profiles of mature upland soils are described below, first for a sedentary soil (i.e. developed directly in the weathered parent rock) and subsequently for a drift soil (i.e. developed in transported material, either peneplain mantle, piedmont colluvium or local lower-slope colluvium). It should be noted that even in the sedentary profile, the first three layers are, strictly speaking, of a drift nature since they consist of gravel derived from the break-down of quartz veins and fine earth brought to the surface by faunal activity and subject to local slope-wash.

FOREST OCHROSOL

Sedentary Profile

On the surface - A thin layer of undecomposed leaf litter underlain by a fraction of an inch of decomposed leaf litter penetrated by feeding roots of trees.

Topsoil I: 0 to 3 ins. - Horizon of maximum humus accumulation; dark grey-brown, sandy or silty loam; crumbly and porous; neutral to slightly acid reaction; main zone of plant feeding roots.

Topsoil II: 3 to 8 ins. - Brown sandy (or silty) loam to light clay; less humous and less crumbly than Topsoil I; slightly to moderately acid reaction; fewer roots than in Topsoil I.

Subsoil I: 8 to 15-20 ins. - Reddish brown (brown or yellow-brown on middle- and lower-slope sites) sandy (or silty) light clay or clay; zone of maximum accumulation of quartz stones and gravel and ironstone concretions where these occur; no visible humus; firm; structureless; slightly porous; moderately to very acid reaction; few roots.

Subsoil II: 15-20 to 30-36 ins. - Reddish brown (brown or yellow-brown on middle and lower slopes), sandy clay or clay; firm; structureless; slightly porous; very acid to highly acid reaction; occasional ironstone concretions in some soils; quartz veins broken but *in situ* where present; few roots.

~~Subsoil III:~~ (Transitional to next horizon) 30-36 to 45-60 ins. - Red, slightly mottled pale yellow (brown with yellow and grey on lower sites), sandy or silty loam to light clay; firm, indurating slightly on exposure; structureless; slightly porous; very acid to highly acid reaction; quartz veins *in situ* where present; rare or no roots.

Weathered substratum: Below 45-60 ins. - Red (or brown) mottled pale yellow, sandy or silty loam; firm *in situ* but friable on exposure; very acid reaction; recognizable as weathered material with depth.

Unweathered rock: May occasionally occur within 6 feet of the surface, but is generally deeper than 10 feet and in many cases apparently does not occur within 50-200 feet of the surface.

N.B. In immature profiles, the subsoil is relatively thin and grades quickly into mottled decomposed rock.

FOREST OCHROSOL

Drift profile

On the surface: A thin layer of undecomposed leaf litter underlain by a fraction of an inch of decomposed leaf litter.

T.S. I: 0 to 3 ins. - Dark grey-brown sandy or silty loam to light clay; humous; crumbly and porous; neutral to slightly acid reaction.

T.S. II: 3 to 9 ins. - Brown sandy or silty light clay; slightly humous; rather friable and porous; slightly to moderately acid reaction.

S.S.: 9 to 18-120+ ins. - Red or reddish brown (occasionally brown or yellow-brown), sandy or silty clay; firm, structureless and porous, sometimes becoming hard on exposure; very acid or highly acid reaction; grades into next horizon.

W.S.S.: 18-120 to 30-140+ ins. - Red and pale yellow mottled (occasionally grey with orange or yellow), sandy or silty clay; very firm and porous, becoming indurated on exposure, or forming vesicular ironpan in shallow profiles; stone-line or gravel layer included at base; very acid or highly acid reaction. (This layer may be thin or absent in peneplain drift profiles). Abrupt change to next horizon.

Underlying rock: Below 30-120+ ins. - This is not necessarily related to the overlying drift although, in fact, sandy clay drifts are usually associated with sandstones or granites and silty clay drifts with phyllites and schists. The rock may be fresh, but is usually weathered, frequently forming a red and yellow mottled, very acid, indurated loam or clay which hardens into vesicular ironpan in shallow profiles.

From the agricultural point of view, Ochrosols are easily tilled and offer freedom of root development, especially in the case of deep drift soils. They are well drained where red, but rather more slowly draining in the subsoil where brown or yellow-brown. When cleared for agriculture they become rather susceptible to drought, especially for shallow-rooted crops and where sandy or gravelly. Available plant nutrients are concentrated in the humous topsoil; lower horizons can supply or retain little until the zone of rock weathering is reached, and this, as has been stated above, may be at such a depth as to be beyond the reach of plant roots. Lower-slope soils where sandy have a lower moisture- and nutrient-holding capacity, but colluvial silty clays associated with gravelly upland soils over Birrimian phyllites may be better in these respects than their upland associates. Associated bottom clays have a better nutrient-holding capacity but need water-control measures to be effected for really satisfactory utilization; they are, however, usually only patchy in occurrence. Sandy bottom soils, extensive in granite areas, are almost barren of nutrients below the humous topsoil and suffer from alternate waterlogging and drought. The most prepossessing depression soils are certain yellowish silty clays developed along some of the larger streams and rivers, particularly in Birrimian areas. These have a fair nutrient status and generally good moisture relationships; they are subject to flooding only for short periods.

Analytical data for two Forest Ochrosol profiles are given in Tables 1a and 2a below and in Tables 1b and 2b at the end of the chapter. Tables 1a and 1b show data for a typical sedentary upland profile over medium-grained biotite granite, representative of soils fairly widely developed around Kumasi and elsewhere in western Ashanti. Tables 2a and 2b show data for a typical sedentary upland profile over Lower Birrimian phyllite; soils similar to this occur over approximately half the Forest Ochrosol belt. The data in these tables show the marked concentration of nutrients in the topsoil typical of the Forest Ochrosols, and make it clear that the greater part of these nutrients is associated with the organic matter. They also indicate the strongly weathered and leached nature of the subsoil and weathered substratum: the granite profile was examined to a depth of 55 feet and at this depth was still in the zone of thoroughly weathered rock, although the original rock structure was clearly apparent far above this depth.

The large amount of coarse material present in the subsoil of the phyllite profile (cf. Table 2b) represents stones and gravel derived from the breakdown of quartz veins which commonly intrude Birrimian rocks. The presence of such large amounts of stones and gravel in soils render them liable to drought during prolonged dry periods. It also considerably reduces the bulk of true soil available for plant roots to utilize: part of the large difference in actual nutrient content between the subsoils of the two profiles for which analytical data are quoted (cf. Tables 1a and 2a) is attributable to the fact that the subsoil of the phyllite profile contains only one-third to one-half as much 'fine earth' as does that of the granite profile (cf. Tables 1b and 2b).

Under natural conditions, topsoils throughout the association contain adequate amounts of plant nutrients. When forest is cleared for cultivation, the nutrient status

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phos- phorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 4	1.2	3032	505	66	548	68,893	2968	346	.619	.170	.010	.057
2. 5	1.6	910	150	30	145	18,802	1125	197	.430	.117	.010	.035
3. 9	1.6	792	306	43	71	15,051	960	327	.228	.153	.009	.011
4. 14	1.6	1175	486	51	73	21,359	1903	585	.193	.132	.006	.006
5. (4)	1.6	233	109	14	10	5,009	355	172	.129	.100	.006	.003
Total for 3 feet		6142	1556	204	847	136,425	7311	1627				

Table 1a. Kumasi series, a representative Forest Ochrosol: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 1b at the end of this chapter.

These data take into account dry density (assumed), the amount of oven-dry fine earth (<2 mm) and the amount of nutrients as expressed in the analytical tables quoted at the end of this chapter. No actual dry density determinations have been made, but a density of 1.2 is assumed for the surface horizon of forest soils and of 1.3 for that of most savanna soils; that of lower horizons is assumed as 1.6 in both forest and savanna soils except where more than 3 per cent organic matter is present, when a value of 1.5 is assumed.

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phos-phorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 2	1.2	2534	510	53	62	55,976	2418	296	.550	.182	.008	.007
2. 9	1.6	982	100	41	117	66,021	4111	1272	.102	.078	.003	.006
3. 10	1.6	149	54	8	40	17,980	1255	644	.038	.023	.002	.005
4. 12	1.6	124	39	7	37	9,232	816	606	.042	.022	.002	.006
5. (3)	1.6	54	34	7	9	4,443	578	331	.032	.033	.003	.003
Total for 3 feet		3843	737	116	265	153,652	9178	3149				

Table 2a. Bekwai series, a representative Forest Ochrosol: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 2b.

is drastically affected. The organic matter is quickly oxidized and the nutrients it holds are released either to be absorbed by a growing crop and weeds, to be 'fixed' by the soil mineral matter and rendered unavailable, or to be leached down and out of the profile. As the organic matter diminishes too, the topsoil loses its crumb structure. It then dries hard if exposed to the sun and is easily puddled when wet, leading to surface run-off and erosion if the soils are not adequately protected by a cover of foliage or a mulch.

The maintenance of the topsoil organic matter is of prime importance in cultivating these soils. This aim is largely achieved in traditional arable farming practice: forest is incompletely cleared so that woody vegetation speedily regenerates after cropping; mixed cropping is practised so that considerable protection is afforded to the soil throughout the cropping period; one of the long-term crops — cassava or plantains — serves to nurse the regenerating natural vegetation after the short-term crops have been reaped; the soil is little disturbed by tillage; crops are taken only for a year or two and then the natural vegetation allowed to regenerate; forest fallows of five to ten plus years intervene before cropping is again attempted, and serve to concentrate sparse or difficultly available nutrients drawn from lower horizons into the regenerated humous topsoil.

Satisfactory methods of maintaining continuous arable cropping have yet to be devised for these soils. At the best, a modified form of forest fallowing is required, frequent green manure crops being required in the rotation in place of the natural regeneration. Alternatively, mulching might serve to protect the soil against erosion and maintain the organic matter content, but this measure is generally considered too expensive to be practicable at present. Trash farming is another possible method needing investigation.

These soils are, in fact, and perhaps not unnaturally, best suited to tree crops. The rainfall totals under which the soils are developed are not adequate for the commercial production of rubber, oil palm or bananas for export, although the two latter crops, together with plantains, yield adequately to supply local needs. When newly cleared from forest, upland soils are suitable for cocoa or coffee, and kola grows satisfactorily on some of the more droughty, open-textured soils over granite. Apart from losses due to diseases and pests, cocoa appears to survive on the mature soils only so long as an adequate organic matter content remains in the topsoil. On silty or gravelly soils, especially where the original forest cover is totally cleared, cocoa often fails to become established or dies out before coming into full bearing, apparently largely due to drought. Even with adequate shade provided, yields decline greatly in most cases after about twenty to thirty years from planting. The best crops on Ochrosols are found on relatively immature soils over biotite or hornblende schists and granites where roots can reach the zone of rock-weathering within about 5-10 feet of the surface; good yields are maintained up to about forty years on such soils. The crop persists, too, although not always highly productively, on some lower-slope soils and mist-zone, scarp-summit soils, apparently because in these moister sites the trees can feed throughout the year and are less liable to suffer from the dry-season drought affecting other soils.

There are few data on manurial requirements on these soils as yet. This is particularly the case with cocoa. Nutrient supplies are ample in newly cleared soils, but the situation deteriorates rapidly during the first few months after clearing, especially under arable crops. If agriculture is to be intensified on these soils, fertilizers will undoubtedly require to be used. Nitrogen and phosphorus are likely to be the major requirements, but calcium, magnesium and potassium deficiencies may perhaps show up after a number of years' intensive cropping. Topsoils are likely to become more acid with cultivation, especially if sulphate of ammonia is used as a nitrogenous fertilizer. Liming to correct this condition needs to be practised with caution since it may interfere with the uptake of other essential nutrients by plant roots. Because of the poor retentive properties of the soils, unless the organic matter status is maintained at a high level, and because of the high rainfall intensities liable to be experienced, split applications of the more soluble fertilizers are likely to give the best results.

The role of organic matter in these soils is particularly important in relation to their phosphorus status. Considerable amounts of this vital element may occur in the soils, but only a small fraction of the total is available to plants at any one time and crops depend for their phosphorus nutrition mainly on the supplies released by the mineralization of the topsoil organic matter. Fallow vegetation — deep rooting, at work for a number of years and perhaps including species able to obtain phosphorus from difficultly soluble compounds — extracts some of its requirements from the subsoil, and it is probably one of the main functions of forest fallows to accumulate phosphorus in the topsoil in readily mineralizable organic forms.

Forest Oxysols

These soils are generally similar in outward appearance to Forest Ochrosols. However, they are generally appreciably paler in colour, the upland soils normally being orange-brown to yellow-brown rather than reddish brown as in the Ochrosols. The humus-stained surface layer is generally thinner and the weathered substratum thicker than in the Ochrosols (cf. Boi series in Figure 4 with Bekwai series in Figure 1).

Oxysols are generally developed in similar parent materials and on similar topography to the Ochrosols, but in addition they are developed over unconsolidated Tertiary deposits in the extreme south-west and in peneplain drifts mantling the high-level erosion surface at c.2,000 feet. They are generally developed under an annual rainfall exceeding 70 inches and thus occur mainly in the south-west corner of the country. They also occur under rather lower rainfall conditions (c.60-70 inches) over highly siliceous rocks (notably Tarkwaian quartzites), on the high-level peneplain surface and, more locally, over certain pyritiferous phyllites in the Lower Birrimian formation, especially in the Birim river basin.

With such large amounts of rainfall flushing the profile, or because of the poor retentive properties of the parent material, the soils are strongly leached. Reaction trends down the profile are very different from those found in the Ochrosols, the surface horizon being the most acid and lower horizons gradually becoming rather less acid: pH values increase from around 4.0-5.0 at the surface to around 4.5-5.3 at depths of 3-6 feet.

Organic matter appears to be generally rather lower in amount than in the Ochrosols although it is rather more deeply distributed down the profile. Visible humus staining, however, may be confined to the surface 1-2 inches. Preliminary analytical studies suggest that the organic matter may have a much lower capacity to retain nutrients than that in Ochrosols.

Bauxite, or bauxitic ironpan, caps the high level peneplain surface and the clay fraction in these soils may be expected to contain a high proportion of sesquioxides; but elsewhere the clay appears to be kaolinitic.

Soils in a typical topographical association are illustrated in Figure 4. Analytical data for a typical

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phos-phorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 3	1.3	192	79	7	70	34,977	1546	143	.093	.063	.002	.017
2. 4	1.6	82	73	4	37	19,147	1099	167	.041	.060	.001	.010
3. 9	1.6	103	70	5	13	18,965	1154	231	.040	.045	.001	.003
4. 11	1.6	189	137	10	57	32,296	2141	508	.031	.037	.001	.005
5. (9)	1.6	157	114	< 4	49	22,550	1597	351	.030	.035	< .001	.005
Total for 3 feet		723	473	26	226	127,935	7537	1400				

Table 3a. Boi series, a representative Forest Oxysol: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 3b.

Oxysol are given in Tables 3a and 3b. These should be compared with those given in Tables 2a and 2b for a Forest Ochrosol, both profiles illustrated being developed over Lower Birrimian phyllite but under different climatic conditions.

With the possible exception of the soils on gentle topography over the Tertiary deposits in the extreme south-west, Oxysols are not suitable, without elaborate precautions, for exposure to arable agriculture because of their strong susceptibility to leaching and erosion under the rainfall conditions obtaining. It might be conjectured that even traditional forest fallowing might be ineffective as a means of maintaining productivity on these soils since it is more difficult to build up nutrient supplies in the topsoil against the strong leaching action of the heavy rainfall. Too-frequent cultivation may result, even with the high rainfall totals experienced, in the replacement of the forest by savanna, with grass species such as Chasmopodium caudatum (Hack.) Stapf or Imperata cylindrica (L.) Beauv. var. africana (Anders.) C.E. Hubbard (spear grass or lalang) dominant, as has happened in parts of Sierra Leone (Waldock et al., 1951).

These soils are pre-eminently suited to such tree crops as rubber and oil palm. This is not so much because of any special properties the soils may possess, but because of the high rainfall conditions under which they normally occur. The high rainfall would also suit bananas, but in general the topography is too broken to suit plantation production and none of the soils is sufficiently fertile to permit continuous production without the use of fertilizers, particularly potash, on a large scale. The deep Tertiary deposits are suitable for coconuts and oil palm but may be too free-draining for rubber. Cocoa does not thrive on such acid soils and is largely confined in such areas to river levees[5]. Rice is a suitable crop for the valley bottoms, but flood control is really required for an increased level of production.

There is little experience with fertilizers on these soils as yet. In improved agriculture, annual crops would be likely to require a wide range of major and minor nutrients, however, particularly nitrogen and phosphorus, and perhaps potash and magnesium. On similarly acid soils in Nigeria and the Belgian Congo, oil palms have responded to potash and sometimes magnesium applications (Haines & Benzian, 1956; Bull & Chapas, 1956). Similar responses may be expected on coconuts on the Tertiary deposits. Magnesium applications

---

[5]These loamy levee soils are, in fact, as acid as the upland soils, indicating that acidity as such is not the determining factor. Preliminary investigations indicate some correlation between the distribution of cocoa and soils with substantial amounts of exchangeable manganese.

have given striking responses with cocoa on acid soils in the Belgian Congo. Such requirements locally can only properly be determined by controlled agronomic studies.

Forest Ochrosol - Oxysol intergrades

Since the different properties of the Ochrosols and Oxysols are primarily attributable to the different rainfall totals the soils receive, the boundary between the groups is not sharp and there is a broad transitional belt between the major areas where the two soils are typically developed. Intergrade soils are also developed over siliceous Tarkwaian rocks under rainfall conditions which would normally give rise to Ochrosols and form a broad belt through the centre of the forest zone. They also occur under very humid conditions on the Atewa range near Kibi and on the higher parts of the Togo ranges.

The intergrade soils have no intrinsic properties of their own, although upland Tarkwaian soils are typically only pale brown or yellow-brown in colour, not reddish brown. The distinctive feature of the soils is taken to be the reaction profile: topsoil pH values lie below 5.5 (usually 5.0-5.4) and lower horizons have similar or slightly lower pH values 4.8-5.3). Other properties are intermediate between the two major groups (see Table 4a).

Rainfall totals of 60-70 inches per annum are rather lower than those considered desirable in other countries for commercial rubber, oil palm and banana production, although production of the two latter crops, together with plantains, is likely to be satisfactory to meet local requirements. The soils are too acid to support satisfactory *cocoa* under present conditions, although the situation may one day be changed if suitable fertilizer techniques can be worked out. Coffee is tolerant of such soil conditions but this crop would also need manuring to obtain sustained satisfactory yields.

Fertilizers would need to be used to increase arable crop production, too. Nitrogen and phosphorus would be the major requirement, and responses might eventually be expected to applications of potash and perhaps magnesian limestone. Arable cropping needs to be practised with caution because of the danger of inducing accelerated soil erosion. The aim should be to keep the organic matter content at as high a level as possible and to protect the soil surface against the impact of the heavy rainfall.

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases: Calcium	Magnesium	Manganese	Potassium	Organic matter	Total Nitrogen	Total phosphorus	'Relative availability' of bases (i.e. fraction of total soil capacity): Calcium	Magnesium	Manganese	Potassium
1. 3	1.2	1782	305	42	212	82,446	4210	342	.391	.110	.006	.024
2. 2	1.5	240	52	14	45	19,026	1172	153	.180	.064	.008	.017
3. 10	1.6	321	54	5	45	9,850	600	135	.276	.074	.004	.020
4. 9	1.6	279	37	1	30	6,238	465	122	.214	.047	.001	.012
5. 9	1.6	450	109	4	70	16,865	1343	387	.113	.045	.001	.009
6. (3)	1.6	123	47	2	16	4,917	511	153	.076	.049	.001	.005
Total for 3 feet		3195	604	68	418	139,342	8301	1292				

Table 4a. Nzima-Boi series, a representative Forest Ochrosol-Oxysol intergrade: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 4b.

Forest Rubrisol - Ochrosol Intergrades

Well developed Forest Rubrisols consist of dark red, firm or plastic, nutty to blocky clays developed over basic rocks, usually under rainfalls less than 60-70 inches per annum. The clay mineral appears likely to be at least partially montmorillonitic, and the profile contains large amounts of bases throughout. Such soils are — unfortunately — not extensive in Ghana, but occur over small basic dykes (usually dolerite).

There are, however, some expanses of soils intermediate between true Rubrisols and the Ochrosols, and these have been mapped separately. Such soils are developed over hornblende and biotite granodiorites near Tafo, in the vicinity of small epidiorite and dolerite intrusions occurring locally throughout the forest zone and in piedmont drifts around Bosumkese hill and certain other basic greenstone inselbergs and outcrops in western Ashanti. Certain of these soils, although containing normal amounts of organic matter, are red to the surface; some, too, appear to contain appreciable amounts of manganese dioxide, although again this is not always visible in the profile. Structure is generally more evident and more stable than in the Ochrosols; topsoils are crumbly to nutty, and lower layers slightly blocky or cloddy, and plastic when wet. Except in the case of piedmont drifts, recognizable weathered rock is usually visible within 3-5 feet of the surface, and the profile may contain unweathered crystals of hornblende, etc., scattered throughout. Although the clay mineral present is presumably predominantly kaolinitic, it appears likely that montmorillonitic clay is present in small proportions also. Typical profiles are shown in Figure 5. Analytical data are given in Tables 5a and 5b.

The base supply from the weathering rock is sufficient to prevent the profiles from becoming strongly leached: topsoils have reaction values of pH 7.0-8.0 and lower layers pH 5.5-6.5, with values rising again in the weathering rock. Under forest the soils are well provided with plant nutrients; the effect of the depletion of the organic matter under cultivation is less serious than in the Ochrosols since the mineral matter has a greater ability to supply and retain nutrients and the topsoils have a more stable structure. Nitrogen, phosphorus and in some cases potash, may need to be added under improved arable cropping and for tree crops, but actual requirements can only be determined by controlled agronomic trials.

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phos-phorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 1.5	1.2	2728	390	127	81	38,987	1983	220	.757	.165	.026	.012
2. 6.5	1.6	2476	313	102	96	29,647	1997	702	.580	.121	.017	.012
3. 6	1.6	252	52	18	26	2,260	186	182	.325	.110	.017	.017
4. 6	1.6	308	66	19	31	1,871	322	165	.318	.115	.014	.016
5. 16	1.6	2262	941	41	212	13,551	1867	1187	.277	.190	.004	.013
Total for 3 feet		8026	1762	307	446	86,316	6355	2456				

Table 5a. Wacri series, a representative Forest Rubrisol-Ochrosol intergrade: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 5b.

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phosphorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 1.5	1.2	2728	390	127	81	38,987	1983	220	.757	.165	.026	.012
2. 6.5	1.6	2476	313	102	96	29,647	1997	702	.580	.121	.017	.012
3. 6	1.6	252	52	18	26	2,260	186	182	.325	.110	.017	.017
4. 6	1.6	308	66	19	31	1,871	322	165	.318	.115	.014	.016
5. 16	1.6	2262	941	41	212	13,551	1867	1187	.277	.190	~~.004~~	.013
Total for 3 feet		8026	1762	307	446	86,316	6355	2456				

Table 5a. Wacri series, a representative Forest Rubrisol-Ochrosol intergrade: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 5b.

These are the most valuable soils in the forest zone. They are better provided with nutrients, have a better moisture-retaining capacity and are more resistant to erosion than the much more widespread Ochrosols. They are almost everywhere under cocoa at present, and, except where affected by swollen shoot disease, yields, appear to be maintained at a high level instead of declining after a number of years as happens on most Ochrosols. It is possible, in fact, that, properly managed, the small area these soils cover could by itself produce about half of the total quantity of cocoa produced from the whole forest zone at present.

Forest Lithosols

These are very shallow, brashy soils developed over hard rock, usually on steep slopes. Because of the resistant nature of the rock or the steep slope, there is little accumulation of weathered material and the profile consists only of a shallow, dark-coloured, humous topsoil overlying little-weathered rock. Such soils are most extensive over Togo quartzites on the Akwapim and Togo ranges. They also occur on the steep Voltaian sandstone escarpment running through the forest zone from Koforidua towards Wenchi and over Tarkwaian quartzites, but have not been mapped separately in these cases. Shallow soils developed over sheet ironpan capping peneplain remnants are included in this category. Such soils are droughty and poorly provided with nutrients, and are best left under forest.

Certain Lithosols[6] developed over basic igneous rocks on the steep flanks of some Upper Birrimian ranges (perhaps better regarded as immature Forest Rubrisols and Brunosols) are much more fertile, and can be used for cocoa production. The slopes of many of these ranges, however, are covered with deep acid drifts washed down from eroding Oxysols on the bauxitic summit-cappings. These steep slopes should not be cleared for arable crop production lest erosion proceed even more rapidly than under natural conditions.

Typical profiles are illustrated in Figure 6.

Forest Regosols[7]

A narrow band of Regosols bordering the coast in the extreme south-west has been shown on the map (in a strip of conventional width) because of its importance for coconut production. The soils here comprise deep, brown sands, slightly humus-stained near the surface, developed in raised beach deposits standing some 5-10 feet above the present beach between

---

[6] Perhaps these would better be regarded as immature Forest Rubrisols and Forest Brunosols.

[7] Further consideration indicates that these soils are, in fact, very 'dilute' Oxysols. Because of their loose sandy nature, however, they would perhaps better be regarded as Regosol - Oxysol intergrades.

approximately Axim and the western frontier and varying in width from a few yards to 4 miles (cf. Fredericksburg series in Figure 7). The soils are highly acid in reaction and almost barren of nutrients. Their great asset lies in their favourable moisture relationships since they receive 80+ inches' well distributed, annual rainfall and permit ample root proliferation. Occasionally, in rather flat sites, the soils develop a weak organic pan at a depth of about 2 feet (Princes). The original coastal scrub and forest cover has now largely been cleared to make way for coconut plantations. On such soils, these palms will undoubtedly require manuring to give good yields, but the actual fertilizers required and details of application are not yet accurately known; preliminary results from Division of Agriculture trials at Atuabo indicate striking responses to nitrogen, however, as well as to phosphorus and potash when used in combination with nitrogen (Gordon, 1956). Applications by way of organic matter may be desirable since chemical fertilizers added directly to these free-draining sands may be leached out of the profile too quickly under the rainfall conditions obtaining.

On the shoreward side, the soils described above grade into a narrow band of contemporary dune sands which give rise to pale yellow, incoherent sands containing shell fragments (Krisin series). On the inland side, the soils sometimes grade directly into yellow-brown Oxysols developed in Tertiary sands; but where old, infilled lagoons occur (as behind Eikwe), they pass into Groundwater Podsols (Atuabo series). The latter consist of 1-3 feet of pale grey or white incoherent sand, humus-stained for a few inches at the surface, overlying a brown, compact, organic pan 1-2 feet thick which grades down into pale-coloured incoherent sand again. These soils are highly acid and almost totally barren of nutrients. The organic pan impedes drainage and root penetration and many of the soils lie waterlogged or flooded throughout much of the year. On the old lagoon flats, they occur under short sedges and grasses with a few clumps of trees and shrubs. In perennially waterlogged sites, black, highly acid, peaty clays occur (Mpataba series). These savanna flats, covering some 4 square miles, have suggested themselves to some observers as potential rice lands. The soils are highly infertile, however, and they are unlikely to support more than poor rough-grazing for some time to come.

Analytical data for a representative Groundwater Podsol are given in Table 13, p.6/75.

Interior savanna zone

Although this zone covers approximately two-thirds of the country, considerably less is known about its soils at present than is known about those of the two other zones. Detailed studies have been confined to soils developed over Voltaian sedimentary rocks which, however, cover the greater part of the zone. Soils over the granites have been studied to some extent, but little is yet known of the soils formed over the various Birrimian and Tarkwaian rocks. The boundaries drawn on the soil map must therefore be regarded as provisional only, and the following account will undoubtedly need considerable modification as more details become known over the next few years.

The major soil groups recognized are Savanna Ochrosols, Groundwater Laterites, Tropical Black Earths, Savanna Brunosols, Tropical Brown Earths, Savanna Lithosols, Grey Acid Gleisols, Grey and Brown Calcium Vleisols and Sodium Vleisols. The units mapped are Savanna Ochrosols, Savanna Ochrosol-Groundwater Laterite intergrades, Tropical Black Earths, Savanna Brunosols, Savanna Ochrosols with some Lithosols and Brunosols, and Acid Gleisols.

In general, the soils of this zone have very much lower contents of organic matter and have a lower nutrient status than forest soils. Over large areas the soils have unfavourable moisture relationships and, in addition, the rainfall is less reliable in occurrence than in the forest zone. The potential productivity of the soils of this zone must on the whole be regarded as appreciably lower than that of the majority of forest soils.

Savanna Ochrosols

These are generally similar in profile form to the Forest Ochrosols but differ from them visibly mainly in that the topsoil is less strongly humus-stained. They consist of red and brown, well drained, friable, porous, loamy soils developed (in the areas where they are mapped separately) over Voltaian sandstones, Lower Birrimian and Tarkwaian phyllites and schists, and certain granites towards the south-west of the zone. They occupy gently undulating to gently rolling, savanna-covered topography under annual rainfalls of 40-55 inches falling, except in the extreme south, in a single rainy season.

Red or reddish brown soils predominate, and brown and yellow-brown, middle- to lower-slope associates appear to be less important than in the forest zone. Depression soils are generally Grey Acid or Neutral Gleisols, but Sodium Vleisols appear to occur in some valley bottoms amongst Ochrosols developed over the Obosum beds in the south of the zone.

Texture varies according to the nature of the parent material. Some soils over Voltaian sandstones are sandy throughout the profile; soils over the major area of Voltaian sandstones and over crystalline rocks (where these give rise to Ochrosols) may have appreciable sand contents, but become at least loamy and often clayey in the lower horizons; soils over phyllites and schists are generally light clay to clay in texture throughout. The clay mineral is believed everywhere to be kaolinitic. Soils on piedmont slopes below rocky hills in the Gambaga highlands, and perhaps elsewhere over Voltaian sandstones, consist of fine material throughout down to bedrock. Elsewhere, upland soils characteristically contain vesicular ironpan or abundant ironstone concretions at some depth in the profile. Over sandstones there is generally from 1 to more than 3 feet of fine earth overlying the ferruginous layer; over other rocks, the ferruginous layer generally occurs within a few inches to the ground surface and over Birrimian rocks it may also contain considerable amounts of quartz gravel and stones.

There is generally less textural variation with topographical site than occurs in the forest zone, and deep, pale-coloured, lower-slope, colluvial sands seem only to be important in a narrow zone, probably coinciding with the derived savanna zone, immediately north of the forest, more particularly over V2 Obosum beds in the Ejura area (see geological map).

An ideal topographical section, except in the higher parts of the Gambaga highlands, consists of a small summit-capping of red soils, usually shallow, over ironpan (which outcrops locally to give rise to Savanna Lithosols), giving way, often below an ironpan outcrop, to red soils containing abundant ironstone concretions and sometimes ironpan boulders covering the major part of the topography. Along minor depressions the lower-slope soils consist of yellow-brown, mottled, silty or sandy clays giving way to grey, mottled, silty clays in the bottoms. Along major valleys the ferruginous layer of the slope soils may outcrop and, in Voltaian areas, hard sandstone may be exposed, in a marked steepening of the slope bordering the valley bottom; in the latter occur grey, slightly mottled, silty or sandy clays. Over Obosum beds in the Ejura area, bottom soils sometimes consist of a foot or so of pale brown sand overlying grey, compact, prismatic sandy clay going down into grey mottled ochre sandy clay with calcareous concretions. These appear likely to be Sodium Vleisols. It is not known at present how extensive such soils may be.

Typical upland profiles over sandstone and phyllite are illustrated in Figure 8. Upland soils differ from Forest Ochrosols mainly in the morphology of the topsoil. There is no continuous leaf-litter layer at the surface, and bare soil is often exposed between the widely spaced grass tussocks. In the south, the surface 3 inches may be mid- to dark grey-brown with organic matter, grading into a further 3-6 inches of soil in which humus-staining gradually disappears and the colour becomes brown or pale reddish brown. More generally, the undisturbed soil is only slightly humus-stained, the colour changing from grey-brown at the surface through pale orange-brown to the colour of the subsoil below about 6-9 inches. Lower horizons closely resemble those of Forest Ochrosols developed over similar parent materials, although it must be noted that ironpan and ironstone-concretionary subsoils are much more common than in the forest zone.

As in Forest Ochrosols, nutrients are concentrated in the topsoil organic matter and the soil mineral matter has little capacity to supply or retain nutrients. Since humus contents are low, there usually being less than 2 per cent organic matter even in the surface layer and lesser amounts below, the soils are generally poorly provided with available nutrients, phosphorus and nitrogen being particularly deficient. Intensive cropping would be expected quickly to exhaust the low reserves of other plant foods. Topsoils are generally almost neutral in reaction; lower horizons are rather less strongly leached than in Forest Ochrosols, and reaction values in the subsoil normally lie around pH 5.5. Representative analytical data for a soil over sandstone are given in Tables 6a and 6b. These should be compared with those given in Tables 1 and 2 to gain an indication of the difference in fertility status between the Forest and Savanna Ochrosols.

Tillage is easy except where sheet ironpan or ironpan boulders lie near the surface. Moisture relationships are less favourable than in the forest soils because of the exposed conditions; evaporation losses are higher and there is loss of water by surface run-off during rainstorms

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phosphorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 5	1.3	605	161	32	79	19,827	668		.284	.124	.011	.019
2. 6	1.6	390	100	12	41	24,729	909	260	.113	.048	.002	.006
3. 8	1.6	518	131	8	77	28,323	1331	563	.081	.034	.001	.006
4. 11	1.6	617	189	11	106	22,564	1400	700	.079	.040	.001	.007
5. (6)	1.6	232	113	5	51	7,456	503	336	.078	.063	.001	.009
Total for 3 feet		2362	694	66	354	102,899	4811	2181				

Table 6a. Mimi series, a representative Savanna Ochrosol from the interior savanna zone: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 6b.

even under natural conditions. Topsoils tend to be droughty and subsoils have poor retentive properties where concretionary or indurated layers exist. Moisture relationships are better in piedmont-slope drifts; and over Obosum sandstones in the Ejura area, a perched water-table develops at depth during the rainy season and moisture is probably available to deep-rooting plants throughout the year.

Savanna Ochrosols are extensively farmed in the Gambaga highlands, around Tamale, in the Techiman-Wenchi area, near Ejura, in central Togoland and around road-side settlements elsewhere. For reasons that are not entirely clear, they are little-settled and farmed in north-west Ashanti and the western half of the Northern Region; many of the soils here are shallow and droughty, however. Yams are the major crop grown, and the deeper soils over Voltaian sandstones are admirably suited to the production of this crop, although the methods of cultivation used quickly deplete the soil of its organic matter. Some maize is grown in the south; guineacorn and millet are more important further north. Tobacco is grown in the Wenchi and Gambaga areas and is being encouraged around Ejura and Damongo. The former Gonja Development Corporation's farm at Damongo is situated on Savanna Ochrosols developed over Upper Voltaian sandstones. Imperata cylindrica quickly proliferates on cropland in the southern half of the zone.

The provision of organic matter, both to supply nutrients and improve the physical condition of the topsoil, should be the chief aim in improving agricultural productivity from these soils. Where stock can be kept, kraal manure should be made and applied. Elsewhere, frequent green-manuring with a perennial or semi-perennial cover crop should be practised. Artificial fertilizers should be added to these to give the best results. Anti-erosion devices are required if large areas of soils are cleared since the exposed soils, even where sandy, are unable to absorb high-intensity rainfall and are readily susceptible to the development of 'cultivation pans' and accelerated erosion.

Associated bottom soils are almost unused at present. They are not particularly fertile but, because of their site, are usually very suitable for rice production. For this to be really successful under the climatic conditions obtaining, some system of water control is required.

Groundwater Laterites and Ochrosol - Groundwater Laterite intergrades

Groundwater Laterites cover very extensive areas over the Voltaian shales (V2) and granites (mainly G1) in the interior savanna zone. They have not been mapped separately because, in many areas, following a change in drainage conditions, the soils show some tendency towards becoming Savanna Ochrosols. True Ochrosols occur locally, as well as occasional Lithosols developed over rock or ironpan outcrops. Some small areas of soils seen over G2 granites belong to the Brunosols and Tropical Black Earths: these cannot be mapped separately here, however.

Groundwater Laterites consist of from a few inches to 2 feet of pale-coloured, sandy or silty loam overlying vesicular, orange and black ironpan (or strongly mottled clay indurating to ironpan on exposure) which goes down at a variable depth into mottled weathered rock. They occur extensively on the upland parts of very gentle topography under savanna vegetation. Their origin is due to poor internal drainage: over V2 shales, drainage is impeded by the horizontal bedding of the impervious bedrock; over granite, drainage is impeded by the clayey nature of the weathering rock. Representative profiles are illustrated in Figure 9.

Over V2 shales, the undisturbed profile (Kpelesawgu series) typically consists of a few inches of greyish, silty or fine-sandy loam, humus-stained for an inch or two at the top, overlying abundant ochreous ironstone concretions of varying sizes in a pale grey clay matrix; at a depth of 3-4 feet the concretionary layer abruptly overlies grey and ochre mottled clay which within a few inches grades into hard shale or mudstone, manganese-stained along the partings. Disturbed soils may be concretionary to the surface. The ferruginous subsoil often contains large ironpan boulders and has itself sometimes hardened into easily crushed, vesicular ironpan. These soils are liable to be waterlogged almost to the surface during the rains, but the water fairly quickly flows through the profile laterally and the soils become dry shortly after the end of the rains.

Over granite (Bubile series), there may be 1-2 feet of brownish yellow to yellow-grey, firm, porous, coarse sand or sandy loam, slightly humus-stained near the surface and becoming faintly mottled ochre towards the base, overlying orange and grey mottled, porous, gritty clay forming easily crushed, vesicular ironpan when exposed; this may contain quartz stones and gravel near the top; it grades at depths of 3-5 feet into grey mottled red or orange, firm, porous, gritty loam or clay gradually becoming recognizable as pale-coloured, weathered granite at depths of 8-15 feet. Small rock outcrops occasionally project in some areas. Where eroded, as near Bawku, hard ironpan may occur at or within an inch or two of the surface. These soils become waterlogged to the top of the ferruginous layer in the rains, but appear to drain less rapidly than the V2 soils, except where the ferruginous layer has hardened, although they eventually dry out deeply during the long dry season.

The intergrade soils occur where drainage is less impeded due either to a more sandy bedrock in the case of Voltaian areas or possibly to a high biotite content in the case of granites; or to recent slight dissection of the topography. In these soils, the topsoil below the humus-stained layer may be yellow-brown to pale orange-brown in colour and the upper part of the ferruginous layer consists of dark-coloured, spherical, ironstone concretions in an orange-brown, porous, loamy matrix in the case of V2 areas or of orange-coloured, semi-hard, gritty, vesicular ironpan in granite areas. Such soils only become waterlogged in the lower part of the profile. They are droughty during dry spells. Where drainage improves still further, true Ochrosols are developed.

All these soils appear to have reaction profiles similar to the Ochrosols, the surface layer being near-neutral and lower horizons moderately to very acid. Organic matter contents decrease from south to north but are generally very low, few soils containing more than 2 per cent in the surface layer and many in the north only about 1 per cent or less; eroded granite soils around Lawra and Bawku are particularly depleted. Available phosphorus is very low, although considerable amounts of this element are fixed by the iron in the subsoil and are almost inaccessible to plants. Nitrogen contents are low, and supplies of other nutrients are low because of the low retentivity of the soil mineral matter and the absence of weatherable minerals within root-range. Representative analytical data are given in Tables 7a and 7b.

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phosphorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 4	1.3	687	122	38	104	13,228	570	130	.512	.150	.021	.040
2. 7	1.6	416	118	46	59	8,899	427	208	.339	.166	.029	.026
3. 9	1.6	57	18	7	12	1,081	60	32	ND.	ND.	ND.	ND.
4. 12	1.6	586	386	76	129	5,465	371	199	.248	.269	.024	.028
5. (4)	1.6	229	163	19	43	805	54	111	ND.	ND.	ND.	ND.
Total for 3 feet		1975	807	186	347	29,478	1482	680				

Table 7a. Kpelesawgu series, a representative Groundwater Laterite: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 7b. N.D. = No Data.

There is little farming of the true Groundwater Laterites over Voltaian rocks, but the greater depth of topsoil makes such soils cultivable in granite areas. Intergrade soils are cultivated to some extent around Tamale and the few other settlements in the vast area covered by V2 shales. Crop yield data are not available but appearances suggest that cereal yields at least are low. Yams are grown, too, in some Voltaian areas; yields are not known, but can only be expected to be low.

Groundwater Laterites are recognized as the poorest soils in the humid tropics (Kellogg & Davol, 1949). Those in Voltaian areas have almost no potentiality for development and can best be relegated to providing poor rough-grazing or set aside for game reserves. The deeper topsoil of the granite soils provides some basis for cultivation, but these soils are infertile and susceptible to drought and to erosion. Increased yields really depend on adding nutrients and improving the physical constitution of the soils. This can best be achieved by adding organic matter. Measures necessary to produce permanently satisfactory returns from such soils are likely to be expensive to apply, however: the soils are fundamentally poor, with a low human-or stock-carrying capacity.

The soils described above occupy the greater part of the topography, from summit to lower slope. At the edge of valley bottoms the ferruginous layer of the upland soils often forms a hard, broken, ironpan outcrop. The valley-bottom soils (cf. Figure 9: Volta series over shale; Kupela series over granite) are closely similar over all rocks and consist of grey, slightly mottled ochre, porous, structureless, silty loams to clays, rather loose at the surface but becoming very firm with depth. Some soils are slightly to moderately acid throughout; others are slightly to moderately acid near the surface but gradually become slightly or moderately alkaline below about 30 inches. Appreciable amounts of soluble salts apparently occur in the lower layers of some soils, both over Voltaian shales and over granite, but it is not yet known how general this feature may be and what agricultural significance it may have. Representative analytical data for a bottom soil in the Voltaian shale area are given in Tables 8a and 8b.

These bottom soils are liable to seasonal water-logging or flooding for varying periods, but generally become thoroughly dry during the dry season. The soils are rarely used, except for dry-season rough-grazing in some northern areas; but some of the larger bottoms, as, for example, along the Nasia river, appear to provide excellent opportunities for large-scale rice cultivation, provided provision is made for adequate water control. The soils are much better provided with nutrients than the adjoining upland soils: cf. Tables 6a, 7a and 8a. Agronomic investigations are required to determine whether salts present in some soils are liable to interfere with cropping, but little difficulty is in fact anticipated under efficient management of drainage.

Savanna Ochrosols with some Lithosols and Brunosols

This mapping unit is co-extensive with the Upper Birrimian (B2) and Tarkwaian outcrops shown on the geological map. No systematic studies have yet been made of the soils developed over these formations under savanna conditions. Brief examinations made along roads suggest that B2 and Tarkwaian phyllites give rise to Savanna Ochrosols as described above, although often with harder ironpan or pan boulders in the profile. B2 greenstones generally form conspicuous, steep-sided hill ranges with Lithosols. In this case the rock weathers brown, friable and loamy. Valleys below such hills may possibly be occupied by brown, structured, cracking clays containing lime concretions at depth, although the presence of such soils — Tropical Brown Earths — has not yet definitely been substantiated. Tarkwaian quartzites form steep rocky hills, as near Banda Nkwanta, with pale-coloured Lithosols consisting of little more than hard rock brash and interstitial sand. Lithosols are also developed over extensive ironpan sheets capping low tabular hills in the Lawra-Nandom area. Valley-bottom soils have not been studied but, except near B2 greenstone hills, probably consist of Grey Acid Gleisols or Grey Calcium Vleisols.

The Ochrosols, often containing abundant ironpan boulders or hard sheet ironpan, and the Lithosols over quartzite and ironpan outcrops, have little agricultural value or potentiality. B2 greenstone soils, as near Nangodi and north of Bawku, are usually intensively farmed and highly eroded, particularly on steep slopes. None the less, the rich nutrient supply from the weathering rock, into which roots can penetrate fairly well because of the steep angle of dip of its schistose cleavage planes, allows almost continuous cropping to be practised although yields are relatively low. The soils' main deficiencies are likely to be nitrogen and moisture. Tropical Brown Earths, if present, will provide good agricultural soils, more suited to plough farming than

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phos-phorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 5	1.3	1359	335	250	135	36,784	1414	345	.329	.134	.044	.010
2. 7	1.6	2123	579	404	173	44,652	2159	489	.313	.141	.044	.009
3. 18	1.6	1686	666	351	160	24,575	1434	425	.266	.174	.041	.013
4. (6)	1.6	1052	552	111	125	4,474	384	117	.319	.276	.025	.019
Total for 3 feet		6220	2132	1116	593	110,485	5391	1376				

Table 8a. Lima series, a representative Grey Neutral Gleisol (?): major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 8b.

to hand cultivation, and, with the addition of nitrogen and phosphorus, will be likely to give sustainedly higher crop yields than any other major soils in the interior savanna zone.

Tropical Black Earths

These are dark grey cracking clays containing lime concretions in the lower part of the profile developed on very gentle upland topography over basic igneous rocks and Voltaian limestones or calcareous shales. They are of small areal importance. The major occurrence, over G2 granite containing frequent basic xenoliths, has been tentatively indicated on the soil map; but other examples, as seen over G2 granite near Pusiga (east of Bawku), over an unknown rock at M.P. 118 on the Tamale-Sawla road, and over V2 magnesian limestone or calcareous shales in a few localities within the Voltaian basin, are too small to be represented on the present map. The soils occur under annual rainfalls of 40-50 inches. The savanna vegetation contains conspicuously fewer trees than adjoining upland soils (Ochrosols or Groundwater Laterites).

On the Bamboi-Bole road near Kwamen Kwesi, the surface 2-3 inches of the soil is a dark grey, porous, crumbly loam consisting entirely of worm casts. This grades into 12-30 inches of dark grey, rather porous, gritty clay, rather heavy and plastic when wet but hard and nutty to cloddy when dry; this layer contains frequent, tiny, ochreous ironstone concretions. Below a sparse quartz stone-line, the soil merges at 15-30+ inches into pale grey, gritty, clayey weathered granite which locally contains calcareous concretions. Spheroidal rock outcrops occurring locally contain numerous large hornblendic xenoliths. These soils are appreciably lighter in texture than Black Clays occurring on the Accra plains.

Black Clays developed over V2 calcareous shales and interbedded dolomitic limestone and shale consist of 1-4 feet of dark to mid-grey or olive-grey, cloddy clay, highly plastic when wet and hard when dry, overlying weathered, clayey shale or hard, brashy limestone. Lime concretions occur below about 30 inches in the deeper profiles. These soils are heavier than the Kwamen Kwesi soils described above, but less heavy than those of the coastal plains.

The nutrient status of these soils is unknown as yet, but they are likely to be deficient in nitrogen; those over V2 rocks may also be short of phosphorus. Cultivation is inhibited at present because the soils are too heavy for hand cultivation and because of the waterlogged condition of the profile following heavy rainfall. Little development can be expected on these soils because of the presence of frequent rock outcrops in granite areas, which would interfere with the ploughing these soils require, and the small extent and remoteness of individual occurrences in V2 areas.

Savanna Brunosols

Present knowledge only allows Savanna Brunosols to be mapped separately where they are developed over Buem volcanic rocks in central Trans-Volta Togoland. Here they occur extensively over gently-undulating topography broken locally by occasional rock outcrops. They support tree savanna with tussocky tall grasses, and receive 55-60 inches' annual rainfall.

The upper-slope soils consist of brown to reddish brown silty clays containing boulders of weathering basalt. The middle slopes carry a mixture of reddish brown, brown and yellow-brown, silty loams to clays containing small, iron-coated boulders of basalt; rock boulders often lie scattered about the ground surface, too. Lower-slope colluvium gives rise to dark brown or brown, cloddy, plastic clays containing lime concretions at depth: these constitute Tropical Brown Earths. Bottom soils comprise brown to dark grey, cloddy, plastic clays, often containing lime concretions to the surface: these are Brown Calcium Vleisols. The lower-slope and bottom soils together occupy about one quarter of the topography. They crack deeply and widely when dry, and small subsidence hollows often occur in the bottom soils. Three of the major soils are illustrated in Figure 10.

These soils are little farmed at present because of their heavy nature and their difficult moisture relationships, but where not badly broken by rock outcrops or too bouldery they appear suitable for development with the aid of heavy machinery and might then become highly productive. This applies particularly to the lower-slope and bottom soils. At present, considerable water is lost by surface run-off, and the soils, except where very bouldery, suffer from impeded internal drainage. On the other hand, they dry hard and compact, cracking deeply, and little moisture remains available for dry-season use. Deep tillage and the provision of frequent drainage ditches, as in the closely similar

Black Earths, would serve to produce a stable, crumbly tilth, give better internal drainage and at the same time improve moisture-retaining capacity.

Complete analytical data are not available at present, but the soils have a high nutrient-holding capacity and are well supplied with calcium and magnesium. Organic matter contents are low, however, and nitrogen is likely to be deficient. Total phosphorus contents may be high, but the proportions available to plants are not yet known and may perhaps be low, especially in the lime-rich depression soils. The soils are suitable for continuous cropping, however, and artificial fertilizers normally need to be added to give sustained high yields where such a practice is possible.

Acid Gleisols

The width of the alluvial tract along the White and Black Volta rivers probably varies from nil to as much as 5 miles. The writer has seen so few sections across it that it seems wiser to represent this tract on the soil map by a strip of conventional width on both banks of the river. Similarly, no attempt has been made to show alluvial tracts along tributary rivers, although these are known to be extensive along the Nasia and are presumably so along other rivers, too. The greater extent of these tracts appears not to be flooded directly by the neighbouring river over-topping its banks, but extensive areas become waterlogged or flooded by water seeping from adjoining upland areas and unable to drain into the river because of the levee.

Aerial photographs reveal an elaborate network of abandoned levees and river channels together with low terrace remnants, and soil patterns are likely to be complex. The major soils along the Volta rivers are thought likely to be grey mottled yellow-brown, porous, silty clays, moderately acid in reaction throughout the profile. Such soils carry high swamp grassland with variable amounts of trees. These are the Acid Gleisols. Soils on alluvial flats extensively developed along some tributary valleys within the Voltaian basin consist of grey, slightly mottled ochre, very silty clays. Some of these are acid in reaction throughout; others become alkaline at moderate depths. Such flats may carry short sedges, or medium or tall grassland; they are generally almost treeless. Analytical data for such a soil (in this case a Neutral Gleisol) from the Nasia basin are given in Tables 8a and 8b.

Soils of other groups also occur. Old levees may be expected to carry yellowish to pale red coarse sands or sandy loams and the present river bank may have pale yellow-brown sands with a dark brown, humous, forest topsoil. Terrace soils consist of red or orange-brown loams to clays, usually becoming mottled at a depth of 3-4 feet; these constitute Ochrosols. Other low-level terrace soils seen along the Red Volta and along the White Volta for some distance after it enters the Voltaian Basin belong to the Tropical Brown Earths. They consist of brown silty clays, plastic when wet but rather firm and cloddy when dry and often cracking widely and developing small subsidence hollows. These soils contain lime concretions below a depth of 2-3 feet, but may be slightly acid in reaction near the surface. Their parent material may possibly have been derived from B2 greenstone areas.

Terrace soils, except, it is believed, the Brown Earths, are sometimes heavily farmed to subsistence crops, and tobacco is grown along the levee banks of the northern course of the White Volta and the Red Volta. Generally speaking, however, the soils of the alluvial tract are little used, mainly, it appears, because of human disease factors (river blindness, sleeping sickness), but possibly also because of the depredations of large game animals which occupy, or migrate seasonally along, these alluvial tracts.

The soils provide a valuable reserve of agricultural land suitable for development by modern techniques. The major soils are unlikely to be more than moderately provided with nutrients, but fertilizers would require to be added in any case for the continuous cropping to which they appear suited. Successful development will involve expensive capital works for drainage and water control, but crop returns — under efficient management — would be likely to make such investment economic. Maize, guineacorn and millet, together with tobacco and pulses might be grown on the better-drained sites, and rice and perhaps sugarcane on lower-lying sites. These soils would be suitable for extensive mechanized farming. Peasant farmers would require at least bullock-drawn ploughs to cultivate these soils.

Little is known of the cultivation requirements of the Brown Earths, but they would appear likely to give high returns under well organized mechanized farming using inorganic fertilizers to maintain fertility.

The reddish terrace soils and levee sands require the application of organic matter to maintain productivity. Because of the irregular distribution pattern of these upland soils, they are probably best suited to small-scale peasant farming. The usual cereals, root crops and vegetables could be grown on the red soils. Mangoes would grow satisfactorily on the sandy levees.

Coastal savanna zone

The characteristic soils of this zone are quite different from those of the interior savanna zone. This appears to be due to the fact that these coastal areas were largely stripped of their former soil mantle during Quaternary fluctuations in sea level and the present-day soils, although developed on a gently undulating landscape similar to that in the interior savanna zone, are much younger with weathering rock usually occurring at only moderate depths in the profile. Geology has therefore a more important influence on soil formation in this zone than in areas where almost all rocks are weathered to the extent that their influence is largely restricted to providing different proportions of the insoluble residues. It is largely for this reason that the soil map appears to be disproportionately detailed over the coastal savanna zone compared with, say, the forest zone where climate is the major determining factor.

The greater extent of this zone is occupied by drift soils. Such soils, as evidence of their drift origin, usually contain a stone-line of quartz gravel separating the soil proper from the underlying rock. Where there has been no source material to provide a stone-line, there is still characteristically a marked discontinuity between the soil and the underlying rock. Despite this discontinuity in the profile, these drift soils are closely tied to the underlying rock, boundaries between soils developed over different rocks often being quite sharp. The fact that the drifts are so tied to the underlying rock indicates that they are not alluvial in origin. The additional facts that in several cases there are no rock outcrops from which fine material could have been washed by sheet or rill flow and that the soils occur over the whole of the topography except the alluvial depressions indicate that the drifts are not primarily colluvial in origin. It appears that biotic agents, mainly the termite (Macrotermes) which constructs the large mounds, are responsible for transferring material from the zone of weathering rock below a layer of lag-gravel (stone-line) to form a superficial drift in which the present soils have developed. Whilst in the termite mound, the mineral particles are subject to further weathering and, as the mound is gradually washed down, the material is distributed over the ground surface by sheet and rill flow. In the material which accumulates, profile development then takes place by normal soil-forming processes.

In all, eight great soil groups have been mapped, viz: Savanna Ochrosols, Regosolic Groundwater Laterites, Tropical Black Earths, Tropical Grey Earths, Acid Gleisols, Sodium Vleisols, Savanna Lithosols and Regosols. These are described in turn below.

Savanna Ochrosols

These are red, brown and yellow-brown, well drained, friable, porous, loamy soils similar to those of the interior savanna zone. In the coastal savanna zone they are mainly developed on gentle topography over the unconsolidated Tertiary deposits in the south of the zone, but also occur on peneplain remnants in the west of the Accra plains and in terrace deposits along the Volta. They mainly receive an annual rainfall of 25-45 inches and carry high grassland with variable, but often substantial, amounts of coastal thicket vegetation in clumps; some areas of Tertiary sands towards the east of the Ho-Keta plains still carry extensive stands of thicket, however, and are better regarded as Forest Ochrosols. Typical profiles are illustrated in Figure 11.

Over the Tertiary deposits, the normal upland profile (Toje series) consists of a foot or so of grey-brown to pale brown, loose to rather firm, porous sandy loam grading into a great depth of uniform, red, firm, porous, structureless, sandy light clay to clay. Ironpan and ironstone concretions are typically absent. Some profiles are neutral or even alkaline in reaction throughout[8], but the most widespread soils appear to become moderately acid below a neutral surface horizon. Organic matter contents are low, and the soils are poorly provided with nutrients, particularly nitrogen and available phosphorus. They allow free root development, and moisture relationships are satisfactory for deep-rooting crops although shallow-rooting crops suffer from drought during the prolonged dry spells liable to occur in this zone. Analytical data for a typical profile are given in Tables 9a and 9b.

---

[8]Possibly as a result of the accumulation of lime in old termitaria which are very frequent on those soils. Substantial amounts of lime concretions have been seen in old termitaria around Legon hill.

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phos-phorus	'Relative availability' of bases (ie. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 3	1.4	695	166	18	149	11,744	503	175	.616	.242	.012	.068
2. 6	1.6	963	228	23	175	13,849	660	332	.537	.210	.010	.050
3. 6	1.6	783	306	29	200	13,849	660	405	.365	.236	.010	.048
4. (21)	1.6	1512	861	41	641	20,880	2535	1506	.202	.190	.004	.044
Total for 3 feet		3953	1561	111	1165	60,332	4358	2418				

Table 9a. Toje series, a representative Savanna Ochrosol from the coastal savanna zone; major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 9b.

Towards the lower slopes amongst the Tertiary sands, and on upland sites, too, where these deposits are shallow, the red soils are replaced by yellow soils with similar characteristics, although the upland soils often become mottled below depths of 3-4 feet. Where the Tertiary deposits run down to the edge of the flats surrounding the coastal lagoons, pale grey to white sands occur. These latter soils, Regosols, are almost sterile.

Red and yellow soils on remnants of the 30-40-foot Volta terrace superficially resemble those over the Tertiary sands, but are more silty, rather heavier and have a better capacity to hold nutrients. Many profiles contain lime concretions, thought to have originated in old termite mounds. The normal soil becomes moderately acid in reaction below a neutral surface horizon.

Peneplain remnants forming summit cappings in the western Accra plains carry red, ironstone-concretionary clays overlain by only a few inches of red or brown sandy loam (Nyigbenya series). The shallowness of the topsoil, together with the droughtiness and low nutrient status, restrict the agricultural value of these soils. Near and to the west of the Accra-Dodowa road, the red soils are succeeded downslope by brown or yellow-brown sandy loams to clay with mottled gravelly lower layers; and, in the bottoms, by grey, mottled, porous, silty clays.

Soils over the Tertiary deposits and Volta terraces are heavily farmed, with cassava the major crop grown. Fallow periods are generally too short, especially near roads, and crops appear poor. The provision and maintenance of an adequate organic matter content is essential if crop yields are to be increased. Drought-resistant crops such as millet and guineacorn, Bambara beans and various pulses are suitable for the conditions, and mangoes appear to do well. These soils would respond well to irrigation, best applied to them by sprinkler methods, and could then support a wide range of cereals, pulses, vegetables and fruit crops provided these were suitably manured. Manuring would be required, too, to give satisfactory returns from coconuts, the most suitable crop for the deep, infertile, pale-coloured, lower-slope soils. The concretionary soils in the west have little agricultural potentiality, but the deeper soils downslope are better and require treatment similar to those over the Tertiary deposits.

Regosolic Groundwater Laterites

No references are known to soils similar to those described below occurring in other parts of the tropics. They are difficult to classify at the great soil group level, and the name used is only tentatively proposed until more information on the soils becomes available.

The soils consist of from a few inches to several feet of pale-coloured sand overlying a mottled, gravelly, sandy clay which in turn overlies weathered acidic gneiss or granite. They occur extensively over the latter rocks on gently undulating upland topography. They receive 25-50 inches annual rainfall and typically carry high grassland with frequent scattered trees and, particularly, abundant Borassus palms; but one extensive series (Simpa) typically carries only short or medium grassland with few trees. Drainage is seasonally impeded by the clay layer or the clayey weathered rock at the base of the profile. There is some evidence that this is due to the presence of a certain amount of sodium in the clay[9] The clay mineral has not yet been determined, but kaolinite is thought likely to predominate; montmorillonite may occur in the weathering rock. Typical profiles are illustrated in Figure 12. Representative analytical data are given in Tables 10a and 10b.

Between Dodowa, Doyum and Agomeda on the Accra Plains, and almost throughout the north-western acidic gneiss belt on the Ho-Keta plains, the soils (Doyum series) consist of 3-5 feet of pale brown coarse sand, humus-stained in the topmost foot, overlying a foot or so of grey and red mottled sandy clay containing quartz stones at the base and with grey and ochre mottled clayey weathered granite[10] below. Rock outcrops are rare or absent. A perched water-table occurs seasonally above the mottled clay horizon; the latter has developed into hard seepage ironpan locally. Associated bottom soils, not extensively developed, are grey, hardpan soils belonging to the Tropical Grey Earths described below.

In the broad acidic gneiss belt crossing the centre of the Ho-Keta plains and over much of the belt to the south indicated on the geological map as basic gneiss, a total

---

[9]This has subsequently been confirmed in the case of Ziwai series, cf. Tables 10a and 10b. This series now appears to have closer affinities to the Sodium Planosols (Tropical Grey Earths) than the Groundwater Laterites.

[10]The few examples of unweathered rock seen in pits indicate a granite lacking in dark minerals.

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phos-phorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 5	1.3	619	282	63	51	18,320	635	91	.409	.308	.031	.017
2. 5	1.6	396	194	20	28	8,878	373	80	.343	.278	.012	.012
3. 10	1.6	777	389	29	181	12,073	639	160	.308	.254	.008	.037
4. 8	1.6	2892	1599	16	100	21,874	1165	253	.313	.285	.001	.006
5. (8)	1.6	3364	1812	< 1	91	5,570	557	127	.394	.351	<.001	.005
Total for 3 feet		8048	4276	128	451	66,715	3369	711				

Table 10a. Ziwai series, a representative Regosolic Groundwater Laterite(?): major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 10b.

area of some 800 square miles, the soils (Ziwai series) and its finer-grained congeners) consist of 1-2 feet of pale yellow-brown, loamy coarse sand, humus-stained near the surface, grading into 1-3 feet of yellow-brown, mottled ochre, sandy loam to clay containing rounded quartz stones at the base; the underlying rock may be thoroughly weathered and strongly mottled with red for a few inches at first, but quickly becomes pale-coloured and loamy, and recognizable as weathered gneiss. Ironpan rarely occurs. Rock outcrops occur very occasionally. Downslope, the sandy superficial layer thins out and there are fairly extensive occurrences of Tropical Grey Earths which are described below. Red, gritty, ferruginized clays occasionally occur on summit sites, and there are red clayey piedmont drifts around the few large inselbergs: these soils belong to the Savanna Ochrosols.

In the western acidic gneiss belt on the Accra plains, the rocks are finer in grain but contain numerous quartz veins. The associated soils (Simpa series) consist of a variable depth, but often less than 1 foot, of medium sand, grey-brown near the surface but becoming pale brown below, overlying 1-6 feet of grey mottled ochre sandy loam to sandy clay containing abundant quartz gravel which is iron-coated in the topmost foot of the layer but clear and pale below; this overlies little-mottled, little-weathered, acidic gneiss containing frequent quartz veins. These soils carry short or medium grassland with few trees. Tropical Grey Earths are extensively developed amongst these soils and upland sites often carry peneplain remnants with concretionary Savanna Ochrosols.

In all these soils, the humous horizon is near-neutral in reaction; lower horizons are slightly to moderately acid, but pH values tend to increase again in the weathering rock. Soils with a deep sandy superficial layer have a very poor nutrient status and are very droughty for annual crops; tree crops, once established, might exploit the seasonal water-table present at depth. Ziwai soils on the Ho-Keta plains are chiefly used for groundnuts and cassava. The sandy layer retains low amounts of nutrients: phosphorus and nitrogen appear likely to be deficient. Lower horizons contain large amounts of mineral bases, but phosphorus reserves are very low. Soluble salts may locally reach toxic levels in the deeper layers. These soils suffer from poor internal drainage during the rainy seasons and *Imperata cylindrica* is an ubiquitous weed. The shallow, gravelly soils of the western Accra plains are little farmed but are extensively grazed. They suffer from alternate internal waterlogging and drought, and trials on the University College Agricultural Research Station, Nungua, indicate that they are particularly deficient in phosphorus.

The deeper soils are only suitable for drought-tolerant crops: cassava, millet, guineacorn and perhaps sisal suggest themselves. Deep placement of superphosphates might be useful in encouraging deeper-rooting in groundnuts. It is desirable to add organic matter, either by natural fallowing or through manures, to maintain fertility and improve the physical constitution in such soils.

The shallower soils might be ridged to improve drainage during the rainy seasons. These would need to be carefully graded to guard against erosion. Natural fallows would both add organic matter, which the soils require, and help to suppress Imperata cylindrica. Phosphatic, nitrogenous and, eventually, potassic and perhaps other fertilizers would need adding for intensive crop production. Groundnuts, millet, guineacorn and cassava are suitable crops; tobacco is also being tried on such soils at Wuti (north of Abor) on the Ho-Keta plains.

Tropical Black Earths

These are dark-coloured, heavy, alkaline, cracking clays. They occur on gentle savanna topography over the main basic gneiss belt crossing the Accra and Ho-Keta plains; small areas cover basic rocks elsewhere. In all, the soils cover some 300 square miles on the Accra plains and a further 300 square miles on the Ho-Keta plains. A further 50 square miles (approximately) occur over basic schists on the Winneba plains. A profile is illustrated in Figure 13. Analytical data are given in Tables 11a and 11b.

The profile form gradually changes from south to north as rainfall increases. Under 25-35 inches rainfall in the south, the soils usually consist of very dark brown to black, cloddy, plastic clay containing calcareous concretions scattered throughout; pale-coloured weathered gneiss occurs at 3-4 feet. Further north on the Accra plains, with 35-45 inches rainfall, there is usually 18-24 inches of very dark grey, cloddy, plastic clay near neutral in reaction grading into mid-grey clay containing abundant calcareous concretions; weathered rock generally occurs at 3-4 feet but shallower soils and rock outcrops occur patchily. Under 45-50 inches rainfall on the Ho-Keta plains, topsoils become

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phos-phorus	'Relative availability' of bases (ie. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 5.5	1.4	7359	2361	62	141	51,095	1760	523	.540	.318	.003	.005
2. 9.5	1.4	12241	4071	ND.	196	42,291	1703	755	.530	.291	ND.	.004
3. 9	1.4	14094	4276	ND.	210	28,992	1181	708	.628	.314	ND	.005
4. 6	1.4	9044	3555	ND.	142	13,321	554	490	.608	.394	ND	.005
5. (6)	1.4	4003	1342	ND.	45	2,541	123	358	.564	.311	ND.	.003
Total for 3 feet		46741	15605	ND.	734	138,240	5321	2834				

Table 11a. Akuse series, a representative Tropical Black Earth: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 11b. N.D. = No Data.

more loamy and porous, and slightly acid in reaction; lower horizons are often olive-grey to olive-brown and contain calcareous concretions below about 18-24 inches; shallow soils and rock outcrops become frequent.

Throughout, associated depression soils consist of dark grey, very heavy, plastic clays, cracking widely and deeply on drying. They are moderately to highly acid in reaction near the surface but gradually become less acid, and eventually alkaline, with depth.

The dark colour of these soils is apparently due to the particular form in which the organic matter occurs. The total organic matter content is actually relatively low, although it is more deeply distributed down the profile than in most of the country's soils. Nitrogen and potash appear to be in relatively short supply, and although moderate amounts of phosphorus occur, and there are large reserves in the weathering rock below, the amount available to plants is likely to be low in the presence of free lime in the profile. There are abundant amounts of calcium and magnesium, on the other hand — more than 20 tons of the former and 7 tons of the latter per acre in the top 3 feet of the profile for which data are given, apart from the large quantities held in the lime concretions. Soluble salts apparently vary in amount: a few soils examined have contained more than 0.2 per cent sodium chloride in the lower layers, but generally they are believed not to occur in harmful quantities.

The clay mineral is almost entirely montmorillonitic. This gives the soils their characteristic physical properties. In the natural state, they are hard and compact when dry, cracking deeply and widely. On wetting, they increase in volume by 40-50 per cent, becoming heavy, plastic and impervious.

The soils are almost uncultivated at present, but similar soils in India and South Africa are known to be intensively farmed and, with the introduction of appropriate techniques, there seems little doubt but that the local soils could be made productive too. In fact, properly handled, they might well become the most productive soils in the country. Their heavy nature, difficult moisture relationships and the erratic nature of the rainfall have inhibited their development earlier. They require the use of heavy cultivation machinery, skilled management and irrigation (together with drainage) and might then produce such crops as rice and sugarcane in particular, as well as other cereals, vegetables, tobacco and fodder plants. The major virtue the soils possess lies in the stable, friable tilth they develop when broken up and kept well drained. They can thus, unlike the majority of the country's soils, be continuously cropped, so long as suitable fertilizers are added and precautions are taken against erosion.

Investigations to discover suitable crops and techniques to suit these soils are being carried out on the Kpong Irrigation Research Station and the University College Agricultural Research Station at Nungua.

Tropical Grey Earths

These are grey hardpan[11] soils occupying very gentle savanna topography over acidic gneisses and schists, mainly in the east of the Accra plains and the south-west of the Ho-Keta plains. To the west of the Black Earths on the Accra plains and to the east of these soils on the Ho-Keta plains, the Grey Earths occupy lower slopes in association with Regosolic Groundwater Laterites on the uplands; in the east of the Accra plains and the extreme south-west of the Ho-Keta plains, however, they occupy the whole topography from summits to bottoms. In all, they cover some 200 square miles on the Accra plains and some 125 square miles on the Ho-Keta plains. They generally receive only 25-35 inches annual rainfall.

They have a distinctive profile (cf. Figure 14). The topsoil consists of up to 12 inches of grey-brown, porous sand or sandy loam, slightly humus-stained near the surface. Below this occurs the hardpan layer consisting of about 12 inches of very hard and compact sandy clay cracking vertically into 6-sided blocks when dry; these prismatic blocks are humus-stained externally near the top; internally and below, they are weakly mottled grey and ochre. The lower part of the profile consists of grey or yellow-brown, weakly mottled ochre, less compact clay containing calcareous concretions. A stone-line at the base overlies moderately to highly-weathered gneiss or schist. The topsoil and upper subsoil are slightly acid in reaction; the lower part of the hardpan horizon and lower horizons are moderately to highly alkaline and contain appreciable amounts — usually about 0.2 per cent — of sodium chloride. The proportion of montmorillonitic clay present apparently varies from about 20-40 per cent; the remainder of the clay is kaolinitic. Analytical data are given in Tables 12a and 12b.

---

[11] Not to be confused with ironpan.

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total nitrogen	Total phos-phorus	'Relative availability' of bases (i.e. fraction of total soil capacity)			
		Calcium	Magnesium	Manganese	Potassium				Calcium	Magnesium	Manganese	Potassium
1. 2	1.3	89	47	6	65	4,270	179	19	.304	.265	.016	.115
2. 10	1.6	941	311	10	319	20,596	1151	114	.498	.272	.004	.087
3. 9	1.6	6679	2073	< 1	811	26,499	1373	205	.560	.287	< .001	.035
4. (15)	1.6	12887	3902	14	660	6,334	528	285	.477	.238	.004	.013
Total for 3 feet		20596	6333	30	1855	57,699	3231	623				

Table 12a. Agawtaw series, a representative Tropical Grey Earth: major nutrients in lbs per acre in surface 3 feet. Detailed analytical data are given in Table 12b.

- 6/55 -

These soils underlie the major grazing areas of the zone, but they are uncultivated. The hardpan both impedes drainage and root penetration, so that plants suffer water-logging in the rainy season and drought at other times. Contents of organic matter, nitrogen and phosphorus are very low, but lower horizons — inaccessible to roots — are well provided with mineral bases.

Development of the soils for agriculture would be expensive. It would involve breaking up the hardpan so as to allow deeper rooting, and improving internal drainage to leach sodium from the clay in the hardpan and sodium salts from lower horizons. Treatment with gypsum would be beneficial in this respect but probably too costly to practice. On disturbance, the soils become highly susceptible to erosion, and careful attention would require to be paid to furrow alignment and field drainage under cultivation. There is no indication what crops might be suitable for the soils if ever developed. Only drought-tolerant millets and guineacorn would suit the soils in their present condition, and these would require nitrogen and phosphorus to be added for successful growth. Investigatory work on these soils is in progress on the University College Agricultural Research Station at Nungua.

Acid Gleisols

Acid soils developed in alluvium are mainly found along the Volta and in the old delta, but also occur fairly extensively along some tributary valleys on the adjoining plains. They comprise a number of very different soils.

The major soils on the Volta levee (Amo series cf. Figure 15) consist of a grey, humous, rather loose, porous, silty topsoil going down into many feet of yellow-brown, mottled grey and red, porous, silty light clay. These soils are rarely flooded today. On the higher areas, the soils are near-neutral at the surface becoming moderately acid below; downslope, they become increasingly acid throughout. The associated slough soils (Tefle series), subject to seasonal flooding, comprise mid-grey, mottled ochre, heavy clays, moderately to highly acid in reaction in the upper part of the profile but becoming less acid with depth. Deep, yellow-brown sands (Chichiwere series) occupy the high river banks.

Around Songaw and Keta lagoons, extensive flats have grey, strongly mottled red, compact clays containing gypsum at depth. These soils become extremely acid in reaction below the surface inch or two, with pH values of 4.0 or below. The acidity of these soils is attributable to free sulphuric acid, the soils apparently having developed in former mangrove swamp alluvia in the old delta in which drainage has now improved.

Over the acidic gneiss areas of the adjoining plains, Tropical Grey Earths similar to those described above are generally developed along valley bottoms. Over the basic gneisses, very heavy, black clays occur in depression sites: these are usually moderately to highly acid in the upper layers but become less acid with depth. Brown, plastic clays, variously acid and alkaline, occur along some valley bottoms on the boundaries between the Black Earths and neighbouring soils. Yellow-brown, mottled, acid silty clays similar to those along the Volta border the lower half of the Todze river which crosses tho Ho-Keta plains.

Small amounts of chewing cane are grown in sloughs along the Volta, and subsistence cropping of cassava and sometimes groundnuts is widespread on the lighter soils. Grazing occurs on the deltaic flats and locally elsewhere, but in general the heavy clays are unused.

The soils of the Volta alluvial tract and certain local stream alluvia offer considerable scope for development. They are not particularly fertile at present, but appear suitable for continuous cropping under which conditions a complete range of fertilizers would eventually need to be added in any case. Drainage control of the lower-lying soils would be required: they would then be excellent for rice and sugarcane production. Pump-irrigation from the Volta or its creeks would benefit the lighter-textured, more-elevated, Amo soils: these would be suitable for cereals, groundnuts, vegetables and tobacco as well as rice and sugarcane. Imperata cylindrica, a noxious weed on the lighter soils, would need to be controlled by occasional fallows under crops such as pigeon pea, although periodic flooding or the growing of dense, tall crops such as sugarcane might be effective, too. The soils appear to contain appreciable amounts of salts at depth, mainly sulphates it is believed; under proper soil management, there need be no danger of toxic effects on plants under irrigation.

The very acid deltaic soils appear likely to be uneconomic to develop under present conditions. Heavy applications of lime would be required to counter the acidity; heavy fertilizer applications would be required initially; a drainage system would need to be provided to control the level of a seasonal brackish water-table; and irrigation would be required to supplement the meagre and erratic rainfall.

Sodium Vleisols

These soils border the saline coastal lagoons and creeks along the lower Volta. They comprise black or dark grey clays, sticky when wet, and hard and blocky when dry, occurring extensively in the less highly saline areas; and mottled sandy loams and clays, encrusted with salt crystals at the surface, occurring on the almost bare lagoon margins. The less saline soils are sometimes intensively cultivated along the lower Volta, where they are annually flooded with fresh water, sugarcane and vegetables being the major crops produced. Drainage control, irrigation and the use of fertilizers and tractors would be required for the improvement of agriculture on these soils. The salt flats are unlikely to be brought under cultivation.

Savanna Lithosols

On the coastal plains, these mainly comprise shallow, droughty soils developed on steep, rocky slopes of inselbergs. (Some inselbergs carry patches of forest, but such soils have not been mapped separately). Those over basic gneisses are black in colour and rather clayey. Over Togo quartzites, the soils are very brashy and the interstitial fine earth is red and loamy. The soils are unfarmed and have little agricultural potentiality.

Regosols

The only soils mapped as Regosols are those developed on the coastal sand dune on either side of the Volta estuary, but similar soils occur locally on lower-slope sites along the southern edge of the Tertiary deposits. The littoral soils (cf. Figure 16) consist of a few feet of yellowish, incoherent, coarse sand, sometimes made greyish by humus-staining near the surface, going down into yellowish coarse sand containing shell fragments and locally, near Keta, hard, laminar, calcareous pan. This lower part of the profile contains a seasonally fluctuating fresh water-table. In the Tertiary deposits, lower-slope profiles consist of a foot or so of greyish, humus-stained, incoherent, medium sand grading down into several feet of pale grey or white sand, locally slightly ironstained, and with a brackish water-table at a depth of 10 or more feet.

The dune sands characteristically support coconut plantations with a sparse ground-cover of short grasses. Where palms have died out from Cape St. Paul wilt disease near Keta, high grassland occurs and cassava is sometimes grown. Under natural conditions, the soils are almost barren of nutrients; but, as the coconut palms often conspicuously indicate, soils around settlements are considerably enriched by the addition of excreta, household refuse and fish remains. Coconuts are sometimes grown on the pale Tertiary sands, but cassava is the usual crop grown and mangoes are often numerous.

Near Keta, intensive cultivation of shallots and maize is practised on artificially built-up soils on the lagoon margins. Dune-sand material is intermixed with the saline lagoon clays; bat and cow dung as well as small fish are added as manure; and water is tapped and run down ditches from the water-table in the sand dune or applied by calabash. There are limited possibilities of extending this form of agriculture because of the restricted area where suitable conditions exist.

The Regosols over Tertiary deposits are droughty and barren. Such soils have little potentiality unless it becomes economic to add large amounts of fertilizers or organic manure and supply irrigation, when they might be used for intensive vegetable production.

Acknowledgements

The author wishes to acknowledge the assistance he has received in the preparation of this chapter from various members of the staff of the Division of Agriculture, Soil and Land-Use Survey Branch, particularly from Mr. A.J. Crosbie, formerly Soil Survey Officer, and Dr. A.S. de Endredy, Soil Analyst. Helpful criticism of the chapter was received from Mr. P.H. Nye, Senior Lecturer in Soil Science in the University College of Ghana, and Dr. P. W. Arnold, Soil Chemist, formerly of the West African Cocoa Research Institute.

Notes on the analytical methods employed

(By A.S. de Endredy, Ph.D., Soil Analyst)

Preparation of the soil sample and gross mechanical analysis.- The gently ground, air-dry soil was passed through a 2 mm. sieve and both the fractions passing and retained by the sieve were weighed separately. The fraction retained by the sieve was further fractionated by sieving into the following fractions: stones, 20 mm.; coarse gravel, were weighed air-dry and the moisture content of the fine earth was determined immediately upon sieving. The moisture content of the coarser fractions is negligible. All results of gross mechanical analysis refer to air-dry material (de Endredy, 1954a).

Mechanical analysis of the fine earth.- The beaker method of sedimentation was used, after removal of calcium carbonate, organic matter and easily soluble manganese peroxide. Fractions were separated according to the international Atterberg scale, i.e. 2-.625, .625-.2, .2-.02, .02-.002 and $<$.002 mm. The percentages reported refer to oven-dry soil (de Endredy, 1954a).

Organic matter.- Organic matter was determined by the method of Walkley-Black, assuming a recovery of 77 per cent against theoretical, i.e. taking one ml. of N potassium dichromate equivalent to 3.9 mg. C. Although this recovery is strictly valid only in the humous horizons of the forest and the red savanna soils, the errors in the lower horizons of these soils and in the entire profile of the Black Earths and related soils of the Accra plains are not too serious because of the generally low carbon content and can be corrected if required (de Endredy, 1954b). Organic matter was calculated by the factor 1.72 from the carbon data.

Total nitrogen.- Total nitrogen was determined by the Kjeldahl method, using a selenium catalyst. The carbon nitrogen ratios were calculated on the basis of carbon values obtained by the Walkley-Black method; consequently they are somewhat low in the Black Earths and related soils (de Endredy 1954a & b).

Moisture.- A 10 gm. sample of the air-dry fine earth was dried in an oven at 105°C to constant weight. Although the moisture content of a freshly ground soil sample may decrease considerably in the first weeks, once the sample becomes really air-dry the moisture content remains remarkably constant in spite of rather large changes in the relative humidity of the air during the year (de Endredy, 1954a).

pH.- The glass electrode was used, employing a soil: water ratio of 1:2. Once the sample is air-dry, the pH remains practically constant (de Endredy, 1954a).

Calcium carbonate.- Calcium carbonate was determined by the Scheibler-Passon method, using 3 N perchloric acid to liberate carbon dioxide (de Endredy, 1954a).

Cation exchange capacity.- A series of experiments has proved that the ammonium acetate method may yield unreliable results. Using .5 N barium acetate solution of pH 8.2 and removing the excess by washing with 80 per cent alcohol, however, remarkably reproducible results are obtained and the sum of the separately determined exchangeable cations and exchangeable hydrogen agree well with the directly determined exchange capacity. Only in a few soils were positive discrepancies observed, i.e. an excess of exchange capacity over the sum of exchangeable cations plus exchangeable hydrogen. Thus the barium acetate method has generally been employed. In montmorillonitic soils, however, exchange capacities determined by both the barium acetate and ammonium acetate method show a tolerable agreement (de Endredy, 1954a; de Endredy & Montgomery, in prep.; Birrell & Gradwell, 1956).

Exchangeable cations.- N ammonium acetate solution of pH = 7 was generally used for leaching and, after removal of ammonium salts, the calcium and magnesium were determined by the improved versenate method, manganese by photometry, potassium and sodium by flame photometry. A technique was developed to correct for any calcium carbonate and water-soluble salts present. In highly calcareous horizons the exchangeable calcium was determined by Hissink's method (de Endredy, 1957).

Conductivity.- The electrical conductivity of a 1:5 soil suspension was measured and corrected to a temperature of 25°C. Conductivity gives a fair indication of the amount of soluble salts present (de Endredy, 1954a).

Total phosphorus.- A 5 gm. sample of the soil was extracted with 70 per cent perchloric acid and the phosphorus determined in the resulting solution by the molybdo-vanadate procedure, using the Spekker photometer with the mercury arc lamp and the Ilford 601 plus Chance OV 1 filter (Quillan, 1955; Nicholas & Pollak, 1950; de Endredy & Quagraine, in prep).

References

BIRRELL, K.S. and GRADWELL, M. 1956. Ion-exchange phenomena in some soils containing amorphous mineral constituents. J. Soil Sci. 7, 130-43.

BRAMMER, H. In preparation. C.F. Charter's interim scheme for the classification of tropical soils. Kumasi, Division of Agriculture, Soil and Land-Use Survey Branch. Occ. Pap. 2.

BULL, R.A. and CHAPAS, L.C. 1956. Some effects of soil applications of magnesium sulphate on the visual symptoms and yields of magnesium deficient oil palms at Calabar. J.W. Afr. Inst. Oil Palm Res. 2(5), 85-91.

de ENDREDY, A.S. 1954a. Analytical methods used in the laboratory of the Department of Soil and Land-Use Survey, Gold Coast. Proc. 2nd Inter-Afr. Soils Conf. 2, 933-43.

———— 1954b. The organic matter content of Gold Coast soils. Trans. 5th Internat. Cong. Soil Sci. 2, 457-63.

———— 1957. Some aspects of the chemistry of Gold Coast soils. (Paper read before a meeting of the West African Science Association, February, 1957. Unpublished.)

———— and MONTGOMERY, C.W. In preparation. Some aspects of cation exchange in Ghanaian forest soils. Kumasi, Division of Agriculture, Soil and Land-Use Survey Branch. Occ. Pap. 2.

———— and QUAGRAINE, K.A. In preparation. Total phosphorus in Ghanaian soils. Kumasi, Division of Agriculture, Soil and Land-Use Survey Branch. Occ. Pap. 2.

GORDON, J. 1956. Coconut fertilizer trial, Atuabo. New Gold Cst Fmr 1, p.54.

HAINES, W.B. and BENZIAN, B. 1956. Some manuring experiments on oil palm in Africa. Emp. J. Exp. Agric. 24, 137-160.

KELLOGG, C.E. and DAVOL, F.D. 1949. An exploratory study of soil groups in the Belgian Congo. Brussels, Institut National pour l'Etude Scientifique du Congo Belge. Serie Sci. 46. p.65.

NICHOLAS, J.W. and POLLAK, F.F. 1950. The isolation of the lines of the mercury arc by filters. Analyst 75, 662-70.

QUINLAN, K.P. et al. 1955. Spectro-photometric determination of phosphorus as molybdo-vanadophosphoric acid. Anal. Chem. 27, 1626-9.

WALDOCK, E.A. et al. 1951. Soil conservation and land use in Sierra Leone. Freetown, Government Printer. pp. 24-5.

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.)						Organic matter per cent				Moisture air-dry soil per cent
	In total soil (air dry)				In fine earth (oven dry)						
	Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	Silt .02-.002	Clay <.002	C	N	C/N	O.M.	
1. 4	Nil	1.0	1.6	97.4	8.51	20.59	3.86	0.286	11.74	6.64	2.56
2. 9	Nil	0.4	12.8	86.8	5.46	13.21	0.71	0.073	9.73	1.22	0.97
3. 18	1.1	0.8	16.9	81.2	5.39	36.36	0.34	0.037	9.19	0.58	1.67
4. 32	0.9	5.0	0.7	93.4	4.44	41.34	0.27	0.041	6.58	0.46	1.73
5. 55	Nil	1.6	5.6	92.8	6.24	47.87	0.22	0.027	8.15	0.38	1.88
6. 94	Nil	1.6	1.9	96.5	10.76	40.22	0.17	0.023	7.39	0.29	2.04
7. 133	Nil	0.6	1.6	97.8	12.25	30.57	0.08	0.025	3.20	0.14	1.54
8. 168	Nil	0.5	1.4	98.1	17.14	11.21	0.05	N.D.	N.D.	0.09	1.12

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25° mohs x 10^6	P (total) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases		
1. 4	7.5	0.072	23.54	14.58	4.00	0.23	1.35	0.48	20.64	N.D.	333
2. 9	7.1	Nil	6.83	2.94	0.80	0.07	0.24	0.20	4.25	N.D.	128
3. 18	5.9	Nil	6.66	1.52	1.02	0.06	0.07	0.14	2.81	N.D.	126
4. 32	5.7	Nil	6.53	1.26	0.86	0.04	0.04	0.16	2.36	N.D.	126
5. 55	5.6	Nil	6.83	0.88	0.68	0.04	0.02	0.19	1.81	N.D.	130
6. 94	5.6	Nil	6.96	0.48	0.41	0.02	0.02	0.24	1.17	N.D.	133
7. 133	5.8	Nil	6.39	0.23	0.42	0.02	0.07	0.23	0.97	N.D.	N.D.
8. 168	5.1	Nil	5.06	0.20	0.32	0.02	0.03	0.14	0.71	N.D.	N.D.

N.D.= No data

Table 1b. Soil group: Forest Ochrosol

Series: Kumasi

Profile No.: PKR 299

Survey: Kumasi Region

Locality: Central Agricultural Station, Kumasi, Ashanti

Site: Upper slope/gentle undulation

Rainfall: 55 inches p.a.

Altitude: 800-850 feet

Vegetation: Forb regrowth

Lower depth of horizon in inches		Mechanical analysis per cent soil (particle size in mm.) — In total soil (air dry): Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	In fine earth (oven dry): Silt .02-.002	Clay <.002	Organic matter per cent: C	N	C/N	O.M.	Moisture air-dry soil per cent
1.	2	Nil	Nil	Nil	100.0	ND	ND	6.11	0.454	13.46	10.51	4.40
2.	11	Nil	3.5	2.6	93.9	ND	ND	1.28	0.137	9.34	2.20	2.30
3.	21	21.4	16.4	20.6		ND	ND	0.71	0.085	8.35	1.22	2.12
4.	33	12.7	42.0	13.9	31.4	ND	ND	0.40	0.061	6.56	0.69	2.02
5.	46	Nil	14.8	6.5	78.7	ND	ND	0.31	0.069	4.49	0.53	2.07
6.	64	Nil	Nil	Nil	100.0	ND	ND	0.28	0.057	4.91	0.48	1.15
7.	79	Nil	Nil	Nil	100.0	ND	ND	0.07	0.047	1.49	0.12	0.92

Lower depth of horizon in inches		pH	CaCO per	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry: Ca	Mg	Mn	K	Na	Total bases	Conductivity 25° mohs x 10^6	P (total) p.p.m.
1.	2	6.4	0.028	43.13	23.74	7.87	0.36	0.30	0.66	32.93	N.D.	556
2.	11	5.1	Nil	16.00	1.63	1.24	0.05	0.10	0.15	3.17	N.D.	424
3.	21	5.0	Nil	13.20	0.50	0.30	0.02	0.07	0.19	1.08	N.D.	436
4.	33	5.1	Nil	10.95	0.46	0.24	0.02	0.07	0.22	1.01	N.D.	453
5.	46	4.9	Nil	9.99	0.32	0.33	0.03	0.03	0.14	0.85	N.D.	395
6.	64	5.5	Nil	6.93	0.22	0.37	0.01	0.03	0.23	0.86	N.D.	402
7.	79	5.4	Nil	6.55	0.29	0.30	0.01	0.09	0.23	0.92	N.D.	N.D.

N.D. = No data

Table 2b. Soil group: Forest Ochrosol

Series: Bekwai

Profile No.: PKR 74

Survey: Kumasi Region

Locality: Near Manso Nkwanta, Ashanti

Site: Upper slope/steeply rolling

Rainfall: 55-60 inches p.a.

Altitude: 1,000 feet

Vegetation: Cocoa

Lower depth of horizon in inches		Mechanical analysis per cent soil (particle size in mm.)						Organic matter per cent				Moisture air-dry soil per cent
		In total soil (air dry)				In fine earth (oven dry)						
		Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	Silt .02-.002	Clay <.002	C	N	C/N	O.M.	
1.	3	Nil	4.0	1.6	94.6	7.59	22.17	2.47	0.189	13.07	4.25	1.78
2.	7	Nil	2.7	1.7	95.6	10.50	27.71	0.82	0.081	10.12	1.41	1.52
3.	16	2.0	23.2	23.2	51.6	11.72	41.94	0.67	0.070	9.57	1.15	2.17
4.	27	Nil	4.9	2.2	92.9	13.88	52.68	0.52	0.059	8.81	0.89	2.33
5.	42	Nil	1.7	0.3	98.0	15.64	54.57	0.42	0.051	8.24	0.72	2.20
6.	66	Nil	0.8	0.7	98.5	17.87	47.82	0.28	0.035	8.00	0.48	2.10
7.	88	Nil	0.7	0.6	98.7	18.40	29.71	0.22	0.032	6.88	0.38	1.56
8.	114	Nil	Nil	Nil	100.0	11.47	21.10	0.18	0.018	10.00	0.31	1.34

Lower depth of horizon in inches		pH	$CaCO_3$ per cent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25° mohs x 10^6	P (total) p.p.m.
					Ca	Mg	Mn	K	Na	Total bases		
1.	3	4.70	Nil	12.60	1.17	0.79	0.03	0.22	0.25	2.46	N.D.	174
2.	7	4.78	Nil	7.31	0.30	0.44	0.01	0.07	0.27	1.09	N.D.	123
3.	16	5.00	Nil	7.83	0.31	0.35	0.01	0.02	0.27	0.96	N.D.	140
4.	27	4.90	Nil	8.42	0.26	0.31	0.01	0.04	0.16	0.78	N.D.	140
5.	42	4.95	Nil	8.47	0.25	0.30	<0.005	0.04	0.13	0.72	N.D.	112
6.	66	5.20	Nil	7.76	0.22	0.25	<0.005	0.02	0.15	0.64	N.D.	107
7.	88	5.20	Nil	6.17	0.19	0.13	<0.005	0.02	0.13	0.47	N.D.	76
8.	114	5.28	Nil	4.93	0.20	0.10	<0.005	0.02	0.22	0.54	N.D.	68

N.D. = No data

Table 3b. Soil group: Forest Oxysol

Series: Boi

Profile No.: LTB 334

Survey: Lower Tano Basin

Locality: Approximately 10 miles north of Esiama, Western Region

Site: Middle slope/steeply rolling

Rainfall: 75 inches p.a.

Altitude: c.150 feet

Vegetation: Forb regrowth

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.) In total soil (air dry) Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	In fine earth (oven dry) Silt .02-.002	Clay < .002	Organic matter per cent C	N	C/N	O.M.	Moisture air-dry soil per cent
1. 3	Nil	Nil	Nil	100.0	25.77	22.74	6.00	0.527	11.39	10.32	2.98
2. 5	Nil	3.8	6.9	89.3	21.19	18.73	1.86	0.197	9.44	3.20	1.52
3. 15	42.6	27.2	10.1	20.1	21.76	19.69	0.80	0.084	9.52	1.38	1.00
4. 24	48.0	34.4	1.6	16.0	11.54	47.99	0.71	0.091	7.80	1.22	2.06
5. 33	Nil	33.8	19.5	46.7	9.31	61.85	0.66	0.090	7.33	1.13	2.53
6. 42	Nil	28.3	9.4	62.3	10.22	70.91	0.43	0.077	5.58	0.74	2.48
7. 60	Nil	27.0	13.8	59.2	15.46	66.43	0.15	0.064	2.34	0.26	2.36
8. 101	13.4	23.1	15.2	48.3	16.81	70.30	0.13	0.064	2.03	0.22	2.36

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry Ca	Mg	Mn	K	Na	Total bases	Conductivity 25^o mohs x 10^6	P (total) p.p.m.
1. 3	5.2	Nil	28.49	11.13	3.14	0.19	0.68	0.30	15.44	N.D.	428
2. 5	4.8	Nil	12.98	2.33	0.83	0.10	0.22	0.20	3.68	N.D.	257
3. 15	5.5	Nil	8.12	2.24	0.62	0.03	0.16	0.18	3.23	N.D.	189
4. 24	5.3	Nil	12.74	2.72	0.60	0.01	0.15	0.21	3.69	N.D.	238
5. 33	5.1	Nil	13.25	1.50	0.60	0.01	0.12	0.21	2.44	N.D.	259
6. 42	4.95	Nil	12.03	0.92	0.59	0.01	0.06	0.12	1.70	N.D.	230
7. 60	5.0	Nil	10.71	0.35	0.42	0.01	0.08	0.09	0.95	N.D.	N.D.
8. 101	5.15	Nil	11.23	0.12	0.11	0.01	0.12	0.20	0.56	N.D.	N.D.

N.D. = No data

Table 4b. Soil group: Forest Ochrosol-Oxysol intergrade

Series: Nzima-Boi intergrade

Profile No.: DKR 61

Survey: Kumasi Region

Locality: Approximately 9 miles WNW of Dunkwa (Ashanti)

Site: Middle slope/gently rolling

Rainfall: c. 60 inches p.a.

Altitude: 450 feet

Vegetation: Forest thicket

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.)						Organic matter per cent				Moisture air-dry soil per cent
	In total soil (air dry)				In fine earth (oven dry)						
	Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	Silt .02-.002	Clay <.002	C	N	C/N	O.M.	
1. 1.5	Nil	0.1		99.9	N.D.	N.D.	5.68	0.497	11.43	9.77	4.27
2. 8	3.0	7.8		89.2	8.63	10.76	0.84	0.097	8.66	1.44	1.63
3. 14	12.9	55.9		31.2	5.84	7.13	0.20	0.028	7.14	0.34	1.32
4. 20	18.5	57.1		24.4	5.97	17.27	0.21	0.062	3.39	0.36	2.54
5. 39	10.6	36.4		53.0	6.39	28.89	0.26	0.062	4.19	0.45	4.28
6. 55	0.9	7.2		92.1	12.41	43.25	0.29	0.058	5.00	0.50	5.40
7. 72	0.2	0.9		98.9	11.35	34.02	0.14	0.042	3.33	0.24	3.78

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25° mohs x 10^6	P (total) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases		
1. 1.5	7.54	0.528	45.06	34.12	7.42	1.15	0.52	0.75	43.96	N.D.	550
2. 8	7.10	Nil	10.33	5.99	1.25	0.18	0.12	0.18	7.72	N.D.	341
3. 14	6.50	Nil	5.82	1.89	0.64	0.10	0.10	0.13	2.86	N.D.	274
4. 20	6.25	Nil	9.29	2.95	1.07	0.13	0.15	0.18	4.48	N.D.	318
5. 39	6.13	Nil	13.55	3.75	2.57	0.05	0.18	0.19	6.74	N.D.	394
6. 55	5.62	Nil	19.49	5.12	5.57	0.08	0.11	0.22	11.10	N.D.	257
7. 72	6.03	Nil	14.12	3.97	4.47	0.10	0.07	0.19	8.80	N.D.	225

N.D. = No data

Table 5b.

Soil group: Forest Rubrisol-Ochrosol intergrade

Series: Wacri

Profile No.: DB 174

Survey: West African Cocoa Research Station

Locality: Block O, Wacri, New Tafo, Eastern Region

Site: Upper slope/gently rolling

Rainfall: 65 inches p.a.

Altitude: 700 feet

Vegetation: Cocoa

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.) — In total soil (air dry): Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	In fine earth (oven dry): Silt .02-.002	Clay < .002	Organic matter per cent: C	N	C/N	O.M.	Moisture air-dry soil per cent
1. 5	Nil	Nil	0.4	99.6	3.73	9.02	0.80	0.0465	17.20	1.38	0.82
2. 11	Nil	Nil	0.8	99.2	3.73	18.94	0.68	0.043	15.81	1.17	1.21
3. 19	Nil	Nil	0.3	99.7	3.83	40.75	0.58	0.047	12.34	1.00	2.29
4. 30	Nil	Nil	0.4	99.6	3.98	39.45	0.34	0.036	9.44	0.58	2.16
5. 41	Nil	6.4	6.1	87.5	4.22	32.21	0.23	0.027	8.52	0.40	1.69
6. 50	Nil	0.3	0.9	98.8	2.75	12.12	0.10	0.012	8.33	0.17	0.67
7. 58	Nil	Nil	Nil	100.0	1.67	2.47	0.01	0.003	3.33	0.02	0.16

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry: Ca	Mg	Mn	K	Na	Total bases	Conductivity 25^0 mohs x 10^6	P (total) p.p.m.
1. 5	6.10	Nil	7.39	2.10	0.92	0.08	0.14	0.33	3.57	N.D.	112
2. 11	5.45	Nil	8.15	0.92	0.39	0.02	0.05	0.27	1.65	N.D.	123
3. 19	5.30	Nil	11.30	0.91	0.38	0.01	0.07	0.33	1.70	N.D.	199
4. 30	5.90	Nil	9.96	0.79	0.40	0.01	0.07	0.43	1.70	N.D.	180
5. 41	5.90	Nil	7.97	0.62	0.50	0.01	0.07	0.51	1.77	N.D.	N.D.
6. 50	4.89	Nil	3.33	0.21	0.25	<0.005	0.03	0.26	0.75	N.D.	N.D.
7. 58	6.40	Nil	0.90	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

N.D. = No data

Table 6b. Soil group: Savanna Ochrosol

Series: Mimi

Profile No.: PNB 25

Survey: Nasia Basin

Locality: Approx. 25 miles W.S.W. of Gambaga.

Site: Upper slope/gently undulating

Rainfall: c. 45 inches p.a.

Altitude: c.500 feet

Vegetation: Cultivation

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.)						Organic matter per cent				Moisture air-dry soil per cent
	In total soil (air dry)				In fine earth (oven dry)						
	Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	Silt .02-.002	Clay <.002	C	N	C/N	O.M.	
1. 4	Nil	15.1	5.3	79.6	ND	ND	0.84	0.062	13.55	1.44	0.87
2. 11	Nil	49.3	14.9	35.8	ND	ND	0.58	0.048	12.08	1.00	1.20
3. 20	Nil	59.6	36.6	3.8	ND	ND	0.52	0.049	10.61	0.89	1.96
4. 32	Nil	57.3	18.5	24.2	ND	ND	0.31	0.036	8.61	0.53	2.12
5. 41	Nil	50.9	22.1	27.0	ND	ND	0.12	0.014	8.57	0.21	2.43
6. 45	Nil	39.1	18.6	42.3	ND	ND	0.12	N.D.	N.D.	0.21	3.94
7. 58	41.3	21.4	10.5	26.8	ND	ND	N.D.	N.D.	N.D.	N.D.	4.32

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity[1]	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25° mohs x 10^6	P (total) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases[2]		
1. 4	7.3	Nil	7.28	3.73	1.09	0.15	0.29	ND	5.26	ND	141
2. 11	6.2	Nil	6.58	2.33	1.09	0.19	0.17	ND	3.78	ND	234
3. 20	6.2	Nil	N.D.	2.35	1.21	0.21	0.26	ND	4.03	ND	260
4. 32	6.6	Nil	11.43	2.83	3.08	0.27	0.32	ND	6.50	ND	193
5. 41	5.7	Nil	N.D.	2.97	3.50	0.18	0.29	ND	6.94	ND	290
6. 45	4.9	Nil	21.59	6.47	8.20	0.09	0.38	ND	15.14	ND	173
7. 58	5.3	Nil	31.66	11.49	13.40	0.38	0.27	ND	25.54	ND	N.D.

1. Barium acetate, pH = 8.2, water washing. N.D. = No data 2. Total without sodium

Table 7b. Soil group: Groundwater Laterite

Series: Kpelesawgu

Profile No.: DNB 239

Survey: Nasia Basin

Locality: Approximately 10 miles south of Bongo Da, Northern Region

Site: Middle slope/very gently undulating

Rainfall: 40-45 inches p.a.

Altitude: 450 feet

Vegetation: Savanna regrowth

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.): In total soil (air dry)				In fine earth (oven dry)		Organic matter per cent				Moisture air-dry soil per cent
	Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	Silt .02-.002	Clay < .002	C	N	C/N	O.M.	
1. 5	Nil	Nil	Nil	100.0	39.75	14.19	1.48	0.098	15.10	2.55	1.62
2. 12	Nil	0.8	0.5	98.7	38.20	17.65	1.06	0.088	12.05	1.82	1.87
3. 30	Nil	10.4	9.5	80.1	37.43	12.00	0.28	0.028	10.00	0.48	1.00
4. 44	Nil	Nil	Nil	100.0	29.62	24.73	0.12	0.018	6.67	0.21	1.48
5. 72	Nil	Nil	Nil	100.0	34.27	19.11	0.08	0.027	2.96	0.14	1.76
6. 92	Nil	Nil	Nil	100.0	25.98	26.84	0.07	0.028	2.50	0.12	2.61
7. 104	Nil	Nil	Nil	100.0	30.09	31.95	0.07	0.023	3.04	0.12	3.19
8. 116	Nil	25.6	12.3	62.1	26.76	41.47	0.07	0.023	3.04	0.12	4.49

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry: Ca	Mg	Mn	K	Na	Total bases	Conductivity 25° mohs x 10^6	P (total) p.p.m.
1. 5	6.4	Nil	14.30	4.70	1.91	0.63	0.14	0.28	7.66	31.4	239
2. 12	6.1	Nil	13.76	4.31	1.94	0.60	0.13	0.23	7.21	< 27.3	199
3. 30	6.0	Nil	6.16	1.64	1.07	0.25	0.08	0.17	3.21	< 27.3	83
4. 44	6.2	Nil	7.71	2.46	2.13	0.19	0.15	0.70	5.63	38.4	55
5. 72	6.9	0.035	9.59	3.01	3.55	0.02	0.15	1.19	7.92	30.7	N.D.
6. 92	8.5	0.022	13.63	4.54	6.00	0.01	0.22	1.63	12.40	47.7	N.D.
7. 104	8.1	0.010	16.41	5.44	7.53	0.03	0.07	1.61	14.68	40.7	N.D.
8. 116	7.8	0.016	30.14	9.78	12.56	0.05	0.23	2.33	24.95	60.1	N.D.

N.D. = No data

Table 8b. Soil group: Grey Neutral Gleisol(?)

Series: Lima

Profile No.: PNB 225

Survey: Nasia Basin

Locality: Approximately 5 miles north of Gushiagu, Northern Region

Site: Bottom/flat

Rainfall: 40-45 inches p.a.

Altitude: 520 feet

Vegetation: Medium grassland

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.)						Organic matter per cent				Moisture air-dry soil per cent
	In total soil (air dry)				In fine earth (oven dry)						
	Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	Silt .02-.002	Clay < .002	C	N	C/N	O.M.	
1. 3	Nil	Nil	Nil	100.0	1.1	5.4	0.73	0.054	13.52	1.26	0.56
2. 9	Nil	Nil	Nil	100.0	1.0	6.9	0.38	0.031	12.26	0.65	0.52
3. 15	Nil	Nil	Nil	100.0	0.9	12.5	0.38	0.031	12.26	0.65	0.71
4. 38	Nil	Nil	Nil	100.0	0.8	21.8	0.16	0.034	4.71	0.28	1.21
5. 76	Nil	Nil	Nil	100.0	1.1	29.7	N.D.	N.D.	N.D.	N.D.	1.75

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25° mohs x 10^6	P (total) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases		
1. 3	7.9	0.02	6.04	3.72	1.46	0.07	0.41	0.15	5.81	N.D.	188
2. 9	7.7	Nil	4.19	2.25	0.88	0.04	0.21	0.11	3.49	N.D.	156
3. 15	6.8	Nil	5.01	1.83	1.18	0.05	0.24	0.17	3.47	N.D.	190
4. 38	5.5	Nil	4.99	1.01	0.95	0.02	0.22	0.19	2.39	N.D.	202
5. 76	5.6	Nil	5.66	1.62	0.98	0.02	0.10	0.30	3.02	N.D.	N.D.

N.D. = No data

Table 9b. Soil group: Savanna Ochrosol

Series: Toje

Profile No.: APA 405

Survey: Accra Plains

Locality: ½ mile west of Tema, Eastern Region

Site: Summit/gently undulating

Rainfall: 25-30 inches p.a.

Altitude: c. 100 feet

Vegetation: Savanna regrowth

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.) — In total soil (air dry): Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	In fine earth (oven dry): Silt .02-.002	Clay < .002	Organic matter per cent: C	N	C/N	O.M.	Moisture air-dry soil per cent
1. 5	Nil	Nil	Nil	100.0	2.57	4.11	0.74	0.044	16.82	1.27	0.71
2. 10	Nil	Nil	Nil	100.0	2.01	3.84	0.29	0.021	13.81	0.50	0.47
3. 20	Nil	Nil	Nil	100.0	1.88	5.26	0.20	0.018	11.11	0.34	0.76
4. 28	Nil	Nil	Nil	100.0	1.39	30.39	0.45	0.041	10.98	0.77	4.26
5. 39	Nil	12.3	6.0	81.7	2.76	28.04	0.14	0.024	5.83	0.24	4.43
6. 54	Nil	14.1	9.6	76.3	4.19	31.84	0.22	0.021	10.48	0.38	4.98
7. 74	Nil	4.2	4.2	91.6	5.10	15.66	0.23	N.D.	N.D.	0.39	3.44
8. 97	4.5	13.1	5.2	77.2	5.54	14.09	0.04	N.D.	N.D.	0.07	3.43

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry: Ca	Mg	Mn	K	Na	Total bases	Conductivity 25° mohs x 10^6	P (total) p.p.m.
1. 5	6.40	Nil	5.23	2.14	1.61	0.16	0.09	0.07	4.07	< 27.8	63
2. 10	5.95	Nil	3.24	1.11	0.90	0.04	0.04	0.05	2.14	< 27.8	45
3. 20	6.05	Nil	3.54	1.09	0.90	0.03	0.13	0.19	2.34	37.6	45
4. 28	6.00	0.024	16.22	5.07	4.63	0.02	0.09	1.75	11.56	35.7	89
5. 39	7.35	0.011	18.31	7.22	6.42	< 0.005	0.10	2.95	16.69	95.2	55
6. 54	8.8	1.391	N.D.	5.96	11.21	0.12	0.13	4.49	21.91	297.6	58
7. 74	8.5	0.078	20.59	7.46	6.61	0.01	0.08	4.30	18.46	124.2	N.D.
8. 97	8.7	0.072	19.94	8.12	7.11	0.02	0.08	3.72	19.05	136.0	N.D.

N.D. = No data

Table 10b. Soil group: Regosolic Groundwater Laterite (?)

Survey: Ho-Keta Plains

Rainfall: 35-40 inches p.a.

Series: Ziwai

Locality: Approximately 5 miles north of Sogakope, Trans-Volta-Togoland Region

Altitude: 130 feet

Profile No.: HK 315

Site: Middle slope/gently undulating

Vegetation: Tall grassland with Borassus palms

6/72

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.): In total soil (air dry)				In fine earth (oven dry)		Organic matter per cent				Moisture air-dry soil per cent
	Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	Silt .02-.002	Clay <.002	C	N	C/N	O.M.	
1. 5.5	Nil	Nil	Nil	100.0	7.3	32.2	1.74	0.103	16.89	2.99	5.95
2. 15	Nil	0.1	0.4	99.5	7.0	36.8	0.84	0.058	14.48	1.44	6.59
3. 24	Nil	0.5	3.5	96.0	8.9	42.0	0.63	0.044	14.32	1.08	7.43
4. 30	2.4	1.0	3.8	92.8	9.0	46.1	0.45	0.032	14.06	0.77	7.99
5. 41	30.6	18.9	3.5	47.0	7.6	39.7	0.17	0.014	12.14	0.29	7.27
6. 48	1.7	12.4	2.8	83.1	10.6	40.9	0.09	N.D.	N.D.	0.15	7.35
7. 57	Nil	1.1	0.8	98.1	11.0	27.2	N.D.	N.D.	N.D.	N.D.	5.92
8. 72	16.1	1.4	0.5	82.0	10.4	13.8	N.D.	N.D.	N.D.	N.D.	3.82

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity[1]	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25^0 mohs x 10^6	P (total) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases		
1. 5.5	6.4	0.05	39.80	21.49	12.66	0.13	0.21	0.60	35.09	56	306
2. 15	7.0	0.09	39.21	20.80	11.40	N.D.	0.17	1.00	33.37	53	257
3. 24	8.2	2.20	41.70	26.20	13.10	N.D.	0.20	2.20	41.70	195	264
4. 30	8.3	5.00	42.90	26.09	16.90	N.D.	0.21	3.10	46.30	222	283
5. 41	8.4	18.80	40.46	22.80	12.60	N.D.	0.13	3.10	38.63	246	409
6. 48	8.4	12.10	41.89	22.10	15.00	N.D.	0.20	3.20	40.50	246	880
7. 57	8.4	2.00	34.00	19.60	14.00	N.D.	0.20	2.80	36.60	229	1535
8. 72	8.6	0.65	22.15	11.88	10.27	N.D.	0.17	1.71	24.03	170	1508

1. Horizons 1 and 2, barium acetate, pH 8.2; horizons 5 and 6, sodium acetate, pH 8.2, water washing; remaining horizons, ammonium acetate, pH 7.0 N.D. = No data

Table 11b. Soil group: Tropical Black Earths

Survey: Kpong Pilot Area, Accra Plains

Rainfall: c. 45 inches p.a.

Series: Akuse

Locality: Traverse 28/32 chains, Kpong Pilot Area, Eastern Region

Altitude: 60 feet

Profile No.: APA 370

Site: Middle slope/very gently undulating

Vegetation: Savanna

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.)						Organic matter per cent				Moisture air-dry soil per cent
	In total soil (air dry)				In fine earth (oven dry)						
	Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	Silt .02-.002	Clay <.002	C	N	C/N	O.M.	
1. 2	Nil	Nil	Nil	100.0	2.52	3.17	0.43	0.031	13.87	0.74	0.57
2. 12	Nil	Nil	Nil	100.0	1.91	4.23	0.34	0.027	12.59	0.58	0.54
3. 21	Nil	Nil	0.1	99.9	2.62	33.68	0.48	0.043	11.16	0.83	5.27
4. 60	Nil	0.1	0.8	99.1	7.15	31.39	0.07	0.010	7.00	0.12	5.41
5. 74	Nil	2.7	0.6	96.7	6.84	31.12	0.04	N.D.	N.D.	0.07	4.94

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity[1]	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25° mohs x 10^6	P (total) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases[2]		
1. 2	6.1	0.025	2.53	0.77	0.67	0.04	0.29	0.41	2.18	70.7	32
2. 12	6.2	Nil	2.56	1.32	0.72	0.01	0.23	0.37	2.65	52.8	32
3. 21	6.5	Nil	17.91	10.42	5.34	<0.01	0.65	2.19	18.60	282.9	64
4. 60	7.6	Nil	20.73	12.16	6.08	0.01	0.32	6.94	25.51	754.4	54
5. 74	8.1	1.48	21.01	9.42	7.42	0.01	0.34	3.00	20.19	713.8	N.D.

1. Ammonium acetate, pH 7.0 2. Corrected for sulphates but not for chlorides N.D. = No data

Table 12b. Soil group: Tropical Grey Earth

Series: Agawtaw

Profile No.: APA 509

Survey: Accra Plains

Locality: ½ mile south of Ashaiman, mile 16½, Accra-Ada road, Eastern Region

Site: Lower slope/gently undulating

Rainfall: 25-30 inches p.a.

Altitude: 100 feet

Vegetation: Savanna

Lower depth of horizon in inches	Mechanical analysis per cent soil (particle size in mm.) — In total soil (air dry)				In fine earth (oven dry)		Organic matter per cent				Moisture air-dry soil per cent
	Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth < 2	Silt .02-.002	Clay <.002	C	N	C/N	O.M.	
1. 2	Nil	Nil	Nil	100.0	N.D.	N.D.	2.02	0.085	23.76	3.47	0.34
2. 8	Nil	Nil	Nil	100.0	N.D.	N.D.	0.27	0.012	22.50	0.46	0.02
3. 23	Nil	Nil	Nil	100.0	N.D.	N.D.	0.08	0.006	13.33	0.14	0.06
4. 31	Nil	Nil	Nil	100.0	N.D.	N.D.	3.10	0.113	27.43	5.33	1.95
5. 47	Nil	Nil	Nil	100.0	N.D.	N.D.	3.58	0.088	40.68	6.16	3.74
6. 61	Nil	Nil	Nil	100.0	N.D.	N.D.	0.13	0.006	21.67	0.22	0.06

Lower depth of horizon in inches	pH	$CaCO_3$ per cent	Cation exchange capacity[1]	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25^{o} mohs x 10^{6}	P (total) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases		
1. 2	5.25	Nil	3.47	0.50	0.31	<0.005	0.05	0.11	0.97	N.D.	52
2. 8	5.65	Nil	0.87	0.18	<0.01	<0.005	0.05	0.14	0.37	N.D.	43
3. 23	5.80	Nil	0.82	0.15	<0.01	<0.005	0.02	0.04	0.21	N.D.	38
4. 31	4.85	Nil	25.64	0.35	0.24	<0.005	0.04	0.09	0.72	N.D.	73
5. 47	4.85	Nil	41.28	0.31	0.16	<0.005	0.02	0.07	0.56	N.D.	84
6. 61	5.90	Nil	1.25	0.15	<0.01	<0.005	0.02	0.03	0.20	N.D.	14

1. Horizons 1-3 and 6, ammonium acetate, pH 7.0 N.D. = No data

Table 13. Soil group: Groundwater Podsol

Series: Atuabo

Profile No.: LTB 443

Survey: Lower Tano Basin

Locality: Atuabo, Western Nzima, Western Region

Site: Flat bottom

Rainfall: c. 85 inches p.a.

Altitude: c. 5-10 feet

Vegetation: Short grass Savanna