FERRIC ACRISOLS:
A CASE STUDY OF KUMASI SERIES, GHANA

A major thesis presented in partial fulfilment
of the requirements for the degree of
Master of Science

By
Paul Derigubaa
Ghana
1985

Approved by:
Drs. J.H.V. van Baren

M.SC.-COURSE IN SOIL SCIENCE AND WATER MANAGEMENT,
AGRICULTURAL UNIVERSITY, WAGENINGEN, THE NETHERLANDS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEDICATION

This thesis is dedicated to my heart felt Daddy, the late Zeng Derigubaa, whom I missed sorrowfully while studying in Wageningen.

ACKNOWLEDGEMENT

I owe immense gratitude and thanks to drs. J.H.V. van Baren of the International Soil Reference and Information Centre, who motivated and guided me throughout the preparation and writing of this thesis.
Many thanks are also due to drs. Driesen and Dijkerman, all of the Agricultural University, who assisted me on the land evaluation aspects of this study. Equally I owe Mr. Miedema of the same university for his untiring advice on the micromorphological and soil genesis of this study.
Finally my sincere thanks go to the Government of the Netherlands who provided funds that enabled me to study in Wageningen.

Paul Derigubaa.

ABSTRACT

For effective land evaluation, the scale for the soil survey should match with the scale of the intended potential users, who are usually small scale farmers. Soil Monolith papers seem to fit in best for this scale of farmers.

Ferric acrisols as a soil unit are well developed and highly leached, red or yellow tropical soils that possess a pronounced argillic horizon and low base saturation.
They are naturally poor in potassium, have low CEC and fix phosphorus due to the high amounts of free iron. They pose Al-toxicity and acidity problems to crop production. They have low available moisture holding capacity and are hence drought proned in ustic or drier moisture regime zones.

Split application of chemical fertilizers and liming materials is necessary to correct their nutrient problems.
In the traditional systems, burnig, fallowing and mound making are some of the farming systems and cultural practices adopted to improve their fertility.

1. INTRODUCTION

1.1 Justification and objective

Soil is the largest component of the earth and is required to support everything - living or dead, active or inactive. Hence its uses are infinite. However, unlike other natural resources such as trees and animals which can be produced or raised to meet a growing demand, soil is fixed in quantity and, to some extent, quality. This means that different kinds of land use compete with a limited amount and quality of soil. It is therefore imperative and inevitable that some uses have to be foregone in favour of others.
As most uses do not only require the soil but the environment in general as well, the term "land" will be used forth with, thus to incorporate the whole complex of properties which together define a "use" requirement.

To select among the potential land uses, soil classification and correlation, and land classification studies are usually undertaken and appropriate criteria formulated to assess the suitability of the land for a given use. The ultimate criterium being that "that use which yields the highest net benefit with sustained productivity to the society" is the most rational choice. International organisations such as FAO as well as national soil survey and research institutions have undertaken many small scale soil evaluations to meet these demands. However, because of the too small a scale (1 to milion or smaller) of such studies, most of the facts and conclusions cannot avoid averages and generalizations. The result is that they are not applicable to the scale of the target group. Direct application of such recommendations undoubtedly meet serious limitations and even hazards.
A larger scale study is in fact required for each land use and each land location. It is this vacuum that the writer wishes to meet using a soil series "Kumasi series" located in the semi-deciduous forest belt of Ghana as a case study. The soil is one of the collections of the International Soil Reference and Information Centre (ISRIC), Wageingen in the Netherlands.

1.2 Scope and limitations

In this study attention is focused on soil genesis and classifications which reflecton the soil characteristics as related to the land qualities and land use requirements of the study.
The FAO-UNESCO legend, USDA and the Ghana classification systems are discussed and the setbacks of each outlined. As land consists of other elements apart from soil, extra issues such as weather/climate and socio-economic factors also are presented.
The qualitative aspects of FAO (1979), Agroecological Zone Evaluation Project for Africa are used for selected crops evaluation. The evaluation is basically a physical one and represents the first of a two stage approach scheme as defined by the FAO Framework for Land Evaluation (1975).
Effective land evaluation results also require that they be checked and backed with practical field trial data. As time is a constraint on the current study, only the theoretical results can be given. It is the intention of the writer to test the results under field conditions on his return home to Ghana.
All terms, unless otherwise specified, are used in accordance with the FAO Framework for Land Evaluation (1975) terminology and that of the Soil Survey Manual (USDA 1951).

2. GENERAL INFORMATION AND SETTING

2.1 General issues on ferric acrisols

2.1.1 Properties and central concept

Acrisols, the general group to which ferric acrisols belong, are the real old tropical soils of regions with a distinct dry and wet season or a monsoon type of climate (Buringh, 1979). They are highly weathered and leached. Hence they are exhaustive and have low base saturation as well as low weatherable minerals. As a result they are chemically poor and to some extent physically limiting to root development due to the high level of argillization (Sanchez, 1973).
Under the FAO-UNESCO legend (1974) acrisols are defined as "soils having an argillic B horizon with a base saturation of < 50% (by NH_4OAc) at least in the lower part of the B horizon within 125 cm of the surface. They lack a mollic A horizon, an albic E horizon that overly a slowly permeable horizon. The distribution pattern of the clay and the tonguing which are diagnostic for planosols, nitosols and podzoluvisols respectively are absent. They should not have an arid moisture regime."
The specific definition ferric acrisol requires in addition to the above properties:

- an ochric A horizon
- ferric properties
- no high organic matter in the B horizon
- no plinthite within 125 cm of the surface
- no hydromorphic properties within 50 cm of the surface.

2.1.2 Global extension

In figure 2.1 the general locations where ferric acrisols are mapped are shown. They are found between latitudes 30° North and 20° South. Table 2.1b shows the distribution by countries. The tropical and subtropical areas of Asia account for some 48.5% of the mapped ferric acrisols followed by Africa of 36.8%. Ferric acrisols are not mapped or are not yet identified in Europe and South America, though associations and inclusions are indicated in South America. In Africa they are most extensive spreading widely in Tanzania, Uganda, Central African Republic and the West semi humid areas, involving Nigeria, Ghana, Ivory Coast and Liberia. In the Asian continent they occur in the more humid parts of the Southeast, comprising Indonesia, India, China and Taiwan. Very extensive inventories are mapped in Papua New Guinea and New Caledonia mainly in the lowlands and the West coasts. Here they have been developed on varied rock types of deeply weathered pleistocene sediments and andesitic rocks.
In the North American continent they are observed on the gently sloping and hilly areas of Northern Alibama, East Texas, Florida and the Missouri states all of the United States of America.

Fig. 2.1 Locations where Ferric Acrisols are mapped in the world according to FAO-UNESCO Vol. II-X

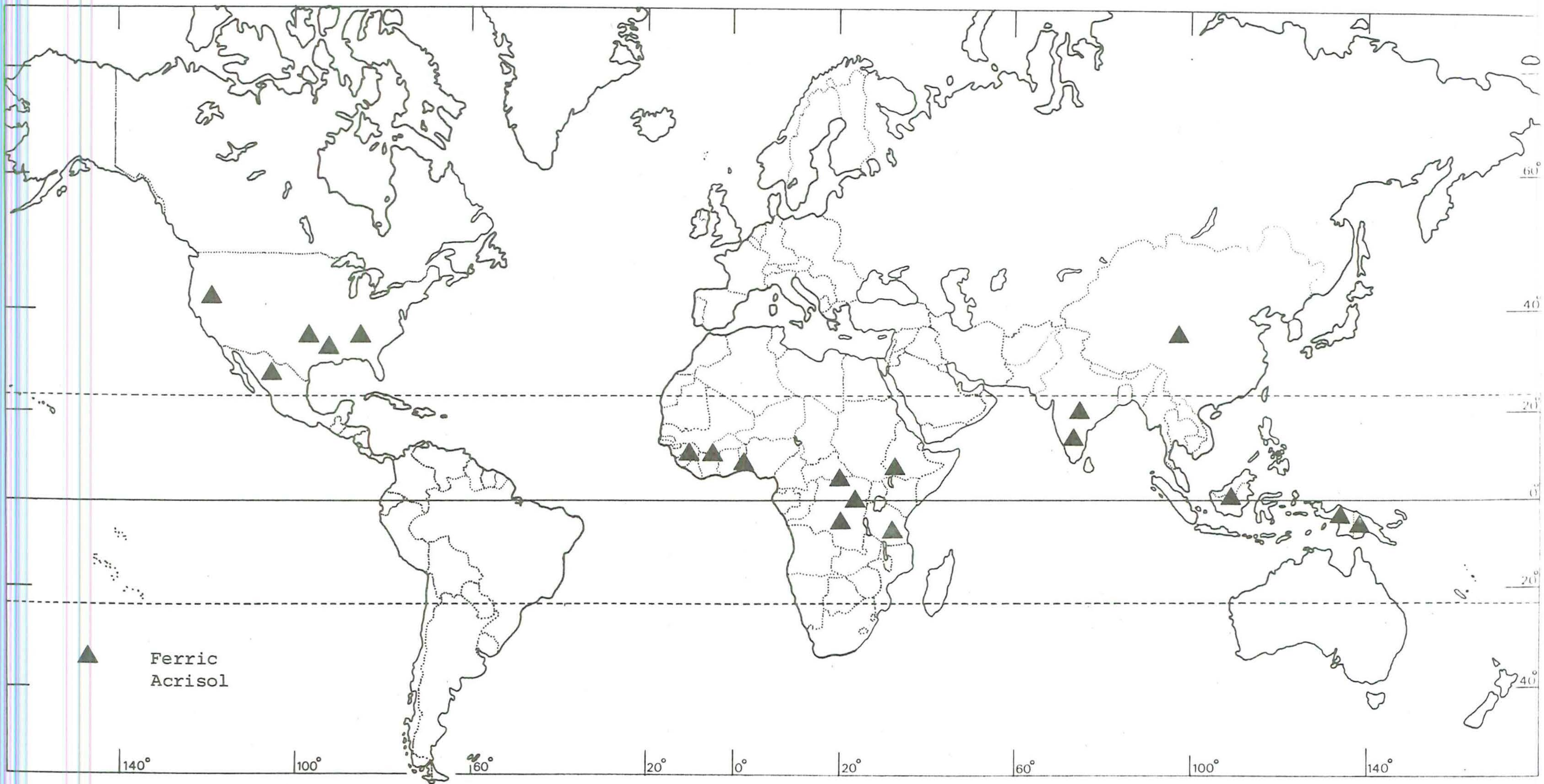


Table 2.1a World distribution of ferric acrisols calculated from FAO-UNESCO Soil Maps 1974 Vols. IV - VI.

	Extension (x 10³ ha)
Africa	58929
Nigeria	3785
Cameroon	75
Ghana	534
Guinea	5374
Ivory Coast	11560
Mali	586
Tanzania	28161
Liberia	836
Ethiopia	478
Central African Republic	4240
Uganda	2137
Chad	42
Zambia	18
Kenya	32
Madagascar	32
% of world total	36.8 %
Asia	77563
China	45112
Taiwan	2123
Sri Lanka	157
Bangladesh	57
India	2739
Sumatra	1908
Java	1120
Kalimantan	3452
Irian Jaya	3380
Lao	1113
Thailand	7632
Viet Nam	3941
Peninsular Malaysia	2665
Singapore	58
Democratic Kampuchea	4106
% of world total	48.5 %

Table 2.1 continued.

	Extension (x 10^3 ha)
Australasia	3927
New Caledonia	206
Papua New Guinea	3721
% of world total	2.5 %
North America (USA)	19580
Northern Alabama + East Texas	6210
Florida	3610
Tennessee + Mississippi + Arkansas	8260
Missouri	1500
% of world total	12.2 %

2.1.3 Global agricultural uses

The agricultural uses of ferric acrisols are varied. In Africa, yams, cassava, groundnuts and maize are cultivated. In most cases thecropsare planted on mounds and ridges raised manually or by machines. Flat planting is equally important involving crops such as rice, banana, cocoa, oil palm, coffee and rubber.
In most of these areas, soil fertility is rejuvenated by alternate fallowing and cropping, land/crop rotations and in the less densly populated areas, shifting cultivation. Permanent or continuous cropping is only common with tree crops and compound farms, the latter considered as gardens for their usually small sizes.
In North America, basically the U.S.A., Maize, cotton, tobacco, vegetables, forage and citrus fruit trees are planted. With regards to the Asian continent, uses include rice and potatoes on the gentle sloping areas and natural forests on the hilly areas of India, while cassave is more prominent in Indonesia on such soils. In some cases exhaustive use of the land has led to the evolution of anthropic savanna dominated by Imperata cylindrica. In addition to thecrops mentioned soyabeans, wheat, peas and poppies are grown in China and Taiwan. In Mexico the most widespreas crops are pineapple and cassava.

The listed crops do not in any way portray that soil is the sole determinant of the choice of crop. There are more complex processes such as climate, man (Sombroek 1965) that mihilate ereptic non-edaphic crop cultivation.

2.2 Regional environmental setting

2.2.1 Weather and climate

Ghana lies between latitudes 4° and 11° North, and longitudes 1° and 3° West. It is hence entirely tropical. The Kumasi series discussed here is located near Kumasi, a town lying in the heart of the country (fig.

2.1a). The weather elements of the whole country are influenced by the movement of two air masses. These are the Northeast Trade Winds and the Southwest Monsoons which oscillate with the rythm of the sun movement. The southwest monsoons originate from the Atlantic Ocean and blow in the southwest direction. They are cool and heavy moisture laden. As the sun "moves" northwards and approaches the Tropic of Cancer so do the southwest monsoons bringing rain with it. The sun "moves" northwards from April till it reaches northmost movement point in July - August. During this period the land air humudity is highly enriched. the data in table 2.3 show a steady rise of the relative land atmospheric humidity from April to a peak in August, and decline thereafter giving ir roughly a parabolic function. With the increased humudity rainfall rises accordingly and potential evapotranspiration falls (see tables 2.2 and 2.4). The temperatures are moderated by the clouds overcast but generally monthly temperatures rarely fall to below 25°C. Temperature variations are minimal, from 4°C to 6°C.

In contrast to this airmass, the Northeast Trade Winds, locally called "Harmattan", are extremely hot and dry. They come from the northeastern direction originating from the Sahara desert carrying a lot of dust. They desiccate the existing air moisture, small water sources and practically all moist objects. During the time they cover the land, trees shed their leaves to prserve moisture. They enter the country from late October (after the monsoons have retreated) and reach their southmost point in February.

The two airmasses meet at a zone called the Intercontinental zone. This zone marks the peak rainfall as the different airmasses undercut each other causing air ascensions, especially the monsoons. It passes through Kumasi twice a year; one in July - June in its nortward journey and the other in October when it is on its return to the south. This explains the bimodal rainfall and two wet seasons as shown in table 2.1b. Farmers have taken careful notice of this and plan their farming activities to match with this pattern. For example during the minor dry season which lasts from late July to late August, the minor cocoa crop is harvested and dried making use of the sunshine. The major harvesting starts late November. Only crops with very short growth duration are cultivated in the minor wet season (late August to middle October), while the major cropping is done during the longer wet period. It must however be emphasized that rainfall in subsahara region is generally more unpredictable than temperatures. Hence agricultural planning using the weather data face enormous risks of crop failure.

2.2.2 Geology and geomorphology

About three-fifths of Ghana is composed of Pre-Cambrian rocks, all more or less metamorphosed and folded (Bates, 1960). The remainder of the country, consisting of the middle section of the basin of the river Volta, together with the valleys of its main tributaries, the Sene, Afram, Mole, Daka and Oti and several comparatively small areas on the coast, is underlain by flat orgently sloping sediments. these sediments are of Palaeozoic age and their base represents the Cambrian unconformity, a regular feature in many parts of African geology. The sediments on the coast range in the age from Devonian to Recent.

CLIMATE

Table 2.1b AVERAGE MONTHLY AND ANNUAL RAINFALL FOR KUMASI IN mm AND NO. OF RAIN DAYS IN BRACKETS

Major dry season				Major wet season					Minor dry season	Minor wet season		Annual Total	No. of Years
Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.		
99.31 (11)	32.00 (3)	22.35 (2)	59.18 (6)	139.19 (10)	146.05 (10)	184.15 (13)	233.68 (17)	124.96 (13)	73.66 (11)	173.48 (17)	200.91 (28)	1488.92	55

Table 2.2. TEMPERATURE IN °C FOR KUMASI

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Average	No. of Years
Maximum	Absolute	33.88	35.00	33.88	33.88	33.33	31.66	30.55	30.55	30.00	31.66	32.77	32.22	32.22	10
	Mean	31.11	32.88	32.05	32.05	30.44	30.16	27.83	27.27	28.05	30.44	30.94	30.55	30.33	
Average Mean Monthly Temperature		26.66	27.72	27.72	27.38	26.11	26.11	24.38	24.16	24.61	25.88	26.05	25.61	26.00	
Minimum	Absolute	19.44	19.44	20.00	20.00	20.00	18.88	18.88	20.55	20.00	18.88	17.22	16.11	18.88	
	Mean	22.22	22.50	22.44	22.72	21.77	22.05	21.00	21.11	21.22	21.33	21.16	20.61	21.66	

Table 2.3 AVERAGE MONTHLY RELATIVE HUMIDITY IN PER CENT FOR KUMASI

Hour	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Average	No. of Years
0900	88	85	87	87	86	88	90	91	91	89	87	90	88	10
1500	50	48	55	61	65	70	74	76	73	67	62	58	63	

SOURCE: KUMASI AIRPORT, 10 km NE OF PROFILE SITE, 300 m a.s.l.

The geology of Ghana is too wide to be covered in detail in a single chapter. Table 2.4 gives a summary of succession and local names and description. attention will be singled on the geology of the study area. Kumasi is occupied by the middle Pre-Cambrian formation which has undergone metamorphic folding. Overlying this formation are sediments which are much younger. These are observed in the area as geosynclined sediments with great intrusion of medium textured grained granites. This sort of complex formation has given rise to the term "Basement Complex" in most literature of West African geology (Miedema and Van Vuure, 1977; Dijkerman, 1981; Peter Ann, 1967). Locally the formation is called Birrimian formation. It is further characterised by large batholiths as well as granodiorites with biotite, muscovites and schists. The sediments on top are predominantly argillaceous while the metamorphic products are mainly phyllites.

Table 2.4 Geological succession in Ghana.

Time Divisions		*Local Name and Description*
Quaternary	Recent	Unconsolidated clays and sands of lagoon, delta and littoral areas.
Tertiary	Upper Tertiary	Partly consolidated red continental deposits of sandy clay and gravel.
	Eocene	Marine sediments, sandstone, glauconitic sandstone, clay and shale, limestone, oil sand.
Mezozoic	Upper Cretaceous	
	Upper Jurassic	'Amisian'. Freshwater series of bouldery and sandy clays and conglomerates.
Palaeozoic	Devonian	'Sekondian'. Marine series of sandstones, shales, black sulphurous shales. 'Accraian'. Middle Devonian only, sandstone and shale.
	Silurian Ordovician Cambrian	'Voltaian'. Sandstone, shale, mudstone, conglomerate, limestone, tillite.
Pre-Cambrian	Upper	'Buem formation'. 'Togo series'. 'Tarkwaian'. Folded and metamorphosed sediments. Not granitized or intruded by granites.
	Middle	'Birrimian'. Geosynclinal sediments and volcanics, partly granitized and greatly intruded by granites.
	Lower	'Dahomeyan'. Massive crystalline gneisses and migmatites representing thick series of argillaceous, calcareous and arenaceous sediments, but with few schist remnants

Note: = unconformity.

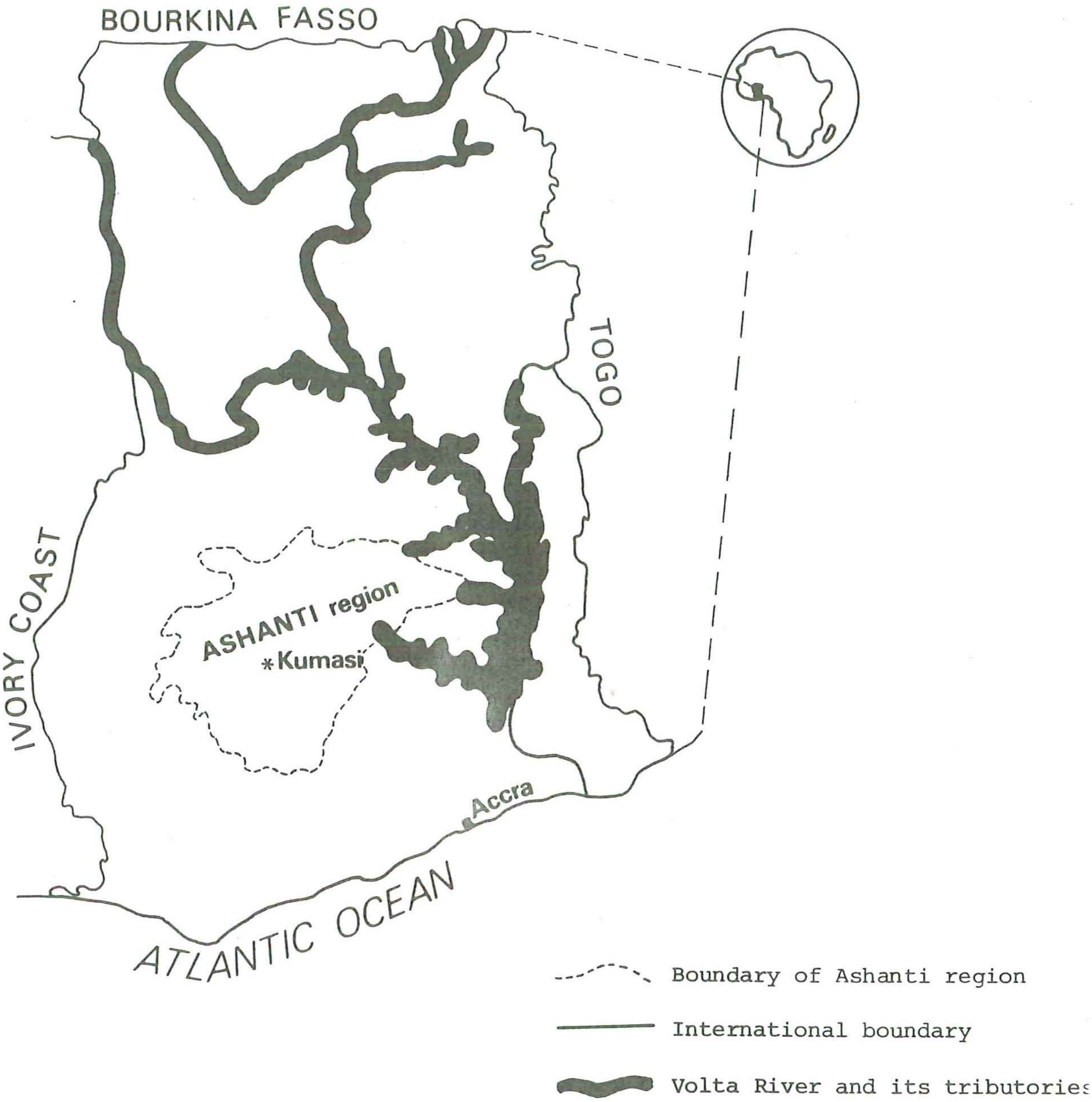


Fig. 2.1a Profile location and Volta river systems

A classical sample analysis of the mineralogy of Kumasi is given in table 2.5. It can be observed that silica (SiO_2) and aluminium oxides (Al_2O_3) form the bulk of the rocks. the mineral composition undoubtedly influences the soil type to be developed.
In fig. 2.2 an illustration of the country (west to east) geological section is drawn. The general observation is that granite is a common base composition throughout. Kumasi lies in the middle of two geosyncline formations - the Bibiani and Konongo towns of lower and upper Birrimian formations respectively.

Table 2.5 Minerals ingranite sample in Kumasi.

Mineral	% by weight
SiO_2	72.59
Al_2O_3	15.18
FeO	4.13
MgO	1.01
CaO	0.45
Na_2O	1.17
K_2O	3.86
H_2O^+	0.81
H_2O^-	0.24
CO_2	0.00
TiO_2	0.12
P_2O_5	0.27
S	0.05
MnO	0.02
SrO	0.00
BaO	0.00
Li_2O	0.00
Cr_2O_3	0.00
V_2O_5	0.00

Source: Junner, N.R. (1959): The geology of the Bosumtwi Calders and surrounding. Kumasi Geological Survey no.8, Ghana.

On the geomorphological scene, the country is divided into four main regions (fig. 2.4). These are:

- the Accra - Ho - Keta plains
- the forest zone
- the Voltaian Basin
- the area of crystalline rocks to the north and west of the Voltaian Basin.

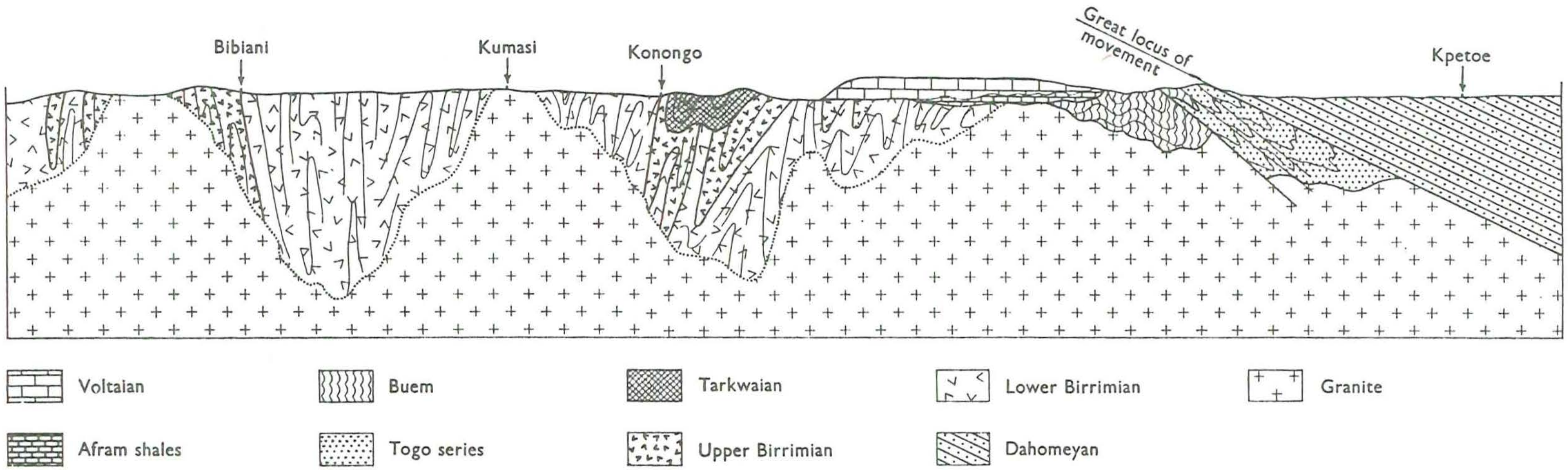


Fig. 2.2 Diagrammatic geological section from the Volta Region to Bibiani.

The Accra - Ho - Keta plains form an area of low relief rarely rising above 7620 cm. Drainage patterns differ on either side of the Volta. On the Accra plains a low watershed running east - west divides the streams flowing north into the Volta from those flowing south to the sea.

The forest zone, which the study area is located, covers some 700 km². The rocks are aligned generally from northeast to southwest. the coast only has small bays and indentations, formed by joints and faults in the rock. there are a number of elongated lagoons, some developed from river outlets which have been deflected along the coast by the drifting sand. Inland there are ancient crystalline rocks. They are steeply dissected and have a youthful topography. The summits of the hills are fairly flat. The deepest valleys are cut down to 4.6 meters below the summits and at this depth they are generally flat-floored. The shallower valleys are v-shaped.

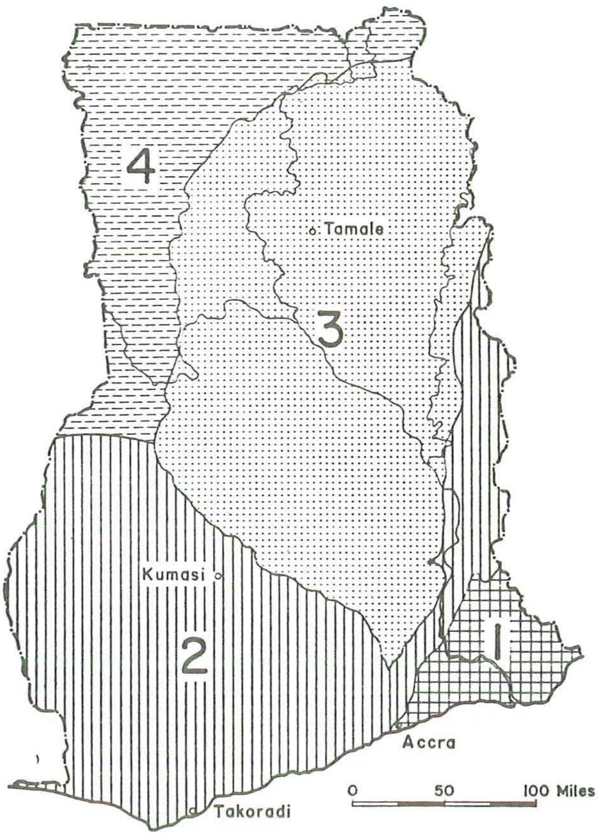


Fig. 2.3 Map showing the geomorphological regions of Ghana.

1. The Accra–Ho-Keta plains.
2. The forest zone (the area of intermediate plateaux).
3. The Voltaian Basin.
4. The area of crystalline rocks to the north and west of the Voltaian Basin.

Over the lower Birrimian rocks the topography is gently rolling. Broad, flat-floored valleys are separated by gently rounded hills. In the upper Birrimian, relief is steeper; the hills rise to some 3 meters above the valleys which are still flat-floored. But the hills are steep-sided and frequently capped with ironpan and bauxite.

The Voltaian Basin rather has very uniform topography. Slopes are gentle everywhere, sloping only towards the rim of the basin and where resistant bands of rock outcrop or peneplain residuals occur. It is the main area where the Volta river and its tributaries flow through. The White Volta enters the basin in the north near Baweku from Burikina Fasso and the black Volta at Bamboi. Most of the tributaries of the Volta, however, have their sources outside the Voltaian Basin. Within the Basin the drainage is centripetal. Throughout the mahor streams and rivers are incised to a depth of 760 cm - 1200 cm. Above the river banks terraces occur at 1829 -2286 cm, 3048 - 3657 cm and 7620 - 9144 cm.

The area of crystalline rocks to the north and west of the Voltaian Basin has very gently undulating topography also, only broken lose and those by low ironpan capped remnants of the mid-Tertiary surface. The topography is further diversified by more extensive ranges of Birrimian and Tarkwaian hills. Much of the area is covered with groundwater laterite soils.

2.2.3 Land use and vegetation

Apart from infrastructure such as roads, buildings etc. the current land use in the area includes cocoa, coffee, cassava, plantain, maize, cowpea, etc. cultivation (table 2.6). The choice of the crop normally depends on how long the area has been cleared and cultivated. For example cocoa is planted on newly cleared lands, maize on somewhat old lands and cassava on exhausted soils.
The natural tree species found include:
Triplochiton scleroxylon, *Celtis mildbraedii*, *Pertersia africana*, *Ceiba pentandra*, *Sterculia rhinopetala*, *Pycnanthus angolensis*, and *Piptadenia africana*.

2.2.4 Farming and land tenure systems

The farming systems in the area, like all others in the other parts of Ghana, have undergone a series of changes as necessitated by the changing scenes of scientific, economic, social and political interactions. Initially shifting cultivation was common. this changed to land rotation as infrastructural developments, such as houses, became difficult to move or expensive to construct in new settlements. As population pressure on land increased, the system changed again into land fallow and later crop rotation.

The system observed today is a sort of hide breed, adopted to suit the current scene. The forest is partly cleared so that woody vegetation speedily regenerates after cropping. Mixed cropping is done and this has a number of reasons. To begin with, arable farming is currently mainly for subsistence. Farmers want to be as much self sufficient and secured against crop failure as possible. Hence they grow a bit of each crop that they need in the household.

Table 2.6 Crops grown in Ashanti Region, Ghana.

Crop	Pure stand	Mixed stand Predom.	Mixed stand Subsid.	Pure stand equiv.	Yield	No. of holders	Ave. size of field
	acres	*acres*	*acres*	*acres*	*lb/acre*		*acres*
ASHANTI REGION							
Cocoa	911,000	747,000	55,000	1,312,000	–	77,600	22.1
Coffee	14,000	4,000	3,000	17,500	–	6,000	3.5
Cola	1,000	0	31,000	16,500	–	–	–
Sugarcane	1,000	0	0	1,000	0	1,000	1.0
Coconut	0	0	0	0	–	–	–
Oil palm	1,000	2,000	126,000	65,000	–	9,900	13.0
Plantain	13,000	77,000	649,000	376,000	5,483	124,100	6.0
Citrus	2,000	10,000	22,000	18,000	–	–	–
Maize	32,000	85,000	25,000	87,000	1,018	80,000	1.5
Rice	7,000	3,000	0	8,500	900	3,200	3.1
Guinea corn	0	0	0	0	–	–	–
Millet	0	0	0	0	–	–	–
Cassava	13,000	37,000	83,000	73,000	8,365	102,900	1.3
Yam	0	5,000	46,000	25,500	4,443	32,500	1.6
Cocoyam	2,000	44,000	368,000	208,000	6,678	114,900	3.6
Groundnut	1,000	1,000	3,000	3,500	1,210	3,200	1.6
Bean	0	0	0	0	–	–	–
Pineapple	0	0	10,000	5,000	7,500	–	–
Vegetable	2,000	9,000	11,000	12,000	–	–	–
Tobacco	0	0	0	0	–	–	–
Rubber	0	0	0	0	–	–	–
Cotton	250	0	0	250	–	–	–
Total	**1,000,250**	**1,024,000**	**1,432,000**	**2,228,750**		**147,700**	

Source: FAO (1974) Increases farm production through fertilizer use: Ghana, Vol.1.

Secondly, from their own experience it is not enough to have money, but whether one can get food or other goods to buy with the money. Thirdly, mixed cropping was handed over to them from past generations and they never experienced soil fertility problems, as compared to the current agitated for monocropping as the main source of plant nutrients is natural fertility. Last but not least, mechanical harvesting or chemical fertilizer application is common only in limited situations. Thus they do not encounter incompatible practices.

The initial land development starts with slashing the vegetation with cutlasses and selective felling of trees. The vegetation slashed is than allowed to dry and burnt. Ploughing and bulldozing are not done. Hence the soil is little disturbed during the land preparation. Sowing is done with cutlasses and hoes, depending on the type of crop to be planted. The greater soil disturbance is with root crops such as cassava, cocoyam and yam, when harvesting must be done by digging. However, these are usually the last crops (especially cassava) in the crop rotation before the fallow period. Fallowing becomes necessary when yields fall below economic thresholds and weed infestation is precarious.

The land tenure system in Kumasi is rather complex and requires lengthy discussion than is probably necessary for this study. Hence only a simplified version is outlined here. In principle all land is vested in the Ashanti*) stool. In practice however, individuals own the land and can dispose of it according to their wishes. Owners either cultivate it themselves with or without hired labour. They may also sell it outright or lease it for cash for a given period of time, after which ownership

* Ashanti is the administrative region of the indigenous tribe Asante of the study area.

is reverted. In some cases the leasing is on shares. The user cultivates and the harvest is shared with the land owner according to the terms of the agreement. In maize farming for example the land owner collects 1/3 of the produce, while 2/3 goes to the user. But all costs from the land development to marketing are borne by the user. For cocoa production the opposite is the case: 1/3 is for the user and 2/3 for the land owner. But here the costs and establishment of the cocoa plantation is the responsibility of the land owner. The user only comes in to maintain the plantation by weeding and also the harvesting of the crop.
In other cases the owner may ask the user to establish the plantation and they share, in which case the portion given to the user becomes the users permanent property. There are all sorts of intermediaries inchange of ownership of the land and the use to which it is put.

3. SITE AND SOIL

3.1 Location of the pedon

The profile GH3, used for the study of Kumasi series, was taken at a site 1 km northwest of the main offices of the Central Agricultural Station, kwadaso and some 8 km west of the Kumasi City offices, 6°40'N and 1°40'E. It stands at some 250 m above mean sea level. It is located on the upper part of a convex slope of 3% and has an undulating surrounding which varies between 2% to 6% in slope (fig. 3.1).
There are no microtopographical features in the area. Standing on a well-drained position of the catena (fig. 3.1) the groundwater table was not reached at 320 cm depth.
There are no outcrops, no stones and no bolders. At the time of the study the profile site was with a semi-deciduous forest. This is locally called "Fofua", connotating a secondary forest as opposed to "Kwayee", a virgin forest.

3.2 Position in the catena

In fig. 3.1 a cross section of the catena to which Kumasi series form part is sketched. The series and its associates belonging to forest Ochrosols (in the Ghana classification system, table 3.2) are red, brown and yellow-brown, relatively weathering products of intermediate or moderatelyu acidic rocks. They extend from the peneplain drifts covering the summit (Boamang series) through somewhat terraces to a flat valley (Ofin series) and the undulating patterns of Chichiwere series. A diagrammatic profile presentation of the associated series is included in fig. 3.1. Generally, the colour of the soils in the subhorizons 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.
In the valley bottom series colour varies 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 the internal drainage conditions on different parts of the topography.

On the well-drained upper slopes the iron is well oxidized and the soils are reddish in colour. As the drainage conditions become poorer downslope, the iron becomes increasingly hydrated (Van Breemen, 1985). In the poorly drained valley bottom, reducing conditions persist throughout much of the year and iron is either washed out of the soil or is present in the ferrous state (reduced state), 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 or rusty stains along root-channels. This phenomenon has been argued for many possible causes and will be discussed in section 3.3 as it is specific for the pedon of study.

It is uncorrect to assign the same textural class to all the series in the catena, even thogh the parent material is the same for all the series (by definition of a catena). The texture is influenced by the topographical site, level of biological activity abd drainage condition.

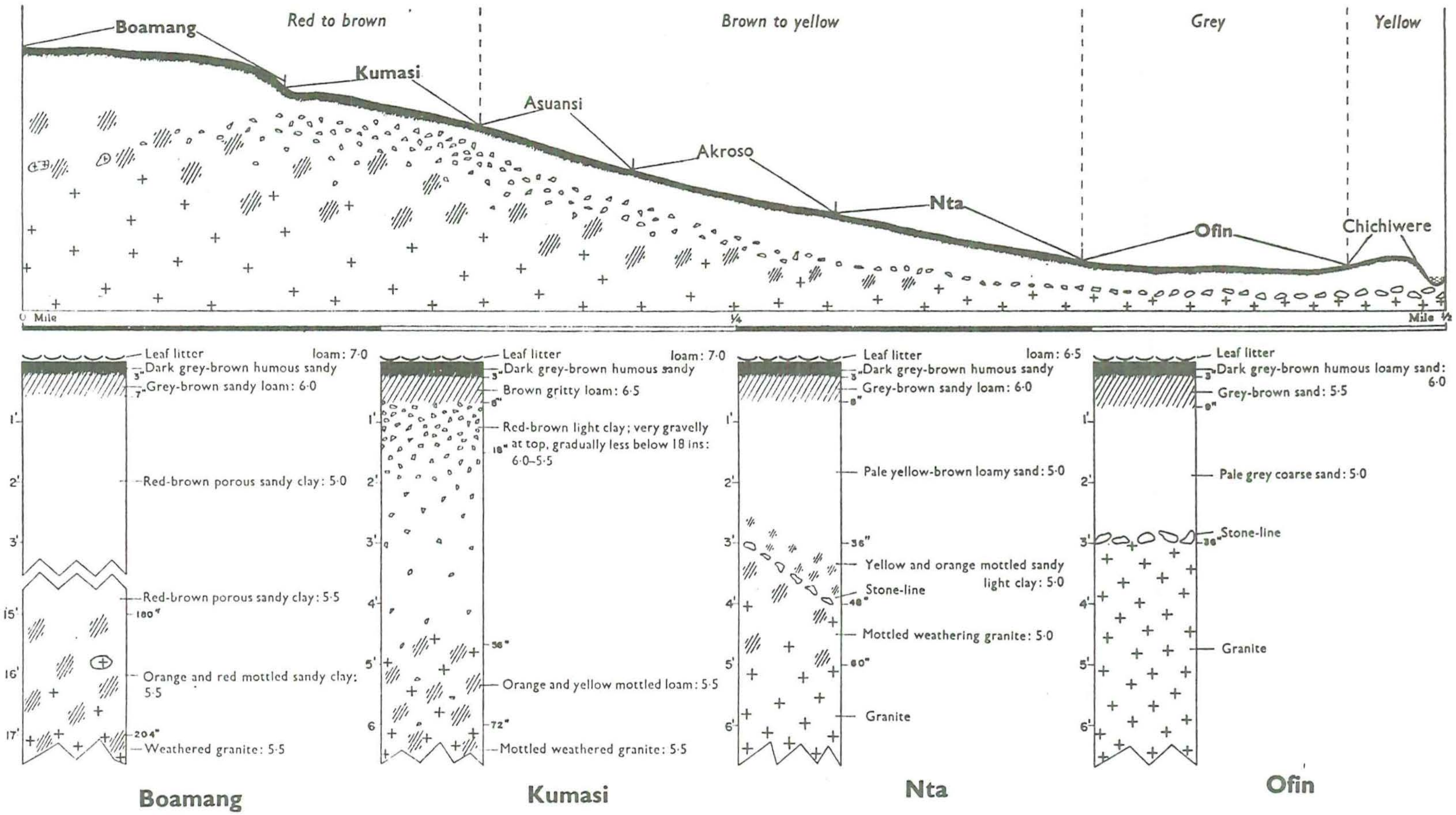


Fig. 3.1 Idealized section illustrating a Ferric Acrisol association over granite and a peneplain residual (near Kumasi airport).

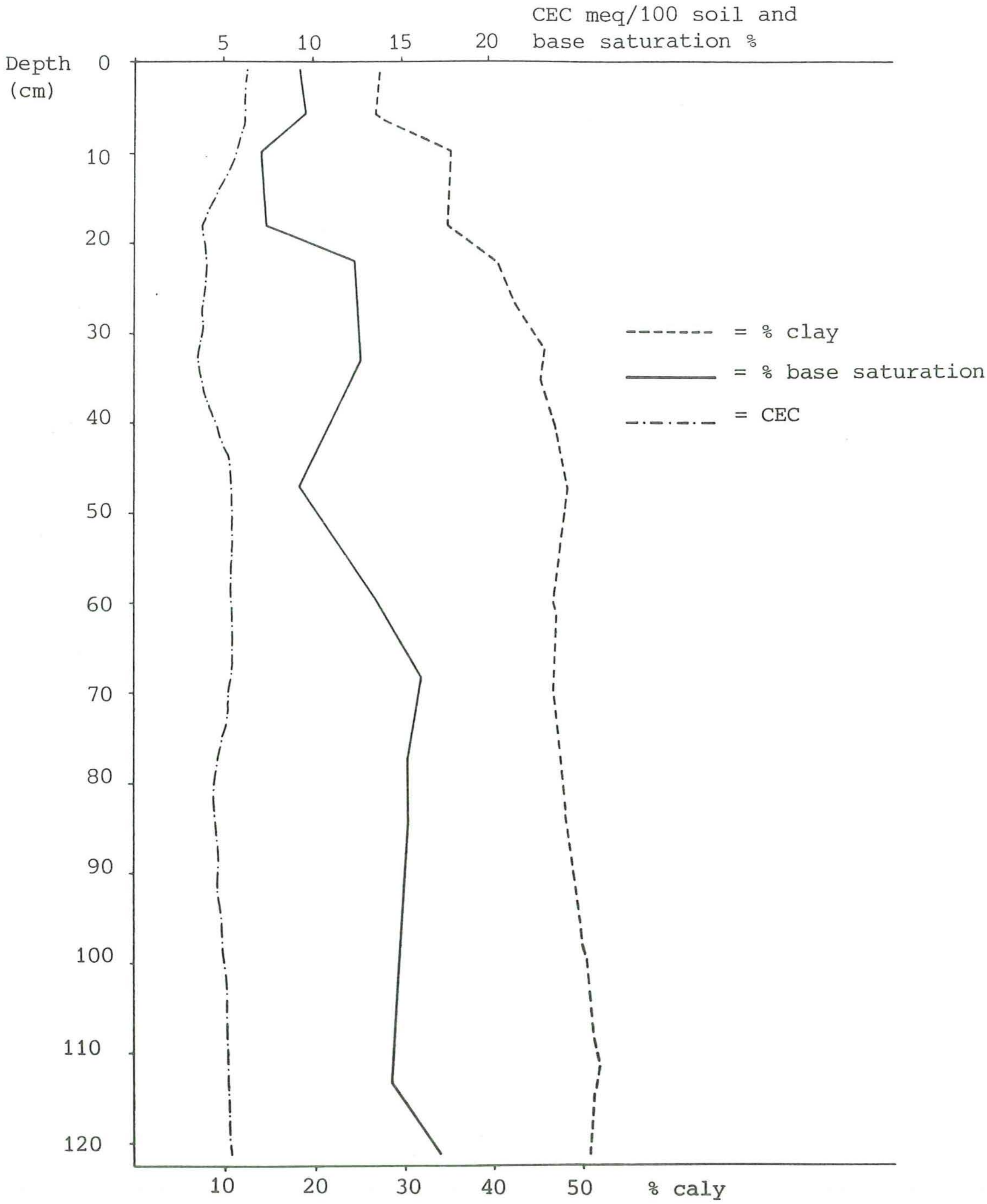


Fig. 3.2 Clay content, CEC and base saturation perc.
Variations as function of depth

The parent material is the same and is derived from schales, phyllites and schists (chapter 2). The clay mineralogy is dominantly kaolinite. There are also iron and alluminium oxides in some of the series, especially in the acidic ones.

3.3 Physio-chemical properties

Most of the analyses carried out on the series show a marked concentration of nutrients in the topsoil (Brammer, 1962; Obeng et al, 1975; ISRIC, 1985) and make it clear that the greater part of these nutrients is associated with the organic matter. The subsoil is strongly weathered and leached, showing but traces of the cations K^+, Mg^{2+} and Ca^{2+} (Appendix A). The parent material is far below 1.7 m although traces of rock can be found above this depth.

In the micromorphological analyses parent materials of pure quartz are seen at 2 m (Appendix B). The pH-H_2O is generally acidic, varying from 4.3 to 4.9. The cation exchange capacity is also low, ranging from 6.6 meq/100 g soil in the bottom to 9.0 meq/100 g soil at the top. This further elucidates that the exchangeable cations are accounted for by the organic matter, and not the minerals. The base saturation is also low in all horizons, again with the maximum in the surface.

These data illustrate that management practices to improve the fertility should be through the application of organic manures. If the chemical fertilizers are applied alone, much of it will leach away. Alternatively split application of the chemical fertilizers can be done by placement method as the last resort.

3.4 Soil genesis

There has been intensive illuviation of clay, organic celloids and iron as evidenced in both the micromorphological studies (Appendix B) and the chemical and physical analysis (Appendix A). From the mineralogical analysis (Appendix C) the soil is dominantly kaolonitic. In summary these analyses show the following soil forming processes.

- Accumulation of organic matter in the topsoil.
- Deep argilization with low CEC and low base saturation.
- A gravel-free surface relative to the subsurface.
- Gley features of iron mottles and glaebules of plinthite in the midhorizons.

The organic matter accumulation is due to the thick vegetative cover. During the short dry season (late November to early March), the trees shed their leaves which decay to enrich the humus content of the soil. Due to optimal conditions for decomposition (high temperatures and well drained condition) peat formation or thick layer of organic matter is not possible. The exponential decrease of cations with depth of soil maybe due to reclycing of nutrients by rooting trees. Lower depths also contain high amounts (114 cm) possibly due to leaching beyond the effective rooting depth.

Soil Taxonomy (USDA, SCS 1975) attributes two conditions for argillic horizon formation Viz:

1) There must be forces to eluviate the argillans down.
2) There must be forces to stop the eluviation and thus illuviate the argillans within the descriptive horizons of the pedon.

From the agropedological point of view, translocation of argillans from surrounding toposequences can also account for argillization provided the translocation is differential, thus providing a rather decreasing amount of clay from bottom to top. This seems to be the situation in the pedon.
There is a dry season as well as a wet season which offer alternate drying and wetting , necessary to eluviate and illuviate. With each cycle consisting of dry and wet seasons, the depth of argillic horizon increases.
Gilkes et al (1973) postulate that the age of the process of argillizationcan be estimated from this with a few chronological wearly measurements.

According to Dommergues and Diem (1982) and Lee (1971) termites and earthworms carry the finer soil particles < 0.2 mm to the surface to build their houses and mounds. When they leave or die these moulds of fine earth are washed down by rainfall particles or through human activity and thus dilute the gravel proportion in the surface.
Miedema (personal communication) and Dijkerman et al (1974) in their study of similar soils in Njala and Makeni in Sierra Leone, additionally postulated this to the surfacial drift translocation of clays from the top parts of thegentle slopes to the middle and upper parts of the slope of the catena in the form of massflow of supersaturated soil solution. This was supported by the evidence of clay cutans in transverse sections of peds in their micromorphological studies.

In a similar analytical study and argument, they attributed the formation of iron mottles and plinthite glaebules to the following geological historical theory as opposed to the alternate oxidation-reduction chemical processes, outlined in section 3.2. According to them, in the old geological Precambrian era, the humid belt of West Africa was all under poorly drained marshy swamps. As time progressed, geological structure transformation occurred with the consequent uplift of the baseline of the groundwater table. thus the upper part of the geomorphology currently attained a well-drained status, while the lower parts are still poorly drained. According to them, the ferrous ions oxidezed irreversibly to ferric oxides and remain as plinthite glaebules up to this date. To acount for the bright red colours Van Breemen (1985) in his lectures on tropical soil formation explained that at near neutral pH-values the solubility of ferric iron is verylow. Thus when the highly mobile ferron ions are released during weathering in the iron rich minerals in moist condition, they move to areas of low concentration by ion chemo-dynamic forces which are orientated towards the well drained areas and are quickly oxidized to the ferriciron form and equally participate as the fine bright colour iron oxides called goethite. Goethite is one of the most abundant mineral identified in the mineralogical analysis (Appendix C).

The mineralogical composition further shows that the pedon is almost at its last stage of of soil development, as most of the minerals are weathered leaving only more stable ones like goethite and quartz.

3.5 Soil classification

Three main classification systems will be dicussed. These are

- the FAO-UNESCO soil legend (1974)
- the USDA Soil Taxonomy (1974)
- the Ghana classification system.

The first two are closely related in some aspects, especially in the diagnostic horizons and properties. The last system is gradually fainting out of use, due to the standardization of classification, currently pursued world wide and in Ghana as well.

3.5.1 FAO-UNESCO soil legend.

3.5.1.1 Diagnostic horizons

The profile GH3 only possesses a few characteristics typifying a mollic epipedon. the required depth is ≧ 25 cm as the texture is clayey. The structure is massive and thecolour value too light within the specified depth. However, it satisfies the P-status and organic matter content requirements. These combined characteristics place the profile GH3 as one with an ochric epipedon. the horizons Ap3 through Bt6 qualify the profile for an argillic subhorizon. This is because it possesses the following properties:

- There is more clay in the illuvial horizon than in the eluvial horizon, 40.8% in Ap3 compared to 33.3% in Ap2. The ratio of clay content to that in the eluvial horizon is more than 1.2 (this is 1.22); since the latter has total clay content 33.3 which falls in the range 15 - 40%.
- The argillic B horizon is more than 100cm which far exceeds the minimum of 15 cm. (Fig. 3.2).
- The soil is massive in some horizons as described in the fiels data sheet (Appendix D) and has some orientated clays (Appendix B) indicated by channel vosepic and glaesepic reorientation special features.
- Peds are met presentin the argillic B horizon and hence the requirements for peds are waived.
- Also the pedon GH3 shows no lithological discontinuity.
- It has no characteristics and properties of a natric horizon.

3.5.1.2 Diagnostic properties

The profile has many coarse mottles with hues redder than 7.5 R. Between 18-114 cm, there are between 25-30% ironstone concretions and gravels with hue from 2.5 YR to 5 YR. The CEC/100 g clay by depth (table 3.1) is lower than the upper limit of 25 meq/100 g clay required for ferric properties. These calculations were even made without correcting for the organic matter content. Hence the values could be much lower. Thus there are ferric properties.

Table 3.1 Organic matter (%) and CEC contents.

Depth (cm)	CEC* meq/100 g clay	Organic matter content** %
0- 7	27.8	5.0
7- 11	21.6	3.3
11- 18	16.7	1.3
18- 23	14.7	1.6
23- 33	12.5	1.0
33- 46	14.3	1.0
46- 70	14.1	0.8
70- 87	11.0	0.7
87-114	11.5	0.7
114-122	12.6	0.7

Source: Calculated using data of Appendix

$$* \quad \text{CEC } (NH_4OAct)/100 \text{ g clay} = \frac{\text{CEC } (NH_4OAct)/100 \text{ g soil}}{\text{g clay}/100 \text{ g soil} \times \frac{1}{100}}$$

** An assumed indicative value of 30% was used as the content of organic matter. This minimum value gives maximum value for organic matter.

3.5.1.3 Classification

The organic matter content calculated is 1.27% weighed average over a depth of 100 cm, assuming the lower limit of 30% organic carbon in the organic matter (organic matter is known to contain between 30% - 61% organic carbon depending on climate and the nature of the organic matter; Slangen, 1982). Thus the organic matter content is insufficient to place GH3 as either a ferrasol or nitosol, as these require 1.35% and 1.5% respectively as the minimum levels per the fine fraction of the earth material. However the diagnostic properties qualify GH3 for an acrisol. That is there is an ochric A horizon directly overlying an argillic B horizon, which was ferric property. The base saturation is less than 50% throughout the horizons. Further it has neither an albic E horizon nor a mollic A horizon overlying a slowly permeable horizon. Thus a planosol is excluded.

The presence of ferric properties and the fact that the percentage of clay decreases from its maximum amount of 54% to 33%, a difference of 21% within 150 cm of the surface, excludes a nitosol. It has no spodic B horizon and hence can not be a spodosol. The absence of an aridic moisture regime rules out the xerosols and termosols (fig. 2.2).

The preclusion of all these classes leaves the profile the only possibility of an ferric acrisol. This is further explained by the fact that there is an ochric A horizon showing ferric properties, but lacking a high organic matter content in the B horizon (defined in 2.3.1.3) as well as no plinthite within 125 cm of the surface; nor does it have hydromorphic properties within 50 cm of the surface in the definition of the FAO-UNESCO soil legend (1974, p.29).

3.5.2 USDA Soil Taxonomy

3.5.2.1 Diagnostic horizons

The epipedon of the profile GH3 has the following properties that satisfy a mollic epipedon:

- Colour value (moist) of 3 from 0-7 cm depth. That is the colour value is less than 3.5.
- Non-massive and not hard soil structure in the same depth.
- P_2O_5 (citric acid) value 28.4 ppm.
- A very low "n" value.

However, italso has the following properties which exclude the occurrence of a mollic epipedon.

- Base saturation of less than 50% in all the horizons.
- The minimum required depth or thickness is 25 cm as the profile has sandy texture.

In further examination following the scheme as outlined in the USDA Soil Taxonomy (1975) pp 28-39, the only diagnostic epipedon is an ochric surface horizon.

The horizons Ap2 through Bt5 form an argillic subhorizon. The definition and soil properties connotative of an argillic subhorizon are the same as those of the FAO-UNESCO legend discussed insection 3.3.1.2.

3.5.2.2 Other diagnostic characteristics

Using 20-80 cm as the control section, the profile has generally a clayey particle size class. However, there is an intermittant clayey - skeletal in the depth 46-70 cm. That is except for this depth which has 35% by volume of rock fragments (≧ 2 mm), the rest has less than 35 % by volume of rock fragment and more than 35% by weight clay in the fine fraction. Both soil moisture and soil temperature are not available for the control section. However deducing from the climatic data in fig. 3.3 and table 2.2 a number of conclusions can be made. Fig. 3.3 shows that the period when potential evapotranspiration exceeds rainfall cumulative and continuous is less than 90 days. Considering the fact that excess and stored moisture ismavailable after the first few days ofrainfall deficit over evapotranspiration it is convincing to conclude that the soil is never dry for a period more than 90 dys within the control section and hence has a udic moisture regime.

Similarly the air temperatures are high, well above 22°C and varying by less than 5°C. Hence the control section soil temperature is assumed to vary within the same range in the equilibrium thermal state between soil and the atmosphere. This gives rise to an isohyperthermic temperature.

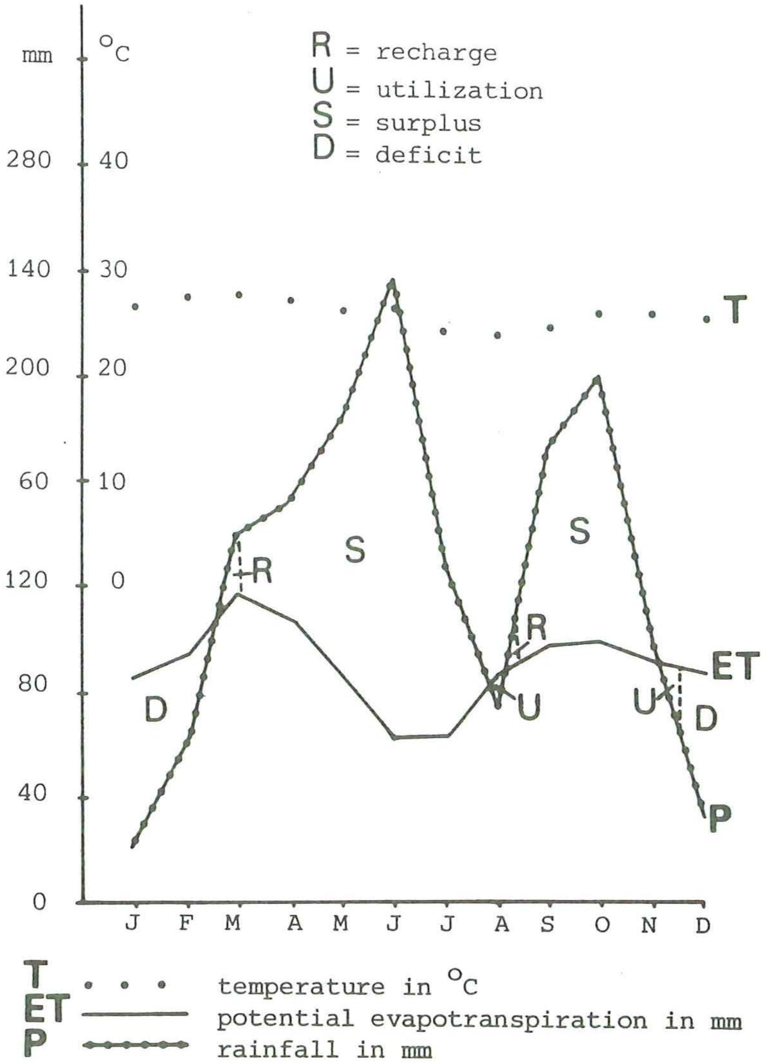


Fig. 3.3: Climatic data and water balance

Month	P (mm)	ETo (mm)
January	22	86
February	59	92
March	139	117
April	146	106
May	184	87
June	234	63
July	125	63
August	74	83
September	173	96
October	201	98
November	99	93
December	32	87
total:	1488	1071

Table 3.2 PROVISIONAL CLASSIFICATION OF SOILS SO FAR DISCOVERED IN GHANA[1]

Order	*Suborder*	*(Soil Group Family)*	*Great Soil Group*	*Great Soil Subgroup*
CLIMATOPHYTIC EARTHS	HYGROPEDS	Latosol	Forest Ochrosol	Red Forest Ochrosol
				Yellow Forest Ochrosol
			Savanna Ochrosol	Red Savanna Ochrosol
				Yellow Savanna Ochrosol
			Forest Oxysol	Red Forest Oxysol
				Yellow Forest Oxysol
		?Basisol	Forest Rubrisol	Red Forest Rubrisol
				Yellow Forest Rubrisol
			Savanna Rubrisol	Red Savanna Rubrisol
				Yellow Savanna Rubrisol
			Forest Brunosol	
			Savanna Brunosol	
	XEROPEDS		(Reddish Prairie ?)	
TOPOHYDRIC EARTHS	PLANOPEDS	Very Acid Planosol ?	Groundwater Podsol	
		Acid Planosol ?	Groundwater Laterite	
		Calcium Planosol	Tropical Black Earth	
			Tropical Brown Earth	
		Sodium Planosol ?	(Tropical Grey Earth)	
	DEPRESSIOPEDS	Very Acid Gleisol	(Savanna Grey Very Acid Gleisol)	
		Acid Gleisol	(Savanna Black Acid Gleisol)	
			(Savanna Brown Acid Gleisol)	
			(Forest Grey Acid Gleisol)	
			(Savanna Grey Acid Gleisol)	
		Neutral Gleisol	(Forest Black Neutral Gleisol)	
			(Savanna Brown Neutral Gleisol)	
			(Forest Grey Neutral Gleisol)	
			(Savanna Grey Neutral Gleisol)	
		Calcium Vleisol	(Black Vleisol)	
			(Brown Vleisol)	
			(Grey Vleisol)	
		Sodium Vleisol	Solonetz ?	
			Solonchak	
	CUMULOPEDS	Cumulosol	Very Acid Bog ?	
			Acid Bog ?	
			Saline Bog ?	
	HYDROPEDS	Hydrosol	Neutral Hydrosol ?	
			Saline Hydrosol	
LITHOCHRONIC 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)	
			(Dune-sand Regosol—without calcareous pan)	
			(Other Regosols)	
	ALLUVIOPEDS	Alluviosol	(Black Alluviosol)	
			(Brown Alluviosol)	
			(Grey Alluviosol)	

N.B. (i) The use of brackets round a term indicates that the nomenclature is still provisional.
(ii) ? before a term indicates that there is some doubt as to the exact place of 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 examined within the group indicated or of the soil group in the group family indicated.

[1] This classification table is based on information available at the end of 1956

3.5.2.3 Classification

Following the key outlined in the USDA Soil Taxonomy p. 91 onwards, the profile is classified as folllows:
The possession of an argillic subhorizon with base saturation less than 35% throughout the whole profile with hue and value of 5 YR and 3 respectively in the epipedon places the profile GH3 into the Ultisol order. Further, it is well-drained and has low organic carbon of about 0.4% in the upper 15 cm of the argillic horizon, which is lower than the minimum level of 0.9% required for a Humult. It is neither a Aquult because the profile is well-drained. The udic moisture regime qualifies the profile for an Udult.

In the great group of the suborder Udults, GH3 has colour value of less than 4 in some but not all parts of the epipedon. Ap2 (11-18 cm) has a colour value of 4. The argillic horizon has a dry colour value less than 5 except for the depth 87-114 cm (Bt5). Hence it can not be a Rhodudult although an intergrade of it at a lower taxa is possible due to the substantial properties of the Rhodudult that the profile has.

As a resuilt of the isohyperthermic temperature regime and other characteristics mentioned earlier, the profile is classified as a Tropudult. Following further thekey, (p. 368) it can be observed that the profile GH3 would have met the requirement for a typic Tropudult, butfor the fact that the CEC requirement is short of. It is only in the topmost epipedon (0-7 cm) that the CEC NH_4OAct is more than 25 meq:100 g clay (table 3.1). The remaining depths are all below this. Thus under the yet to be completed subgroup taxa, GH3 is an orthoxic Tropudult. It may be recalled that GH3 was not considered as possessing oxic horizon because the illuvial clay difference just exceeded the upper limit of 20 within 1.5 m from themaximum to the minimum clay content horizons. Al other qualities of an oxic horizon were observed. Thus even though incomplete, the current level of classification at the subgroup fits GH3 quite well.

For the family differentiae, GH3 has a clayey-skeletal particle size class withinthe control section and a kaolinitic mineralogy as well as an isohyperthermic temperature regime. Thus in the USDA classification system GH3 isclassified fully except for the series as orthoxic Tropudult, clayey-skeletal, kaolinitic, isohyperthermic.

3.5.3 Ghana classification system

Before the introduction of the current systems discussed above, a highly simplified classification system worked out by Vine and Charter was adopted (Brammer, 1956) see table 3.2. Under this scheme, soils are divided into three orders as:

Climatophytic earths	- climate and relief are dominant soil forming factors
Topohydric earths	- relief and drainage are more important
Lithochronic earths	- parent material and time play the major role in the soil forming processes.

Thus the classification at theorder level was only based on a combination of soil forming factors. The first two important factors were used to give the soil the higher category. They are then subdiveded into lower categories as shown in table 3.2. Under thisscheme GH3 is given the name Red Forest Ochrosol. This classification system is said to be suitable for West African soils (Ahn, 1970), most probably because it avoided most of the soil properties that complicate current classification systems.

The major drawback of this system is that too much attention is focussed on the genesis with little attention to morphology and other more stable soil characteristics. Thus the classification cannot be easily correlated with systems.

4. LAND EVALUATION ASPECTS

4.1 Introduction

A comprehensive land evaluation requires that both the land and its use systems be well defined and formulated. As land evaluation is a subset of the whole process of land use planning and the latter involves comparison of different land units with different land utilization types (LUTS) it requires more than just one land unit or one LUT (FAO 1974). To fulfil this requirement, three other ferric Acrisols chosen from different climatic set-ups are evaluated together with GH3. This will throw more light on any changes in agricultural suitabilities of ferric Acrisols as a result of environmental differences. The selected profiles are:

a. Moramange - Madagascar. This is in the southern hemisphere with one pronounced wet and dry season each. It is essentially tropical with temperatures generally above 15°C and below 25°C (See appendix 1 and 4) This profile is abbreviated as MAD in later references of this essay.

b. Nakhon Phanon Station Amphoe, Muang, Thailand. this is also a tropical climate with monsoon rainfall and temperature patterns. Details on its temperature, rainfall and soil descriptions are given in appendices 1 and 3. the profile is abbreviated as NP in later references.

c. Manusi division, Tawau, Sabah. Abbreviated as MAN, this profile has a humid tropical climate. However, climatic data were not available. Only the profile description is given in appendix 2. thus in the evaluation land qualities requiring climatic data were not evaluated.

Beek (1978) outlined that the LUT's to be included in a land evaluation should be chosen in close consultation with the commisioning authority of the evaluationproject. As the purpose of this study is not aproject but the description and evaluation of soil profiles the LUT's are chosen from the writers experience in the area of GH3 and the general current land uses with ferric Acrisols. The major land use type considered is rainfed agriculture. To narrow it down to LUT's, the following specific crops were selected:

1. Maize - Zea mais
2. Rice - Oryza sativa for dryland only.
3. Groundnut - Arachis hypogea
4. Cassava - Manihot utilisima

The management and input levels are considered to be subsistence farming and low input as well as low capital investment. The farm holdings are thus small, often less than two hectares per farm family of less than six members.

4.2 Land qualities

In the Guidelines for Land Evaluation for Rainfed Agriculture (FAO 1983 p. 78), 25 possibly important land qualities are listed (see table 4.1).

From these the following have been selected for this particular study.

1. Temperature regime
2. Moisture availability
3. Oxygen availability
4. Nutrient status
5. Rooting conditions
6. Soil workability
7. Erosion hazard

The assessment of: radiation regime, conditions affecting germination and establishment, air humidity as affecting growth; conditions for ripening, flood hazard, climatic hazards, pests and diseases and storage and processing conditions will not be treated because of lack of data. For the land qualities: potential for mechanisation, land preparation and clearance requirements, access within the production unit, size of potential management units, location and conditions affecting timing of production, are not considered because they are not applicable to a LUT with low input requirement.

Nutrient availability will be treated in combination with nutrient retention. Escess of salts is not important as all ferric Acrisols by definition are neither saline nor alkaline. Soil toxicities in ferric Acrisols are associated with excess aluminium as a result of low pH values. hence this will be combined in the assessment of nutrient status.

4.2.1 Temperature regime

In considering this land quality the following aspects were taken into account.

- Lower temperature limiting crop growth
- Optimal temperature for the growth of the crop
- Operating temperature but with limitation
- Upper limit temperature beyond which cfrop growth is limiting.

The adaptability of the various crops were curled from the agro-ecological zone evaluation (FAO 1978). Fig. 4.1 further shows the relationship between temperature and its effect on the growth performance of a crop (Driessen et al, in print).

In table 4.2 the suitability calsses for the selected crops and profiles are shown. There were no weather data for Sabah (MAN) profile.

Fig. 4.1 Indicative temperature effect on plant growth

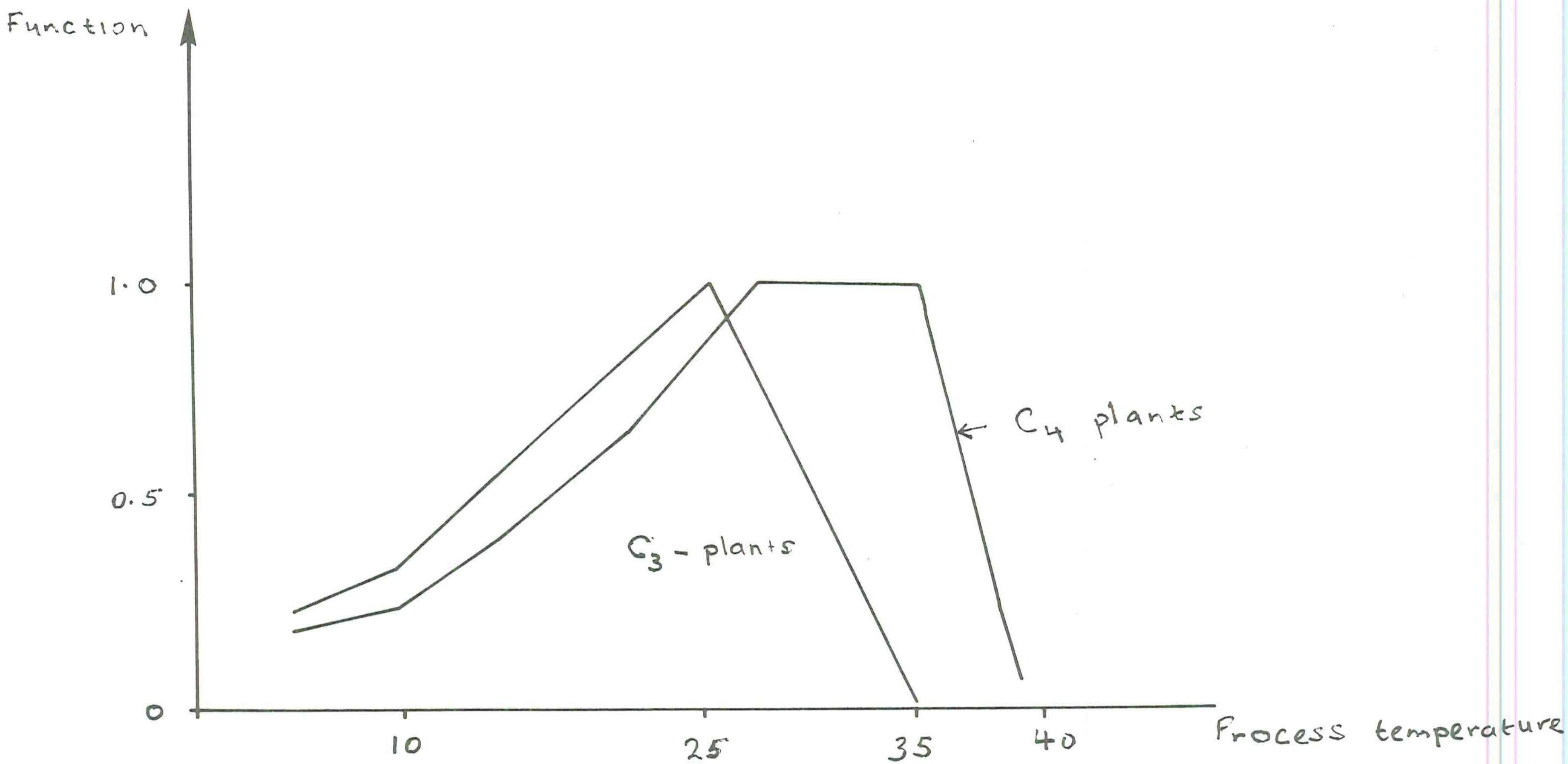


Table 4.2 Temperature suitability classes.

	Optimal temp. °C	GH3	MAD	NP	MAN
Growth period aver. temp. °C		27.4	22.6	27.4	-
Maize	30-35°C	2	2	2	-
Cassava	25-30°C	1	2	1	-
Rice	25-30°C	1	2	1	-
Groundnut	25-30°C	1	2	1	-

Ratings:
Highly suitable = 1
Moderately suitable = 2
Marginally suitable = 3
Not suitable = 4

4.2.2 Moisture availibility

The moisture availability is determined by the available water holding capacity. The latter is defined as the difference between the moisture content at pF 2.0 and pF 4.2. It can therefore be realized that moisture availability is a function of:

- Rainfall
- Evapotranspiration
- Available water holding capacity
- available water from groundwater table through capillary rise (Dijkerman 1979, p. 3.1)

Due to lack of measured pF moisture content values, theavailable water content for each profile was determined using the texture - moisture correlation curves (fig. 4.2 and fig. 4.3) which were established using tropical soils, mainly Acrisols of Sierra Leone (Dijkerman, in preparation).
Thus, from

$$AW = \Sigma\ (FC - WP) * d_s * \left(\frac{100}{100 + G}\right) * Rd \qquad (1)$$

where:

AW = available moisture (mm)

FC = moisture content at 1/3 atm. (% by weight)

WP = moisture content at 15 atm. (% by weight)

d_s = bulk density, assumed as $1.49/cm^3$

Rd = chosen effective rooting depth

= 50 cm for rice and 90 cm for the other crops

G = percentage gravels.

The factor $\frac{100}{100 + G}$ is used to correct for gravel content reducing the

Fig. 4.2 Relationship between sand content and moisture content at 1/3 atm.

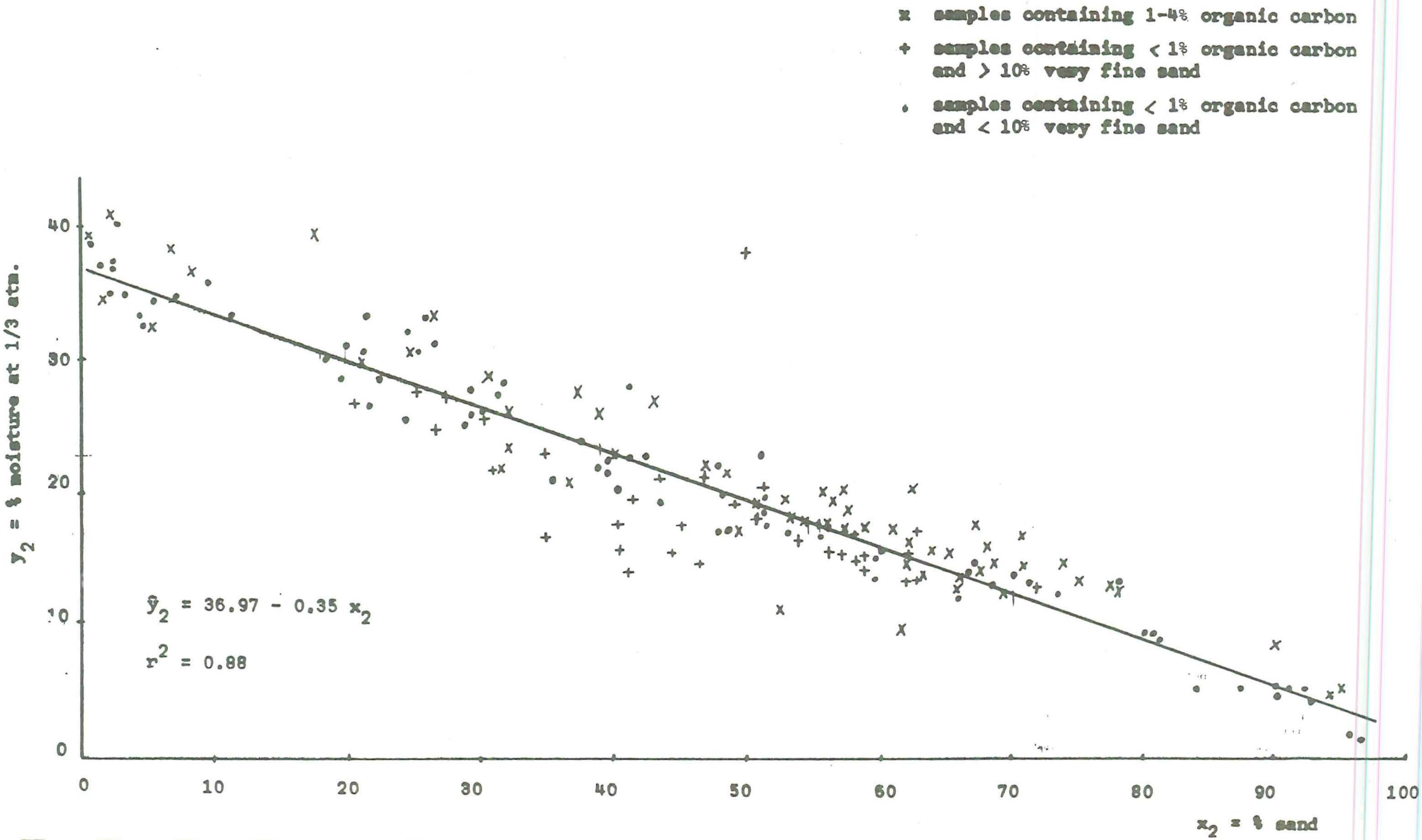
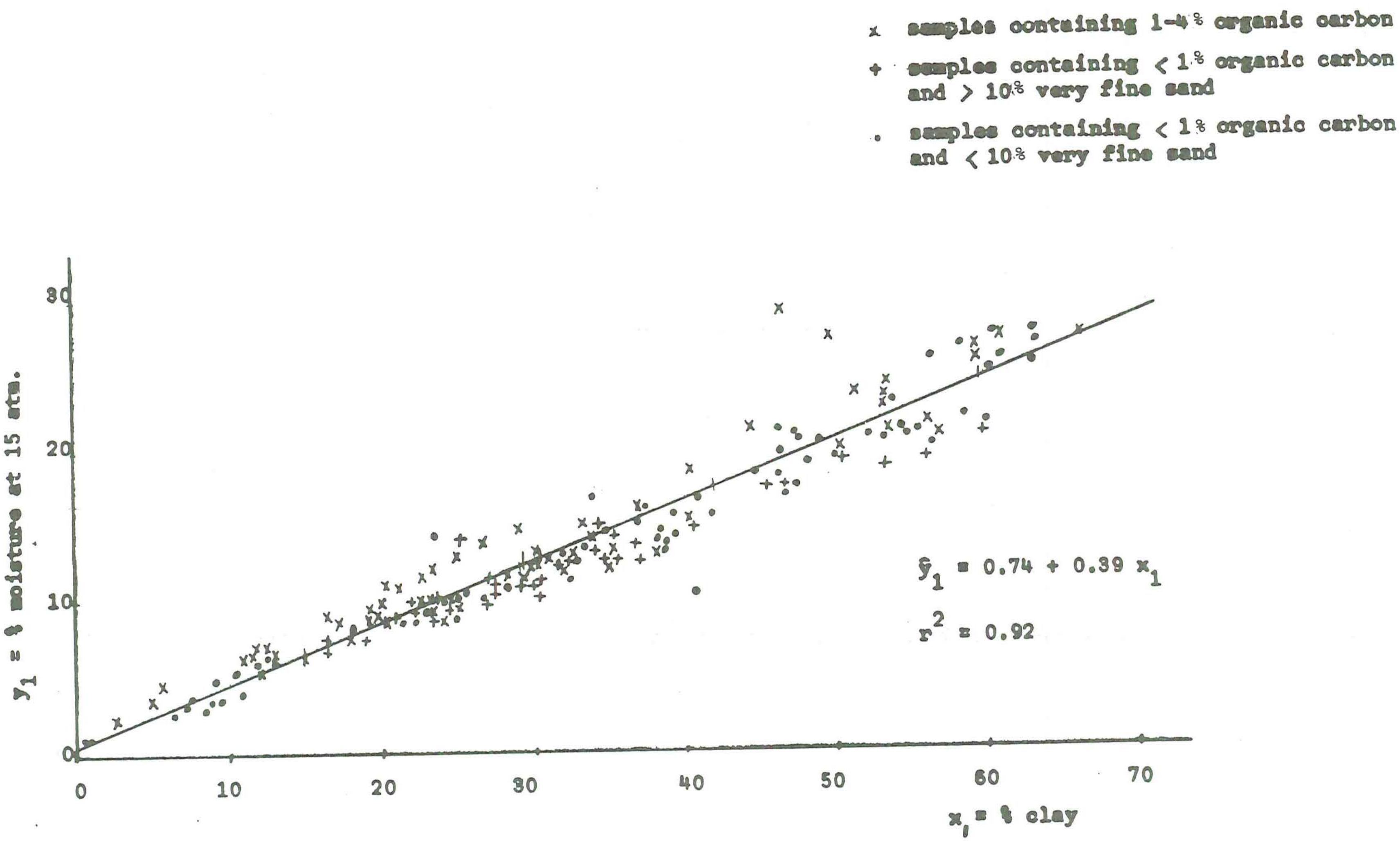


Fig. 4.3 Relationship between clay content and moisture content at 15 atm.



moisture content. These calculated AW values are used as the ST_0 in equation (2) which follows next.
Using the water balance equation (2) for a soil with a low groundwater level as developed by Thornthwaite-Mather (Vand er Molen 1983, p. III.10.1) thevarious profiles waterbalances were calculated (tables 4.4 - 4.9).

$$ST = ST_0 \; e^{\frac{APWL}{ST_0}} \qquad (2)$$

where

ST = actual available moisture (mm)

ST_0 = maximum available water that can be stored = AW

APWL = accumulated potential water loss (mm)

Table 4.3 Calculated water contents (%)

	GH3	MAD	NP	MAN
FC %	23	13	18	30
WP%	16	10	6	25
FC - WP %	7	3	12	5
AW for 50 cm depth (mm)	50	24	84	35
AW for 90 cm depth (mm)	90	43	151	63

Using this table and tables 4.4 - 4.9 the final water availability rating is given in table 4.10.

Table 4.10 Water availability ratings.

	GH3	MAD	NP	MAN
Maize	1	3d	2	2
Cassava	1	3d	1	2
Rice	1	2	1	3d
Groundnuts	1	3d	1	3d

d = drought proned

4.2.3 Oxygen availability

The amount of oxygen available in the root zone is influenced by:
- The occurrence of rainfall in excess of crop requirement
- Drainage situation
- The aeration porosity atfield capacity
- Groundwater table

The waterbalance tables 4.4 - 4.9 are used to estimate the excess water condition; the textural classes to connotate aeration and the drainage class as indicated in the profile descriptions are used for the drainage condition. Thefinal rating for the oxygen availability is given in table 4.11.

Table 4.4 Waterbalance in mm for Kumasi at rooting depth 90 cm.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
P	22	59	139	146	184	234	125	74	173	201	99	32	1488
PE	86	92	117	106	87	63	63	83	96	98	93	87	1071
P-PE	-64	-33	22	40	97	171	62	-9	79	103	6	-55	
APWL	119	152	-	-	-	-	-	9	-	-	-	55	
ST	24.0	16.6	38.6	78.6	90	90	90	81.4	90	90	90	48.8	
ΔST	-24.8	-7.4	22	40	11.4	0	0	-8.6	8.6	0	0	-41.2	
AE	46.8	66.4	117	106	87	63	63	82.6	96	98	93	73.2	
S			0	0	85.6	171	62						
D	39.2	25.6						0.4	68.4	103	6	13.8	

ST_o = 90

where

P = rainfall (mm)

PE = potential evapotranspiration

APWL = accumulated potential waterloss

ST_o = maximum available soil moisture

AE = actual evapotranspiration

S = surplus rainfall over transpiration

D = deficit soil moisture

Table 4.5 Waterbalance for Nakhon Phanom Station for rooting depth 90 cm.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
P	12	12	18	36	96	240	480	480	612	312	48	12	2358
PE	102.3	134.4	170.5	189	151.9	120	102.3	89.9	93	105.4	96	93	
P-PE	-90.3	-122.4	-152.5	-153	-559	120	377.7	390.1	519	206.6	-48	-81	
APWL	219.3	341.7	494.2	647.2	703.1	-	-	-	-	-	48	129	
ST	35.5	15.7	5.7	2.1	1.4	121.4	151	151	151	151	110	64.3	
ΔST	-29	-19.6	-10.0	-3.6	-0.7	120	29.6	0	0	0	-41	-45.7	
AE	41	31.6	28.0	39.6	97	120	102.3	89.9	93	105.4	89	57.7	
S						0	0	390.1	519	206.6			
D	61.3	102.8	142	149.4	54.9						7	35.3	

$ST_o = 151$

Table 4.6 Waterbalance for Moramanga for rooting depth 90 cm.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
P	306.5	259.2	231.3	71.0	42.4	45.7	45.4	35.4	26.1	38.6	135.7	266.8
PE	85.7	90.0	86.6	77.1	72.9	72.0	75.4	77.1	86.6	94.3	128.6	137.1
P-PE	220.8	169.2	144.7	-6.1	-30.5	-26.3	-30.0	-41.7	-60.5	-55.7	7.1	129.7
APWL	-	-	-	6.1	36.6	62.9	65.9	107.7	168.1	223.8	-	-
ST	43	43	43	37.3	18.4	10	9.3	3.5	0.9	0.2	7.3	43
ΔST	0	0	0	-5.7	-18.9	-8.4	-0.7	-5.8	-2.6	-0.7	7.1	35.7
AE	85.7	90	86.6	76.7	61.3	54.1	46.1	41.2	28.7	39.3	128.6	137.1
S	220.8	169.2	144.7								0	0
D				0.4	11.6	17.9	29.3	35.9	57.9	55		

$ST_o = 43$

Table 4.7 Waterbalance for Moramanga Madagascar for rooting depth 50 cm.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
P	306.5	259.2	231.3	71.0	42.4	45.7	45.4	35.4	26.1	38.6	135.7	266.8
PE	85.7	90.0	86.6	77.1	72.9	72.0	75.4	77.1	86.6	94.3	128.6	137.1
P-PE	220.8	169.2	144.7	-6.1	-30.5	-26.3	-30.0	-41.7	-60.5	-55.7	7.1	129.7
APWL	-	-	-	6.1	36.6	62.9	65.9	107.7	168.1	223.8	-	-
ST	24	24	24	18.6	5.2	1.7	1.5	0.3	0	0	7.1	24
ΔST	0	0	0	-5.4	-13.4	-3.5	-0.2	-1.2	-0.3	0	7.1	16.9
AE	85.7	90.0	86.6	76.4	55.8	49.2	45.6	36.6	26.4	38.6	128.6	137.1
S	220.8	169.2	144.7	-	-	-	-	-	-	0	0	112.8
D	-	-	-	10.8	26.8	7	0.4	2.4	0.6	-	-	-

ST_o = 24 mm.

Table 4.8 Waterbalance for Kumasi, Ghana for rooting depth 50 cm.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
P	22	59	139	146	184	234	125	74	173	201	99	32	1488
PE	86	92	117	106	87	63	63	83	96	98	93	87	1071
P-PE	-64	-33	22	40	97	171	62	-9	77	103	6	-55	417
APWL	119	152	-	-	-	-	-	9	-	-	-	55	
ST	4.6	2.4	24.4	50	50	50	50	41.8	50	50	50	16.6	
ΔST	-12	-2.2	22	25.6	0	0	0	-8.2	8.2	0	0	-33.4	
AE	34	61.2	117	106	87	63	63	82.2	96	98	93	65.4	
S	-	-	0	14.4	97	171	62	-	68.8	103	6	-	
D	52	30.8	0	-	-	-	-	0.8	-	-	-		

ST_o = 50 mm

Table 4.9 Waterbalance for Nakhon Phanom Station, Amphoe Muang, Thailand.
Method: according to Thornthwaite - Mather (Van der Molen, 1983), for rooting depth 90 cm.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
P	12	12	18	36	96	240	480	480	612	312	48	12
PE	102.3	134.4	170.5	189	151.9	120	102.3	89.9	93	105.4	96	93
P-PE	-90.3	-122.4	-152.5	-153	-559	120	377.7	390.1	519	206.6	-48	-81
APWL	219.3	341.7	494.2	647.2	703.1	-	-	-	-	-	48	129
ST	6.2	1.4	0.2	0	0	84	84	84	84	84	47.4	32.0
ΔST	-25.8	-4.8	-1.2	-0.2	0	0	0	0	0	0	-36.6	-24.4
AE	37.8	16.8	19.2	36.2	96	120	102.3	89.9	93	105.4	84.6	36.4
S	-	-	-	-	-	36	377.7	390.1	519	206.6	-	-
D	51.6	9.6	2.4	0.4	0.0	-	-	-	-	-	73.2	48.8

$ST_0 = 84$ mm, $ST = ST_0 \; e^{-\frac{APWL}{ST_0}}$

Table 4.11 Oxygen availability classes rating.

	GH3	MAD	NP	MAN
Maize	1	2	1	-
Rice	1	1	1	-
Groundnuts	1	2dw	1	-
Cassava	1	2dw	1	-

dw = high watertable limiting drainage atlower depths.

4.2.4 Nutrient status

Nutrient status of a soil isone of the most important soil qualities. However, it is complex and difficult to access in precise and quantitative terms. For it is not the total amount of a nutrient alone that is important but its balances with others. In the following analyses the aspects of nutrient status considered include:

- Presence and amount of weatherable minerals
- Nutrient retention capacity (CEC)
- Special nutrient problems.

Weatherable minerals are the unstable primary and secondary products of weathered rock or other parent materials which can still weather further to realize vital plant nutrients essentially phosphate and the cations Ca^{2+}, Mg^{2+} and K^{+}.

The nutrient retention capacity is determined by the CEC. Thus when the exchange complex sites are all filled with cations, the rest of the cations remain in the soil solution and are easily leached or translocated out of the required location.

Special nutrientproblems relate to nutrient toxicities such as Al-toxicity, salinity, alkalinity and acidity. Relating these issues to the study profiles, it can be observed that all the profiles lack weatherable minerals as they are highly weathered.

The CEC's are all low (< 10 meq/100 g soil). The main special nutrient problem is Al-toxicity. The pH values are very low, allare below 5.5. Hence calcicales such as groundnuts and cotton can not be cultivated on such soils. For rating all the profiles have rating class = 3wse, where

w = lack of weatherable minerals
s = Al-toxicity and/or low pH values
e = low CEC.

FAO chemical degradation method: chemical degradation for this purpose is defined as the impoverishment of thesoil chemical elements and compounds necessary for plant nutrition as a result of excess leaching. The factors taken into account include: climate, soil properties, topography and human factors. As a result of lack of data, human factor is not included in this evaluation.

For the climate.

$$C = \sum_{1}^{12} \frac{(P - PET)}{100} \quad , \; P\text{-}PET > 0$$

where

C = climate factor

P = rainfall per month

PET = potential evapotranspiration per month.

The soil factor ratings are listed as:

Soil texture	Fine	Medium	Coarse
Rating	2	1	0.5
Clay type	kandite kaolinite		illite, smectite montmorillonite
Rating	1		0.25

Topography was divided into slope classes and ratings assigned as follows:

Slope class %	0-8	8-70	> 20
Rating	0.3	0.5	1

The various rrating factors were multiplied together and the suitability classes established as follows:

		BS < 50%	BS > 50%
None to slight	= 1	< 1.25	< 2.5
Moderate	= 2	1.25 - 2.5	2.5 - 5
High	= 3	2.5 - 5	5 - 10
Very high	= 4	> 5	>10

In table 4.12 these suitabilities are listed.

Table 4.12 Nutrient retention by chemical degradation suitability method.

	GH3	MAD	NP	MAN
Climate	5.6	6.7	16.1	-
Texture	0.5	2	1	-
Claytype	1	1	1	-
Topography	0.3	0.5	0.3	-
Final rating	0.84	6.7	4.83	-
Suitability	1	n	n	

4.2.5 Rooting conditions

Rootability depends on the following soil conditions (Dijkerman, 1979):
- Very dense layers
- Layers with uniform size
- Layers with voids that are not permanent open
- Layers with poor aeration
- Layers with low moisture holding capacity
- Layers with poor chemical conditions

These situations limit the development of a sound rooting system. They are matched with the prevailing conditions in the profile description (Appendices) and a suitability table made (table 4.13).

Table 4.13 Rootability classification.

	GH3	MAD	NP	MAN
Maize	1	1	2a	2a
Rice	1	1	2a	2a
Cassava	2a	2a	3ap	2a
Groundnuts	2a	2a	3ap	2a

a = Al-toxicity and other associated toxicities at low pH values
p = Platy layer limiting root penetration.

4.2.6 Soil workability

The main factors affecting workability in these profiles include the soil structure, consistence and texture in the topsoils. A good structure in the topsoil is necessary to be able to work in the soil. This means a heterogenous pore system created by a high biological activity and a high structure stability. Too heavy soils stick to tools and equipment. In the scheme outlined in table 4.14 the various profiles were evaluated and the results tabulated in table 4.15.

Table 4.15 Workability suitability classes

	GH3	MAD	NP	MAN
Structure	1	1	2	2
Consistence	1	1	3	2
Texture (clay content	1	3	1	1
Suitability	1	3t	3c	2

1 = highly suitable
2 = moderately suitable
3 = marginally suitable
t = too heavy texture (high clay content)
c = plastic, hard to dig as a whole

Table 4.14 CLASSES FOR ASSESSMENT OF ROOT PENETRATION (ENTIRE PROFILE) OR WORKABILITY (TOPSOIL)

	Class for (root penetration (entire profile) (workability (topsoil)					
	1 Easy	2 Moderate		3 Difficult		4 Very difficult
Consistence when moist 1/	Friable, very friable, loose	Firm	Very firm	Very firm	Extremely firm	Extremely firm
Structure	Any	Any	Moderate or strong medium or fine blocky; any class of granular or crumb	Coarse or very coarse blocky; any class of prismatic, columnar or platy; weak grade of any type; massive	Any other than as listed for Severe	Coarse or very coarse blocky, prismatic or columnar; massive
Other features of consistence				Profile as a whole hard to dig when dry		Plastic very stiff and very sticky when wet; very hard when dry
Textures usually present	All sands and loamy sands; many loams; some sandy clays and clays where largely kaolinite and sesquioxides	Range from sandy loams to clays		Mostly clays and sandy clays, some sandy clay loams		Clays, usually heavy clays

1/ The equivalent classes of consistence when dry (hard, etc.) may be employed.

Source: Guidelines for Landevaluation for rainfed Agriculture (p. 99)

4.2.7 Erosion hazard

In this analysis two different approaches are used to assess erosion hazard by water. Wind erosion, even though important, will not be treated due to insufficient data. The two approaches are:

- FAO method of USLE
- FAO method of soil physical degradation

FAO method of USLE:
Because of the detailed data, often required by the universal soil loss equation (USLE), FAO adopted a method to simplify the data requirement (FAO - UNEP - UNESCO 1979, p. 13). Under this scheme the factors considered are rainfall aggressivity, soil erodibility, topography and land use management.
The equation used is:

$$A = R * K * L * S * C * P$$

where

A = Soil loss (mm/year)

R = Rainfall factor

K = Soil erodibility factor

L = Length of slope factor

S = Slope gradient factor

C = Crop management factor

P = Erosion control practices factor

R is estimated inthis method from:

$$R = \sum_{1}^{12} \frac{p^2}{P}$$

where

p = monthly precipitation

P = annual precipitation

The K-factor is determined using the textural classes as follows

Coarse textured	= 0.2
Medium textured	= 0.3
Fine textured	= 0.1
Stony or gravelly phase	= 0.5

The L- and S-factors were combined and used as follows:

Slope %	0-8	0-20	8-30	>30
T = L * S	0.35	0.2	3.5	8

The C-factor was determined for arable cropland as follows:

Cropland in savanna ecology	C = 0.8
Cropland in forest ecology	C = 0.4

That is crops cultivated in a savanna environment have a C-factor twice that of a forest environment. it is not clear why specific crops or crop groups were not used. Maybe the intrinsic reasons for using vegetative environment are: the relative amount of organic matter supply, remains of roots and the chances of runoff from and out of the surrounding areas.

The P-factor is considered here due to lack of data. In the final rating the following suitability classes were used:

	Soil loss (mm/year)
None to slight	< 0.6
Moderate	0.3 - 3.3
High	3.3 - 13.3
Very high	> 13.3

In table 4.16 the final ratings are given.

Table 4.16 Erosion hazard assessment using FAO adopted USLE equation.

Rating	GH3	MAD	NP	MAN
R	158.2	210.2	425.7	-
K	0.2	0.1	0.3	0.3
T	0.35	0.2	0.35	0.35
C	0.4	0.4	0.8	0.4
A	4.4	1.7	3.6	-
Rating	3	2	3	-

2 = moderate
3 = high

FAO method of soil physical degradation:
This method was developed to asses the potential danger of soil deterioration as a result of the rainfall factor in the area and the soil texture and clay mineralogy. The rainfall factor was calculated from:

$C = \frac{p^2}{P}$:	0 - 50	50 - 500	500 - 1000	> 1000
Rating:	0 - 5	5 - 7.5	7.5 - 10	10

Irrigated or flooded soils have 10 as the rating.

The soil factor was estimated using the erodilbility class as established under the FAO adopted USLE method and other soil parameters as follows:

Soil factor

a. Erodibility class	1	2	2	
b. $\frac{silt}{clay}$ ($\frac{2-5\mu}{< 2\mu}$)	< 1.5	1.5-2.5	2.5-3.5	> 3.5
c. $\frac{1.5 \text{ fine silt } (20-50\mu) + 0.75 \text{ coarse silt } (20-50\mu)}{\text{clay } (< 2\mu) + (10 * \text{Om\%})}$	< 1.2	1.2-1.6	1.6-2.0	> 2
Rating	0.001	0.1	0.75	1

Topography factor was also assessed according as:

Slope %	0 - 8	8 - 20	> 20%
Rating	1	0.5	0.3

Human factors were not considered in this analysis due to lack of information. The total suitability of the profiles is given in table 4.17.

Table 4.17 Soil erosion classes according to FAO physical degradation method.

	GH3	MAD	NP	MAN
(a) Climate factor	158.7	210.2	425.7	-
Rating	5.5	6	7.2	-
(b) Soil factor				
i Erodibility	3	2	3	-
ii $\frac{silt}{clay}$	0.2	0.5	2.2	-
iii $\frac{1.5 \text{ fine silt} + 0.75 \text{ coarse silt}}{\text{clay} + 10 * 0.\text{m } \%}$	0.24	0.15	0.1	-
Rating	0.1	0.1	0.75	-
(c) Topography factor %	3-5	5-10	5-10	-
Rating	0.3	0.5	0.3	-
Final rating	0.2	0.3	1.6	-
Suitability	**1**	**1**	**2**	-

Comment on the two methods.
In the suitabilities one can notice great variations. The chemical degradation gives higher ratings generally more than the USLE method. For more meaningful results one may prefer the USLE method to the chemical degradation because the former considers more than just one land characteristic. In any case the various suitabilities need to be calibrated with real field results on the crop performance so as to determine the relative usefulness.

4.3 Fertility Capability Classification (FCC)

This evaluation method was developed, used and tested by Sanchez et al, (1982). It assesses the general suitability of soils but specifically their fertility status. Under this classification method, the selected profiles have the following suitabilities.

GH3	C C' e a i K
MAD	C e a i K
NP	S L e h K
MAN	L C' e a K

Explanation of the system: the FCC consists of three categorial levels:

1. **Type:** The texture of the plough layers or surface 20 cm; indicated by the first capital letter.
   L = loamy
   C = clayey: > 35% clay
   S = sandy topsoil loamy sands and sands (by USDA definition)

2. **Substrata type - texture of subsoil:** Used only if there is a marked textural change from the surface or if a hard root-restricting layer is encountered within 50 cm. The symbols have the same meanings as in the type.

3. **Modifiers:** The system provides for 13 modifiers of which for the selected profiles under study only the following are applicable.

   a = Aluminium toxicity: pH < 5.0 in 1:1 H_2O except in organic soils.

   e = CEC of ploughlayer < 7 meq/100 g soil by summation of cations at pH 7 or CEC < 4 meq/100 g soil by Σ bases + unbuffered Al. Low ability to retain nutrients against leaching, mainly K, Ca and Mg. Heavy applications of these nutrients and of N - fertilizers should be split. Potential danger of overliming also prevails.

   i = (Fe - P fixation): % free Fe_2O_2-clay > 0.2 or hues redder than 5 YR and granular structure.

   K = K - deficiency: < 10% weatherable minerals in silt and sand fraction within 50 cm or exchangeable K < 0.20 meq/100 g soil or K < 2% of Σ of bases, if Σ of bases < 10 meq/100 g.

   h = (acidity): 10 - 60% Al saturation of CEC by Σ bases and unbuffered Al within 50 cm or pH in 1:1 H_2O between 5.0 and 6.0.

CONCLUSIONS AND DISCUSSION

From the analysis so far presented, ferric Acrisols have nutrient limitations. The main problems include phosphorus fixation, potassium deficiency andd aluminium toxicity. Temperature is generally not a limitation to the selected locations of ferric Acrisols.

As the available moisture holding capacities are low, they will suffer from moisture stress in ustic or drier moisture regimes. Oxygen availabilíty is no problem, except where a poorly drained subhorizon is encountered. Rooting may be impeded, due to the high argillization. Generally ferric Acrisols are easy to work in, again except for heavy textured ones.

The erosion possibility of these soils is low, given good management practices that maintain a vegetative cover. As the main constraint is nutrient status, split application of potassium, phosphorus and sometimes nitrogen fertilizers are necessary to give good crop yields. To increase the pH values it is required to apply liming materials. However, there is a risk of over liming due to the low CEC.

To solve these problems, the local farmers usually fallow the land to allow it to rejuvenate through natural fertilization by vegetative regrowth.
The bushes are slashed down, allowed to dry and then burnt. The ash produced supply the liming materials and potassium. In some areas mounds are raised, increasing the rooting depth, the volume of which plants can feed, as well as lowering the groundwater table to which the crops are subjected to in certain regions.
However, as the population increases, the pressure on land will rise, the fallowing period will be shortened and the soil will not regain its natural fertility level.

More research is needed to ascertain the benefits of these farming and cultural practices to maintaining and improving the fertility of a number of soils that is the ferric Acrisols.

REFERENCES

Acquaye, D.K., and J.W. Oteng, 1972. Factors influencing the status of phosphorus in surface soils of Ghana. Ghana Journal of Agricultural Science, Vol.5 p.221-228, University of Ghana, Legon, Ghana.

Adu, V.S., 1984. Kumasi Series, Soil Research Institute, Kumasi, Ghana.

Adu, S.V., and J.A. Mensah-Ansah, 1969. The classification of Ghanaian soils for cocoa rehabilitation. Ghana Soil Research Institute, Conference paper no.39, p.15, Kwadaso-Kumasi, Ghana.

Ahn, P., 1975. West Africa Soils. University of Nairobi, Oxford University Press, London.

Ahn, P., 1959. The principal areas of remaining original forest in western Ghana and their agricultural potential. Ghana Department of Soil and Land Use Survey branch, Accra, Ghana.

Bampo-Addo, A., K.V. Raman and M.M. Mortland, 1969. Clay mineral status of some major soil series in Ghana. Soil Science Vol.107, p.119-125. Michigan state University, East Lansing, U.S.A.

Brammer, H., 1956. Charter's Interim Scheme for the classification of tropical soils. Gold Coast Department of soil and land use survey, Kumasi, Ghana.

Bourgeat, F., 1972. Sols sur socle ancien à Madagascar. Orstom, Paris, p.286.

Burridge, J.C., and P. Ahn, 1965. A spectro-graphic survey of representative Ghana forest soils. Journal of soil Science, Vol.16, p.296-309.

FAO, 1978. Agro-ecological Zones Project, Vol.I.

FAO, 1974. Increased Farm Production through fertilizer use: Ghana technical report, Vol.1-2.

FAO, 1975. Guidelines for Rainfed Agriculture Land Evaluation.

FAO, 1974. Reports, World Soil Resources. Soil Correlation tour in Ghana. First meeting of the West African Sub-Committee on soil correlation for soil evaluation and management, Accra, Ghana.

FAO-UNESCO, 1974. Soil Map of the World, Vol.I-IV.

Ghana Soil and Land Use Survey, 1956. Diagrams illustrating some typical Ghana soils. Ghana Department of soil and Land Use Survey Report, Accra, Ghana.

Gilkes, R.J., G. Scholz and G.M. Dimmock, 1973. Lateritic deep weathering of granite. Journal of Soil Science, Vol. 24 p.523-535.

Greenland, D.J., (Editor) 1981. Characterization of soils. Oxford University Press, Oxford.

Meiklejohn, J., 1962. Microbiology of the nitrogen cycle in some Ghana soils. Emperical Journal Experimental Agriculture, Vol.30, p.115-126. Rothamsted Experimental Station, Harpenden.

Mengel, K. and E.A. Kirby, 1982. Principles of plant nutrition. International Potash Institute, Worblaufen, Bern.

Obeng, H.B., 1976. Soils of Kumasi prison farm, Soil Research Institute, Kumasi, Ghana.

Obeng, H.B., 1971. The major soil groups of Ghana and their potential for agricultural development. Journal of the Association for the advancement of Agricultural Sciences in Africa, Vol.1, p.19-27, Soil Research Institute, Council for Scientific and Industrial Research, Kumasi, Ghana.

Odell, R.T., et al, 1974. Characteristics, classification and adaptation of soils in selected areas in Sierra Leone, West Africa. Bulletin 748, Agricultural Experimental Station. University of Illinois, Bulletin 4, Njala University College, University of Sierra Leone, Freetown, Sierra Leone.

Sanchez, P.A., W. Conto and S.W. Buol, 1982. The Fertility Capability Soil Classification System: Interpretation, application and modification. Geoderma 27, p.283-309.

Sanchez, P.A., 1976. Properties and management of soils in the tropics. John Wiley and Sons Printing Press Ltd. New York.

Scholten, J.J., and W. Boonyawat, 1971. Detailed reconnaissance soil survey of Nan Province, Department of land development, Report SSR no.90, Bangkok, Thailand.

Smith, G.K., 1962. Land capabilty classification of the soils of Ghana. Ghana Ministry of Agriculture; Scientific Services Division no.31, Accra, Ghana.

Veldkamp, W.J., 1979. Land evaluation of valleys in a tropical rain forest area. Thesis. Agricultural University, Wageningen, the Netherlands.

Wills, J.B., 1962. Agriculture and land use in Ghana. Ghana Ministry of Food and Agriculture, Accra, Ghana.

Weather and climate data Moramanga, Madagascar. (Bourgeat, 1972, p. 286).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average Temperature (°C)	22.5	22.4	21.8	20.0	18.3	16.2	15.4	15.7	17.1	19.1	21.3	25.2
Rainfall (mm)	306.5	259.2	231.3	71.0	42.4	45.7	45.4	35.4	26.1	38.6	135.7	266.8
Pot. evapotranspiration (mm)	85.7	90.0	86.6	77.1	72.9	72.0	75.4	77.1	86.6	94.3	128.6	137.1

Weather and climate data, Nakhon Phanon Thailand. (Dent 1968, pp.31-33).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average Temperature (°C)	21.4	25.2	27.6	29.0	28.1	27.1	27.1	26.7	26.6	26.2	24.8	22.0
Rainfall (mm)	12.0	12.0	18.0	36.0	96.0	240.0	480.0	480.0	612.0	312.0	48.0	12.0
Pot. evapotranspiration (mm)	102.3	134.4	170.5	189	151.9	120	102.3	89.9	93.0	105.4	96.0	93

1. Description and analytical data of soil profile examined in Ghana on Kumasi series.

Classification:
- Forest Ochrosol (Ghana)
- "Sol Ferrallitique fortement désaturé, remanié, medal" (French)

Topo site : Upper slope
Slope : 3%
Drainage : Well drained
Altitude : 249 m (830 ft.)
Vegetation : Moist deciduous forest
Rainfall : 1473 mm (58 ins)

Parent material: Residual loam derived from decomposed granite.

Horizon	Depth (cm)	Description
Ap1	0- 7	Dark reddish brown (5YR 3/2); sandy clay loam; Coarse and fine granular; friable; many fine and mediumroots; pH 4.4; abrupt wavy boundary.
Ap2	7- 11	Dark reddish brown (5YR 3/3); sandy loam; weak fine granular friable; many fine roots; pH 4.6; clear wavy boundary.
Ap3	11- 18	Yellowish red (5YR 4/6); sandy loam; massive; firm; few fine ironstone gravel and concretions (about 5% by volume); common fine roots; pH 4.5; clear wavy boundary.
Bt1	18- 23	Yellowish red (5YR 4/6); gravelly clay loam; massive; firm common ironstone gravel and Fe concretions (about 25% by volume); pH 4.5; clear wavy boundary.
Bt2	23- 46	Red (2YR 4/8); gravelly clay; massive; firm; few fine roots; common ironstone gravel and concretions (about 25% by volume); pH 4.9; clear wavy boundary.
Bt3	46- 70	Red (2.5YR 4/8); gravelly clay; massive; firm; few fine roots; many ironstone gravel and concretions (about 35% by volume); pH 4.9; clear wavy boundary.
Bt4	70- 87	Red (2.5YR 4/8); gravelly clay; Massive; firm; common ironstone gravel and Fe concretions (about 25% by volume); pH 5.0; clear wavy boundary.
Bt5	87-114	Red (2.5YR 5/6); gravelly clay; massive; firm; common ironstone gravel and concretions (about 30% by volume); white mica specks; pH 5.2; clear wavy boundary.
Bt6	114-151	Red (10YR 5/6); gravelly clay with common fine faint yellowish red (5YR 5/6) mottles; massive; friable; common ironstone gravel and concretions (about 25% by volume); white mica specks; pH 5.2; clear wavy boundary.
Bt7	151-201	Red (2.5 4/8); gritty claywith common fine distinct yellowish red (5YR 5/8) mottles; massive; firm; few ironstone gravel (less than 5% byvolume); pH 5.2; clear irregular boundary.

CODE ISM: GH3 YEAR: 74 (C34 → K1t) COUNTRY: GHANA

Horizon	Depth (cm)	Particle size distribution (µm in weight %) sand 2000–1000	1000–500	500–250	250–100	100–50	silt 50–20	20–2	clay < 2	pH H_2O	pH KCl	Org. Matter C %	N %	C/N %
Ap1	0- 7	6.4	18.5	14.5	11.4	3.7	4.0	8.0	33.3	4.3	3.8	1.49	0.32	6.7
Ap2	7- 11	3.3	13.6	15.1	10.5	3.8	4.5	8.0	40.8	4.2	3.8	1.00	0.12	8.3
Ap3	11- 18	4.2	19.4	14.6	8.7	3.4	3.4	6.7	39.6	4.5	3.4	0.40	0.10	4.0
Bt1	18- 23	5.7	18.6	12.1	6.9	2.7	3.3	5.6	45.0	4.6	3.4	0.49	0.06	8.2
Bt2	23- 33	8.7	18.5	8.7	4.8	2.2	2.7	4.9	49.4	4.6	3.4	0.30	0.06	5.0
Bt2	33- 46	7.1	18.1	8.3	4.5	2.0	3.6	3.9	52.6	4.7	3.9	0.30	0.06	5.0
Bt3	46- 70	9.2	20.0	8.2	4.1	1.9	2.5	4.1	50.1	4.8	4.0	0.24	0.03	8.0
Bt4	70- 87	8.2	18.8	7.0	3.9	1.9	3.9	4.6	54.7	4.7	4.0	0.21	0.04	5.3
Bt5	87-114	9.2	14.5	5.7	4.7	2.1	4.3	5.0	53.7	4.8	4.0	0.21	0.04	5.3
Bt6	114-122	7.8	12.8	7.2	6.0	1.8	4.4	7.4	52.7	4.9	4.0	0.18	0.04	2.5

	'Free'	P_2O_5	moist	Exchangeable cations (meq/100g)							
	Fe_2O_3		%	Ca	Mg	K	Na	Sum	CEC	BS	EC 2.5
Depth (cm)	%								meq/100g	%	mS/cm x 10^3
0- 7	0.37	28.4	1.4	2.00	0.32	-	-	2.32	9.26	25	0.23
7- 11	3.01	-	1.4	1.50	0.25	-	0-04	1.79	8.92	20	0.19
11- 18	3.01	-	1.3	1.50	0.25	-	-	1.75	6.61	26	0.09
18- 23	2.99	-	1.3	1.50	0.28	-	0.04	1.82	6.61	28	0.05
23- 33	3.59	14.2	1.5	1.50	0.25	-	0.04	1.79	6.18	29	0.04
33- 48	3.80	14.2	1.5	1.50	0.25	-	-	1.75	7.51	23	0.04
48- 70	3.85	14.2	1.5	2.10	0.35	-	-	2.45	7.06	35	0.03
70- 87	3.94	28.3	0.9	1.50	0.25	-	-	1.75	5.71	31	0.03
87-114	4.73	30.5	1.7	1.50	0.28	-	-	1.78	6.19	29	0.04
114-122	5.16	16.3	1.6	2.00	0.32	-	-	2.32	6.63	35	0.02

FERRIC ACRISOL Af

Modal rejuvenated ferralitic soil — Madagascar

Reference	F. Bourgeat, *Sols sur socle ancien à Madagascar*, p. 286. Paris, ORSTOM, 1972
Location	East of Moramanga
Altitude	932 m
Physiography	Upper Tertiary plateau dissected by existing hydrographic system; profile taken from narrow shelf with a slight 5 to 10% slope
Drainage	Impeded at depth
Parent material	Migmatite
Vegetation	Dense bush of *Philippia* sp., *Helichrysum* div., *Aristida* div., bracken
Climate	Tropical, little contrast; rainfall 1 500 mm; temperature 19.4°C; two dry months

Profile description

Ah	**0-15 cm**	Yellowish brown (10YR 3/2) moist clay humus horizon; some small (a few mm) weathered minerals; structure of ill-defined clods with strong very fine crumb substructure, high degree of structuring; strong cohesion; very strong porosity; very good rooting; at the surface some scattered weathering residues with an ironstone crust; abrupt transition to the next horizon.
E	**15-40 cm**	Yellow (7.5YR 7/8 dry) reddish yellow (5YR 7/8 moist) clay horizon; shiny crystalline quartz; subangular blocky breaking to granular; slightly compact *in situ*; low to medium porosity; weak rooting; gradual boundary.
Bt	**40-60 cm**	Yellowish red (5YR 7/8 dry, 2.5YR 5/8 moist) clay horizon; stronger medium blocky structure tending toward massiveness; less compact than the previous horizon; pronounced tubular porosity; indurated elements (weathering residues and root-shaped gibbsitic concretions) appearing reworked but not arranged in stone lines; clear boundary.
Bg	**60-90 cm**	Reddish yellow (7.5YR 7/8 dry, 5YR 5/8 moist) clay horizon with rust mottles of ill-defined boundary; shiny quartz and fine black iron and manganese concretions; strong blocky; shiny ped faces and strong cohesion; fairly high porosity between the peds, low or zero within them.
BCg	**90-130 cm**	Light red (2.5YR 5/8 dry, 2.5YR 4/8 moist) clay horizon with redder mottles and some yellowish streaks; some unidentifiable minerals at the bottom; strong medium blocky; shiny ped faces; exceptional degree of structuring; strong cohesion; low porosity.
Cg	**130-290 cm**	Purplish red (10R 5/3 dry, 10R 4/3 moist) clay horizon with rust mottles; rich in loam and decomposing minerals; coarse blocky; medium to low porosity.
C	**> 290 cm**	Pale red (10R 6/4 dry and 10R 5/8 moist) silty clay horizon rich in unidentifiable minerals.

Horizon	Depth cm	pH		Cation exchange me %									$CaCO_3$ %
		H_2O	KCl	CEC	TEB	% BS	Ca	Mg	K	Na	Al	H	
Ah	0—15	4.8		13.1	0.43	3	0.12	0.12	0.125	0.068			
E	15—40	5.0		3.9	0.27	7	0.07	0.16	0.023	0.016			
Bt	40—60	4.9		1.9	0.25	13	0.05	0.17	0.015	0.016			
Bg	60—90	4.8		2.4	0.20	8	0.05	0.14	0.010	0.005			
BCg	90—130	4.9		2.0	0.30	15	0.05	0.20	0.029	0.021			
Cg	130—290	4.9		1.6	0.20	12	0.05	0.14	0.006	0.005			
C	>290	4.9		1.3	0.24	18	0.05	0.16	0.004	0.030			

Horizon	Sol. salts	Organic matter				Particle size analysis %						Flocc. index
		% C	% N	C/N	% OM	stones	c. sand	f. sand	silt	clay	texture	
Ah		5.9					12.0	6.4	22.5	48.1		
E		0.9					11.2	5.0	15.5	59.8		
Bt							15.7	5.2	9.3	68.5		
Bg							12.3	4.0	19.4	51.3		
Bcg							13.3	7.0	21.0	55.2		
Cg							7.1	6.2	45.4	42.1		
C							11.4	8.2	48.6	30.0		

Horizon	Total elements in me/100 g												
	Ca	Mg	K	Na									
Ah	0.4	2.2	0.26	0.07									
E	0.6	2.7	0.19	0.17									
Bt	0.8	4.8	0.10	0.02									
Bg	1.6	1.8	0.08	0.08									
BCg	1.2	1.5	0.10	0.02									
Cg	1.9	0.5	0.12	0.08									
C	1.2	7.7	0.06	0.48									

Horizon	Triacid attack											
	Ignition loss	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	$\frac{SiO_2}{Al_2O_3}$						
	Percent											
E	18.7	14.6	14.6	32.6	2.8	0.8						
Bt	17.5	18.0	13.2	33.7	1.9	0.8						
Bg	15.9	25.0	11.2	32.6	1.4	1.3						
BCg	14.2	29.9	10.1	33.0	1.4	1.5						
Cg	14.0	30.3	17.9	33.6	4.1	1.5						
C	14.1	31.9	15.3	32.9	1.8	1.6						

FERRIC ACRISOL Af

Location	Nakhon Phanom station, Amphoe Muang, Thailand
Altitude	150 m (approximately)
Physiography	Undulating low terrace
Drainage	Well drained
Parent material	Old alluvial deposit
Vegetation	Annual crops
Climate	Monsoon tropical; rainfall 2 150 mm (approx.); rainy season from May through November.

Profile description

Ap	**0-8/12 cm**	Dark brown (10YR 3/3) and light brownish grey (10YR 6/2 dry) sandy loam; moderate common fine granular structure but on the lower portion strong medium platy structure; hard, dry, particularly in plough sole; slightly sticky and slightly plastic; common very fine vesicular and interstitial pores; few fine root pores; common mixing of dark and light spots by ploughing; many fine roots; clear wavy boundary; pH 5.0.
E	**8/12-40 cm**	Dark brown (10YR 4/3) and greyish brown (10YR 5/2 dry) sandy loam; weak fine subangular blocky structure; firm, slightly sticky and slightly plastic; few very fine vesicular and interstitial pores; few fine root pores; common bleached sand grains; few fine roots; compact pan-like; clear smooth boundary; pH 6.0.
EB	**40-53 cm**	Strong brown (7.5YR 5/6-5/8) sandy loam; weak fine subangular blocky structure; very firm, slightly sticky and plastic; patchy thin cutans in root pores; common very fine to fine vesicular and interstitial pores; few fine animal pores; few fine roots; gradual smooth boundary; pH 4.5.
BE	**53-72 cm**	Yellowish red (6YR 5/6) sandy clay loam; weak medium subangular blocky structure; firm, sticky and plastic; broken thin cutans in pores and some patchy cutans on peds; common very fine vesicular pores, few very fine to fine tubular pores; few fine roots; gradual smooth boundary; pH 4.5.
Bt	**72-119 cm**	Yellowish red (5YR 5/6) sandy clay loam; few fine, very faint mottles; moderate medium subangular blocky structure; friable, sticky and plastic; continuous moderately thick clay skins in larger pores; patchy thin cutans around peds; common very fine to fine tubular and vesicular pores; few fine roots; gradual smooth boundary; pH 4.5.
Btg1	**119-147 cm**	Yellowish brown (10YR 5/4) matrix and common fine faint mottles with strong brown (7.5YR 5/6) colour; sandy clay loam; weak fine subangular blocky structure; friable, sticky and plastic; clay skins similar to above horizon; common very fine to fine tubular and vesicular pores; very fine roots; gradual smooth boundary; pH 4.5.
BCg	**147-153+ cm**	Light yellowish brown (10YR 6/4) matrix, mottled colour (7.5YR 5/8), common fine distinct mottles; fine sandy clay; weak fine subangular blocky structure; friable, sticky and plastic; patchy thin cutans in pores and around peds; common very fine to fine tubular and vesicular pores; very few roots; pH 4.5.

FERRIC ACRISOL
Thailand

Horizon	Depth cm	pH		Cation exchange me %									$CaCO_3$ %
		H_2O 1 : 1	KCl 1 : 1	CEC	TEB	% BS	Ca	Mg	K	Na	Al	H	
Ap	0–8/12	5.4	4.6	5.7	1.6	28	1.0	0.3	0.1	0.2		4.1	
E	8/12–40	6.4	5.1	6.4	2.3	36	1.7	0.3	0.1	0.2		4.1	
EB	40–53	5.7	5.0	4.8	1.6	33	1.0	0.4	0.04	0.2		3.2	
BE	53–72	5.2	4.5	5.8	1.0	17	0.5	0.2	0.1	0.2		4.8	
Bt	72–119	5.2	4.7	5.2	0.5	10	0.2	0.1	0.04	0.2		4.7	
Btg	119–147	5.0	4.7	6.0	0.6	8	0.2	0.1	0.1	0.2		5.4	
BCg	147–153+												

Horizon	Sol. salts		Organic matter				Particle size analysis %						Flocc. index
			% C	% N	C/N	% OM	Stones	C. sand	F. sand	Silt	Clay	Texture	
Ap			1.07	0.08	13			59.1		28.0	12.9	sl	
E			0.63	0.06	10			10.3	45.7	28.0	16.0	sl	
EB			0.36	0.05	7			55.0		27.3	17.6	sl	
BE			0.29	0.04	7			10.6	41.8	25.7	21.9	scl	
Bt			0.26	0.03	9			52.7		26.9	20.4	scl	
Btg			0.22	0.03	7			10.1	40.3	27.4	22.2	scl	
BCg													

FERRIC ACRISOL Af

Location	Manusi division, Tawau, Sabah
Altitude	20 m (approximately)
Physiography	Weakly dissected low coastal plain
Drainage	Well drained
Parent material	Old colluvial volcanic ash
Vegetation	Oil palm plantation
Climate	Humid tropical; rainfall 1 800 mm (approx.) with weak maximum from May to August

Profile description

Ah	**0-2 cm**	Dark greyish brown (10YR 4/2) loam; moderate to strong medium granular; very hard; very common roots; clear smooth boundary to
E	**2-10 cm**	Yellowish brown (10YR 5/4) and dark greyish brown (10YR 4/2) due to worm-cast, loam to sandy clay loam; moderate to strong fine to medium subangular blocky and coarse granular; hard (dry); many roots; gradual smooth boundary to
EB	**10-20 cm**	Dark yellowish brown (10YR 4/4) sandy clay loam; strong medium subangular blocky; very hard; many roots; few fine fragments of decomposing moderately hard rock; common moderately thick humus staining along cracks and pores; common roots; diffuse smooth boundary to
BE	**20-30 cm**	Yellowish brown (10YR 5/6) clay loam; structure as above; rock fragments as above; common roots; common moderately thick humus staining along cracks and pores; diffuse smooth boundary.
Bt1	**30-45 cm**	Brown to dark brown (7.5YR 4/4) sandy clay to clay loam; structure similar to above; hard; common decomposed rock fragments as above; common roots; diffuse boundary to
Bt2	**45-60 cm**	Brown to strong brown (7.5YR 4/4) sandy clay with few fine distinct light olive grey (5Y 6/2) mottles; structure as above; hard; broken thin clay cutans on ped surfaces and pore channel; decomposed rock fragments as above; common roots; diffuse boundary to
Bt3	**60-87 cm**	Reddish brown (5YR 5/4) clay with common fine distinct light olive brown (2.5Y 5/4) mottles; structure as above; firm (moist); decomposed rock as above; few fine reddish concretions; few roots; broken thin cutans on ped surfaces; diffuse boundary to
Bt4	**87-120 cm**	Yellowish red (5YR 5/6) clay with common medium to coarse distinct light yellowish brown (2.5Y 6/4) mottles; strong coarse subangular blocky; firm; decomposed rock fragments as above; iron concretions as above; few roots; broken thick cutans on ped surfaces; abrupt wavy boundary to
Ccs1	**120-153 cm**	Yellowish red (5YR 4/8) clay with common coarse distinct light yellowish brown (2.5Y 6/4) mottles; abundant (± 80%) (2-10 mm diam.) hard subangular dusky red iron concretions; common rounded stones (25 mm diam.); decomposed rock fragments as above; slightly firm; abrupt wavy boundary to
Ccs2	**153-210 cm**	Red (2.5YR 5/6) clay with common to many coarse light yellowish brown (2.5Y 6/4) mottles; moderately medium subangular blocky; many iron concretions (size as above), but decreasing in depth; few decomposed rock fragments; friable to firm.

FERRIC ACRISOL
Sabah

›rizon	Depth cm	pH		Cation exchange me %									Ext. Al KCl IN ppm
		H_2O	KCl	CEC	TEB	% BS	Ca	Mg	K	Na	Al	H	
	2–10	4.0	3.5	6.41		21	0.82	0.43	0.06	0.02		0.51	139
E	20–30	3.8	3.5	4.95		6	0.14	0.09	0.03	0.02		0.40	225
	30–45	4.0	3.5	5.10		6	0.08	0.07	0.03	0.02		0.51	231
	45–60	3.8	3.5	6.17		3	0.06	0.04	0.03	0.01		0.41	224
3	60–87	3.8	3.5	6.99		2	0.03	0.02	0.03	0.02		0.41	291
4	87–120	3.8	3.5	7.85		1	0.06	0.01	0.03	0.02		0.41	283
I	120–153	3.8	3.7	6.02		2	0.03	0.01	0.04	0.02		0.51	249

rizon	Sol. salts		Organic matter				Particle size analysis %						Flocc. index
			% C	% N	C/N	% OM	Stones	C. sand	F. sand	Silt	Clay	Texture	
			1.93	0.13				19.5	44.1	10.4	20.0		
E			0.47	0.05				17.3	41.3	11.2	27.8		
			0.39	0.04				18.5	38.3	10.5	29.5		
			0.30	0.04				14.8	31.8	9.7	41.6		
3			0.28	0.04				12.6	26.7	0.7	56.2		
			0.26	0.03				10.8	19.9	7.5	57.0		
			0.23	0.03				36.5	19.0	6.9	34.3		

Mineral x-ray analysis of the clay fraction

SAMPLE 5 74	41	42	44	46	48	50					OBSERVATIONS
aolinite	+++	+++	+++	+++	+++	+++					
Mica/Illite											
Low charge mectite High charge											
ermiculite											
nlorite											
oil-chlorite											
xed-layer	0-tr	0-tr	0-tr	0-tr	0-tr	tr.					
artz	tr.	tr.	tr.	0-tr	0-tr	0-tr					
ldspars											
thite	tr-x	tr-x	tr-x	tr-x	tr-x	tr-x					

tr. = trace

+ – +++ = estimate of relative abundance.

X – XXX = non clay minerals