CLASSIFICATION OF THE SOILS OF GHANA

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Godfried Kofi Asamoa
1961

CLASSIFICATION OF THE SOILS OF GHANA

By

Godfried Kofi Asamoa

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Soil Science

1961

ABSTRACT

CLASSIFICATION OF THE SOILS OF GHANA

by Godfried Kofi Asamoa

Many systems of soil classification are possible. In fact there can be as many as there are objectives for classifying soils. As a prelude to the discussion of the classification of the soils of Ghana past, present and proposed systems of other countries are reviewed. This reveals some changing concepts in soil classification. The early systems of soil classification were based on the geology of the parent material. Since Dokuchaiev's recognition of the soil forming factors (climate, vegetation, parent material, topography and time) as a function of the soil many systems based on these were developed. Recent trends in soil classification are toward the choice of soil properties, particularly morphological characteristics which reflect soil genesis, as criteria.

Charter's proposed scheme for the classification of the soils of Ghana is critically examined. Since the author has not done any field studies on the soils of Ghana the results of work so far completed by the Ghana Division of Soil and Land-Use Surveys have been largely drawn upon. In addition to current literature on the soils of Ghana profile descriptions and laboratory data were supplied for ten representative soil series. A, B, C, letter symbols and genetic

designations are proposed for the horizons of each of these series. An attempt is made to place these soils within the proposed system of the United States (the 7th Approximation). While there was little difficulty with the placement of the ground water podzol, tropical black and gray earths the placement of the other series with the oxisols was difficult. This is due to the lack of knowledge about the latosols. At present, with the scanty descriptive and laboratory data, it appears that Charter's system may be better than the 7th Approximation for grouping the latosols and latosolic soils of Ghana.

The soils of Ghana have been described according to the major vegetation zones (forest, interior savannah and coastal savannah) to which they are closely related. This description and the classification of the soils of Ghana reveal some general problems of soil classification in the tropics. Knowledge about tropical soils is scanty and there is lack of cooperation between workers of the various countries. The soils are relatively featureless. This makes the choice of properties for differentiation somewhat difficult. Some unique processes of soil formation in the tropics make difficult the direct application of methods of temperate regions. The need for careful morphological description and detailed laboratory data has been emphasized for a sound classification of soils of the tropics. The interrelationships of the soils should be sought through the soil formation factors. The major soil groups and their related land use have been discussed. Since Ghana is mainly an agricultural country, it is recommended that agronomic investigations should go along with the improvement of the classification of the soils.

For improving the classification of the soils of Ghana the following suggestions were made: The nomenclature should be improved to call to mind readily the important properties of the soils. The possibility of using vernacular names should be investigated. Morphological properties having some genetic significance should be preferred as criteria for differentiation. For this approach detailed description and laboratory data are essential. Additional research involving soil moisture determinations, soil texture, bulk density, aggregation, porosity and other soil properties hitherto overlooked, is recommended. Statistical approach should be adopted for sampling in soil surveys and for other agricultural research. It is recommended that soil survey data be used for land capability classifications for various purposes.

The purpose for classifying the soils of Ghana is to organize our knowledge about them so that their properties may be remembered and their relationships easily understood for a specific objective. The usefulness of the classification of these soils, therefore, will depend on how well it serves this purpose.

CLASSIFICATION OF THE SOILS OF GHANA

By

Godfried Kofi Asamoa

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Soil Science

1961

ACKNOWLEDGEMENTS

The author expresses his gratitude to Dr. E. P. Whiteside for all the advice and encouragement received in the author's program of studies at Michigan State University, particularly during the preparation of this manuscript and to Dr. Louis Wolfanger, for his advice during the absence of Dr. Whiteside.

He thanks Mr. H. B. Obeng, and the staff of the Soil Survey Branch of the Ghana Division of Agriculture for providing him with the data that made the preparation of this thesis possible. The author also thanks Dr. G. D. Smith of U.S.D.A. and Professor I. F. Schneider for providing him with copies of the 6th and 7th Approximations respectively for early study.

Finally the author wishes to express his gratitude to members of the Soil Science staff of Michigan State University, and in particular to members of the committee, who have helped in making his study at M.S.U. a success.

TABLE OF CONTENTS

INTRODUCTION

The purpose of this study is threefold:

1. to acquaint the writer with work that has been done on the soils of Ghana;
2. to help in correlating the most important soils of Ghana with those of other countries;
3. to reveal some of the gaps in our knowledge about the soils of Ghana, and suggest means of improving their classification.

It was not possible for the writer to carry out any field studies on the soils of Ghana. Hence the results of work so far completed by the Ghana Division of Soil and Land-Use Surveys, have been largely drawn upon in preparing this manuscript. This handicap makes discussion of the classification of Ghana soils and their placement in the 7th Approximation a delicate undertaking. Besides the 7th Approximation is only a proposed classification in its trial stages. However, these drawbacks will not defeat the purpose of this work.

Soil classification and survey work is comparatively recent in the tropics. In Europe and in the United States advanced systems of soil classification have been worked out through many years of studies. Our limited knowledge about tropical soils is revealed in the 7th Approximation (47);

the stage of approximation reached with tropical soils is behind those for soils of other regions. It is pointed out that the classification of tropical soils is the weakest part of all systems of soil classification in Europe and in the United States. Kellogg (27) emphasized the need for detailed soil surveys in the tropics with classification according to carefully defined units of lower categories. Efforts being made to overcome these shortcomings are discussed in the following pages. In order to properly evaluate soil survey and classification efforts in Ghana it is necessary to review various systems of soil classification, including the recently proposed comprehensive system of the USDA (47).

II. REVIEW OF THE LITERATURE ON SYSTEMS OF SOIL CLASSIFICATION (PAST, PRESENT AND PROPOSED)

Early Systems in Other Countries

In the seventeenth and eighteenth centuries the educated class in Europe had little incentive for the study of soils or agriculture. This was so because people looked down on agriculture as dirty and menial. Early concepts of the soil were therefore, developed in other fields such as botany, chemistry and geology. According to the botanical concept (42) soils were classified on the basis of the natural vegetation or the crops they supported; e.g., wheat soils, oak soils, etc.

The work of early chemists and plant physiologists, notably Joseph Priestley, Scheele, Ingenhousz and Senebier, paved the way to the discovery that the soil furnishes a very small but indespensable part of plant food (42). Traditionally the soil has been looked upon as a medium for plant growth (47). Today man's interest in the soil is chiefly centered around this function.

In the early nineteenth century, interest in the study of soils was aroused. At about this time the geologist's concept was developing. The first attempt to study soils outdoors was made by geologists (1). Notable among them were Fallou, Sprengel and Thaer (2). They treated the soil as a function of the parent material. Thaer classified soils on the basis of texture. He recognized clayey soils, sandy soils, sandy loam and humus. The classifications of Fallou and Sprengel were genetic; i.e., based on the origin of weathered products from rocks (2). They classified soils into:

1. nontransferred soils (essential original soils);
2. transferred soils (e.g., valley soils, lake soils).

Later, concepts involving zonality were developed by Richthofen and Walther (2). These men were geographers or geologists, who travelled widely and saw differences among soils of great regions. Richthofen (1880) postulated that the soil was a product of physical processes determined by climate, topography and parent material. His classification consists of the following major groups (2):

1. autogenous (residual) soils;
2. equilibrium soils;
3. soils of denudation;
4. soils of sedimentation.

Walther (1885-1890) was among the first to classify soils on the basis of climate. He emphasized the effect of climate on the nature of rock and on the process of rock weathering. He classified soils into: boreal soils, temperate soils, desert soils, and tropical soils.

At about this time the study of the soil as a science began in Russia. Dokuchaiev (2), father of modern soil science,

laid the foundation. According to him soil is merely a function of the five soil forming factors (climate, vegetation, parent material, topography, and time). It is interesting to note here that Jenny (23) put this idea into an equation but emphasized the independent nature of each factor. The classification scheme developed by Dokuchaiev is outlined in "Soils and Men" (3) and lately it has been tabulated in the 7th Approximation (46). (See Table 1). Dokuchaiev classified soils into: normal soils, transitional soils and abnormal soils. The normal soils, similar to the zonal great soil groups of today, express zonal effect. The abnormal soils represent a young state of development and lack characteristics of zonal soils. Further subdivisions of these groups may be seen in the Table 1b.

In 1900, Dokuchaiev's student, Sibirtsev classified soils into three orders; zonal, intrazonal and azonal. The zonal soils he said owed their properties mainly to the effect of climate and vegetation; intrazonal soils were soils of which the dominant factors of formation were topography and extremes of parent material. The azonal soils were equivalent to Dokuchaiev's abnormal soils.

It should be noted that the above two systems were based on ideas of soil genesis. Glinka (1908-1925) asserted that "the morphology of a soil is the result of internal soil

TABLE 1.--1886 Classification of Soils by V. V. Dokuchaiev

According to position (to presence of primary genetical features)	According to origin	According to climatical region (and to humus content)	According to zeolite clay (each soil)
	I cl. Dry land vegetative soils	1. Light gray northern soils	Sandy sandy-loamy Loamy Clayey
		2. Gray transitional soils	
		3. Chernozean soil soils	
		4. Chestnut transitional soils	
A. Normal		5. Southern brown alkaline soils Primary Secondary Periodical Eroded Burrowed	
	II cl. Dry land moor soils	6. Soils of swamped forests	
		7. Meadow soils	
	III c. Moor (bog) soils in potentia)	8. Tundra soils 9. Peats 10. Water logged flood plains etc.	
B. Transitional			
	IV. cl. Washed soils		
	V. cl. Dryland sedimentary soils		
C. Abnormal	VI cl. Sedimentary soils		

TABLE 1b

Final (1900) Classification of Soils by V. V. Dokushaiev

Class A: Normal, Otherwise Dryland Vegetative or Zonal Soils

	I	II	III	IV	V	VI	VII
Zones	Boreal	Taiga	Forest-steppe	Steppe	Desert-steppe	Aerial or desert zone	Subtropical
Soil types	Tundra (dark brown soils)	Light gray podzolized soils	Gray and dark gray soils	Cherno-zian	Chestnut and brown soils	Aerial soils, yellow soils, white soils.	Laterite or red soils

Class B: Transitional Soils

I	IX	X
Dry land moor-soils or moor-meadow soils	Carbonate containing soils (rendzina)	Secondary alkali soils

Class C: Abnormal

X	XI	XIV
Moor soils	alluvial soils	Aeolian soils

forming processes controlled by climate." He therefore set up a classification system, which was based on morphology as well as factors of soil genesis. He attributed the origin of soil properties to two major changes (2):

1. changes in organic matter, and
2. decomposition of minerals.

Both changes are controlled by climate. His scheme reflects the effect of climate and vegetation. He recognized five major "types":

1. Laterite type,
2. Podzol type,
3. The Steppe type,
4. Alkaline type,
5. Bog type.

Gedroiz (1925) was among the first to emphasize morphological properties of soils as criteria for classification. The colloidal properties of soils (nature of exchangeable cations) was the basis of his scheme. Although his major groups were chernozem type, alkaline type, Podzol type and Laterite type, it was his hope that a system which relates closely genetic features to texture might be developed. It is not possible to outline the schemes of all the important Russian workers in this review. But a brief mention may be made of others: Vilenskii, Zakharov, Vysotskii and Volobuev used essentially

Glinka's approach (7). Their classifications were based on separate factors of pedogenesis. Kossovitch, Tumin and Neustruev used pedogenic processes as a basis for their classification (7) et. Neustreuv divided soils into automorphic and hydromorphic groups. In 1925 Afanasiev put forth a classification system modified after Dokuchaiev and Sibirtsev; he recognized the regimes of climate, vegetation, water, geomorphology and salt. Under each of these the normal, transitional and abnormal soils were developed. These three men adopted the "geographic-environmental" approach to soil classification (7).

Early and Present System in the United States

The Russian school of thought had great impact on soil classification in the United States of America. Early workers in the U.S., like their contemporaries in Europe, laid emphasis on geology. In 1889 the USDA used soil type* as a fundamental unit of classification (1). Hilgard (1860-1906) was notable among the early workers because he recognized the importance of soil formation factors including climate (22). In his report on the soils and agriculture of Mississippi (21) he showed how soils and their properties are related to the type of vegetation. Coffey (1912) recognized the soil as an

---

*Soil type, as used here, is a subgroup or category under the soil series based on the texture of the surface soil.

independent body (47). He stressed the need for using morphological characteristics as criteria for soil classification and classified soils into:

1. Acid soils,
2. Dark colored prairie soils,
3. Light colored timbered soils,
4. Black swamp soils,
5. Organic soils.

Each class was subdivided into series on the basis of parent material and the series was further subdivided on the basis of texture.

Marbut (1908-1935) greatly influenced thought in soil classification in the United States. Being a geologist he started with the ideas of the old school of geology. Later he was influenced by the work of Glinka and following that he greatly underemphasized the role of parent material (33). Marbut developed the concept of the soil as an independent natural body with three dimensions and profile characteristics. The classification of normal soils was one of his major interests. In his scheme of soil classification (3) he presented two great divisions: (1) Pedocals (having a carbonate enriched subsoil), and (2) Pedalfers (having a subsoil with concentrations of iron and aluminum oxides). Further subdivisions are shown in Table 2*.

---

*Table 2 adopted from Soils and Men (3, p. 938).

TABLE 2.--Soil Categories

Category VI	Pedalfers (VI-I)	Pedocals (VI-2)
Category V	Soils from mechanically comminuted materials Soils from siallitic decomposition products Soils from allitic decomposition products	Soils from mechanically comminuted materials
Category IV	Tundra Podzols Gray-Brown Podzolic soils Red soils Yellow soils Prairie soils Lateritic soils	Chernozems Dark-brown soils Brown soils Gray soils Pedocalic soils of Arctic and Tropical regions
Category III	Groups of mature but related soil series Swamp soils Gley soils Rendzinas Alluvial soils Immature soils on slopes Salty soils Alkali soils Peat soils	Groups of mature but but related soil series Swamp soils Gley soils Rendzinas Alluvial soils Immature soils on slopes Salty soils Alkali soils Peat soils
Category II	Soil series	Soil series
Category I	Soil units or types	Soil units or types

Baldwin, M., Kellogg, C. E. and Throp, J. Soil Classification. 1938 Soils and Men. USDA Yearbook of Agriculture, p. 938.

The year 1938 saw the revival and modification of Sibirtsev's zonal, intrazonal and azonal concept by Baldwin, Kellogg and Thorp (3). Their scheme of classification is similar to Marbut's, but differs from it in one important aspect: the azonal soils were raised to the level of zonal and intrazonal soils. The detailed scheme presented in the 1938 classification was revised by Thorp and Smith in 1949 (46). The three dimensional concept of the soil individual was stressed. Since Marbut's time the trend in soil classification in the United States has been toward an increasing recognition of morphological characteristics with genetic significance as criteria.

Proposed Comprehensive System

With the increase of knowledge, the need for developing a new system was felt among the soil survey staff of USDA. This led to the publication of the 7th Approximation of a comprehensive system of soil classification. In this proposed system some of the short-comings of the previous systems were revealed (47). For example, definition of the classes were vague, and the systems were based primarily on the factors of soil genesis or properties of the virgin soil in the natural landscapes. The new system takes into full consideration changes taking place within the soil as a result of man's influence. Certain assumptions that guided the development of the system were outlined (47).

According to Cline (13), "The purpose of any classification is so to organize our knowledge that the properties of the objects may be remembered and their relationships may be understood most easily for a specific objective." In developing the nomenclature for the proposed system this idea was brought up in the statement that "the most useful names are those that are most easily remembered, suggest some of the properties of the objects, and show the position of the class in the system" (47), (see Table 3 for names of higher categorical classes).

In the proposed system the following categories, starting at the highest level of abstraction have been divised: VII, Order; VI, Suborder; V, Great Soil Groups; IV, Subgroups; III, Family; II, Soil Series; and I, Soil Type. It is stated, moreover, that the type is to be eliminated as a category in the proposed system.

There are ten <u>orders</u> and some of these correspond closely to Coffey's major classes and Dokuchaiev's types (47). The major kinds of differentia used for the soil order are presence or absence, and nature of diagnostic horizons and their features; major differences in soil moisture, and major differences in kinds and amounts of organic matter. No attempt will be made here to describe the various orders. However, attention is

TABLE 3.--Names of Proposed Orders, Suborders, and Great Groups of Soils

Order	Suborder	Great group
1. Entisol	1.1 Aquent	1.11 Cryaquent
		1.12 Psammaquent*
		1.13 Hydraquent
		1.14 Haplaquent
	1.2 Psamment....	1.21 Quarzopsamment
		1.22 Orthopsamment*
	1.3 Ustent	1.31 Psammustent*
		1.32 Orthustent*
	1.4 Udent.......	1.41 Cryudent
		1.42 Argudent
		1.43 Hapludent
		1.44 Plaggudent
2. Vertisol.......	2.1 Aquert......	2.11 Grumaquert
		2.12 Mazaquert
	2.2 Ustert......	2.21 Grumustert
		2.22 Mazustert
3. Inceptisol	3.1 Aquept......	3.11 Halaquept
		3.12 Umbraquept*
		3.13 Fragaquept
		3.14 Cryaquept
		3.15 Ochraquept*
	3.2 Andept......	3.21 Cryandept
		3.22 Durandept
		3.23 Ochrandept*
		3.24 Umbrandept*
		3.25 Hydrandept
	3.3 Umbrept.....	3.31 Cryumbrept
		3.32 Haplumbrept
		3.34 Anthrumbrept
	3.4 Ochrept.....	3.41 Cryochrept
		3.43 Eutrocherpt
		3.44 Dystrochrept
		3.45 Ustochrept
		3.46 Fragochrept

TABLE 3 (Continued)

Order	Suborder		Great Group
4. Aridisol	4.4 Orthid......	4.11	Camborthid
		4.12	Durorthid
		4.13	Calcorthid
		4.14	Salorthid
	4.2 Argid.......	4.21	Haplargid
		4.22	Durargid
		4.23	Natrargid
		4.24	Nadurargid
5. Mollisol......	5.1 Rendoll.....	5.11	---(Rendoll)
	5.2 Alboll	5.21	Argalboll
		5.22	Natralboll
	5.3 Aquoll......	5.31	Haplaquoll
		5.32	Argaquoll
		5.33	Calcaquoll
		5.34	Duraquoll
		5.35	Natraquoll
	5.4 Altoll.....	5.41	Vermaltoll
		5.42	Haplaltoll
		5.43	Argaltoll
		5.44	Calcaltoll
		5.45	Natraltoll
	5.5 Udoll......	5.51	Vermudoll
		5.52	Hapludoll
		5.53	Argudoll
	5.6 Ustoll.....	5.61	Vermustoll
		5.62	Haplustoll
		5.63	Argustoll
		5.64	Durustoll
		5.65	Calcustoll
		5.66	Natrustoll
6. Spodosol......	6.1 Aquod......	6.11	Cryaquod
		6.12	Humaquod*
		6.13	Ferraquod
		6.14	Placaquod
		6.15	Thermaquod

TABLE 3 (Continued)

Order		Suborder		Great group	
				6.16	Duraquod
		6.2	Humod.......	6.21	Orthumod
				6.22	Thermhumod
		6.3	Orthod*.....	6.31	Cryorthod
				6.32	Placorthod
				6.33	Typorthod
		6.4	Ferrodd.....		
7.	Alfisol.......	7.1	Aqualf......	7.11	Albaqualf
				7.12	Glossaqualf
				7.13	Ochraqualf
				7.14	Umbraqualf
				7.15	Fragaqualf
				7.16	Natraqualf
		7.2	Altalf.....	7.21	Cryaltalf
				7.22	Typaltalf
				7.23	Natraltalf
				7.24	Fragaltalf
		7.3	Udalf......	7.31	Agrudalf
				7.32	Typudalf
				7.33	Fragudalf
				7.34	Glossudalf
				7.35	Fraglossudalf
		7.4	Ustalf.....	7.41	Durustalf
				7.42	Natrustalf
				7.43	Rhodustalf
				7.44	Ultustalf*
				7.45	Typustalf
8.	Ultisol.......	8.1	Aquult.....	8.11	Plintaquult
				8.12	Ochraquult*
				8.13	Umbraquult*
				8.14	Fragaquult

TABLE 3 (Continued)

Order	Suborder		Great group	
	8.1	Ochrult.....	8.21	Plintochrult
			8.22	Rhodochrult
			8.23	Typochrult
			8.24	Fragochrult
	8.3	Umbrult.....	8.31	Plintumbrult
			8.32	Typumbrult
9. Oxisol........				
10. Histosol......				

*Used temporarily for want of a better name. The prior formative element is duplicated in such a way that two different subgroups may have identical names.

drawn to Table 5 in the 7th Approximation (47), which shows their approximate equivalents in the revised classification of Baldwin, Kellogg and Thorp. It should be noted that the humic gley soils were redistributed among several orders. Subdivisions of the orders into <u>suborders</u> is based primarily on chemical or physical properties that reflect either the presence or absence of water logging or moderate genetic differences due to climate or vegetation, and minerological differences. The differentiating characteristics used for the <u>great groups</u> were defined on the basis of diagnostic horizons and their arrangement. Emphasis is placed on properties least apt to be destroyed by tillage or corrosion. Dark red or dark brown surface colors, and major differences in irreversible consistence changes of surface layers, are also used as differentiae. At the <u>subgroup</u> level we have the central concept of the great group (the orthic group) and its intergrades. The differentiae for the <u>families</u> are properties which are important to plant growth; i.e., properties affecting soil air, soil water, plant-root relationships and nutrient supplying capacities for the major elements other than nitrogen. The differentiae selected for horizons below the plow layer are texture, thickness of horizon, mineralogy, reaction, consistence, and permeability. The authors pointed out that the families are not well defined and the subgroup definitions are incomplete. The major properties used as series differentiae are those of the solum below the plow layer. "These properties should be observable or inferred with reasonable assurance." They must have at least limited singificance to soil genesis. The soil type has been dropped as a category in this proposed system. If this proposed system is to be used effectively the need for lower categories in relation to land use cannot be overlooked.

The 7th Approximation has certain definite advantages. It includes all known soils, and it has given due consideration to changes taking place within virgin soils as a result of man's influence. Morphological properties which have genetic significance are used as differentiae. Temperature and moisture conditions of soils are also used as differentiae at the great group level. It should be noted that both temperature and moisture can be regarded as genetic properties. Their use as differentiae at this level is encouraging because it shows that both genetical and morphological properties are closely related.

As proposed the 7th Approximation has some draw-backs; all the classes have not been studied in such detail as to permit their classification to the same level. For example the classification of tropical soils (Oxisols) and organic soils (Histosols) lags behind the others. Definitions of classes in the other subgroups and lower categories are not complete.

It is also likely that the nomenclature will not be easy to manage at the initial stages. As new knowledge accumulates, it is hoped, these shortcomings will be overcome. The proposed system is now in its trial stages. It is, therefore, too early to evaulate its usefulness.

From the above historical review of soil classification efforts it is evident that repeated attempts have been made to improve the systems as knowledge of the soils increased. This is desirable since classification is conceptual and reflects the knowledge of the period. The models of classification we build up should be used to search for new facts, which will in turn improve the classification.

Types of Classification Systems

Many types of classification of soils are possible. In fact there can be as many systems as there are objectives for classigying soils. However, each type may belong to one of the following two groupings: (1) Technical system of classification, or (2) Taxonomic systems of classification. Technical systems are those based on one or more characteristic features or properties which are important and of value for a particular objective (51); an example is land-use capability classification. The usefulness of such limited purpose classification depends on the importance of properties chosen for the objective. Cline (13) refers to those systems which assume that there is order in nature and attempt to organize natural phenomena in the light of this concept as "taxonomic." In the existing taxonomic systems soils are classified on the basis of the operating soil forming processes as they are inferred from the morphology of the soil profile.

Today, trends in the choice of criteria are toward observable or inferred morphological properties which have at least limited genetic significance. A point of contention between some soil scientists is whether a system should be called "natural" or "artificial." Kubiena (29) referred to Leeper's system as artificial and Leeper (31) objected to the use of the term natural for Kubiena's system. Such contentions arise, because people accord different meanings to the same term. The terms "technical" and "taxonomic" as used above are to be preferred to "natural" and "artificial," since the latter lead to confusion. The types of classifications discussed above and in the following pages are taxonomic.

Methods of approach to soil classification differ from country to country and for objectives. Manil (32) discussed two broad methods of approach:

1. analytic and descending (genetic approach);
2. synthetic and ascending. [Kubiena (30) in the Soils of of Europe refers to these as division and classification, respectively.]

The descending and analytic types of classification start from the highest categorical level. They may be based on genetic factors per se or on pedogenetic processes or on properties that reflect pedogenetic factors or processes. This type of approach is used by European classificationists. The synthetic and ascending type may be based on profile morphology with or without genetic considerations. Manil (32) stated that the synthetic and ascending classification is possible only when a large body of knowledge has been accumulated at the lowest categorical level.

In the United States the synthetic and ascending approach is used with genetic considerations. The use of morphological properties, which reflect soil genesis is becoming increasingly important in soil classification.

Basic principles guiding any natural classification have been discussed by Cline (13). The principles of differentiation as he outlined them are very important in soil classification. These principles are again seen in the assumptions underlying the development of the 7th Approximation (47). Here, only the criteria for soil classification will be considered.

In soil classification some properties must be chosen as the basis of grouping. These are the differentiating characteristics (13). According to Cline the differentiating characteristics should be associated with the greatest possible number of covarying properties. They should be such that the most precise and meaningful statement can be made about the soils. Properties of the soils themselves should be used. Accidental characteristics which vary independently of these differentiae are sometimes used with them in the lower categories.

Morphological characteristics are used as criteria in the U. S. Genetical factors though not used as criteria serve as indexes to properties of the soil that are criteria (13). Genetical properties help in classifying at higher levels of abstraction and in placing soil boundaries in the field. Van Eck and Whiteside (48) point out that the making of accurate soil maps requires an understanding of soil genetics.

Criteria of Soil Classification

Marbut (33) proposed ten important criteria used for differentiating at the level of soil type: These are: number of horizons in the profile, color of the various horizons, texture, structure, relative arrangement of horizons, chemical composition, thickness of horizon, thickness of the true soil, character of the soil material and geology of the soil material. Cline (13) reported that no one has since then improved upon this list. But Whiteside (49) subsequently outlined some changes in the criteria used since Marbut. He grouped the criteria according to whether they are properties of the soil body or of its individual horizons as follows:

I. <u>Properties of the soil body</u>.

1. Number of horizons in the soil profile.
2. Relative arrangement of the horizons
3. The thickness of the true soil.
4. Mineralogical and chemical composition of the parent rock.
5. Texture of the parent rock.
6. Structure or fabric of the parent rock.
7. Shape.
8. Temperature.
9. Moisture.
10. Degree of development.
11. Age.
12. Air?
13. Biology?

II. <u>Properties of the soil horizons</u>.

14. Texture.
15. Structure.
16. Consistence.
17. Color.
18. Chemical composition.
19. Mineralogical composition.
20. Thickness.

These gave twice as many properties as originally proposed by Marbut. Since then in the United States, the following properties have been added to the second group: porosity, nature of horizon boundaries, changes on wetting and drying, ease of dispersion and N values. These new properties have been used as criteria in the 7th Approximation. The N value is not a completely new property since it is a combination of a number of properties (moisture, texture, organic content, and chemical composition) outlined above. However, moisture content of soil horizons in the field, which is included in the N value, is a new property.

It should be noted that the properties used are only good as long as the objective of the classification remains unchanged, and they maintain their original importance to this objective. It may be necessary to further increase the number of these properties as our knowledge of soils increases, or drop some of them. However, there is a limit to the number of properties that should be used. Although this limit is not fixed, the number should not be so large as to unnecessarily complicate the system or so small as to over-simplify it.

III. SOILS OF GHANA: CLASSIFICATION AND SURVEY EFFORTS

Soil survey and soil classification in Ghana as in many tropical areas, lags behind the development of other branches of agricultural investigation (notably crop and animal husbandry). An organized attempt to carry out a country-wide survey was started in 1948 (8 and 9) with the formation of the Soil Survey Division in the Department of Agriculture. The division was headed by the late Hon. C. F. Charter. Mr. Charter started work in Ghana as a soils specialist at the West African Cocoa Research Institute, Tafo. It is interesting to note that, in Ghana, the concern for a closer study of soils was caused by "swollen shoot," a virus disease of cocoa. At the initial stages of investigation research was directed toward finding the cause of the disease. The soil as a medium of growth for the cocoa plant constituted one of the areas of search.

The Soils Division was faced with many initial problems: there was the difficulty of recruiting qualified senior staff and training locally recruited junior staff. Much effort was expended during this period on the construction and equipping of administrative and technical offices, laboratories, stores and workshops (11). Charter (11) deserves credit for meeting all these demands efficiently.

The initial survey and mapping of all the soils of the country is still in progress. However, considerable data have been accumulated to justify an attempt at developing a scheme of classification and the making of a provisional map of the soils of the country. Charter's (12) provisional scheme of classification of soils so far discovered in Ghana is discussed in the following section. This scheme was later revised by Brammer (4 and 5). He made certain suggestions for improving it. With the limited detailed descriptive data at hand, this scheme of classification can be only provisional.

Charter's Proposed Scheme of Soil Classification

As stated by Brammer (4) the basis of Charter's interim scheme for the classification of tropical soils is the formula: soil = f (climate, vegetation, parent material, relief and drainage, and age). The approach to this classification is, therefore, genetic. Since detailed morphological descriptions have not been made for most of the soils, this genetic approach is to be expected.

The system as it is presented in outline includes four soil orders. The soil forming factors are used as criteria for differentiating at this level. One or two of the factors having predominant influence on the development of the soils form the basis of the grouping:

Soil Orders	Dominant Factor or Factors Influencing Development
I Climatophytic earths	Climate and vegetation
II Topoclimatic earths	Relief and climate
III Topohydric earths	Relief and drainage
IV Lithochronic earths	Parent material and/age

At the level of the suborder different characteristics were used to differentiate in each of the above order.

I The Climatophytic Earths

These are the normally well drained soils. They are differentiated on the basis of depth of penetration of rainfall or thoroughness of leaching.

Suborders:

A. Hygropeds, soil profile through leached to groundwater

B. Xeropeds, soil profile not through leached.

II The Topoclimatic Earths

The Topoclimatic earths have not been further subdivided because they are not found in Ghana.

III Topohydric Earths

Topohydric earths are soils with poor drainage conditions. It should be noted that at this level two different criteria have been used for differentiation. The first four suborders are differentiated on the basis of the nature of the topographic site, while the fifth is characterized by accumulation of peat at the surface.

Suborders

A. Planopeds: Poor drainage due to flat or very gentle topography.

B. Clinopeds: Soils affected by water seeping from upslope and precipitating chemical substances from solution.

C. Depressiopeds: Soils developed in poorly drained depressions (receiving runoff or seepage waters from adjoining areas).

D. Hydropeds: Soils developed under open water in shallow lagoons, rice paddies, etc.

E. Cummulopeds: Soils developed in depressions with peat accumulation.

IV Lithochronic Earths

Lithochronic earths are the soils with restricted profile development. Differentiation into suborders is according to the particular factor retarding development.

Suborders	Factor Retarding Development
A. Lithopeds	Resistant rock or erosion on steep slope
B. Regopeds	Inert nature of loose sandy parent material
C. Alluvioped	Constant addition of fresh alluvium to the surface.

The differentiating characteristic used for subdividing the suborders into families of great soil groups is usually the reaction of the profile.

Order I - Climatophytic earths

Suborder A - Hygropeds. These are subdivided into families on the basis of mineral base supplying power of the parent material.

Family - 1. Latasols. These are soils developed over highly weathered parent material and in which the clay fraction is predominantly iron and aluminum sesquioxides and kaolinite.

2. Basisols. These are developed in parent material relatively rich in bases and the clay fraction has some montmorillonite together with kaolinite, and iron and aluminum sesquioxides.

Suborder B - Xeropeds. The suborder Xeropeds are not further subdivided since their presence in Ghana is doubtful.

Order II - Topoclimatic earths are not further discussed for the reason given above.

Order III - The great soil group families of the suborders of Topohydric earths are differentiated according to the nature of the reaction of the groundwater influencing the soils. Very acid,

acid, neutral, calcium and sodium group families are recognized. (See Table 4 for names.)

Order IV - Suborders of the Lithochronic earths, except the Lithopeds are not further differentiated into families of great soil groups. The Lithopeds are simply divided into two family groups: the Basimorphic Lithosols and Non-basimorphic Lithosols, somewhat as are the Hygropeds.

Within the families of the great soil groups are differentiated on the basis of natural vegetation under which they develop (forest or savanna) color, and trend of reaction in the soil profile. Brammer (4) points out that the color and reaction trends are used as criteria only in so far as they serve as manifestations of other fundamental differences in soil properties.

The great soil groups are further subdivided into <u>soil series</u> mainly on the nature of the parent material in which individual soils are developed. These have not been listed in Table 4, except for the ten series for which placement within the 7th Approximation was attempted.

The above scheme of classification is based on ideas similar to those that guided some of the earlier European systems of classification. It has the weakness of relying mainly on

TABLE 4.--Provisional Classification of Soils So Far Discovered in Ghana, after Charter, and placement of the Soil Series in Ghana in the 7th Approximation.

W.B.

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

(ii) ? before a term indicates that there is some doubt as to the exact plans 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 family indicated.

ORDER	SUBORDER	(SOIL GROUP FAMILY)	GREAT SOIL GROUP	GREAT SOIL SUBGROUP	SERIES
			Forest Ochrosol	Red Forest Ochrosol Yellow Forest Ochrosol	Bekwai (9.43), Kumasi (9.43)
	HYGROPEDS				
•		Latosol	Savannah Ochrosol	Red Forest Oxysol Yellow Forest Oxysol	Mimi (9.43), Toje (9.51)
		Basisols			
			Forest Oxysol?	Red Savannah Ochrosol Yellow Savannah Ochrosol	Boi (9.32)
CLIMATOPHYTIC EARTHS					
			Forest Rubrisol	Red Forest Rubrisol Yellow Forest Rubrisol	
	XEROPEDS				
			Savannah Rubrisol		
			Forest Brunosol Savannah Brunosol	Red Savannah Rubrisol Yellow Savannah Rubrisol	
			(Reddish Prairie?)		
					Atuabo (6.150)
			Groundwater Podsol		
					Kpelesawgu (9.11–9.12)
			Groundwater Laterite		
		Very Acid Planosol?			
	PLANOPEDS				
		Acid Planosol?	Tropical Black Earth Tropical Brown Earth		
					Akuse (2.11)
		Calcium Planosol			
		Sodium Planosol?			Agawtaw (7.15)
	CLINOPEDS	Very Acid Gleisol			
			(Savannah Gray Very Acid Gleisol)		
		(Tropical Gray Earth)			Wacri (7.32)
TOPOHYDRIC EARTHS					
	DEPRESSIOPEDS	Acid Gleisol	(Savannah Black Acid Gleisol) (Savannah Brown Acid Gleisol) (Forest Gray Acid Gleisol) (Savannah Grey Acid Gleisol)		
		Neutral Gleisol	(Forest Black Neutral Gleisol) (Savannah Brown Neutral Gleisol) (Forest Gray Neutral Gleisol) (Savannah Gray Neutral Gleisol)		
		Calcium Vleisol	(Black Vleisol) (Brown Vleisol) (Gray Vleisol)		
		Sodium Vleisol	Solonetz? Solonchak		
	CUMULOPEDS				
		Cumulosol	Very Acid Bog? Acid Bog? Saline Bog?		
	HYDROPEDS	Hydrosol	Neutral Hydrosol? Saline Hydrosol		
		Basimorphic Lithsol	(Black Basimorphic Lithosol) (Brown Basimorphic Lithosol) (Red Basimorphic Lithosol)	(Yellow Basimorphic Lithosol)	
	LITHOPEDS	Non-Basimorphic Lithosol			
			(Non-Basimorphic Lithosol)		
LITHOCHRONIC EARTHS					
	REGOPEDS		(Dune-sand Regosol—with calcareous pan—without calcareous pan) (Other Regosols)		
	ALLUVIOPEDS	Alluviosol	(Black Alluviosol) (Brown Alluviosol) (Gray Alluviosol)		

the factors of soil genesis and processes of pedogenesis as criteria. This is undesirable because in the choice of factors of soil genesis as differentiating characteristics, theories have been allowed to overrule observable facts. As Yalon (51) stated elsewhere, the interdependence of soil forming factors makes it difficult to relate soil properties to definite soil forming factors with any certainty. If great care is not exercised the classification becomes one of external soil forming factors rather than of the soil. The analytic and descending approach (32) adopted here indicates that detailed knowledge about the morphology of the soils is lacking. At this early stage of soil surveys in Ghana the authors could not be blamed. They made the right approach.

The lack of morphological descriptions and the need for precise observations was pointed out by Kellogg (27) in his preliminary suggestions for the classification and nomenclature of the great soil groups in tropical and equatorial regions. At least at the great soil group level and at lower levels of abstraction adequate detailed description of morphological properties must precede the choice of important morphologic characteristics as criteria. The trend today, particularly in the U.S., is toward the choice of morphological properties which are observable or can be inferred with some certainty from morphology and limited experimental data. Those morphological properties, which have some correlation with genetic properties and the soil formation factors (genetical properties) are preferable (48). Principles guiding such a choice have been outlined by Cline (13).

In the above system the subdivision of the order Topohydric earths is said to be based on the nature of topographic sites. But the Cummulopeds are differentiated from the Depressiopeds only on the basis of the peaty surface accumulation. This is a violation of the principle that all classes of the same category of a single population should be based on the same characteristics. It is clear that presence of peat accumulation is not used as criteria throughout the rest of the suborders. Therefore, it would be better to consider the separation of the cummulopeds from the depressiopeds at a lower level of abstraction, if the peat soils are only found in depressions, unless the peat horizon is morphologic evidence of a topographic site. If, however, peaty soils occur at sites other than in depressions then the raising of the peaty (organic) soils to level of soil order as in the 7th Approximation may be considered. Here again accurate observation and description of the nature of the peat (thickness, etc.) are necessary before taking any step. (This principle is sacrificed in order to avoid many additional categories in the 7th Approximation).

The differentiation of the series, merely on the nature of the parent material, is inadequate without properly correlated morphology and may lead to gross errors. However, this is a case where the genetical factors of soil formation are useful as simplifying relationships among soils in a category based on available information about the soils concerned. Obviously, the parent material from which the soil is presumed to be formed is no longer there to be seen. But, the nature of the parent material may commonly be inferred beyond any reasonable doubt from the properties of the parent rock and from the remaining weathered material, as outlined by Marshall and Haseman (35), and Whiteside (49). The morphological characteristics of the soil horizons will serve as described criteria.

The use of type of vegetation (forest or savanna) at the great soil group level has one serious disadvantage. The type of farming practices adopted in Ghana (bush fires, clearing of forest vegetation, etc.) are likely to change the characteristics of a typical savanna or forest soil within a matter of years. These should only be used as indicators to certain morphological properties or to serve as a generalization of the relationships involved in the morphological differences.

Description of the Major Soils of Ghana

Ghana has a tropical climate. The year is divided into two seasons, a rainy and a dry season. The pattern of rainfall distribution and intensity follow the major vegetational zones to which the soils are very closely related.* The Southwestern part of the country, with tropical rain forest, has a mean annual rainfall of over 80 inches. The annual rainfall in the other forest areas ranges from 60 to 70+ inches. In the interior savannah zone the annual rainfall range is about 44 to 55 inches. There is a special coastal savannah area with 25 to 35 inches of annual rainfall. In the forest zones there are two peaks of rainfall; the lower peak occurs around May to June and the high peak occurs in September to October. November to February are relatively dry. Most of the interior savannah areas experience one marked peak of rainfall (September to October) with a pronounced dry season.

The mean annual temperature is about 80 to 85^{o}F. Temperature variation between the hottest and coldest months increases as one goes inland (northwards), but there is only a few degrees variation in temperature.

The landscape consists of plains, river basins, scarps and mountain ranges. The northeast and northwest portions have scarp regions. The Accra plains (Volta river plains) occur in the southeast. The Kwahu range runs southeast to

---

*See map in Appendix 1 for distribution of great soil groups.

northwest. Southeast of this range we have conspicuous drainage patterns of rivers running north and south. In the Accra plains the dissection is low with isolated hills of Archean rocks (basic gneisses). Superficial deposits of talus occur on steep slopes and on the bottom of the slopes. On less steep ground a thicker soil mantle covers practically the whole country. River alluvium in the deltaic region of the Volta grade into lagoon deposits. These lagoons are a possible origin of the black clays* found in these areas.

The Akwapim-Togo range runs from southeast to northeast. Selective erosion and peneplaination are believed to have played a major role in shaping the landscape.

As stated earlier all the soils of Ghana have not yet been surveyed. The map in Appendix 1 shows the schematic distribution of great soil groups. Brammer (4) made it clear that this map has been greatly generalized and is only provisional. Soil boundaries, in areas not yet surveyed, have been drawn in by extrapolation using geological boundaries and isohyets as a guide.

The soils differ, according to the three major vegetation zones: forest, interior savanna, and coastal savanna. The following general descriptions of soils under the different

---

*For a detailed petrographic description of these black clays the reader is referred to Stephens discussion (45).

vegetation zones have been summarized from Brammer's (4) report. Diagrams of soil profiles representative of each group are shown in Appendix 2.

Forest Zones

The soils of the forest zones have greater accumulation of organic matter in the surface horizon than soils of the savanna zones. This is accounted for by more leaf fall and less decomposition of organic matter under forest conditions. Jenny (24), who studied two tropical forested soils of Colombia and compared them with California forest soils, attributed the higher level of nitrogen and organic matter in the tropical forest soils to higher additions of nitrogen in rainwater and higher non-symbiotic and symbiotic nitrogen fixation. He stressed the latter possibility since large numbers of leguminous trees occur in the tropical forest areas. He also observed that several hundred years seem to be required to build soil organic matter to a nearly steady state. Annual rainfall ranges from 35 inches to over 80 inches in these zones. The soils are developed over different types of rocks: igneous, metamorphic and sedimentary.

The major soils of the Forest Zones are Latosols. These are subdivided into the great groups of Forest Ochrosols and Forest Oxysols.

<ins>Forest Ochrosols</ins> are the most extensive and most important soils of the forest zone. They are developed in the weathering products of intermediate or moderately acidic rocks in peneplain drifts and in terrace alluvium. These soils, occupying the upland portions of gently undulating to strongly rolling topography, are relatively well drained. Their colors range from red through brown to yellow-brown. Color differences are associated with slope and drainage conditions. Associated with these are the poorly drained soils of the bottoms. It has been noted that textural differences are related to the nature of the parent materials (4). Detailed descriptions of Kumasi and Bekwai series (model profiles from a granite and a phyllite rock) are given below in Tables 5 and 6, respectively. Profile diagrams for these soils are shown in Appendix 2.

<ins>Forest Oxysols</ins> are similar to the Ochrosols but have paler colors. They have thinner surface horizons but thicker subsoils than Ochrosols. The annual rainfall in areas of the Oxysol is (60 to 70+") generally higher than in Forest Ochrosol areas (35 to 65"). This higher rainfall accounts for greater leaching of the soil, which gives rise to the paler colors and lower pH values. A profile description for a model Oxysol, the Boi series is given in Table 7. Since this profile is also developed from phyllite it may be compared to the Bekwai profile.

TABLE 5a.--Description of Kumasi Series, A Representative Forest Ochrosol

SERIES:	Kumasi	Ref. PKR 299/1-14
LOCALITY:	Central Agricultural Station Kumasi, Ashanti	Rainfall: 55"/yr. Altitude: 800-850 ft.
SITE:	Upper slope/ gentle undulation	Soil group: Forest Ochrosol
SOURCE:	Well	
PARENT ROCK:	Biotite Granite	
VEGETATION:	Bush Regrowth	

Ref.no.	Horizon: Depth in inches	Horizon: Proposed A,B,C system symbol*	Horizon: Proposed genetic designation**	Description***
299/1	0-4	A1	Vh	Moderate to dark yellowish brown (10YR 3/3 to 4/2); humic; light loam, with occasional fine quartz gravel; pH 7.2.
299/2	4-9	A2	Ei	Moderate yellowish brown, (10YR 4/3), gritty loamy sand, with rare subangular quartz gravel; rare root fibers; pH 6.8.
299/3	9-18	B2t1	II It	Light brown (5YR 5/4); gritty light clay, very frequent fine and coarse gravel; occasional ironstone concretions; pH 5.7; many rootlets.
299/4	18-32	B2t2cn	II Iti	Light brown to brownish orange (5YR 5/6); gritty light clay, very frequent fine and coarse quartz gravel, frequent subangular small quartz stones; frequent ironstone concretions; pH 5.2; many rootlets.

TABLE 5a (Continued)

Ref.no.	Depth in inches	Horizon: Proposed A,B,C system symbol	Horizon: Proposed genetic desig- nation	Description
299/5	32-55	B2t3	II R1	Light brown to brownish orange (5YR 5/6); slightly gritty light loam, very frequent fine and coarse quartz gravel; very rare ironstone concretions; pH 5.1; rare rootlets.
299/6	55-94	B2t4	IIR2	Light brown to brownish orange (5YR 5/6); slightly cloddy; light loam, frequent quartz gravel; occasional ironstone concretions; occasional patches of weathered rock; pH 5.0; rare rootlets.
299/7	94-133	B2t5	IIIRZ	Light brown to brownish orange (5YR 5/6) with strong brown (2.5YR 3/6) mottles; slightly cloddy; light loam; included frequent veins of aplite; pH 4.9; rare rootlets.
299/8	133-204	C1	IIIZm1	Moderate reddish brown (10R 3/6 to 10R 4/4) with light yellowish brown to moderate orange (7.5YR 7/6) mottles; structureless; light loam; completely weathered coarse grained biotite granite with veins of aplite; pH 4.9; some rootlets.
299/9	204-293	C21	IIIZm2	Moderate reddish brown (10R 3/4) with light grayish red to light reddish brown (10R 6/3) and moderate orange (5YR 6/8) mottles; light loam; weathered coarse grained biotite granite with veins of weathered aplite; pH 4.0.

TABLE 5a (Continued)

Ref.no.	Horizon: Depth in inches	Proposed A,B,C system symbol	Proposed genetic desig-nation	Description
299/10	293-342	C22	III Zm3	Moderate reddish brown (10R 3/4) with pale yellowish pink to brownish pink (7.5YR 8/2) and dark orange yellow (7.5YR 6/8) mottles; light loam; weathered coarse grained biotite granite with included, frequent aplite veins; pH 5.0.
299/11	342-408	C23	III Zm3	Moderate reddish brown (10R 3/4) with pale yellowish pink to brownish pink (7.5YR 8/2) and pale to moderate orange yellow (10YR 8/6), mottles; light loam; weathered coarse grained biotite granite with very frequent weathered aplitic veins; pH 5.0.
299/12	408-444	C3	III Zm4	Moderate reddish brown (10R 3/4) with light to moderate orange yellow (10YR 8/8) and pinkish gray (5YR 8/1) mottles; same textures as above; less weathered aplitic veins; pH 5.0.
299/13	444-540	R	III Zm5	Moderate reddish brown (10R 3/4) with light to moderate orange yellow (10YR 8/6) and light grayish red to light reddisn brown (10R 6/3) mottles; massive; weathered coarse grained biotite granite with very frequent thick veins of aplite, pH 4.9.

TABLE 5a (Continued)

Ref.no.	Depth in inches	Horizon: Proposed A,B,C system symbol	Horizon: Proposed genetic designation	Description
299/14	540-660	R	III Zm6	Completely weathered coarse grained biotite granite, pH 4.9.

*See reference (47).

**See reference (50).

***Color names according to: ISSC-NBS Method of Designating Colors and a Dictionary of Color Names, 1955. Nat. Bur. Standards Cir. 553, Gov't Printing Office, Washington 25, D. C.

TABLE 5b.--Major Nutrients in Pounds Per Acre in the Surface Three Feet of Kumasi Series.*

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

*These data take into account dry density (assumed), the amount of oven-dry fine earth (<2 mm.) and the amount of nutrients as expressed in Table 5c. No actual dry density determinations have been made, but a density of 1.2 is assumed for the surface horizon of forest soils and of 1.3 for that of most savanna soils that of lower horizons is assumed as 1.6 in both forest and savanna soils except where more than 3 percent organic matter is present, when a value of 1.5 is assumed.

TABLE 5c.--Detailed analytical data for Kumasi Series.

Lower depth of horizon in in.	Mechanical analysis, percent (particle size in mm.)						Organic matter, percent				Mois-ture air-dry soil percent
	In total soil (air dry				In fine earth (oven dry)						
	Stones > 22	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth <2	Silt .02-.002	Clay <.002	C	N	C/N	O.M.	
1. 4	Nil	1.0	1.6	97.4	8.51	20.59	3.86	0.286	11.74	6.64	2.56
2. 9	Nil	0.4	12.8	86.8	5.46	13.21	0.71	0.073	9.73	1.22	0.97
3. 18	1.1	0.8	16.9	81.2	5.39	36.36	0.34	0.037	9.19	0.58	1.67
4. 32	0.9	5.0	0.7	93.4	4.44	41.34	0.27	0.041	6.58	0.46	1.73
5. 55	Nil	1.6	5.6	92.8	6.24	47.87	0.22	0.027	8.15	0.38	1.88
6. 94	Nil	1.6	1.9	96.5	10.76	40.22	0.17	0.023	7.39	0.29	2.04
7.133	Nil	0.6	1.6	97.8	12.25	30.57	0.08	0.025	3.20	0.14	1.54
8.168	Nil	0.5	1.4	98.1	17.14	11.21	0.05	N.D.	N.D.	0.09	1.12

TABLE 5c (Continued)

Lower depth of horizon in in.	pH	$CaCo_3$ percent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25°mohs x 10^6	P (tl.) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases		
1. 4	7.5	0.072	23.54	14.58	4.00	0.23	1.35	0.48	20.64	N.D.	333
2. 9	7.1	Nil	6.83	2.94	0.80	0.07	0.24	0.20	4.25	N.D.	128
3. 18	5.9	Nil	6.66	1.52	1.02	0.06	0.07	0.14	2.81	N.D.	126
4 32	5.7	Nil	6.53	1.26	0.86	0.04	0.04	0.16	2.36	N.D.	126
5. 55	5.6	Nil	6.83	0.88	0.68	0.04	0.02	0.19	1.81	N D.	130
6. 94	5.6	Nil	6.96	0.48	0.41	0.02	0.02	0.24	1.71	N.D.	133
7. 133	5.8	Nil	6.39	0.23	0.42	0.02	0.07	0.23	0.97	N.D.	N.D.
8. 168	5.1	Nil	5.06	0.20	0.32	0.02	0.03	0.14	0.71	N.D.	N.D.

N D. = No data

TABLE 6a.--Description of Bekwai Series, a Representative Forest Ochrosol

SERIES:	Bekawi	Ref. PKR 74/1-7
LOCALITY:	Near Manso Nkwanta, Ashanti	Rainfall: 55-60"/yr.
SITE:	Upper slope/steeply rolling	Altitude: 1,000 ft.
SOURCE:	Profile Pit	Soil group:
PARENT ROCK:	Phyllite	Forest Ochrosol
VEGETATION:	Cocoa	

Ref. no.	Depth in inches	Horizon Proposed A,B,C, system symbol	Proposed genetic desig- nation	Description
74/1	0-2	Ap	Vh	Moderate brown (7.5YR 4/4); humic; light loam, crumbly and porous; pH 5.8+.
74/2	2-11	B2t1	It	Strong brown (5YR 4/7); light clay; occasional irregular large and small ironstone concretions; rare fine quartz gravel; cloddy and slightly compact; pH 4.8.
74/3	11-21	B2t2cn1	II Iti	Light brown to brownish orange (5YR 5/6); light clay, frequent irregular large and small ironstone concretions; frequent angular and subangular coarse quartz gravel, occasional-brash or ferruginised phyllite; cloddy and compact and gravelly; pH 4.6.
74/4	21-33	B2t3cn2	II R	Brownish orange (5YR 5/8); heavy loam; frequent irregular large and small ironstone concretions, frequent brash of ferruginised phyllite frequent angular and subangular quartz gravel, rare cauliflower head, occasional angular and subangular quartz stones; cloddy and compact and gravelly; pH 4.6.

TABLE 6a (Continued)

Ref.no.	Horizon: Depth in inches	Proposed A, B, C system symbol	Proposed genetic designation	Description
74/5	33-46	Cl	III RZ	Yellow red faintly mottled yellow and red. Light loam, occasional irregular large and small ironstone concretions, occasional angular and sub-angular coarse quartz gravel, occasional brash of ferruginised phyllite. Cloddy and compact; pH 5.0.
74/6	46-64	C21	III Z1	Yellow green and yellow red mottled: light loam of decomposing phyllite; schistose and friable; pH 5.2.
74/7	64-79	C22	III Z2	Pale reddish brown gray and yellow mottled; light loam of decomposed phyllite schistose and friable; pH 5.2.

TABLE 6b.--Major Nutrients in Pounds per Acre in Surface Three Feet of Bekwai Series.*

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total N	Total P	"Relative availability" of bases (i.e. fraction of total soil capacity)			
		Ca	Mg	Mn	K				Ca	Mg	Mn	P
1. 2	1.2	2534	510	53	62	55,976	2418	296	.550	.182	.008	.007
2. 9	1.6	982	100	41	117	66,021	4111	1272	.102	.078	.003	.006
3. 10	1.6	149	54	8	40	17,980	1255	644	.038	.023	.002	.005
4. 12	1.6	124	39	7	37	9,232	816	606	.042	.022	.002	.006
5. (3)	1.6	54	34	7	9	4,443	578	331	.032	.033	.003	.003
Total for 3'		3843	737	116	265	153,652	1978	3149				

*See footnote Table 5b.

TABLE 6c.--Detailed Analytical Data for Bekwai Series.

Lower dept of horizon in in.		Mechanical analysis, percent (particle size in mm.)						Organic matter, present				Moisture air-dry soil percent
		In total soil (air dry)				In fine earth (oven dry)						
		Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth	Silt .02-.002	Clay < .002	C	N	C/N	O.M.	
1.	2	Nil	Nil	Nil	100.0	N.D.	N.D.	6.11	0.454	13.46	10.51	4.40
2.	11	Nil	3.5	2.6	93.9	N.D.	N.D.	1.28	0.137	9.34	2.20	2.30
3.	21	21.4	16.4	20.6	41.6	N.D.	N.D.	0.71	0.085	8.35	1.22	2.12
4.	33	12.7	42.0	13.9	31.4	N.D.	N.D.	0.40	0.061	6.56	0.69	2.02
5.	46	Nil	14.8	6.5	78.7	N.D.	N.D.	0.31	0.069	4.49	0.53	2.07
6.	64	Nil	Nil	Nil	100.0	N.D.	N.D.	0.28	0.057	4.91	0.48	1.15
7.	79	Nil	Nil	Nil	100.0	N.D.	N.D.	0.07	0.047	1.49	0.12	0.92

TABLE 6c (Continued)

Lower depth of horizon in in.	pH	$CaCo_3$ percent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25^{o}mohs x 10^{6}	P (tl.) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases		
1. 2	6.4	0.028	43.13	23.74	7.87	0.36	0.30	0.66	32.93	N.D.	556
2. 11	5.1	Nil	16.00	1.63	1.24	0.05	0.10	3.17	3.17	N.D.	424
3. 21>	5.0	Nil	13.20	0.50	0.30	0.02	0.07	0.19	1.08	N.D.	436
4. 33	5.1	Nil	10.95	0.46	0.24	0.02	0.07	0.22	1.01	N.D.	453
5. 46	4.9	Nil	9.99	0.32	0.33	0.03	0.03	0.14	0.85	N.D.	395
6. 64	5.5	Nil	6.93	0.22	0.37	0.01	0.03	0.23	0.86	N.D.	402
7. 79	5.4	Nil	6.55	0.29	0.30	0.01	0.09	0.23	0.92	N.D.	N.D.

N.D. = No data

TABLE 7a.--Description of Boi Series, A Representative Forest Oxysol

SERIES:	Boi	Ref. LTB 334/1-9
LOCALITY:	Approximately 10 miles North of Esiama, Western Region	Rainfall: 75"/yr.
		Altitude: c. 150 ft.
		Soil group: Forest Ochrosol
SITE:	Middle slope/steeply rolling	
SOURCE:	PP 3' x 6' x 11.5'	Survey: Lower Tano Basin
PARENT ROCK:	Phyllite	
VEGETATION:	Forb regrowth	

	Horizon			
Ref.no.	Depth in inches	Proposed A, B, C system symbol	Proposed genetic desig- nation	Description
334/1	0-3	A1	Vh	Grayish yellowish brown (10YR 5/2); humic; silty light clay; crumbly and slightly compact; pH 4.6.
334/2	3-7	A2	Em	Light grayish yellowish brown to light yellowish brown (10YR 6/3); very slightly humic; silty light clay; cloddy and compact; very rare scattered ironstone concretions, pH 4.8.
334/3	7-16	B2tcn	Ri1	Strong yellowish brown (10YR 5/6); silty clay; very rare quartz stones and gravel; frequent ferruginised rock brash; structureless and very compact; very frequent ironstone con- cretions; pH 4.8+.
334/4	16-27	B2t	Ri2	Strong yellowish brown (10YR 5/6); silty light clay; occasional quartz gravel; very rare ferruginished brash; structureless and very compact, rare ironstone concretions; pH 5.0.

TABLE 7a (Continued)

Ref.no.	Depth in inches	Horizon: Proposed A,B,C system symbol	Proposed genetic desig- nation	Description
334/5	27-42	C 1	RZ	Orange brown, very slightly mottled with red; silty clay, occasional quartz gravel; rare traces of weathered rock; cloddy and compact; very rare ironstone concretions; pH 5.2.
334/6	42-66	C2	RZ2	Pale orange brown, mottled hellow, red and olive; silty light clay; rare traces of decomposing rock; slightly cloddy and slightly compact; pH 5.2+
334/7	66-88	C3	Zil	Pale yellowish brown, mottled yellow and grey; silty light clay; very frequent patches of de- composing rock; slightly cloddy and compact; pH 5.4.
334/8	88-114	C4	Zi2	Gray, yellow and red mottled; silty light clay, abundant patched of decomposing rock; structureless and slightly friable; pH 5.6.
334/9	114-138	C5	Zi3	Silty light clay; decomposed rock; structureless and friable; pH 5.6+.

TABLE 7b.--Major Nutrients in Pounds Per Acre in the Survace Three Feet of Boi Series.*

Horizon thickness in inches		Dry density (assumed)	Exchangeable bases				Organic matter	Total N	Total P	"Relative availability" of bases (i.e. fraction of total soil capacity)			
			Ca	42	Mn	K				Ca	Mg	Mn	P
1.	3	1.3	192	79	7	70	34,977	1546	143	.093	.063	.002	.017
2.	4	1.6	82	73	4	37	19,147	1099	167	.041	.060	.001	.010
3.	9	1.6	103	70	5	13	18,965	1154	231	.040	.045	.001	.003
4.	11	1.6	189	137	10	57	32,296	2141	408	.031	.037	.001	.005
5.	(9)	1.6	157	114	<4	49	22,550	1597	351	.030	.035	<.001	.005
Total for 3'			723	473	26	226	127,935	7537	1400				

*See footnote Table 5b.

TABLE 7c.--Detailed Analytical Data for Boi Series.

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

TABLE 7c (Continued)

Lower depth of horizon in in.		pH	$CaCo_3$ percent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25^{o}mohs x 10^6	P (tl.) p.p.m.
					Ca	Mg	Mn	K	Na	Total bases		
1.	3	4.70	Nil	12.60	1.17	0.79	0.03	0.22	0.25	2.46	N.D.	174
2.	7	4.78	Nil	7.31	0.30	0.44	0.01	0.07	0.27	1.09	N.D.	123
3.	16	5.00	Nil	7.83	0.31	0.35	0.01	0.02	0.27	0.96	N.D.	140
4.	27	4.90	Nil	8.42	0.26	0.31	0.01	0.04	0.16	0.78	N.D.	140
5.	42	4.95	Nil	8.47	0.25	0.30	$<$0.005	0.04	0.13	0.72	N.D.	112
6.	66	5.20	Nil	7.76	0.22	0.25	$<$0.005	0.02	0.15	0.64	N.D.	107
7.	88	5.20	Nil	6.17	0.19	0.13	$<$0.005	0.02	0.13	0.47	N.D.	76
8.	114	5.28	Nil	4.93	0.20	0.10	$<$0.005	0.02	0.22	0.54	N.D.	68

N.D. = No data

Organic matter is generally lower in Oxysols than in the Ochrosols and distributed to lower horizons. The clay fraction of the Oxysols occurring at higher elevations, associated with bauxite or bauxite-iron-pan cappings, contains a high proportion of sesquioxides.

Forest Ochrosol-Oxysol intergrades occur between the areas of Oxysols and Ochrosols. These are transitional soils and have properties intermediate between the two groups.

Forest Rubrisols, as described by Bramman (4) p. 25, consist of dark red, firm or plastic, nutty or blocky clays developed over basic rocks. The clay mineral fraction has at least some montmorillonite. The profile contains large amounts of bases. But, unfortunately such soils have limited distribution in Ghana. They are developed, usually, over small basic rock dikes. However, there are larger areas of Rubrisol-Ochrosol intergrades. These are developed over hornblende and biotite granodiorites. (See map in Appendis 1 for their distribution.) They have brighter colors, higher exchange capacity, and better developed structure than the forest ochrosols. The description of a typical profile, the Wacri series, with analytical data is given below in Table 8.

Other groups of forest soils include Lithosols and Regosols, which occur in limited areas (see map). Brammah (4)

TABLE 8a.--Description of Wacri Series, A Representative Forest Ochrosol

SERIES:	Wacri	Ref: DB 174/1-7
LOCALITY:	Block O, Wacri, New Tafo, Eastern Region	Rainfall: 65"/yr. Altitude: 700 ft.
SITE:	Upper slope/gently rolling	Soil group: Forest Rubrisol-Ochrosol intergrade
SOURCE:	Profile pit	
PARENT ROCK:	Dark nornblende rock	
VEGETATION:	Good cocoa canopy	

Ref. no.	Depth in inches	Horizon: Proposed A, B, C system symbol	Horizon: Proposed genetic desig- nation	Description*
174/1	0-1.5	Ap	Vh	Grayish brown (7.5YR 3/2); fine sandy clay; crumbly; pH 7.5; very frequent root fibers.
174/2	1.5-8	B11	Iti	Moderate brown (7.5YR 4/4); sandy clay; occasional quartz gravel and stones; loose; pH 7.1.
174/3	8-14	B12	It2	Moderate brown (7.5YR 4/3); sandy clay with occasional quartz stones and dominant quartz gravel; loose; pH 6.5.
174/4	14-20	B2t	It3	Strong brown (5YR 4/6); sandy clay, dominant quartz gravel and fragments of rotten rock; friable; pH 6.2.
174/5	20-39	B2tcn1	IZ1	Strong brown (5YR 4/8); clay, with frequent quartz gravel and frequent frag- ments of ferruginised rotten rock; friable; pH 6.1.
174/6	39-55	B2tcn2	IZ2	Strong brown (5YR 4/8) with gray, mottles; clay, with frequent fragments of ferrunginised rotten rock; friable; pH 5.6.

TABLE 8a (Continued)

	Horizon			
Ref.no.	Depth in inches	Proposed A,B,C system symbol	Proposed genetic desig-nation	Description
174-7	55-72	C	Zi	Dull brown, mottled gray and red-brown; fine sandy clay; dominant fragments of ferruginised rotten rock; pH 6.0.

*Munsell notations determined for another Wacri profile Ref. No. 186/1-9.

TABLE 8b.--Major Nutrients in Pounds Per Acre in the Surface Three Feet of Wacri Series*.

	Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total N	Total P	"Relative availability" of bases (i.e. fraction of total soil capacity)			
			Ca	Mg	Mn	K				Ca	Mg	Mn	P
1.	1.5	1.2	2728	390	127	81	38,987	1983	220	.757	.165	.026	.012
2.	6.5	1.6	2476	313	102	96	29,647	1997	702	.580	.121	.017	.012
3.	6	1.6	252	52	18	26	2,260	186	182	.325	.110	.017	.017
4.	6	1.6	308	66	19	31	1.871	322	165	.318	.115	.014	.016
5.	16	1.6	2262	941	41	212	13,551	1867	1187	.277	.190	.004	.013
Total for 3'			8026	1762	307	446	86,316	6355	2456				

*See footnote Table 5b.

TABLE 8c.--Detailed Analytical Data for Wacri Series

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

TABLE 8c (Continued)

Lower depth of horizon in in.		pH	$CaCo_3$ percent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth oven dry						Conductivity 25^{o}mohs x 10^6	P (tl.) p.p.m.
					Ca	Mg	Mn	K	Na	Total bases		
1.	1.5	7.54	0.528	45.06	34.12	7.42	1.15	0.52	0.75	43.96	N.D.	550
2.	8	7.10	Nil	10.33	5.99	1.25	0.18	0.12	0.18	7.72	N.D.	341
3.	14	6.50	Nil	5.82	1.89	0.64	0.10	0.10	0.13	2.86	N.D.	274
4.	20	6.25	Nil	9.29	2.95	1.07	0.13	0.15	0.18	4.48	N.D.	318
5.	39	6.13	Nil	13.55	3.75	2.57	0.05	0.18	0.19	6.74	N.D.	394
6.	55	5.62	Nil	19.49	5.12	5.57	0.08	0.11	0.22	11.10	N D.	257
7.	72	6.03	Nil	14.12	3.97	4.47	0.10	0.07	0.19	8.80	N.D.	225

N.D. = No data

suggests that the Lithosols may be regarded as immature Forest Rubrisols and Brunosols, and the Regosols as very weak Oxysols or Regosol-Oxysol intergrades. These soils are associated along the coast with dune sand, peaty clays in water-logged areas and with Ground Water Podzols (Atuabo series). A profile description and analytical data are given for the Atuabo Series in Table 9 below. The Ground Water Podzol is characterized by an organic subsoil pan 1 to 2 feet thick. (See diagram in Appendix 2).

Soils of the Interior Savanna Zone

The interior savanna zone covers about two-thirds of the country. Unfortunately, however, less is known about its soils than about those of the other two zones. Soil boundaries in this area are provisional. They follow more or less geological boundaries.

The major soil groups recognized in this large area may be seen on the accompanying provisional map in Appendix 1. In general these soils have lower organic matter than forest soils and they are also lower in nutrient content. This is the reverse of conditions in temperate regions. The following reasons may account for the lower organic matter content, of the soils of the savannah grassland areas: (1) The grasses and shrubs have less extensive root systems which are unable to circulate bases in the deeply leached soils and use them

TABLE 9a.--Description of Atuabo Series, a Representative Ground Water Podzol

SERIES: Atuabo
LOCALITY: Atuabo, Western Nzima, Western Region
SITE: Flat bottom
SOURCE: PP 3' x 6' x 5 1/12'
PARENT ROCK:
VEGETATION: Short grass savanna

Ref: LTB 443/1-6
Rainfall: c. 85"/yr
Altitude: c. 5-10 ft.
Soil group: Ground-water Podzol

Ref.no.	Horizon: Depth in inches	Horizon: Proposed A,B,C system symbol	Horizon: Proposed genetic desig-nation	Description
443/1	0-2	A1	VE	Light brownish gray (2.5Y 6/1); slightly humic, silty fine sand; structureless and loose; pH 4.6
443/2	2-8	A21	EM 1	Yellowish gray (10YR 7/1); silty fine sand; structure-less and loose; pH 5.0.
443/3	8-23	A22	Em 2	Yellowish gray (10YR 8/1); silty fine sand; structure-less and loose; pH 4.8+.
443/4	23-31	Bhir1	Ihi 1	Moderate olive brown (2.5Y 4/2); silty loamy fine sand; slightly cloddy and slightly compact; occasional lumps of organic pan; pH 4.4; very frequent rusty roots.
443/5	31-47	Bhir2m	Ihi 2	Moderate yellowish brown (10YR 4/3); loamy sand; cloddy and very compact; organic pan; pH 4.6.
443/6	47-61	Bhir3	IP	Yellowish gray to pale orange yellow (10YR 8/2); fine sand; structureless and loose; occasional fragments of or-ganic pan; pH 5.0.

TABLE 9b.--Detailed Analytical Data for Atuabo Series

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

TABLE 9b (Continued)

Lower depth of horizon in in.	pH	$CaCo_3$ percent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25^{o}mohs x 10^6	P (tl.) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases		
1. 2	5.25	Nil	3.47	0.50	0.31	$<$0.005	0.05	0.11	0.97	N.D.	52
2. 8	5.65	Nil	0.87	0.18	$<$0.01	$<$0.005	0.05	0.14	0.37	N.D.	43
3. 23	5.80	Nil	0.82	0.15	$<$0.01	$<$0.005	0.02	0.04	0.21	N.D.	38
4. 31	4.85	Nil	25.64	0.35	0.24	$<$0.005	0.04	0.09	0.72	N.D.	73
5. 47	4.85	Nil	41.28	0.31	0.16	$<$0.005	0.02	0.07	0.56	N.D.	84
6. 61	5.90	Nil	1.25	0.15	$<$0.01	$<$0.005	0.02	0.03	0.20	N.D.	14

1. Horizons 1-3 and 6, ammonium acetate, pH 7.0

N.D. = No data

for growth (26). (2) There is less leaf fall under the savannah conditions. (3) The rate of organic matter decomposition is more rapid in the open savannah areas, and (4) Overgrazing and bush fires in the savannah areas may also be important factors. The moisture relation of these soils are poor owing to unfavorable rainfall distribution. Most of the interior savannah area has one peak of rainfall (August - October) and a prolonged dry season (November - March), but the forest areas have two peaks of rain.

Two important groups of soils in this area are described below. The Mimi series (Table 10) represents a typical Savanna Ochrosol whereas the Kpelesawgu series (Table 11) represents a typical Groundwater Laterite. Besides these Brammer (4) described the following less extensive soil groups of this area: Savanna Lithosols, Brunosols, Tropical Black Earths, and acid Gleisols (See appendixes 1 and 2).

Soils of the Coastal Savanna Zone

The soils of this zone have been influenced largely by the geology of the area (4). It is believed that the old weathered mantle was removed during quaternary fluctuations in sea level. Rock weathering is, therefore, more recent and less deep than in the previous areas (4). The complex origin of the soils is evidenced in the presence of a stone line within the soil profile. It is postulated that the stone lines represent

TABLE 10a.--Description of Mimi Series, A Representative Savannah Ochrosol

SERIES:	Mimi	Ref: PNB 139/1-7
LOCALITY:	Approx. 25 miles W.S.W. of Gambaga	Rainfall: 45"/yr. Altitude: 500 ft.
SITE:	Upper slope/gently undulating	Soil group: Savanna Ochrosol
SOURCE:	Profile Pit	
PARENT ROCK:	Sandstone	
VEGETATION:	Cultivation	

Ref.no.	Depth in inches	Horizon: Proposed A,B,C system symbol	Horizon: Proposed genetic desig-nation	Description
139/1	0-5	Ap	Ep	Moderate yellowish brown (10YR 4/3); humic; sandy light loam; structureless and loose; pH 6.0.
139/2	5-11	B2t1	Iti 1	Moderate brown (5YR 4/4); sandy clay; structureless; loose; pH 5.6.
139/3	11-19	B2t2	Iti 2	Strong brown (2.5YR 4/6); sandy clay; slightly cloddy; and porous; pH 5.4+.
139/4	19-31	B2t3	Iti 3	Strong brown (2.5YR 4/6); light clay, slightly cloddy and porous; pH 5.6+.
139/5	31-41	B2tcn	IZ	Grayish reddish orange (2.5 YR 5/6); cloddy and slightly compact; light clay; occasional small and large iron concretions; rare weathered non-ferruginished sandstone brash; pH 5.6+.
136/6	41-50	C2	Zm	Grayish reddish orange (2.5YR 6/6); loamy sand: cloddy and compact; decomposing non-ferruginised slightly micaceous sandstone; pH 5.0.
139/7	50-58	C	P	Underlying non-ferruginised sandstone weathering pale gray and orange; rock.

TABLE 10b.--Major Nutrients in Pounds Per Acre in the Surface Three Feet of Mimi Series.*

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

*See footnote in Table 5b.

TABLE 10c.--Detailed Analytical Data for Mimi Series

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

TABLE 10c (Continued)

Lower depth of horizon in in.	pH	$CaCo_3$ percent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25^{o}mohs x 10^6	P (tl.) p.p.m.
				CA	Mg	Mn	K	Na	Total bases		
1. 5	6.10	Nil	7.39	2.10	0.92	0.08	0.14	0.33	3.57	N.D.	112
2. 11	6.45	Nil	8.15	0.92	0.39	0.02	0.05	0.27	1.65	N.D.	123
3. 19	5.30	Nil	11.30	0.91	0.38	0.01	0.07	0.33	1.70	N.D.	199
4. 30	5.90	Nil	9.96	0.79	0.40	0.01	0.07	0.43	1.70	N.D.	180
5. 41	5.90	Nil	7.97	0.62	0.50	0.01	0.07	0.51	1.77	N.D.	N.D.
6. 50	4.89	Nil	3.33	0.21	0.25	$<$0.005	0.03	0.26	0.75	N.D.	N.D.
7. 58	6.40	Nil	0.90	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

N.D. = No data

TABLE 11a.--Description of Kpelesawgu Series, A Representative Ground-water Laterite

SERIES:	Kpelesawgu	Ref. DNB 239/1-7
LOCALITY:	Approx. 10 mi. south of Bongo Da, Northern Region	Rainfall: 40-45"/yr. Altitude: 450 ft.
SITE:	Middle slope/very gently undulating	Soil group: Ground-water Laterite
SOURCE:	PP 5' x 3' and 5/46	
PARENT ROCK:	Mudstone	
VEGETATION:	Savanna regrowth	

Ref.no.	Depth in inches	Horizon: Proposed A,B,C system symbol	Horizon: Proposed genetic designation	Description
239/1	0-4	Alcn	Ei	Light brown (7.5YR 5/4); humic light loan containing frequent ironstone concretions; occasional manganese concretions; granular, loose; pH 6.6; occasional root fibers.
239/2	4-11	B2cnl	Ii 1	Light brown to dark orange yellow (7.5YR 6/6); light clay; abundant strongly stained manganese dioxide and irregular ironstone concretions; structureless; compact; pH 6.0.
239/3	11-20	B2cn2	Ii 2	Light brown to moderate orange (5YR 6/6); light clay; with concretions similar to those in the above horizon but with slightly bigger concretions; compact; pH 5.8.
239/4	20-32	B2cn3	Ii 3	Light brown to dark orange yellow (7.5YR 6/6); light clay; tightly packed strongly stained manganese dioxide concretions; irregular ironstone concretions; occasional cauliflower heads; concretionary; very compact; pH 5.8.

TABLE 11a (Continued)

		Horizon		
Ref.no.	Depth in inches	Proposed A,B,C system symbol	Proposed genetic designation	Description
239/5	32-41	B2cn4	Ii 4	Light yellowish brown (7.5 YR 7/4); light clay; slightly stained manganese dioxide concretions; irregular spherical and small ironstone concretions; concretionary; compact, pH 5.4.
239/6	41-45	C	Zm	Light brown (7.5YR 6/4) mottled brownish-pink (7.5 YR 7/2); clay; decomposing mudstone containing frequent flakes of the rock; very rare manganese stains present; slightly cloddy; slightly compact; pH 5.4.
239/7	45-58	R	Pc	Underlying rock of solid mudstone containing manganese patches along the irregular planes; rock.

TABLE 11b.--Major Nutrients in Pounds Per Acre in the Surface Three Feet of Kpelesawgu Series.*

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases Ca	Mg	Mn	K	Organic matter	Total N	Total P	"Relative availability" of bases (i.e. fraction of total soil capacity) Ca	Mg	Mn	P
1. 4	1.3	687	122	38	104	13,228	5[illegible]0	130	.512	.150	.021	.040
2. 7	1.6	416	118	46	59	8,899	427	208	.339	.166	.029	.026
3. 9	1.6	57	18	7	12	1,081	60	32	N.D.	N.D.	N.D.	N.D.
4. 12	1.6	586	386	76	129	5,465	371	199	.248	.269	.024	.028
5. (4)	1.6	229	163	19	43	805	54	111	N D.	N.D.	N.D.	N.D.
Total for 3'		1975	807	186	347	29,478	1482	680				

*See footnote Table 5b.

TABLE 11c.--Detailed Analytical Data for Kpelesawgu Series

Loser depth of horizon in in.		Mechanical analysis, percent (particle size in mm.) In total soil (air dry)				In fine earth (oven-dry)		Organic matter, present				Mois-ture air-dry soil percent
		Stones > 20	Coarse gravel 20-6.25	Fine gravel 6.25-2	Fine earth	Silt .02-.002	Clay < .002	C	N	C/N	O.M.	
1.	5	Nil	15.1	5.3	79.6	N.D.	N.D.	0.84	0.062	13.55	1.44	0.87
2.	11	Nil	49.3	14.9	35.8	N.D.	N.D.	0.58	0.048	12.08	1.00	1.20
3.	20	Nil	59.6	36.6	3.8	N.D.	N.D.	0.52	0.049	10.61	0.89	1.96
4.	32	Nil	57.3	185.	24.2	N.D.	N.D	0.31	0.036	8.61	0.53	2.12
5.	41	Nil	50.9	22.1	27.0	N.D.	N.D	0.12	0.014	8.57	0.21	2.43
6.	45	Nil	39.1	18.6	42.3	N.D.	N D	0.12	N.D.	N.D.	0.21	3.94
7.	58	41.3	21.4	10.5	26.8	N.D.	N.D.	N.D.	N.D	N D.	N.D	4.32

TABLE 11c (Continued)

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

1. Barium acetate, pH = 8.2, water washing

2. Total without sodium

N.D. = No data

old erosion surfaces. The nature and properties of these coastal savannah soils have been largely influenced by termites (Macrotermers) as a biotic factor. Macrotermes transfer fine soil material from below the surface and mix organic matter with subsurface layers. These activities are carried out through the building of termite mounds. The transfer of finer material from below by the termites is another possible origin of stone-lines within the solum (4).

Profile descriptions are given below for the three major groups of soils in this area: Savannah, Ochrosol the Toje series (Table 12), a Tropical Black Earth, the Akuse series (Table 13) and a Tropical Gray Earth, the Agawtaw series (Table 14). (Also see map and diagrams in Appendix 1 and 2). In addition to these series smaller amounts of Regosolic Ground Water Laterites, acid Gleisols, sodium Vleisols, Lithosols and Regosols also occur.

TABLE 12a.--Description of Toje Series, A Representative Savannah Ochrosol

SERIES:	Toje	Ref: AP 405/1-5
LOCALITY:	1/2 mile west of Tema, Accra Plains	Rainfall: 25-30"/yr.
		Altitude: c. 100 ft.
SOURCE:	Profile pit	Site: Summit/gently undulating
PARENT ROCK:		
VEGETATION:	Savannah regrowth	Soil group: Savannah Ochrosol

Ref.no.	Depth in inches	Horizon: Proposed A, B, C system symbol	Horizon: Proposed genetic designation (50)	Description
405/1	0-3	A11	EV 1	Grayish brown (5YR 3/2); humic; fine sand; slightly crumbly and loose; pH 7.0.
405/2	3-9	A12	Ei 1	Moderate brown (5YR 3/3); less humic; fine sand with plant root channels; slightly crumbly and loose; pH 6.8.
405/3	9-15	A13	Ei 2	Moderate brown (5YR 4/3); fine sand, weak granular and fairly compact; pH 6.2.
405/4	15-38	B21	Ii 1	Strong brown (2.5YR 3/6); light loam; slightly granular and fairly compact; pH 5.6.
405/5	38-76	B22	Ii 2	Strong brown (2.5YR 3/6); light loam with frequent fine quartz gravels; slightly granular and compact; pH 5.6.

TABLE 12b.--Major Nutrients in Pounds Per Acre in the Surface Three Feet of Toje Series.*

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases Ca	Mg	Mg	K	Organic matter	Total N	Total P	"Relative availability" of bases (i.e. fraction of total soil capacity) Ca	Mg	Mn	P
1. 3	1.4	695	166	18	149	11,744	503	175	.616	.242	.012	.068
2. 6	1.6	963	228	23	175	13,849	660	332	.537	.210	.010	.050
3. 6	1.6	783	306	29	200	1,3849	660	405	.365	.236	.010	.048
4. (21)	1.6	1512	861	41	641	20,880	2535	1506	.202	.190	.004	.044
Total for 3'		3953	1561	111	1165	60,332	4358	2418				

*See footnote in Table 5b.

TABLE 12c.--Detailed Analytical Data for Toje Series

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

TABLE 12c (Continued)

Lower depth of horizon in in.		pH	$CaCo_3$ percent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25^{o}mohs x 10^6	P (tl.) p.p.m.
					Ca	Mg	Mn	K	Na	Total bases		
1.	3	7.9	0.02	6.04	3.72	1.46	0.07	0.41	0.15	5.81	N.D.	188
2.	9	7.7	Nil	4.19	2.25	0.88	0.04	0.21	0.11	3.49	N.D.	156
3.	15	6.8	Nil	5.01	1.83	1.18	0.05	0.24	0.17	3.47	N.D.	190
4.	38	5.5	Nil	4.99	1.01	0.95	0.02	0.22	0.19	2.39	N.D.	202
5.	76	5.6	Nil	5.66	1.62	0.98	0.02	0.10	0.30	3.02	N.D.	N.D.

N.D. = No data.

TABLE 13a.--Description of Akuse Series, A Representative Tropical Black Earth

SERIES:	Akuse	Ref: APA 370/1-8
LOCALITY:	Kpong Pilot area, Traverse 28/32 chains, Accra Plains	Rainfall: c. 45"/yr.
		Altitude: 60 ft.
SOURCE:	PP 4' x 4' x 6'	Site: Middle slope/ very gently undulating
PARENT ROCK:	Hornblende gneiss	
VEGETATION:	Savannah	Soil Group: Tropical Black Earth

Ref.no.	Horizon: Depth in inches	Horizon: Proposed A,B,C system symbol	Horizon: Proposed genetic designation (50)	Description
370/1	0-5.5	A11	VZ 1	Brownish gray (10YR 3/1); clay; slightly crumbly and slightly tenacious; pH 6.4.
370/2	5.5-15	A12	VZ 2	Brownish gray (10YR 3/1); less humic; clay; occasional patches of rock particles; rare $CaCO_3$ concretions; cloddy and plastic; pH 8.0.
370/3	15-24	A13	Zt	Olive gray (5Y 4/1); clay; occasional $CaCO_3$ concretions; rare MnO_3 concretions; cloddy and plastic; pH 8.4.
370/4	24-30	A14	Zt 2	Olive gray (5Y 4/1); clay; occasional $CaCO_3$ concretions; cloddy and plastic; pH 8.4.
370/5	30-41	A15	Ztk 1	Light olive gray (5Y 5/1); clay; frequent $CaCO_3$ concretions; occasional quartz gravel and stones; cloddy and fairly compact, pH 8.6+.
370/6	41-48	A16	Ztk 2	Light olive gray (5Y 5/1); with faint light olive brown (2.5Y 5/6 mottles; clay with abundant $CaCO_3$ concretions and occasional quartz gravel; slightly cloddy and compact; pH 8.8+.

TABLE 13a (Continued)

Ref.no.	Depth in inches	Horizon: Proposed A,B,C system symbol	Horizon: Proposed genetic designation	Description
370/7	48-57	C	Ztm	Light olive gray (5Y 5/2); slightly mottled orange brown and black; clay; abundant patches of decomposed rock; slightly cloddy and compact; pH 8.4+.
370/8	57-72	R	Zm	Light olive gray (5Y 5/1 - 5/2), with light olive brown (2.5Y 5/6) mottles; decomposed rock of hornblende gneiss; pH 8.2.

TABLE 13b.--Major Nutrients in Pounds Per Acre in the Surface Three Feet of Akuse Series.*

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total N	Total P	"Relative availability" of bases (i.e. fraction of total soil capacity)			
		Ca	Mg	Mn	K				Ca	Mg	Mn	P
1. 5.5	1.4	7359	2361	62	141	51,095	1760	523	.540	.318	.003	.005
2. 9.5	1.4	12241	4071	N.D.	96	42,291	1703	755	.530	.291	N.D.	.004
3. 9	1.4	14094	4276	N.D.	210	28,992	1181	708	.628	.314	N.D.	.005
4. 6	1.4	9044	3555	N.D.	142	13,321	554	490	.608	.394	N.D.	.005
5. (6)	1.4	4003	1342	N.D.	45	2,541	123	358	.564	.311	N.D.	.003
Total for 3'		46741	15605	N.D.	734	138,240	5321	2834				

*See footnote Table 5b.

TABLE 13c.--Detailed Analytical Data for Akuse Series

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

TABLE 13c (Continued

Lower depth of horizon in in.		pH	$CaCo_3$ percent	Cation exchange capacity	Exchange complex m.e./100 gm. fine earth, oven dry						Conductivity 25°mohs x 10^6	P (tl.) p.p.m.
					Ca	Mg	Mn	K	Na	Total bases		
1.	5.5	6.4	0.05	39.80	21.49	12.66	0.13	0.21	0.60	35.09	56	306
2.	15	7.0	0.09	39.21	20.80	11.40	N.D.	0.17	1.00	33.37	53	257
3.	24	8.2	2.20	41.70	26.20	13.10	N.D.	0.20	2.20	41.70	195	264
4.	30	8.3	5.00	42.90	26.09	16.90	N.D.	0.21	3.10	46.30	222	283
5.	41	8.4	18.80	40.46	22.80	12.60	N.D.	0.13	3.10	38.63	246	409
6.	48	8.4	12.10	41.89	22.10	15.00	N D.	0.20	3.20	40.50	246	880
7.	57	8.4	2.00	34.00	19.60	14.00	N D.	0.20	2.80	36.60	229	1535
8.	72	8.6	0.65	22.15	11.88	10.27	N.D.	0.17	1.71	24.03	170	1508

1. Horizons 1 and 2, barium acetate, pH 8.2; horizons 5 and 6, sodium acetate, pH 8.2, water washing; remaining horizons, ammonium acetate, pH 7.0.

N.D. = No data

TABLE 14a.--Description of Agawtaw Series, A Representative Tropical Gray Earth

SERIES:	Agawta	Ref: AP 509/1-5
LOCALITY:	Junction on Tema Road	Rainfall:25-30"/yr.
SOURCE:	Profile pit	Altitude: 100 ft.
PARENT ROCK:		Site: Lower slope/ gently undulating
VEGETATION:	Savanna	Soil group: Tropical gray earth

Ref.no.	Depth in inches	Horizon: Proposed A,B,C system symbol	Horizon: Proposed genetic designation	Description
509/1	0-2	A11	Eh 1	Dark grayish, yellowish brown (10YR 3/2); humic; fine sand; structureless and coarse; pH 6.6.
509/2	2-12	A12	Eh 2	Dark yellowish brown (10 YR 3/3); fine sand; structureless and loose; pH 6.0.
509/3	12-21	B21t	Ith	Grayish yellowish brown (10YR 4/2), with light yellowish brown (10YR 6/4) mottles; cloddy and compact clay; pH 6.2.
509/4	21-60	B22t	Itn 1	Light olive brown (2.5Y 6/2), with light grayish yellowish brown and light yellowish brown (10YR 6/3) mottling; cloddy and compact clay; rare calcium carbonate concretions; pH 7.0.
509/5	60-74	B23t	Itn 2	Light olive brown (2.5Y 6/2), with light greyish olive to dark grayish yellow (5Y 6/3) mottles; clay; frequent calcium carbonate concretions; pH 7.2.

TABLE 14b.--Major Nutrients in Pounds Per Acre in the Surface Three Feet of Agawtaw Series.*

Horizon thickness in inches	Dry density (assumed)	Exchangeable bases				Organic matter	Total N	Total P	"Relative availability" of bases (i.e. fraction of total soil capacity)			
		Ca	Mg	Mn	K				Ca	Mg	Mn	P
1. 2	1.3	89	47	6	65	4,270	179	19	.304	.265	.016	.115
2. 10	1.6	941	311>	10	319	20,596	1151	114	.498	.272	.004	.087
3. 9	1.6	6679	2073	<1	811	26,499	1373	205	.560	.287	<.001	.035
4. (15)	1.6	12887	3902	14	660	6,334	528	285	.477	.238	.004	.013
Total for 3'		20596	6333	30	1855	57,699	323.	623				

*See footnote in Table 5b.

TABLE 14c.--Detailed Analytical Data for Agawtaw Series

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

TABLE 14c (Continued)

Lower depth of horizon in in.	pH	$CaCo_3$ percent	Cation exchange capacity	Exchange complex m.e/100 gm. fine earth, oven dry						Conductivity 25^{o}mohs x 10^6	P (tl.) p.p.m.
				Ca	Mg	Mn	K	Na	Total bases		
1. 2	6.1	0.025	2.53	0.77	0.67	0.04	0.29	0.41	2.18	70.7	32
2. 12	6.2	Nil	2.56	1.32	0.72	0.01	0.23	0.37	2.65	52.8	32
3. 21	6.5	Nil	17.91	10.42	5.34	<0.01	0.65	2.19	18.60	282.9	64
4. 60	7.6	Nil	20.73	12.16	6.08	0.01	0.32	6.94	25.51	754.4	54
5. 74	8.1	1.48	21.01	9.42	7.42	0.01	0.34	3.00	20.19	713.8	N.D.

1. Ammonium acetate, pH 7.0

2. Corrected for sulphates but not for chlorides

N.D. = No data

IV. THE PLACEMENT OF SOME IMPORTANT SERIES OF GHANA SOILS IN THE 7TH APPROXIMATION

The author is aware of the danger of attempting to place these soils, for which there is a scarcity of quantitative data, with what is considered to be the most likely groups described in the 7th Approximation. The attempt made here is only tentative, and deserves further consideration in the future. At present it is impossible to place all the known soils of Ghana in the 7th Approximation since there are little available data for most of them. However, there are enough data for the ten representative series discussed below to warrant an attempt at their placement. Most of these series can be placed easily within Order 9: Oxisols. But further subdivisions are difficult. This is partly due to the fact that the Oxisols have not been classified in many details in the 7th Approximation, and partly because of insufficient data. For example, the presence of plinthite that has not hardened, if any, has not been described. The series for which a placement is suggested here are: Kumasi Series, Bekwai, Boi, Atuabo, Wacri, Mimi, Kpelesawgu, Toje, Akuse and Agawtaw Series. Profile descriptions and analytical data for these soils were obtained from Obeng (37) and are shown in Tables 5 through 14.

Munsell color readings were not made for the Agawtaw, Toje and Kumasi series at the time they were sampled. The readings recorded here were made from boxed profile samples which have been kept in the museum for two to three years. All color readings were made in the moist condition. The color readings for the Wacri series were made on another Wacri profile and not the same one as that for which the description and data are given (37).

The textures described have been determined by the procedure described in Appendix 3.

The placement of these soils in the 7th Approximation is indicated in Table 4. The reasons for these placements are given for each soil below:

<u>Kumasi Series</u>

The Kumasi series belongs to the order of Oxisols because it has an oxic horizon and plinthite. It may be placed with the suborder Ustox because it occurs in a region of a single pronounced dry season (November - February), and it has less than 50% base saturation between depths of 20 and 50 inches from the surface. It belongs to the great group 9.43 because it has an ochric epipedon. It has some resemblance to 9.32 (the base saturation of the oxic horizon is less than 25% between depths of 20 and 50 inches below the surface).

Bekwai Series

This soil is placed with the order Oxisol because of the presence of an oxic horizon and plinthite. It belongs to the suborder Ustox because the region in which it occurs experiences a pronounced dry season (November - February), and between depths of 20 and 50 inches below the surface the base saturation is less than 50% in the oxic horizon. It is placed with the great group 9.43 because it has an ochric epipedon.

Boi Series

The Boi series, a Forest Oxysol, is placed with the order Oxisols for the following reasons: it has an oxic horizon and argillic horizons with plinthite. The parent rock is basic. It belongs to the suborder Udox because of the humid conditions giving rise to moisture in all the horizons at all times and low base saturation in the oxic horizon. The original native vegetation was tropical rain forest. It is placed with the great group 9.32 for the following reasons: it has moist color values of more than 3, and it occurs at low elevation and the climate is warmer than for 9.31. But the organic matter in the surface horizon is probably high for this class.

Atuabo Series

The Atuabo series, a Ground Water podzol, is placed with the Spodosols because of the presence of a spodic horizon, thick enough to withstand the effect of cultivation. Since it is saturated with water at some seasons, it belongs to the suborder Aquod. It is a Thermaquod because the mean annual temperature is greater than 60°F and it belongs to the orthic subgroup for lack of an argillic horizon below the spodic horizon.

Wacri Series

The Wacri series is placed with the order alfisol because of the following reasons: it has an argillic horizon with a base saturation (determined by sum of bases plus exchange acidity) that is greater than 35%: it occurs in a humid climate, and has an ochric epipedon.

It belongs to the suborder Udalf because it has a mean annual temperature of more than 8.3°C (47°F); and it is usually or always moist in some part of the solum; it lacks the characteristics of wetness that are associated with the aqualfs.

It is placed with the great group Typudalf because it has no fragipan and no albic horizon that tongues into the argillic horizon; the chroma between Ap and the argillic horizon is 4; the ochric epipedon has a gradual boundary with the argillic horizon. It is possible that this great group intergrades to a great group of Ochrults, for example Rhodochult because of the following reasons; it has moist color values of 4 and chromas higher than 3; the argillic horizonhas a hue as red or redder than 7.5YR.

Mimi Series

Mimi series, a representative Savanna Ochrosol from the interior savanna zone, belongs to the order Oxisol because of the presence of an oxic horizon and plinthite. Since it is found in a region with a pronounced dry season (however, the horizons remain relatively moist) and it has redder colors and higher base saturation than the Udox it may be placed with the suborder Ustox. It belongs to the great group 9.43.* The Mimi series is placed in the same great group as the Kumasi and Bekwai soils. In view of the fact that Charter's system does differentiate among the ochrosols of the savanna and forest regions it may be better than the 7th Approximation for classifying the Oxisols at the present state of knowledge about these soils. It has an ochric epipedon with color value more than 3 and organic carbon less than 2% in the upper 10 inches.

Kpelesawgu Series

The Kpelsawgu series, a Ground Water Laterite, is placed with the order Oxisol because of the presence of an oxic

---

*The Mimi series is placed in the same great group as the Kumasi and Bekwai soils. In view of the fact that Charter's system does differentiate among the ochrosols of the savanna and forest regions it may be better than the 7th Approximation for classifying the Oxisols at the present state of knowledge about these soils.

horizon and plinthite. Because of evidence of wetness above the shale horizon (presence of ironstone and manganese concretions, stains of manganese dioxide and pale gray colors) it is placed with the suborder Aquox. It belongs to the great group 9.11 because it has some plinthite within 12 inches of the surface that has not hardened. Since mottles of low chromas are absent it is placed with the subgroup 911-9.3.

Toje Series

Toje series, a Coastal Savannah Ochrosol is placed under the order Oxisol because of the presence of an oxic horizon and plinthite. It belongs to the suborder Idox because some of the horizons are dry in the dry season and there is more than 50% base saturation in the oxic horizon, and it belongs to the great group Haplidox because the oxic horizon extends beyond 40 inches below the surface, and the plinthite is hardened.

Akuse Series

The Akuse series, a Tropical Black Earth, is placed with the order Vertisol because it has more than 25% clay and more than 30 milli-equivalents of exchange capacity per 100 grams of soil in all horizons below the surface 2 inches; and it develops deep vertical cracks in the dry season. It belongs to the suborder Aquerts because it has chromas of less than

1.5 throughout the upper 12 inches and the hues are not redder than 10YR; some concretions of manganese are present within the surface 30 inches; it occurs on very gently undulating topography. Because of the gray colors, self-mulching surface, and seasonal saturation with drying and vertical cracking in the alternate dry season, it is placed with the great group, Grumaquert.

Agawtaw Series

The Agawtaw series, a Tropical Gray Earth, belongs to the order Alfisol because of the presence of an argillic horizon (12 to 74") with base saturation more than 35% of the sum of cation exchange. It experienced marked seasonal variation in rainfall and the vegetation is grass with scattered trees (savannah).

It is placed with the suborder Aqualf because of the presence of mottles, iron, and manganese concretions; the chromas are 1 to 3 below the A_1 horizons, and the hues are 2.5Y or yellower.

Because it has more than 15% sodium saturation (in the natric horizon with prismatic structure) it is placed with the great group Natraqualf.

V. DISCUSSION

Considerations on Some Problems of Soil Classification in the Tropics

The major problem of soil classification in the tropics is the scanty knowledge of the soils. Research on tropical soils has been hindered by several factors. As pointed out elsewhere (47) workers in the tropics had their training in temperate regions. There is, therefore, the tendency to interpret observations with a bias dictated by their knowledge of soils of temperate regions. This problem will be reduced if these workers remain in the tropics long enough to make detailed studies. Unfortunately, most of the competent workers stay only for short periods. There is, therefore, a growing need for training men on the spot. Soil studies should be encouraged in the local institutions.

Another problem is the lack of cooperation among workers in the various countries. According to Pendleton (38) some of the able workers become isolated. This is particularly true in Africa, where diverse countries work in colonies situated in similar geographic regions. However, the inter-African soils conference is an effort to remedy this situation.

The soils of the tropics are relatively featureless. This makes the choice of properties for differentiation somewhat difficult.

Some unique processes of soil formation operate in the tropics, which make difficult the direct application of the A,B,C system of profile description. For example, Green (17) pointed out that in the tropics topography plays an important role in catenary association of soils; substances leached from a higher member of a catena are deposited in lower members. There is thus a kind of lateral movement of water downhill. The A,B,C units, he said, recognize a vertical movement of water. According to Pendleton (38) silica sesquioxide ratio determinations for colloidal clay by the international method may lead to erroneous interpretations for some tropical soils; because in some horizons iron oxides are precipitated in the form of concretions.

In the tropics the soils are relatively deep owing to the intensity and time of weathering. Soil horizons in general are not very distinct. Thus, there is a problem of distinguishing some soil horizons from the parent material. This was considered by Robinson (40) as an important distinction that should be made.

A group of soils now known as latosols has been a source of confusion in terminology. The confusion arose by applying Buchanan's term laterite to some soils in the tropics. The terms laterite and lateritic were thus used by various authors to describe tropical soils with reddish colors.

Kellogg (26) suggested the term Latosol and used it for some soil groups in the Belgian Congo. Sivarajasingham (44) discussed the term laterite fully and clarified some of the misunderstandings in the use of the term.

Laterite is not the only problem of terminology for tropical soils. Color names have often been applied to soils of different morphology. Costa (15) discussed some of the problems of nomenclature of tropical soils. According to him the chief source of difficulty is in the use of the term laterite and some terms derived from it. The steps taken in the nomenclature in the 7th Approximation will solve some of these difficulties of confused terminology. However, there is much to be studied about the Oxisols to enable coining of suitable names for defined categories and classes below the suborder level.

The above are only some of the problems of classification of tropical soils. These and other difficulties can be solved only through detailed studies of the soils and their interrelationships through soil formation factors. There is the need for careful morphological descriptions. Sufficient laboratory data should be collected to enable a sound classification to be made.

At the initial stages careful description of the soils, mapping units, etc. is necessary. Concurrently, an attempt should be made to classify them into known great soil groups or to devise more useful ones showing the interrelationships among these soils, relations to their environment, and relationships to soils in other countries. This will also aid in the correlation of the soils in the various countries and permit interchange of basic knowledge concerning their use, management and improvement.

The Major Soil Groups and Their Related Land Use

In Ghana not much work has been done in classifying soils according to land capability. However, the Soil Survey Division has done much to relate the various soil groups to their agricultural use. The following account is summarized largely from Brammer's report (4).

Soils of the Forest Zones

These soils are used mainly for agricultural purposes. However, forestry is becoming important in recent years.

Forest Ochrosols have good tilth, but under cultivation they become susceptible to drought. Available plant nutrients are concentrated in the top soil and at greater depths in the zone of rock weathering. The distribution of nutrients within the profile of typical forest ochrosols can be seen from Tables 5b, 5c, 6b and 6c. There is rapid loss of organic matter when the forest vegetation is cleared and the land is cultivated. Maintenance of organic matter in the top soil is, therefore, a problem in cultivating these soils. Brammer recommends three crops for these soils. Cocoa and coffee are the major crops on the upland soils, bananas, plantains, and cocoyams are also grown, but these produce only moderate yields for local consumption. Cocoa, which is the main cash crop of the country, does well with adequate organic matter supply and under moist conditions. Where these soils are droughty yields of cocoa decrease after 20-30 years from planting (4). C. F. Charter (10) stressed the need for manuring cocoa in order to maintain and augment the level of production. Kola grows well on the droughty soils.

The Forest Oxysols are suited to rubber and oil palms owing to the high rainfall. Good yields of bananas are also obtained on these soils. These soils are too acid to support a good crop of cocoa. However, it has been noted that where these acid soils contain appreciable amounts of exchangeable manganese, cocoa does well on them. Brammer (4) pointed out that there is some correlation between the distribution of cocoa and soils with substantial amounts of exchangeable manganese. The valley bottom soils are suited for rice production.

Intergrade soils between forest ochrosols and oxysols support satisfactory cocoa. Coffee on these soils requires manuring. Brammer (4) recommends that forest lithosols over the quartzites of the Akwapim-Togo range should be left under forest. But those on more basic parent material can be used for cocoa production.

Soils of the Interior Savanna Zone

These soils, like previous groups, have their nutrients concentrated in the top soil. They are generally poor in nutrients and low in organic matter. Droughty conditions exist in the savanna areas. The major crop on the Savanna Ochrosols are yams. Corn is grown in the south while guinea-corn and millet are more important further north. The bottom soils are suited for rice production. The Ground Water Laterites and the Ochrosol-Ground Water Laterite intergrades are poor in nutrients. The true Ground Water Laterites with pans are little used for farming. Yams and cereal crops are grown in some areas. These soils and their intergrades are generally used for pasture and grazing, especially in the dry season. This use needs to be investigated and improved.

Soils of the Coastal Savanna Zone

The Ochrosols of this region have good physical conditions and good water relationships in the wet season. But the prolonged dry season is a problem in their better utilization. They are generally low in organic matter and fertility.

However, local areas of termite mounds and earthworm activity are relatively higher in fertility (35).

Drought resistant crops such as millet, guinea corn, beans and various pulses are recommended (4). Tree crops like mangoes are extensively grown in the Accra plains. Coconuts are grown in the bottom soils, for which they are most suited.

The Tropical Black Earths of the coastal region, like those of the interior region, are almost uncultivated at present. They are too "heavy" for hand cultivation. However, they are suitable for continuous cultivation and the use of machinery may be necessary. According to Brammer (4), rice, vegetables, tobacco, sugar cane and fodder crops can be grown on these soils. But fertilization and irrigation are necessary. Cotton and sorghum is grown on similar soils in Tanganyika (40). Investigations to discover suitable crops and methods of cultivation are being carried out by the University College Agricultural Research Station and the Kpong Irrigation Research Station.

The Tropical Gray Earths are used mainly for grazing. The presence of the clay pan presents a problem for the cultivation of these soils. Drought resistant millets and guinea corn are recommended. Cassava and groundnuts are grown in the lighter soils.

From the above account it may be inferred that the major factors controlling the distribution of crops between the zonal soils of the savannah and those of the rain forest regions are climatic and edaphic. But within an area occupied by the same group of soils, soil characteristics determine local land use patterns. Depth to parent rock, slope, and degree of erosion are some of the important local factors that control use.

The major problems of agricultural use of the soils of the three regions are those of maintaining high organic matter levels in the top soil, improving fertility, and establishing good moisture relationships in the dry season. The native systems of agriculture aim at solving these problems. Unfortunately, however, some of the practices adopted lead to soil deterioration. Shifting cultivation under the native system cannot cope with increasing demands of food by the expanding populations. Efforts are being made to improve the system. In the Congo (26) the corridor system of shifting cultivation has been experimented with to reduce the length of fallow period. Mixed cultures of shallow and deep rooted crops are some of the means adopted to cope with the unfavorable vertical distribution of nutrients within the solum.

In Ghana, as well as in other tropical regions, there are systems for maintaining organic matter levels. Use of farm-yard manure, crop residues, green manure and cover crops, ridge and mound farming, and early burning of grasses are practiced. Unfortunately, the practice of manuring and use of cover crops is not widespread among native farmers. Since there is no suitable leguminous cash crops like clover in Europe and America, Crowther (16) suggested that leguminous cash crops like groundnuts (peanuts) and beans be grown and the land laid to rest with cultivated fodder crops.

Mulching or intercropping and shade crops may be practiced to conserve moisture, for such crops as bananas and coffee, in the dry season. This method is recommended elsewhere (19) by Griffith.

Generally, fertilizer application is not practiced by farmers in Ghana. However, some knowledge of fertilizer response and placement has been gained at the experiment stations. Green (18) reported work by Nye in Ghana. The latter found that corn responded to nitrogen (ammonium sulphate) and P_2O_5 (superphosphate) but gave no response to potassium. It has been found that soils of the coastal savanna region do not respond to lime (18). In general, Nye (18) observed that on the savannah region phosphorus and nitrogen are the main needs for groundnuts, corn, sorghum, millet, rice and cotton. Responses to calcium and potassium have been rare. Groundnuts showed a need for sulphur but not for potassium.

Consideration should be given to a more extensive use of the soils of the drier savanna areas for pasture and grazing. Forestry, game and recreational uses of some of the less productive latosolic soils should be given some consideration in the development of the land resources. It is believed that agronomic investigations should go along with the improvement of the classification of the soils of Ghana.

Suggestions for Improving the Classification of the Soils of Ghana

The author would like to point out here that the following suggestions are being made, not in condemnation of the outlined provisional system, but for general consideration only. He is aware of the danger of undertaking to do this without any personal experience with the soils. However, it is hoped that some of these suggestions may be useful.

Nomenclature

The nomenclature used at the highest categorical level, the soil order, in Charter's (5) provisional system is derived from the names of the predominant soil forming factors. Since these factors are only presumed to be the predominant ones they may not form a valid basis for naming the soils. It would be better if the names would be coined after the most pronounced morphological properties of the soils. Some of these properties may be hidden but can be revealed by chemical or physical tests, e.g., the predominance of allophane in certain soils derived from volcanic ash. Master horizons and the nature of surface horizons may be suggestive for names of the orders. In coining these names, their ease of remembrance and the extent to which they reflect genetic characters and show genetical relationships among the groups should be borne in mind. A detailed study of the soils should be made with a view to adopting some of the names proposed for the higher categories in the 7th Approximation. At the great group level in the 7th Approximation names reflect moisture relations and temperatures of the soils. In Ghana, where catenary associations are important the idea of drainage associated with topographic site may be suggested in the names for sub-orders. This attempt has been made in the present provisional system and the 7th Approximation. The use of vegetative cover names for the great soil groups (e.g., forest ochrosol, etc.) may be misleading for reasons pointed out above. Color names as pointed out elsewhere (15) may also cause confusion. For names to be derived from diagnostic morphologic features detailed field descriptions should be reinforced with laboratory data.

The use of place names for the series is in accordance with the practice in other countries. In the 7th Approximation names for lower categories than the ones indicated in Table 3 have not been developed. For the soils of Ghana, the possibility of using names that suggest distinguishing characteristics of the series, or types may be investigated. In this connection an attempt to use vernacular names that recall some of these properties may be made. This is not an easy job since there are about five principal languages. However, Twi names may be used throughout most of the regions. These vernacular names should be direct translations from English which is used as the scientific language.

Choice of Criteria for the Classification

The use of soil forming factors as criteria for differentiating the soil orders is objected to because these factors are not easily observed or measured properties of the soils. As already pointed out morphologic characteristics that are the results of soil forming processes (soil genesis) or reflect genetical relationships (soil genetics) should be used as criteria. Properties of diagnostic horizons, as used in the 7th Approximation, are recommended for trial. The assumed predominance of the effect of a particular factor, say parent material, may be complicated by the fact that other soil forming factors are co-varying with it. Morphologic features that are less sensitive to change in environment, but showing recognizable changes with intensity of the effect of soil factors, such as vegetative cover, slope, drainage, etc., should receive correspondingly greater consideration. The soil formation factors which are genetical or independently variable properties aid in understanding the interrelationships among the morphological or dependently variable soil properties.

The use of topographic site, or nature of parent material to differentiate at the suborder level may also be objected to. According to Krusekopf (28) slope may be an important factor in land use, but it is not a soil forming factor and cannot be used as a criterion in taxonomic soil classification. This view is rather drastic. In my opinion, slope or topography is actually a soil forming factor, as well as a property of the soil body, and can be used together with related soil profile properties as a criterion.

The use of soil reaction as a criterion for differentiating soil group families should be re-examined. Soil reaction or other dependently variable properties alone cannot be used since two soils which are morphologically or genetically different may have the same reaction. Recognizable morphological differences which are associated with reaction may be used together with it; e.g., calcium carbonate horizons, etc.

At lower categorical levels the properties of master horizons and diagnostic surface horizons as suggested in the 7th Approximation may be used in addition to others. Soil moisture, which is apparently quite important in Ghana, may also be used. Owing to uniformity of temperature, this property may not be very useful in differentiating at lower categories in the tropics. Particular attention should be paid to the nature of plinthite, and careful descriptions made.

Descriptions and Laboratory Data

If morphological characteristics are to be used as criteria for the classification, then the need for detailed descriptions and adequate laboratory data becomes paramount. Detailed descriptions are fundamental to any sound system of classification. Profile descriptions as well as mapping unit descriptions should be systematic and in detail. Precise descriptions of soil structure, consistency, boundaries between horizons and their nature, plant roots and their distribution, mottles on ped surfaces and in the interiors, etc., are now commonly lacking. Detailed descriptions of geology, topography, climate, vegetation and ages of landscapes are also necessary. These should be helpful in conjunction with the soil profile properties in discovering interrelationships among the soils and their relationships to the landscape which permit more accurate and rapid mapping of soils.

Additional Research Needs

Taking into consideration the many obstacles which the soil survey staff has to meet, present research efforts are praiseworthy. There has been an awareness of the need for laboratory data for the most important soil groups described above. These are being supplied. However, if we are to correlate our soils with those of other countries, there is need for more intensive research.

Some of the criteria used in the 7th Approximation demand a careful analysis of the type of clay and the percentage present in each horizon. It is, therefore, necessary that these determinations be made on representative samples of all known soils in the country. Certain chemical analyses such as the potassium content of clays and their silica and sesquioxide ratios may be determined with a view to identifying component minerals and studying the processes of soil genesis.

The N value (47) which is given by the formula

$N = \frac{A - 2}{L + 3H}$, where,

A = percentage of water in the soil under field conditions (calculated on a dry soil basis),

L = percent clay, and

H = percent organic matter (organic carbon X 1.724),

should be calculated for soils for which this may apply. Investigation as to whether this N value has any significance for land use or correlation with other soil properties needs to be made in the tropics.

Moisture determinations are being made for air dry soils.

Research should be conducted on moisture tension determinations at various moisture tensions of from 0.06 to 15. atmospheres. At the low tensions these measurements should be on natural structural aggregates or undisturbed core samples. The relation of the moisture contents of the various tensions should be related to field capacities of the soils, and the wilting points of native plants or irrigated crops. If there are other properties with which available moisture holding capacities may be more closely correlated, than texture, these relationships should be clarified and used in soil classification. The textural classification of the soils needs re-examination and correlations need to be made with those of other countries.

Bulk density determinations are desirable in investigating soil air - soil water relationships. Other physical data on soil aggregation and porosity need to be obtained.

Since Ghana is mainly an agricultural country soils research should be geared towards land utilization and improved crop production. Without this the National Soil Survey will not achieve its purpose.

A statistical approach to sampling in soil surveys and for other agricultural research purposes should not be overlooked.

The above suggested needs for research are not exhaustive. More problems will be discovered in the process of research and the search for solutions will continue. In a country where soils work is relatively new it will take some time to tackle all these problems efficiently. To carry out these suggestions there is need for strengthening the Soils Division of the Department of Agriculture and the Soils Divisions of the local university and technical colleges. It requires training of soil scientists on the spot. Specialists in the various branches of Soil Science are needed to carry out an effective soils research. To meet these requirements effectively and efficiently cooperation between the colleges and the government department is necessary.

Conclusions

A review of the past, present, and proposed systems of soil classification reveals the fact that each system is directly related to the state of knowledge about soils at the time of classification. Each system is an attempt to improve upon the previous one. Thus with the increase of knowledge new systems will be devised to replace old ones. As long as knowledge about soils remains incomplete classifications will continue to be approximations only. According to Simonson (43) answers obtained today will sooner or later be superceded.

Soil classification has some continuing problems; there are the problems of arriving at a clearer concept of the soil individual, nomenclature and precise definition of terms to meet universal acceptance, and the selection and weighing of properties used in differentiating classes and categories. With the growing desire to evolve a system that will be applicable to soils of all regions of the world these problems become more pronounced.

The concept of the soil individual has passed through a series of changes. The definition of a "pedon" in the 7th Approximation (47) is the most recent and precise. However, the areal extent and lower depth limit are arbitrarily chosen. Since the soil population, unlike those of plants and animals, does not consist of discrete individuals this problem will remain with us. Jones (25) questioned whether any form of systematics is applicable to soils since classification must necessarily involve systematic organization of individual units. If we remember that classification is conceptual there can be no doubt in our minds that the process of individuation can be carried out. We are building up models to fit our observations.

An effort is being made to overcome difficulties in terminology. It remains to be seen what will result from the trial being given to the proposals contained in the 7th Approximation.

As descriptions become more precise, measurements more quantitative and our understanding of soil genesis and soil genetics becomes more complete, the choice of the most meaningful morphologic characteristics as criteria will become relatively easy.

The classification of the soils of Ghana is passing through historical stages similar to those of other countries. Hardy's (20) account of soil classification in the Caribbean region showed that early workers there used the soil formation factors as criteria. The trend toward the use of morphological properties is well marked in the United States. This trend is desirable in tropical areas for a sound system of soil classification. There is a great need for detailed descriptions of Ghana soils and detailed laboratory research. The classification can improve only through the accumulation of knowledge about our soils.

Although limited purpose classification is not the subject here, attention may be drawn to the use of soil survey data in land capability classifications for various purposes. The purpose of any classification is to organize our knowledge about the objects we classify so that their properties may be remembered and their relationships easily comprehended for specific purposes, including increased understanding of the soils. This should be our goal in working out any system of classification. The usefulness of the classification of the soils of Ghana will depend on how well it serves this purpose.

BIBLIOGRAPHY

1. Ableiter, J. K., 1949. Soil classification in the United States, Soil Sci. 67: 183-191.

2. Afanasaiev, J. N., 1927. The classification problem in Russian Soil science, U.S.S.R. Acad. Sci. Ped. Invest. 5: 1-50.

3. Baldwin, M., Kellogg, C. E., and Thorp, J. 1938. Soil classification. 1938 Yearbook of Agriculture. U.S. Dept. of Agr., Gov't Printing Office, Washington, D. C., pp. 908-983.

4. Brammer, H., 1959. Soils of Ghana, Ghana Division of Agriculture, Soil and Land Use Survey Branch. Divisional Paper No. 6 (unpublished).

5. _____. 1956. C. F. Charter's interim scheme for the classification of tropical soils.

6. _____. 1959. Classification of Ghanaian soils; soils of Ghana. Ghana Division of Agriculture, Soil and Land Use Survey Branch, Divisional Paper No. 6: 5-9.

7. Bisinski, J J., 1959. The Russian approach to soil classification and its recent development. Jour. Soil Sci. 10: 14-27.

8. Charter, C. F., 1949. Methods of soil survey in use in the Gold Goast. Bull. Agric. Congo Belge 40: 109-120.

9. _____. 1949. The organization of Soil surveys in British West Africa. African Regional Scientific Conference Proceeding, Vol. 2.

10. ____________, 1953. The need for manuring cocoa in the Gold Coast in order to maintain and augment the level of production. Report of the Cocoa Conference, London, The Cocoa, Chocolate and Confectionary Alliance, Ltd., London, 1953, pp. 145-147.

11. _____. 1954. Report on the work accomplished by the soil survey organization of the Gold Coast since the Goma soils conference, 1948. Inter African Soils Conference, Vol. 11: 1233-1244.

12. _____. 1954. Colloquium on Soil Classification Trans. 5th International Cong. Soil Sci. V. 4: 492-99.

13. Cline, M. G., 1949. Basic principles of soil classification, Soil Sci. 67: 81-89.

14. Cline, M. G., et al, 1955. Soil Survey, Territory of Hawaii, U.S.D.A. publication Series 1939, No. 25. Gov't Printing Office, Washington, D. C.

15. Costa, J. V. (Botelho Da), 1954. Some points of nomenclature of tropical soils. Inter African Soils Conference Proc. 2. Leopoldville, Belgian Congo.

16. Crowther, E. M., 1949. Soil fertility problems in tropical agriculture, Commonwealth Bureau of Soil Sci., Tech. Comm. No. 46: 134-142.

17. Green, H., 1945. Classification and use of tropical soils. Soil S. S. Amer. Proc. 10: 392-396.

18. _____, 1954. Fertilizer prospects in Africa, 5th Internat'l. Congress of Soil Sci. Leopoldville, Vol. 1: 148-150.

19. Griffith, G., 1949. Fertility problems in Uganda, Commonwealth Bureau of Soil Sci., Tech. Com. No. 46: 160-165.

20. Hardy, F., 1949. Soil classification in the Caribbean region, Commonwealth Bureau of Soil Science, Tech. Com. No. 46.

21. Hilgard, E. W., 1860. Geology and agriculture in the State of Mississippi, E. Baseksdale, State Printer.

22. _____. 1906. Soils, their formation, properties, composition and relations to climate and plant growth in the humid and arid regions.

23. Jenny, H., 1941. Factors of soil formation. McGraw-Hill Publishing Co.

24. _____. 1950. Causes of the high nitrogen and organic matter content of certain Tropical Soils. Soil Sci. 69: 63-69.

25. Jones, T. A., 1959. Soil classification, a destructive criticism, Jour. Soil Sci. 10: 196-200.

26. Kellogg, C. E. and Davol, F. D., 1949. An exploratory study of soil groups in the Belgian Congo, I.N.E.A.C. publication Series No. 46.

27. Kellogg, C. E., 1949. Preliminary suggestions for the classification and nomenclature of great soil groups in tropical and equatorial regions, Commonwealth Bureau of Soil Sci., Tech. Com. No. 46: 76-85.

28. Krusekopf, H. H., 1943. Objectives and criteria of soil classification, S. S. S. Amer. Proc. 8: 374-376.

29. Kubiena, W. L., 1958. The classification of soils, Jour. Soil Sci. 9: 9-19.

30. ______. 1953. The Soils of Europe, Thomas Murby & Company, London.

31. Leeper, G. W., 1956. The classification of soils, Jour. Soil Sci. 7: 59-64.

32. Manil, G., 1959. General considerations on the problems of soil science, Jour. Soil Sci. 10: 5-13.

33. Marbut, C. F., 1922. Soil classification--life and work of C. F. Marbut, pp. 85-94. Art Craft Press, Columbia, Missouri.

34. Marbut, C. F., 1927. Soil classification, Proc. 1st International Congress of Soil Sci. 5: 1-13.

35. Marshall, C. E., and Haseman, J. F. 1942. The quantitative Evaluation of Soil Formation and Development by Heavy mineral studies:--A grundy Silt loam profile. S. S. S. Amer. Proc. 7: 448-

36. Nye, P. H., 1955. Some soil forming processes in the humid tropics--the action of soil fauna. Journ. of Soil Sci. 6: 73-83.

37. Obeng, H. B., 1960. Personal correspondence (unpublished).

38. Pendleton, R. L., 1949. Classification and mapping of tropical soils, Commonwealth Bureau of Soil Sci., Tech. Com. No. 46.

39. Riecken, F. F., 1945. Selection of criteria for the classification of certain soil types of Iowa into great soil groups. S. S. S. Amer. Proc. 10:319-325.

40. Robinson, G. W., 1949. Some considerations on soil classification, Jour. Soil Sci. 1: 150-155.

41. Rounce, N. V., 1949. Soil classification and survey in relation to land rehabilitation and expansion in Usikuma , Tanganyika, Commonwealth Bureau of Soil Sci., Tech. Com. No. 46: 121.

42. Russel, E. J., 1950. Soil conditions and plant growth, 8th ed. Longmans, p. 1-23.

43. Simonson, R. W., 1952. Lessons from the first half century of soil survey, Soil Sci. 74: 249-251.

44. Sivarajasinghan, S., 1959. Nature and origin of laterite, M.S. Thesis, Cornell University.

45. Stephen, I., 1959. A petrographic study of tropical black earth from the Gold Coast, Journ. Soil Sci. 4: 211-219.

46. Thorp, J., Smith, Guy D., 1949. Higher categories of soil classification, Soil Sci. 67: 117-126.

47. U.S.D.A., 1960. Soil classification--a comprehensive system--The 7th Approximation.

48. Van Eck and Whiteside, E. P., 1958. Soil classification as a tool in predicting forest growth. First North American Forest Soils Conf., Mich. Agr. Exp. Stat. East Lansing, Michigan.

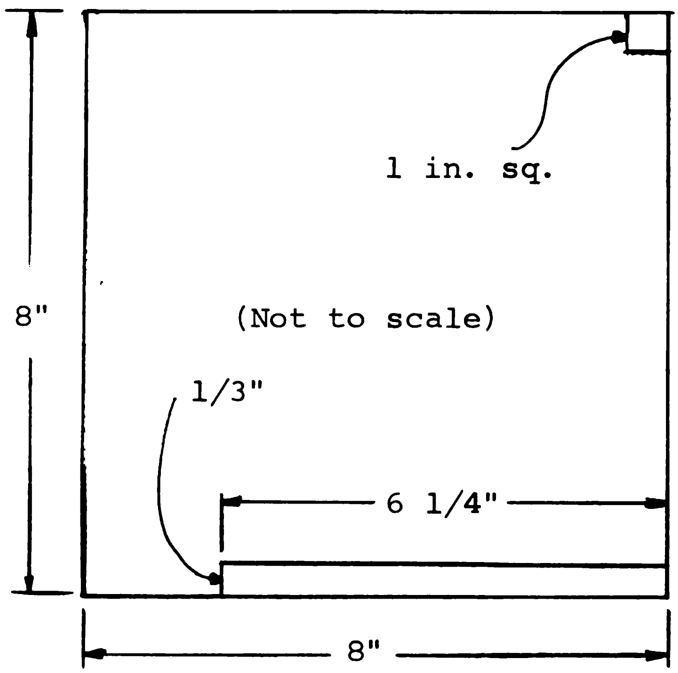
49. Whiteside, E. P., 1954. Changes in the criteria used in soil classification since Marbut. S. S. S. Amer. Proc. 18: 193-195.

50. _____. 1959. A proposed system of genetic soil horizon designation, Soils and Fertilizers, XXII: 1-8.

51. Yaalon, Dan., 1959. Classification and nomenclature of soils in Israel. Taxonomic comparison and genetic relationship with soils from other countries. The Hebrew University of Jerusalem, Department of Geology, Publication No. 221.

APPENDIX 3

TEXTURE TEST



Equipment

A number of cash bowls,

Wooden mortar and pestle,

Wooden board (see diagram),
8" x 8" with a square 1" each side, drawn in one corner, a length of 6.5" marked along one side, 1/3" from the edge,

a 2 mm. sieve.

Method

1. Place samples in cash bowls on table in order of horizon.

2. Pick out large concretions and nodules, gravels and stones.

3. Grind each sample separately in a wooden mortar with a wooden pestle, to break clods and crumbs down into ultimate particles. Coarse grit, sand and small concretions are to be ground down.

4. Sieve with 2 mm. sieve into cash bowls again.

5. Add water and knead until sticky point is reached, i.e., the point where the samples just does not stick to the fingers or other objects.

6. Try to form ball (1" in diameter) by rolling between the hands.

7. Form roll 1/3" thick, 6 1/4" long by rolling with palm of hand on board.

8. Bend roll, while lying on board, to form a circle 2" in diameter.

9. Wash hands, board, mortar pestle and cash bowls between each test.

Results

The test will stop at stage 6, 7, or 8. The texture is then given as follows:

Form	Texture	Symbol
A. Sample will form a cone, but not a ball	Sand (if smooth grains) Grit (if sharp grains)	▲
B. Form a ball but not a roll	Loamy sand	●
C. Forms a roll:		
(a) Ill formed	Light loam	— — —
(b) Well formed	Loam	———
(c) Almost a circle	Heavy loam	⌒ showing extent of bending
D. Forms a circle		◌
(a) Hardly	Light clay	
(b) Easily	Clay	○

Further subdivisions are given by visual inspection, e.g.:

A. Coarse sand (2.0 - 0.2 mm.)

Fine sand (0.2 - 0.02 mm.)

B. Loamy coarse sand

Loamy fine sand

Loamy micaceous sand

C. (a) Light fine sandy loam
Light coarse sandy loam
Light micaceous sandy loam

Similarly, (b) and (c)

D. Light micaceous clay

[redacted]

Pocket has:
2 Append.

[redacted]

[redacted]