# THE SUITABILITY OF SOME TYPIC PALEUDULTS FOR OIL PALM PRODUCTION

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By

Walter T. Wiles

Thesis Committee:

Haruyoshi Ikawa, Chairman
Goro Uehara
Yoshinori Kanehiro

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Agronomy and Soil Science.

THESIS COMMITTEE

H. Ikawa

Chairman

Y. Kanehiro

Goro Uehara

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# INTRODUCTION

In the Soil Taxonomy (Soil Survey Staff, 1975), soils with similar soil properties are grouped together. They are six categories in the Soil Taxonomy and they are the order, suborder, great group, subgroup, family, and series. The heterogeneity of each category is reduced, or the homogeneity is increased, in going from the order to the soil series. At the family category, the soils indicate properties, such as texture, mineralogy and soil temperature, that are important for agricultural and non agricultural uses. The general objective of this study, therefore, is to illustrate how soils classified according to the Soil Taxonomy can be used to rate soils for a specified use.

The soil selected for the study is the clayey, kaolinitic, isohyperthermic family of the Typic Paleudults. This soil was selected because it is one of the soils being used by the Benchmark Soils Project (1978) in "testing the hypothesis that similar soils in similar environments have similar characteristics and, therefore, require similar agrotechnology." Additional studies of the same soil will increase the knowledge of the particular soil and make this study as well as that of the Benchmark Soils Project more meaningful.

In this study, furthermore, the soils are rated for the production of oil palm. Oil palm was selected because it is one of the most important oil crops in the tropics, being second only to coconuts. There are still large areas of the tropics that can be utilized for the production of oil palm.

The specific objectives are:

1. Compare the morphological, chemical, and physical properties of five soils of the clayey, kaolinitic, isohyperthermic family of

the Typic Paleudults.

2. Prepare a list of the range in the soil characteristics of these soils.

3. Compile a list of criteria and constraints for the production of oil palm.

4. Propose a soil suitability rating for these five soils for the production of oil palm.

# REVIEW OF LITERATURE

## The Soils

The Ultisols are the fourth most common soil order, covering 11 percent of the tropics (Sanchez, 1976). In the earlier soil classification systems, the Ultisols were grouped as Red-Yellow Podzolic and Reddish Brown Lateritic soils occurring on rolling, gently undulating or hilly landforms (Simonson, 1949; McCaleb, 1959). According to Thorp and Smith (1949), the Red-Yellow Podzolic soils with a textural B horizon are very important tropical soils.

According to the Soil Taxonomy (Soil Survey Staff, 1975), Ultisols are mineral soils to mid to low latitude, that are strongly weathered, with translocated clay in an argillic horizon. They are usually moist with precipitation exceeding evapotranspiration during some seasons of the year, and the bases removed by leaching exceed or equal the amount released by weathering. Ultisols are strongly acidic and the base saturation by the sum of cations is less than 35 percent at a depth of 1.8 meters below the soil surface or 1.25 meters below the upper boundary of the argillic horizon, whichever is deeper. These criteria were selected to reflect the extensive leaching of the Ultisols (Buol et al., 1973). Normally, extractable aluminum is high in these soils except in the Paleudults and other pale-groups (Soil Survey Staff, 1975). The inherent low fertility and base status of the Ultisols has been, and continues to be, important limitations to agricultural use. When managed properly, however, they represent a vast potential for agricultural production.

Typic Paleudults represent the central concept of the great group, which according to the Soil Survey Staff (1975), "is a freely well drained soil, with an ochric epidedon, that has little or no plinthite and has an argillic horizon that is loamy or clayey." Soils of the clayey, kaolinitic, isohyperthermic family, in addition to having the properties of the typic subgroup, have 35 percent or more clay by weight in the fine earth fraction. The isohyperthermic soil temperature regime corresponds to a mean annual soil temperature of 22° C (72° F) or higher and the difference between the mean summer and the mean winter soil temperatures at a depth of 50 cm is less than 5° C (9° F) (Soil Survey Staff, 1975).

## The Oil Palm

The oil palm (Elaeis guineensis Jacq.) is a tropical crop grown throughout most of the tropics between latitudes 15° N and 15° S (Werkhoven, 1966; Hartley, 1967; Purseglove, 1975). It can grown on a variety of soils but not much work has been reported relating to the use of specific soils for its production. Soils that are desirable for optimum production should be on a flat or gently sloping terrain, deep, with well-developed structure and friable consistence (Ng, 1968; Werkhoven, 1966; Williams and Hsu, 1970). Drainage must be good for adequate oxygen supply. Water availability must also be good. The water requirement of oil palm is high but plant growth is adversely affected by a permanent high water table (Werkhoven, 1966; Tinker, 1976). Purvis (1956) noted that they were many secondary roots at 1.5 meters--the maximum depth which he investigated.

In many areas, the oil palm flourishes on acid soils of pH 4 to 6 but may have an optimum range of pH 5.5 to 6. Work on oil palm nutrient requirement has been centered around the major macronutrients.

A review of the literature shows that N, P, K, and Mg are the major nutrients removed from the soil by the oil palm and that the total nutrient demand of oil palm varies with location, soil, and growth stages of the oil palm. For example, oil palm has a high nutrient demand in its early growth stages. Based on data presented by Hartley (1967) and Corley et al. (1976), a soil must supply approximately 1.3 kg N and 0.2 kg K to each palm per year. Tinker (1964) noted that virtually all oil palm soils need more K than the other nutrients.

Corley et al. (1976) also stated that levels of extractable K below 0.15 to 0.20 meq/100 grams of soil resulted in the deficiency of K. Work done in Nigeria and Malaysia showed that the oil palm required N in its early years. Phosphorus requirement is not high except in soils rich in Fe and Al. In general, oil palm with its large annual total production of dry matter, removes considerable amounts of nutrients from the soil. Based on results of work done over a 20-year period, Tinker (1964) estimated the amount of nutrients removed as being approximately 130 kg/ha/year N, 30 kg/ha/year P, and 160-200 kg/ha/year K.

## The Rating of Soils

Soil suitability is concerned with the direct usefulness of soils for a particular purpose. Earlier schools of though had used soil suitability as being parallel to land capability or land suitability (Vink, 1962; FAO, 1976). Then, it was concerned with the inherent capacity of the soil to perform at a given level of a general use.

Vink (1975) defined soil suitability as the physical suitability of soils and climate for the production of a specific crop or group or sequence of crops for other defined uses or benefits. The suitability being within a specified socio-economic contec context but not considering economic factors specific to areas of land.

The concept of soil suitability is more meaningful in terms of specific kinds of soil use, each having their individual requirements (FAO, 1976). The suitability of a soil is determined by the particular combinations of major properties--the qualities the soil possesses (Ng, 1968). Soil qualities are results of the interactions between soil characteristics, crop requirement, and/or the environment. Soil quality has been noted (FAO, 1976) as a complex attribute of soil properties which performs distinctly in its influence on the suitability of soil for specific kind of use. In this study, the rating is developed by comparing the qualities of each type of soil with the requirements of the specified use.

Soil qualities that influence the growth of the oil palm include availability of moisture, oxygen, and nutrients (Hartley, 1967; Ng, 1968; FAO, 1976; Corley et al., 1976). Soils, not including the human and social implications of land, is a narrow concept but can be wider when similar soils are recognized in different parts of the world supporting different land use (Vink, 1975).

Land capability, used as a parallel to soil suitability, is an interpretive grouping of soils for specified purposes. The land capability classification, presented by Klingebiel and Montgomery (1961), grouped soils into eight capability classes based on their suitability for cultivation and other uses and their limitations. The classes are subdivided into subclasses and capability units to accommodate the kinds of hazards or limitations (for example, depth, wetness, erosion), and group soils with similar response to management. The system of land capability classification appears to be primarily for agricultural interpretation and that limitations rather than potentials are emphasized, an emphasis which poses as a disadvantage.

Storie (1933) developed the Storie Index for the numerical rating of soils. The Storie Index expresses numerically the relative degree of suitability, or value, of a soil for general intensive agriculture. The rating is based on the evaluation of characteristics such as depth, texture, and drainage. Factors such as availability of water for irrigation and climate, are not considered. Characteristics inherent in the soil series are repeatedly used in calculating the index. There has been several modifications of this approach using a multiplicative rather than an additive model, which shows the dominating influence of a limiting factor (for example, Sahara et al., 1972; Riquier, 1974).

The review of other systems by Olson (1974) and Teaci and Burt (1974) provides more insight on the land capability classification. In Hawaii, the former Land Study Bureau of the University of Hawaii used a modification of the Storie Index on productivity rating to prepare a land classification for the island of Oahu (Sahara, et al., 1972).

# MATERIALS AND METHODS

## The Soils

The soil descriptions and the laboratory data of the five profiles of the clayey, kaolinitic, isohyperthermic family of the Typic Paleudults were obtained from various published and unpublished sources (Empresa Brasileira de Pesquisa Agropecuaria, Ministry of Agriculture, Brazil; Soils Division, Ministry of Agriculture, Liberia; Department of Agriculture, Ministry of Agriculture, Malaysia; and the Benchmark Soils Project of the University of Hawaii). These samples came from various parts of the tropics including Africa, South America, and Southeast Asia. The names of the soil series, their locations, some of the genetic factors, and current use are listed in Table 1. Although the soil series names of Liberia and Malaysia are official names, the series names of Brazil, Cameroon, and the Philippines are tentative names.

The Frexeiras series is a soil devoted to sugarcane production in Alagoas, on the eastern coast of Brazil. The Barombi-Kang series is being considered by the Benchmark Soils Project of the University of Hawaii in testing the transferability of agrotechnology in certain parts of the tropics on the basis of the similarity of the soils, in this particular case, Cameroon. The Kolahun series is one of the soils of the Foya Agricultural Project in Liberia (Soil Division Staff, 1976). The Lanchang series is a soil presently in secondary forest in Peninsular Malaysia. Finally, the Tugbok series is a soil also being used by the Hawaii Benchmark Soils Project, in Mindanao, the Philippines.

Table 1. Genetic factors and current use of the five Typic Paleudults

| | Soil Series | | | | |
|---|---|---|---|---|---|
| | Frexeiras | Barombi-Kang | Kolahun | Lanchang | Tugbok |
| Location | Brazil | Cameroon | Liberia | Malaysia | Philippines |
| Approx. Latitude | 9° S | 4° N | 8½° N | 3½° N | 7° N |
| Parent Material | Gneiss | Basalt | Granite, gneiss | Grano-diorite | Andesite |
| Elevation | 130 m | 180 m | 200 m | 50 m | 200 m |
| Rainfall | 1720 mm | 2450 mm | 2000-2500 mm | 1840-2510 mm | 2500 mm |
| Slope | 27 percent | 1-3 percent | 0-8 percent | 6 percent | 2-5 percent |
| Physiography | Lower third of hillside | Undulating topography | Gently sloping to sloping upland | Undulating topography | Lower plain |
| Drainage | Well-drained | Well-drained | Well-drained | Well-drained | Well-drained |
| Current Use | Sugarcane | Cocoa, coffee | Rice, oil palm | Secondary forest | Fruit orchard |

The physical and chemical data of the five soil series were analyzed according to methods outlined in the Soil Survey Investigation Report No. 1 (Soil Survey Staff, 1972). Samples of the Frexeiras series were analyzed at the National Soil Survey Laboratory in Lincoln, Nebraska; the Barombi-Kang series was analyzed by the Hawaii Benchmark Soils Project; the Kolahun series was also analyzed at the National Soil Survey Laboratory in Lincoln, Nebraska; while the Lanchang series was analyzed by the Department of Agriculture of Ministry of Agriculture in Kuala Lumpur, in Malaysia. The Tugbok series was also analyzed by the Hawaii Benchmark Soils Project.

The descriptions of soils and the laboratory data were examined by comparing the profile descriptions and the tables of data, respectively. The laboratory data were studied further by preparing a linear correlation matrix of the chemical and physical soil properties. The results of the statistical analysis were used to select variables which could be displayed graphically. The results were further used to determine the range in the characteristics of the soils selected for the study.

## The Oil Palm

The phenological requirements of the oil palm were obtained by consulting the literature (Corley et al., 1976; FAO, 1976, Hartley, 1967; Ng, 1967; Purseglove, 1975; Purvis, 1956; Williams and Hsu, 1970). A table was then created showing the important requirements for the growth and production of oil palm.

Oil palm is a tropical perennial monocotyledon which comes into production three to four years after planting. The flowers are borne on separate male and female inflorescences which arise from the leaf axils. The fruit of the oil palm is a drupe. It consists of a pericarp, made up of exocarp, mesocarp (often wrongly called pericarp), and endocarp (shell), surrounding usually one, but sometimes up to four kernels. Figure 1 shows an oil palm orchard, while Figure 2 shows a young oil palm bearing fruit.

The oil palm is a high oil-producing plant. Its oil is contained in the mesocarp and endosperm of the ripe fruit. These oils are of different chemical composition and are extracted separately.

Male and female flowers of the oil palm plant are produced in cycles of variable duration. Normally not more than one flower on a palm will be at anthesis at any one time, hence self pollination is rare. The oil palm has a tendency to produce a high proportion of male flowers in situations with moisture stress, on poor soils, and on steep slopes. The early development of the inflorescence takes two and a half to three years and the first fruit normally ripens during the third year after planting.

The yield is measured in fruit bunches, oil, or oil-bunch ratio. Yield increases with age and reaches a plateau in about eight to ten years after which a gradual decline sets in. Yield per hectare per year varies with location and ranges from 15 to 30 tons of fruit bunch per hectare per year with about 23 to 24 percent oil. With a normal planting density of 150 trees per hectare, yield in tons bunches/ha/year ranges from 15 to 20 in Nigeria, from 20 to 25 in Malaysia, and from 25 to 30 in Sumatra (Werkhoven, 1966; Corley et al., 1976).

The average productive life span of a plantation grown oil palm is 25 to 35 years. The oil palm has an adventitious, deep rooting system, which can be restricted by a shallow water table.

Figure 1. An oil palm orchard near Johore Baru, Peninsular Malaysia

Figure 2. Young oil palm with fruit, near Johore Baru, Peninsular Malaysia

Based on the climatic parameters of the Soil Taxonomy, the optimum growth of oil palm is limited to only two or three of the 20 ecological zones (Table 2).

## The Rating of Soils

A soil and its environment have many separate but related characteristics. The effects of soil characteristics, soil quality, and the environment, therefore, must be considered together and in relation to the specified crop. The determination of soil suitability for a specific use, furthermore, requires a thorough knowledge and understanding of the fundamentals of soil and crop sciences.

An ideal method of predicting soil suitability for crop production should be based on crop yield data--crop yield being a function of soil, climate, variety, and management factors. Periaswamy (1976) stated that similarly classified soils could be used as a guide in rating soils when the exact rating procedure was unknown.

Proposed approaches to predicting soil suitability--Like land capability or land evaluation, several models or approaches have been used to determine soil suitability. The use of additive, subtractive, multiplicative, and complex equations are discussed by Riquier (1974).

A qualitative method lacks precise calculation of costs and returns. Relative suitability is based mainly on the physical potential of the soil with little or no emphasis on economics. In this study, this method will be used because of its simplicity. Furthermore, limited data necessitates the use of the qualitative rather than the quantitative approach. Efforts must, however, be made in the future to improve the choice of parameters and criteria and also to develop a reasonable

Table 2. Optimum moisture and temperature regimes for the production of oil palm

| Temperature Regime | Moisture Regime | | | | |
|---|---|---|---|---|---|
| | Aquic | Perudic | Udic | Ustic | Aridic or torric |
| Isofrigid | not suited | not suited | not suited | not suited | not suited |
| Isomesic | not suited | not suited | not suited | not suited | not suited |
| Isothermic | not suited | not suited | not suited | not suited | not suited |
| Isohyperthermic | not suited | poor-fair | good | fair | not suited |

quantitative model.

Soil quality--The relative importance of a particular soil characteristic differs in different environments so that only rarely is a single parameter able to dictate the suitability of a soil for that use. In addition, the suitability of soils for a given use is not related directly to single characteristic but by a combination of interacting characteristics.

In this study, soil characteristics that are important for the production of oil palm are grouped under four qualities--moisture, drainage, nutrient, and energy. Based on the range in characteristics of the soils and the criteria used for growing the crop, the soil qualities are rated as being not suited, poor, fair, and good for different levels of their soil characteristics. For each of the soil qualities, a soil is rated as being not suited if the soil quality is not suited for oil palm; as being poor if the soil quality barely sustains oil palm; as being air if only marginal for oil palm; and as being good if suited for oil palm. Based on the overall rating of the qualities, the soil is finally rated again as being in one of the previous categories.

The matching of soil qualities to crop requirements represents the central idea of a suitability interpretation and, as stated previously, is based on the functional relationships that exists between the soil qualities and the crop requirements.

# RESULTS AND DISCUSSION

## The Soils

The profile descriptions and the laboratory data of the five soils are presented in the following pages and tables. Several of the soil properties are especially important in classifying the soils. At the same time, they are important in assessing the agricultural potential of the soils. Properties such as texture, including the distribution of the clay within the soil profile, organic C content, cation exchange capacity, the extractable bases, base saturation, and the climatic parameters, among others, are used to classify soils and to rate them for agricultural purposes.

In this section, the properties will be studied to confirm the classification of the soils according to Soil Taxonomy, namely the clayey, kaolinitic, isohyperthermic family of the Typic Paleudults. At the same time, the soils will be rated to determine their suitability for oil palm production.

Soil structure--Structure is the grouping of sand, silt, and clay-sized particles into stable aggregates. The relative proportion of sand, silt, and clay in a soil is called texture. Soil structure is influenced by the organic matter content, texture, the nature of the extractable cations and the mineralogy of the fine earth fractions. Mutual flocculation between negatively and positively charged surfaces in highly weathered soils can also lead to well-aggregated structure (El-Swaify and Emerson, 1975). Oxides and hydroxides of Fe and Al, when present in adequate amounts, are known to bind the smaller particles into larger aggregates as a continuous matrix.

The availability of nutrients, water, and oxygen for optimum plant growth is influenced by soil structure and texture. In soils with good structure, texture does not seem to be as good an indicator of soils-water characteristics, or its air-water relationship, as structure.

## Frexeiras Sandy Clay Loam (Brazil)

Classification: Typic Paleudults, isohyperthermic. Red-Yellow Podzolic Dystrophic (Epialic), latosolic moderate A horizon loamy/clayey semi-evergreen tropical forest hilly. Location: Highway BR-101, roadsign km 57.8, in a roadbank on right side of highway, in a sugarcane trail. Frexeiras, Alagoas. Sampling Date: March 9, 1977. Vegetation: Primitive--semi-evergreen tropical forest. Present use is sugarcane crop. Climate: Udic, isohyperthermic. Parent material: Gneiss. Precambrian complex. Weathering residues of given rock somewhat influenced by detrital coverage. Physiography and Slope: At lower third of hillside, 27 - 30% slope, under sugarcane. Relief hilly. Elevation: 130 meters. Drainage: Well drained. Erosion: Sheet erosion, moderate. Remarks: Termites and ants activity in Ap, A3, B1t and B21t. Profile described moist. Source: Soil Study Tour Guide. International Soil Classification Workshop, Brazil (1977).

| Horizon | Description |
|---|---|
| Ap | 0 to 22 cm; dark grayish brown (10YR 4/2, moist), grayish brown (10YR 5/2, dry) sandy clay loam; moderate fine granular and very fine and fine subangular blocky; many fine and very fine, and few medium and coarse pores; firm, plastic, sticky; common roots; occurrence of coal; clear smooth boundary. |
| A3 | 22 to 37 cm; dark brown (10YR 4/3, moist), yellowish brown (10YR 5/4, dry) sandy clay; weak fine subangular and angular blocky; common very fine and fine, and few coarse pores; firm, very plastic, sticky; few roots; fine iron concretions; clear smooth boundary. |
| B1t | 37 to 68 cm; strong brown (7.5YR 5/6, moist), common fine and distinct mottles of brownish yellow (10YR 6/8, moist) clay; weak fine angular and subangular blocky; common very fine and fine, and few coarse pores; few weak clay films; firm, plastic, sticky; few roots; fine iron concretions; gradual smooth boundary. |
| B21t | 68 to 102 cm; strong brown (7.5YR 5/8, moist), common medium and distinct mottles of yellowish red (5YR 5/8, moist) clay; weak medium prismatic and moderate fine angular and subangular blocky; common very fine and fine, and few coarse pores; common weak clay films; firm, plastic, sticky; very few roots; diffuse smooth boundary. |
| B22t | 102 to 154 cm; red (2.5YR 4/6, moist), few medium and prominent mottles of reddish yellow (7.5YR 6/8, moist) clay; moderate medium prismatic and strong fine subangular and angular blocky; common very fine and few coarse pores; common weak clay films; firm, plastic, sticky; very few roots; fine iron concretions; gradual wavy boundary. |

| Horizon | Description |
|---|---|
| B23t | 154 to 214 cm; red (2.5YR 5/6, moist) and strong brown (7.5YR 5/8, moist) clay; weak medium prismatic and moderate fine subangular and angular blocky; common very fine and fine pores; few weak clay films; firm, plastic, sticky; very few roots; diffuse wavy boundary (40 - 62 cm). |
| B3t | 214 to 279 cm; red (2.5YR 4/6, moist) clay (micaceous); weak medium prismatic and moderate fine subangular and angular blocky; firm, slightly plastic, slightly sticky. |

Table 3. Laboratory data of the Frexeiras sandy clay loam

| Depth | Horizon | Particle Size Analysis |  |  | Bulk Density | Water Content |  |  | Org C | Tot N | C/N | Extr Iron |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Sand | Silt | Clay |  | .1-bar | .3-bar | 15-bar |  |  |  | Fe | $Fe_2O_3$ |
| --cm-- |  | -----Pct LT 2 mm------ |  |  | --g/cc-- | --------pct--------- |  |  | pct | pct |  | -----pct------ |  |
| 0-22 | Ap | 60.3 | 11.4 | 28.3 |  |  |  | 13.10 | 1.60 | 0.094 | 17 |  |  |
| 22-37 | $A_3$ | 55.7 | 9.6 | 34.7 |  |  |  | 15.50 | 1.27 | 0.075 | 17 |  |  |
| 37-68 | $B_{1t}$ | 42.5 | 11.0 | 46.5 |  |  |  | 20.30 | 0.55 | 0.053 | 10 |  |  |
| 68-102 | $B_{21t}$ | 28.8 | 13.4 | 57.8 |  |  |  | 25.80 | 0.56 |  |  |  |  |
| 102-154 | $B_{22t}$ | 29.4 | 19.6 | 51.0 |  |  |  | 24.50 | 0.35 |  |  |  |  |
| 214-270 | $B_{3t}$ | 34.2 | 23.5 | 42.3 |  |  |  | 21.6 | 0.14 |  |  |  |  |

| Depth | Extr Bases |  |  |  |  | Extr Acid | Cat Exch Cap |  | Extr Al | Base Sat |  | pH |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Ca | Mg | Na | K | Sum |  | $NH_4OAc$ | Sum |  | $NH_4OAc$ | Sum | $H_2O$ | KCl | Diff |
| --cm-- | -------------------------------meq/100 g soil---------------------------------- |  |  |  |  |  |  |  |  | -------pct------ |  |  |  |  |
| 0-22 | 0.3 | 0.5 | 0 | 0.2 | 1.0 | 8.0 | 7.6 | 9.0 | 1.3 | 13 | 11 | 4.6 | 4.0 | -0.6 |
| 22-37 | 0.1 | 0.2 | 0 | 0.1 | 0.4 | 7.4 | 663 | 7.8 | 1.2 | 6 | 5 | 4.4 | 3.9 | -0.5 |
| 37-68 | 0.1 | 0.5 | 0 | 0.1 | 0.7 | 6.6 | 6.8 | 7.3 | 0.7 | 10 | 10 | 4.5 | 4.1 | -0.4 |
| 68-102 | 0.1 | 0.9 | 0 | 0.2 | 1.2 | 5.8 | 4.8 | 7.0 | 0.2 | 25 | 17 | 5.1 | 4.6 | -0.5 |
| 102-154 | 0.1 | 1.2 | 0 | 0.1 | 1.4 | 5.2 | 4.4 | 6.6 | 0.1 | 32 | 21 | 5.4 | 4.7 | -0.7 |
| 214-270 | tr | 0.4 | 0 | 0.1 | 0.5 | 5.3 | 4.7 | 5.8 | 0.9 | 11 | 9 | 5.2 | 4.4 | -0.8 |

## Barombi-Kang Clay (Cameroon)

Classification: Typic Paleudults, clayey, kaolinitic, isohyperthermic. Location: Barombi-Kang Experiment Station, ONAREST. Sampling Date: 1977. Described and Collected by: G. W. van Barneveld, H. E. Verwey, T. Nyobe, and J. Akwar, FAO Soil Resources Project, Ekona. Vegetation: Experimental coffee. Climate: Udic (2460 mm rainfall), isohyperthermic. Parent Material: Basalt. Physiography and Slope: Slightly undulated old volcanic surfaces around Kumba; 1 to 3 percent slopes. Elevation: 180 meters. Drainage: Well drained; medium runoff; moderate permeability. Source: G. W. van Barneveld, FAO Soil Resources Project, Ekona.

| Horizon | Description |
|---|---|
| A11 | 0 to 8 cm; dark brown to brown (10YR 4/3) moist, and dark yellowish brown (10YR 4/4) dry clay; moderate medium subangular blocky and granular structures; friable, slightly sticky, slightly plastic; common fine roots; common very fine and fine medium pores; slightly acid; charcoal fragments; clear smooth boundary. |
| A12 | 8 to 17 cm; dark yellowish brown (10YR 4/4) moist, and yellowish brown (10YR 5/4) dry clay; moderate medium subangular to angular blocky structures; friable, sticky, plastic; common fine roots; common fine and few medium pores; acid; few charcoal fragments; clear, smooth boundary. |
| B1 | 17 to 37 cm; dark yellowish brown to yellowish brown (10YR 4/4 to 5/4) moist, and yellowish brown (10YR 5/5) dry clay; moderate to weak angular to subangular blocky structures; friable, sticky, plastic; thin discontinuous clay films on ped surfaces; few fine and medium roots; common fine and few medium pores; acid; few very fine ferrugenous concretions (sand size); very few charcoal fragments; gradual smooth boundary. |
| B21 | 37 to 75 cm; yellowish brown (10YR 5/5) moist and dry (10YR 5/6 clay; very weak to weak medium prisms breaking into weak medium angular blocky structure; friable to firm, sticky, plastic; common thin continuous and discontinuous clay films on ped surfaces; very few fine and medium roots; common fine and few medium pores; acid; few very fine and fine ferrugenous concretions (sand size); diffuse smooth boundary. |
| B22 | 75 to 250 cm; yellowish brown (10YR 5/6) moist and dry (10YR 5/7) clay; weak medium and coarse angular blocky structure; friable, sticky, plastic; few thin discontinuous clay films on ped surfaces; very few fine roots; few fine and medium pores; acid; very few very fine and fine ferrugenous concretions (sand size). |

Table 4. Laboratory data of the Barombi-Kang clay

| | | Particle Size Analysis | | | Bulk | Water Content | | | Org | Tot | | Extr Iron | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | Horizon | Sand | Silt | Clay | Density | .1- bar | .3- bar | 15- bar | C | N | C/N | Fe | $Fe_2O_3$ |
| --cm-- | | ------Pct LT 2 mm------ | | | --g/cc-- | --------pct-------- | | | pct | pct | | -----pct----- | |
| 0-8 | $A_{11}$ | 15.2 | 17.7 | 67.2 | | | | | 2.53 | | | 6,69 | 9.56 |
| 8-15 | $A_{12}$ | 13.2 | 17.0 | 69.8 | | | | | 2.19 | | | 5.25 | 7.51 |
| 17-37 | $B_1$ | 8.3 | 14.1 | 77.5 | | | | | 0.86 | | | 6.78 | 9.69 |
| 45-65 | $B_{21}$ | 7.1 | 11.3 | 81.6 | | | | | 0.56 | | | 7.46 | 10.67 |
| 90-110 | $B_{22}$ | 5.6 | 9.3 | 85.1 | | | | | 0.31 | | | 5.50 | 7.86 |
| 110-120 | $B_{223}$ | 4.7 | 9.4 | 85.8 | | | | | 0.25 | | | 7.15 | 10.22 |
| 150-185 | $B_{224}$ | 4.0 | 11.6 | 84.4 | | | | | 0.13 | | | 6.35 | 9.08 |

| | Extr Bases | | | | | Extr | Cat Exch Cap | | Extr | Base Sat | | pH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | Ca | Mg | Na | K | Sum | Acid | $NH_4OAc$ | Sum | Al | $NH_4OAc$ | Sum | $H_2O$ | KCl | Diff |
| --cm-- | --------------------------------meq/100 g soil-------------------------------- | | | | | | | | | ------pct------ | | | | |
| 0-8 | 8.06 | 1.62 | 0.07 | 0.33 | 10.08 | 11.23 | 19.12 | 19.22 | 0.04 | 53 | 52 | 5.47 | 4.83 | -0.64 |
| 8-15 | 6.47 | 1.43 | 0.04 | 0.19 | 8.13 | 12.95 | 17.36 | 21.08 | 0.05 | 47 | 38 | 5.50 | 4.97 | -0.53 |
| 17-37 | 1.48 | 0.94 | 0.02 | 0.26 | 2.70 | 13.91 | 9.99 | 16.61 | 0.12 | 27 | 16 | 4.51 | 4.36 | -0.15 |
| 45-65 | 2.62 | 0.96 | 0.05 | 0.04 | 3.67 | 11.25 | 8.60 | 14.92 | 0.10 | 43 | 24 | 4.78 | 4.74 | -0.04 |
| 90-110 | 1.32 | 0.96 | 0.01 | 0.04 | 2.32 | 10.66 | 8.24 | 12.98 | 0.04 | 28 | 18 | 5.02 | 4.80 | -0.22 |
| 110-120 | 0.96 | 0.72 | 0.01 | 0.05 | 1.74 | 9.32 | 8.20 | 11.06 | 0.13 | 21 | 16 | 5.03 | 4.52 | -0.55 |
| 150-185 | 1.17 | 0.81 | 0.09 | 0.04 | 2.11 | 10.26 | 9.08 | 12.37 | 0.06 | 23 | 17 | 4.91 | 4.71 | -0.20 |

# Kolahun Sandy Clay Loam (Liberia)

Classification: Typic Paleudults, clayey, kaolinitic, isohyperthermic. Location: Type location is Lofa County, Liberia, approx. 0.5 mile north of Foya Kamara. See Profile 66 location on Foya Development Map, Soil Div. Vegetation: Most of these soils are in secondary forest and are farmed at intervals to rice and cassava. Small areas are in bananas, plantains, citrus, coffee, cacao, and oil palm. Considerable acreages are in rubber. All of these crops are well suited to the Kolahun soils. The rest of the acreages are in virgin forest. Climate: Mean annual precipitation is about 2000 to 2500 mm (80 to 100 inches) and mean annual air temperature is about 26 degrees C (79 degrees F). Physiography and Slope: Kolahun soils are on gently sloping to sloping uplands. Slopes range from 0 to 8 percent. Drainage: Well drained. Runoff is slow to medium. Permeability is moderately slow. Source: Soil Series Descriptions and Classification of the Soils of Liberia. Soil Div., Ministry of Agriculture, Government of Liberia, and U. S. Agency for International Development. July, 1977. 84 pp.

| Horizon | Description |
|---|---|
| A1 | 0 to 15 cm; very dark grayish brown (10YR 3/2) sandy clay loam; weak subangular blocky structure; friable, slightly sticky; many roots, few insect cavities; few pores; strongly acid; gradual smooth boundary. |
| A3 | 15 to 28 cm; brown (10YR 5/3) sandy clay; moderate medium subangular blocky structure; friable, slightly sticky; many roots; few pores; few insect cavities; patchy clay films; strongly acid; gradual smooth boundary. |
| B21t | 28 to 36 cm; yellowish red (5YR 5/6) sandy clay; moderate medium subangular blocky structure; friable, slightly sticky; common roots; common fine and medium pores; few insect cavities; patchy clay films; strongly acid; gradual smooth boundary. |
| B22t | 36 to 61 cm; yellowish red (5YR 5/8) sandy clay; moderate medium subangular blocky structure; friable, slightly sticky; common medium and coarse irregular quartz grains; few roots; few insect burrows; patchy clay films; strongly acid; gradual smooth boundary. |
| B23t | 62 to 84 cm; yellowish red (5YR 5/6) sandy clay; moderate medium subangular blocky structure; friable, slighly sticky; 5 to 10 percent quartz and ironstone pebbles 8 to 15 mm in diameter; patchy clay films; strongly acid; gradual smooth boundary. |

| Horizon | Description |
|---|---|
| B24t | 84 to 178 cm; yellowish red (5YR 5/8) sandy clay; moderate medium subangular blocky structure; friable, slightly sticky; few very fine roots; patchy clay films; strongly acid; few scattered masses of plinthite. |

Table 5. Laboratory data of the Kolahun sandy clay loam

| Depth | Horizon | Particle Size Analysis<br>Sand | <br>Silt | <br>Clay | Density | Water Content<br>.1-bar | <br>.3-bar | <br>15-bar | Org C | Tot N | C/N | Extr Iron<br>Fe | <br>$Fe_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| --cm-- | | ------Pct LT 2 mm------ | | | --g/cc-- | --------pct-------- | | | pct | pct | | -----pct----- | |
| 0-15 | $A_1$ | 60.8 | 10.5 | 28.7 | | | | 12.4 | 1.93 | | | 2.1 | 3.0 |
| 36-61 | $B_{22t}$ | 51.3 | 10.7 | 38.7 | | | | 12.6 | 0.83 | | | 2.6 | 3.7 |
| 84-178 | $B_{24t}$ | 45.0 | 15.1 | 39.9 | | | | 14.1 | 0.30 | | | 3.3 | 4.7 |

| Depth | Extr Bases<br>Ca | <br>Mg | <br>Na | <br>K | <br>Sum | Extr Acid | Cat Exch Cap<br>$NH_4OAc$ | <br>Sum | Extr Al | Base Sat<br>$NH_4OAc$ | <br>Sum | pH<br>$H_2O$ | <br>KCl | <br>Diff |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| --cm-- | ------------------------------meq/100 g soil------------------------------ | | | | | | | | | -----pct------ | | | | |
| 0-15 | 1.1 | 0.3 | 0 | 0.1 | 1.5 | 12.5 | 10.5 | 14.0 | 0.5 | | 11 | 5.1 | 4.0 | -1.1 |
| 36-61 | 0.3 | 0.0 | 0 | 0.1 | 0.4 | 6.0 | 4.4 | 6.4 | 0.6 | | 6 | 5.2 | 4.0 | -1.2 |
| 84-178 | 0.3 | 0.0 | 0 | 0.1 | 0.4 | 5.4 | 2.5 | 5.8 | 0.7 | | 17 | 5.5 | 4.3 | -1.2 |

## Lanchang Clay Loam (Malaysia)

Classification: Typic Paleudults, clayey, isohyperthermic. Location: Lanchang - Kg. Balok Rd., Temerloh District, Malaysia. Vegetation: Secondary jungle. Parent Material: Granodiorite. Physiography and Slope: Undulating topography; 6 percent. Elevation: 50 meters. Drainage: Well drained. Source: Characteristics of Some Soils in Peninsular Malaysia. Malaysian Soc. of Soil Science, Kuala Lumpur. Aug. 1977.

| Horizon | Description |
|---|---|
| Ap | 0 to 15 cm; dark yellowish brown (10YR 4/4) clay loam; strong crumb and some fine medium subangular blocky; very friable; many fine and medium roots; many pores; many charcoal fragments; gradual wavy boundary. |
| B1t | 15 to 33 cm; yellowish brown (10YR 5/6) clay; weak to moderate, medium and coarse subangular blocky breaking to medium and fine granules; friable; patchy discontinuous clayskins on ped faces and continuous along root channels; many fine and medium roots; many pores; few termite nests; diffuse boundary. |
| B21t | 33 to 58 cm; yellowish brown (10YR 5/8) clay; coarse and medium subangular blocky; friable; discontinuous to continuous clayskins on large ped faces and along root channels; many fine roots; few channels; many pores, diffuse boundary. |
| B22t | 58 to 89 cm; yellowish brown (10YR 5/8) clay; moderate to strong, medium and fine subangular blocky breaking to fine subangular blocky; friable; patchy to discontinuous clayskins on larger ped faces; few fine and medium roots; many pores; few channels; diffuse boundary. |
| B23t | 89 to 120 cm; yellowish brown (10YR 5/8) clay; moderate coarse and medium subangular blocky; friable; discontinuous to continuous clayskins on large ped faces; few coarse and medium roots; few pores; no channels; diffuse boundary. |
| B24t | 120 to 167 cm; yellowish brown (10YR 5/8) clay; moderate coarse and medium subangular blocky; friable to slightly firm; discontinuous to continuous clayskins on large ped faces; few fine roots; no channels; few pores; diffuse boundary. |
| B25t | 167 to 210 cm; reddish yellow (7.5YR 6/8) clay with few indistinct fine yellowish red (5YR 5/8) mottles; moderate coarse and medium subangular blocky; friable to slightly firm; discontinuous to continuous clayskins on large ped faces; few fine roots; no channels; few pores; diffuse boundary. |

| Horizon | Description |
|---|---|
| B3t | 210 to 237 cm; reddish yellow (7.5YR 6/8) clay with few fine and medium distinct yellowish red (5YR 5/8) and brownish yellow (10YR 6/8) mottles; moderate and coarse medium and fine subangular blocky; friable to slightly firm; discontinuous to continuous clayskins on larger ped faces; very few fine roots; no channels; few pores; sharp boundary. |
| C(R) | 237 to 250 cm; weathering parent material with some weathered feldspars and few iron-coated quartz gravel. Matrix color strong brown (7.5YR 5/8); massioc structure. |

Table 6. Laboratory data of the Lanchang clay loam

| Depth | Horizon | Particle Size Analysis |  |  | Bulk Density | Water Content |  |  | Org C | Tot N | C/N | Extr Iron |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Sand | Silt | Clay |  | .1-bar | .3-bar | 15-bar |  |  |  | Fe | $Fe_2O_3$ |
| --cm-- |  | -------Pct LT 2 mm------ |  |  | --g/cc-- | --------pct-------- |  |  | pct | pct |  | ------pct------ |  |
| 0-15 | Ap | 42.9 | 21.9 | 35.2 |  |  |  |  | 2.33 | 0.20 | 12 | 6.80 | 9.72 |
| 15-33 | $B_{1t}$ | 30.1 | 19.0 | 50.9 |  |  |  |  | 0.93 | 0.14 | 7 | 7.41 | 10.59 |
| 33-58 | $B_{21t}$ | 26.3 | 15.5 | 58.2 |  |  |  |  | 0.77 | 0.11 | 7 | 7.96 | 11.23 |
| 58-89 | $B_{22t}$ | 24.4 | 14.3 | 61.3 |  |  |  |  | 0.54 | 0.10 | 5 | 8.22 | 11.75 |
| 89-120 | $B_{23t}$ | 24.3 | 11.8 | 63.9 |  |  |  |  | 0.25 | 0.07 | 4 | 7.93 | 11.34 |
| 120-167 | $B_{24t}$ | 23.0 | 13.4 | 63.6 |  |  |  |  | 0.22 | 0.06 | 4 | 8.23 | 11.77 |
| 167-210 | $B_{25t}$ | 21.8 | 11.5 | 66.7 |  |  |  |  | 0.15 | 0.05 | 3 | 8.52 | 12.18 |
| 210-250 | $B_{3t}$ | 20.0 | 14.7 | 65.3 |  |  |  |  | 0.21 | 0.04 | 5 | 8.91 | 12.74 |
| 237-250 |  | 33.9 | 19.0 | 47.1 |  |  |  |  | 0.14 | 0.03 | 5 | 9.97 | 14.25 |

| Depth | Extr Bases |  |  |  |  | Extr Acid | Cat Exch Cap |  | Extr Al | Base Sat |  | pH |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Ca | Mg | Na | K | Sum |  | $NH_4OAc$ | Sum |  | $NH_4OAc$ | Sum | $H_2O$ | KCl | Diff |
| --cm-- | ----------------------------------------------meq/100 g soil---------------------------------------------- |  |  |  |  |  |  |  |  | ------pct----- |  |  |  |  |
| 0-15 | 0.25 | 0.27 | 0.08 | 0.18 | 0.78 | 15.28 | 8.64 | 16.06 | 2.9 | 9 | 5 | 3.5 | 3.4 | -0.1 |
| 15-33 | 0.04 | 0.06 | 0.03 | 0.16 | 0.29 | 8.88 | 5.68 | 9.17 | 2.3 | 5 | 3 | 3.8 | 3.7 | -0.1 |
| 33-58 | 0.04 | 0.06 | 0.03 | 0.06 | 0.19 | 8.08 | 5.53 | 8.27 | 2.1 | 3 | 2 | 4.0 | 3.6 | -0.4 |
| 58-89 | 0.07 | 0.06 | 0.05 | 0.03 | 0.21 | 6.88 | 4.72 | 7.09 | 1.7 | 4 | 3 | 4.5 | 3.8 | -0.7 |
| 89-120 | 0.08 | 0.10 | 0.05 | 0.05 | 0.28 | 6.08 | 4.36 | 6.36 | 1.4 | 6 | 4 | 4.6 | 4.0 | -0.6 |
| 120-167 | 0.07 | 0.03 | 0.03 | 0.03 | 0.16 | 5.10 | 4.12 | 5.26 | 0.6 | 4 | 3 | 4.9 | 4.4 | -0.5 |
| 167-210 | 0.10 | 0.04 | 0.03 | 0.03 | 0.20 | 4.60 | 4.40 | 4.80 | 0.6 | 4 | 4 | 5.2 | 4.4 | -0.8 |
| 210-237 | 0.07 | 0.03 | 0.03 | 0.04 | 0.17 | 4.88 | 4.20 | 5.05 | 0.6 | 4 | 3 | 5.3 | 4.8 | -0.5 |
| 237-250 | 0.05 | 0.02 | 0.03 | 0.05 | 0.15 | 4.10 | 3.40 | 4.25 | 0.4 | 4 | 3 | 5.3 | 4.5 | -0.8 |

## Tugbok Clay Loam (Philippines)

Classification: Typic Paleudults, clayey, kaolinitic, isohyperthermic. Location: Approx. 300 meters from arboretum to the center of Lot 9, Bur. of Plant Industry Experiment Sta. at San Gabrial, Davao City, Mindanao, The Philippines. Approx. 25 km from Davao City proper. Sampling Date: Mar. 17, 1977. Described and collected by Valmidiano, M. D. Yacas, and B. G. Cagauan, Jr. Vegetation: Newly plowed; normally used for the production of seeds of maize and upland rice. Adjoining fields are planted to abaca. Climate: Udic, isohyperthermic. Parent Material: Andesite. Physiography and Slope: Lower part of volcanic piedmont plain; gently slopping; 2 percent with 3 to 5 percent across. Elevation: Approx. 200 meters. Drainage: Well drained. Erosion: Slight. Remarks: Colors are for moist soil. Source: Bureau of Soils, Dept. of Agriculture, The Philippines.

| Horizon | Description |
|---|---|
| Ap | 0 to 18 cm; black (5YR 2.5/1) clay loam; weak, fine and medium subangular blocky structure parting to moderate fine granular; slightly firm, slightly sticky, plastic; common fine roots; clear smooth boundary. |
| B21t | 18 to 37 cm; dark reddish brown (5YR 3/2) moist, (5YR 4/3) dry clay; moderate to strong coarse and medium subangular blocky structure; firm, sticky, plastic; common fine roots; common fine pores; moderately thick patchy clay films on ped faces; gradual smooth boundary. |
| B22t | 37 to 74 cm; dark reddish brown (5YR 3/3) moist, (5YR 4/3) dry clay; moderate coarse and medium subangular blocky structure; firm, sticky, plastic; few fine roots; common fine pores; few termite holes; thick clay films on ped faces; gradual smooth boundary. |
| B23t | 74 to 100 cm; dark reddish brown (5YR 3/3) moist, (5YR 4/4) dry clay; moderate medium subangular blocky structure; firm, sticky, plastic; common fine pores; few termite holes; thick clay films on ped faces; diffuse smooth boundary. |
| B24t | 100 to 140 cm; reddish brown (5YR 4/4) moist, dark brown (7.5YR 4/4) dry clay; moderate medium and fine subangular blocky structure; slightly firm, sticky, plastic; common fine pores and few coarse pores, few termite holes; thin and thick clay films on ped faces; diffuse smooth boundary. |
| B3t | 140 to 160 cm; reddish brown (5YR 4/4) moist, dark brown (7.5YR 4/4) dry clay; weak to moderate medium subangular blocky structure; slightly firm, sticky, plastic; common fine pores and few coarse pores; thin clay films on ped faces; gradual smooth boundary. |

| Horizon | Description |
|---|---|
| C | 160 to 200 cm; dark brown to brown structure; slightly firm, slightly sticky, plastic; few black (N 2/) Mn coating on ped faces; few partially weathered gravel and stone. |

Table 7. Laboratory data of the Tugbok clay loam

| | | Particle Size Analysis | | | | Water Content | | | Org | Tot | | Extr Iron | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | Horizon | Sand | Silt | Clay | Density | .1-bar | .3-bar | 15-bar | C | N | C/N | Fe | $Fe_2O_3$ |
| --cm-- | | ------Pct LT 2 mm------- | | | --g/cc-- | --------pct-------- | | | pct | pct | | ------pct------ | |
| 0-18 | Ap | 17.8 | 21.8 | 60.4 | | | | | 1.49 | 0.18 | 8 | 4.94 | 7.06 |
| 18-37 | $B_{21t}$ | 15.8 | 10.8 | 73.4 | | | | | 0.56 | 0.11 | 5 | 5.29 | 7.56 |
| 37-74 | $B_{22t}$ | 7.8 | 15.2 | 77.0 | | | | | 0.48 | 0.10 | 5 | 5.84 | 8.35 |
| 74-100 | $B_{23t}$ | 0.8 | 10.8 | 88.4 | | | | | 0.48 | 0.07 | 7 | 6.15 | 8.79 |
| 100-140 | $B_{24t}$ | 0.0 | 7.6 | 92.4 | | | | | 0.41 | 0.06 | 7 | 5.97 | 8.54 |
| 140-160 | $B_{3t}$ | 0.0 | 9.6 | 90.4 | | | | | 0.37 | 0.06 | 6 | 5.97 | 8.54 |
| 160-200 | C | 2.8 | 17.8 | 79.4 | | | | | 0.28 | 0.04 | 7 | 5.95 | 8.51 |

| | Extr Bases | | | | | Extr | Cat Exch Cap | | Extr | Base Sat | | pH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth | Ca | Mg | Na | K | Sum | Acid | $NH_4OAc$ | Sum | Al | $NH_4OAc$ | Sum | $H_2O$ | KCL | Diff |
| --cm-- | ------------------------------meq/100 g soil------------------------------ | | | | | | | | | ------pct----- | | | | |
| 0-18 | 7.49 | 1.84 | 0.06 | 1.98 | 11.37 | 9.13 | 20.58 | 20.50 | 0.06 | 55 | 55 | 5.05 | 4.40 | -0.55 |
| 18-37 | 3.70 | 1.74 | 0.18 | 0.66 | 6.28 | 11.94 | 19.26 | 18.22 | 3.30 | 33 | 34 | 4.82 | 3.79 | -1.03 |
| 37-74 | 2.24 | 1.79 | 0.19 | 0.46 | 4.68 | 12.79 | 20.28 | 17.47 | 3.97 | 23 | 27 | 4.69 | 3.62 | -1.07 |
| 74-100 | 2.75 | 1.98 | 0.02 | 0.37 | 5.30 | 12.94 | 24.62 | 18.24 | 4.08 | 22 | 29 | 4.61 | 3.56 | -1.05 |
| 100-140 | 3.17 | 1.86 | 0.26 | 0.36 | 5.65 | 12.32 | 21.25 | 27.97 | 4.25 | 27 | 31 | 4.65 | 3.58 | -1.07 |
| 140-160 | 4.16 | 1.76 | 0.29 | 0.37 | 6.58 | 14.61 | 22.10 | 21.19 | 3.96 | 30 | 31 | 4.70 | 3.61 | -1.09 |
| 160-200 | 5.22 | 1.75 | 0.35 | 0.37 | 7.69 | 13.11 | 24.33 | 20.80 | 3.54 | 32 | 37 | 4.70 | 3.59 | -1.11 |

The surface horizons of the five soils have moderate fine granular structure to weak and moderate, very fine, fine, and medium subangular blocky structure. Most of the subsurface horizons have moderate, medium and fine subangular blocky structure. The Frexeiras and Barombi-Kang soils have some moderate fine angular and weak medium prismatic structures. Thus, these soils have favorable physical properties associated with the subangular blocky structure.

Particle size distribution--Particle size distribution refers to the percentages of sand, silt, and clay-size particles of the fine earth fraction (2 mm or less). The data of the five soils are presented in Tables 3 through 7.

In the Soil Taxonomy (Soil Survey Staff, 1975), the particle size class or the texture of control section is considered at the family category of classification. Soil texture is an explicit property which is related to implicity properties, such as, drainage, water and nutrient holding capacity, and soil aeration. Soil texture, furthermore is a non controllable property which influences, to some extent, other physical, chemical, and biological properties.

The data indicate that all of the soils used in this study belong to the clayey family of Soil Taxonomy (Tables 3 through 7). The surface texture of these soils, however, varies from a sandy clay loam, a clay loam, to clay (See soil descriptions). Table 8 shows that the clay content have high correlation with extractable acidity and cation exchange capacity. These results indicate that cation exchange capacity is related with clay content and that much of this clay is H-saturated.

Table 8. Matrix of linear correlation of the soil properties

|  | X1 Clay | X2 Org. C | X3 Total N | X4 Extr. Fe | X5 Extr. acid | X6 $NH_4$ CEC | X7 Sum CEC | X8 Extr. Al | X9 Sum BS | X10 pH $H_2O$ | X11 pH KCl | X12 Delta pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X1 | 1.00 | -.38* | -.33 | -.24 | .45** | .56** | .52** | .29 | .49** | .06 | .08 | .02 |
| X2 |  | 1.00 | .82** | -.34 | .42* | .23 | .42* | -.11 | .32 | -.14 | -.02 | .17 |
| X3 |  |  | 1.00 | -.42* | .27 | .58** | .55** | .15 | .18 | .03 | -.12 | -.14 |
| X4 |  |  |  | 1.00 | -.36* | -.31 | -.38* | .04 | -.32 | -.24 | .13 | .46** |
| X5 |  |  |  |  | 1.00 | .76** | .91** | .49** | .56** | -.35* | -.36* | -.01 |
| X6 |  |  |  |  |  | 1.00 | .92** | .59** | .85** | -.03 | -.32 | -.37 |
| X7 |  |  |  |  |  |  | 1.00 | .42* | .84** | -.11 | -.21 | -.11 |
| X8 |  |  |  |  |  |  |  | 1.00 | .16 | -.52** | -.86** | -.44* |
| X9 |  |  |  |  |  |  |  |  | 1.00 | .28 | .11 | -.20 |
| X10 |  |  |  |  |  |  |  |  |  | 1.00 | .72** | -.39* |
| X11 |  |  |  |  |  |  |  |  |  |  | 1.00 | .35* |
| X12 |  |  |  |  |  |  |  |  |  |  |  | 1.00 |

Total N and Extr. Fe, n = 19 and 26, respectively; others, n = 32
d.f. = n - 2 = 30; P .05, r = .349; P .01, r = .449
d.f. = n - 2 = 24; P .05, r = .388; P .01, r = .496
d.f. = n - 2 + 17; P .05, r = .456; P .01, r = .575

$NH_4$CEC = cation exchange capacity by ammonium acetate extraction; Sum CEC = cation exchange capacity by sum of cations; Sum BS = base saturation is sum of bases divided by Sum CEC; and delta pH = $pH_{KCl}$ - $pH_{H_2O}$

The clay distribution within the subsurface horizons, the argillic horizon, can be seen in Figure 3. The percentage of clay does not decrease from its maximum amount by more than 20 percent of that maximum within a prescribed depth. The soils, therefore, are classified as Paleudults rather than Tropudults.

Organic carbon and total nitrogen--The values of organic C and total N are also presented in Tables 3 through 7. Organic matter content may be calculated by multiplying the organic C values by a conversion factor of 1.724.

Within each profile, the organic C decreases with depth. The organic C content of the surface soil ranges from approximately 1.4 to 2.5 percent. These values, are not high enough to meet the requirements of the Humults and these soils are classified as Udults.

Table 7 shows that organic C is directly related to total N, extractable acid, and cation exchange capacity by sum of cations. According to Sanchez (1976), organic matter not only helps to reduce P-fixation and improve soil structure, but also to maintain the cation exchange capacity.

The total N similarly decreases with depth. The positive correlation between organic C and total N as expected is highly significant. The data represent three of the five profiles (n = 19).

Extractable iron--The extractable Fe ranges from 2 to 3 percent in Kolahum soil to as much as 7 to 8 percent in the Lanchang soil. The presence of free Fe is associated with highly weathered soils (Russell, 1973) and is also a function of the parent material. The parent material of the Kolahun soil is derived from an acidic igneous

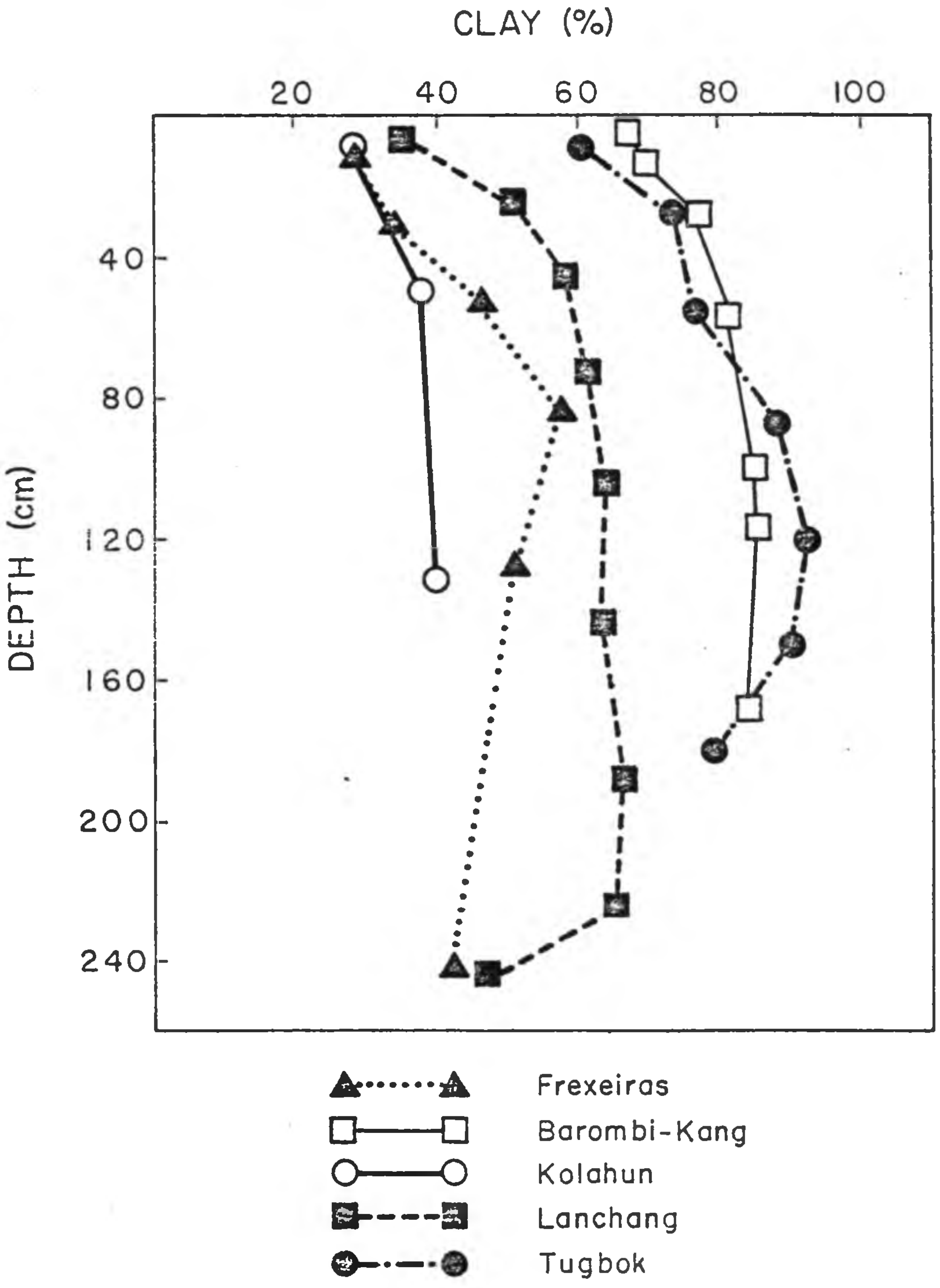

Figure 3. Clay distribution within the subsurface horizons of the five Typic Paleudults

rock, while that of the Lanchang soil is derived from an intermediate extrusive igneous rock.

Table 8 shows a highly significant correlation between the extractable Fe and delta pH. There is also significant correlation between extractable Fe and extractable acidity. The correlation matrix does not include the extractable Fe data of the Frexeiras soil as they were not available. Although the extractable $Fe_2O_3$ is as high as 10 to 11 percent in the Barombi-Kang soil and 11 to 12 percent in the Lanchang soil, it is not high enough to meet the requirements of the oxidic mineralogy in the family classification of the Soil Taxonomy. The five soils, therefore, are classified as a kaolinitic family.

The $Fe_2O_3$ value is obtained by multiplying the Fe value by a factor of 1.4297.

Extractable bases and extractable acidity--Tables 3 through 7 show that there is a tendency for the extractable bases to be higher in the surface soils than in the subsoils. Furthermore, the Barombi-Kang and Tugbok soils have a higher sum of bases than the other soils. These two soils also have higher extractable acidity than the others. In all five soils, the extractable acidity makes up a considerable portion of the pH-dependent charge exchange capacity (Figure 4).

Cation exchange capacity and base saturation--Tables 3 through 7 show the values of cation exchange capacity (CEC) as determined (1) by the neutral ammonium acetate extraction procedure and (2) by the sum of cations (Soil Survey Staff, 1975). Except for the Tugbok soil, the other soils show a higher CEC by both methods in the surface soils

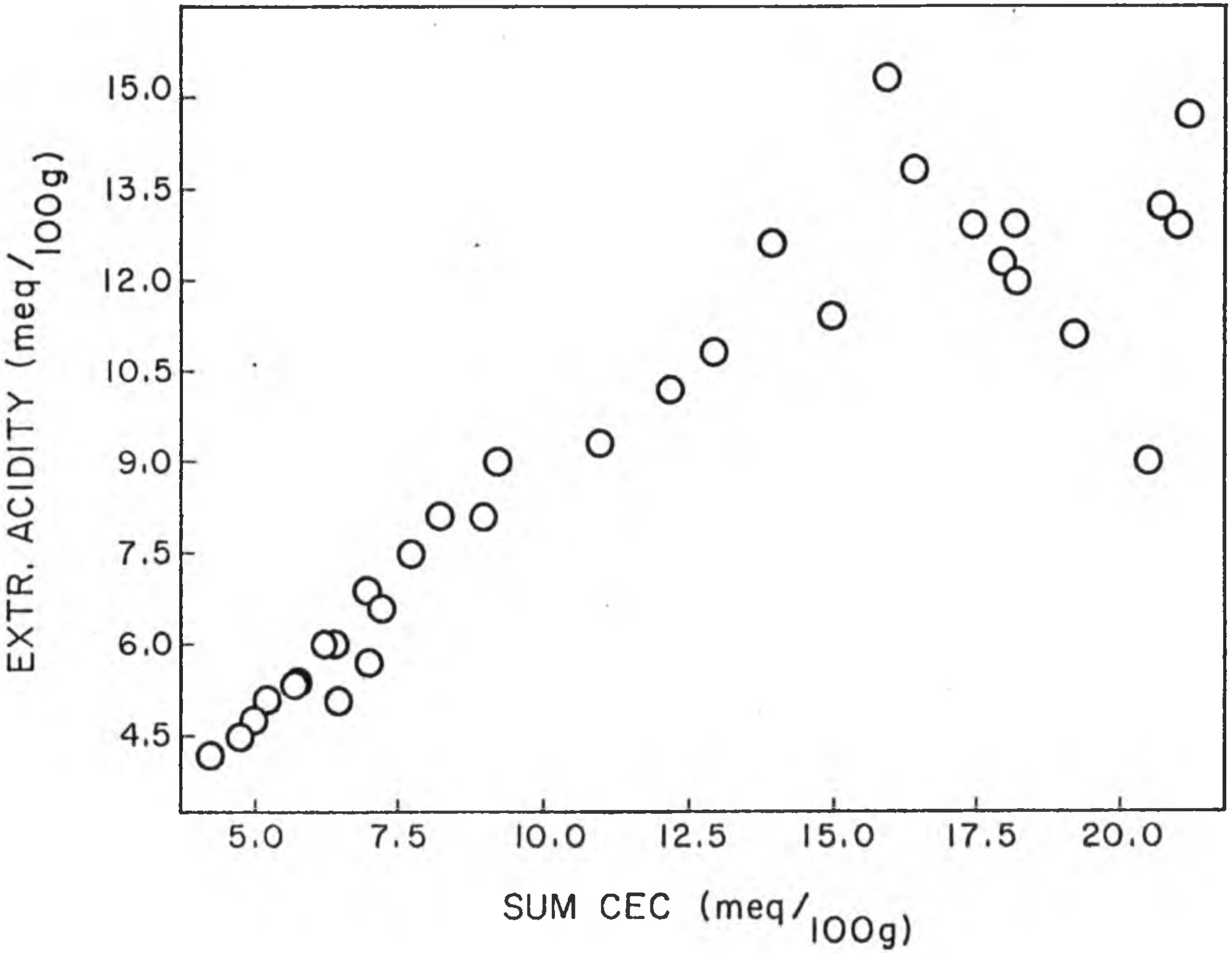

Figure 4. Relationship between extractable acidity and the cation exchange capacity (sum of cations)

than in the subsoils. Again, except for the Tugbok soil, which shows similar values by the two methods, the other soils show the CEC by the sum of cations to be higher than the CEC by ammonium acetate. Table 8 further shows that the correlation of the values as determined by the two methods to be highly significant ($r = 0.91$). Such findings suggest that CEC can be determined by only one method instead of by two methods.

In this study, the Barombi-Kang and Tugbok soils are soils with "high CEC," while the Frexeiras, Kolahun, and Lanchang soils are soils with "low CEC."

The base saturation is in turn significantly correlated with CEC. That is, the soils with the high CEC also have high base saturation and those with low CEC have low base saturation. All of the base saturation values at the prescribed soil depth are less than 35 percent and thus meet one of the general requirements of the Ultisols. The base saturation is also significantly correlated with extractable acid.

<u>Extractable aluminum and soil acidity</u>--Extractable Al interferes with the uptake of water and the uptake and translocation of nutrient elements (Rio and Pearson, 1964; Evans and Kamprath, 1970). The acidity of mineral soils are due to the $H^+$ released from the hydrolysis of $Al^{3+}$ and related compounds. Below pH 5.5, $Al^{3+}$ becomes the principle cation exchange complex (Coleman and Thomas, 1967).

Table 8 shows that extractable Al is significantly correlated with extractable acid, CEC, and pH. Figure 5 shows a plot of extractable Al and pH. This relationship is in agreement with the

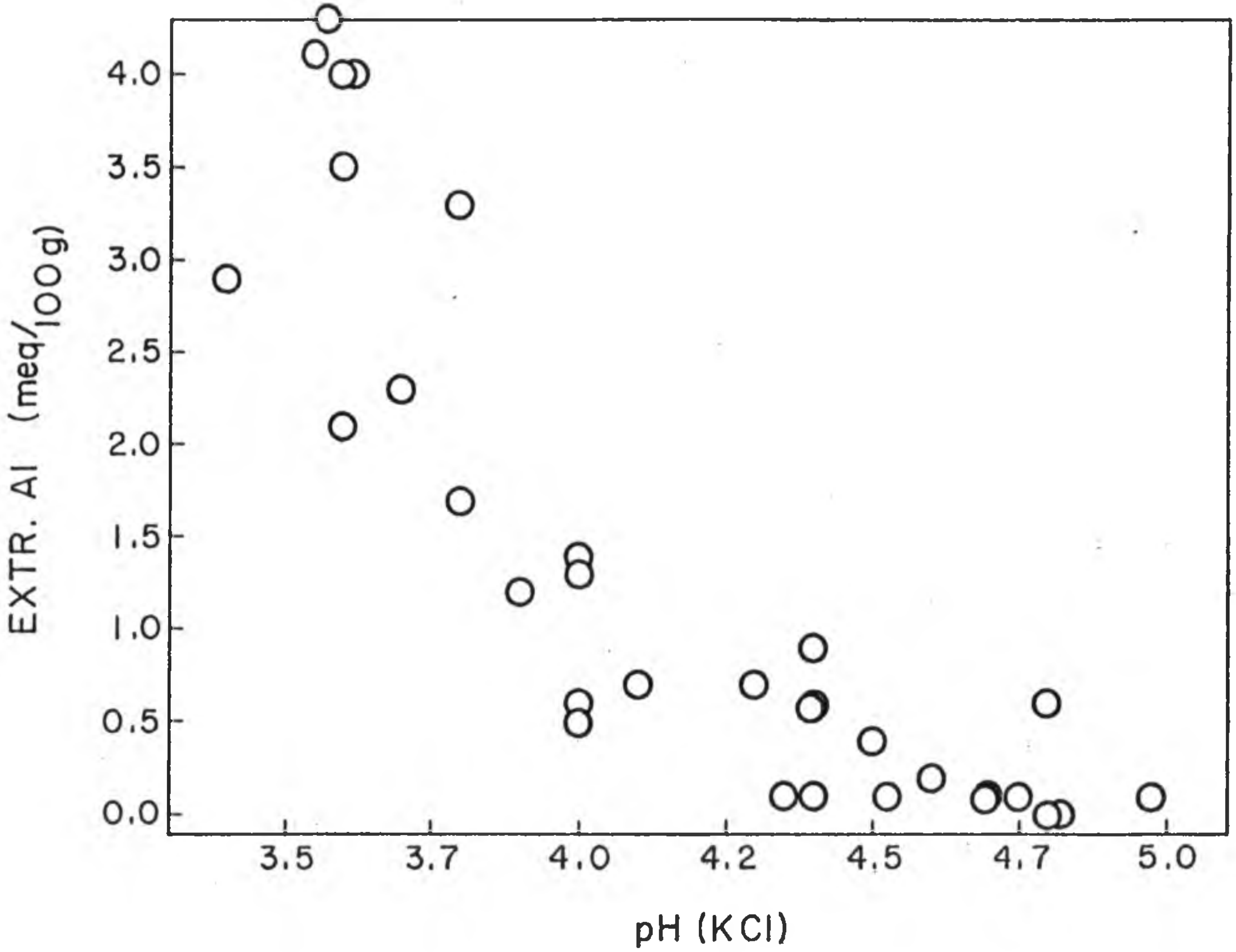

Figure 5. Relationship between extractable aluminum and pH in KCl

relationship in other Ultisols as reported in the literature as well as shown by unpublished data of Hawaii and Puerto Rico.

Figure 6 further shows that when extractable acidity ranges from about 9 to 13 meq, the extractable Al is low, less than 0.5 meq, mostly less than 0.2 meq. If extractable Al and acid are plotted against pH in $H_2O$, there is significant amount of extractable acid at about pH 5, although the extractable Al is generally quite low.

Delta pH is the difference of pH in KCl and in water. A negative delta pH value is an indication of negative net surface charge (Mekaru and Uehara, 1972). The pH in water ranges from 3.5 to 5.5 in the upper portion of the solum--being most acid in the Lanchang and Frexeiras soils.

## The Classification of the Soils

The occurrence of the soils in low to mid latitudes, the presence of argillic horizon, and a base saturation of less than 35 percent at 1.25 meters below the upper boundary of the argillic horizon or 1.8 meters below the soil surface classify these soils in the order Ultisols. The moisture control section, being dry for less than 90 days (cumulative), and the freely-drained, low humus profiles make these Ultisols as Udults. The absence of a lithic or paralithic contact, the presence of a thick argillic horizon with less than 10 percent weatherable minerals, and no plinthite forming a continuous phase classify these soils as Paleudults. The central concept of the Paleudults makes these soils Typic Paleudults. At the family level of classification, a clay content of more than 35 percent by weight in the fine earth fraction places these soils in the clayey

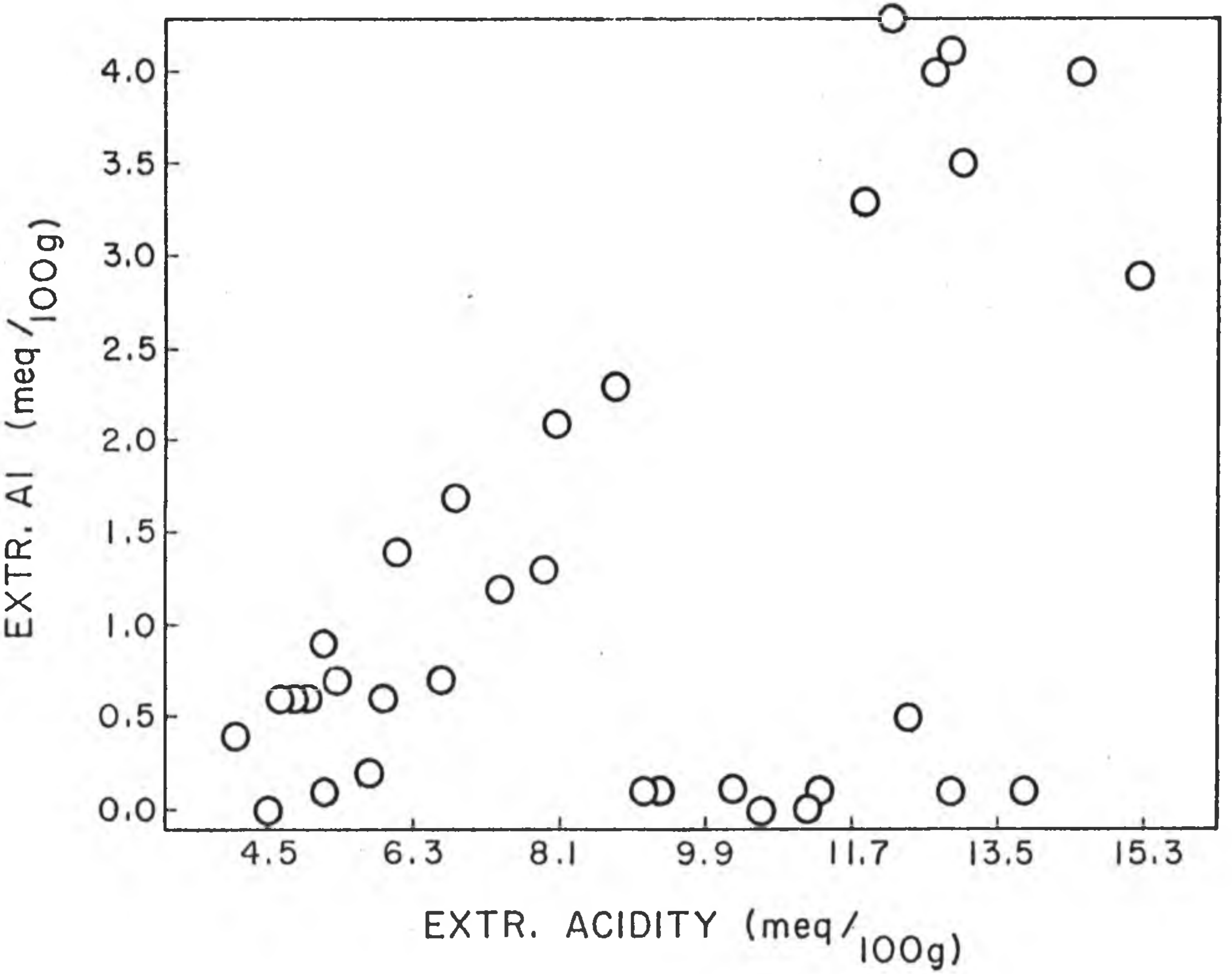

Figure 6. Relationship between extractable aluminum and extractable acidity

particle size class. The temperature regime of these soils is isohyperthermic. These soils are characterized by less than 5° C (9° F) difference between the mean summer and the mean winter soil temperatures and a mean annual soil temperature of 22° C (72° F) or higher.

Based on the above properties, the Frexeiras, Barombi-Kang, Kolahun, Lanchang, and Tugbok soil series are classified as the clayey, kaolinitic, isohyperthermic family of Typic Paleudults.

## The Range in the Characteristics of the Soils

No two profiles are ever alike precisely even within a given soil phase. The definitions of taxonomic units allow for ranges in characteristics such as color, reaction (pH), depth, texture, and so on. This section is intended to show allowable ranges in soil properties for the series class as currently conceived. In so far as practicable, quantitative limits are given for the ranges in properties. The ranges specified must fall within those of the family in which the series is classified (Soil Survey Staff, 1951).

Soil families are relatively homogeneous classes but have ranges in their properties wide enough to include soils that differ for many purposes. The significance of differences in properties among soil series of a family depends on the combinations of these properties. Consequently no specific property or group of properties has been selected, assigned limits, and applied consistently across families or groups of families as is done for the higher categories.

The range in characteristics of the five soil series used in this study is summarized in Table 9. There are important differences in

Table 9. Summary of the range in characteristics of the Typic Paleudults

| Frexeiras (Brazil) | Barombi-Kang (Cameroon) | Kolahun (Liberia) | Lanchang (Malaysia) | Tugbok (Philippines) |
|---|---|---|---|---|
| 1. Surface horizon is dark grayish brown (10YR 4/2) to dark brown (10YR 4/2); B horizon are strong brown (7.5YR 5/6, 5/6), red (2.5 YR 4/6, 5/6), with brownish yellow (10YR 6/8), yellowish red (5YR 5/8), and reddish yellow (7.5YR 6/8), mottles. | Surface horizons are dark brown to brown (10YR 4/3); B2 horizons are yellowish brown (10YR 5/5). | Surface horizons are very dark grayish brown (10YR 3/2) to brown (10YR 5/3); B2 horizons are yellowish red (5YR 5/6, 5/8). | Surface horizon is dark yellowish brown (10YR 5/6); B2 horizons are yellowish brown (10YR 5/8) to reddish yellow (7.5YR 6/8). | Surface horizon is black (5YR 2.5/1); B2 horizons are dark reddish brown (5YR 3/2, 3/3) and reddish brown (5YR 4/4). |
| 2. Cation exchange capacity of the subsoil ranges from 5 to 8 meq/100 g of soil. | Cation exchange capacity of the subsoil ranges from 11 to 15 meq/100 g of soil. | Cation exchange capacity of the subsoil ranges from 5 to 7 meq/100 g of soil. | Cation exchange capacity of the subsoil ranges from 4 to 9 meq/100 g of soil. | Cation exchange capacity of the subsoil ranges from 11 to 15 meq/100 g of soil. |
| 3. Sum of bases of the subsoil ranges from 0.5 to 1.5 meq. | Sum of bases range from 1 to 4 meq. | Sum of bases is less than 1 meq. | Sum of bases is less than 0.5 meq. | Sum of bases of the subsoil ranges from 4 to 7 meq. |

some of the properties of the five soil series. For example, the slope of the Frexeiras series differes from those of the other soil series although it did not affect the soil profile (Table 12). There are also textural differences in the surface horizons of these soils. Based on the range in characteristics of the five soil series, the Barombi-Kang series is selected as the most average series in the group.

## Crop Requirements

The cultivation of oil palm is confined to the low land areas of the humid equatorial regions because the crop requires a warm topic tropical climate and high rainfall. The oil palm has a high moisture requirement. Like all plants, the oil palm requires all the macro- and micronutrients but it has an especially high demand for N and K. The application of fertilizer at planting and a split application of N fertilizer during the first year can satisfy the N requirement. Potassium is essential for good growth in the juvenile period and during fruiting periods in the producing years (FAO, 1976; Werkhoven, 1966).

Soil qualities that influence the growth of oil palm include the availability of moisture, oxygen (drainage), nutrient, and energy. The soil qualities and the crop requirements for the production of oil palm are summarized in Table 10.

## Suitability of the Five Soil Series for Oil Palm

As mentioned in the introduction, one of the objectives of this study is to propose a soil suitability rating for the production of oil palm in the group of soils selected for this study. The suitability of soils for various uses is described in standard soil survey reports. Such reports provide the land user with information about soil behavior so that he can make appropriate decisions for utilization of the soils. When the method of determining soil suitability is fully developed, the soil survey report, which will include the suitability, is expected to become more useful.

The three-class system of rating soil suitability is essentially that proposed by the Soil Conservation Service, USDA. It must be stressed that the three-class system is intended to reflect the present fertility or behavior of the soils for a specific use. The parameters used to predict the suitability of the five soils for the production of oil palm could be considered as being either controllable or non controllable (Uehara and Ikawa, 1974). The former would be parameters that could be changed or managed by man (for example, pH, base saturation), while the latter would be parameters that normally could not be changed by man (for example, texture or slope).

Using the proposed procedure, the list of criteria, soil qualities, and ratings were prepared as Table 10, 11, 12, and 13. The rating of the five soils as good, fair, or poor for oil palm was made through the use of the above-mentioned tables and presented in Table 14. Table 14 shows that with the exception of the Frexeiras soil, all of the soils are rated good. The Barombi-Kang and Tugbok soils, however, rate slightly better than the Kolahun and Lanchang soils. The Frexeiras soil is rated fair on the basis of the slope (27-30 percent), not because slope affects moisture, but because slope also affects workability of the land.

Table 10. Land qualities and crop requirements for oil palm production

| Land Quality | Characteristics | Criteria |
|---|---|---|
| Moisture | Rainfall | 2,000 mm (80 inches)[1] |
| | Texture | Sandy clay loam to clay[2] |
| | Slope | <20 percent[2] |
| Drainage | Drainage | Moderately well drained[3] |
| | Depth | >0.9 meters (36 inches)[5] |
| | Structure | Blocky to prismatic[2] |
| Nutrient | N | 0.13%[1] |
| | P | 3 ppm[4] |
| | K | 0.15-0.2 meq/100 g soil[5] |
| | Reaction (pH) | 4 to 6[4] |
| | CEC | >3 meq/100 g soil[3] |
| | Elevation-max. | 180 meters (600 ft)[1] |
| Energy | Temperature-max. | 29°-32° C (85°-98° F)[1] |
| | Sunshine | 5 to 7 hrs/day or 1,500 hrs/yr[4] |

Sources:

[1] Hartley, C. W. 1967. The oil palm. Longmans. Bristol.

[2] Ng, S. K. 1968. Soil suitability for oil palm in west Malaysia.

[3] Werkhoven, J. 1966. The manuring of the oil palm. Hannover, Germany.

[4] FAO. 1976. Framework for land evaluation. Soils Bulletin No. 22. FAO, Rome.

[5] Corley et al. 1976. Oil palm research. Elsevier, Amsterdam.

Table 11. List of parameters to rate the suitability of the five Typic Paleudults for the production of oil palm

| Parameters | |
|---|---|
| Noncontrollable | Controllable |
| Climate | Moisture regime |
| Rainfall | Structure |
| Temperature | K content |
| Soil | Base Saturation |
| Slope | pH |
| Texture | CEC |
| Depth | |
| Drainage | |
| Elevation | |

Table 12. Soil qualities and soil characteristics of the five Typic Paleudults

| Soil Quality | Soil Series | | | | |
|---|---|---|---|---|---|
| | Brazil (Frexeiras) | Cameroon (Barombi-Kang) | Liberia (Kolahun) | Malaysia (Lanchang) | Philippines (Tugbok) |
| <u>Moisture</u> | | | | | |
| Rainfall | 1,721 mm | 2,450 mm | 2,000-2,500 mm | 1,837-2,513 mm | 2,500 mm |
| Texture | Clayey | Clayey | Clayey | Clayey | Clayey |
| Slope | 27-30% | 1-3% | 0-8% | 6% | 2-5% |
| Moisture regime | Udic | Udic | Udic | Udic | Udic |
| <u>Drainage</u> | | | | | |
| Drainage | Well drained | Well drained | Well drained | Well drained | Well drained |
| Depth | 270 cm | 185 cm | 178 cm | 250 cm | 200 cm |
| Structure | Subangular/ angular blocky | Subangular/ angular blocky | Subangular blocky | Subangular blocky | Subanuglar blocky |
| <u>Nutrient</u> | | | | | |
| Base Sat. | 9-21% | 16-24% | 6-7% | 2-4% | 27-34% |
| K content | .1-.2 meq | 0.04-.33 meq | 0.1 meq | .06-.18 meq | 0.3-2.0 meq |
| pH | 4.4-5.4 | 4.5-5.5 | 5.1-5.5 | 3.5-5.3 | 4.6-5.0 |
| CEC | 7-9 meq | 16-21 meq | 6-14 meq | 7-16 meq | 17-21 meq |
| <u>Energy</u> | | | | | |
| Temperature regime | Isohyperthermic | Isohyperthermic | Isohyperthermic | Isohyperthermic | Isohyperthermic |
| Moisture regime | Udic | Udic | Udic | Udic | Udic |

Table 13. Rating of the soil qualities for oil palm

| Soil Quality Level | Poor | Fair | Good |
|---|---|---|---|
| Moisture | | | |
| Rainfall | 1,000 mm | 1,000-2,000 mm | >2,000 mm |
| Texture | Sandy | Loamy | Clayey |
| Slope | >20% | 10-20% | <10% |
| Moisture regime | Aquic | Ustic | Udic |
| Drainage | | | |
| Drainage | Poorly | Mod. well | Well |
| Depth | <1 m | 1-1.5 m | >1.5 m |
| Structure | Platy | Granular | Blocky |
| Texture | Clayeg | Loamy | Sandy |
| Nutrient | | | |
| Base saturation | <10% | 10-20% | 20-35% |
| Sum of bases | <2 meq | 2-5 meq | >5 meq |
| K content | <0.1 meq | 0.1-0.15 meq | >0.15 meq |
| pH | <3.5 | 3.5-4.5 | 4.5-6.0 |
| CEC (meq/100 g soil) | <6 meq | 6-12 meq | >12 meq |
| Energy | | | |
| Temperature | <15° C | 15-22° C | >22° C |
| Moisture regime | Aquic | Udic | Ustic |

Table 14. Suitability of the five soil series for oil palm production

| Soil Series | Soil Quality Rating | | | | Suitability Rating |
|---|---|---|---|---|---|
| | Moisture | Drainage | Nutrient | Energy | |
| Frexeiras | Fair | Good | Good | Good | Fair |
| Barombi-Kang | Good | Good | Good | Good | Good |
| Kolahun | Good | Good | Fair | Good | Good |
| Lanchang | Good | Good | Fair | Good | Good |
| Tugbok | Good | Good | Good | Good | Good |

# SUMMARY AND CONCLUSIONS

The soil descriptions and the laboratory data of five profiles of the clayey, kaolinitic, isohyperthermic family of the Typic Paleudults were obtained from various published and unpublished sources. The general objective of this study was to illustrate how soils classified according to the Soil Taxonomy could be used to rate soils for a specified use--in this case, the production of oil palm. The specific objectives were (1) to compare the morphological, chemical, and physical properties of these soils, (2) to prepare a list of the range in the soil characteristics, (3) to compile a list of criteria and constraints for the production of oil palm, and (4) to propose a soil suitability rating for these five soils for the production of oil palm. The soil properties were examined by comparing the profile descriptions and the tables of data, and the laboratory data were studied further by statistical analysis. Soil characteristics that were important to the production of oil palm were then grouped under four qualities--moisture, drainage, nutrient, and energy. Based on the range in characteristics of the soils and the criteria used for growing the crop, the soil qualities were rated as being not suited, poor, fair, and good for different levels of soil characteristics. Finally, by matching the soil qualities with the requirements of oil palm, the suitability of the five soils for oil palm were determined.

Based on the results of this study, the following conclusions are made:

1. The five soils of the clayey, kaolinitic, isohyperthermic family of the Typic Paledults have varying ranges in the morphological, physical, and chemical properties.

2. Specific soil characteristics must be used to develop or define soil qualities for a specified use.

3. Using the soil qualities and the crop requirements, soils can be rated as to its suitability for a specified use, in this particular case, the production of oil palm.

4. By matching the soil qualities with the requirement of the oil palm, the study showed that, with the exception of the Frexeiras soil, the Barombi-Kang, Kolahun, Lanchang, and Tugbok soils are suited for oil palm. The Barombi-Kang and the Tugbok soils rate slightly better than the Kolahun and Lanchang soils.

5. The Frexeiras soil rated only fair for oil production on the basis of steep slope; not because slope affects moisture, one of the soil qualities, but because slope affects workability of the land.

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