PN AAR-230
ISN: 36772

The Soils of IITA

A detailed description of eight soils near Ibadan, Nigeria with special reference to their agricultural use.

by

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(Approved for publication April, 1974)

SUMMARY

Soils of the International Institute of Tropical Agriculture are described as regards their distribution, morphology, classification, physical, chemical and mineralogical characteristics. Results of this study may be applied to comparable soils under similar agro-ecological conditions elsewhere in Nigeria. The study was oriented toward supplying relevant data to facilitate optimum agronomic utilization of the soils for sustained food crop production.

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ACKNOWLEDGEMENT

The authors are grateful for the help received from Dr. T. L. Lawson for providing climatological information.

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INTRODUCTION

An understanding of the basic soil properties is essential for developing soil management practices that will maintain the productive potential of a soil. This is particularly true for tropical soils with inherent properties of low cation exchange capacity, low organic matter content, low water holding capacity and structural instability, which make them vulnerable to soil erosion. This report describes the pedological, physical and chemical properties of major soil series at the IITA. The results are applicable to soils occurring under similar ecological conditions elsewhere in Western Nigeria. The soil properties are interpreted with the objective of agronomic utilization of these soils, especially in regard to food crop production. Environmental data on climate, hydrology and vegetation are included to facilitate such an interpretation. A generalized analysis of the results is given in the text and the details of the morphological, physical and chemical characteristics of each soil series studied are found in the appendices.

The eight soils described belong to the Ekiti, Iwo, Egbeda, Ibadan, Gambari, Apomu, Iregun (2 profiles) and Matako series. Most common are the upland soils on plateaus and upper convex slopes, represented by the Iwo, Egbeda and Ibadan series. The lower concave slopes to the valley bottoms are represented by the Apomu series and the two Iregun soil profiles, whereas the Matako series is a sandy representative of the hydromorphic valley bottoms.

The upland and the slope soils are suited for crops, such as maize, cowpeas, pigeon peas and cassava. For these soils, erodibility, drought susceptibility and high soil temperatures are severe limiting factors for sustained food crop production, which can only be overcome by appropriate soil and crop management practices. The sandy upland and slope soils, e.g. the Ibadan and Apomu, are especially drought susceptible and, moreover, leaching losses of applied nutrients tend to be high.

A general problem is the rapid decline in organic matter content after forest clearing, which may be overcome by crop residue management and appropriate crop rotations.

Soils of the hydromorphic valley bottoms have poor drainage conditions during the rainy season. These soils are, therefore, most suitable for rice cultivation. During the early dry season upland crops such as soybeans and certain vegetable crops can be successfully grown without supplementary irrigation.

ENVIRONMENTAL DATA

Situation and topography

IITA is situated at latitude 7° 30' N and longitude 3° 54' E, Ibadan. It occupies about 1000 ha. Topography is rolling with dominant slopes between 3 and 10%. Steeper slopes, up to 25%, occur locally whereas flatter tracts of land are found on small plateaus and in wider valley bottoms. Elevation varies between 186 and 240 m. The landform is that of an eroded pediment plain, with well incised valleys forming a trellis pattern.

Geology and parent materials

IITA is situated in a region underlain by metamorphic rocks, belonging to the Pre-Cambrian Basement Complex. The major rock type found at IITA is banded gneiss, a gray quartz-biotite plagioclase-horneblende paragneiss, which weathers rapidly so that fresh outcrops are not numerous. Alternating with the banded gneiss are strata of quartzites and quartz schists, which are more resistant to weathering. In addition, the Ibadan granitic gneisses are also found in aligned outcrops or ledges. The Ibadan granitic gneiss is a horneblende-biotite orthogneiss occurring as intrusions in the older rocks.

Parent materials of the soils of IITA can be subdivided into four distinct groups according to their origin:

1. Materials produced by the weathering of Basement Complex rocks in place, which vary in composition according to the nature of the underlying rocks. Moreover, variations in weathering occur according to the topographic situation. Thus, weathering in the hydromorphic lower slopes generally produces a compact clayey parent material, whereas in the better drained positions a saprolite, retaining its original rock structure, is found.

2. Stoneline materials, which originated as quartz and quartzite pediment gravels of late glacial age but have subsequently been mixed and moved along the slopes. No stonelines are found in shallow soils on some crests and steep slopes, where they have been removed by erosion. Stonelines are also absent in the lowest parts of the valleys, indicating recent incision of the valleys.

3. Colluvial and alluvial materials of varying texture, which have deposited on lower slopes and in valleys. These materials usually contain a limited amount of gravels.

4. Biogenetic surface material, i.e. stonefree material, which was brought up by termites and earthworms, forming the surface layers of most soils.

Hydrology

Sizeable aquifers in the Basement Complex are rare. Shallow groundwater is found in localized fractured strata or faults and in places where the impervious subsoil or bedrock forms a trough.

Streams and creeks are intermittent. Surface water flow stops after the onset of the dry season (December-January) and resumes usually in May.

Streams and creeks are fed by direct rainfall, interflow and runoff. Interflow water reaches the stream by way of numerous springs spread along the lower slopes of the valleys. Runoff is mainly responsible for the abrupt peaks in the flow of streams and creeks. In forested areas streams are mainly fed by interflow, while runoff is the main contributing source from the cleared land.

Climate

Ibadan, and particularly IITA, lies essentially in a zone of transition between the humid and subhumid tropical climates. The rainfall has a characteristic bimodal distribution with peaks in June and in September and a period of lower precipitation in August. December through February constitute the major dry season. A significant portion of the rains comes as relatively intense thundershowers, often with moderate to strong, gusty winds. The annual rainfall is variable, ranging from 788 mm to 1884 mm within a 20-year period, (1953-1972 University of Ibadan Station data).

Annual temperatures range from an average minimum of 21.3 C to an average maximum of 31.2 C. Extreme daily minimum and maximum of 8.3 C and 38.0 C respectively have been observed.

Mean monthly average relative humidities reach a minimum in February and a maximum in August. Potential evapotranspiration, ET_p, is marked by a single peak in March but falls to its lowest values in August when insolation is also at a minimum. The ET_p computed by Turc's (1961)* formula, together with other pertinent climatic data based on observations taken at the University of Ibadan Station, and assumed applicable to IITA, are given in Table 1. A 30-year average of the monthly rainfall from Moor Plantation, about 25 km southwest of IITA is given for comparison.

*Turc, L. (1961). *Evaluation des besoins en eau d'irrigation; evapotranspiration potentielle.* Ann Agron. 1961 12(1) 13-49.

Table 1: Climatic data, Ibadan. *(Data from the Geography Department,*

	Jan.	Feb.	Mar.	April	May	June
Average maximum temperature (°C)	32.9	34.6	33.8	32.4	31.5	29.8
Average minimum temperature (°C)	20.1	21.7	22.4	22.2	21.8	21.4
Average mean temperature (°C)	26.5	28.2	28.1	27.3	26.7	25.6
Average relative humidity (%)	63	61	67	74	76	80
Mean potential evapotranspiration (mm)	112	114	132	126	123	109
Mean bright sunshine hours (monthly)	229.2	214.6	212.8	194.2	214.0	163.3
Mean rainfall (mm)	3.4	30.2	102.7	129.3	151.0	184.6
Mean rainfall (mm) (Moor Plantation)	9.4	21.1	79.5	132.5	168.1	194.1

Vegetation

IITA is situated in the ecological zone of moist lowland tropical forest. The climax vegetation is moist semi-deciduous forest. The vegetation at IITA was a pattern of secondary forest, cocoa plantations, and arable crops in rotation with bush regrowth before the clearing of large parts of the station.

SOIL DISTRIBUTION, MORPHOLOGY

Soil map

Soils at IITA were surveyed at a scale of approximately 1:8000 by the Soil Survey Section, IART, University of Ife. Figure 1 is a simplified version of the map. Profiles are described in Appendix B.

Unit 1 comprises mainly the Egbeda, Olorunda and Iwo series* developed from in situ weathered gneisses and in some cases from micaschists. The superficial horizons are formed in biogenetic material, which is underlain by a gravelly layer, varying in thickness and in percentage of coarse fragments. Profiles 2 and 3 are Iwo and Egbeda series respectively.

Unit 2 groups the Ibadan series derived from gneisses and the Okemessi series from quartzites and quartz schists. Both series are sandy in the surface horizon and contain considerable amounts of quartzite and quartz gravels. Profile 4 is an Ibadan series soil.

Unit 3 represents the areas with rocks at shallow depth or outcropping. Only part of these soils are indicated on the map; they occur frequently as minor inclusions among the soils of units 1 and 2. Ekiti soils are very shallow to bedrock. Profile 1 is an example. Balogun and Asejire soils are deeper, but characterized by heterogenous profiles. They usually contain rock scree and slightly weathered gneiss and granite boulders.

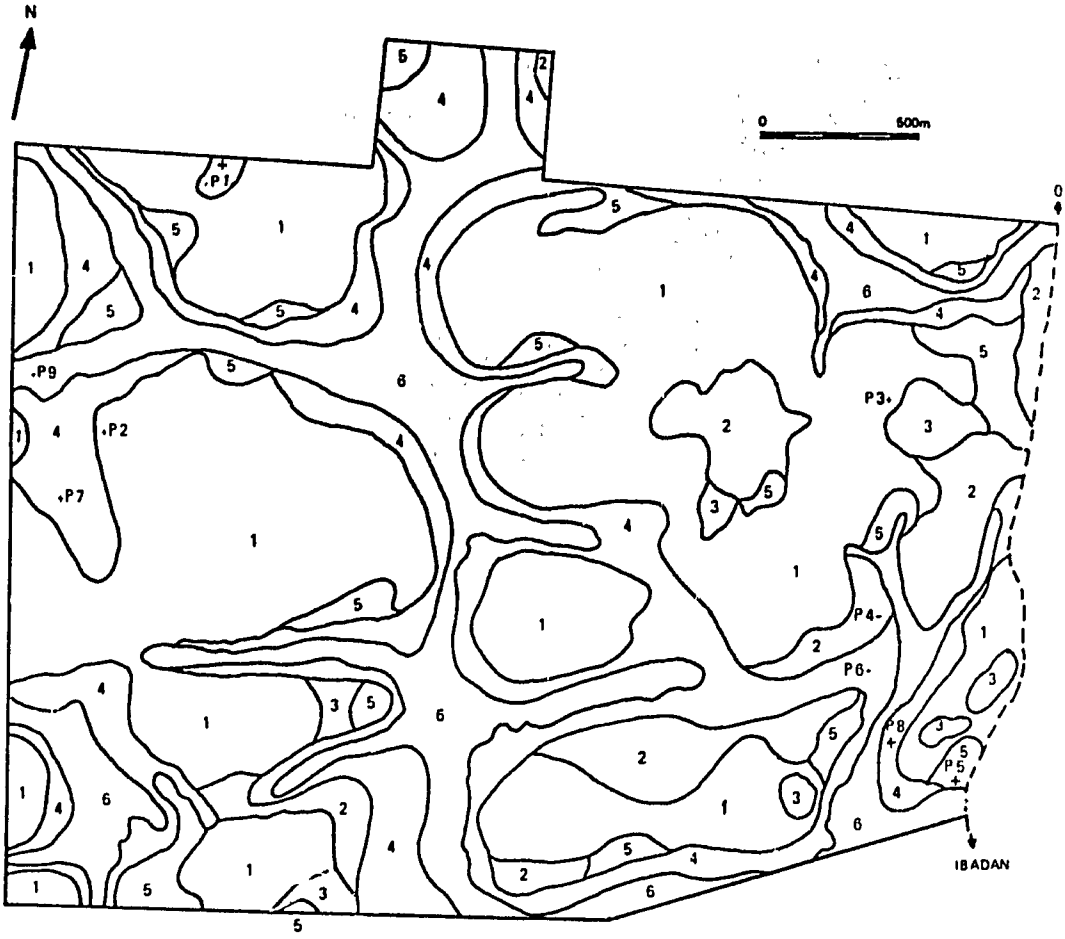
Unit 4 groups the soils of the lower concave slopes; mainly sandy Apomu and medium textured Iregun series, which are formed on non-gravelly slope colluvium to a depth of at least 50 cm. Very locally, more clayey Oba series soils are found. Soils of this unit are not hydromorphic when situated well above the valley bottoms, but gleyed subsoils are observed in the lower positions. Profile 6 is an Apomu series, profile 7 a non-hydromorphic Iregun series and profile 8 a hydromorphic Iregun series, which is transitional to the Tago series of Unit 6.

Unit 5 represents the soils of which the profile characteristics are domi-

*Series determination according to Smyth, A and R. Montgomery, 1962 Soils and Land Use in Central West Nigeria. Government of Western Nigeria, 265p.

University of Ibadan)

July	Aug.	Sept.	Oct.	Nov.	Dec.
28.0	27.5	28.7	30.2	32.0	32.3
21.4	20.8	21.2	21.2	21.5	20.3
24.7	24.2	25.0	25.7	26.8	26.3
82	83	82	78	70	64
97	95	105	115	118	119
116	88.4	112.1	160.1	231.2	206.7
145.5	112.3	195.0	182.7	37.1	7.7
156.7	101.1	189.0	176.0	49.5	7.1



LEGEND

1 Predominantly clayey upland soils (Eqbeda, Olorunda and Ivo series)
2 Gravelly and sandy upland soils (Ibadan and Oke-messi series)
3 Shallow upland soils with frequent rockout crops (Ekiti, Assejire and Balogun)
4 Lower slope soils, coarse to medium textured (Apomu and Irequn series)
5 Lower and middle slope soils with abundant laterite (Gambari series)
6 Valley soils, complex (Adio, Jago, Matako, Oshun and Ikire series)

•P7: location and number of profiles described in text.

Fig. 1. Simplified soil map of IITA.

nated by the presence of hard iron and manganese formations (laterite), usually in the form of concretions. These soils, belonging to the Gambari series, are essentially heterogenous. Only the major areas of the unit are indicated. These soils usually occur in narrow bands and isolated spots along middle to lower slopes and their location is characterized by a distinct slope break. Profile 5 is the concretionary variant of the Gambari series, which contains plinthite.

Unit 6 is a complex group of valley bottom soils, which are subdivided according to their texture and their drainage. It comprises the following series:

Adio series:	poorly drained, predominantly clayey.
Jago series:	poorly drained, medium textured.
Matako series:	poorly drained, predominantly sandy.
Oshun series:	very poorly drained, clayey.
Ikere series:	very poorly drained, medium to coarse textured.

These soils do not contain any appreciable amount of gravels in at least the upper 50 cm. Profile 9 is a Matako series soil.

The relative topographical and geomorphological positions of the profiles, selected for this study are given in Figure 2.

Soil variability

With few exceptions, immediately after clearing soils at IITA are heterogenous, with changes occurring at distances of a few meters. The soil vari-

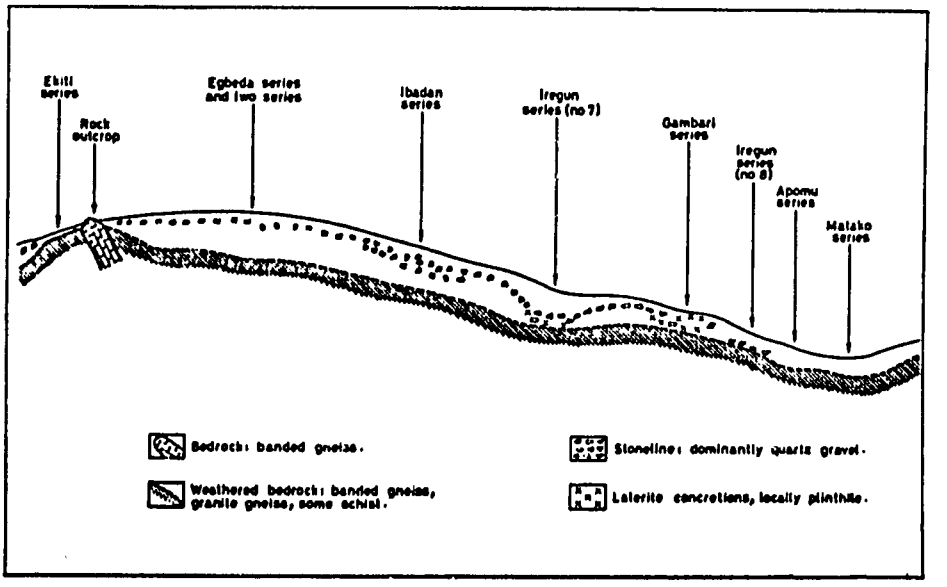


Fig. 2. Schematic cross section of a toposequence at IITA.

Table 2: Comparative classification of selected IITA soil series.

No.	Series	U.S.D.A.	F.A.O.	I.N.R.A.
1.	Ekiti	Paralithic* Ustropept	Eutric Cambisol	*sol peu évolué non climatique d'érosion*
2.	Iwo	Oxic Paleustalf	Ferric Luvisol	*sol ferrallitique faiblement désaturé remanié*
3.	Egbeda	Oxic Paleustalf	Ferric Luvisol	*sol ferrallitique faiblement désaturé remanié*
4.	Ibadan	Oxic Paleustalf	Ferric Luvisol	*sol ferrallitique faiblement désaturé remanié*
5.	Gambari	Typic* Plinthustalf	Plinthic Luvisol	*sol ferrallitique faiblement désaturé remanie*
6.	Apomu	Psammentic* Ustorthent	Albic Arenosol	*sol peu évolué non climatique d'apport colluvial*
7.	Iregun	Oxic Haplustalf	Ferric Luvisol	*sol ferrallitique faiblement désaturé appauvri*
8.	Iregun	Udic Haplustalf	Ferric Luvisol (gleyic)	*sol hydromorphe peu humifère à pseudogley*
9.	Matako	Aeric Tropaquent	Mollic Gleysol	*sol hydromorphe peu humifère à pseudogley*

* Tentative subgroups, not mentioned in Soil Taxonomy.

ability is a serious limitation for field experimentation. Several parameters, often working independently, cause this variability. These can be grouped into biogenetic, geogenetic and pedogenetic parameters. The variations in depth, thickness and composition of the gravel layer or "stone line", and the lateral differentiation of the underlying in situ weathered material, are among the major causes of permanent soil variability.

Representative soil profiles and classification

Profile descriptions and analytical data of nine representative soil series are given in Appendix B. Descriptions were made according to the FAO format. Classification at the higher level of generalization is given in accordance with the main systems now in use in West Africa, i.e. the U.S.D.A., the F.A.O. and the I.N.R.A. (French) systems*. The location of the profiles is given on the map (Fig. 1). In Table 2 the comparative classification of the described profiles at IITA is given. It should be noted that the series in western Nigeria were established well before the selection of criteria for distinguishing the taxa at higher levels of classification. Hence, several series comprise of more than one higher classification taxon. A typical example of this is the Iregun series (Profiles 7 and 8, Appendix B).

Most of the deep, well drained upland soils belong to the great group of Paleustalfs (USDA) and can be classified exclusively with the oxic subgroup in view of their low CEC values per 100 g clay. No such provision is made in the FAO legend. The West African *"sols ferrallitiques faiblement desaturés"* coincide largely with the oxic subgroup of the Paleustalfs. The correlation between Alfisols (USDA) and Luvisols (FAO) is tentative and subject to confirmation by further analytical work.

*USDA: Soil Taxonomy. 1974.

FAO: Key to the soil units for the soil map of the world, 1970. FAO Doc. Agl: SM/70/2.

INRA: *Classification des Sols, 1967. Commission de Pédologie et de Cartographie des Sols.*

PHYSICAL PROPERTIES

Surface soils

Physical characteristics of the surface soil horizons are shown in Table 3.

The average texture is sandy loam, with a low percentage of silt, which is typical of these tropical soils. The coarseness of the sand fraction and the low silt percentage are reasons why the field classification frequently qualifies the IITA upland soils as "sandy". Loamy sand or sand occurs only locally in the surface layers, e.g. in soils belonging to the Apomu series and in some soils of the Jago association in the valley bottom. Sandy clay loam surface horizons occur frequently among Egbeda series soils and in the clayey members of the Jago association.

The gravel content of the surface soils is variable and depends upon the degree of erosion of the profiles. Slightly gravelly to gravelly surface soils are found in the upland (Profiles 1 – 5); whereas the lower slope and bottom land soils have a negligible gravel content (Profiles 6 – 9).

Water holding capacity for these soils, in general, is low. Water retention at zero suction is positively correlated with the percentage clay and

negatively with the sand fraction (Fig.3). The degree of correlations between the clay content and water retention diminishes at higher suction values.

Bulk density values are mostly low to moderately low. Fine surface soils have values of 1.3 g cm^{-3} or less. Field penetrometer readings are dependent on gravel concentration and soil moisture content at the time of measurement. In general, under forest bush regrowth, penetrometer readings are low (0.1 to 0.25 kg cm^{-2}), as may be expected in such soils with a loose to very friable consistency in the superficial layers.

Gravel content and stone lines

Most upland soils (Units 1, 2 and 3) as well as the soils with laterite (ironstone gravel, Unit 5) have a pronounced gravel horizon or stone line at shallow depth, and contain varying amounts of fine gravels in the subsoil. The soils of Units 4 and 6 lack gravel horizons at shallow depth.

The size and content of the gravels, as well as the thickness of the stone lines vary considerably within and among series. Most gravelly are the soils of Units 2, 3 and 5. In these soils the layers with a high concentra- of gravels are generally thicker than 60 cm. In other upland soils the gravel layer is thinner and the gravel content lower.

In the gravel layers or stone lines, penetrometer readings are generally high, ranging from 1.33 to more than 4.5 kg cm^{-2} in most soils. High penetrometer readings indicate the rigidity of the matrix, which may be one of the main reasons of poor root penetrability of various crops through the stone lines. The overall bulk density of the stone line depends on the gravel concentration and ranges from 1.4 to 1.7 g cm^{-3}. A low bulk density of the interstitial fine earth (particles smaller than 2 mm) is indicative of a larger volume of voids in the undisturbed soils under secondary forest and bush regrowth.

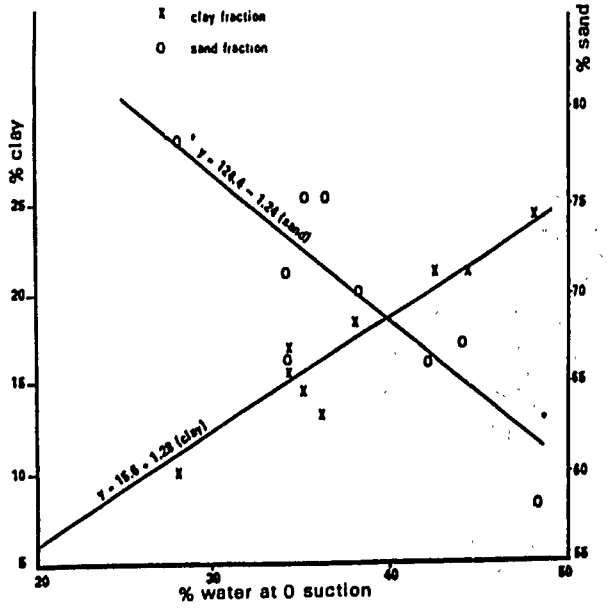


Fig. 3. Relation between water retention (%) at 0 suction and the clay and sand fractions in surface soils.

Table 3: Main physical characteristics of IITA surface soils.

Properties	Range	Mean
Sand %	58.3 – 78.3	69.7
Silt %	11.2 – 18.5	13.2
Clay %	10.3 – 25.0	17.0
Gravel %	1.0 – 25.0	8.6
Water retention at zero suction (%)	26.0 – 48.5	35.8
Water retention at 0.1 bar suction (Field capacity for coarse textured soils %)	10.0 – 23.0	16.2
Water retention at 0.3 bar suction (Field capacity approx. %)	8.5 – 21.0	14.0
Water retention at 15 bar suction (Wilting point)	3.0 – 9.5	4.7
Difference between moisture content at 0.3 and 15 bars %	4.5 – 15.5	8.2
Moisture equivalent %	6.3 – 14.7	10.1
Bulk Density (g cm^{-3}) of fine earth fraction	1.01 – 1.56	1.26
Penetrometer reading (kg cm^{-2})	0.23 – 1.17	0.55

Infiltration rates

The IITA soils under secondary forest, have a high infiltration rate. Infiltration rates in cm hr^{-1} at two hours after starting the infiltration were: Iwo 5.4, Ekiti 6.0, Gambari 17.4 Iregun (Profile 8) Apomu and Matako 24, Egbeda 45, Iregun (Profile 7) 66, and Ibadan 72. The different rates are not particularly related to the macromorphology of the profiles; however, the high rate for the Ibadan soil series may be attributed to its very gravelly and sandy texture.

The high initial intake rates are indicative of the predominance of macro pores as well as of a high lateral hydraulic conductivity of the soils under a forest vegetation.

After forest clearing and use of the land for cultivation, infiltration rates decline rapidly, mainly because of surface sealing (crust formation) of the exposed soil. This structural degradation is caused by direct raindrop impact in soils not protected by vegetation or some form of mulch.

Available-water holding capacity

The available-water holding capacity of the soil above the gravel horizon, i.e. the maximum amount of water available to plants the horizon can store, is generally low for most of the upland soils. The Matako soil series has the highest available-water holding capacity – 20.0 cm of water. This is a hydromorphic soil with a deep profile underlain by a slowly permeable clayey horizon of high water retention capacity. The available-water holding capacity of the deep Iregun (Profile 7) and Apomu profile is 9 and 7 cm, respectively. Because of the shallow nature of rest of the upland soils, the available-water holding capacity of the profile above the gravel horizon is low. It varies from 1.0, 1.2, 1.6, 2.1 and 2.4 to 3.1 cm for the Iwo, Egbeda, Ekiti Gambari, Iregun (Profile 8) and Ibadan series, respectively. Crops with poor root penetrability and high water requirements should be grown on Iregun and Matako series. The Apomu soil, because of a sandy texture and low available-water holding capacity, is drought susceptible. The Egbeda, Iwo, Ibadan and Gambari soils have higher available water in the layers below the gravel horizon and deep rooting crops suffer less from drought stress.

Soil erodibility

The structural stability to raindrop impact is low for the Ekiti, Egbeda, Iwo and Gambari soils. Upon clearing of these soils from forest, direct impact of raindrops will result in detachment of soil particles and subsequent sealing of the surface soil. The surface sealing is responsible for drastic changes in soil infiltrability and causes a sharp increase of runoff losses and erosion. The above mentioned soil series, because of their location in the soil toposequence (Fig.2) are susceptible to runoff and soil erosion. Though the structural stability of Matako and Iregun soils is also low, their gentle slopes make them relatively less vulnerable to soil erosion. Soil and crop management practices should take these characteristics into account.

Soil temperature

In general the drought susceptible soil series will undergo large fluctuations in soil temperature when cleared and clean cultivated. The Ekiti, Egbeda, Apomu, Gambari and Ibadan soil series will give greater problems from high soil temperature than Iregun and Matako. The maximum soil temperature at 5 cm depth can reach as high as 42 to 45 C, particularly in the early stages

of crop growth as compared to a steady value of 28-30 C for soils under forest. The hydromorphic Iregun and Matako soils will have less problems due to high soil temperature because of a favorable moisture regime and depth of root penetration.

CHEMICAL PROPERTIES

Some chemical properties of the surface horizons of the nine profiles are summarized in Table 4. The data are characteristic of IITA surface soils under secondary forest and bush regrowth.

The soils are slightly acidic and contain small amounts of exchangeable Al. The high degree of base saturation indicates that the soils are not excessively leached.

Soil under forest fallow contains moderate amounts of Ca, Mg and K in the surface layer (Table 4). The relatively high amount of total N in most of the surface soils suggests that a substantial amount of the nitrogen may be mineralized during the first cropping season after clearing. The "available P" (Bray P_1) content falls within the range of low to medium-low, suggesting that most crops would respond to P application.

Quartz-sand and kaolinite are the predominant soil minerals in the well-drained upland soil series (Egbeda, Iwo and Ibadan). Organic matter thus contributes a large portion of the cation exchange capacity of the surface soil. Loss of soil organic matter due to inadequate crop and soil management would lead to increased leaching loss of cationic nutrients. The CEC values of the hydromorphic soil (Iregun series, Profile 8) are considerably higher due to the presence of a moderate amount of smectite clay in the profile.

Table 4: Chemical properties of surface soils.

Soil property	Range			Mean
pH (H_2O)	5.2	–	6.9	6.2
Organic C, %	0.94	–	2.48	1.50
Effective CEC, me/100g soil	1.96	–	9.34	6.20
Base saturation, %	86	–	98	94
Nutrient elements, pp2m				
Total N	1540	–	3500	2780
Exchangeable Ca	268	–	2660	1612
Exchangeable Mg	151	–	638	343
Exchangeable K	70	–	305	180
Non-exchangeable K	116	–	2525	349
Available P (Bray P_1)	6	–	46	16

The magnitude of CEC value of the lower horizons in each profile depends upon the clay content and clay mineralogy. In the well-drained soils (Egbeda, Iwo and Ibadan series), the CEC values calculated in me per 100g of clay vary from 6 to 13. The CEC values of clay of the lower horizons of the hydromorphic soils, especially in those materials weathered in situ, are considerably higher. A CEC value of more than 50 me per 100g of clay was found in the Iregun subsoil (Profile 8). The autochtonous clayey subsoils of the Matako and Gambari series show values of 24 and 36 me per 100g of clay, respectively.

Exchangeable cations in all soils are predominantly Ca and Mg. Percentage base saturation in all cases is greater than 80% throughout the profiles with the exception of the lower horizons of Ibadan and Matako series.

Exchangeable K content in surface horizons ranges from 0.1 to 0.4 me/100g. The Ekiti, Iwo and Gambari soils have relatively high exchangeable K contents throughout their profiles. In the other soils, exchangeable K content is highest in the uppermost horizons and decreases to below 0.1 me/100g in the subsequent horizons.

Non exchangeable K varies widely among the nine soil series, ranging from 7 to 220 ppm in the Egbeda profile to 290 to 1,060 ppm in the Gambari profile. This variability is probably associated with the localized occurrence of mica veins in the parent rocks in the area rather than with soil type.

Total P content ranges from 150 to 450 ppm in the surface horizons and decreases slightly with depth. Organic P comprises 40 to 60% of total P in the surface soils; Fe-bound phosphate and occluded phosphate comprise more than 90% of the inorganic P throughout the profiles.

Total S ranges from 200 to 500 ppm in the surface layers (0 – 15 cm) and decreases sharply with depth within each profile. Organic S comprises more than 95% of total S in the surface soil.

CLAY MINERALOGY

Clay minerals were determined in five of the nine profiles representative of different pedogenetic environments along the toposequence. Clay minerals were identified by electron microscopy, X-ray diffraction, infrared and differential thermal analyses.

Results are summarized in Table 5. Kaolinite is the most abundant clay mineral. Goethite was found in all soils. Micas present in the clay fraction are an indication of a relatively low degree of weathering in these soils in comparison with highly weathered soils elsewhere in the lowland humid tropics.

The presence of tubular halloysite and of trioctahedral micas in the Ekiti soil indicates the relatively low degree of weathering under free drainage. The presence of feldspar in the clay fraction also points to the youthfulness of the Ekiti profile.

The predominance of kaolinite and Fe oxide minerals in the clay fraction of the Egbeda and Gambari series are indicative of strong weathering.

The presence of moderate amounts of smectite (montmorilonite) in the hydromorphic Iregun soil (Profile 8), particularly in the deeper layers, is a function of clay mineral formation under conditions of impeded drainage in the presence of a sufficient supply of divalent cations, mainly Mg.

Table 5: Minerals present in the clay fraction of Ekiti, Egbeda, Gambari and Iregun profiles.

Soil	Horizon	Classification	Minerals in clay fraction
Ekiti	A	Ustropept	Kt**, Hy**, Mi(t)*, Mi*, Go*, Qz* Fd#
	B		Kt**, Hy**, Mi(t)*, Mi*, Go*, Fd#
Egbeda	A	Paleustalf	Kt***, Mi*, Go*, Hm*
	B		Kt***, Go*, Hm*, Mi#
Gambari	A	Plinthustalf	Kt***, Mi*, Go*, Sm#
	B		Kt***, Mi*, Go*, Hm*
Iregun (Profile 8)	A	Aquic Haplustalf	Kt**, Sm**, Mi*, Go*
	B		Kt** Sm**, Go*, Hm*
Apomu	A	Ustorthent	Kt**, Sm**, Mi*, Go*
	C		Kt**, Sm**, Mi*, Go*

NOTE:

Kt—kaolinite, Hy—halloysite (tubular), Mi(t)—trioctahedral mica, Mi—dioctahedral mica, Sm—smectite (montmorillonite), Go—goethite, Hm—hematite, Qz—quartz, Fd—feldspar: ***—large amount (>40%), **—moderate amount (10—40%) *—small amount (<10%), #—trace amount.

Appendix A:

Analytical Methods

Soil physical analyses included bulk density, penetrometer and infiltration rate determined in the field. Undisturbed core samples were used to determine bulk density. The weight and volume of soil and skeleton materials were separately determined in the laboratory to facilitate the determination of overall bulk density and that of the soil matrix between the stones. Penetrometer readings were obtained by using a field penetrometer whereas the soil infiltrability was determined with a double ring infiltrometer using a Mariotte bottle technique to maintain a constant head of water.

Moisture retention characteristics of the fine earth fraction (<2 mm) were obtained by a combination of tension table and pressure plate apparatus for a series of suction pressures. Moisture equivalent values were obtained by subjecting the saturated soil samples to a centrifugal force of 1000 g. Soil mechanical analysis data are based on the hydrometer method using sodium hexametaphosphate as a dispersing agent. The upper plastic limit was determined with a Casagrande Liquid Limit Device while the lower plastic limit was found by determining the moisture content of the soil at which it rolls out into filaments 3.2 to 4.8 mm in diameter. Shrinkage characteristics were determined by volume changes in soil on drying according to the A.S.T.M. method designated as D427-39.

The available water holding capacity of soil horizons was calculated as follows:

$$A.W.C. = (F.C. - W.P.) \quad (D_S / D_W)\ h\ (1 + M_G/M_S)^{-1}$$

where A.W.C. = Available water capacity in cm

F.C. = Moisture retained at 0.3 bar suction

W.P. = Moisture retained at 15 bar suction

D_S = Overall soil density

D_W = Density of water

M_G = Weight of coarse material (>2 mm)

M_S = Weight of fine earth (<2 mm)

h = Thickness of soil horizon.

Chemical analysis of the soils were conducted according to the following procedures:

- Soil pH was determined on a Beckman Zeromatic pH meter using a combination glass electrode. The pH was determined both in water and in 1 *N* KCl suspension at 1:1 soil to solution ratio.

- Organic carbon content in soil was determined by the dichromate – oxidation method of Walkley and Black.

- Total N was determined by Kjeldahl digestion and the N content in the digest measured colorimetrically on the Technicon Model II Autoanalyzer.

- Effective cation exchange capacity (CEC) was determined by the summation of all exchangeable cations. Exchangeable bases were measured by extraction with neutral *N* NH_4OAc and the exchangeable Al and H were determined by extractions with *N* KCl.

- Available P in soil was determined by the Bray No. 1 method.

- Non-exchangeable K was determined by concentrated H_2SO_4 extraction.

Appendix B: **Profile 1**

Ekiti Series.

- Reference No. 035
- Topography: 5% slope, upper part of ridge, rolling.
- Vegetation: Secondary bush
- Parent material: Slope coluvium from materials derived from banded gneiss; weathered gneiss at shallow depth.
- Drainage: Well drained.

A_1: 0-16 cm, dark brown (7.5YR 3/2)* slightly gravelly coarse sandy loam; some Fe concretions, some small weathered rock-fragments; moderate fine crumb structure; loose; many roots; many fine interstitial and common fine tubular pores; gradual wavy boundary.

B: 16–46 cm, dark brown (7.5YR 4/3), gravelly coarse sandy loam; quartz and Fe concretions, some weathered rock-fragments, increasing with depth; weak medium subangular blocky structure; loose;

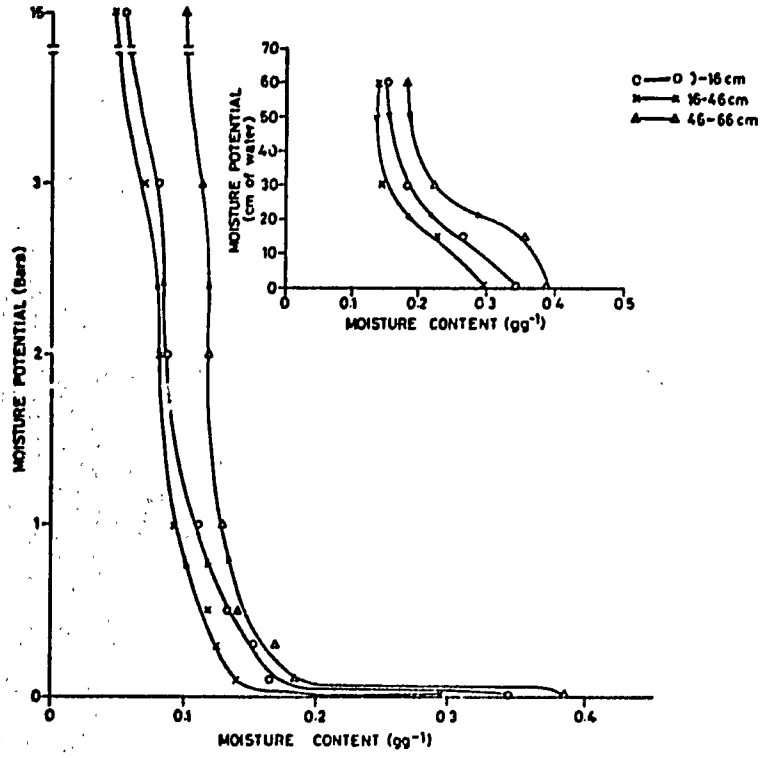


Fig. 4. High and low energy soil moisture characteristics, Profile No. 1, Ekiti series.

Soil physical characteristics

Depth cm	Gravel %	Mechanical analysis % Sand	Silt	Clay	Penetrometer readings kg cm^{-2}	Bulk density g cm^{-3} Overall	Fine earth	Plasticity index	Shrinkage Limit	Ratio	Moisture equivalent %
0–16	10	66.2	18.5	15.3	0.25	1.15	1.01	0	–	–	12.3
16–46	27	64.2	16.1	19.7	0.58	1.40	1.24	0	–	–	10.6
46–66	18	55.3	14.0	30.7	1.00	1.56	1.50	6	18.6	1.8	16.0

Chemical properties

Depth cm	pH (H_2O)	KCl	Exchangeable cations, me/100g Ca	Mg	K	Na	Mn	Al	H	CEC me/100g	Organic C %	Total N %	Bray P ppm	Non-exch. K ppm	Base Saturation %	C/N ratio
0–16	6.9	6.1	5.66	1.78	0.34	0.07	0.01	0.03	0.28	8.37	1.56	0.140	5.6	505	94	11
16–46	6.1	5.7	3.38	1.00	0.25	0.07	0.05	0.02	0.28	5.25	0.74	0.058	3.4	230	91	13
46–66	6.2	4.9	3.40	0.86	0.13	0.06	0.04	0.01	0.39	5.09	0.35	0.035	4.7	590	88	10

many roots; common fine tubular pores; clear wavy boundary.

IIC: 46–52/72 cm, multicolored gravelly sandy clay loam; reddish brown (5YR 4/3) matrix, with prominent red (2.5YR 5/3) mottles and very pale brown (10YR 7/4) weathered rock; original rock structure increasingly visible with depth; penetration of material from overlaying horizons in larger rootholes and other voids; moderate fine subangular blocky structure; slightly sticky, slightly plastic; common roots; common fine tubular pores, mainly oriented in direction of rockstrike; irregular clear to abrupt boundary.

R: 52/72 cm+, weathering banded gneiss (paralithic contact).

Appendix B: **Profile 2**

Iwo Series.

- Reference No. 028
- Topography: 3% convex slope; side of small plateau.
- Vegetation: Secondary forest.
- Parent material: Sedentary material derived from banded gneiss, overlain by colluvium, and by biogenetic material in the surface layer.
- Drainage: Well drained.

A_1: 0–15 cm: brown (7.5YR 4/3) slightly gravelly sandy loam; moderate fine crumb structure; many roots; many interstitial pores; clear wavy boundary.

IIA_3: 15–28 cm, reddish brown (5 YR 4/3) gravelly sandy clay loam; quartz gravels and Fe/Mn concretions; moderate fine subangular blocky structure; friable; many roots; common tubular pores, gradual wavy boundary.

IIB_1: 28–45 cm, reddish brown (5YR 4/4) gravelly sandy clay; quartz

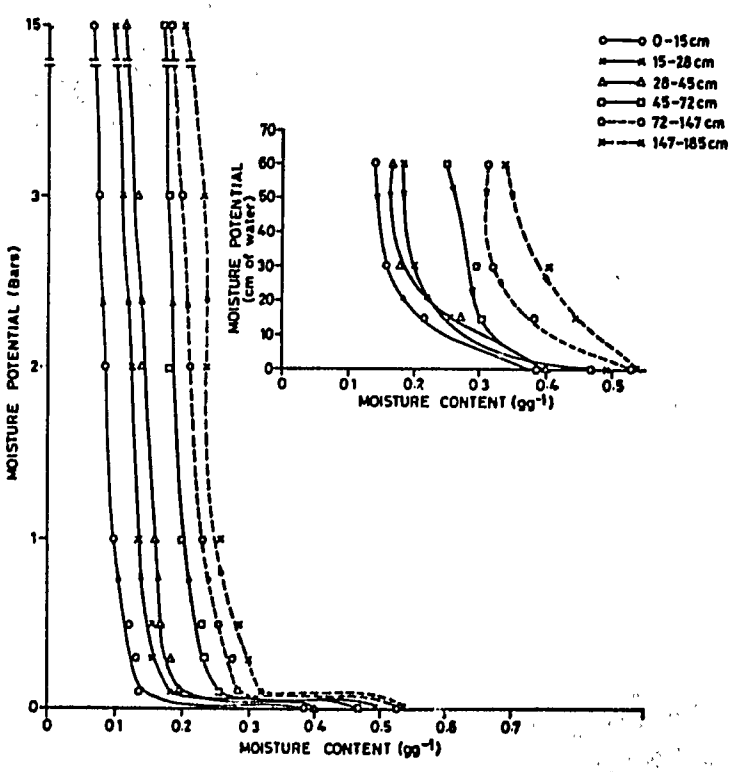


Fig. 5. High and low energy soil moisture characteristics, Profile No. 2, Iwo series.

Soil physical characteristics

Depth cm	Gravel %	Mechanical analysis % Sand	Silt	Clay	Penetrometer readings kg cm^{-2}	Bulk density g cm^{-3} Overall	Fine earth	Plasticity index	Shrinkage Limit	Ratio	Moisture equivalent %
0–15	13	70.4	12.4	17.6	0.58	1.20	1.17	0	–	–	13.5
15–28	39	54.4	23.0	22.6	0.67	1.36	1.29	2	16.1	1.9	14.2
28–45	41	46.4	12.0	41.6	1.83	1.52	1.37	15	16.7	1.9	17.1
45–72	28	38.4	10.0	51.6	4.33	1.48	1.40	6	20.1	1.8	23.4
72–147	31	22.3	23.4	54.3	4.5	1.49	1.40	7	23.4	1.7	26.8
147–185	16	20.9	24.8	54.3	4.5	1.43	1.38	8	26.3	1.6	29.7

Chemical properties

Depth cm	pH H_2O	KC1	Exchangeable cations, me/100g Ca	Mg	K	Na	Mn	A1	H	CEC me/100g	Organic C %	Total N %	Bray P1 ppm P	Non-exch. K ppm	Base Satura-tion %	C/N ratio
0–15	6.3	5.8	4.93	1.31	0.23	0.06	0.12	0.06	0.11	6.82	1.54	0.154	2.8	100	98	10
15–28	6.2	6.0	5.75	1.75	0.27	0.07	0.14	0.06	0.11	8.15	1.66	0.181	1.1	116	98	9
28–45	6.3	5.5	2.74	0.78	0.22	0.05	0.03	0.12	0.22	4.16	0.49	0.046	0.7	89	92	11
45–72	6.3	5.9	2.88	0.92	0.32	0.05	0.03	0.12	0.05	4.37	0.50	0.048	0.4	110	96	10
72–147	6.3	5.2	2.89	0.91	0.32	0.05	0.03	0.10	0.07	4.37	0.28	0.035	0.8	116	96	7
147–185	6.0	5.1	2.40	1.38	0.24	0.06	0.01	0.13	0.01	4.23	0.13	0.019	0.1	86	97	7

gravels and Fe/Mn concretions; moderate fine subangular blocky structure; broken, thin cutans; firm; common roots; many fine tubular inped pores; clear wavy boundary.

IIIB$_2$t: 45–72 cm, yellowish red (5YR 4/6) gravelly clay; quartz gravels and Fe/Mn concretions; scattered reddish yellow (7.5YR 6/8) spots of feldspar pseudomorphs; moderately strong fine subangular blocky structure; broken cutans on peds and in pores; firm; common roots; diminishing with depth; many fine tubular inped pores; gradual wavy boundary.

IIIB 3 & C: 72–147 cm, the horizon is composed of 60% B material and 40 percent C material, mainl weathered feldspar. Multicolored yellowish red (5YR 4/5) and red dish yellow (7.5 6/8) gravell clay; quartz gravels and soft Fe, Mn concretions; common, fine distinct red (2.5YR 5/8) mottles moderately strong,medium,angula blocky structure; patchy broke cutans in Bt; firm; few fine roots common fine tubular pores;diffus wavy boundary.

IIIC: 147–185 cm+, multicolored re 2.5YR 5/8) to reddish yello 3.5YR 6/8) gravelly clay, wit ligh yellowish brown (10YR 6/4 streaks, indicating the origina rock structure; many fine roots few pores.

Appendix B: Profile 3

Egbeda Series

- Reference No. 001
- Topography: 1% convex slope on ridge
- Vegetation: Secondary forest.
- Parent material: Sedentary material derived from banded biotite gneiss overlain by colluvium and by biogenetic material in the surface layer.
- Drainage: Well drained.

A_1 0–5 cm, dark brown (7.5YR 4/3) gravelly sandy loam; strong fine crumb structure; very friable; many roots, many fine and medium vesicular and interstitial pores; clear wavy boundary.

IIA_3: 5–15 cm, strong brown (7.5YR 4/4) gravelly sandy clay loam; weak fine subangular blocky structure; friable; many roots; many fine interstitial, common fine tubular pores; gradual, wavy boundary.

IIB_1: 15–45 cm, reddish brown (5YR 4/3) gravelly sandy clay; moderate

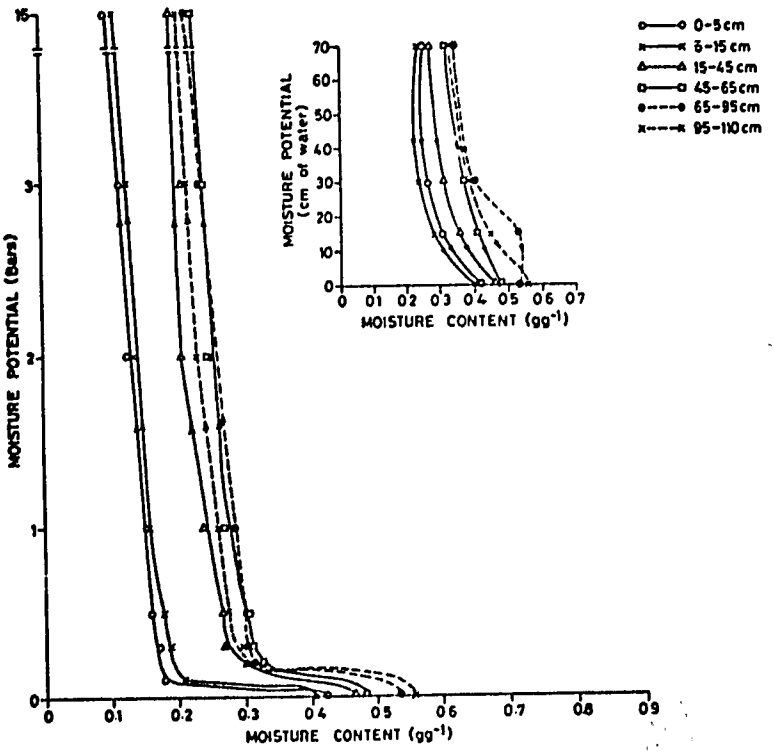


Fig. 6. High and low energy soil moisture characteristics, Profile No. 3, Egbeda series.

Soil physical characteristics

Depth cm	Gravel %	Mechanical analysis % Sand	Silt	Clay	Penetrometer readings kg cm^{-2}	Bulk density g cm^{-3} Overall	Fine earth	Plasticity index	Shrinkage Limit	Ratio	Moisture equivalent %
0–5	25	66.9	11.8	21.3	0.58	1.40	1.25	3	19.1	1.8	11.8
5–15	20	57.9	16.8	25.3	0.92	1.42	1.28	5	17.9	1.9	15.3
15–45	45	48.9	13.8	37.3	1.33	1.40	1.19	9	24.5	1.7	17.3
45–65	40	29.9	13.8	56.3	1.92	1.40	1.37	10	29.3	1.6	25.9
65–95	40	29.6	6.1	64.3	2.08	1.49	1.45	6	28.9	1.6	27.9
95–110	30	20.2	14.4	65.4	3.33	1.47	1.42	10	25.3	1.6	26.0

Chemical properties

Depth cm	pH H_2O	KCl	Exchangeable cations, me/100g Ca	Mg	K	Na	Mn	Al	H	CEC me/100g	Organic C %	Total N %	Bray P1 ppm P	Non-exch. K ppm	Base Saturation %	C/N ratio
0–5	6.5	5.9	3.50	1.20	0.39	0.10	0.09	0.01	0.16	5.45	1.54	0.138	14.9	77	97	11
5–15	6.4	5.4	5.20	1.31	0.15	0.05	0.11	0.01	0.16	6.99	1.50	—	6.3	220	98	—
15–45	6.8	5.7	3.52	1.35	0.12	0.05	0.05	0.03	0.14	5.26	0.76	0.063	2.5	98	97	12
45–65	6.4	5.1	3.05	0.89	0.10	0.10	0.02	0.04	0.13	4.33	0.28	0.040	0.7	83	96	7
65–95	6.0	5.5	2.90	0.75	0.11	0.10	0.03	0.06	0.11	4.06	0.26	0.044	0.7	7	96	6
95–110	5.9	5.4	2.75	0.68	0.10	0.75	0.04	0.06	0.11	4.49	0.18	0.040	0.7	7	96	4

fine subangular blocky structure; broken, thin cutans; consistence masked by gravel; common roots; common fine tubular pores; gradual wavy boundary.

IIB_2t: 45–65 cm, reddish brown (2.5YR 4/3) gravelly clay; moderately strong fine subangular blocky structure; continuous, moderately thick cutans; firm; common roots; common fine tubular pores; gradual wavy boundary.

$IIIB_2t$: 65–95 cm; red (2.5YR 4/5) gravelly clay; locally very gravelly with fine angular quartz and laterite concretions; moderately strong fine subangular blocky structure; continuous moderately thick cutans; firm; common roots; common fine tubular pores;diffuse wavy boundary.

$IIIB_3t$: 90–110 cm+; gravelly clay, mottled with dark red (2.5YR 3/8) and reddish yellow (7.5YR 7/6); moderate medium to coarse subangular and angular blocky structure; patchy, moderately thick cutans; firm; common roots; common fine tubular pores.

Appendix B, Profile 4

Ibadan Series.

- Reference No. 033
- Topography: 7% flat slope on side of a ridge.
- Vegetation: Thicket regrowth after clearing.
- Parent material: Very gravelly quartzitic slope colluvium, overlaying sedentary material from banded gneiss; biogenetic material in the surface layer.
- Drainage: Well to somewhat excessively drained.

A_{11}: 0–25 cm, dark brown (7.5YR 4/2) slightly gravelly sandy loam; moderate fine crumb structure; loose; many roots; many fine interstitial pores; some larger voids; clear wavy boundary.

II A_{12}: 25–50 cm, dark reddish brown (5YR 3/4) gravelly sandy loam; mainly quartz gravels from 0.5–5 cm diameter; moderate fine crumb structure; loose; many roots, de-

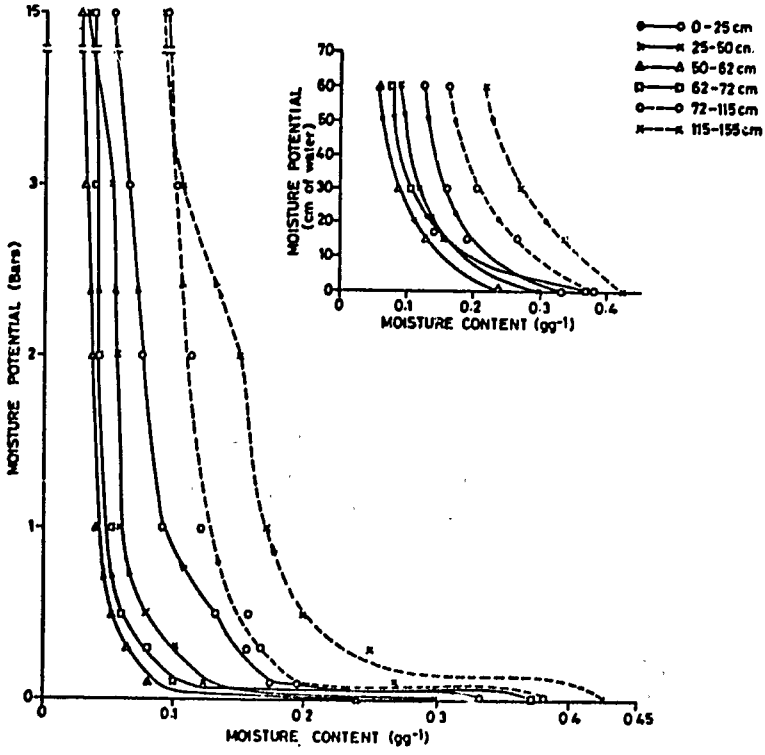


Fig. 7. High and low energy soil moisture characteristics, Profile No. 4, Ibadan series.

Soil physical characteristics

Depth cm	Gravel %	Mechanical analysis %			Penetrometer readings	Bulk density g cm-3		Plasticity index	Shrinkage		Moisture equivalent
		Sand	Silt	Clay	kg cm-2	Overall	Fine earth		Limit	Ratio	%
0–25	9	71.0	11.7	17.3	0.50	1.48	1.46	0	—	—	9.0
25–50	44	71.6	11.1	17.3	2.25	1.45	1.25	0	—	—	4.5
50–62	60	80.6	6.1	13.3	> 4.50	1.65	1.32	0	—	—	4.5
62–72	50	76.6	7.1	16.3	> 4.50	1.66	1.08	0	—	—	5.0
72–115	35	58.2	5.4	36.4	4.10	1.65	1.45	5	14.9	2.0	12.9
115–155	14	49.2	13.4	37.4	3.90	1.70	1.61	6	18.7	1.8	18.0

Chemical properties

Depth cm	pH		Exchangeable cations, me/100g							CEC me/100g	Organic C %	Total N %	Bray P1 ppm P	Non-exch. K ppm	Base Saturation %	C/N ratio
	H_2O	KC1	Ca	Mg	K	Na	Mn	A1	H							
0–25	6.5	5.8	3.70	1.00	0.17	0.08	0.01	0.13	0.39	5.68	1.34	0.102	5.4	115	87	13
25–50	6.5	5.9	2.12	0.50	0.10	0.07	0.05	nd*	0.30	3.34	0.44	0.033	3.6	675	85	13
50–62	6.3	5.6	1.15	0.25	0.04	0.04	0.02	0.01	0.29	2.00	0.19	0.017	4.2	450	75	11
62–72	6.3	5.5	1.[illegible]5	0.33	0.05	0.05	0.02	nd	0.40	2.50	0.22	0.017	5.8	50	76	13
72–115	6.3	5.3	2.32	0.54	0.05	0.05	0.01	0.02	0.28	3.47	0.30	0.025	2.3	88	86	12
115–155	6.3	5.3	2.35	0.58	0.04	0.04	nd	0.01	0.30	3.52	0.13	0.025	2.5	75	86	5

*nd — not detectable

creasing in size and number with depth; some coarse, many fine interstitial pores; some larger voids, gradual wavy boundary.

II A_3: 50–62 cm, reddish brown (5YR 4/4) very gravelly loamy sand; some quartz stones up to 10 cm along the long axis; weak fine and medium crumb structure; very friable; common roots; many fine interstitial pores; some larger voids; clear wavy boundary.

II B_1: 62–72 cm, reddish brown (5YR 5/4) very gravelly sandy loam; weak medium crumb and weak medium subangular blocky structure; patchy thin cutans; very friable; common roots; many fine interstitial pores common fine tubular pores; clear wavy boundary.

III B_2t: 72–115 cm, yellowish red (2.5–5YR 4/8) gravelly sandy clay; moderate medium subangular blocky structure; patchy thin cutans, continuous, moderately thick cutans in pores; friable; common roots; common fine tubular pores; some soft iron nodules; gradual wavy boundary.

III B_3: 115–155 cm+; slightly gravelly sandy clay, mottled with yellowish red (5YR 4/8) and brownish yellow (7.5YR 6/8), the latter being saprolite with feldspar structure; moderate, medium and coarse angular blocky structure; broken, thin cutans in pores; friable; few roots; common fine tubular pores.

Appendix B, Profile 5

Gambari Series

- Reference No. 030
- Topography: 15% convex slope; slope break in lower part of long, flat slope.
- Vegetation: Secondary forest.
- Parent material: Sedentary material from banded gneiss, overlain by colluvium layers and by biogenetic material in the surface layers.
- Drainage: Imperfectly drained.

A_1: 0–18 cm, dark brown (7.5YR 3/2) gravelly sandy clay loam; moderate fine and medium crumb structure; soft; many roots; many fine to coarse interstitial pores; voids; clear wavy boundary.

IIA_3 cn: 18–36 cm, strong brown (7.5YR 4/4) very gravelly coarse sandy loam; gravels are mainly Fe/Mn concretions with blackish and yellowish red (5YR 5/6) colors; structure and consistence masked by gravel; common roots; many fine and medium interstitial and tubular pores; gradual wavy boundary.

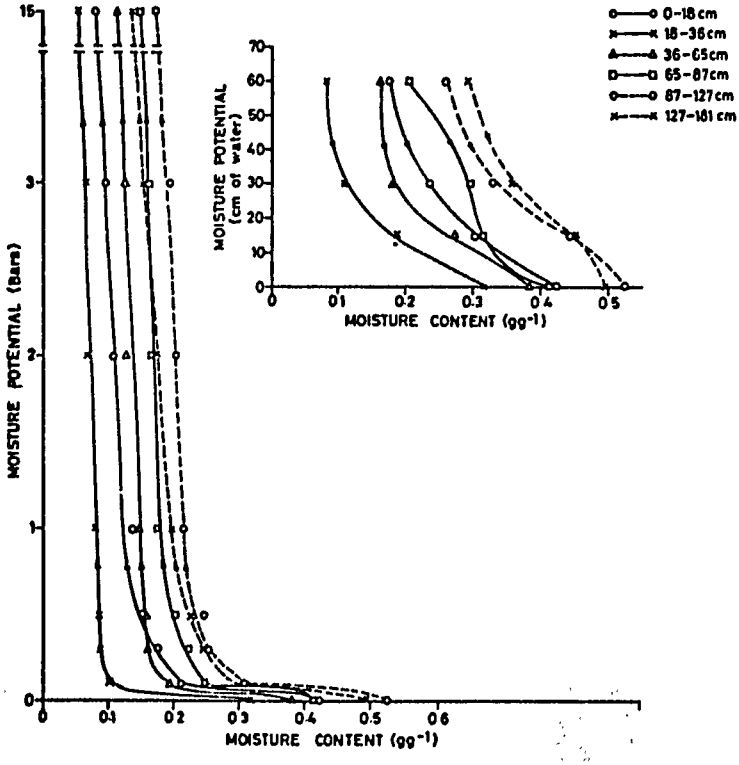


Fig. 8. High and low energy soil moisture characteristics, Profile No. 5, Gambari series.

Soil physical characteristics

Depth cm	Gravel %	Mechanical analysis % Sand	Silt	Clay	Penetrometer readings kg cm^{-2}	Bulk density g cm^{-3} Overall	Fine earth	Plasticity index	Shrinkage Limit	Ratio	Moisture equivalent %
0–18	17	66.3	12.7	21.0	1.17	1.57	1.56	3	19.0	1.8	14.6
18–36	72	70.2	10.7	19.1	2.58	1.60	0.84	0	—	—	14.0
36–65	73	53.7	14.0	32.3	3.17	1.52	0.71	2	18.0	1.9	16.6
65–87	54	43.0	13.7	43.3	2.17	1.50	1.06	8	18.5	1.9	22.1
87–127	19	35.0	18.1	46.9	1.75	1.40	1.33	9	24.6	1.7	21.6
127–181	17	47.0	22.7	30.3	1.67	1.42	1.40	6	21.3	1.8	22.8

Chemical properties

Depth cm	pH H_2O	KC1	Exchangeable cations, me/100g Ca	Mg	K	Na	Mn	A1	H	CEC me/100g	Organic C %	Total N %	Bray P1 ppm P	Non-exch. K ppm	Base Saturation %	C/N ratio
0–18	6.5	5.6	6.65	1.83	0.30	0.12	0.04	0.07	0.33	9.34	1.84	0.175	4.2	358	96	11
18–36	6.9	5.3	2.50	1.15	0.19	0.09	0.05	0.06	0.44	4.48	0.44	0.044	2.2	287	89	10
36–65	6.5	5.1	3.85	1.37	0.26	0.10	0.01	0.04	0.36	5.99	0.36	0.046	1.1	535	93	8
65–87	6.2	4.8	4.84	2.32	0.20	0.09	0.01	0.07	0.43	7.96	0.36	0.048	3.2	680	94	8
87–127	6.2	4.8	6.10	2.46	0.15	0.12	0.05	0.08	0.42	9.38	0.32	0.038	1.8	1062	95	8
127–187	6.0	4.5	6.10	4.02	0.10	0.17	0.02	0.06	0.44	10.91	0.12	0.017	1.1	1212	95	7

$IIB_{21}t$ cn: 36–65 cm, multicolored, mainly red (2.5YR 5/6) and yellowish red (5YR 5/6) very gravelly sandy clay loam; gravels are mainly Fe/Mn concretions and plinthite nodules; moderate, medium and fine subangular blocky structure in matrix; thick broken cutans; soft; common roots; many fine and medium tubular pores; clear wavy boundary.

$IIB_{22}t$ cn: 65–87 cm, plinthite; very gravelly clay, multicolored in reticulate pattern, main colors from yellowish red (5YR 5/8) to yellow (10YR 7/8); many moderately hard Fe/Mn concretions and quartz gravels; moderate fine subangular blocky structure; broken moderately thick cutans; firm; few roots; many fine tubular pores; clear wavy boundary.

IIIB3: 87–127 cm, reddish brown (5YR 5/4) gravelly clay, many fine distinct mottles; many laterite concretions and plinthite nodules; moderate medium subangular blocky structure; thin, patchy cutans, distinct in pores and channels; friable; few roots; common fine and few coarse tubular pores; gradual wavy boundary.

IIIC: 127–181 cm+, gravelly clay loam with inherited banded rock structure (saprolite), clearer with depth; very pale brown (10YR 7/3) matrix, many medium and coarse, prominent mottles, dominantly yellowish brown (10YR 5/6) and strong brown (7.5YR 4/8); weak medium and coarse angular blocky structure; firm; no cutans but in spots some clay-humus infiltration along vertical ped faces; few roots; few fine tubular pores.

Appendix B, Profile 6

Apomu Series

- Reference No. 032
- Topography: 8% slightly concave slope on the side of a valley.
- Vegetation: Thicket regrowth after shifting cultivation.
- Parent material: Semi-recent slope colluvium, overlaying an older stony colluvial layer at more than 100 cm depth.
- Drainage: Somewhat excessively drained but temporary water logging occurs in C horizon.

A_1: 0–9 cm, dark brown (7.5YR 3/2) loamy sand–sandy loam, weak fine crumb structure; loose; many roots; many fine interstitial pores; clear smooth boundary.

AC: 9–36 cm brown (7.5YR 4/3) loamy sand; weak fine and medium crumb structure; loose; common roots; many fine interstitial and common fine tubular pores; gradual smooth boundary.

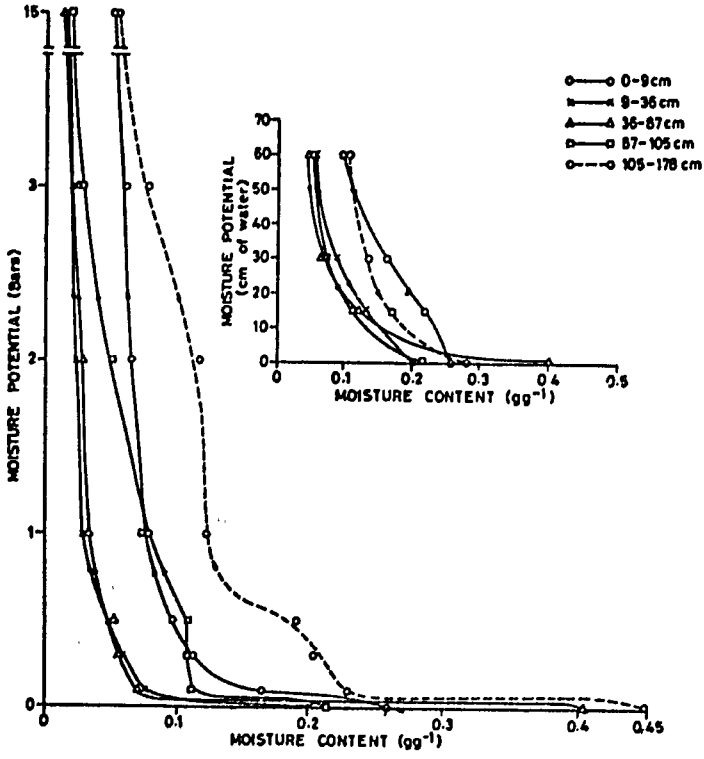


Fig. 9. High and low energy soil moisture characteristics, Profile No. 6, Apomu series.

Soil physical characteristics

Depth cm	Gravel %	Mechanical analysis % Sand	Silt	Clay	Penetrometer readings kg cm^{-2}	Bulk density g cm^{-3} Overall	Fine earth	Plasticity index	Shrinkage Limit	Ratio	Moisture equivalent %
0–9	2	78.3	11.4	10.3	0.23	1.22	1.20	0	–	–	8.7
9–36	3	82.2	7.4	10.4	0.25	1.36	1.33	0	–	–	3.6
36–87	4	87.0	2.7	10.3	0.50	1.50	1.49	0	–	–	2.8
87–105	5	82.2	5.1	12.7	1.50	1.52	1.51	0	–	–	4.0
105–178	30	74.2	5.1	20.7	2.08	1.54	1.54	0	–	–	8.3

Chemical properties

Depth cm	pH H_2O	KC1	Exchangeable cations, me/100g Ca	Mg	K	Na	Mn	Al	H	CEC me/100g	Organic C %	Total N %	Bray P1 ppm P	Non-exch. K ppm	Base Saturation %	C/N ratio
0–9	6.0	5.6	3.95	1.68	0.26	0.08	0.13	0.05	0.12	6.27	2.48	0.175	12.4	114	97	14
9–36	6.3	5.7	1.05	0.46	0.06	0.05	0.07	0.02	0.14	1.85	0.30	0.031	2.8	30	91	10
36–87	6.3	5.6	1.67	0.12	0.04	0.02	0.02	0.01	0.16	1.04	0.08	0.010	2.6	23	84	8
87–105	6.1	5.2	0.80	0.16	0.03	0.05	0.01	0.02	0.14	1.21	0.05	0.010	3.2	19	87	5
105–178	6.0	4.8	1.72	0.38	0.11	0.04	0.02	0.02	0.14	2.43	0.13	0.019	3.5	34	93	7

C_1: 36–87 cm; brown (7.5YR 5/4) loamy sand; very weak, medium crumb structure; loose; common roots; many fine interstitial and common fine tubular pores; gradual smooth boundary.

C_2: 87–105 cm; brown (7.5YR 5/4) loamy sand with common coarse distinct reddish brown (5YR 4/4) mottles; structureless single grained to weak medium crumb structure; loose, slightly hard when dry; few roots; common fine and medium interstitial and few. fine tubular pores; scattered small hard brown Fe/Mn concretions in lower part of the horizon; clear wavy boundary.

IIBtb: 105–178 cm+, gravelly sandy clay loam, mottled with brown (7.5YR 5/4) matrix and many distinct coarse and medium mottles, mainly yellowish red (5YR 4/7); moderate, medium subangular blocky structure; broken thin cutans, mainly in pores; few roots; common fine tubular pores; frequent subrounded quartz gravels (0.5–3 cm).

Appendix B, **Profile 7**

Iregun Series

- Reference No. 031A
- Topography: 2% flat slope, at the head of a slight depression.
- Vegetation: Bush regrowth after shifting cultivation.
- Parent material: Old coluvium derived from weathered basement complex rocks.
- Drainage: Well drained.

A_1: 0–16 cm; dark brown (7.5YR 3/2) sandy loam; moderate fine crumb structure; soft; many roots; many fine interstitial and tubular pores; clear smooth boundary.

A_3: 16–27 cm, brown (7.5YR 4/4) sandy clay loam; weak fine subangular blocky structure; soft; common roots; many fine tubular pores; gradual smooth boundary.

AB: 27–44 cm, brown (5–7.5YR 4/4) sandy clay loam; moderate fine subangular blocky structure; no

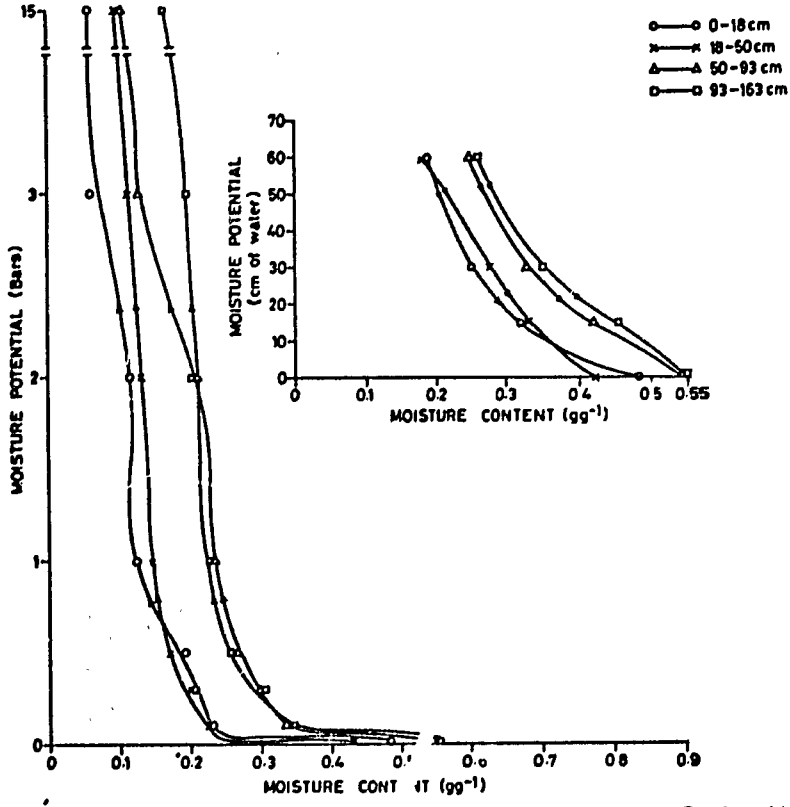


Fig. 10. High and low energy soil r oisture characteristics, Profile No. 7, Iregun series.

Soil physical characteristics

Depth cm	Gravel %	Mechanical analysis % Sand	Silt	Clay	Penetrometer readings kg cm^{-2}	Bulk density g cm^{-3} Overall	Fine earth	Plasticity index	Shrinkage Limit	Ratio	Moisture equivalent %
0–16	1	75.2	11.2	13.6	0.42	1.30	1.26	0	–	–	6.3
16–27	1	70.6	9.1	20.3	0.92	1.25	1.22	0	–	–	7.6
27–44	1	57.2	11.2	31.6	2.58	1.23	1.24	6	15.1	1.9	11.4
44–110	1	48.0	8.4	43.6	> 4.5	1.41	1.40	7	15.9	1.9	17.2
110–135	16	51.0	2.4	46.6	3.75	1.34	1.30	5	14.6	2.0	15.8
135–167	38	52.0	14.4	33.6	3.33	1.57	1.35	5	17.6	1.9	16.0

Chemical properties

Depth cm	pH H_2O	KCl	Exchangeable cations, me/100g Ca	Mg	K	Na	Mn	Al	H	CEC me/100g	Organic C %	Total N %	Bray P1 ppm P	Non-exch. K ppm	Base Saturation %	C/N ratio
0–16	6.5	5.6	1.84	0.63	0.14	0.04	0.02	0.01	0.07	2.75	0.66	0.077	23	150	97	9
16–27	6.3	4.7	1.09	0.66	0.10	0.03	0.03	0.02	0.10	2.03	0.40	0.052	21	133	94	8
27–44	5.9	4.7	1.40	0.87	0.14	0.04	0.04	0.02	0.14	2.65	0.40	0.052	12	175	94	8
44–110	5.8	4.7	2.06	0.60	0.12	0.06	0.06	0.02	0.14	3.06	0.44	0.052	7	118	95	8
110–135	6.0	4.8	1.94	0.94	0.10	0.08	0.08	0.02	0.14	3.05	0.30	0.044	7	113	95	7
135–167	6.0	5.2	1.85	0.74	0.09	0.07	0.07	0.02	0.10	2.94	0.26	0.035	9	38	96	7

cutans on peds but some root channels; slightly hard; many fine tubular pores; gradual smooth boundary.

$B_{21}t$: 44–110 cm, yellowish red (5YR 4/6) sandy clay; moderate fine subangular blocky structure; patchy, thin cutans, clear cutans in pores and root channels; hard; common roots; many fine tubular pores; gradual smooth boundary.

$B_{22}t$: 110–135 cm, strong brown (7.5YR 5/6) gravelly sandy clay; weak fine subangular blocky structure; no cutans on peds but some in root channels; slightly hard; common roots; many fine tubular pores; few small brown and black plinthite nodules; gradual smooth boundary.

BCcn: 135–167 cm+, strong brown (7.5YR 5/6) gravelly sandy clay loam; weak medium subangular blocky structure; no cutans; hard: few roots; common fine tubular pores; frequent small reddish brown (2.5YR 4/4) and black nodules, mostly soft (plinthite), partly hard (laterite), increasing with depth.

Appendix B, Profile 8

Iregun Series, transition to Jago Series.

- Reference No. 031.
- Topography: 6% concave lower slope towards valley bottom.
- Vegetation: Abandoned orchard with citrus and banana, secondary regrowth of shrubs.
- Parent material: Local slope colluvium over gravelly older colluvium.
- Drainage: Imperfectly drained; groundwater at less than 100 cm depth during periods of heavy rainfall.

A_1: 0-18 cm, brown (10YR 4/3) sandy clay loam; moderate fine crumb structure; very friable; many roots; many fine and medium interstitial pores; many fine mica flakes; gradual smooth boundary.

B_1t: 18-50 cm, brown (10YR 5/3) slightly gravelly sandy clay loam; faint fine mottles, increasing with depth; weak medium and coarse subangular blocky structure; patchy thin cutans on peds, distinct cutans in most pores; plastic and

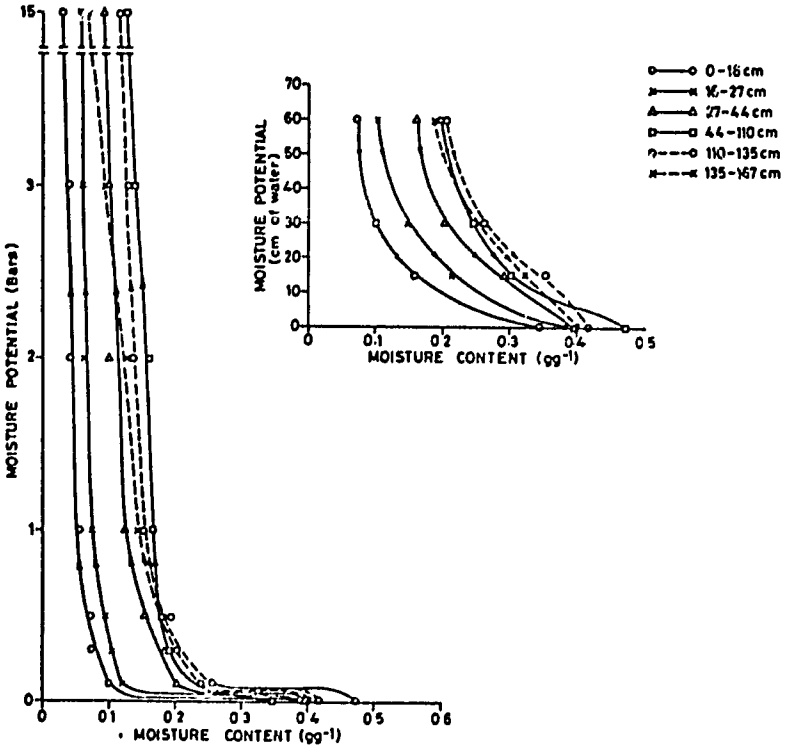


Fig. 11. High and low energy soil moisture characteristics, Profile No. 8, Iregun/Jago series.

Soil physical characteristics

Depth cm	Gravel %	Mechanical analysis % Sand	Silt	Clay	Penetrometer readings kg cm^{-2}	Bulk density g cm^{-3} Overall	Fine earth	Plasticity index	Shrinkage Limit	Ratio	Moisture equivalent %
0–18	2	58.3	16.7	25.0	0.92	1.22	1.21	3	18.6	1.8	14.7
18–50	8	54.3	13.7	35.0	1.08	1.48	1.46	6	16.4	1.9	16.2
50–93	34	46.3	7.7	46.0	1.42	1.58	1.00	9	18.6	1.9	24.8
93–165	24	48.2	14.7	37.1	1.08	1.38	1.35	13	19.5	1.9	25.1

Chemical properties

Depth cm	pH H_2O	KC1	Exchangeable cations, me/100g Ca	Mg	K	Na	Mn	A1	H	CEC me/100g	Organic C %	Total N %	Bray P1 ppm P	Non-exch. K ppm	Base Satura-tion %	C/N ratio
0–18	6.0	5.1	6.00	2.66	0.19	0.09	0.09	0.02	0.14	9.19	1.46	0.171	3.9	93	98	9
18–50	6.2	4.6	5.22	2.06	0.10	0.12	0.05	0.02	0.10	7.67	–	0.060	1.2	55	98	–
50–93	6.4	4.9	11.75	5.77	0.14	0.61	0.02	0.01	0.19	18.49	–	0.033	2.5	63	99	–
93–165	6.7	5.4	12.75	5.87	0.11	0.85	0.01	0.02	0.19	19.80	–	0.027	5.3	55	99	–

slightly sticky; common roots; many fine and medium tubular pores; gradual wavy boundary.

B_2tg: 50-93 cm, brown (10YR 5/3) gravelly sandy clay with many coarse distinct clear yellowish brown (10YR 5/6) mottles; moderate coarse subangular blocky structure patchy thin cutans on peds and in pores; plastic and slightly sticky; common roots; common fine and medium tubular pores; clear wavy boundary, abrupt in places.

Cg: 93-165 cm+, pale brown (10YR 6/3) gravelly sandy clay with local layers of coarser angular quartz gravels (0.5-3 cm); many coarse distinct clear yellowish brown and strong brown mottles; moderate coarse angular blocky structure; no clear cutans; plastic and slightly sticky; few roots; common fine and medium pores.

Appendix B, **Profile 9**

Matako Series

- Reference No. 034
- Topography: 1% slightly concave lower slope in a U-shaped valley.
- Vegetation: Well developed secondary forest with many oilpalms (Elaeis).
- Parent material: Sandy alluvium and colluvium over older, possibly sendentary, clay.
- Drainage: Somewhat poorly drained. Wet season drainage is poor due to lateral seepage; groundwater is at less than 50 cm depth during most periods with heavy rains. Dry season groundwater not reached at less than 200 cm.

A_1: 0–40 cm, very dark gray (10YR 3/1) sandy loam; weak fine crumb structure; loose; many roots; many fine interstitial pores; clear wavy boundary.

C_1: 40–60 cm, grayish brown (10YR 5/2) loamy sand; structureless single grained; loose; common roots: few pores; gradual wavy boundary.

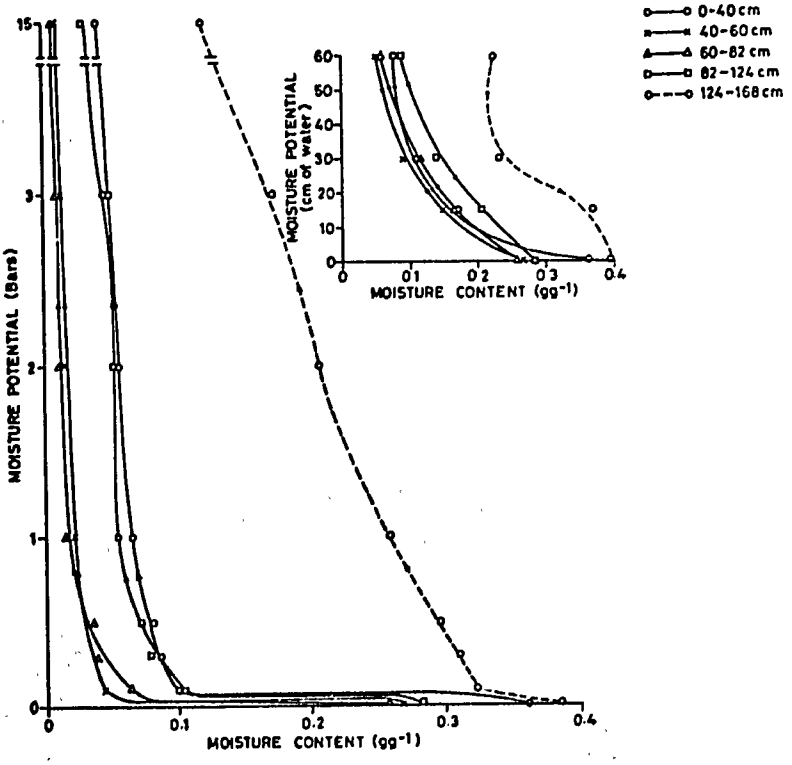


Fig. 12. High and low energy soil moisture characteristics, Profile No. 9, Matako series.

Soil physical characteristics

Depth cm	Gravel %	Mechanical analysis % Sand	Silt	Clay	Penetrometer readings kg cm^{-2}	Bulk density g cm^{-3} Overall	Fine earth	Plasticity index	Shrinkage Limit	Ratio	Moisture equivalent %
0–40	1	75.0	12.7	12.3	0.33	1.28	1.26	0	–	–	9.8
40–60	1	84.0	9.8	6.2	0.58	1.51	1.50	0	–	–	2.0
60–82	1	84.0	6.9	9.1	1.33	1.56	1.53	0	–	–	3.6
82–124	3	76.5	8.5	15.1	> 4.5	1.68	1.67	0	–	–	7.7
124–168	4	43.5	9.5	47.0	> 4.5	1.67	1.76	11	14.9	2.0	42.4

Chemical properties

Depth cm	pH H_2O	KCl	Exchangeable cations, me/100g Ca	Mg	K	Na	Mn	Al	H	CEC me/100g	Organic C %	Total N %	Bray P1 ppm P	Non-exch. K ppm	Base Saturation %	C/N ratio
0–40	5.2	4.5	0.67	0.81	0.09	0.08	0.01	0.03	0.27	1.96	0.94	0.119	7.2	58	86	8
40–60	6.0	4.9	0.47	0.21	0.03	0.05	nd	0.02	0.28	1.06	0.07	0.008	4.2	15	68	9
60–82	6.1	4.9	0.47	0.13	0.02	0.03	nd	0.02	0.58	1.25	0.04	0.004	3.6	13	41	10
82–124	6.3	4.3	0.49	0.74	0.04	0.26	0.01	0.03	0.28	1.85	0.05	–	2.9	65	83	–
124–168	6.4	4.7	1.58	6.83	0.09	2.24	nd	0.01	0.29	11.04	0.04	0.004	3.9	130	97	10

C_2: 60–82 cm, brown (7.5–10YR 5/3) loamy sand; common fine and medium faint brown mottles; structureless single grain; loose; common roots; many fine tubular pores; abrupt irregular boundary.

C_3g: 82–124 cm, gray (10YR 5/1) sandy loam; many fine and medium distinct yellowish brown mottles; very weak fine subangular blocky structure; slightly hard; common roots; many fine tubular pores; abrupt wavy boundary.

IIC4g: 124–160 cm+, gray (5YR 5/1) slightly gravelly clay; many fine distinct yellowish brown mottles; weak medium angular blocky structure; very firm, non sticky and plastic when wet; common fine tubular pores; few fine (2–10 mm) angular quartz gravels.

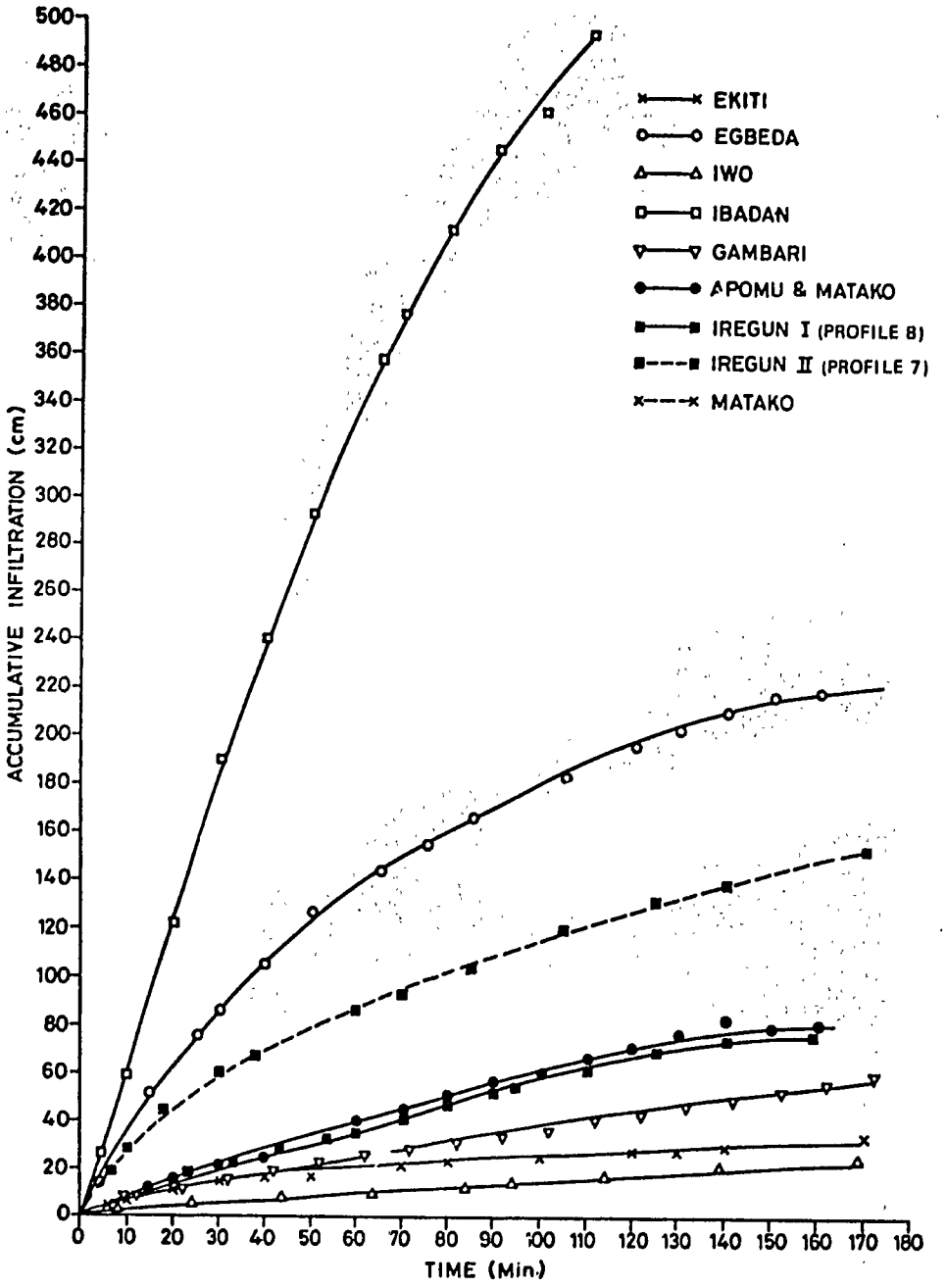


Fig. 13. Field infiltration rates of representative IITA soils.

Appendix D.

Tentative land evaluation at IITA

Land type* / Crop	1	2 & 3	4 Higher	4 Lower	6
Maize	II_A	II_B	II_B	II_A	IV/II_A
Cassava	II_A	II_A	II_A	II_A	IV
Yam	II_B	IV	III	II_A	IV/II_A
Rice	IV	IV	IV	II_B	II_A/I
Cowpeas	II_A	II_B	II_B	II_A	IV/III
Pigeon Peas	II_B	III	II_B	III	IV
Soybeans	II_B	IV	IV	II_A	IV/II_A

*See map on page 8. Unit 5 is not included in this evaluation. Two values are given for land type 6; the first is suitability for the main growing season and the second pertains either to dry season crops or to improved land conditions.

KEY: I – Suitable with no or few limitations

II – Moderately suitable, increasing limitations

A – Recurrent inputs are economical

B – Recurrent inputs are not economical

III – Marginal, severe limitations

IV – Unsuitable