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9. ABSTRACT

Four benchmark sites were selected along a rainfall gradient from Lome, Togo, to Calabar, Nigeria, along the coast of West Africa. Through this climosequence, rainfall increased from 900 to 2600 mm per annum. Soils of the three driest sites were characterized as Paleustalfs, while those at the wettest site were Paleudults. Cropping patterns through the climosequence were studied. Population pressure was found to be as significant a parameter as rainfall in determining the patterns. In a series of field experiments with maize, cassava, and soybeans at the benchmark sites, it was found that fertilizer at the rates used was not more economic than traditional practices, although more uniform spacing and improved cultural practices increased yields in the absence of fertilizers. Previous results of other workers were used to estimate the productivity of two cultivation systems of differing intensities. The more intensive system involved cropping a single site for two to five years rather than shifting sites each year in the less intensive system. Although the more intensive system appeared to be more productive, the less intensive system appeared to be more favored by local farmers because it produced a more dependenable yearly income and was more suitable to the technological resources of the population.

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A WEST AFRICAN SOIL CLIMOSEQUENCE AND SOME ASPECTS OF FOODCROP POTENTIAL

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University for the Degree of

Master of Science

by

Terry Robert Forbes

August 1975

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BIOGRAPHICAL SKETCH

The author was born in Chico, California on the 8th of February 1946. He attended elementary and high school in Avon, Ohio. He majored in biological science and graduated with a Bachelor of Arts degree from Johns Hopkins University, Baltimore, Maryland in 1968. Subsequently, he taught biology and chemistry for three years at a secondary school in the Republic of Zaire.

ACKNOWLEDGEMENTS

I am sincerely grateful to the Department of Agronomy of Cornell University for supporting me throughout my studies with both teaching and research assistantships without which it would have been impossible to continue my education. Also, special thanks go to the International Institute of Tropical Agriculture in Ibadan, Nigeria for providing funds and facilities for the completion of the research described in this thesis.

I would like to express special thanks to Dr. Richard W. Arnold, my committee chairman, for his advice and guidance throughout the period of data collection and the writing of this thesis and for the moral support he gave me during a visit to the West African sites in August 1974. Appreciation is also extended to Dr. Marlin G. Cline who helped me develop my course of studies at Cornell and laid the necessary groundwork with IITA for the work in West Africa. I would also like to express sincere appreciation to Dr. F. R. Moormann of IITA for his expert guidance in the gathering and organization of the data and his help in arranging a multitude of technical problems including the analysis of samples and the necessary field and transportation facilities. Special thanks go to Dr. Daniel G. Sisler, my minor committee member, for his enlightening remarks and views on my thesis problem and for his help in preparing the final form.

I was very fortunate throughout my stay in Nigeria and Togo to meet and confer with many professional workers who gave me much needed practical and theoretical advice on conditions in each area. I am sincerely grateful to the following people for their help: M. Sant'ana (Ministere de l'Agriculture, Lome, Togo), Mr. Fagbemi (MANR, Shagamu, Nigeria), Mr. Adekunle (IART, Ikenne, Nigeria), Dr. T. Johnson (NIFOR, Benin City, Nigeria), Mr. P. J. Ikpeme (Obio-Akpa Model Farm, Abak, Nigeria), and Mr. M. Ekandem (Federal Ministry of Agriculture, Uyo, Nigeria).

I am grateful to Dr. W. H. Reeves (IITA) for his friendliness and support during my stay in Nigeria and to Dr. A. Juo (IITA) for his advice and help with the analysis of soil samples. I enjoyed and appreciated the friendship and cooperation of Alain Gallez during my stay at IITA.

Lastly, I thank my parents for their encouragement and understanding during the times when I was many miles from home.

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INTRODUCTION

In the spring of 1973 Dr. F. R. Moormann of the International Institute of Tropical Agriculture, Ibadan, Nigeria, proposed a study concerning a climosequence comprised of a lithologically continuous zone of sedimentary parent materials extending from Lome, Togo to Calabar, Nigeria over which the annual rainfall increases gradually from Lome to Calabar. Dr. M. G. Cline of Cornell University made the initial arrangements for the study and Dr. R. W. Arnold undertook its supervision and visited the West African sites in August 1974. Mr. T. R. Forbes, a graduate student in the Department of Agronomy of Cornell University, Ithaca, New York, made the study. Field research started in September 1973 and concluded in December 1974.

The objectives of the study were the following:

1. Characterize the climate and soils at four benchmark sites. This involved collecting data on the mean monthly and annual levels of precipitation, the average number of raindays per month, the heaviest daily rainfall per month, mean monthly temperatures, mean monthly potential evapotranspiration (PET) and mean monthly global radiation for each benchmark site. In terms of soils the major upland, well-drained soils and important associated soils were studied and described for each benchmark site. This also

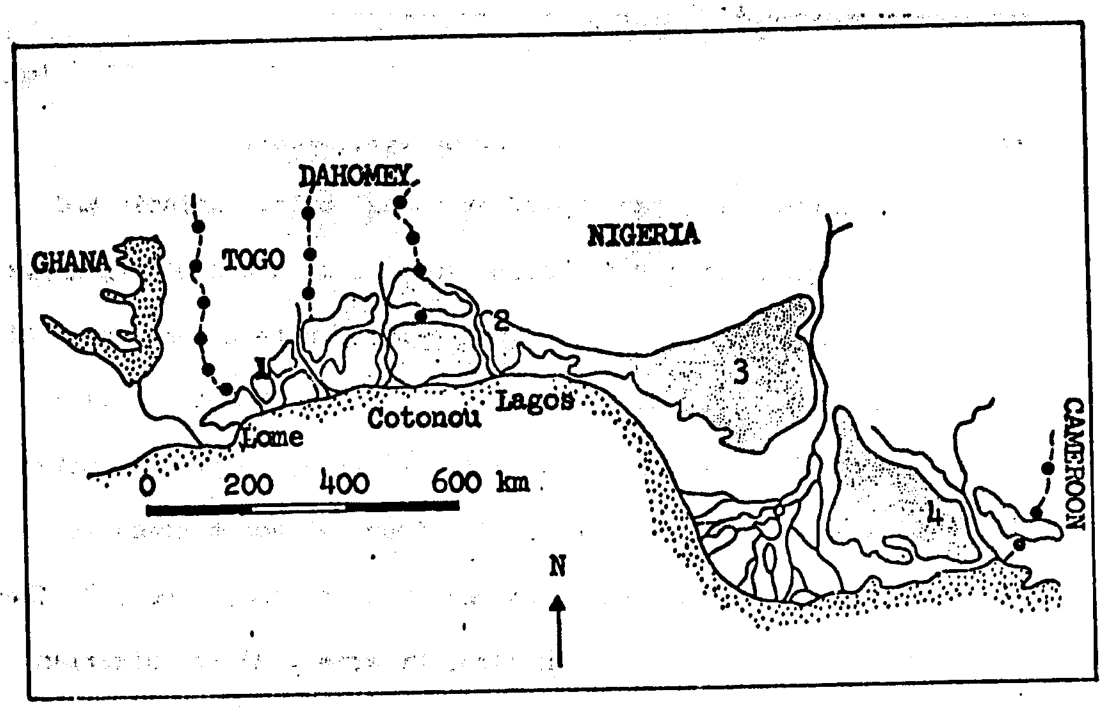
meant characterizing the five major soil-forming factors: climate (as specified above), parent material, topography, organisms and time. More specific objectives for soils were demonstrating the existence of cutans on some or most peds in B-horizons having at least a sandy clay texture and showing the resaturation of the exchange complex in the argillic horizon at the lower rainfall sites, thus placing these soils in the unlikely classification of Alfisols. Ultisols were expected at the higher rainfall areas due to higher rates of leaching of the exchange complex.

2. Characterize systems of local farming at each benchmark area. This involved the determination of the kinds of crops grown and their rotations, the average size of farms and the cultural systems of management such as length of fallows, methods of land preparation, planting, weeding, control of pests and harvesting. There was no preconceived hypotheses concerning variations on the traditional system of shifting cultivation due to high population densities in some areas.

3. Determination of agronomic potential and major limiting factors to the realization of that potential. Agronomic potential was determined by measuring average yields of major foodcrops at each benchmark area. To avoid confusion these yield levels were determined for two distinct cultural systems, the system of traditional management and the system of experimental management. It was

hypothesized that major factors in the yield level of any given foodcrop would be the length of time which a soil had been under cultivation and the length of fallows employed. Those areas having a high demographic pressure and intensive use of soils were expected to show lower yield levels. Also it was hypothesized that the higher rainfall sites would show lower yield levels due to more intense leaching of soils. Two field experiments were conducted in a low and high rainfall area using the same treatments to show the importance of fallows and the diminution in yield with intensive cultivation even with the use of optimum levels of fertilizers.

Since there was a paucity of existing soils, climatic and agronomic information for the climosequence as a whole, benchmark areas were chosen near major administrative centers where some of these data could be found through agricultural agencies. Also major gaps in information could be filled in by a more intensive study of farms in smaller areas. The four benchmark areas were: 1) Mission Tove (approximately 25 km north of Lome, Togo), 2) Ikenne (approximately 10 km east of Shagamu, Nigeria), 3) the Nigerian Institute for Oil Palm Research (approximately 25 km northwest of Benin City, Nigeria), 4) Obio-Akpa Model Farm (approximately 6 km west of Abak, Nigeria). In this report, these areas will be referred to as: 1) South Togo, 2) Ikenne, 3) Benin-NIFOR, and 4) Abak benchmark areas respectively (Figure 1). Where some kinds of data from benchmark areas were not available data from nearby areas were used after checking to see that there were no significant differences in soils and climate. In each area the necessary agricultural officers were contacted and asked to cooperate in the choice of sites, the gathering of existing soil, climatic and agronomic data and support in contacting local farmers.



1 South Togo Benchmark Area
2 Ikenne Benchmark Area
3 Benin-NIFOR Benchmark Area
4 Abak Benchmark Area

Fig. 1: Location of Bench mark Study Areas on Plio-Pleistocene Coastal Formations (after F. R. Moormann, 1975).

A word of caution must be given about all of the data and observations relating to: cultural practices, size of farms, composition of foodcrops grown, and yields of foodcrops under traditional and experimental management. This information was gathered between September 1973 to December 1974 and refers specifically to that period. The study areas were too big and too distant from each other to make statistically valid sampling by one person possible. Some of these data reflect judgments by the author, after consulting many agricultural workers familiar with the study areas.

Background

A climosequence is a soil system throughout which the factors of parent material, topography and time remain constant or within defined narrow limits. Differences in soil properties are thought to have been produced by differences in climate (moisture and temperature regimes) and organisms across the climosequence. The principle of climosequences can be derived in part from the theory proposed in Hans Jenny's Factors of Soil Formation. Five soil-forming factors: climate, organisms, topography, parent material and time are responsible for the observed nature and properties of soils and can be expressed by the following equation:

Soil system = f(climate, organisms, relief, parent material, time)

(Jenny, 1941)

According to Jenny, differences in rainfall or soil moisture functions markedly affect the landscape, especially the type of vegetation and the nature of soils. Most studies of climosequences have been made on mountainous transects. In these studies parent material, time and topography remain constant but differences in elevation produce different moisture and temperature regimes. The climatic factor in these areas includes both moisture and temperature differences. In this West African study the temperature regime (isohyperthermic) remains constant. Differences in soil properties can therefore be related to differences in quantity and distribution of precipitation and differences in kinds of organisms, as lithology of the parent material and elevation remain nearly constant throughout.

Several studies were made in the Great Plains and other areas of the continental United States by Jenny and others in which only rainfall quantity and distribution and organisms were independent variables. Soil properties such as the kind, quantity and distribution of clay throughout the soil profile, quantities of organic matter and nitrogen, exchangeable cations and others were determined in an attempt to find out how these properties varied with moisture indexes. Direct causal relationships between these properties and the climatic factor, moisture, were not postulated (Jenny, 1941).

The second aspect of this study involved the determination of the foodcrop potential for the major soils in each area. Foodcrop potential may be conceived as analogous to Jenny's concept of soil productivity. The soil is not separated from the local climate and a concept more closely related to land is necessary. The foodcrop potential of this land or producing system can best be measured by the yields of a crop per unit area (Jenny, 1941). The yield is dependent on the factors expressed in the equation below:

Yield = f(climate, plant, man, parent material, time)
(Jenny, 1941)

Parent material is used here in the sense that once the natural vegetation of a soil has been altered and other changes have been made by man such as plowing, the soil must be considered as parent material since one of the soil-forming factors have been changed (Jenny, 1941). In this study climate, man and parent material ("soil" in the layman's sense) are independent variables with plants and time remaining suitably constant over the climosequence. The factor "man" is particularly hard to define but includes at least the cultural systems and management. The cultural systems and management in turn are determined by such variables as demographic pressure and availability of land, level of technology used by the farmer, education and other socio-economic factors. Although this study will describe some of the socio-economic factors as they occur in the study areas, the main concern was to make a qualitative judgment about the feasibility of growing certain foodcrops at each benchmark area. To make this judgement existing cropping data were gathered, farmers' yields weighed and field experiments conducted at Ikenne and Abak benchmark areas.

GENERAL DATA

Geological history of the benchmark areas

During the end of the Cretaceous period the sea gradually invaded the coast of West Africa (Slansky, 1962). At the same time weathered detritus from the continent containing mostly quartz sand and kaolinitic clay was transported to the coasts. During this period, different modes of deposition are recognized: fluvial, estuarine or coastal deposition and lagoonal or deltaic (these modes of deposition apply to Plio-Pleistocene also). The Cretaceous sedimentary rocks are completely covered by younger sediments and only in the Ikenne area do these older formation outcrop locally in incised valleys.

The soils in this study were formed on younger Plio-Pleistocene coastal formations. Deposition started with a short period of marine sedimentation during an invasion of the sea. Soon continental deposition followed during a regression of the sea.

Again, mostly quartz sand and kaolinitic clay were transported. During this period, erosion and the capacity of streams and rivers to transport sediments increased. It was probably at this time that much of the older surface (end of Cretaceous) in the general area of Ikenne was eroded and reworked before being recovered. This younger sedimentation, which is not reported by contemporary geologists, explains the similar nature of the surface materials of Ikenne to the other areas.[1]

Before the deposition of the coastal plain sands (Plio-Pleistocene) erosion formed the depressions of Lama (Togo and Dahomey) and Ewekoro (Nigeria) and exposed calcareous Cretaceous and Eocene sediments. During this period (probably a sea regression) the major north-south drainage system was formed (Slansky, 1962). Deposits from Ikenne southward include a recent cover of Plio-Pleistocene coastal plain sands materials (Figure 2). The other three benchmark areas are on coastal plain sands which extend to great depth.

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[1]Geological maps (Jones and Hockey, 1964) show the Ikenne area to be underlain by sediments dating from the end of Cretaceous. However, the surface sediments are more similar to Plio-Pleistocene sediments found at the other benchmark areas (personal communication, F. R. Moormann, 1974).

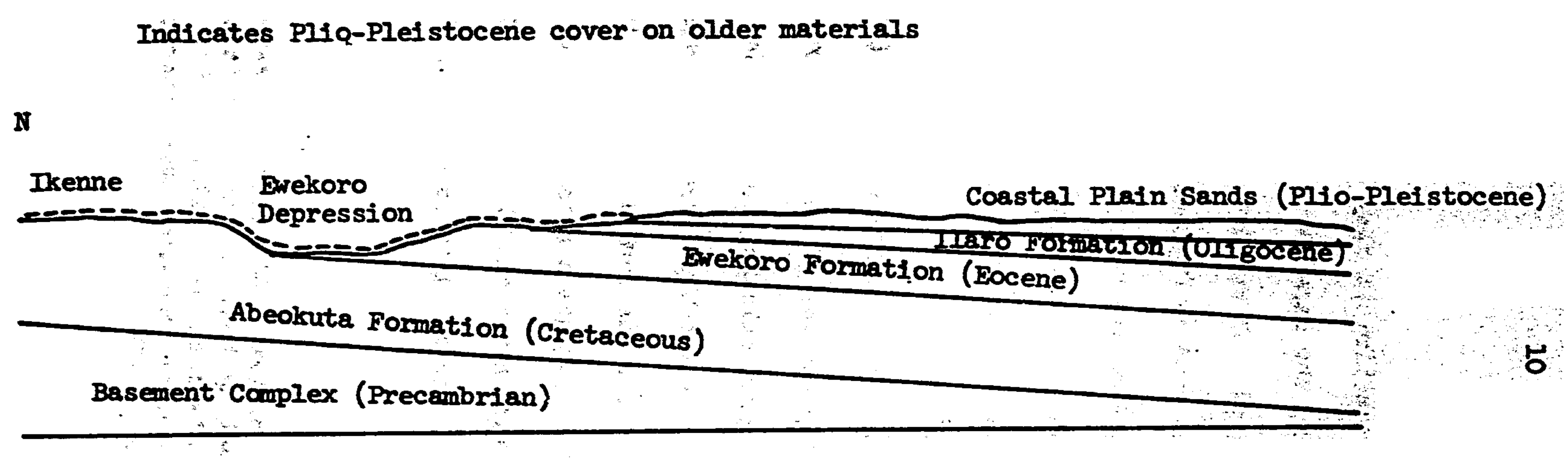

Fig. 2. Idealized geological crossection from Ikenne south towards Logos Lagoon.

Parent materials

The surface materials in which all of the upland soils are formed are coastal plain sands (Plio-Pleistocene) or more recent colluvial overburden derived from this formation. These materials when weathered have a sandy clay texture. The sand fraction is quartz and the clay fraction is a mixture of kaolinite and sesquioxides, mainly iron oxides. The very similar nature of the soils formed on these undulating plateaus is probably due to the highly weathered nature of the sediments prior to deposition, and to the effects of mixing and mass movement on these surfaces during periods of erosion following the Pleistocene (personal communication, F. R. Moormann, 1974).

On the coastal plain sands two variations in soil parent materials can be seen locally and regionally. Regionally, the coastal formations have two facies: 1) a finer facies, expecially at depth in the central or northern regions of the coastal plain sands formations and 2) a coarser fancies, in the upper layers especially, in the southern areas of the formation (Slansky, 1962). Upland soils on the undulating plateaus of the northern area tend to be more clayey from the surface, while sandier surface soils were formed in the southern area of the coastal plain sands formations.

Locally, soils formed on slopes in dissected areas of the undulating plateaus tend to be quite sandy to depths up to two meters due to the sandy nature of the parent material (sandy colluvial overburden which has been transported from the plateau surface).

The highly weathered nature of these sediments is illustrated by the chemical composition in Table 1.

Table 1. Chemical composition of coastal plain sands (Plio-Pleistocene) (after Slansky, 1962)

Percent oxide composition of brown, fine clayey sand (15m depth) at Bopa, Dahomey

SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+CO_2	P_2O_5	MnO
56.9	13.4	11.9	___	1.4	0.4	0.2	2.1	14.4	0.3	trace

Geomorphology and landforms

In the study areas, the geological strata from the Cretaceous upwards form a cuesta relief pattern with a dip of approximately 1% towards the sea. Dissection is slight where interfluve areas comprise up to 90% of the drainage basin. On these undulating plateaus, slopes usually do not exceed 2%. Close to major rivers and their tributaries, the landscape is more dissected and interfluve areas comprise 60% or less of the area (Jeje, 1969). The summits are remnants of the undulating plateaus which dominate else-where. The Abak area is the most dissected landscape studied. It gently rolling and the high points are remnants of an undulating plateau. Another feature of the Abak area is the presence of "suspended" valleys. These valleys occur as first and second order valleys with no definite stream bed for the outward movement of water. The valleys appear to be filling in, whereas third and fourth order valleys appear to be downcutting. The Benin-NIFOR area is also dissected, though to a lesser degree. The Ikenne and south Togo benchmark areas show the least dissection. Schematic crossections of the relief and locations of the pedons are given in Appendix II along with the pedon descriptions.

Climatic parameters

Rainfall increases from west to east, temperature remains uniform, potential evapotranspiration, and average global radiation decrease slightly as seen in Table 2. Detailed monthly figures for each benchmark area are in Appendix I.

Table 2. Annual climatic data for four benchmark areas

Parameter	Location			
	South Togo	Ikenne	Benin-NIFOR	Abak
1. Mean annual precipitation (mm.)	893	1425	1844	2610
2. Mean annual PET (mm.)	1360	1340	1330	1250
3. Mean annual temperature (°C)	26.4	no data	26.1	26.0
4. Mean daily global radiation (<u>per annum</u>) Langleys/day	421	no data	380	354
5. Number of raindays <u>per annum</u>	62	125	152	171

Vegetation

The natural vegetation was difficult to discern throughout most of the study areas due to disruption of the forest cover by shifting cultivators. The secondary climax vegetation for all the areas is forest and at Benin-NIFOR where there is a low population density, remnants of more mature forest can be observed.

In the cultivated areas around south Togo the bush fallow is composed of grasses, the most predominant being: Imperata cylindrica, Andropogon sp., and Panicum maximum with some woody shrubs. There are baobab trees (Adansonia digitata), evidence of a drier climate (Guinea savanna) and some oil palms (Elaeis guineensis) and coconut palms (Cocos hucifera). It is possible that the baobab was introduced by the north-south migration of nomadic tribes (personal communication, F. R. Moormann, 1974).

Near Ikenne and Benin-NIFOR the early bush fallow is composed almost entirely of Eupatorium odoratum (a newly introduced weed which has taken over as the predominant fallow vegetation in the last 10 to 15 years). In older fallows shrubs and trees dominate. Trees such as Triplochitan scleroxylan, Clorophora excelsa, Mitragyna stipulosa and Terminalia ivorensis are predominant forest species (personal communication, T. Johnson, NIFOR, 1974). In the Ikenne area oil palms and kola (Cola acuminata) are common as permanent trees in areas of shifting cultivation. These are the only trees never cut by shifting cultivators due to their economic value. Acioa barteri and Pueria sp. are the predominant woody shrubs.

In Abak the early bush fallow is Eupatorium odoratum mixed with numerous oil palms and a few woody shrubs such as Acioa barteri and Pueria sp. Usually no further forest regeneration occurs in this densely populated area between cultivation periods in the shifting cultivation cycle. Locally, small areas with shrubs or forest may be observed.

Data summary

The only environmental factors which differ between benchmark areas are those related to quantity and distribution of precipitation (Table 3).

Table 3. Summary of environmental factors across the climosequence.

	South Togo	Ikenne	Benin-NIFOR	Abak
1. Annual precipitation (mm.)	893	1425	1850	2610
2. Drier months	July, Aug., Sept., Nov., Dec., Jan., Feb.	Nov., Dec., Jan., Feb.	Nov., Dec., Jan., Feb.	Dec., Jan., Feb.
3. Estimated soil moisture regime	Ustic	Ustic	Ustic (marginal to Udic)	Udic
4. Climax vegetation	Forest	Forest	Forest	Forest
5. Relief	Gently Undulating Plateaus	Gently Undulating Plateaus	Gently Undulating Plateaus	Gently Undulating Plateaus
6. Geological materials	Coastal Plain Sands	Coastal Plain Sands	Coastal Plain Sands	Coastal Plain Sands

GENERAL CHARACTERISTICS OF WELL-DRAINED SOILS OF THE STUDY AREAS

Presence of an argillic horizon

The B-horizon of the well-drained upland soils is an argillic horizon. Researchers in Togo have found that there is less clay in the layers below 3m than in the 1 to 3m layer. It is also thought that the thickness of the superficial sandy layer is a result of the equilibrium of the erosion of sand to the depressions and the eluviation of clay to the lower horizons (FAO, 1967). Studies of Alagba soils of southern Nigeria have shown a co-migration of clay and dithionite-extractable Fe which indicates the mechanical migration of clay-size mineral particles from the A to the B horizons (Juo, Moormann and Maduakor, 1973).

The author always observed cutans on some or most peds in the examination of the B-horizons having at least a sandy clay texture. In B-horizons of lighter textures clay bridges between the quartz sand grains were always observed (see soil descriptions in Appendix II).

Soil moisture regime

Specific data on the soil moisture regimes were not available for any of the soils in the four benchmark areas. The soils are thought to have either an udic or ustic soil moisture regime. In an udic oil moisture regime the moisture control section is not dry in any part for as long as 90 cumulative days. An ustic soil moisture regime implies that the moisture control section is dry in some or all parts for more than 90 cumulative days in most years, while the control section is moist in some part for more than 180 cumulative days or is continuously moist for at least 90 consecutive days in some part. In view of the predominant textures of the soils studied, the soil moisture control section would commonly include the soil between approximately 20 to 60 cms depth (Soil Taxonomy, 1973).

Sufficient climatic data, mean monthly rainfall, mean monthly temperatures and potential evapotranspiration figures were available for estimating soil moisture and temperature regimes for each region (see Appendix I and Figs. 3-6).

The temperatures and potential evapotranspiration figures do not vary significantly throughout the year in any one region or for the four regions taken together. The most striking differences are seen in the magnitude and distribution of rainfall from area to area. South Togo (Lome) has the lowest annual rainfall with approximately 900 mm. The potential evapotranspiration exceeds the precipitation for approximately eight months of the year (Fig. 3). The soil moisture regime is estimated to be ustic. The soil temperature regime is isohyperthermic.

The Ikenne area has an annual precipitation of 1500 mm. The potential evapotranspiration exceeds the precipitation approximately 5 out of 12 months (Fig. 4). The soil moisture regime is estimated to be ustic and the temperature regime isohyperthermic.

The Benin-NIFOR area has approximately 1800 mm of annual precipitation and four months during which the potential evapotranspiration exceeds the monthly rainfall (Fig. 5). The soil moisture regime is probably ustic but transitional to udic. The exact determination would require measurements during a number of years. The staff at NIFOR

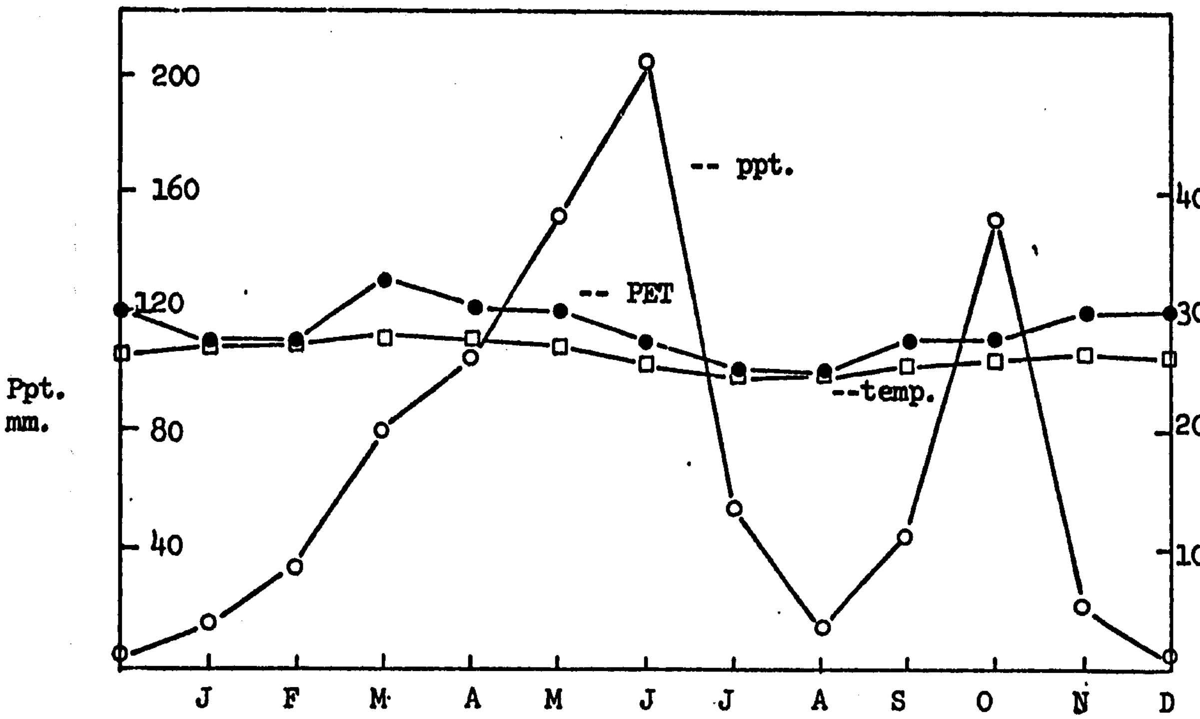

Fig. 3. Mean monthly rainfall, potential evapotranspiration and temperatures for South Togo (Lome) benchmark area.

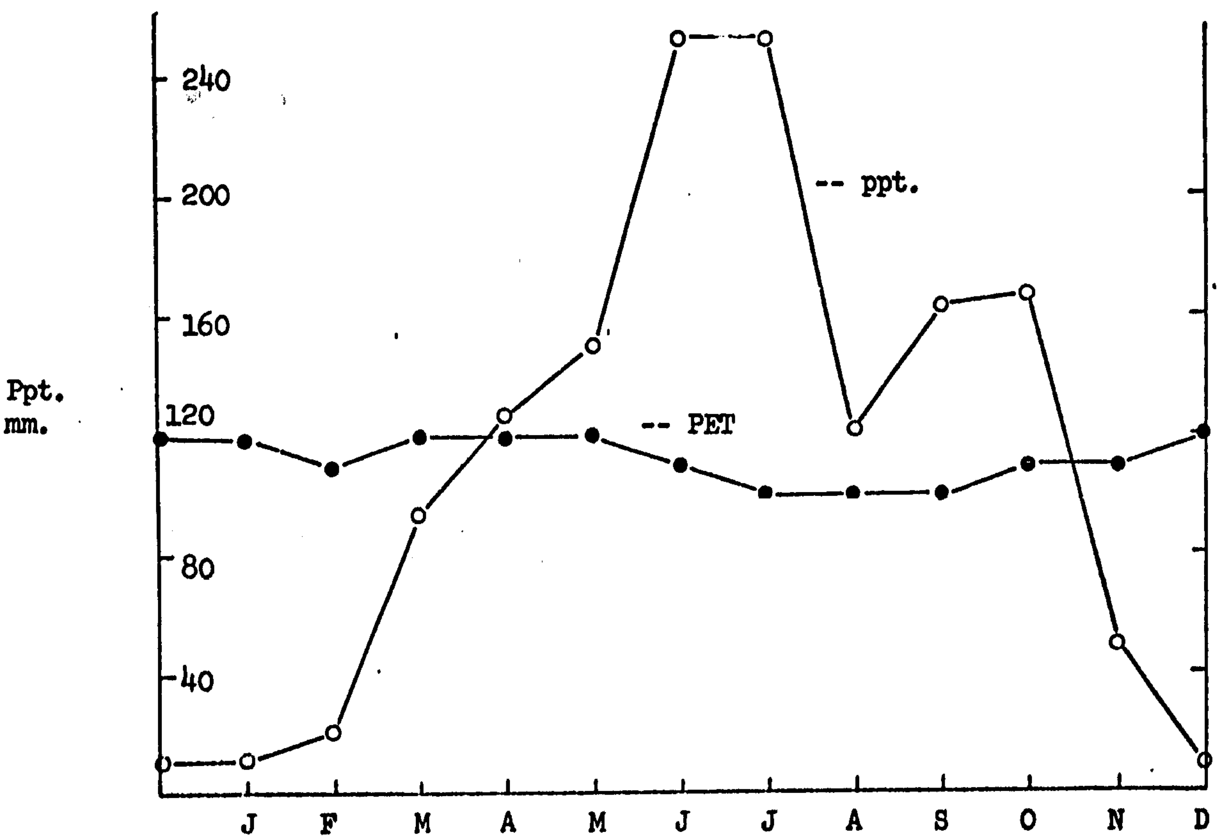

Fig. 4. Mean monthly rainfall and potential evapotranspiration for Ikenne benchmark area.

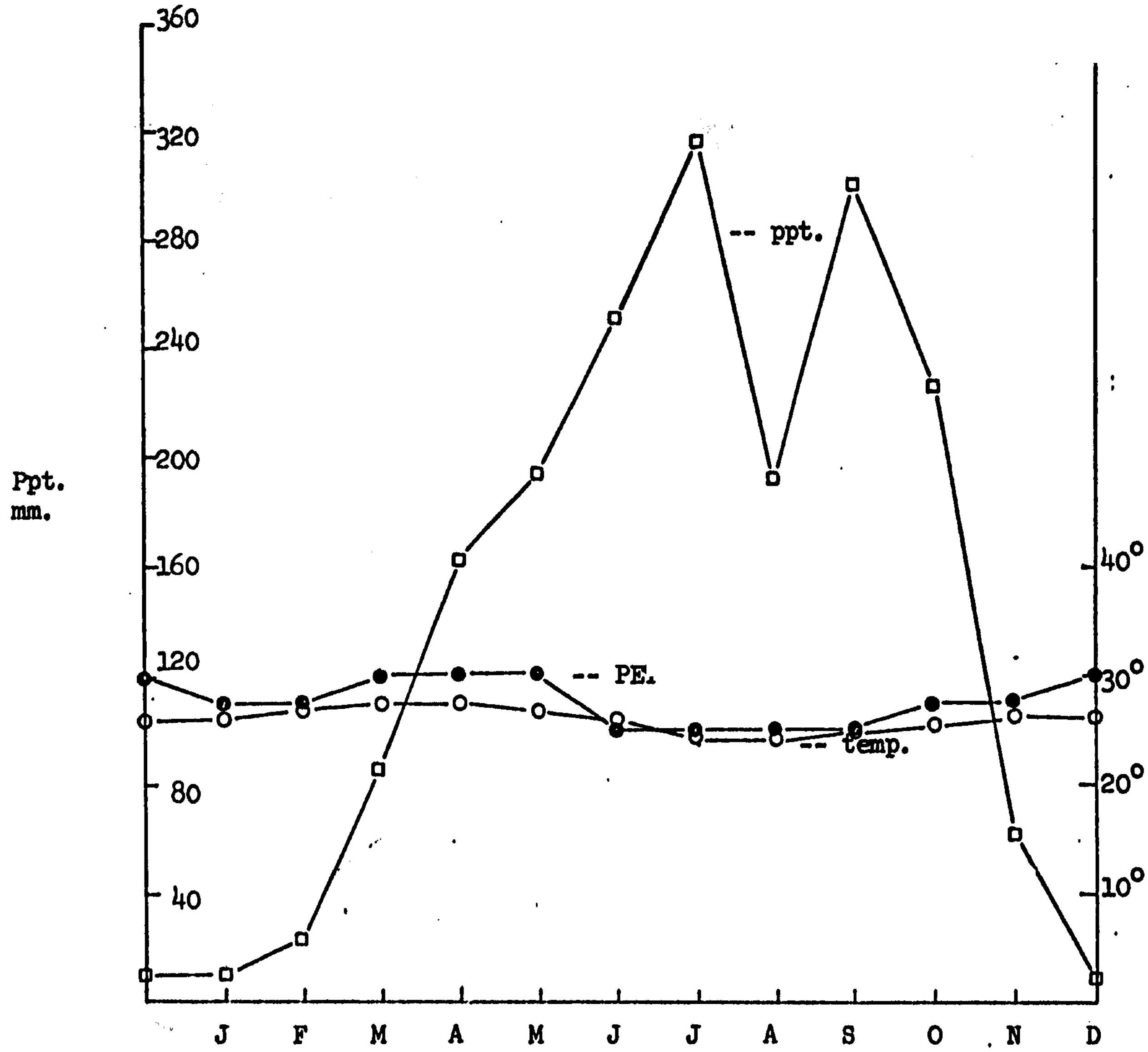

Fig. 5. Mean monthly rainfall, potential evapotranspiration and temperatures for Benin-NIFOR benchmark area.

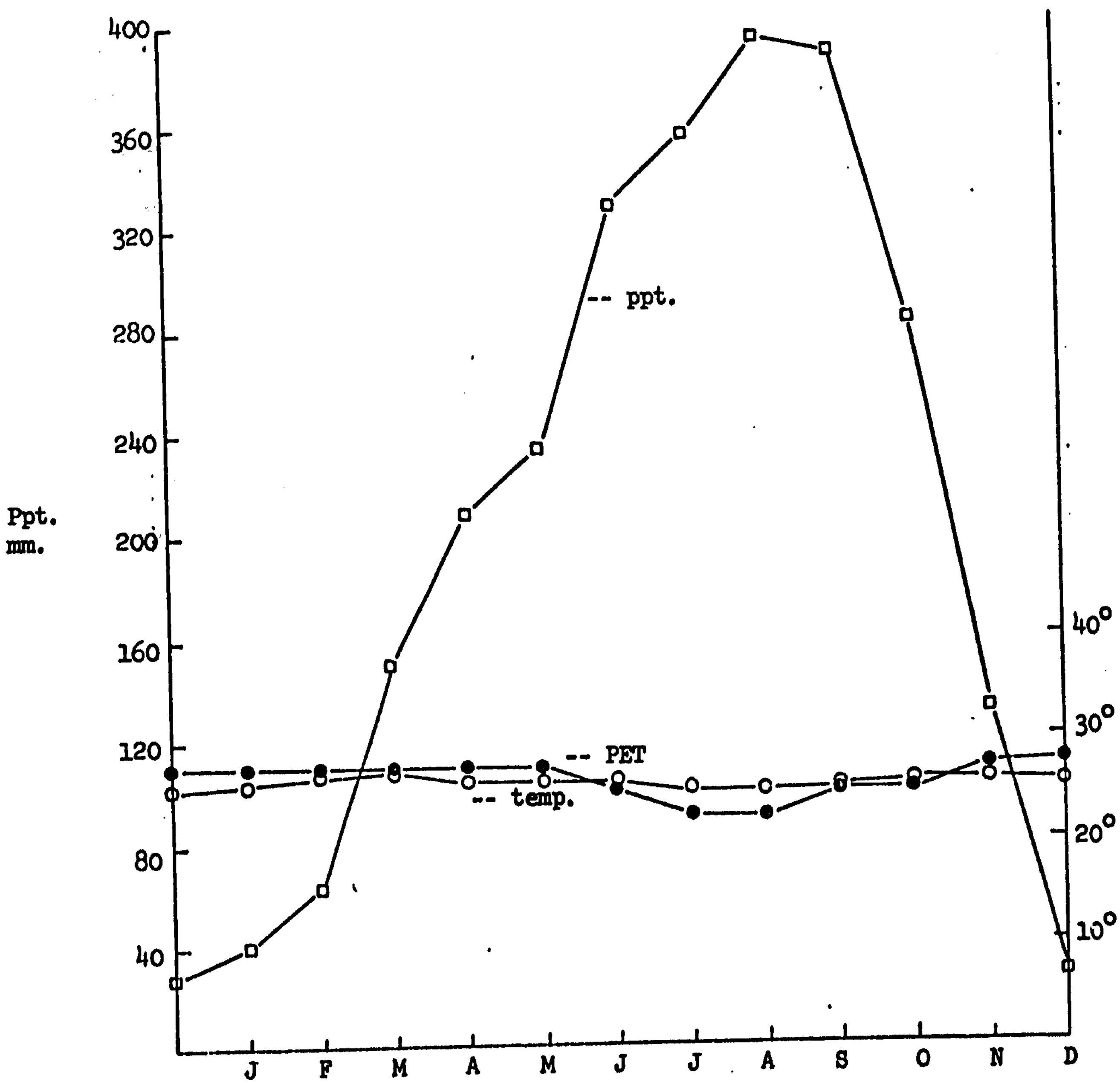

Fig. 6. Mean monthly rainfall, potential evapotranspiration and temperatures for Abak benchmark area.

have observed that oil palms of the area sometimes show signs of drought stress during the long dry season. This may be indicative of an ustic moisture regime.

The Abak annual rainfall is approximately 2600 mm and the potential evapotranspiration exceeds the monthly rainfall for only three months of the year (Fig. 6). It is unlikely that the control section is dry for more than 90 cumulative days. A study of the soil moisture regime under very similar climatic conditions in Sierra Leone (van Vuure and Miedema, 1973) indicate an udic regime. The author took soil samples from the Abak site during the first week of February 1974. At this time (the end of the long dry season) the greater part of the control section was still moist. On the basis of this observation and an interpretation of the rainfall pattern, the soil moisture regime is estimated to be udic and the temperature regime isohyperthermic.

Degradation

In studying the fertility of soils formed on the Plio-Pleistocene coastal plain sands certain French sorkers in Dahomey and Togo have distinguished "degraded" and "nondegraded" forms of surface soils. In their research they have been unable to give generally valid and precise definitions to these terms. In an effort to analytically pinpoint certain soil properties which were affected by degradation phenomena soil samples were taken from benchmark areas and analyzed. The results were not able to confirm any of the possible factors given in the following discussion on degradation. For this reason, the discussion is hypothetical and is presented only to indicate that there are many facts yet unknown on this problem. The inconclusive analytical results are given in Appendix II under the appropriate soil pedon description.

In general, it seems that the state of being degraded is most easily distinguished by the appearance of the soil surface and the type of fallow vegetation. The degraded vegetation differs for each benchmark area. Exceptionally low yields of maize (*Zea mays*), cassava (*Manihot esculenta*) and other foodcrops are obtained on the degraded soils.

On these soils one observes a "shifting" phenomenon or microerosion characterized by the physical separation at the surface of the sandy matrix and darker colored clay and organic matter. Shifting or micro-erosion usually occurs on fields where the vegetative cover is poor, such as cassava fields, where there is little or no plant residue and the standing crop provides very limited protection from heavy rains and intense heating by the sun. The clay and organic matter are washed away or at least separated from the sand fraction producing a mottled or splotchy appearance of pure bleached quartz sand and pockets of darker clay and organic matter. Gentle monsoon rains over long periods of time tend to separate and move clay and organic matter downslope whereas intense rainstorms carry the complete soil, clay, organic matter and sand downslope. The structure of degraded surface soils is unstable and reverts to single-grain (personal communication, F. R. Moormann, 1973). This phenomenon was seen on most of the sandier soils of intensively cultivated fields in all study areas.

Degradation has been thought to involve some of the following: 1) erosion and loss of clay increasing the sandiness of the surface horizon, 2) loss of organic matter, 3) excessive leaching of exchangeable bases, 4) loss of available P, 5) instability of structure, 6) possibly minor element deficiencies, 7) increase in exchangeable H and Al and 8) other unknown factors.

THE SOUTH TOGO BENCHMARK STUDY AREA

Setting

This was the only study area where detailed soil, climatic and agronomic data were already available because of the studies of FAO, the Togolese Ministry of Agriculture, Togolese and French research organizations such as ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer), BDPA (Bureau de Developpement et Production Agricole), SORAD (Societe Regionale d'Amenagement et de Developpement) and IRAT (Institut de la Recherche Agronomique et Technique). Because so many soil series had already been identified in these studies of the sedimentary region of southern Togo, specific soil series were selected for study according to their extent.

The climate is dry, semi-hot equatorial typical of a coastal savanna belt where the highest average daily temperature is less than 33.5°C, the annual rainfall between 44 and 100% of the potential evapotranspiration and the dry season one to three months long (Papadakis, 1965). The major rainy season begins in March with thermal thunderstorms. In May the rains increase and by June monsoon rains are dominant. Around mid-July the major or first rainy season ends. A short dry season starts and continues to early September at which time the monsoon rains start again but never reach the intensity of June. During some years this short rainy season is practically non-existant. There is an important gradient of rainfall with the highest rainfall found in the northern edge of the sedimentary region. There is also considerable annual variability in total rainfall and rainfall distribution.

The predominant topography of the coastal plain sands formation in Togo is a series of undulating plateaus ranging from sea level to 100 meters in the north. Streams and rivers on the plateau form a dendritic pattern (Slansky, 1962).

Even though the region is classified as semi-hot equatorial most of the vegetation is Guinea savanna. The most humid part may be derived savanna with a dry deciduous climax forest which has almost totally disappeared. Most of the region is covered by degraded tree savanna with baobabs, oil palms and coconut palms as the main secondary trees with low woody shrubs which survive the recurrent burning. The only areas where one finds remnants of a tropical forest are along rivers or streams or in small areas of sacred forests (FAO, 1967).

Soil pedons

Four important soil pedons were chosen for study. These pedons are referred to by their series designations as mapped in a detailed reconnaissance survey by FAO in the early 1960's. The series names are Legbako, Kodjin, Klckome and Ganave.

All descriptions, topographic positions and analytical data for the soil pedons are given in Appendix II.

The Legbako series (Appendix II, no. 1)

The Legbako series is a clayey, kaolinitic, isohyperthermic member of the Oxic Paleustalfs. This series is the most typical upland soil formed on the undulating plateaus of the coastal plain sands. It corresponds well in morphology with the Alagba series of Ikenne and Benin-NIFOR, Nigeria. The Legbako series covers the greatest surface area in the coastal plain sands (Terres de Barre) area in southern Togo, approximately 69,000 hectares (FAO, 1967).

Legbako soils are reddish brown sandy clay soils. The sandy clay usually occurs abruptly at depths of 40 to 60 cm. The surface textures vary from sand to sandy loam. These soils usually occur on surface I of the undulating plateaus (Appendix II). The soil is deep and porous and shows no mottling.

The colors of the surface horizons (Ap and A3) range from 5YR3/4, dark reddish brown, to 2.5YR3/2, dark reddish brown. The B2t horizon is also dark reddish brown, 2.5YR3/4 to 2.5YR3/6.

The pH and percent base saturation remain constant to the depth examined, approximately 1.8 m, at 5.5 and 98% respectively. The CEC also remains fairly constant at 4meq/100g of soil down to the depth examined.

The Kodjin series (Appendix II, no. 2)

The Kodjin series is also a clayey, kaolinitic, isohyperthermic member of the Oxic Paleustalfs. The soil is found on surface I (or possibly surface II) of the undulating plateaus of the coastal plain sands (Appendix II). The Kodjin series is not as extensive as the Legbako series covering an area of only 9,000 hectares (FAO, 1967).

Kodjin surface soil is dark reddish brown becoming dark red (dry) at depth. The surface is sandy clay loam to sandy clay and becoming clay with depth. The clay texture usually occurs rather abruptly at 40 to 60 cm depth. The B2t horizons are always clay. The soil is deep, porous, shows no mottling and has well-defined structure.

The colors of the surface horizons (Ap, A3) range from 2.5YR2.5/4 to 10R3/4, dark reddish brown to dusky red, respectively. The B2t horizons range from 10R3/4 to 2.5YR3/6, dusky red to dark reddish brown, respectively.

The pH and percent base saturation, as in the Legbako series, remain constant to a depth of approximately 1.8 m, at 5.5 and 98% respectively, The CEC is approximately 3meq/100 g of soil throughout.

Kodjin soils can occur separately, especially in the northern areas of the coastal plain sands, or as "island" patches within larger expanses of Legbako soils.

There are two current explanations for the heavier texture of the surface: 1) it is a remnant of a Legbako soil that was heavily eroded washing away the sandy surface layer, and 2) it was derived from a clayier parent material to begin with and as such has not experienced an intense translocation of clay. Kodjin soils are found mainly in the northern stretches of the coastal plain sands formation where the parent material was clayier than that further south (personal communication, M. Santanna, Ministry of Agriculture, Lome, 1974) (Slansky, 1962).

The Klekome series (Appendix II, no. 3)

The Klekome series, a clayey, kaolinitic, isohyperthermic member of the Oxic Paleustalfs occurs on surface III (sandy colluvium) (Appendix II). It corresponds well morphologically with the Kulfo series of Benin-NIFOR, Nigeria. The surface area covered by the Klekome series in Togo is approximately 11,700 hectares (FAO, 1967).

Klekome soils are dark reddish brown throughout. The surface is usually sandy becoming sandy clay loam or sandy clay with depth. The heavier sandy clay texture may occur at approximately 1 m or may not be apparent in a profile having a depth of at least 2 m. The surface horizons (Ap, A3) range from sand to sandy loam in texture. The texture often increases slightly to sandy clay loam or sandy loam at a depth of 50 to 80 cm (B2t). B2t or argillic horizons are also distinguished by thin clay bridges formed between the quartz sand grains. The soil is deep and porous but has a slightly weaker or less well-defined structure than the Legbako and Kodjin series.

The colors of the surface horizons (Ap, A3) range from 5YR3/3 to 5YR3/4, dark reddish brown. The B2t horizons are 2.5YR3/4, dark reddish brown.

The pH of the horizons remains fairly constant at about 5.5. The base saturation remains at approximately 100% in the surface horizons but decreases slightly to approximately 80% in samples taken at depths approaching 2m. The CEC is low at about 2.4meq/100 g of soil but are slightly higher at the surface due to increased amounts of organic matter.

The Ganave series (Appendix II, no. 4)

The Ganave series is probably a clayey, kaolinitic, isohyperthermic member of the (Plinthic) Oxic Paleustalfs. The soil is found on depositional surface IV (Appendix II). The surface area covered by the Ganave series in southern Togo is approximately 10,000 hectares (FAO, 1967).

Ganave soils are grayish brown becoming pale brown with brownish and reddish mottles at depth. The surface textures (Ap, A3 horizons) range from sand to loamy sand becoming sandy clay loam or sandy clay with depth (B2t). The heavier texture usually occurs abruptly at a depth of 50 to 70 cm. B2t or argillic horizons are distinguished by thin patchy argillans. The soils examined typically become more porous and exhibit stronger structure with depth. Many medium and coarse tubular pores are seen at depths of approximately 1 m. The soil is also distinguished by brownish mottles near the surface becoming reddish yellow and forming red concretions at depths of approximately 1 m.

Colors of surface horizons range from grayish brown, 10YR5/2, to brown, 10YR5/3. Argillic horizons range from brown, 10YR5/3, to light yellowish brown, 10YR6/4 and very pale brown, 10YR7/3. Surface mottles are strong brown, 7.5YR5/6, becoming reddish yellow, 5YR6/6, with depth. Concretions are typically bright red, 2.5YR4/6. The concretions are probably ironstone gravel in a matrix of discontinuous plinthite.

There are no chemical data for the Ganave pedon.

Soil characteristics affecting agronomic potential

As shown by Table 4, Klekome and Ganave series have soil characteristics more limiting to agronomic potential than Legbako or Kodjin series in the South Togo benchmark area.

Climatic characteristics affecting agronomic potential

Average climatic data for the area are given in Appendix I and Table 2.

The diurnal range of temperature is greatly influenced by the proximity of the coast. The areas in the interior show the greatest amplitudes. The average yearly variation of temperature is limited for the region as a whole to approximately 3.3°C.

Table 4. Soil characteristics affecting agronomic potential. South Togo benchmark area.

Characteristic	Soil: Legbako	Kodjin	Klekome	Ganave
1. Limitations to rooting depth	None	None	None	Ironstone gravel in B2t (similar to pan)
2. Texture	sandy surface over clayey subsoil	clayey throughout	sandy throughout	sandy surface over clayey subsoil
3. Surface soil aggregate stability[a]	slightly stable	moderately stable	unstable	slightly stable
4. Permeability	moderate	moderate	rapid	moderate
5. Drainage class	well-drained	well-drained	excessively well-drained	imperfectly drained
6. Erosion problems[b]	microerosion and gully formation	possible gully formation	much microerosion and gully formation	microerosion
7. Limiting chemical properties	low CEC low exchangeable K	low CEC low exchangeable K	low CEC low exchangeable K, low OM	---
8. Susceptibility to degradation[c]	moderate	slight	very high	moderate

[a]This refers in particular to the tendency of breaking up crumb or subangular blocky structure to single-grain structure.

[b]Microerosion is a phenomenon of particle separation, i.e. the separation of sand from clay and organic matter.

[c]Degradation is a phenomenon associated with changes of surface soil, ground cover, and decreased yields. Susceptibility is a qualitative judgment based on observed field conditions.

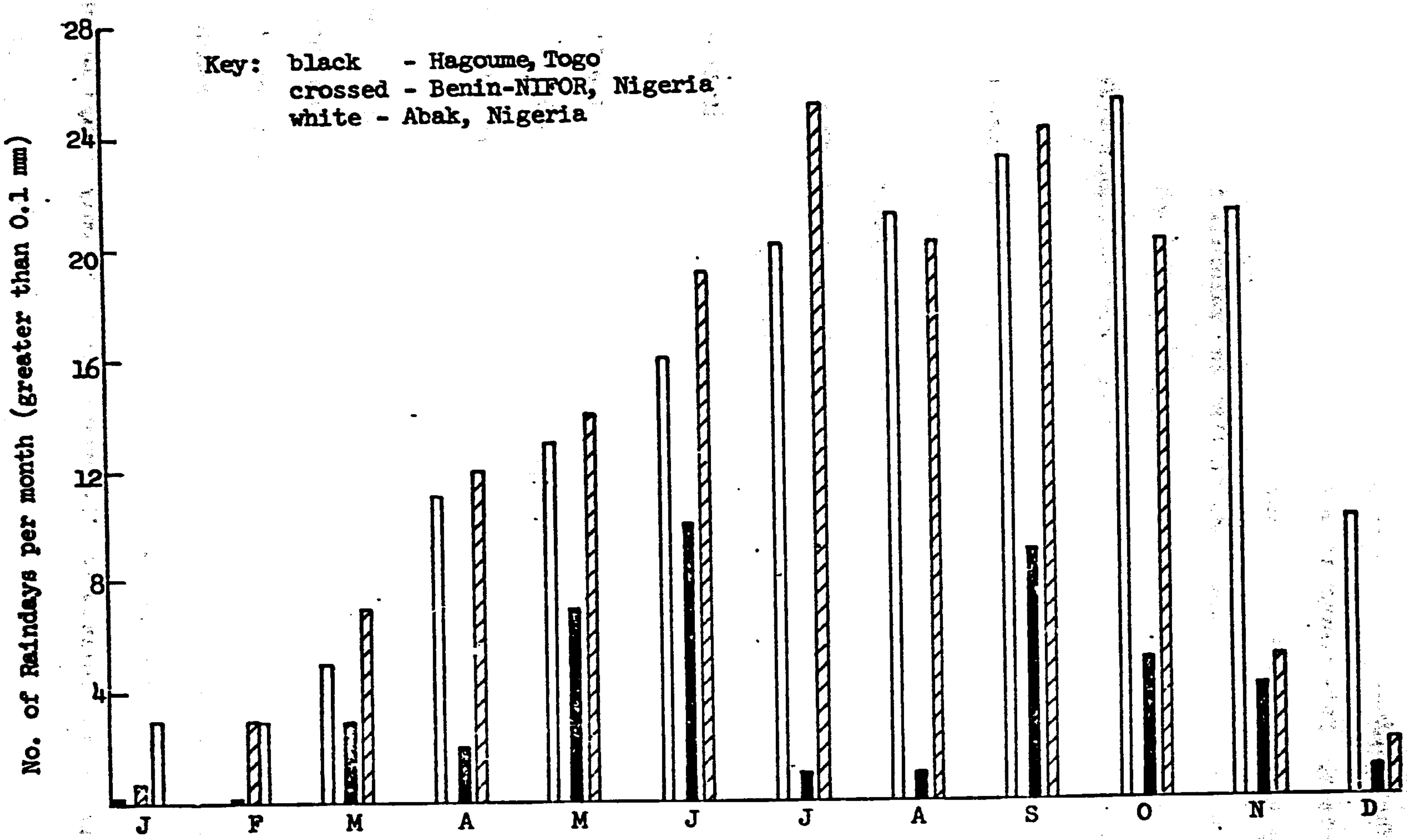

Fig. 7. Rainfall distribution in South Togo, Benin-NIFOR, and Abak benchmark areas.

The rainfall is variable both between years and from one locality to another. It's common to have a downpour in one place and no precipitation at all 10 km away. The region of southern Togo differs from the other benchmark areas in that the rainfall increases, from 800 to 1300 mm, as one goes from the coast to the northern edge of the sedimentary plateau (FAO, 1967). In all other benchmark areas of this study the reverse is true.

The low annual precipitation and its distribution into two seasons is a liability to foodcrop production. This is especially true for the southernmost region, where in some years the short rainy season does not provide enough precipitation to cover the deficit caused by evapotranspiration (Appendix I and Fig. 7).

The potential evapotranspiration is greater than rainfall about 9 months of the year (Appendix I and Fig. 3).

The heaviest showers occur near the coast. Shower intensity diminishes toward the northern part of the sedimentary plateau (FAO, 1967). The sandier, exposed soils nearest the coast are the most susceptible to erosion.

Rain distribution is the single most important climatic parameter affecting agronomic productivity of the south Togo area. For Hagoume, Togo (near Lome), the number of raindays (days when the precipitation is greater than 0.1 mm) attains a maximum of 10 during the month of June. The planting months of March and April have 3 and 2 respectively and the maximum for the second season is only 9 days in Septem-

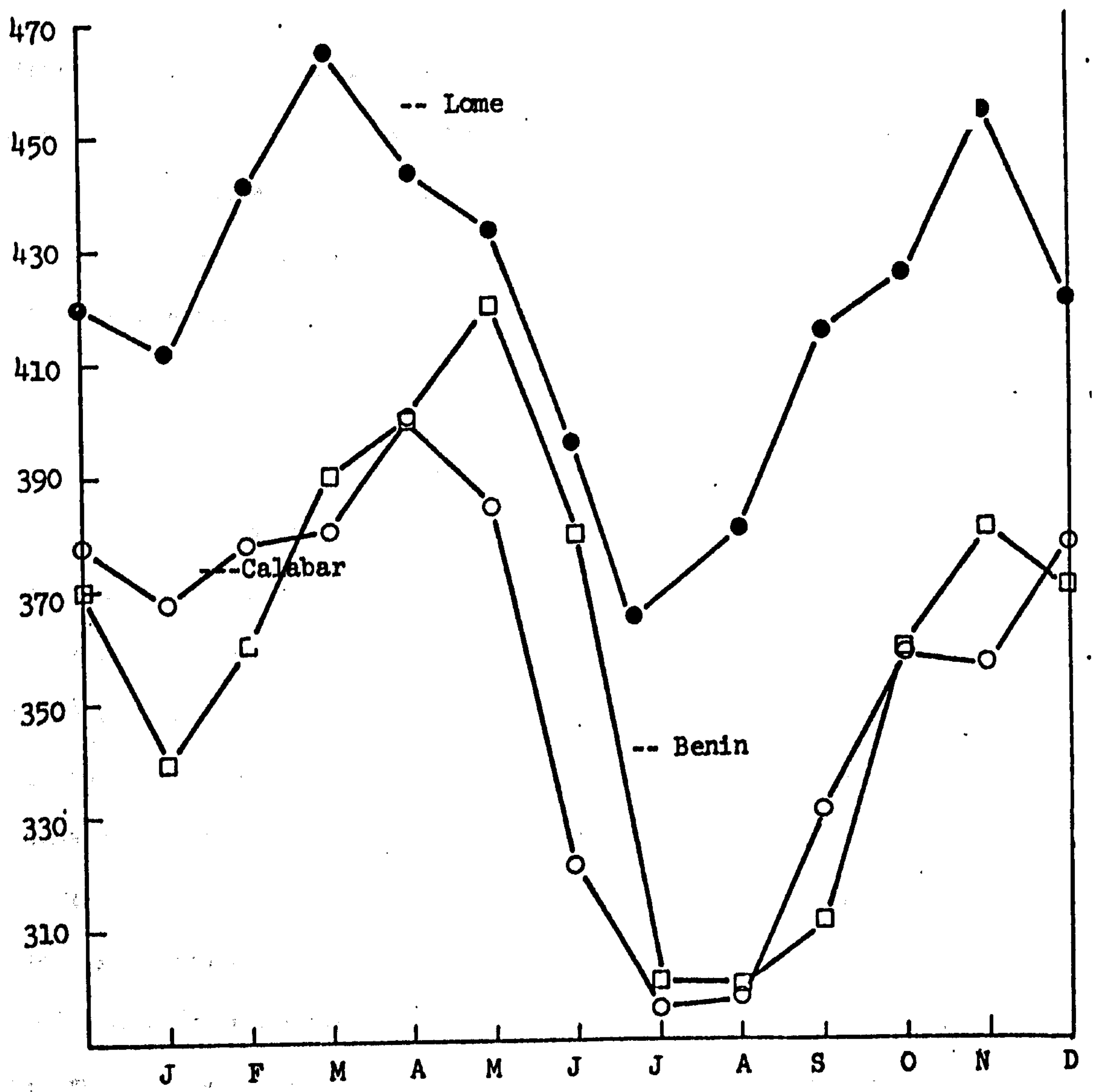

Fig. 8. Mean monthly global radiation (Ly/day) for South Togo, Benin-NIFOR and Abak benchmark areas.

ber (see Fig. 7). This is a clear indication of the recurrent drought problems during the two growing seasons and the second in particular (personal communication from workers on BDPA and SORAD projects in Anecho, Togo).

The annual average radiation is 421 Langleys/day for the south Togo area. As the growing season progresses the level of the radiation diminishes (Appendix I and Fig. 8). The daily average from April to July is 409 Langleys/day and from September to November 431 Langleys/day. Radiation, in view of these values, appears sufficient for foodcrop production.

Human factors affecting agronomic potential

The main form of cropping management in southern Togo is shifting cultivation. In this area demographic pressures are so intense that suitable fallow periods for regeneration of soil fertility are no longer possible. In times past when sufficient land was available a farmer might leave a parcel in fallow 5 to 8 years after cropping it 2 to 3 years. The demographic pressures no longer permit such lengthy fallows and the result is a general degradation of soils. Fallows are presently 2 to 3 years at most. In southern Togo the rural population density is approximately 137 inhabitants/km^2 (FAO, 1967).

Calculations from data given in Table 5 show that the average farm size in southern Togo is 1.85 hectares irrespective of the percentage of available land under cultivation.

Table 5. Farm statistics for southern Togo (after FAO, 1967).

		Administrative Region		
		Lome	Anecho	Tsevie
1.	Total surface in ha.	28,000	142,000	320,000
2.	Surface cultivated in ha.	18,272	60,331	38,297
3.	Percent surface cultivated of total surface	64%	43%	12%
4.	Number of farms	9,676	33,285	19,581
5.	Number of cultivators per farm	2.1	1.9	2.6
6.	Surface area in ha. covered by each cultivator	0.88	0.94	0.74

The rotation and composition of crops on these farms seem to be dictated as much or more by local traditions and nutritional habits than by searching for the most suitably adapted crop to a particular soil. Maize and cassava are by far the predominant crops of the region (Table 6). Yams (Discorea rotundata) and cocoyams (Colocasia antiquorum) assume minor importance only in the more humid regions such as Tsevie (1200 mm rainfall per annum).

The system is shifting cultivation where the land is left to fallow for several years then intensively cultivated until the yields diminish to an uneconomic level. These diminished yields are mainly due to the diminishing fertility of the soil, weeds, pests, and diseases. Thereafter, the parcel is given another period of fallow. Traditionally, the soils are at least 50% under fallow at any one time. Alluvial areas where the vegetation is thicker and harder to clear are perhaps 80% under fallow (FAO, 1967).

Table 6. Foodcrop composition on farms in southern Togo (after FAO, 967).

	Administrative Region		
	Lome	Anecho	Tsevie
	% of cultivated surface area by crop		
1. Maize	47.9	44.2	38.2
2. Rice (*Oryza sativa*)	----	----	----
3. Cassava	30.0	34.1	21.0
4. Sweet potatoes (*Impomoea batatas*)	0.2	0.2	0.7
5. Yams	----	----	4.4
6. Cocoyams	----	----	5.7
7. Ochra (*Hibiscus esculentus*)	0.9	0.6	0.9
8. Tomatoes (*Lycopersicon esculentum*)	1.9	0.3	0.6
9. Peppers (*Piper sp.*)	0.6	0.2	0.9
10. Bigeon Peas (*Cajanus cajan*)	3.1	3.9	0.8
11. Peanuts (*Arachis hypogaea*)	7.3	2.3	6.1
12. Tree crops	8.1	14.2	24.7

The regions of Lome and Anecho having the most intensive agriculture have modified somewhat this system. Here maize and cassava are grown almost continuously, except for an occasional fallow of 1 to 2 years. The maize is planted during the long rainy season and shortly thereafter interplanted with cassava. The cassava is then harvested prematurely after 10 to 12 months. Soil degradation under this modified system is increased and yields drop to an unusually low level (4 to 5 tons of fresh tubers/ha.).

In areas of traditional shifting cultivation the following techniques are practiced. Each year toward the middle of the dry season a parcel of land is cleared by cutting down trees, shrubs, weeds and left to dry. Oil palm trees are left standing because of their economic importance, but their leaves are heavily trimmed so that their shade does not greatly hinder the growth of foodcrops. This pile of dry material is burned so that a few kilograms of fertilizer is produced. The soil is hoed by hand, incorporating the burned material into the surface layer of the soil. After the rains start maize is planted 3 to 4 seeds to a hill in no particular spacing. The maize is never thinned. At the same time hills of tomatoes, ochra, peppers, peanuts, etc., are planted between the hills of maize. In some cases the maize culture may be repeated depending on the fertility of the soil. It is then interplanted with cassava cuttings or the cassava may be planted during the first season usually a month after the maize and other crops have started to grow.

In the more intensive agriculture of the Lome-Anecho area the maize is usually planted on the flat in lines at a rather wide spacing and shortly afterwards interplanted with cassava cuttings. Fortunately in this area mulching practices have been started using the stalks, leaves and other trash left over from harvest. In general fertilizers are not used and maize is not planted during the second rainy season.

Yields under traditional management

Yields per hectare are particularly low for such foodcrops as maize and legumes (Table 7).

Table 7. Crop yields under traditional management (vegetables and tubers - fresh weight, grains - dry weight of grain).

Crop	Yields (tons/hectare)
1. Maize	0.8
2. Cassava	8.0
3. Pigeon peas	0.4
4. Peanuts	0.3
5. Ochra	0.8
6. Peppers	0.3
7. Tomatoes	1.5

Yields under experimental management

Several experiments have been conducted by BDPA (Bureau de Developpement et Production Agricole) in southern Togo on soils formed on coastal plain sands. This organization attempts to regenerate degraded soils in the region of Anecho. Most of the soils fall into the Legbako, Klekome or Ganave series. The regeneration techniques include plowing at different depths, maximum utilization of fertilizers, additions of organic matter and the use of rotations which include maize followed by a legume and a suitable cover crop during the dry season. Yields of maize (first season) are significantly improved using modern management techniques. These yields diminish with continued cultivation even with the use of fertilizers and modern tillage practices (Table 8).

Table 8. Yields of foodcrops under experimental management (after SORAD, 1973).

Year and Season	Crop	Kg. dry grain (maize cow-peas) or fresh weight (cassava)/hectare
1. First yr.-first season	maize	1400
2. First yr.-second season	maize	900
3. Second yr.-first season	maize	800
4. Second yr.-second season	maize	300
5. Second yr.-second season	cowpeas (Vigna sp.)	450
6. Third yr.-first and second seasons	cassava	12,500

THE IKENNE BENCHMARK STUDY AREA

Setting

The study of the Ikenne benchmark area was divided up into two parts. Soil characterization and agronomic trials were conducted at the Institute for Agricultural Research and Training (IART), Ikenne. The soil pedons had previously been described by F. R. Moormann of IITA and associates. Information on cultural practices and yields on local farms were obtained in cooperation with the Ministry of Agriculture and Natural Resources (MANR), Remo Division at Shagamu. With the help of an interpreter, a number of local farmers were interviewed to get information on the kinds of crops .anted and their yields. No detailed soil surveys or corresponding agronomic data were available for the area.

The climate is humid, semi-hot equatorial (forest belt), with the highest average daily temperature less than 33.5°C. The area has monsoon rains with 1 to 3 dry months and the rainfall surplus over evapotranspiration is less than 1000 mm (Papadakis, 1965). The first and longer rainy season starts in March with peak precipitation in June. A short dry season follows in August when potential evapotranspiration (PET) exceeds precipitation. Then a second rainy season, of longer duration and more predictability than the one at Lome extends from September to the end of October (see Fig. 3).

Although detailed soil moisture studies were not made, it appears that the soil control section would be dry for periods of time as long as 90 consecutive days in a year indicating an ustic soil moisture regime.

The topography does not differ from the normal pattern of undulating plateaus of the coastal plain sands formations.

Although the underlying geological formations at Ikenne are older (end of Cretaceous) than the Plio-Pleistocene coastal plain sands at the other benchmark sites, the surface layers have been eroded, reworked and covered with Plio-Pleistocene coastal plain sands material (see Fig. 2) (personal communication F. R. Moormann, 1974).

The vegetation of the area is composed of low woody shrubs and small trees mixed in with the predominant vegetation, _Eupatorium odoratum_. This plant, according to those living and working in the area, arrived sometime in the late 1950's and soon spread over large areas of southern Nigeria. Along with Eupatorium odoratum the fallowed areas included kola trees and oil palms.

Soil pedons

The Alagba series (Appendix II, no. 5)

The Alagba series is a clayey, kaolinitic, isohyperthermic member of the Oxic Paleustalfs. This soil is typical of the upper surface (surface I) of the undulating plateaus of the Ikenne region. It corresponds well morphologically and chemically (down to at least 2 m) with the Legbako soils of southern Togo.

These soils are reddish brown sandy clays with the sandy clay usually occurring abruptly between 40 and 60 cm. The surface layer ranges in texture from sand to sandy loam. The soils usually occur on upper slopes of the undulating plateaus but can be observed below layers of ironstone gravel on the actively eroding surface (surface III) (see topographic position descriptions in Appendix II). The soil is deep and porous and contains no mottling in the sandy clay layer.

The many pieces of pottery fragments found in the upper 60 cm of the soil are evidence of recent mixing by human activities.

The colors of the Ap and A3 horizons can vary slightly but are usually 5YR3/3 to 3/4, dark reddish brown. The B horizons are also dark reddish brown, 2.5YR3/6 to 3/4.

The pH diminishes slightly with depth but never further than 5.0 in the lower argillic horizon. The CEC is usually 8 to 10 meq/100 g of soil at the surface, diminishing abruptly to approximately 2 to 3 meq/100 g of soil in the argillic horizon. The percent base saturation ranges from 95% in the surface horizons to 80% in the argillic horizon.

The Owode series (Appendix II, no. 6)

The Owode series is a clayey, kaolinitic, isohyperthermic member of the Oxic Haplustalfs. Owode soils are brown sandy clays with a grayish brown sandy surface. They occur either on a lower surface (surface II) when associated with Alagba soils or may occur on the upper surface (surface I) without Alagba.

The texture of the grayish brown (10YR3/2) surface layer varies from loamy sand to sandy loam. A reddish-brown (5YR4/4) to brown (10YR3/2) sandy clay loam to sandy clay usually occurs abruptly between 40 and 60 cm. Mottled clay with small reddish (2.5YR4/6) concretions occur between 100 to 140 cm.

Owode soils are only moderately well-drained and may remain moist for a longer time than Alagba soils during the dry season.

The upper 50 to 60 cm contain similar evidence of mixing or disturbance as the Alagba profiles due to pottery found at these depths.

The CEC of the surface horizon is usually 8 to 10 meq/100 g of soil dropping to 2 to 3 meq/100 g in the subsoil. There is approximately 100% base saturation until well into the mottled horizon.

The Atan series (Appendix II, no. 7)

The Atan series is a clayey, kaolinitic, isohyperthermic member of the Plinthic Paleustults. These soils have similar morphological characteristics as the Owode soil except that the mottled sandy clay layer is closer to the surface, between 60 and 90 cm. The grayish brown (10YR4/2) surface layer can have textures ranging from sand to sandy clay loam. A sandy clay layer starts at 30 to 50 cm and is brown (10YR5/3) changing to mottled light brownish gray. The subsoil is gray (10YR6/2 to 6/1) with chromas of 2 or less due to a water table which comes within 100 to 140 cm of the surface each year. Dark red (2.5YR3/6) concretions formed from plinthite occur at approximately 90 cm.

The soils usually occur in depressions of undulating relief (surface II) (see topographic positions in Appendix II) below Alagba or Owode series. The soil is imperfectly drained at the height of the rainy season (June).

The surface soil has a CEC of approximately 8 to 10 meq/100 g of soil decreasing to 2 to 4 meq/100 g of soil in the lower horizons. The base saturation decreases rapidly from 100% in the surface horizon to 30 to 40% in the mottled and argillic horizons.

Soil characteristics affecting agronomic potential

Among the soils studies at this site, Alagba soils have characteristics least limiting to foodcrop production (Table 9).

Table 9. Soil characteristics affecting agronomic potential. Ikenne benchmark area.

Characteristic	Soil: Alagba	Soil: Owode	Soil: Atan
1. Limitations to rooting depth	None	Bulk density increase in mottled zone[a]	Bulk density increase in mottled zone
2. Texture	Sandy surface over clayey subsoil	Sandy surface over clayey subsoil	Sandy surface over clayey subsoil
3. Surface soil aggregate stability[b]	slightly stable	slightly stable	slightly stable
4. Permeability	moderate	slow	slow
5. Drainage class	well-drained	moderately well-drained	imperfectly drained
6. Erosion problems[c]	microerosion and gully formation	severe microerosion	severe microerosion
7. Limiting chemical properties	low CEC low exchangeable K low available P	low CEC low exchangeable K low available P	low CEC low exchangeable K low available P increase acidity with depth
8. Susceptibility to degradation[d]	moderate	slight	high

[a]See remark attached to Owode description in Appendix II.

[b]This refers to the tendency of crumb or subangular blocky structure to break up into single-grain structure.

[c]Microerosion is a phenomenon of particle separation, i.e. the separation of sand from clay and organic matter.

[d]Degradation is a phenomenon associated with changes of surface soil, ground cover, and decreased yields. Susceptibility is a qualitative judgment based on observed field conditions.

Climatic characteristics affecting agronomic potential

The diurnal flucutuation of temperature is slightly greater than Lome due to the greater distance to the coast. The yearly range of temperatures is not great and the maximum temperature is always less than 33.5°C (Papadakis, 1965).

The annual rainfall is sufficient in most years for most crops during the two growing seasons (March to November). The potential evapotranspiration does not exceed the rainfall at any one month during the growing season (Fig. 4 and Appendix I).

The potential evapotranspiration exceeds rainfall during the months of January, February, March, November and December. The total potential evapotranspiration for the year (1,340 mm) is less than the total precipitation (1,426 mm) (Fig. 4 and Appendix I).

July, August and October (Appendix I) are months when extremely heavy showers are known to occur. Exposed fields, especially those under cassava only, would be hardest hit by these storms.

Rainfall is very evenly distributed for the growing months of March to October and in most years there should be no droughts greater than one week during this time.

Human factors affecting agronomic potential

In this area population pressure is not a limiting factor, in most cases, to fallow lengths needed to restore soil fertility when shifting cultivation is practiced. Although no reliable census figures could be found, the author interviewed several farmers over a large area (approximately 16 km^2). When asked the question whether there was any available land if the farmer wanted to expand operations the answer was always affirmative. In only one case was a farmer cultivating a field almost continuously. This farmer was a tenant not originally from the area.

The farms seen were usually small. The average size being approximately 1.5 to 2 hectares. This area was usually divided up into small plots scattered here and there. This was especially tru of farmers who tilled their land with family labor only. In a few cases farmers were cultivating their parcels collectively, especially for such crops as rice or tomatoes, and increasing the total land area cultivated.

The composition of crops grown in the area seemed to be highly variable but maize and cassava were always included at some point in the rotation. The following cropping combinations were observed:

1. Maize (first year) followed by cassava and cowpeas the second year.
2. Maize (first season) intercropped with cassava which grew for 15 months to 2 years.
3. Yellow yams (<u>Discorea alata</u>) interplanted with maize with a full complement of local vegetables such as melon (<u>Telfaria sp.</u>), ochra, peppers, cocoyams and others followed by cassava.
4. Monocropping of upland rice (first season followed by inter-

cropping of tomatoes, maize and cassava (second season).

5. Monocropping of upland rice with a fallow the second season.

6. Alternate monocropping of upland rice or maize (both the first season only).

An important factor in the choice of crop composition seemed to be the amount of land which the farmer had in kola production. Kola is a tree crop grown and marketed extensively in the region. The farmers that had the most kola trees were the ones who used the most traditional combinations and rotations, keeping most of the foodcrops grown for family consumption. The other farmers who did not depend on kola production incorporated some of the innovative rotations of rice, tomatoes, etc., along with traditional rotations and combinations on other plots.

The author made several traverses through Ode-Lemo, 3 km south of Ikenne, to get an idea of land use. Kola and cassava were the predominant crops grown (Table 10).

Table 10. Land use at Ode-Lemo (Ikenne area).

Crop	% of land under crop
1. Kola	51
2. Cassava	23
3. Pineapple (Ananas comosus)	8
4. Maize[a]	6
5. Other foodcrops	3
6. Fallow	9
	100

[a]Maize would normally be more predominant since the survey was made during the second growing season.

The traditional management system is shifting cultivation. There are some modifications in this system which seem to be due to two factors: 1) the amount of land which a particular farmer has under kola and 2) the ability of the farmer to cultivate profitably high paying crops such as rice or tomatoes. If the farmer has a sizeable amount of land (more than two hectares) and does not have most of it planted in kola he can fallow his plots for at least 5 to 10 years and follow the practices of shifting cultivation. Under this system yellow yams are planted first (February) in the most fertile spots followed by maize (March, April) which is interplanted with melons, cocoyams, ochra and peppers. After 2 to 3 weeks or a month the farmer starts interplanting the whole area with cassava cuttings (May).

Where the farmer is trying to grow crops such as rice or tomatoes he may devote the plot strictly to these crops with no rotations, leaving the field in fallow during the second rainy season in the case of rice, or growing two crops of tomatoes (both early and late season), or planting tomatoes in September and interplanting with cassava during October. These systems would be employed in areas where land competition with kola plantations is not too great.

In general, fertilizers were not used, particularly in the case of yams, maize, cassava and local vegetables. But some farmers were attempting to use them in the management of less traditional crops such as tomatoes and rice.

In all cases except one where a farmer was experimenting with rather large fields of rice (1 to 2 hectares), tillage was done with short-handled hoes after the woody bush had been cut with machetes and burned.

Weeding was done twice on most farms, the first time one month after planting, the second two months or ten weeks after planting. Only rarely were crops, such as rice or tomatoes, weeded three times.

The farmers generally complained of insect and bird problems with rice and maize and grasshopper problems with cassava. No one had any efficient means of control over these pests.

None of the farmers, unlike the case in southern Togo, complained of drought as a limiting factor to farming.

Yields under traditional management

Yields of foodcrops per hectare are low for maize, rice and cowpeas (Table 11).

Table 11. Crop yields under traditional management (vegatables and tubers - fresh weight, grains - dry weight of grain).

Crop	Yield - tons / hectare
1. Maize	1.0
2. Cassava[a]	6.0 to 9.0
3. Yellow yams	1.3 to 5.0
4. Cocoyams	2.0
5. Tomatoes	2.0
6. Rice (upland)	0.5
7. Cowpeas	0.2

[a]Some tubers may be up to two years old.

Yields under experimental management

Several fertility trials were carried out by the Ministry of Agriculture and Natural Resources (MANR) at Shagamu, Remo Division (5 km west of Ikenne). These trials were always in cooperation with a local farmer in order to convince him of the need to use fertilizers and improved varieties. Unfortunately the soil series designiations or even a cursory description of the texture or soil color were not recorded. One is not certain whether the trials were carried out on Alagba, Owode, Atan or other soils. Improved varieties of maize (NS1) and rice (IR20) always gave higher yields and second season maize yields were always inferior to the first season (Table 12).

Table 12. Yields of foodcrops under experimental management (vegetables and tubers - fresh weight, grains - dry weight of grain).

Crop (variety)	Average yield (kg/ha)	Range in yield (kg/ha)
1. Early maize (NS1)	2400	2100 to 2700
2. Early maize (local white)	1900	650 to 2900
3. Late maize (local white)	800	500 to 1100
4. Upland rice (OS6)	1700	700 to 2700
5. Upland rice (IR20)	2400	2000 to 2700
6. White yams	5400	4700 to 6000
7. Yellow yams	7700	---
8. Cassava (Tabiapa)	6150	3000 to 9500

THE BENIN-NIFOR BENCHMARK STUDY AREA

Setting

This area was unique among the four in that the farming system approached most closely a true system of shifting cultivation. Large plots are cut down from secondary forest and burned in January and February, cultivated for one to two years and then allowed to revert back to fallow and eventually forest. Each year a new area is cultivated cooperatively by members of a nearby village. This continuance of a viable shifting cultivation is due for the most part to a low population density.

Much of the soils information was gathered with the help of the staff of the Nigerian Institute for Oil Palm Research (NIFOR) approximately 20 km northwest of Benin City. There was no existing detailed soils information for the area except some suitably studies for oil palm production by H. Vine et al. Some agronomic information was available through the Research Branch of the Ministry of Agriculture and Natural Resources, Midwestern State, Benin City, Nigeria.

The climate is humid semi-hot equatorial typical of a coastal forest belt where the highest average daily temperature is less than 33.5°C. One to three months are dry and there is an annual rainfall surplus, exceeding evapotranspiration, of 1000 mm (Papadakis, 1965). The major rainy season begins in March and continues until July (see Fig. 5) and is followed by a short but not too severe dry season in August. The second rainy season starts in September and finishes during the first part of November. The long dry season lasts from late November until the following March. From Fig. 5 it can be seen that the area might be transitional from an ustic to an udic soil moisture regime. There are probably 90 cumulative days during which the soil moisture control section is dry, these soils are then placed in an ustic moisture regime. More has to be done, such as a regular collection of soil moisture samples, to be certain. Also a study of different areas to the south should be conceived to determine where the ustic regime leaves off and the udic begins.

The area is included in the coastal plain sands (Plio-Pleistocene). In the literature the formation is sometimes referred to as "Benin Sands".

The topography is typically a series of long, wide undulating plateaus. In areas where a major stream has dissected the landscape, the relief becomes more rolling.

The predominant vegetation of the area is humid tropical forest. The areas of recent fallow are dominated by Eupatorium odoratum and low woody shrubs (see "general data" for a more detailed listing of major forest species).

Soil pedons

Two important soil pedons were chosen for study. These pedons fall into Alagba and Kulfo series designations (Moss, 1957).

All descriptions, topographic positions and analytical data are given in Appendix II.

The Alagba series (Appendix II, no. 8)

Alagba is a clayey, kaolinitic, isohyperthermic member of the Oxic Paleustalfs. This pedon may be atypical due to a high Ca and Mg saturation of the CEC throughout the profile (see analytical data Appendix II). The soil is typical of those found on the undulating plateaus of coastal plain sands in this area. It corresponds well morphologically and chemically with the Alagba (Ikenne) and Legbako (South Togo) series described previously. The characteristics and ranges coincide roughly with those given under the discussion of the Alagba pedon at the Ikenne site (no. 5, Appendix II and discussion).

The Kulfo series (Appendix II, no. 9)

The Kulfo series is a clayey, kaolinitic, isohyperthermic member of the Typic Paleustults. The soil is typically found on depositional surfaces of sandy colluvium below breaks in slopes of the undulating plateaus or in concave depressions slightly below the plateau surface. The soil is morphologically similar to the Klokome series of Lome, Togo. The chemistry and classification are different due to the higher leaching environment of Benin.

The surface textures from 0 to 50 cm are never finer than a sandy loam and range to sand. At a depth of 50 to 70 cm the texture becomes sandy clay loam and may stay as such down to a depth of 200 or more cm or the texture may become sandy clay at 100 to 130 cm. The predominant characteristic of this soil distinguishing it from Alagba series is the deeper, coarser surface texture.

Surface colors are always dark reddish brown but may range from 5YR3/3 to 2.5YR3/6. The argillic horizons are always dark reddish brown, 2.5YR3/4 to 3/6.

Another characteristic of the Kulfo soils is the existence of a dark, buried Ap horizon found at a depth of 40 to 50 cm. A throrough survey by many auger borings in the area always showed this characteristic present. Pottery fragments were also frequently found at this depth. This indicates that a great deal of colluviation and mass movement of the surface has taken place in recent times perhaps the last 5000 years (personal communication, R. W. Arnold, 1974). Traditional farming techniques such as ridging to a depth of 30 to 40 cm may in part explain this accelerated movement of surface materials.

The pH, lower than Alagba soils of the same area, is between 4.0 to 4.3 and remains constant with depth. The CEC is also low throughout at 2 to 3 meq/100 g of soil. The percent base saturation is also low throughout at 20 to 30%.

Soil characteristics affecting agronomic potential

The Kulfo series has more characteristics limiting to agronomic potential than the Alagba series (Table 13).

Table 13. Soil characteristics affecting agronomic potential Benin-NIFOR area.

Characteristic	Soil: Alagba	Soil: Kulfo
1. Limitations to rooting depth	None	None
2. Texture	sandy surface over clayey subsoil	sandy throughout
3. Surface soil aggregate stability[a]	slightly stable	unstable
4. Permeability	moderate	rapid
5. Drainage class	well-drained	excessively well-drained
6. Erosion problems[b]	microerosion and gully formation	microerosion and gully formation
7. Limiting chemical properties	low CEC low exchangeable K low available P	low CEC low exchangeable K low available P low pH
8. Susceptibility to degradation[c]	moderate	very high

[a]This refers in particular to the tendency of crumb and subangular blocky structure to break up to single-grain structure.

[b]Microerosion is a phenomenon of particle separation, i.e., the separation of sand from clay and organic matter.

[c]Degradation is a phenomenon associated with changes of surface soil, ground cover, and decreased yields. Susceptibility is a qualitative judgment based on observed field conditions.

Climatic characteristics affecting agronomic potential

Mean monthly temperatures do not fluctuate greatly throughout the year (see Fig. 5 and Appendix I). The mean annual temperature is 26°C. There is no significant difference between this and other study areas.

Precipitation is not a limiting factor to foodcrop production in this area. The short dry season during the month of August is not severe since the potential evapotranspiration is still lower than the level of rainfall (see Fig. 5).

Potential evapotranspiration exceeds precipitation only during the months of December, January and February and partially during the months of March and November. The total rainfall, 1,844 mm, exceeds the annual potential evapotranspiration, 1,220 mm, permitting some significant leaching of the soil.

Records of maximum daily rainfall (see Appendix I) show Benin-NIFOR to have exceptionally heavy rainfalls during the months of July to October and moderately heavy rainfalls during the dry season. These exceptional rainfalls are higher than for any other area studied. Erosion can be a major problem especially as more soils are cultivated more intensively in the future.

Rainfall is distributed fairly evenly throughout the growing months of April to October (see Fig. 7 and Appendix I) so that long periods of drought during the growing season should not be a problem.

During the first growing season the average radiation is 388 Langleys/day. The radiation diminishes as the season continues (see Fig. 8). During the second growing season (August to November) the radiation is even lower at 356 Langleys/day. These values are higher than those of the Abak benchmark area but lower than those of Lome for the same season.

Human factors affecting agronomic potential

The Benin-NIFOR study area is the least populated of all the areas studied. There are no impediments for most of the local farmers to practice shifting cultivation much as their ancestors must have done. This means that a parcel of land is cropped 1 to 2 or 3 years maximum and allowed to go into fallow for at least 10 to 15 years.

The average size of farms is hard to determine since most farmers interviewed in this area were part of a cooperative scheme by the local village to farm one large area freshly cleared from secondary forest. The average size of farms as estimated by the local ministry of agriculture is about 1 to 1.5 hectares (Occasional report, Benin City, 1966).

After the bush is burned white yams are interplanted with maize, melons, ochra, peppers, cocoyams, etc. In September or slightly before the area may then be interplanted with cassava. Cassava may be replanted in the area after harvesting the first crop. In this case no care is given to the cassava and it grows along with the fallow regrowth. White yams take predominance in this area along with cassava and maize (Table 14).

Table 14. Area cultivated per crop on peasant farms (Benin-NIFOR) (after Notes on Peasant Agriculture, Benin City, 1966)

Crop	Area cultivated per farm (hectares)
1. White yams	0.5
2. Cassava	0.5
3. Maize	0.43
4. Cowpeas/pigeon peas	0.1
5. Rice (some farms)	0.2

The system is shifting cultivation as described previously in the South Togo discussion. Only one point may be added here. A lot of shifting cultivation in the Benin-NIFOR area is done on government forest reserves. First, the mature economic trees are harvested then the farmers are permitted to come in and clear and burn the rest of the bush. At the same time that they are planting their crops they are obliged to plant tree seedlings provided them by the forestry department.

Yields under traditional management

Specific yields were not determined in this area.

Yields under experimental management

The data for this section has been gathered from two sources: 1) the Research Branch of the Ministry of Agriculture and Natural Resources of Midwestern State and 2) research on fallows and cropping carried out in field trials at NIFOR. As in most of the cases in this paper where locally derived data was used there was no mention or description of the kind of soil involved. Only the soil for the research being currently carried out at NIFOR could be determined with certainty.

Experiments with early and late maize were started under conditions of continuous cultivation with and without application of fertilizers. The following results clearly show a diminution over time in the yields even on fertilized plots (Table 15).

Table 15. Yields of maize (dry grain) under continuous cropping (after Annual Report 1965/66, Midwestern State).

Treatment	Yield (kg/ha)					
	Year 1	2	3	4	5	6
Early maize with fertilizer	2170	1408	678	1116	699	751
without fertilizer	2024	1158	417	459	751	302
Late maize with fertilizer	260	657	396	250	---	---
without fertilizer	166	292	135	62	---	---

In none of the years in these experiments with both early and late maize was the application of fertilizers profitable, i.e., the price or profit for the increase in yields did not cover the costs of the fertilizers (Experiment Report 1964. Midwestern State). Another important aspect of the results is the reduction in yield with time even with the continuous application of fertilizers. This suggests that the process of degradation had taken place quite rapidly in these soils.

Another set of fertilizer and mulching experiments was carried out for white yams which are not just a "prestige" crop as in other areas studied but an economic foodcrop grown extensively in the area. Optimum yield trials were conducted for white yams and cassava (optimum levels of mulch and fertilizers were applied). Yields for these crops did not significantly drop off during the trial period (Table 16).

Table 16. Optimum yields for white yams and cassava (fresh weight of tubers) (after Experiment Report 1964, Midwestern State).

Crop	Yield (kg/ha)		
	Year 1	2	3
1. White yam	14,190	16,070	---
2. Cassava (improved variety)	21,070	25,600	24,600
3. Cassava (local variety)	13,700	19,400	12,500

In ongoing fallow and fertilizer trials currently being undertaken by the Federal Ministry of Agriculture at NIFOR four types of fallow vegetation were tried for their effect on soil regeneration. The fallows were <u>Acioa barteri</u>, <u>Pueraria phaseoloides</u>, <u>Panicum maximum</u> and natural bush. After 3 years of fallow of the above vegetation, 2 years of early and late maize, and 1 year of cassava were cultivated. Fertilizing the fallows vs. the crops was also tried. There were no significant differences seen in yields depending on the kind of fallow or whether the fallow or the crop had been fertilized. Yields of approximately 3130 kg of dry grain per hectare of early maize and 1560 kg/ha of late maize seemed to be the average for the fertilized plots. Sixteen to twenty tons of an improved variety of cassava were found on the fertilized plots (Kalamkhar, NIFOR, personal communication, 1974). The soils for all of these plots are Alagba series.

Previously, continuous cropping had been tried on this same site at NIFOR. The results were similar to those of the Research Branch of the State ministry. Levels of yields dropped off on both fertilized and unfertilized plots after about 2 years of continuous cropping and would not come back up to initial levels no matter how much fertilizer was applied.

THE ABAK BENCHMARK STUDY AREA

Setting

Due to the recent past of the Nigerian civil war, this region had the greatest paucity of existing agronomic, soils and meterological information. However, the author was fortunate to find help from local agricultural officers who provided a great deal from their own personal experience. The area most studied was the area within a 10 km radius of the Obio-Akpa Model Farm, Abak.

The climate of the region is humid semi-hot equatorial with one or more months non-humid but no dry month (Papadakis, 1965). The rainy season starts in late February and continues until late November (Fig. 6). During this period there is one continuous rainy season with no short dry period intervening. Although no continuous soil moisture data exist it is assumed that the soil moisture control section in any part would not be dry for 90 cumulative days; therefore the soils would fall in an udic soil moisture regime.

The area is underlain by sandy clays of the coastal plain sands (Plio-Pleistocene) formation.

The topography of most of the area is typically undulating plateaus. Like the Benin-NIFOR site the area immediately surrounding the Obio-Akpa Model Farm is more dissected and rolling.

Due to the high population density of the area, little of the original vegetation of a superhumid rainforest can be seen because of the intensive cultivation and diminishing length of fallows in the region. The predominant vegetation consists of oil palms and bush fallow composed mostly of Eupatorium odoratum, Acioa barteri, and Anthonotha macrophylla (Obi and Tuley, 1973).

Soil pedons

Two soil pedons at the Obio-Akpa Model Farm, Abak, were chosen for study. The upland soil has the series designation, Uyo. The series designation of the lowland imperfectly drained pedon is not known.

Two supplementary descriptions may be found in Appendix II. All data and descriptions are given in Appendix II.

The Uyo series (Appendix II, no. 10)

The predominant and most characteristic soil of the undulating plateaus of the area is the Uyo series. The soil is classified as an Oxic Paleudult, clayey, kaolinitic, isohyperthermic family. The Uyo soils are morphologically similar to the Alagba and Legbako soils except that the colors are pale yellowish browns and the soils are highly leached due to the high rainfall of the area. Sandy clay, as in Alagba soils, usually occurs abruptly at 40 to 60 cm. The surface horizons range in texture from sand to sandy loam. The color of the surface horizons ranges from 7.5YR3/2 to 5YR2/2, dark brown to dark reddish brown, depending on the amount of burning and cultivating which has taken place.

The sandy clay layers or B horizons range in color from 7.5YR4/4 or 7.5YR3/2, dark brown, for the upper layers which are darker and duller than the lower B material, probably due to a greater accumulation of organic matter. The lower B horizons are 5YR4/4 to 4/8, reddish brown to yellowish red. Another characteristic of the B horizons is that the material becomes more friable or looser with depth, even though the texture does not change.

The upper 60 cm of most soils show signs of mixing, i.e., bits of charcoal fragments or lumps of clayier material are found. This is probably due to the local practice of deep ridging and mounding on farms.

The pH is usually 4.5 to 4.8 at the surface diminishing slightly to 4.3 in the argillic horizon. The CEC may range from 4 to 6 meq/100 g of soil in the surface depending mainly on the amount of organic matter present. The lower horizons usually have 3 to 4 meq/100 g of soil. The base saturation may vary in the surface horizons but is usually 10 to 20% in the argillic horizon.

The lowland pedon (Appendix II, no. 11)

This pedon is characteristic of the lowland areas between the undulating plateaus, surface IV (see Appendix II). Surface IV is filled with colluvium and alluvium carried down from surfaces I, II, and III. The soil is classified as an Aeric (Plinthic) Paleaquult, clayey, kaolinitic, isohyperthermic family. The soil is morphologically similar to the Ganave and Atan series described for the South Togo and Ikenne benchmark areas respectively.

The soil is characterized by a sandy colluvial surface probably of recent deposition and is usually grayish brown, 10YR5/2 to 5/4. An abrupt transition follows to the argillic horizon ranging in texture from sandy clay loam to sandy clay. The argillic horizon has a grayish brown matrix, 10YR5/3 to 6/3, with distinct soft reddish brown mottles becoming bright red concretions with depth. The horizon becomes lighter gray with hues and chroma decreasing with depth.

The range in chemical properties is approximately the same as that described above for the Uyo series.

Miscellaneous soils

Two other sites were selected for profile studies. Both soils were variations of the Uyo series. One was an eroded phase of the Uyo soil (see Appendix II). Most of the sandy surface had probably eroded away due to the steep slope of the site. The second soil was characterized by a very black surface and unusually high quantities of exchangeable bases. The site must at one time have been a palm oil extraction "factory" where much refuse and burned kernals have enriched the soil. Although neither soil was typical for the region as a whole, both are representative of special conditions found throughout the area. Descriptions and analytical data for these soils can be found in Appendix II.

Soil characteristics affecting agronomic potential

Both soils have many characteristics limiting their agronomic potential. Perhaps one may determine the use of each soil by its drainage characteristics. For example the lowland soil may be ideal for the production of swamp rice and the upland for cassava (Table 17).

Climatic characteristics affecting agronomic potential. Abak benchmark area.

The mean monthly temperatures are given in Appendix I. The range is the same for all other study areas and is not limiting.

The quantity of rainfall during the growing season from late

Table 17. Soil characteristics affecting agronomic potential. Abak benchmark area.

Characteristic	Soil: Uyo	Soil: Lowland
1. Limitations to rooting depth	None	Bulk density increase in mottled zone
2. Texture	sandy surface over clayey subsoil	sandy surface over clayey subsoil
3. Surface soil aggregate stability[a]	slightly stable	unstable
4. Permeability	moderate	slow at height of rainy season
5. Drainage class	well-drained	imperfectly drained
6. Erosion problems[b]	severe microerosion and mass movement of surface sand down-slope, gully formation	severe microerosion
7. Limiting chemical	low CEC, low exchangeable K, low pH, large quantities of exchangeable Al&H	low CEC, low exchangeable K, low pH, large quantities of exchangeable Al&H
8. Susceptibility to degradation[c]	very high	very high

[a]This refers in particular to the tendency of crumb or subangular blocky structure to break up to single-grain structure.

[b]Microerosion is a phenomenon of particle separation, i.e., the separation of sand from clay and organic matter.

[c]Degradation is a phenomenon associated with changes of surface soil, ground cover, and decreased yields. Susceptibility is a qualitative judgment based on observed field conditions.

February to mid-November is not a limiting factor to the growth of crops. More important is the long range influence of high rainfall on the excessive leaching of nutrients in the soils of the area. Indeed much work needs to be done on the efficient application of soluble fertilizers without excessive losses due to leaching and microerosion.

The potential evapotranspiration is significantly lower than the level of rainfall throughout the growing season, except for February (Fig. 6). This is a good reason to recommend early March as a safe planting date for crops such as maize.

The level of maximum precipitations is significantly lower than all the other study areas (see Appendix I). One would not expect excessive erosion problems under normal cultivation practices (except for microerosion under poorly covered areas). Also a luxurious vegetative cover is another factor that must be taken into consideration. In most places the soil is protected by a thick undergrowth of vegetation which does not completely dry out even during the dry season. Where this vegetative cover is not disturbed or proper ridging of contours is practiced, there should be a minimum transport of soil material even during heavy rainfalls. The author has observed that roadways are protected from erosion in this area (unlike the other areas) by vegetation which grows right up to the edge of the pavement. Also streams of the area are virtually clear and carry very slight loads of sediment.

There are more than an ample number of raindays from March to November so that in most years protracted dry spells in the growing season should not occur (see Appendix I).

This area has the lowest mean monthly radiation in Langleys/day of the study areas. From March to November, the average monthly radiation is 347 Langleys/day which is lower than some places (Athens, in temperate regions during their growing season.

Human factors affecting agronomic potential. Abak benchmark area.

The demographic pressure at the Abak area is the highest of any of the study areas. Fallow periods are very short (1 to 2 years), if there are any at all, except for chiefs or a few other rich farmers who have large land holdings and can afford longer fallows.

Farm size is variable depending on the importance of the person in the village. Some chiefs may have 50 to 100 hectares at their disposition. The average farmer has approximately 1 to 1.5 hectares. The farms are usually divided into small plots scattered around the village.

Cassava is the major foodcrop of the area followed by maize, yams and various vegetables such as Telfaria sp., peppers, ochra, cocoyams and others. When a farmer has a freshly fallowed field he may plant water yam (Dioscorea sativa) and/or white yam followed by maize, ochra, Telfaria, tomatoes and other vegetables. Cassava is interplanted after the maize is harvested.

When the farmer has little land and insufficient fallow length or where the site has many oil palms which are needed for oil production the following combinations may be planted under the palms:

1. early maize, cocoyam and vegetables interplanted with cassava,
2. cassava alone.

Kitchen gardens around living compounds have a very importa function in food production for the family. The major crops are usually vegetables such as tomatoes, peppers, Telfaria, garden egg (Solanum sp.), leafy greens (Amaranthus sp.), yams along with plantain (Musa paradisiaca), bananas (Musa paradisiaca sapientum), pawpaw (Carica papaya), and citrus (Citrus sp.).

The traditional management system is shifting cultivation with some modifications. The modifications are due to two factors:

1. the incentive to produce as much oil palm nuts as possible for cash,
2. the scarcity of land and its subsequent low fertility due to short fallows.

Because of these competitive pressures foodcrops are usually planted on oil palm sites. Cassava is by far predominant on these soils.

The following cultural systems were observed in the area:

1. Maize with vegetables followed by cassava and fallow. This approaches most closely shifting cultivation practices of slash and burn during the dry season, early cultivation of maize (February and March) followed by cassava (July throug

September). After harvesting the field is allowed to revert back to fallow for about 5 years.

Maize, cassava and cocoyams under oil palm plantations. During the dry season bush undergrowth is cut and burned and the tops of palms are trimmed to allow crops sufficient light. Maize, vegetables and cocoyams (February and March) are then interplanted followed by cassava (July through September). The cassava grows for one or two years and harvested as needed. The oil palm canopy is permitted to reestablish and the cassava and weeds compete for sunlight.

Cassava under oil palms. The same technique of trimming palms and burning as described above is followed. Cassava alone is planted and harvested as needed after 1 to 2 years of growth.

Yams in fields of Acioa barteri followed by maize, vegetables, and cassava and finally fallow. Acioa trees are trimmed back to the stump and the trash burned. Yams are planted in heaps then interplanted with early maize and vegetables. Cassava is planted later (same time as above) and harvested as needed as the parcel slowly reverts back to fallow and the Acioa shrubs grow back.

Kitchen gardens. Plots near houses which receive heavy doses of garbage, trash and manure are continuously cultivated for yams, tomatoes, Telfaria, maize, plantains, pawpaw and bananas.

It was observed that sandy surface textures, high rainfall and excessive leaching, and the practice of ridging and pulling soil from a maximum depth of 50 cm leads to rapid microerosion and soil degradation on peasant farms. Exposed surfaces, especially under cassava, often shows separation of quartz sand from darker areas of organic matter and clay (microerosion). At the same time these areas are quickly overrun by bracken (Pteridim aquilinum) as the predominant weed. Bracken grows best on acid, leached, sandy soils. In the past the growth of bracken indicated that a fallow was needed. Now there is insufficient land for long fallows. Cassava giving extremely low yields (down to 2 tons/hectare) is seen growing in bracken quite often. Fertilizers are not generally used due to the difficulty of procurement and the low level of response.

Yields under traditional management

Major foodcrops were sampled and weighed on local farms. Most yields were low except for some samples of cassava (Table 18).

Table 18. Crop yields under traditional management (vegetables and tubers - fresh weight, grains - dry weight). Abak benchmark area.

Crop	Yield (tons/hectare)
1. Maize (local)	0.5
2. Cassava[a]	3.0 to 10.0
3. White yams	1.0 to 3.0
4. Cocoyams	1.5
5. Tomatoes	1.0
6. Cowpeas	0.1

[a]Some tubers may have been two years old.

Yields under experimental management

The information for this section was gathered from data from trials carried out by the Federal Department of Agricultural Research at Uyo, Southeast State.

Cassava yields are adequate. Maize and rice yields are low but characteristic of the region (Table 19).

Table 19. Yields of foodcrops under experimental management (vegetables and tubers - fresh weight, grains - dry weight). Abak benchmark area.

Crop and variety	Yield (kg/hectare)
1. Maize (local)	1,483 to 2,174
2. Cassava (local)	7,000 to 15,000
3. Upland rice (IR24)	3,849
4. Upland rice (OS6)	1,936
5. Lowland rice (OS6)	1,163
6. Cowpeas	460

FIELD EXPERIMENTS

Introduction

Field experiments to compare the yields of first season maize were conducted at the Institute for Agricultural Research and Training (IART), Ikenne, Western State and Obio-Akpa Model Farm, Abak, Southeast State, Nigeria. Field experiments on the yields of second season maize, soybeans (Glycine soja), and 10-month old cassava were conducted at Obio-Akpa Model Farm, Abak only.

These experiments were designed to:

1. measure yields under specified soil and climatic conditions
2. observe the extent to which certain local cultural practice determine yield level,
3. compare the Ikenne yields of first season maize with those of the more humid higher rainfall area in Obio-Akpa, Abak,
4. show the importance of fallows to the regeneration of soil fertility,
5. determine whether improved management practices would be profitable to a local farmer.

Maize, cassava, and soybeans were chosen as indicator crops. The maize used was a variety developed at IITA, composite B. The cassava was a local variety. The soybeans were variety Bossier.

Sites

At the IART Farm in Ikenne, Western State, three different sites were selected to monitor differences between a well-drained cultivated soil ("cropped"), a well-drained soil fresh from bush fallow ("bush fallow"), and an imperfectly drained soil fresh from fallow ("bush fallow"). They are:

1. an Alagba soil which had been continuously cultivated for the last 5 years ("cropped Alagba"),

an Alagba soil which had been in bush fallow for at least 10 years ("Alagba bush fallow"), an Atan soil which had been in bush fallow for at least 10 years ("Atan bush fallow").

At the Obio-Akpa Model Farm at Abak, two sites were chosen. Both were Uyo soils:

1. an Uyo soil fresh from fallow, the soil had been in fallow for at least 15 years ("Uyo bush fallow"). A description of the soil is given in Appendix II, no. 13, Uyo series, highly saturated phase.
2. an Uyo soil which had been cultivated for at least 5 years ("cropped Uyo"). A description of the soil is given in Appendix II, no. 10, Uyo series.

Treatments

The treatments were selected to monitor the effect of modern cultivation practices, i.e., the use of fertilizers, versus local cultivation practices, specifically the effects of burning or cleared bush and mixed cropping.

Maize treatments (first and second season)

Treatment 1: "Traditional, burning, no fertilizer." Maize was intercropped and managed according to local methods. In this treatment the farmer was provided with maize seed (IITA composite B) and told to plant it plus anything else he wished, as he would do in his own plots, and to use his own style of management concerning burning, planting and weeding.

Treatment 2: "Experimental, no burning, fertilizer [and liming, first season only at Abak]." IITA's composite B maize was planted; recommended spacing, fertilizer and weeding practices were followed.

Treatment 3: "Experimental, burning, no fertilizer." Composite B maize was spaced and weeded according to IITA recommended practices. The bush collected from the plot was burned on the plot before tilling and planting.

Treatment 4: "Experimental, burning, fertilizer [and liming first season only at Abak]." The bush collected from the plot was burned on the plot before tilling. Composite B maize was spaced, fertilized, and weeded according to IITA recommendations.

assava treatments (Abak only)

Treatment 1: "Traditional, burning, no fertilizer." Cassava was intercropped with maize and in some cases other assorted crops such as ochra, peppers, tomatoes etc. and managed according to local methods. A local variety of cassava was used.

Treatment 2: "Experimental, no burning, fertilizer [and liming, Abak only]." The same local variety was spaced, weeded, and fertilized according to IITA recommended practices.

Soybean treatments (Abak only)

Treatment 1: "Experimental, burning, no fertilizer." The Bossier variety was spaced and weeded according to IITA recommended practices. Previous crop residue (first season maize) was burned on the plot before tilling and planting.

Treatment 2: "Experimental, no burning, fertilizer." Variety Bossier was spaced, weeded and fertilized according to IITA recommended practices.

Treatment 3: "Experimental, burning, fertilizer." Variety Bossier was spaced, weeded, and fertilized according to IITA recommended practices. Previous crop residue (first season maize) was burned on the plot before tilling and planting.

Second season maize (Abak only)

The treatments were the same as those for the first season maize described previously for Ikenne and Abak with the exceptions that there were no "traditional" treatments (local farmers do not plant second season maize) and there was no second application of lime. The plots of fertilized treatments of soybeans and second season maize were the same plots which had been fertilized for the first season maize treatments. Similarly, the burned plots were also the same plots on which the original bush had been burned for the first season maize experiments.

Experimental design

Complete randomized block design with four replications at each site was used.

Plot size

The dimensions were: 8 x 13 m (Abak, first season maize and cassava); 4 x 6.5 m (Abak, second season maize and soybeans); 3.75 x 6 m (Ikenne, first season maize).

Plot sizes were reduced for the Ikenne site to save time and labor: the 8 x 13 m plots at Abak were difficult and time-consuming to prepare.

Cropping

Maize, variety composite B of IITA, a local variety of cassava, and Bossier soybeans were used. The maize was planted with a spacing of 75 x 25 cm, giving a population of 53,200 plants/hectare. Three seeds were planted per hill and thinned to one plant per hill after 10 days. Cassava cuttings were planted at a spacing of 75 x 90 cm. Soybeans were planted at the same spacing as maize.

Weeding

All plots were hand weeded twice, 3 to 4 weeks and 6 to 7 weeks after planting for all crops.

Fertilizer rates

Maize and cassava were fertilized with 120N, $90P_2O_5$, 60 K_2O and 500 $CaCO_3$ at Abak only, in Kg/ha. N, as urea, was applied as follows: 1/3 N broadcast before planting, 2/3 N applied in bands 5 weeks after planting for maize and cassava. Soybeans at Abak were fertilized with 30 N, 30 P_2O_5, and 0 K_2O. The total compliment of fertilizers for soybeans was broadcast before planting; the same was done for maize and cassava (broadcasting) except for the N application described above.

Tilling

All plots were cleared of stumps and bush, except for the "traditional" treatment and tilled by hand with a short-handled hoe.

Soil sampling

Composite soil samples were taken at each site to a depth of 30 cm. The bush fallow UYO site is somewhat atypical of the area as shown by the high base saturation (Table 20).

Results - first season maize

The highest yields were found on the cropped Alagba site (old clearing) at Ikenne. Clearly, these results are not those expected for this site. Several problems were involved which might explain these results. Firstly, the germination on the cropped site was poor on some of the plots; by the time the author inspected the site

Table 20. Analytical data for soil samples (0-30 cm) taken from experimental sites (Ikenne and Abak).

Soil parameter	Uyo bush fallow	Cropped Uyo	Alagba bush fallow	Cropped Alagba	Atan bush fallow
1. pH (H_2O)	5.5	4.3	6.0	5.5	6.0
2. Organic C (%)	1.10	0.9	0.75	0.70	0.60
3. CEC meq/100 g of soil	4.14	2.55	5.28	4.47	2.26
4. Ca	3.09	0.40	3.19	2.89	1.10
5. Mg (NH_4OA extractable cations meq/100 g soil)	0.92	0.17	1.81	1.15	0.67
6. K	0.06	0.07	0.09	0.09	0.31
7. Na	0.03	0.02	0.04	0.03	0.02
8. Mn	0.04	0.02	0.06	0.07	0.09
9. Fe	0	0	0	0	0
10. Available P (ppm)	26.00	6.25	4.25	2.50	2.50
11. Total acidity (Al & H)	0	1.88	0.08	0.24	0.08
12. Base saturation (%)	100	26.2	98.4	94.6	96.4
13. Texture	sandy loam	sandy loam	sandy loam	sandy loam	sandy loam

(he had been busy at the Abak experimental site) it was too late to replant.[2] The yields for these underpopulated plots were corrected

[2]As a result the remaining plants may have grown unusually well and, thus, increased the appearance of the overall yield.

at harvest time depending on the amount of grain harvested from the remaining maize plants. This may have given an exaggerated yield in some cases. Secondly, when the author chose the sites a "parcel continuously cropped for at least five years" was asked for. It was later revealed that not only had the parcel been continuously cropped for five years but that large amounts of fertilizers had been applied there during the cropping. A residual effect of fertilizers especially P, may also help to explain the high yields at the cropped site. It is the opinion of the author therefore that the results at the cropped site should not be taken as a valid representation of the yield level for first season maize at a cropped Alagba site (Table 21).

Table 21. Maize yields (first season) at Ikenne on Alagba and Atan soils.

Treatment	Dry grain kg/ha Cropped Alagba	Bush fallow Alagba	Bush fallow Atan
Traditional, burning no fertilizer	1289	2055	1819
Experimental, no burning, fertilizer	4915	3285	4884
Experimental, burning, no fertilizer	5854	3535	3620
Experimental, burning, fertilizer	5566	4388	4985

Yields at the cropped Uyo (old clearing) site were distinctly poorer than all the others (Table 22).

Table 22. Maize yields (first season) at Abak on Uyo soils.

Treatment	Dry grain kg/ha	
	Cropped Uyo	Bush fallow Uyo
Traditional, burning no fertilizer	199	1763
Experimental, no burning, fertilizer, lime	1998	4486
Experimental, burning, no fertilizer	648	2592
Experimental, burning, fertilizer, lime	2380	4188

The importance of fallows and techniques of land preparation at the Abak site (Uyo soils) can be seen in Fig. 9. Two important points are made. Firstly, in all cases the fallowed sites produced significantly higher dry grain yields for all treatments. Fallows are very important to any farming system in this highly leached environment.

Secondly, given that the revenue for dry maize grain is $115.39/ton at the local market and that the cost of land preparation for "experimental" treatments is $1500/hectare, the maximum difference between yields for the "traditional, burning, no fertilizer" treatment and any "experimental" treatment for the "cropped" site (a difference of 2181 kg/ha) and "bush fallow" site (a difference of 2723 kg/ha) does not give enough revenue to offset the increased cost of land preparation on either site for the "experimental" treatments (Fig. 9).

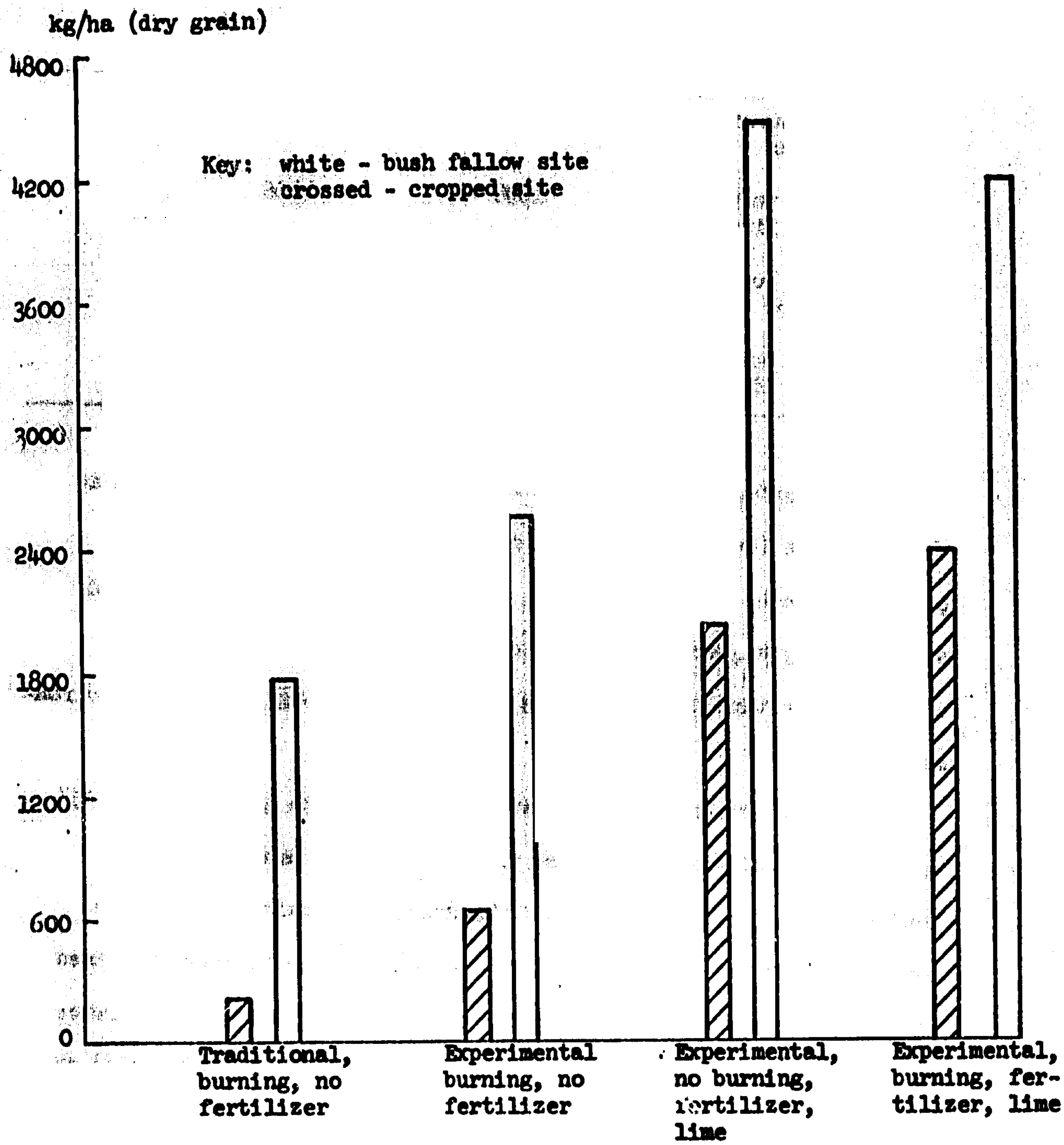

Fig. 9. Contribution of fallow to dry maize grain yield (kg/ha) (early maize) at Abak field experiment.

Approximately $1500 in labor is needed to clear completely one hectare of land for any "experimental" treatment, i.e., the total removal of all bush and oil palm stumps. Stumps were not removed for a "traditional" treatment, the bush and oil palms were cut back and burned only. This labor cost was calculated on the observation that approximately 1000 manhours at $1.50/hour, hand labor, were needed to clear one hectare of all stumps. In this case, local farmers appear to have good economic reasons for not wanting to clear away all the bush during land preparation.

Most yields increased with the application of fertilizers except for the Alagba cases. Another interpretation was made concerning the economic feasibility of local farmers applying similar amounts of fertilizers to their parcels.

Input costs of fertilizers and lime were calculated based on prices paid at IITA. The returns for the harvested crop were calculated assuming that dry maize grain sells in bulk for $115.39/ton. This was the actual price paid to farmers at Shagamu, Western State (near Ikenne). All calculations were made for one hectare. The input costs were higher for Abak due to the addition of lime which was not necessary at Ikenne (Table 23).

In all cases at the Ikenne sites it would be more profitable to use improved varieties and planting methods but to burn the cleared bush on the plot and not to apply fertilizers given existing fertilizer costs and market prices of dry maize grain (Table 24).

Table 23. Experimental input costs per hectare at Ikenne and Abak for first season maize.

Fertilizer	Price per 50 kg	Price per hectare
1. Single superphosphate	$ 10.03	$ 100.30
2. Muriate of potash	9.24	18.48
3. Urea	9.12	54.72
Total cost - Ikenne		$ 173.50
4. Lime	11.25	112.50
Total cost - Abak		$ 286.00

Profits for the traditional plots must also take into account returns for other foodcrops such as cassava produced on the same plot. There was insufficient time to harvest the cassava from these plots.

In order for farmers on Alagba or Atan soils to realise a similar or greater profit with the use of fertilizers than those not using fertilizers but burning only it would be necessary for the government to subsidize the total cost of fertilizers or for dry grain yields to increase approximately 1500 kg/ha with the same fertilizer input.

This is only one point on a production function and may not be valid for other rates of fertilizer application, assuming that the price of fertilizers and dry maize grain remains constant.

In the case of the Abak sites, fertilizer application at the rates used would constitute a loss on the cropped Uyo site. Also

Table 24. Returns per hectare for dry maize grain at the Ikenne site for Alagba and Atan soils.

Soil and treatment	Market price for yield	Price of inputs	Profit
1. Cropped Alagba:			
Traditional, burning, no fertilizer	$ 148.74	--	$ 148.74
Experimental, no burning, fertilizer	567.14	$ 173.50	393.64
Experimental, burning, no fertilizer	675.49	--	675.49
Experimental, burning, fertilizer	642.26	173.50	468.76
2. Bush fallow Alagba:			
Traditional, burning, no fertilizer	273.13	--	273.13
Experimental, no burning, fertilizer	379.06	173.50	205.56
Experimental, burning, no fertilizer	407.91	--	407.91
Experimental, burning, fertilizer	506.33	173.50	332.83
3. Bush fallow Atan:			
Traditional, burning, no fertilizer	209.89	--	209.89
Experimental, no burning, fertilizer	563.56	173.50	390.06
Experimental, burning, no fertilizer	417.71	--	417.71
Experimental, burning, fertilizer	575.22	173.50	401.72

on the cropped Uyo site the return on plots which were burned only the profit is hardly enough to be an incentive to grow any maize at all. This was confirmed by the fact that most farmers in the Abak area did not grow maize (since most of their plots were intensively cultivated due to the high population pressure) or grew it only on compound plots near the dwellings where refuse was thrown. On the bush fallow Uyo site the most profitable treatment was again (as in the Ikenne case) burning only and no fertilizer applications (Table 25). However, the profits in this case were not as great as those for the Ikenne site.

For farmers using fertilizers and lime on Uyo soils to realize a greater profit than those burning only it would be necessary for the government to subsidize completely the costs of these inputs for intensively cropped soils (which is the normal case here) or subsidize approximately 40% of the inputs on exceptional soils such as bush fallow Uyo. Dry grain production on fertilized and limed land would have to increase by approximately 2,500 kg/ha on cropped sites or 650 kg/ha on exceptional sites such as bush fallow Uyo. This represents only one point on a production function and may not be valid for other rates of fertilizer application assuming that the price of fertilizers and dry maize grain remains constant.

Fallows are important to the regeneration of soil fertility even with the use of fertilizers. However, it may also be shown that fallows in some cases may be a lavish and wasteful use of land depending on the system of fallow regeneration which farmers choose or are forced

Table 25. Returns per hectare for dry maize grain at the Abak site for Uyo soils.

Soil and treatment	Market price for yield	Price of inputs	Profits
1. Cropped Uyo:			
Traditional, burning, no fertilizer	$ 22.96	--	$ 22.96
Experimental, no burning, fertilizer, lime	230.49	$ 286.00	- 55.51
Experimental, burning, no fertilizer	74.72	--	74.72
Experimental, burning, fertilizer, lime	274.63	286.00	- 11.37
2. Bush fallow Uyo:			
Traditional, burning, no fertilizer	203.43	--	203.43
Experimental, no burning, fertilizer, lime	517.58	286.00	231.58
Experimental, burning, no fertilizer	299.09	--	299.09
Experimental, burning, fertilizer, lime	483.20	286.00	197.20

to employ (Tables 26 and 27). The results at the Abak site for the best treatment, "experimental, burning, fertilizer and lime" on both "cropped" and "bush fallow" sites were used (Table 22). Two rotation models were considered: 1) early maize monocropped on 100 hectares of fresh land with a rotation of 5 years production - 10 yrs. fallow - 5 yrs. of production - 10 yrs. of fallow - 5 yrs. of production - 10 yrs. of fallow - 5 yrs. of production - 10 yrs. of fallow (for a total of 60 yrs.), with all of the 100 ha being used for each 5 yr. production period, 2) early maize monocropped on 10 ha parcels of 100 hectares of fresh land with 10 ha being farmed at a time for one year then left to fallow for ten years. Over 60 years there are 55 one-year periods of production on 10 ha parcels and 5 years of nonproduction for all of the 100 hectares.

The following assumptions are made: 1) a ten year fallow is the optimum period of regeneration; 2) five years of production is the longest length of time for which these soils can be economically cultivated even with the use of fertilizers (five year periods were used because this data was available from field experiments); 3) the first year of production after 10 years of fallow gives 4188 kg of dry maize grain/ha; 4) the second through fifth years give 2380 kg of dry maize grain per hectare each year (Table 22) (a gradually downward trend is probably more characteristic but sufficient data is not available to extrapolate the trend); 5) optimum fertilizer applications are made.

Model 1, the more intensive system of cultivation of all the land for five-year periods followed by 10-year fallows, is the most productive of the two systems in terms of overall yield of dry maize grain for the 60 year period (Table 26).

Model 2, the less intensive system of cultivation, resembles more closely the system of traditional shifting cultivation where smaller parcels of land are cultivated and higher priced crops such as maize and white yams are grown during the first year after clearing the bush fallow. This system seems more lavish and wasteful in terms of the

Table 26. Total yield of dry maize grain (first season only) for an intensive cultivation system on 100 hectares over a 60 year period.

	Kg dry maize grain/100 ha
1. Yield first year of five year period	418,800
2. Yield for years 2-5 of five year period	4 x 238,000 = 952,000
3. Total yield for one 5-year period	1,370,800
4. Total yield for four 5-year cultivation periods during 60 years	5,483,200

land resources available (Table 27). It is, however, more suited to the technological resources of the local farmer and provides a harvestable crop each year.

Table 27. Total yield of dry maize grain (first season only) for the less intensive cultivation system on 100 hectares over a 60 year period.

	Kg dry maize grain/100 ha
1. Yield/10 ha parcel <u>per annum</u>	41,880
2. Total yield for 55 producing years of 60 total years from 10 ha parcels for 100 ha of land	2,303,400

Results - cassava trial

Cassava was harvested at Abak only. The cassava planted at

Ikenne was too diseased by bacterial wilt and leaf mosaic to give a representative yield for the region. The cassava yields were higher on the cropped Uyo site than on the bush fallow site (Table 28).

Table 28. Cassava yields (10 months old) at Abak on Uyo soils.

Treatment	Fresh tubers, kg/ha	
	Cropped Uyo	Bush fallow Uyo
Traditional, burning, no fertilizer	17,170	9,340
Experimental, no burning, fertilizer	17,308	14,973

The results suggest that on the cropped site the application of fertilizers (the same level as applied to the maize plots) may be equal in effect to the burning of the cleared bush from the plot.

Results - second season maize (Abak only)

Second season maize yields are always low at all of the four benchmark areas and for this reason one rarely finds farmers growing this crop from July to November. Field trials were carried out at Obio-Akpa Model Farm to test this generalization. The yields were characteristically low and uneconomical (Table 29).

Results - second season soybean trial (Abak only)

Little data was available on the yields of such legumes as soybeans in the high rainfall area. Most farmers in this area do not grow a legume crop due to the exceptionally low yields. Given the high

Table 29. Yields of dry maize grain for the second growing season at Abak on Uyo soils.

Treatment	Yield, kg/ha	
	Cropped Uyo	Bush fallow Uyo
Experimental, burning, no fertilizer	82	385
Experimental, no burning, fertilizer	99	463
Experimental, burning, fertilizer	176	883

population density of the area most yields would probably resemble those on the cropped Uyo site, the bush fallow site produced yields significantly higher (Table 30). In both cases no significant response to fertilizers was noted. This was probably due in part to the lack of potash application and the low level of exchangeable K in these soils.

Table 30. Yields of dry soybean grain for the second growing season at Abak.

Treatment	Yield, kg/ha	
	Cropped Uyo	Bush fallow Uyo
Experimental, burning, no fertilizer	170	676
Experimental, no burning, fertilizer	119	722
Experimental, burning, fertilizer	144	610

The analysis of results of all the field experiments described above could have been improved by an analysis of variance between treatments and sites; however, all of the raw data was not available in Ithaca to accomplish this. Also the usefulness of the data could have been extended by an analysis of surface soil samples for each treatment at each site. There was not enough time nor were surface soil samples available for this purpose.

SUMMARY AND CONCLUSIONS

A large area of soils extends along the coast of West Africa from Lome, Togo to Calabar, Nigeria formed over arenaceous sedimentary parent materials of Plio-Pleistocene age. The rainfall increases from west to east over this coastal formation yet the temperature regime remains constant. Four benchmark areas were selected along this rainfall gradient to characterize the dominant soils (Table 31) and relate these soil-climatic parameters to foodcrop production.

Table 31. Classification of the important well-drained soils formed over Plio-Pleistocene coastal plain sands as a function of rainfall.

Benchmark Area	Annual rainfall (mm)	Wet season (no. of months)	Classification (USDA) Soil Taxonomy) of dominant upland soils
South Togo	900	4 to 5	Oxic Paleustalf
Ikenne	1400	7 to 8	Oxic Paleustalf
Benin-NIFOR	1850	8	Oxic Paleustalf to Typic Paleustult
Abak	2600	9	Typic Paleudult

All major upland soils were found to have deep argillic horizons, although micropedological and thin-section studies should be undertaken to prove this definitively. Also, as expected, the argillic horizons of soils at the lower end of the rainfall gradient (South Togo, Ikenne and some Benin-NIFOR benchmark soils) showed a resaturation by bases, Ca in particular, of the exchange complex thus putting these soils into the USDA classification as Alfisols. Excessive leaching at the higher end of the rainfall gradient (Abak and some Benin-NIFOR soils) placed these soils into the USDA classification order of Ultisols. As expected, the agronomic potential of most of the Alfisols was greater than the Ultisols.

To determine potential for foodcrop production at each benchmark area, the following crops were studied: maize, cassava, and yams, in particular, with secondary emphasis on cocoyams, rice, groundnuts, cowpeas, pigeon peas, tomatoes and others. The typical production levels varied for most of these crops across the climosequence. Production at the same benchmark area varied depending on whether a traditional or experimental management system was followed and how long the soil had been under cultivation.

First-season maize seems to be most suited to the medium rainfall areas around Ikenne (Fig. 10). More maize is presently grown in the low rainfall areas such as South Togo and Ikenne than the higher rainfall areas such as Benin and Abak. This may be a rather recent development due to the high population pressures in Abak and the rapid leaching of soils there.

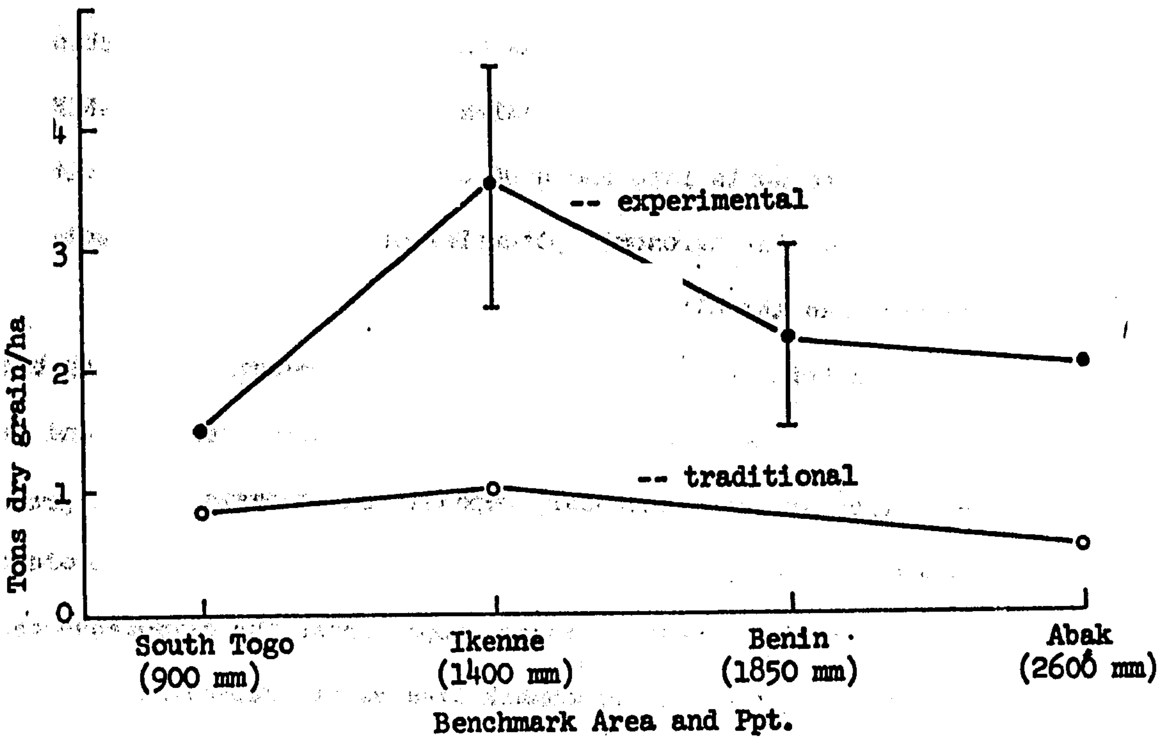

Fig. 10. Yields of first season maize across the climo-sequence.

Cassava seems to be reasonably well adapted, at least under traditional methods of cultivation, throughout the climosequence (Fig. 11). Experimental varieties and management techniques seem to show the greatest advances in the wetter areas of the climosequence, Benin and Abak benchmark areas.

Yams do not grow at the low rainfall area of South Togo (Fig. 12). At present, due to the low population density and sufficient fallow lengths, yams do particularly well in the Benin benchmark area. One would expect similar yields in Abak but short fallows are forcing yams to be replaced by cassava.

Cowpeas and other legumes such as groundnuts, pigeon peas, and soybeans are better suited to the low rainfall end of the climosequence (Fig. 13).

The author observed a similar distribution of treecrops such as oil palms, kola, and rubber across the climosequence. Oil palms were better adapted to the high rainfall areas of Benin and Abak and actually competed with foodcrops for land in Abak. Kola was better suited to the medium rainfall area of Ikenne and competed for growing space with foodcrops there. Rubber was better suited to the high rainfall areas of Benin and Abak and it was not observed to compete directly with foodcrops in these areas.

Abak and South Togo have the most limiting factors to foodcrop production. The potential of the Benin area appears to be underutilized (Table 32).

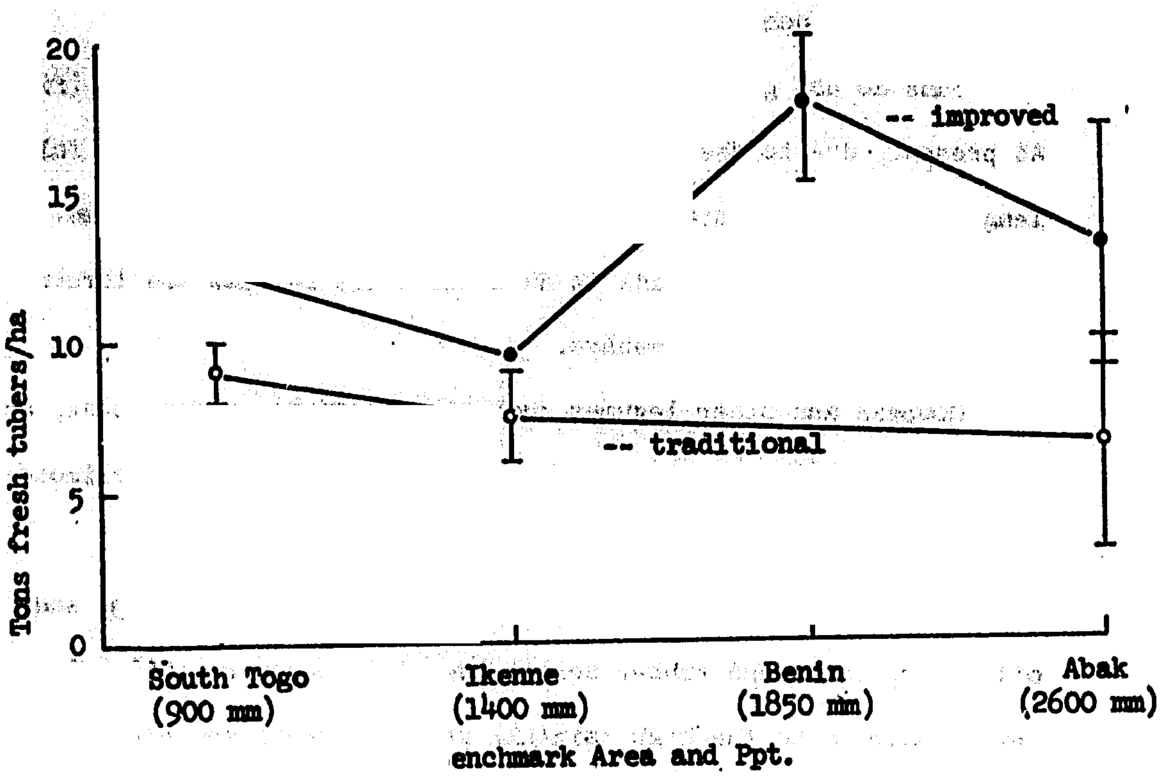

Fig. 11. Yields of cassava across the climosequenc

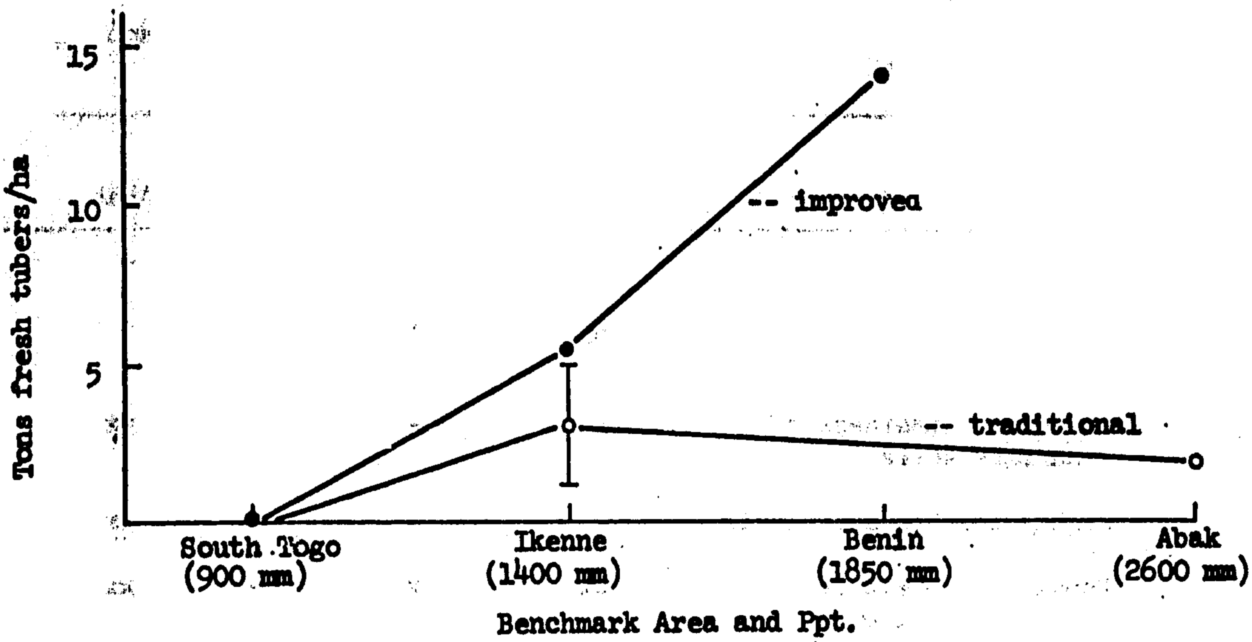

Fig. 12: Yields of white yams across the climosequence.

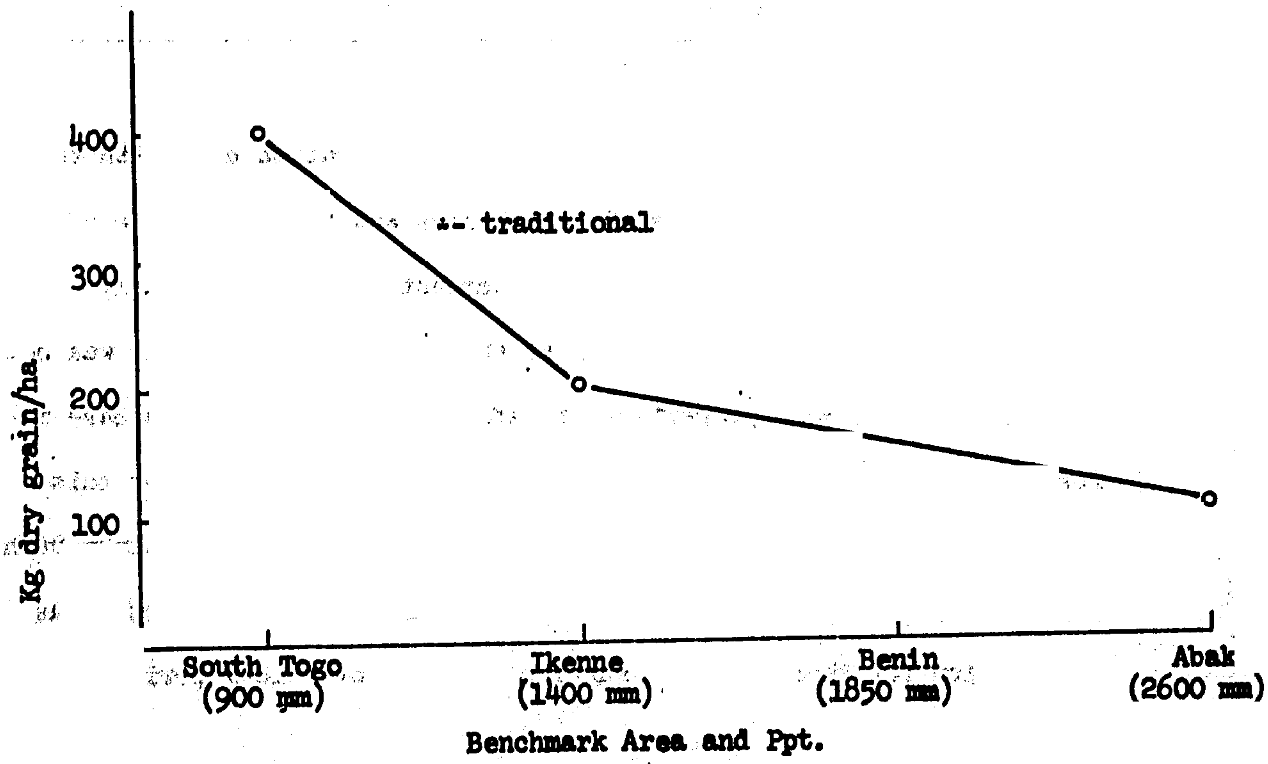

Fig. 13. Yields of cowpeas across the climosequence.

Table 32. Major limiting factors to foodcrop production at each benchmark area.

Factors	Benchmark areas			
	South Togo	Ikenne	Benin	Abak
Insufficient rainfall	xx	-	-	-
Poor rainfall distribution	xx	x	-	-
Increased sandiness of surface soils	x	-	-	xx
Highly leached acid soils		-	x	xx
Population pressure (reduced fallows)	xx	x		xx
Competition with cas tree crops		xx		xx

Key: - not a problem
x moderate problem
xx severe problem

The loss of fertility with continuous cultivation even with the application of optimum levels of fertilizers and the importance of sufficient lengths of bush fallow was demonstrated, particularly by the field experiments conducted at Abak benchmark area. It was not determined which soil properties are affected and cause a decrease in fertility with continuous cultivation by the research done for this thesis. One could not state with certainty which are the optimum bush fallow lengths nor determine the most economic periods of continuous cultivation for these soils. Further research over long periods of time needs to be done to determine optimum fallow and cultivation rotations.

The results of the field experiments at Ikenne and Abak demonstrated that there is still no package of experimental management techniques which can increase the income of the local farmer of these soils above the tried and true traditional methods. In all cases, the burning of cleared bush was more economical than the application of fertilizers for the production of maize. And there seems to be little hope at this point that the price of fertilizers will drop in the near future. However, similar experiments should be carried out at lower rates of fertilizer application or different approaches to fertilizer technology studied.

Two models of shifting cultivation were hypothesized for some of the results of field experiments undertaken at Abak benchmark site. Local farmers seem to follow more closely the less intensive system of cultivation model for two reasons: 1) the system provides a dependable yearly source of income and 2) the system depends on the cultivation of small parcels suitable to the technology available to the farmer. Yields over a long period of time were shown to be lower than yields from the more intensive system even though each system incorporated 10 year fallow periods. The less intensive system of cultivation seems to be more characteristic for the Benin-NIFOR benchmark area, emphasizing again the underutilization of available land in this area. The more intensive model seems to be more viable for large areas of open land which can cultivated mechanically and supervised by the government thus diminishing the necessity of a single farmer to derive a yearly income from one particular parcel of land. Both models of shifting cultivation break down in the presence of large population pressures where 10 year fallow periods are not at all possible. More study needs to be done on this problem and viable models developed to determine the best way of incorporating the necessary fallows into the cultivation system.

Finally, it is important to emphasize the limits of adaption and yields of particular crops to any given soil-climate combination and the many human factors which influence this adaptatior

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APPENDICES

APPENDIX I

CLIMATIC DATA OF THE FOUR BENCHMARK AREAS

Table 33. Mean monthly climatological figures - South Togo (Lome) benchmark area.

Month	Mean Monthly Rainfall (mm) (10 yrs.)	No. of raindays (>0.1 mm) (Tsevie)	Heaviest Daily Rainfall (mm)	Mean Monthly Temp. (°C) (10 yrs.)	Mean Monthly PET (mm)	Mean Monthly Global Radiation (Ly/day)
Jan.	17	1	60	26.8	110	412.7
Feb.	37	2	72	27.5	110	441.6
March	80	4	56	27.9	130	465.2
April	10	6	90	27.6	120	444.7
May	15	9	15	26.9	120	433.0
June	20	11	98	25.6	110	395.2
July	5	6	74	24.6	100	365.6
August	16	4	51	24.6	100	380.6
Sept.	48	6	68	25.6	110	415.9
Oct.	153	8	107	25.8	110	425.2
Nov.	21	4	56	26.7	120	454.5
Dec.	6	1	48	26.9	120	420.7

Table 34. Mean monthly climatological figures - Ikenne benchmark area.

Month	Mean Monthly Rainfall (mm) (9 yrs.)	No. of raindays (>0.1 mm) (9 yrs.)	Heaviest Daily Rain-fall (mm)	Mean Monthly Temp. (°C)	Mean Monthly PET (mm)	Mean Monthly Global Radia-tion (ly/day)
Jan.	12	2	36	--	120	--
Feb.	22	2	63	--	110	--
March	94	8	57	--	120	--
April	127	.0	53	--	120	--
May	152	.3	88	--	120	--
June	252	19	70	--	110	--
July	253	19	123	--	100	--
August	121	14	122	--	100	--
Sept.	165	17	65	--	100	--
Oct.	168	15	111	--	110	--
Nov.	50	5	72	--	110	--
Dec.	10	1	20	--	120	--

Table 35. Mean monthly climatological figures - Benin (NIFOR) benchmark area.

Month	Mean Monthly Rainfall (mm) (22 yrs.)	No. of Raindays (>0.1 mm) (Benin City)	Heaviest Daily Rain-fall (mm)	Mean Monthly Temp. (°C) (Benin City)	Mean Monthly PET (mm)	Mean Monthly Global Radia-tion (ly/day)
Jan.	11	1	69	26.4	110	395.6
Feb.	25	3	79	27.2	110	399.9
March	85	7	66	27.5	120	400.6
April	162	12	74	27.5	120	426.5
May	195	14	119	26.9	120	424.7
June	253	19	94	25.6	100	363.1
July	318	25	190	24.4	100	325.3
August	195	20	180	24.4	100	308.5
Sept.	300	24	142	25.0	100	335.2
Oct.	227	20	175	25.8	110	386.6
Nov.	62	5	43	26.7	110	392.8
Dec.	11	2	18	26.1	120	401.6

Table 36. Mean monthly climatological figures - Abak benchmark area.

Month	Mean Monthly Rainfall (mm) (17 yrs.)	No. of raindays (>0.1 mm) (17 yrs.)	Heaviest Daily Rainfall (mm) (Uyo)	Mean Monthly Temp. (°C) (Calabar)	Mean Monthly PET (mm)	Mean Monthly Global Radiation (ly/day) (Calabar)
Jan.	41	3	13	25.8	110	368.1
Feb.	64	5	15	26.9	110	377.2
March	150	11	35	27.2	110	380.1
April	208	13	32	26.7	110	399.9
May	234	16	38	26.4	110	384.5
June	328	20	64	25.8	100	320.7
July	358	21	57	25.6	90	295.2
August	394	23	56	25.0	90	297.4
Sept.	388	25	70	25.3	100	330.8
Oct.	284	21	89	25.8	100	359.6
Nov.	132	10	40	26.4	110	356.2
Dec.	28	3	36	25.8	110	378.4

APPENDIX II

PROFILE DESCRIPTIONS AND ANALYTICAL DATA OF SOIL PEDONS

Chemical methods for the determination of analytical data

Particle size class

Particle sizes were determined by the hydrometer method of mechanical analysis after dispersing the soil particles with sodium hexametaphosphate.

pH

Two pH determinations were made: 1) 1:1 soil/water ratio, 2) 1:1 soil/1N KCl ratio. The pH's were then measured electrometrically.

Percent organic C

Organic C was determined by the Walkley-Black method.

Percent total N

Total N was determined by the regular macro-Kjeldahl method.

Extractable cations (Ca, Mg, K, Na, Mn, Fe)

Cations were extracted with 1N NH_4OAc. K, Na, and Ca were then determined on a flame photometer. Mg and Mn were determined on an atomic absorption spectrometer. Fe was determined colorimetrically by the phenanthroline method.

Exchangeable acidity

Al and H were first extracted with 1N Kcl then titrated with 0.05N NaOH using phenophthalein indicator.

Available P

Available P was determined by the Bray No. 1 method.

Topographic positions of the South Togo benchmark soil pedons

The Legbako and Kodjin series occur on undulating plateaus where the slope is very slight, 1 to 2%. In these and the following topographic position descriptions surface I represents the oldest most stable surface, surface II an intermediate surface, probably an ancient pediment of surface I, surface III the actively eroding surface and surface IV the depositional surface (Fig. 14).

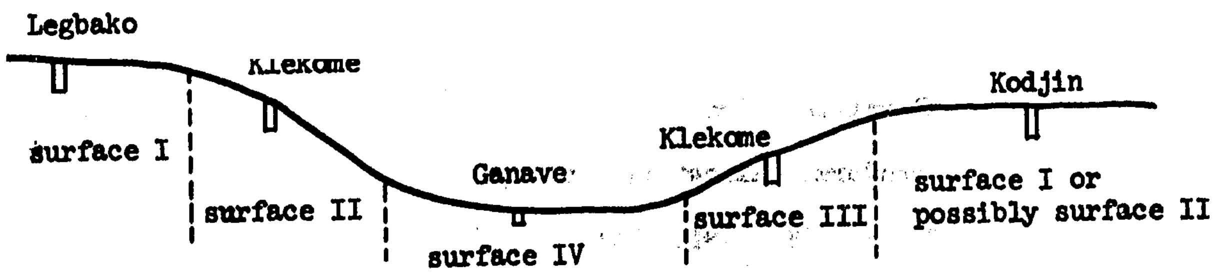

Fig. 14. Topographic positions of South Togo benchmark pedons.

Soil pedon description, Legbako series (profile no. 1)

Information on the site

IITA (International Institute of Tropical Agriculture)

lab no. 102

Soil classification: Oxic Paleustalf (conceptually a re-saturated Oxic Paleustult)

Family: clayey, kaolinitic, isohyperthermic

Examination date: January 5, 1974 by T. R. Forbes

Location: Mission Tove, (Tsevie), Togo

Elevation: 75m.

Landform: Almost flat plateau

Slope: 2%, S-SE, flat

Vegetation: Oil palms and grass regrowth after shifting cultivation

General information on the soil

Parent material: Sandy clay surface sediment of the Plio-Pleistocene coastal plain sands formation

Drainage: Well-drained

Moisture conditions: Soil dry down to 60 to 70 cm.

Groundwater: none, no standing water in profile during rainy season

Rock outcrops: none

Erosion: nil

General aspect of the soil

Dark reddish brown sandy loam surface becoming dark red sandy clay with depth.

Profile description

Horizon	Depth (cm.)	Morphology
Ap	0-12	Dark reddish brown (5YR 3/4, dry), dark reddish brown (2.5YR 2.5/4, moist); sandy loam; moderate coarse to medium crumb structure; very friable, soft, slightly plastic and non-sticky; many micro and very fine, discontinuous, random, inped pores and common, coarse, discontinuous, random, inped, tubular pores; many prominent medium and coarse, rounded and subrounded quartz sand grains; termite burrows and channels; common fine and medium and a few coarse roots; clear, wavy boundary.
A3	12-15	Dark reddish brown (5YR 3/3, dry), dark reddish brown (2.5YR 2.5/4, moist); sandy clay loam; moderate medium to fine subangular blocky structure; non-sticky, slightly plastic, friable, slightly hard; many micro and very fine, discontinuous, random, inped and interstitial pores; common, medium and coarse, continuous, random, inped, tubular pores (seemed to be due to faunal activity); many rounded and subrounded medium and coarse quartz sand grains; common medium, coarse and fine roots; gradual, smooth boundary.
B2t	50-165	Dark reddish brown (2.5YR 3/4, moist); sandy clay; moderate, medium to fine subangular blocky structure; slightly sticky, plastic, friable; thin, broken, glossy cutans around and between many, medium rounded and subrounded quartz sand grains; many micro and very fine, discontinuous, random, inped, interstitial pores and a few coarse, continuous, random, inped, tubular pores (faunal activity); pottery fragment found at 89 cm.; a few medium and a very few coarse roots.

Remarks: During the first examination of these pedons in early January (middle of the long dry season) these soils were dry down to at least 60 to 70 cm. During a subsequent examination in early April the soils were moist down to 30 to 40 cm and quite dry below to at least 100 cm. This situation was confirmed by several borings in the respective areas.

Table 37. Pedon no. 1, Legbako series, analytical data.

Parameter	Horizon			
	Ap	A3	B2t	B2t
Depth (cm)	0-12	12-50	50-165	250-270
Particle size class (%)				
clay	13.2	24.0	44.0	47.2
silt	9.0	6.0	4.0	5.8
sand	77.8	70.0	52.0	47.0
pH (H_2O) (1:1)	5.3	5.5	5.5	--[a]
pH (KCl) (1:1)	4.4	4.6	4.5	--[a]
Organic C %	0.4	0.4	0.35	0.23
Total N %	0.021	0.021	0.018	0.015
Extractable cations meq/100 g of soil				
Ca	1.95	2.03	1.82	--[a]
Mg	1.80	1.46	1.92	--
K	0.11	0.03	0.04	--
Na	0.16	0.16	0.17	--
Mn	0.11	0.09	0.02	--
Fe	0	0	0	--
Exchangeable acidity meq/100 g. of soil				
Al	0	0	0	--[a]
H	0	0	0	--
CEC, sum of cations	4.13	2.77	3.97	
Base saturation, %	100	100	100	

[a]Indicates that no determination was made.

Three Legbako surface samples (0 to 30 cm) were analyzed:

1) Nondegraded, currently under oil palm bush for at least ten years.

2) Degraded 1, cultivated continuously for five years and currently under cassava.

3) Degraded 2, currently being "regenerated" by BDPA agronomists.

Soil pedon description, Kodjin series (profile no. 2)

Information on the site

IITA lab no. 104

Soil classification: Oxic Paleustalf (conceptually a resaturated Oxic Paleustult).

Family: clayey, kaolinitic, isohyperthermic.

Examination date: January 4, 1974 by T. R. Forbes

Location: Kouve, (Tabligbo), Togo.

Elevation: 90 m.

Landform: Almost flat plateau.

Slope: 1%, S-SE, flat.

Vegetation: Oil palms with <u>Terminalia</u>, regrowth after shifting cultivation.

General information on the soil

Parent material: sandy clay or clay sediments of the Plio-Pleistocene coastal plain sands formation.

Drainage: Well-drained.

Moisture conditions: Soil dry down to 60 to 70 cm.

Degradation of Legbako soils

Legbako soils have a tendency to become degraded under intensive cultivation with insufficient or no fallows. Several surface samples from Legbako soils which were considered degraded or nondegraded by Togolese agricultural officers were analyzed by IITA in an effort to pinpoint characteristics which define the state of being "degraded" or "nondegraded." The data do not show major differences in properties thought to be important in degradation (Table 38).

Table 38. Analytical data for three Legbako surface soils (0 to 30 cm).

Soil parameter	Nondegraded	Degraded I	Degraded 2
1. pH	6.3	6.1	6.3
2. Organic carbon (%)	0.7	0.7	0.25
3. CEC meq/100 g of soil	4.67	5.75	2.58
4. Ca (NH$_4$OAc, Extractable cations, meq/100 g soil)	2.70	3.79	1.60
5. Mg	1.66	1.56	0.67
6. K	0.08	0.12	0.06
7. Na	0.14	0.18	0.13
8. Mn	0.02	0.02	0.04
9. Fe	0	0	0
10. Available P (ppm)	4.66	3.50	8.16
11. Total N(%)	0.08	0.07	0.04
12. Total Acidity (Al&H)	0.08	0.08	0.08
13. Base saturation (%)	98	98	97
14. Texture	sandy loam	sandy clay loam	loamy sand

Groundwater: None, no standing water in profile during rainy season.

Rocky outcrops: None.

Erosion: Nil.

General aspect of the soil

Dark reddish brown sandy clay loam or sandy clay surface becoming a dark reddish brown or dusky red clay with depth.

Profile description

Horizon	Depth (cm.)	Morphology
Ap	0-14	Dark reddish brown (2.5YR 2.5/4, moist), dark reddish brown (5YR 3/4, dry); sandy clay loam; moderate medium to very fine subangular blocky structure; non-sticky, slightly plastic, very friable, slightly hard with some loose parts, dry; clay coatings seen on faunal pores; many very fine and fine, discontinuous, random, inped pores and common, medium, discontinuous and continuous exped, interstitial and tubular pores; many rounded and subrounded, medium to coarse quartz sand grains; common fine and medium and a few coarse roots; clear, wavy boundary.
A3	14-44	Dusky red (10R 3/4, moist), dark reddish brown (2.5YR 3/4, dry); sandy clay; moderate coarse to medium subangular blocky structure; slightly sticky, plastic, friable, slightly hard to hard, dry; thick clay coatings in faunal pores; many very fine and fine, discontinuous, random, inped, interstitial pores and some medium and coarse inped, tubular pores; many medium and coarse rounded and subrounded quartz sand grains; pottery fragment (6-7 cm. long and 2-3 cm. wide) found at 35 cm. depth; common coarse and medium roots; gradual, wavy boundary.

B2t	44-120	Dark reddish brown (2.5YR 3/4, moist), dark red (2.5YR 3/6, dry); clay; moderate coarse to medium subangular blocky structure; sticky, plastic, friable, hard, dry; thin patchy cutans in upper part of horizon becoming continuous and thick with depth; many very fine and fine, continuous and discontinuous, inped, interstitial and tubular pores; a few medium and coarse, continuous, inped, tubular pores; large faunal voids approximately 5x5x8 cm.; common medium and a few coarse roots.

Table 39. Pedon no. 2, Kodjin series, analytical data.

Parameter	Horizon Ap	A3	B2t
Depth (cm)	0-14	14-44	44-120
Particle size class (%)			
clay	12	20	45
silt	11.8	8	5
sand	76.2	72	50
pH (H_2O) (1:1)	5.3	5.7	5.55
pH (KCl) (1:1)	4.9	5.0	4.6
Organic C %	0.7	0.55	0.95
Total N %	0.03	0.02	0.02
Extractable cations meq/100 g of soil			
Ca	2.89	2.10	2.00
Mg	1.20	1.00	1.46
K	0.09	0.03	0.03
Na	0.16	0.14	0.14
Mn	0.01	0.01	0.04
Fe	0[a]	0	0
Exchangeable acidity meq/100 g of soil			
Al	0	0	0
H	0	0	0.04
CEC, sum of cations	4.35	3.28	3.71
Base saturation, %	100	100	99

[a]Indicates no measureable quantity.

Soil pedon description, Klekome series (profile no. 3)

Information on the site

IITA lab no. 105.

Soil classification: Oxic Paleustalf (conceptually a resaturated Oxic Paleustult).

Family: clayey, kaolinitic, isohyperthermic

Examination date: January 3, 1974 by T. R. Forbes.

Location: Mission Tove, (Tsevie), Togo.

Elevation: 65 m.

Landform: Break of undulating plateau.

Slope: 3%, S-SE, gently sloping.

Vegetation: Grassy fallow of Digitaria and Imperata after shifting cultivation.

General information on the soil

Parent material: Sandy colluvium from plateau surface of the Plio-Pleistocene coastal plain sands formation.

Drainage: Well-drained to somewhat excessively well-drained.

Moisture conditions: Soil dry down to 60 to 90 cm.

Groundwater: None, no standing water in profile curing rainy season.

Rock outcrops: None

Erosion: Nil.

General aspect of the soil

Deep sandy to sandy clay profile changing from brown or reddish brown surface to red below.

Profile description

Horizon	Depth (cm.)	Morphology
Ap	0-16	Dark reddish brown (5YR 3/3, moist), dark reddish brown (5YR 4/3, dry); loamy coarse sand; weak medium to very fine subangular blocky structure; non-sticky, non-plastic, very friable, soft, dry; many fine and medium, discontinuous, random, exped, interstitial pores; many rounded and subrounded coarse sand grains; abundant fine and common medium and coarse roots; clear, wavy boundary.
A3	16-50	Dark reddish brown (5YR 3/3, moist), dark reddish brown (2.5YR 3/4, dry); loamy coarse sand; moderate medium to fine subangular blocky structure; non-sticky, non-plastic, very friable, slightly hard, dry; many fine to micro, discontinuous, random, inped, tubular pores; many rounded and subrounded medium to coarse quartz sand grains; small ferruginous sandstone chips (1 to 2 cm. long) found occasionally; a few fine roots and a very few medium and coarse roots; gradual, wavy boundary.
B21t	50-90	Dark reddish brown (2.5YR 3/4, moist and dry); sandy clay loam; moderate fine to medium subangular blocky structure; slightly sticky, non-plastic, friable, slightly hard, dry; thin, patchy clay bridges between rounded and subrounded quartz sand grains; many micro and very fine, discontinuous, random, inped, interstitial pores; a few medium and fine roots; gradual, wavy boundary.
B22t	90-190	Dark reddish brown (2.5YR 3/4, moist); sandy clay; moderate medium to very fine subangular blocky structure; slightly sticky, non-plastic, friable, slightly hard, dry; very thin, patchy clay bridges between rounded and subrounded quartz sand grains (less distinguishable than previous horizon); many micro and very fine, discontinuous, random, inped, interstitial pores; very few medium and fine roots.

Table 40. Pedon no. 3, Klekome series, analytical data.

Parameter	Horizon			
	Ap	A3	B21t	B22t
Depth (cm)	0-16	16-50	50-90	90-190
Particle size class (%)				
clay	10	11.2	24	31.2
silt	6	3	2.8	3.8
sand	83.2	85.8	73.2	65
pH (H_2O) (1:1)	5.3	5.6	5.6	5.7
pH (KCl) (1:1)	4.7	4.8	4.8	3.8
Organic C %	0.6	0.53	1.08	0.5
Total N %	0.02	0.02	0.02	0.03
Extractable cations meq/100 g of soil				
Ca	2.56	1.00	1.29	0.92
Mg	1.35	0.82	1.02	0.70
K	0.06	0.04	0.03	0.03
Na	0.13	0.14	0.12	0.13
Mn	0.02	0.04	0.01	0.04
Exchangeable acidity meq/100 g of soil				
Al	0 [a]	0	0	0
H	0	0	0	0.56
CEC, sum of cations	4.12	2.04	2.47	2.38
Base saturation, %	100	100	100	76

[a]0 indicates no measurable quantity.

Degradation of Klekome soils.

Although Klekome soils are theoretically very susceptible to degradation, the following analytical data (Table 41) do not show any differences in properties thought to be important in degradation.

Table 41. Analytical data for two Klekome surface soils (0 to 30 cm.)

Soil parameter	Degraded	Nondegraded
1. pH (H_2O)	6.4	6.1
2. Organic C (%)	0.5	0.35
3. CEC meq/100 g of soil	3.42	2.94
4. Ca	2.20	1.80
5. Mg	0.89	0.82
6. K	0.07	0.06
7. Na	0.15	0.15
8. Mn	0.03	0.04
9. Fe	0	0
10. Available P (ppm)	3.50	4.66
11. Total N (%)	0.05	0.04
12. Total acidity (Al & H)	0.08	0.08
13. Base saturation (%)	98	98
14. Texture	loamy sand	loamy sand

Soil pedon description, Ganave series (profile no. 4)

Information on the site

IITA lab no. (no chemical analyses made).

Soil classification: (Plinthic) Oxic Paleustalf (estimated) (conceptually this is a resaturated Oxic Paleustult).

Family: clayey, kaolinitic, isohyperthermic (estimated).

Examination date: November 21, 1974 by T. R. Forbes.

Location: Ganave, Togo.

Elevation: 65 m.

Landform: Almost flat plateau with slightly concave depressions 100 m in diameter.

Slope: 1%, S-SE, flat.

Vegetation: Grass regrowth, *Imperata cylindrica*, after shifting cultivation.

General information on the soil

Parent material: sandy colluvium of Plio-Pleistocene coastal plain sands formation.

Drainage: Imperfectly drained.

Moisture conditions: Slightly moist (except A_p horizon) but drying out rapidly at time of examination.

Groundwater: None, but most likely within one meter of the surface at some time during the year.

Rockoutcrops: None.

Erosion: Nil.

General aspect of the soil

Deep grayish and brown sandy to sandy clay profile with bright red concretions increasing with depth

Profile description

Horizon	Depth (cm.)	Morphology
Ap	0-29	Grayish brown (10YR 5/2, dry) with a few, fine, distinct, sharp brownish mottles; medium to fine sand; very weak fine to coarse subangular blocky structure; very friable, non-plastic, non-sticky, soft, dry; many fine and very fine, discontinuous, random, inped interstitial pores; many rounded and subrounded bleached white quartz sand grains; common medium and fine roots; gradual, wavy boundary.
A2	29-47	Brown (10YR 5/3, moist) with common, fine, distinct, sharp brownish mottles; loamy medium sand; very weak fine to coarse subangular blocky structure; very friable, non-sticky, non-plastic; many fine and very fine, discontinuous, random, inped, interstitial pores; common, medium, discontinuous, random, inped tubular pores; many rounded and subrounded bleached white quartz sand grains; common medium and coarse roots; gradual, wavy boundary.
B21t	47-80	Brown (10YR 5/3, moist) with many medium and coarse, distinct, sharp, strong brown (7.5YR 5/6) mottles forming particularly in pores or larger voids (up to 2 to 3 cm. in diameter, mottles tend to be slightly harder than matrix when dry); sandy clay loam; moderate medium to coarse subangular blocky structure; friable, non-sticky, slightly plastic, slightly hard, dry; thin patchy cutans between rounded and subrounded quartz sand grains thickening in some pores; many very fine and fine, discontinuous, random, inped, interstitial pores and common, medium and a few coarse, discontinuous, random, inped, tubular pores; many faunal voids (0,5 to 3 cm. in diameter) which seem to have been made by ants; some medium and a few fine roots; gradual, wavy boundary.

IIB22t	80-120	Light yellowish brown (10YR 6/4, moist) with many coarse, distinct, diffuse, reddish yellow (5YR 6/6) mottles, a few fine and medium strong brown (7.5YR 5/6) mottles, and common (15%) coarse, prominent, sharp red (2.5YR 4/6) concretions (20% discontinuous plinthite), gravelly sandy clay; strong medium to very coarse subangular blocky structure; firm, nonsticky, plastic; thin broken cutans between rounded and subrounded quartz sand grains; many fine and very fine, discontinuous, random, inped, interstitial pores; many medium and common coarse, discontinuous, random, inped, tubular pores; several faunal voids 3 to 7 cm. in diameter; a few medium roots; gradual, wavy boundary.
IIB23t	120-170	Very pale brown (10YR 7/3, moist) with many coarse, distinct, diffuse reddish yellow (5YR 6/6) mottles becoming prominent, sharp red (2.5YR 4/6) soft concretions and a few, fine and medium strong brown (7.5YR 5/6) mottles (20% discontinuous plinthite); sandy clay; moderate medium to coarse sub-angular blocky structure; friable, non-sticky, plastic; thin broken cutans between rounded and subrounded quartz sand grains becoming thicker in pores; many fine and very fine, discontinuous, random, inped, interstitial pores and many medium and common, coarse, discontinuous, random, inped, tubular pores; a few faunal voids 5 to 7 cm. in diameter; a few medium and fine roots.

Topographic positions of the Ikenne benchmark soil pedons

All three pedons, Alagba, Owode and Atan, occur on undulating plateaus where the slope is very slight (1 to 2%). Alagba soils are found on the oldest and most stable surface, surface I. Owode and Atan soils are formed on surface II, a pediment formed from materials of actively eroding surface III and surface I. A layer of ironstone gravel and ferruginous sandstone is exposed on surface III (Fig. 15). The exposure of this layer was due to erosion and re-working of younger overlying materials during or shortly after Plio-Pleistocene.

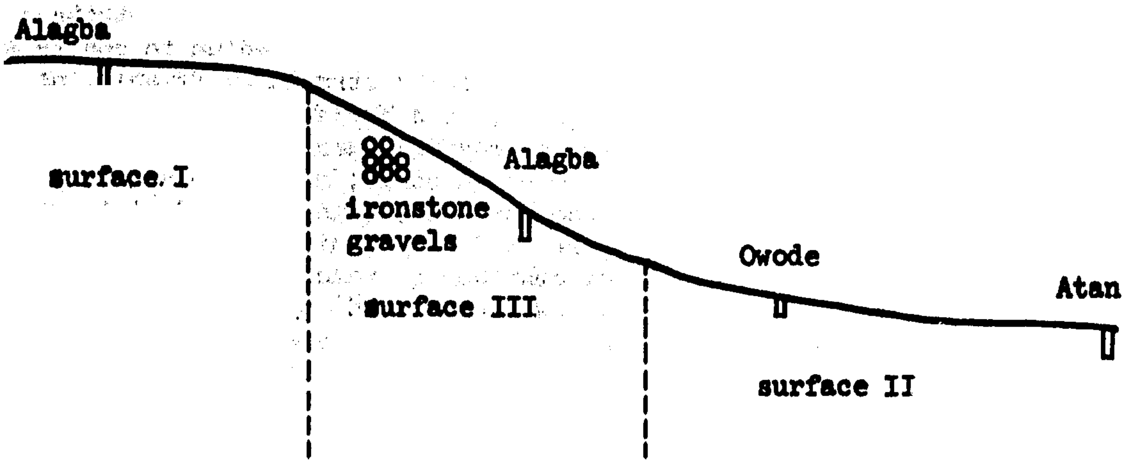

Fig. 15. Topographic positions of Ikenne benchmark pedons.

Soil pedon description, Alagba series (profile no. 5)

Information on the site

IITA lab no. 80

Soil classification: Oxic Paleustalf (conceptually a resaturated Oxic Paleustult).

Family: clayey, kaolinitic, isohyperthermic.

Examination date: July 12, 1973 by F. R. Moormann and P. le Mare.

Location: Ikenne IART Station, Western State, Nigeria.

Elevation: 55 m.

Landform: Gently undulating plateau.

Slope: 4%, SW, flat.

Vegetation: Dense regrowth of Eupatorium odoratum, after clean clearing and several years of cultivation.

General information on the soil

Parent material: Deeply weathered clayey sediments, uniform in lithology and texture to a depth of at least 4 meters.

Drainage: Well-drained.

Moisture conditions: Moist throughout.

Groundwater: None at any time of the year to profile depth.

Biological activity: Worm casts at the surface; subterranean termite chambers, up to 15 cm. in several places in the profile.

Human activities: Pieces of pottery scattered throughout upper 50 cm.

General aspect of the soil

Deep, red clayey soil with sandy surface soil up to 30 cm.

Profile description

Horizon	Depth (cm.)	Morphology
Ap	0-13	Dark reddish brown (5 YR 3/3, moist); sandy loam; moderate fine crumb structure; very friable, slightly sticky, non-plastic; many fine and medium interstitial pores; common fine tubular random pores; many fine and medium roots; gradual, smooth boundary.
A3	13-30	Dark reddish brown (5YR 3/3, moist); sandy loam; weak medium subangular blocky structure; very friable, slightly sticky, non-plastic; common fine and medium interstitial pores and many fine tubular random, inped pores and some medium, tubular pores; some larger voids; many fine and common medium roots; gradual, smooth boundary.
B1	30-45	Dark reddish brown (2.5YR 3/4, moist); sandy clay loam; weak to moderate fine subangular blocky structure; friable, slightly sticky, slightly plastic; thin patchy cutans on some ped surfaces, clear clay movement in larger pores; many fine, common medium, random, tubular, inped pores; common fine, some medium roots; gradual, smooth boundary.
B21t	45-105	Dark red (2.5YR 3/6, moist); sandy clay, moderate fine subangular blocky structure; firm, slightly sticky, plastic; broken thin cutans on most peds, more distinct in pores; many fine, tubular, random, inped pores; some larger voids and channels; common fine roots, diminishing with depth, some medium roots; diffuse, smooth boundary.
B22t	105-150	Dark red (2.5YR 3/6, moist); sandy clay; moderate fine subangular blocky structure; firm, slightly sticky, plastic; broken thin cutans, locally moderately thick; very distinct clay movement in pores; common fine, tubular, random, inped pores, fewer than in previous horizon and gradually diminishing; some faunal channels; few fine roots.

Remarks: Visible sand grains throughout the profile are most commonly subrounded, but many are rounded (F. R. Moormann, 1973).

Table 42. Pedon no. 5, Alagba series (Ikenne), analytical data.

Parameter	Horizon				
	Ap	A3	B1	B21t	B22t
Depth (cm)	0-13	13-30	30-45	45-105	105-150
Particle size class (%)					
clay	13	15.6	30.6	44.6	--[a]
silt	14.6	4.2	4.2	2.2	--
sand	72.4	80.2	65.2	53.2	--
pH (H_2O) (1:1)	6.1	5.6	5.0	5.1	5.1
pH (KCl) (1:1)	5.6	5.0	4.3	4.3	5.0
Organic C%	1.56	0.7	0.44	0.3	0.22
Total N %	2.16	0.06	0.05	0.05	0.03
Extractable cations meq/100 g of soil					
Ca	5.36	1.82	1.42	1.60	1.87
Mg	2.89	0.72	0.68	0.57	0.49
K	0.25	0.04	0.03	0.04	0.06
Na	0.16	0.14	0.13	0.13	0.13
Mn	0.16	0.10	0.09	0.05	0.03
Fe	0[b]	0	0	0	0
Exchangeable acidity meq/100 g of soil					
Al	0	0	0.18	0.15	--
H	0.22	0.08	0.3	0.3	--
CEC, sum of cations	9.04	2.90	2.83	2.84	--
Base saturation, %	98	97	75	84	--
P (Bray) ppm	5.9	1.6	0.4	0.4	0.4

[a]-- indicates that no determination was made.

[b]0 indicates no measurable quantity.

Degradation of Alagba soils

The effects of degradation are slightly more noticeable in these results than the previous ones made for South Togo soils probably because the process is a bit faster in Ikenne due to greater leaching. Of interest is the increase in total acidity and decrease in base saturation for the intensively cultivated soils (Table 43).

Table 43. Analytical data for three Alagba surface soils (0 to 30 cm).

Soil parameter	Nondegraded	Degraded 1	Degraded 2
1. pH (H_2O)	6.1	5.2	5.2
2. Organic C (%)	0.70	0.50	0.65
3. CEC meq/100 g of soil	3.54	2.16	3.15
4. Ca	2.40	0.99	1.40
5. Mg	0.82	0.41	0.59
6. K	0.05	0.06	0.08
7. Na	0.14	0.23	0.13
8. Mn	0.06	0.07	0.08
9. Fe	0	0	0
10. Available P (ppm)	6.99	5.39	3.39
11. Total N (%)	0.08	0.04	0.08
12. Total acidity (meq) (Al & H)	0.08	0.40	0.88
13. Base saturation (%)	98	82	72
14. Texture	sandy loam	loamy sand	sandy loam

Soil pedon description. Owode series (profile no. 6)

Information on the site

IITA lab no. 69.

Soil classification: Oxic Haplustalf (conceptually a resaturated Oxic Haplustult).

Family: clayey, kaolinitic, isohyperthermic.

Examination data: May 31, 1973 by F. R. Moormann and G. Murdoch.

Location: Ikenne IART Station, Western State, Nigeria.

Elevation: 29 m.

Landform: Gently undulating plateau, profile is situated on weakly pronounced rise.

Slope: 1%, W, flat.

Vegetation: Dense regrowth of *Eupatorium odoratum* and some shrubs after two years of monoculture of maize on completely cleared land.

General information on the soil

Parent material: Sandy colluvium over clayey sediments of Tertiary or Secondary age containing a few weathered ferruginous sandstones at 50 to 70 cm.

Drainage: Well-drained.

Moisture conditions: Moist throughout.

Groundwater: No groundwater at time of examination, temporary groundwater in deeper mottled horizons during or immediately after peak of rainy season.

Human influence: Surface soil shows effect of mechanical plowing.

General aspect of the soil

Deep reddish, clayey profile with brownish sandy surface layers and strongly mottled, lighter textured subsoil.

Profile description

Horizon	Depth (cm.)	Morphology
Ap	0-15/20	Very dark grayish brown (10YR 3/2, moist); sandy loam; weak fine crumb structure; non-sticky, non-plastic, very friable; many fine tubular and interstitial pores; a few faunal voids; charcoal fragments; local mixing with underlying horizon; many fine and a few medium roots; clear, wavy boundary.
A2	15/20-55	Brown (10YR 4/3, moist); faintly mottled in lower part; sandy loam; weak fine and medium subangular blocky structure; very friable; many fine and common tubular, random, inped pores; some charcoal fragments; common fine roots diminishing with depth; clear smooth boundary.
B21t	55-90	Reddish brown (5YR 4/4, moist) with common fine faint and a few fine distinct reddish mottles; sandy clay loam; moderate fine subangular blocky structure; firm; thin broken cutans around most peds, moderately thick on ped surfaces and pores; humus infiltration along vertical ped surfaces with a chroma of 1 lower than matrix; many fine, common medium tubular, random, inped pores; some faunal voids; common fine, few medium roots; gradual, smooth boundary.
B22t	90-120	Yellowish red (5YR 4/6, moist) with common, medium and coarse, distinct, clear, reddish (2.5YR 3/6 and 4/6) and yellow mottles: sandy clay loam; moderate, fine and medium subangular blocky structure; firm; broken thin cutans on most peds, thicker on some vertical peds, local clay-humus infiltration along vertical peds and root channels diminishing with depth; common fine, few medium and coarse, tubular, random, inped pores; common fine roots; gradual, smooth boundary.

B3	120-175	Yellowish red (5YR 5/5, moist) strongly mottled with many medium and some coarse, prominent, clear, red (2.5YR 4/6) to reddish yellow (7.5YR 6/6) mottles; sandy clay loam; moderate fine and medium subangular blocky structure; firm; broken thin cutans on peds and in pores diminishing with depth; some clay-humus infiltration along larger root channels; common fine, random, tubular pores; Fe/Mn nodules rounded, medium hard to hard, less than 5% in weight; few fine roots; diffuse, smooth boundary.
C	175-190	Light yellowish brown (10YR 6/4, moist) matrix with light gray (10YR 7/2) spots and tongues, with many medium, prominent, clear, red (2.5YR 4/6) to reddish yellow (7.5YR 5/6) mottles; sandy clay loam; moderate fine subangular blocky structure; firm; thin patchy cutans mainly in redder area and pores; common fine tubular, random pores; few, hard Fe/Mn nodules; very few fine roots.

(F. R. Moormann, 1973)

Remarks: The bulk density increases in the area of the mottled zone. The following are the means of bulk density and porosity values calculated for the Owode profile (Table 44). Five samples for each determination were used.

Table 44. Average bulk density and porosity values for Owode profile.

Depth (cm)	Bulk density (g/cc)	Percent pore space
10	1.31	51
30	1.45	45
60	1.56	41

Table 45. Pedon no. 6, Owode series, analytical data.

Parameter	Horizon					
	Ap	A2	B21t	B22t	B3	C
Depth (cm)	0-15	15-55	55-90	90-120	120-175	175-190
Particle size class						
clay	14.2	10.7	32.6	33	24.8	31.7
silt	11.6	14.3	9.2	12.6	2.0	13.3
sand	74.2	75	58.2	54.4	73.2	55
pH (H_2O) (1:1)	7.7	6.9	6.5	6.6	5.2	5.0
pH (KCl) (1:1)	7.2	6.1	5.5	5.7	4.3	4.0
Organic C %	0.57	0.20	0.23	0.23	0.17	0.07
Total N %	0.04	0.03	0.03	0.03	0.03	0.02
Extractable cations meq/100 g of soil						
Ca	8.98	1.73	3.49	2.60	1.58	1.39
Mg	0.63	0.23	0.84	1.55	0.98	0.79
K	0.42	0.16	0.42	0.60	0.96	1.13
Na	0.18	0.11	0.13	0.13	0.13	0.11
Mn	0.09	0.02	0.01	0.01	0.02	0.03
Exchangeable acidity meq/100 g of soil						
Al	0 [a]	0	0	0.01	0.29	0.64
H	0	0	0	0	0.23	0.20
CEC, sum of cations	10.3	2.25	4.89	4.90	4.00	4.3
Base saturation, %	100	100	100	100	92	80
P (Bray) ppm	42.9	17.3	0.8	0.6	0.4	2.4

[a]0 indicates no measurable quantity.

Soil pedon description, Atan series (profile no. 7).

Information on the site

IITA lab no. 79.

Soil classification: Plinthic Paleustult.

Family: clayey, kaolinitic, isohyperthermic.

Examination date: June 11, 1973 by F. R. Moormann.

Location: IART Station, Ikenne, Western State, Nigeria.

Elevation: 26 m.

Landform: Almost flat, wide valley.

Slope: Less than 1%, S, flat.

Vegetation: Regrowth of Eupatorium odoratum on completely cleared land, used in previous years for sugar cane production. Nearby: young rubber plantation, poor growth of rubber.

General information on the soil

Parent material: Plio-Pleistocene coastal sediments, the low pH and increasing amounts of total S with depth indicate that the coastal sediments may have mangrove sulfate soils at one time.

Drainage: Imperfectly drained.

Groundwater: No groundwater during most of the year; temporary watertable during height of the rainy season at approximately 1 m or deeper.

General aspect of the soil

Brownish sandy surface soil over increasingly mottled grayish subsoil with plinthite.

Horizon	Depth (cm)	Morphology
Ap	0-20	Dark grayish brown (10YR 4/2, moist); sandy loam; weak fine crumb structure at surface, structureless single grain below; very friable; common fine interstitial pores in upper part, common fine, random tubular pores below; many fine, common medium roots; clear, wavy boundary.
A2	20-38	Brown (10YR 5/3, moist); sandy loam; weak fine subangular blocky structure; very friable, non-sticky, non-plastic; many fine, common medium random, inped tubular pores; many fine, a few medium roots; clear, wavy boundary.
B1	38-61	Brown (7.5YR 5/4, moist) with common fine and medium faint mottles, somewhat redder than matrix and becoming more distinct with depth; sandy clay loam; moderate fine subangular blocky structure; firm, slightly sticky, slightly plastic; patchy thin cutans on many peds, more distinct in larger pores and root channels, clay-humus infiltration along old root or termite channels; many fine, common medium, few large random, tubular, inped pores; common faunal voids up to 2 cm in diameter; many fine, few medium roots; clear, wavy boundary.
B2t	61-93	Brown (10YR 5/3, moist), mottled with many fine and medium, prominent, sharp red (2.5YR 4/6) mottles (20% discontinuous plinthite); sandy clay loam; moderate fine subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy cutans, more distinct in pores; clay-humus infiltration along old root channels or termite channels; many fine, few medium roots; gradual, wavy boundary.
B3	93-160	Light brownish gray (10YR 6/2, moist) matrix passing to gray (10YR 6/4, moist) with depth, many (20%) medium and coarse, prominent, sharp, red (2.5YR 3/6) mottles with browner fringes which harden upon alternate wetting and drying (plinthite); slightly gravelly sandy clay; weak, medium subangular blocky structure; firm, slightly sticky, slightly plastic; thin patchy cutans on some peds, more distinct in pores and root channels, some clay-humus infiltration along old root or termite channels; common fine random tubular inped pores diminishing with depth; moderately hard Fe nodules within red mottles, approximately 10% by weight, mostly less than 1.5 cm in diameter; common fine roots diminishing with depth.

Remarks: The "azonal" occurance of this Ultisol in an area dominated by Alfisols is due to the origin and nature of the parent rock. The clay in the subsoil has developed from pyrites clays and shales, as indicated by the increasing S content with depth. As in other tertiary formations (e.g., Bende clay, Eocene), the soil material has some characteristics of an acid sulfate soil. (F. R. Moorman, 1973).

Table 46. Pedon no. 7, Atan series, analytical data.

Parameter	Horizon A1	A2	B1	B2t	B3
Depth (cm)	0-20	20-38	38-61	61-90	90-180
Particle size class (%)					
clay	8.6	7.2	25.2	29.2	27.2
silt	18.2	16.6	11.6	12.6	8.6
sand	73.2	76.2	63.2	58.2	64.2
pH (H_2O) (1:1)	5.7	5.3	4.7	4.6	4.8
pH (KCl) (1:1)	5.1	4.3	3.8	3.8	3.8
Organic C %	0.5	0.2	0.24	0.18	0.10
Total N %	0.06	0.02	0.03	0.02	0.02
Extractable cations meq/100 g of soil					
Ca	2.5	0.5	1.0	0.91	0.30
Mg	0.88	0.2	0.57	0.56	0.21
K	0.25	0.05	0.08	0.07	0.05
Na	0.18	0.13	0.16	0.15	0.16
Mn	0.08	0.03	0[a]	0	0
Exchangeable acidity meq/100 g of soil					
Al	0	0.05	0.81	1.12	1.95
H	0.14	0.14	0.49	0.47	0.64
CEC, sum of cations	3.95	1.10	2.11	3.28	3.31
Base saturation, %	98	83	58	52	22
P (Bray) ppm	4.6	1.2	0	0.4	0

[a]0 indicates no measurable quantity.

Topographic positions of the Benin benchmark pedons

The topographic positions identified were similar to other areas and are shown schematically in Fig. 16.

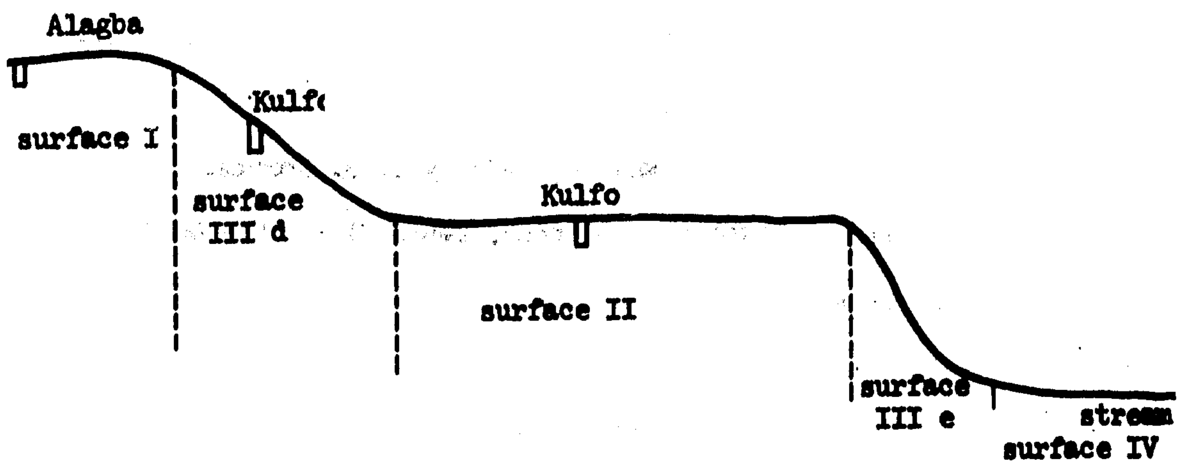

Fig. 16. Topographic positions of Benin benchmark pedons.

Surface I is the oldest, most stable surface and has predominantly Alagba soils. Surface II is formed for the most part by sandy colluvium from surface I. Surface IIId is also a depositional surface covered by sandy colluvium. Kulfo soils are found on surfaces IIId and II. Surface IIIe is the newest actively eroding surface going down to a small surface IV near the stream.

Soil pedon description, Alagba series (Benin-NIFOR)(profile no. 8)

Information on the site

IITA lab no. 109.

Soil classification: Oxic Paleustalf (conceptually a resaturated Oxic Paleustult).

Family: clayey, kaolinitic, isohyperthermic

Examination date: May 24, 1974 by T. R. Forbes.

Location: NIFOR Main Station, Benin City, Midwest State. Nigeria.

Elevation: 85 m.

Landform: Almost flat plateau.

Slope: 1%, N-NE.

Vegetation: Leguminous weed ground cover under oil palm plantation.

General information on the soil.

Parent material: Sandy clay surface sediment of the Plio-Pleistocene coastal plain sands formation.

Drainage: Well-drained.

Moisture conditions: Soil moist when examined.

Groundwater: None, no standing water in profile during rainy season.

General aspect of the soil

Deep red clayey soil with a sandy loam surface.

Profile description

Horizon	Depth (cm)	Morphology
Ap	0-17	Dusky red (2.5YR 3/2, moist; 2.5YR 6/2, dry); coarse sandy loam; weak medium subangular blocky structure; very friable, non-sticky, slightly plastic; many very fine and fine discontinuous, random, inped interstitial pores and a few, medium, random, inped, tubular pores; abundant rounded and subrounded quartz sand grains; much worm (worm casts on surface) and some ant activity; frequent fine and a few medium roots; gradual, wavy boundary.
A3	17-53	Dark reddish brown (2.5YR 3/2, moist); coarse sandy loam; very weak medium to coarse subangular blocky structure; very friable, non-sticky, non-plastic; many very fine and fine, discontinuous, random, inped, interstitial pores; many rounded and subrounded quartz sand grains; some earthworm activity; frequent fine and medium roots; clear, wavy boundary.
B1	53-67	Dark reddish brown (2.5YR 3/3, moist); sandy clay loam; very weak medium to coarse subangular blocky structure; very friable, non-sticky, slightly plastic; very patchy, thin cutans between some quartz sand grains; many very fine and fine, discontinuous, random, inped, interstitial pores; many rounded and subrounded quartz sand grains; slight earthworm activity; a few medium and coarse roots; clear, wavy boundary.
B21t	67-110	Dark reddish brown (2.5YR 3/4, moist) with a slightly higher chroma in the interior of peds; sandy clay; moderate medium to coarse subangular blocky structure; friable, very slightly sticky, plastic; thin, broken cutans between most sand grains with occasional thicker cutans in pores; many very fine and fine, discontinuous, random, inped, interstitial pores and common, medium and coarse, discontinuous, random, inped vesicular and tubular pores; many rounded and subrounded quartz sand grains; a few animal or termite burrows (5x10x45 mm); a few medium and coarse roots; gradual, wavy boundary.

B22t	110-150	Dark red (2.5YR 3/6, moist); clay; moderate medium to coarse subangular blocky structure; friable, very slightly sticky, plastic; moderately thin, broken cutans with thick cutans in pores; many very fine and fine, discontinuous, random, inped, interstitial pores and common medium and coarse, discontinuous, random, inped, vesicular and tubular pores; many rounded and subrounded quartz sand grains; a few medium and some coarse roots.

Table 47. Pedon no. 8, Alagba series (Benin-NIFOR), analytical data.

Parameter	Horizon				
	Ap	A3	B1	B21t	B22t
Depth (cm)	0-17	17-53	53-67	67-110	110-150
Particle size class (%)					
clay	17	14	20	34	35.2
silt	8.8	2.8	2	0[a]	1
sand	74.2	83.2	87	66	63.8
pH (H_2O) (1:1)	4.7	5.2	5.4	5.3	5.2
pH (KCl) (1:1)	4.1	4.5	4.6	4.7	4.5
Organic C %	1.46	0.8	0.75	0.5	0.5
Total N %	0.11	0.05	0.04	0.04	0.04
Extractable cations meq/100 g of soil					
Ca	6.49	3.29	3.69	3.49	1.40
Mg	1.10	0.28	0.25	0.08	1.51
K	0.72	0.02	0.02	0.02	0.02
Na	0.16	0.14	0.14	0.14	0.13
Mn	0.05	0	0	0	0.02
Exchangeable acidity meq/100 g of soil					
Al	0	0	0	0	0.16
H	0	0	0	0	0.24
CEC, sum of cations	8.52	3.73	4.10	3.73	3.48
Base saturation, %	100	100	100	100	89

[a]0 indicates no measurable quantity.

Degradation of Alagba soils (Benin benchmark area)

Two surface samples were analyzed: one fresh from secondary forest and the second from an adjacent field which had been cropped for two years. No significant differences were found (Table 48).

Table 48. Analytical data from two Alagba surface soils (0 to 30 cm) (Benin benchmark area).

	Soil parameter		Forest	Cropped
1.	pH (H_2O)		4.1	4.0
2.	Organic C (%)		0.85	1.0
3.	CEC meq/100 g of soil		2.42	2.64
4.	Ca		0.50	0.40
5.	Mg	(NH_4OAc extractable cations, meq/100 g of soil)	0.14	0.20
6.	K		0.06	0.08
7.	Na		0.02	0.02
8.	Mn		0.02	0.02
9.	Fe		0 [a]	0
10.	Available P (ppm)		5.00	6.25
11.	Total N (%)		-- [b]	--
12.	Total acidity (meq) (Al & H)		1.68	1.92
13.	Base saturation (%)		30.5	27.1
14.	Texture		--	--

[a] 0 indicates no measurable quantity.

[b] -- indicates no determination was made.

Soil pedon description, Kulfo series, (profile no. 9)

Information on the site

IITA lab no. 107.

Soil classification: Oxic Paleustult.

Family: clayey, kaolinitic, isohyperthermic.

Examination date: September 6, 1974 by T. R. Forbes.

Location: NIFOR Main Station, Benin City, Nigeria.

Elevation: 75 m.

Landform: convex slope just below break in plateau, undulating with no outstanding microtopography.

Slope: 5% to the NE.

Vegetation: leguminous cover under oil palm plantation.

General information on the soil

Parent material: sandy colluvium and sandy clay sediment of Plio-Pleistocene coastal plain sands.

Drainage: well-drained to somewhat excessively drained.

Moisture conditions: soil was moist throughout when described.

Groundwater: none, no standing water in profile during rainy season.

General aspect of the soil

Deep dark reddish brown sandy loam surface changing to dark, reddish brown sandy clay loam with depth.

Profile description

Horizon	Depth (cm)	Morphology
Ap	0-14	Dark reddish brown (5YR 3/3, moist); loamy coarse sand; very weak fine to medium subangular blocky structure; very friable, non-sticky, non-plastic; many fine, discontinuous, random, inped, interstitial pores and common, medium, discontinuous, random, inped, tubular pores; some very apparent bleached white rounded and subrounded sand grains on surface and many rounded and subrounded quartz sand grains throughout horizon; common fine and medium roots; gradual, wavy boundary.
B2	14-37	Dark red (2.5YR 3/6, moist); coarse sandy loam; weak medium to fine subangular blocky structure; very friable, non-sticky, non-plastic; many fine, discontinuous, random, inped, interstitial pores and common, medium, discontinuous, random, inped, tubular pores; many rounded and subrounded quartz sand grains; large faunal void, 8x6x10 cm; common medium and fine roots; gradual, wavy boundary.
IIAp	37-63	Dark reddish brown (2.5YR 3/4, moist), chroma of peds somewhat lighter when crushed; coarse sandy loam; weak medium to fine subangular blocky structure; very friable, non-sticky, non-plastic; many fine, discontinuous, random, inped, interstitial pores and common, medium, discontinuous, random, inped, tubular pores; many rounded and subrounded quartz sand grains; a few bits of small charcoal fragments; common medium and fine roots; gradual, wavy boundary.
IIB1	63-87	Dark red (2.5YR 3/6, moist); sandy clay loam; weak coarse to medium subangular blocky structure; very friable, non-sticky, very slightly plastic; occasional, thin, patchy clay bridges between rounded and subrounded quartz sand grains; many fine and very fine, random, inped interstitial pores; many medium and fine, discontinuous, random, inped, tubular pores; common medium and some fine roots; gradual, wavy boundary.

IIB21t	87-123	Dark red (2.5YR 3/6, moist); sandy clay loam; weak coarse to medium subangular structure; very friable, non-sticky, very slightly plastic; thin, broken clay bridges between rounded and subrounded quartz sand grains thickening in pores; many fine and very fine, random, inped, interstitial pores and many medium and fine, discontinuous, random, inped, tubular pores; common medium and some fine roots; gradual, wavy boundary.
IIB22t	123-160	Dark red (2.5YR 3/7, moist); sandy clay loam; weak coarse to medium subangular blocky structure; very friable, non-sticky, very slightly plastic; many thin, broken clay bridges between rounded and subrounded quartz sand grains, some thick cutans in pores; many fine and very fine, random, inped, interstitial pores and many medium and fine, discontinuous, random, inped, tubular pores; a few medium and some coarse roots.

Remarks: There appears to be a recent accumulation of material to 37 cm over the classifiable profile. The sediment is similar to the upper horizon of the soil below and may represent a depositional phase of the classified soil.

Table 49. Pedon no. 9, Kulfo series, analytical data.

Parameter	Horizon					
	Ap	B_2	IIAp	IIB1	IIB21t	IIB22t
Depth (cm)	0-14	14-17	37-63	63-87	87-123	123-160
Particle size class (%)						
clay	12.2	15.2	16.2	20.2	22.2	23.2
silt	4	2	1	1	1.0	0 [a]
sand	83.8	82.8	82.8	78.8	76.8	76.8
pH (H_2O) (1:1)	4.1	4.1	4.2	4.2	4.3	4.3
pH (KCl) (1:1)	3.3	3.5	3.8	3.8	3.8	3.8
Organic C %	1.02	0.55	0.2	0.03	0	0
Total N %	0.06	0.05	0.04	0.04	0.04	0.03
Extractable cations meq/100 g of soil						
Ca	0.61	0.24	0.18	0.17	0.17	0.15
Mg	0.10	0.04	0.02	0.02	0.02	0.02
K	0.06	0.03	0.01	0.01	0.01	0.01
Na	0.12	0.11	0.11	0.08	0.10	0.12
Mn	0	0	0.01	0.01	0.02	0.03
Exchangeable acidity meq/100 g of soil						
Al	1.41	1.68	1.54	1.55	1.28	1.35
H	0.19	0.32	0.46	2.05	0.32	0.25
CEC, sum of cations	2.49	2.42	2.33	3.89	1.92	1.93
Base saturation, %	36	17	14	7	17	17

[a]0 indicates no measurable quantity.

Topographic positions of Abak benchmark pedons

The following topographic positions are given to the soils described (Fig. 17):

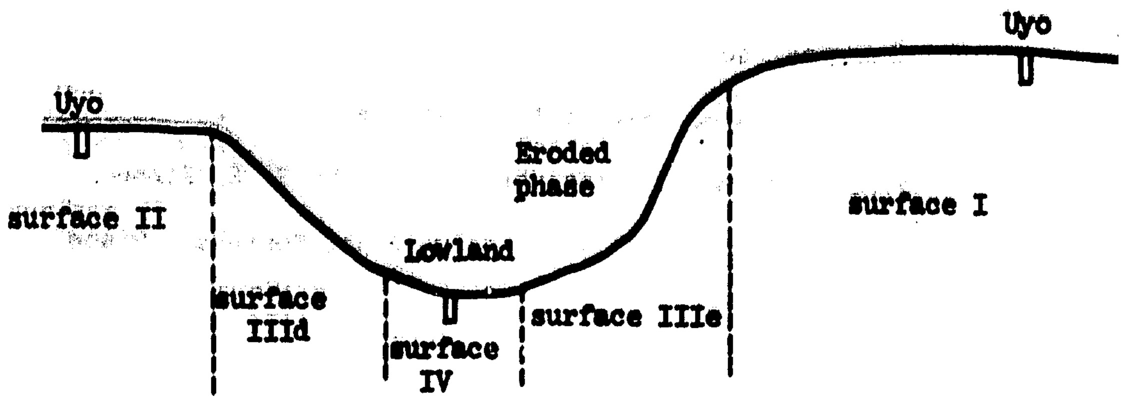

Fig. 17. Topographic positions of Abak benchmark pedons.

Surface I is the oldest and most stable surface and is representative of the undulating plateaus of the region as a whole. Surface II is almost indistinguishable from surface I except for a slightly lower elevation (probably a pediment of a slightly eroded surface I). The soils of surfaces I and II are indistinguishable morphologically. Surface IIId is a current erosion surface over which materials are presently being deposited. Surface IIIe is carried away leaving a sandy clay layer nearer the surface. Surface IV is the depositional surface of colluvium.

Soil pedon description, Uyo series (profile no. 10).

Information on the site

IITA lab no. (no analytical data for this profile)

Soil classification: Oxic Paleudult (estimated) (marginal to Oxic Hapludult).

Family: clayey, kaolinitic, isohyperthermic.

Examination data: September 4, 1974 by T. R. Forbes.

Location: Obio-Akpa Model Farm, Abak, Southeast State, Nigeria.

Elevation: 70 m.

Landform: Almost flat summit of undulating plateau.

Slope: 1%, S-SW, flat.

Vegetation: Oil palms and Eupatorium odoratum regrowth after shifting cultivation.

General information on the site

Parent material: Sandy clay surface sediments of Plio-Pleistocene coastal plain sands formation.

Drainage: well-drained.

Moisture conditions: soil moist throughout profile.

Groundwater: none, no standing water in profile during rainy season.

General aspect of the soil

Brownish sandy loam to sandy clay loam surface becoming yellowish red sandy clay with depth.

Profile description

Horizon	Depth (cm)	Morphology
A1	0-17	Dark reddish brown (5YR 2/2, moist); sandy loam; weak medium to very fine subangular blocky structure; very friable, non-sticky, non-plastic; many fine and very fine, discontinuous, random, inped, interstitial pores; many prominent rounded and subrounded white quartz sand grains accumulating on the surface; much ant and termite activity; common fine and medium roots; gradual, wavy boundary.
A3	17-37	Dark brown (7.5YR 3/2, moist); sandy clay loam; weak medium to fine subangular blocky structure; very friable, non-sticky, slightly plastic; common fine and medium, discontinuous, random, inped, tubular pores and many fine, discontinuous, random, inped, interstitial pores; many rounded and subrounded white quartz sand grains; occasional charcoal fragments 2-4 mm in diameter; much ant and termite activity; common fine and medium roots; clear, wavy boundary.
B21t	37-68	Brown (7.5YR 4/4, moist)(when kneaded color becomes slightly darker); sandy clay; moderate coarse to fine subangular blocky structure; friable, non-sticky, slightly plastic; common, thin patchy clay bridges between rounded and subrounded quartz sand grains becoming thicker and more continuous in medium size pores; many fine, discontinuous, random, inped, tubular pores and many fine and very fine, discontinuous, random, inped, interstitial pores; darker sandy material from above filling a few larger faunal pores; some faunal voids for ant or termites 1-2 cm in diameter; common medium and some coarse roots; gradual, wavy boundary.
B22t	68-102	Reddish brown (5YR 4/4, moist); sandy clay; moderate coarse to medium subangular blocky structure; friable, non-sticky, slightly plastic; common thin, patchy clay bridges between rounded and subrounded quartz sand grains; common medium, discontinuous, random, inped, tubular pores and many very fine and common fine, discontinuous, random, inped, interstitial pores; a few coarse and medium roots; diffuse, wavy boundary.

B23t	102-147	Yellowish red (5YR 4/8, moist), sandy clay; weak to moderate coarse to medium subangular blocky structure; friable, non-sticky, slightly plastic; occasional, thin, patchy clay bridges between rounded and subrounded quartz sand grains; soil has less "glossy" more "floury" or dull appearance than horizon above; many fine, discontinuous, random, inped, tubular pores and many very fine, discontinuous, random, inped, interstitial pores; a few medium roots; diffuse, wavy boundary.
B24t	147-290	Yellowish red (5YR 4/8, moist); sandy clay; weak coarse to medium subangular blocky structure; very friable, non-sticky, slightly plastic; occasional thin, patchy, clay bridges between rounded and subrounded quartz sand grains; common fine and very fine, discontinuous, random, inped, interstitial pores; occasional medium and coarse roots.

Remarks: Top 40-60 cm have been mixed as seen by charcoal fragments and chunks of sandy clay material in some places from the horizon below. Bulk densities increase with depth (Table 50).

Table 50. Bulk densities and percent pore space for the Uyo pedon (0-50 cm).

Depth (cm)	Bulk density and standard deviation	Percent pore space
10	1.265 ± 0.037	52.2
20	1.278 ± 0.088	51.7
30	1.379 ± 0.049	47.9
40	1.373 ± 0.095	48.1
50	1.571 ± 0.051	43.1

Table 51. Pedon no. 10, Uyo series, particle size class data.

Particle size class and depth (cm)	Horizon					
	Ap	A3	B21t	B22t	B23t	B24t
Depth (cm)	0-17	17-37	37-68	68-102	102-147	147-290
clay	11	16	30	30	26	23
silt	7	8	2	2	2	3
sand	82	76	68	68	72	74

Degradation of Uyo soils

Problems of degradation (degraded vegetation such as bracken (Pteridim aquilinim) and exceptionally low yields for crops such as maize) are very prevalent in soils of this high rainfall area due to excessive leaching and overcultivation. As in the previous cases laboratory analyses could not pinpoint any specific properties involved other than low pH's and higher quantities of exchangeable Al and H (Table 52).

Table 52. Analytical data for three Uyo surface soils (0-30 cm).

Soil parameter	Nondegraded	Degraded 1	Degraded 2
1. pH (H_2O)	4.4	4.5	4.0
2. Organic C (%)	0.8	1.0	1.0
3. CEC meq/100 g of soil	2.71	3.32	2.73
4. Ca	0.5	0.6	0.1
5. Mg	0.21	0.21	0.04
6. K	0.22	0.07	0.06
7. Na	0.02	0.02	0.03
8. Mn	0.01	0.02	0.02
9. Fe	0	0	0
10. Available P (ppm)	152.5	81.2	36.3
11. Total N (%)	--	--	--
12. Total acidity (meq)(Al&H)	1.68	2.40	2.48
13. Base saturation (%)	38.0	28.0	9.2
14. Texture	sandy clay loam	sandy clay loam	sandy clay loam

Soil pedon description, lowland site (Obio-Akpa, Abak)(profile no. 11)

Information on the site

IITA lab no. 108.

Soil classification: Aeric (Plinthic) Paleaqult.

Family: clayey, kaolinitic, isohyperthermic.

Examination data: May 18, 1974 by T. R. Forbes.

Location: Obio-Akpa Model Farm, Abak, Southeast State, Nigeria.

Elevation: 60 m.

Landform: flat, valley bottom, slightly concave.

Slope: 0%.

Vegetation: Oil palm bush, woody shrubs and sedges.

General information on the soil

Parent material: sandy colluvium and alluvium from upper surfaces of coastal plain sands.

Drainage: imperfectly drained.

Moisture conditions: soil moist when examined.

Groundwater: none at the time of examination, there was standing water at the site from the end of June to the end of October, 1974.

General aspect of the soil

Deep gray sandy to sandy clay loam profile with bright red concretions and mottling starting at approximately 60 cm depth.

Profile description

Horizon	Depth (cm)	Morphology
Ap	0-8	Black (5YR 2.5/1, moist); loamy coarse sand; single grain structure; very friable, non-sticky, non-plastic; many very fine and fine, discontinuous, random, interstitial pores; many apparent white quartz sand grains, rounded and subrounded; some ant and termite activity, burrows 2-3 cm in width; abundant fine and medium roots; abrupt, irregular boundary.
A2	8-29	Grayish brown (10YR 5/2, moist); coarse sand; single-grain to very weak fine to medium subangular blocky structure; very friable, non-sticky, non-plastic; many very fine to fine, discontinuous, random, interstitial pores; many rounded and subrounded white quartz sand grains; some ant and termite activity; common medium and coarse roots; gradual, wavy boundary.
IIB21t	29-62	Brownish gray (10YR 5/2, moist) with a few, medium, prominent strong brown (7.5YR 5/6) mottles and a few, medium prominent dark reddish brown (5YR 3/4) concretions, 5-10 mm in diameter, concretions blend into soft mottles at the edges (10% discontinuous Plinthite); sandy clay loam; very weak medium to coarse subangular blocky structure; very friable, non-sticky, slightly plastic; very thin, patchy clay bridges between rounded and subrounded quartz sand grains; many fine, discontinuous, random, inped, interstitial pores and a few medium, discontinuous, random, inped, tubular pores; some ant and termite activity; clear, wavy boundary.
IIB22tcn	62-125	Brown (10YR 5/3, moist) with very frequent large (30-40 mm in diameter) dark reddish brown (5YR 3/4) concretions surrounded by strong brown (7.5YR 5/6) mottles (30% discontinuous Plinthite); sandy clay loam; very weak medium to coarse subangular blocky structure; very friable, non-sticky, slightly plastic; thin, patchy clay bridges between rounded and subrounded quartz sand grains; many fine, discontinuous, random, inped, interstitial pores; a few medium roots; gradual, wavy boundary.

IIB23tcn 125-190 Light brownish gray (10YR 6/2, moist) with very frequent, large (30-40 mm in diameter), dark reddish brown (5YR 3/4) concretions with some strong brown (7.5YR 5/6) mottles (30% discontinuous Plinthite); sandy clay loam; weak medium to coarse subangular blocky structure; friable after chunks are chipped away from profile, non-sticky, slightly plastic; thin, patchy clay bridges between rounded and subrounded quartz sand grains; many fine, discontinuous, random, inped, interstitial pores; a few medium roots.

Table 53. Pedon no. 11, lowland site (Abak), analytical data.

Parameter	Ap	A2	IIB21t	IIB22tcn	IIB23tcn
			Horizon		
Depth	0-8	8-29	29-62	62-125	125-190
Particle size class (%)					
clay	10	13	24	18.2	31.2
silt	17.8	5.8	8.8	13	10.8
sand	72.2	81.2	67.2	68.8	58.0
pH (H_2O) (1:1)	4.6	4.3	4.1	4.5	4.5
pH (KCl) (1:1)	3.8	3.7	3.8	4.0	3.8
Organic C %	3.75	0.33	0.13	0.38	0.83
Total N %	0.24	0.05	0.05	0.05	0.05
Extractable cations meq/100 g of soil					
Ca	1.85	0.22	0.19	0.17	0.14
Mg	0.88	0.06	0.05	0.02	0.02
K	0.45	0.07	0.03	0.03	0.02
Na	0.17	0.14	0.14	0.15	0.13
Mn	0.04	0 [a]	0	0	0
Exchangeable acidity meq/100 g of soil					
Al	1.16	1.28	1.98	2.21	3.43
H	0.44	0.32	0.42	0.19	0.17
CEC, sum of cations	4.99	2.09	2.81	2.77	3.91
Base saturation, %	68	23	15	13	8

[a]0 indicates no measurable quantity.

Soil pedon description, Uyo series (eroded phase), (profile no. 12)

Information on the site

IITA lab no. 106.

Soil classification: Oxic Paleudult.

Family: clayey, kaolinitic, isohyperthermic.

Examination date: May 18, 1974 by T. R. Forbes.

Location: Obio-Akpa Model Farm, Abak, Southeast State, Nigeria.

Elevation: 70 m.

Landform: break of upper plateau surface.

Slope: 10%.

Vegetation: Oil palm, bamboo and Eupatorium odoratum after cultivation of maize and cassava.

General information on the soil

Parent material: sandy clay sediment of the Plio-Pleistocene coastal plain sands formation.

Drainage: well-drained.

Moisture conditions: soil moist at time of examination.

Groundwater: none, no standing water in the profile during the rainy season.

General aspect of the soil

Deep, well-drained clayey soil with brown surface becoming yellowish red at depth.

Profile description

Horizon	Depth (cm)	Morphology
Ap	0-10	Dark brown (7.5YR 3/2, moist); sandy clay; very weak fine to medium subangular blocky structure; friable, non-sticky, plastic; many very fine and fine, discontinuous, random, inped, interstitial pores, some large tubular pores filled with brown (7.5YR 4/4) material probably brought up by ants and termites; many rounded and subrounded quartz sand grains; termite and ant burrows; frequent, fine to medium roots; clear, wavy boundary.
B21t	10-30	Brown (7.5YR 4/4, moist) with a few yellowish red mottles (5YR 4/6, 2 mm in diameter); sandy clay; very weak medium to coarse subangular blocky structure; very friable, non-sticky, plastic; thin, patchy clay bridges becoming thicker in pores; many fine and very fine, discontinuous, random, inped, interstitial pores; many rounded and subrounded quartz sand grains; much termite and ant activity; common fine and coarse roots; gradual, wavy boundary.
IIB22t	30-53	Strong brown (7.5YR 5/6, moist) with a few yellowish red (5YR 4/6) mottles; clay; very weak coarse subangular blocky structure; very friable, non-sticky, slightly plastic; thin, patchy clay bridges between rounded and subrounded quartz sand grains thickening in the pores; many very fine and fine, discontinuous, random, inped, interstitial pores; common medium and coarse roots; gradual, wavy boundary.
IIB23t	53-90	Yellowish red (5YR 5/8, moist) with yellowish red (5YR 4/6) clayey mottles covering approximately 2-3% of the surface; clay; very weak medium to coarse subangular blocky structure; very friable, non-sticky, plastic; thin, broken clay bridges between rounded and subrounded quartz sand grains becoming thicker in pores; many very fine and fine, discontinuous, random, inped, interstitial pores; common medium and coarse roots; gradual, wavy boundary.

IIB3	90-137	Yellowish red (5YR 5/8, moist); clay; very weak medium to coarse subangular blocky structure; very friable, non-sticky, plastic; a very few thin, patchy clay bridges between sand grains; many very fine and fine, discontinuous, random, inped, interstitial pores; many rounded and subrounded quartz sand grains; a few medium roots.

Remarks: Yellowish red mottles are probably pieces of rotten ferruginous sandstone in the parent material.

Table 54. Pedon no. 12, Uyo series, eroded phase, analytical data.

Parameter	Horizon Ap	B21t	IIB22t	IIB23t	IIB3
Depth (cm)	0-10	10-30	30-53	53-90	90-137
Particle size class (%)					
clay	21	37	40	39.2	40
silt	9.8	5.8	2	6.8	4
sand	69.2	57.2	58	54	56
pH (H_2O) (1:1)	4.2	4.4	4.4	4.3	4.2
pH (KCl) (1:1)	3.2	3.5	3.5	3.6	3.7
Organic C %	1.4	0.64	0.95	0.58	0.25
Total N %	0.07	0.06	0.05	0.05	0.05
Extractable cations meq/100 g of soil					
Ca	0.37	0.18	0.18	0.14	0.16
Mg	0.15	0.04	0.03	0.02	0.02
K	0.09	0.03	0.02	0.02	0.03
Na	0.14	0.13	0.13	0.12	0.12
Mn	0 [a]	0	0	0	0
Exchangeable acidity meq/100 g of soil					
Al	1.42	1.46	1.46	1.41	1.32
H	1.78	2.14	1.74	1.39	1.08
CEC, sum of cations	3.95	3.98	3.56	3.10	2.73
Base saturation, %	19	10	10	10	12

[a]0 indicates no measurable quantity.

Soil pedon description, Uyo series (highly saturated phase), (profile no. 13)

Information on the site

IITA lab no. 101.

Soil classification: Typic Paleudoll (conceptually a re-saturated Oxic Paleudult).

Family: clayey kaolinitic, isohyperthermic.

Examination data: February 13, 1974 by T. R. Forbes.

Location: Obio-Akpa Model Farm, Abak, Southeast State, Nigeria.

Elevation: 75 m.

Landform: summit of almost flat, undulating plateau, with much microrelief with depressions 5 m in diameter and 1 m deep around the area.

Slope: 1%, N-NW, flat.

Vegetation: Oil palms and Eupatorium odoratum.

General information on the soil

Parent material: sandy clay sediment of the Plio-Pleistocene coastal plain sands formation.

Drainage: well-drained.

Moisture conditions: soil dry to approximately 30 cm at time of examination.

Groundwater: none, no standing water in profile during rainy season.

Human influence: quite extensive as seen by the microtopography (depressions), bits of pottery found at 90 cm in the profile, and the very dark black color of accumulated material in the surface horizons.

General aspect of the soil

Black sandy surface horizon becoming yellowish red sandy clay with depth.

Profile description

Horizon	Depth (cm)	Morphology
Ap	0-21	Black (2.5YR 2/0, moist and dry); sandy loam; weak very fine to fine subangular blocky structure; very friable, non-sticky, non-plastic, soft; common fine to medium, discontinuous, random, inped, interstitial pores; many white rounded and subrounded quartz sand grains; occasional orange-brown pottery fragment; much ant and termite activity; frequent fine and common medium and coarse roots; clear, irregular boundary.
A12	12-30	Very dark gray (10YR 3/1, moist and dry); loamy medium sand; weak medium to very fine subangular blocky structure; very friable, non-sticky, non-plastic, soft; common very fine and fine, discontinuous, random, inped, interstitial pores; many fine, discontinuous, random, inped, tubular pores; a few coarse, continuous, inped, tubular pores (termites); many rounded and subrounded quartz sand grains; common fine and medium roots; clear, wavy boundary.
BA	30-50	Brown (7.5YR 4/4, moist and dry); loamy medium sand; moderate coarse to medium subangular blocky structure; friable, non-sticky, non-plastic, slightly hard; many fine, discontinuous, random, inped, interstitial pores and common, medium, discontinuous, random, inped, tubular pores; many rounded and subrounded quartz sand grains; some termite channels; common fine and medium roots; gradual, wavy boundary.

B1	50-86	Brown (7.5YR 4/4, moist); sandy clay loam; moderate coarse to medium subangular blocky structure; friable, non-sticky, plastic; some thin, patchy clay bridges between rounded and subrounded quartz sand grains; common fine and medium, discontinuous, random, inped, tubular pores; occasional charcoal fragments; common medium and some coarse roots; gradual, wavy boundary.
B21t	86-150	Brown (5-7.5YR 4/6-5/6, moist); sandy clay; moderate coarse to medium subangular blocky structure; friable, non-sticky, slightly plastic; some thin, patchy clay bridges between rounded and subrounded quartz sand grains becoming thicker in pores; common fine and medium, discontinuous, random, inped, tubular pores; a few, medium and coarse roots; gradual, wavy boundary.
B22t	150-184	Brown (5-7.5YR 5/6, moist); sandy clay; moderate coarse to medium subangular blocky structure; friable, non-sticky, plastic; common thin, patchy clay bridges between rounded and subrounded quartz sand grains with thicker cutans in pores; common fine and medium, discontinuous, random, inped, tubular pores; some medium and coarse roots.

Table 55. Pedon no. 13, Uyo series, highly saturated phase, analytical data.

Parameter	Horizon				
	Ap	A12	B+A	B1	B2t
Depth (cm)	0-21	21-30	30-50	50-86	86-184
Particle size class (%)					
clay	6	10	-- [a]	20	28
silt	6	3	--	2.8	0.8
sand	88	87	--	77.2	71.2
pH (H_2O) (1:1)	5.4	5.6	5.6	5.6	5.6
pH (KCl) (1:1)	4.7	4.8	4.8	4.5	4.2
Organic C %	2.7	1.05	0.5	0.35	0.28
Total N %	0.08	0.03	0.02	0.02	0.02
Extractable cations meq/100 g of soil					
Ca	9.55	3.29	1.79	1.66	1.43
Mg	2.14	0.3	0.07	0.11	0.48
K	0.09	0.03	0.03	0.03	0.03
Na	0.17	0.14	0.13	0.12	0.13
Mn	0.08	0.02	0.01	0.01	0.01
Exchangeable acidity meq/100 g of soil					
Al	0 [b]	0	0	0	0
H	0.04	0	0	0.11	0.22
CEC, sum of cations	12.07	3.78	2.03	2.04	2.30
Base saturation, %	99	100	100	95	90

[a]-- indicates no determination was made.

[b]0 indicates no measurable quantity.