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Geoelectric Evaluation of Subsoil for Optimum Cocoa Yield in Parts of Ondo State, Southwestern Nigeria

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Abstract
Geoelectrical resistivity and direct pitting investigations of subsoils from different cocoa plantations across two senatorial districts of Ondo state, Nigeria were conducted with a view to delineating the subsoil units, identifying the nature and composition of the subsoil units and determining the influence of geology, subsoil resistivity and thickness on the growth and yield of cocoa plants. The study involved reconnaissance geological mapping, Schlumberger vertical electrical resistivity sounding and direct pitting techniques. Eight sounding data were collected with ABEM SAS 1000 resistivity meter. The interpretation of the sounding data involved partial curve matching and computer iteration techniques with direct pitting and geological data as control. Three to four distinct subsurface geoelectric/geologic layers were identified. These included the topsoil; the weathered layer/fractured basement/cretaceous sediment and basement bedrock. The layer resistivity's range were 126 - 2306; 37 – 1453 and ∞ ohm-m respectively while the thickness values of the upper two layers were 0.6 – 1.9 m; 1.9 - 25.2 m respectively. The weathered/fractured column and cretaceous sediments constituted the dominant water saturated unit. Resistivity and thickness thresholds of 37 - 511 ohm-m and 1.9 - 19.8 m are suggestive of a significant proportion of clay and sand in the soil identified with Idanre, Oda-Akure and Ondo farm sites that usually gave optimum yields. However, other farm sites as Arimogija, Ikpemen and Ago Panu in Owo, Ibulesoro-Akure and Ile-Oluji soil profiles graded into more sandy soils with resistivity and thickness/depth thresholds of the topsoil and weathered layers between 126 - 2306 ohm-m and 5.3 – 35.2 m respectively. It was concluded that the relatively thick column of the weatherable products of the gray gneiss/charnockitic rocks as sandy clay/clayey sand of the upper two layers may have remained the most important underlying geologic units for optimal growth of cocoa in the state.
Keywords: Schlumberger, Sounding, Resistivity, Thickness, Soil, Weatherable.

1. Introduction

Cocoa is a major export crop in Nigeria with Ondo State being the most prominent cocoa producer in the country (Olujide and Adeogun, 2006 and Olubamiwa and Adhuze, 2008). Over 50 % of the total export or utilized locally per annum comes from the state (Adegeye, 1996). However, Ondo state has some regions where cocoa production is optimum and the production in these regions has increasingly dropped over the years (Table 1). The general fall in the production of cocoa may include but not limited to the following; unstable price, lack of intensives to farmers, geology/soil and or geographical condition. Efforts at sustaining optimum cocoa production in these regions and other areas have necessitated this present study. While the price and others are treated as not limiting factors to the growth of cocoa, the geology and soil physical condition are regarded intrinsically natural and limiting factors and hence form the bases of a geoelectrical/geological survey.

Although, many tree crops including cocoa plant growth or yield involves a complex interaction between the nutrient level and the above natural factors. But in most soils under fallow or forest cover in West Africa where cocoa is extensively grown, soil nutrient level is not a limiting factor to the growth of cocoa where soil structure and water retention are adequate (Opeke, 1997). In the same vein, rainfall may not have constituted a limiting factor since cocoa thrives within a wide range of rainfall from 1000 - 3000 mm per annum (Opeke, 1997).

However, previous records on soil survey within the cocoa belts of Nigeria in Smyth and Montgonery, 1962; Omotosho, 1971; Opeke, 1997; Sanchez, 2002; Hartemink, 2006 posited that a significant percentage not less than 62 % of Nigeria cocoa is grown on best suited soils while 38 % on poor or very unsuitable soils due to decline in physico-chemical properties of the soils.

Ololade *et al.* (2010) earlier work on selected cocoa plantations across Ondo state, Nigeria (Table 2) showed that soils of the various farm locations not greater than 0.45 m depth are not significantly different from one another in terms of chemical properties but differ with decreasing soil profile or physical condition. These disparate levels of progress call for examination, among other things, of the general geoelectrical characteristics of the soil profiles or units and their contributions to the growth and yield of cocoa particularly at depth within and beyond 0.45 m or typical profiles of selected cocoa soils in Ondo state and other areas with same geological setting. Cocoa is a tap-rooted plant with root penetration domiciled between 0.25 – 1.25 m sub - aerially.. It requires among other things deep well-drained soils, free from iron concretions, high in nutrient and adequate clay contents.

Geoelectrical or dc resistivity survey technique has been employed in the present work. The technique is an essential element in many near-surface probes in recent time. Its potential and limitations had been exploited in all areas of different geological settings for the delineation and characterization of different subsurface units/soil structural or textural condition. The technique is inexpensive in terms of cost and time compare to direct pitting method and it is tended to supply reliable subsurface information over depth ranges that are much greater than the depth ranges of the direct pitting technique.

The presence of clay minerals decreases the resistivity of water-bearing rocks significantly through ion-exchange processes (Sch¨on, 1996). In hard rock environments, geological processes tend to alter rock unit to reduce its resistivity. Such processes include weathering, dissolution, hydrothermal alteration, faulting and shearing which increase the surface area, porosity and permeability of rock unit, and hence decrease its resistivity. Conversely, compaction and metamorphism of all rock types may result in lower porosities and permeabilities. Resistivity is, therefore, a widely varying parameter, not only from lithology to lithology, but also within a particular formation as shown in Figure 1 (Ward, 1990 a; Peter, 2003; Mohammed, 2007 and Mohammed *et al.,* 2012). The above submission informed the use of the geoelectrical or dc resistivity survey technique.

2. Site Description

2.1 Site Location, Areal Extent and Geomorphology

Ondo state is one of the Nigerian southwestern states located along the coast of west-Africa, with a coastline of about 73 km (45.2 mi). It lies between latitudes $5^0 45^1$N and $7^0 52^1$N and longitudes $4^0 20^1$E and $6^0 05^1$E.with an areal extent of about 15,500 km^2. The state is bounded in the east by Edo and Delta States, in the west by Osun and Ogun states, in the north by Ekiti and Kogi States and to the South by the Bight of Benin and the Atlantic Ocean. The cocoa plantations/farm sites selected include; Oda farm-Akure, Ibulesoro farm-Akure, Government Farm in Idanre, Ago Panu-Owo, Ikpenme-Owo, Ile-Oluji farm and Bagbe in Ondo (Table 2/Figure 1) with the Federal and State built highways that provide or aid accessibility.

The Ondo State where these farm sites are located is composed of lowlands and rugged hills in several places. The land rises from the coastal part of Ilaje/Ese-Odo (<15 m a.s.l) in the south, to the rugged hills of the north-eastern and central portion in the Akoko and Akure-Idanre area respectively. Generally, numerous meandering rivers and small river channels typical of sedimentary and basement settings respectively drain the entire state and the flows are southwards to the Atlantic Ocean. Among these rivers are the Owena, Ohewa, Ogbese, Ose and Oni rivers.

The state generally is of the lowland tropical rain forest type, with distinct wet and dry seasons. The mean temperature ranges between 27 - 30^0c. (Duze and Ojo, 1982), while mean relative humidity is between 70 - 75 %. The mean annual rainfall ranges between 1300 - 2000 mm. This wide range of the climatic condition may have responsible for the sustained growth of cocoa trees in the state. The vegetation is composed of many varieties of hard-wood timber such as *Melicia excelsa, Antaris africana, Terminalia superba, Lophira procera* and *Symphonia globulifera* in the south while woody savannah such as *Blighia sapida* and *Parkia biglobosa* is in north. However, over the study areas, human interference has modified the vegetation.

Table 1. Yield Data (Ranking) of Cocoa in Ondo State Between 2003 – 2007* (after Ololade *et al.*, 2010)

S/N	Location	Local Government	2003 (MT)	2004 (MT)	2005 (MT)	2006 (MT)	2007 (MT)
1	Ikpemen	Owo	3491^{E}	5543^{D}	4056^{D}	5083^{D}	3745.5^{D}
2	Ago-Panu	Owo	3491^{E}	5543^{D}	4056^{D}	5083^{D}	3745.5^{D}
3	Ile-Oluji	Ile-Oluji/Oke-Igbo	4661^{D}	4873.5^{E}	3682^{E}	4211^{E}	4152^{C}
4	Idanre	Idanre	14703.5^{A}	15419^{A}	14334.5^{A}	17015^{A}	11306^{A}
5	Oda-Akure	Akure South	6024^{C}	7997.5^{C}	7862.5^{C}	5116^{C}	3706.5^{E}
6	Bagbe-Ondo	Ondo West	13669.5^{B}	12023^{B}	8986.5^{B}	12287^{B}	8563.5^{B}

Data from Ondo State Ministry of Agriculture, Nigera. **MT: Metric tonne.**
Ranking Order: *1st =A, 2nd =B 3rd =C, 4th = D, 5th* = E

Table 2. Locations/Descriptive Features of Sampling Sites (after Ololade *et al.*, 2010)

Sampling Locations	Local Government	Points		Meteorological			Biological	
		Eastings	Northings	Temp. °C	Rainfall (mm)	Height (m)	Farming Method	Challenges
Ikpemen	Owo	786974	802260.1	29.85	3.93	287.5	H/SL	Procurement of inputs
Ago-Panu	Owo	788966	806436.5	29.85	3.93	260.3	H/SL	Dry cocoa stands, no nursery, anthill, squirrel
Ile-Oluji	Ile-Oluji/ Oke-Igbo	705658	792032.6	31.68	4.86	253.3	H/SL	No information
Idanre	Idanre	737410	793852.0	32.13	3.54	297.6	H/SL	Mistletoe on trees and other epiphytes
Oda-Akure	Akure South	748307	792318.7	33.09	4.57	324.6	H/SL	Squirrel, epiphytes on trees
Bagbe-Ondo	Ondo West	704188	771096.6	32.5	6.56	227.2	H/SL	Anthill, squirrel, stealing, bush burning

H/SL: Hiring/sharing labourers

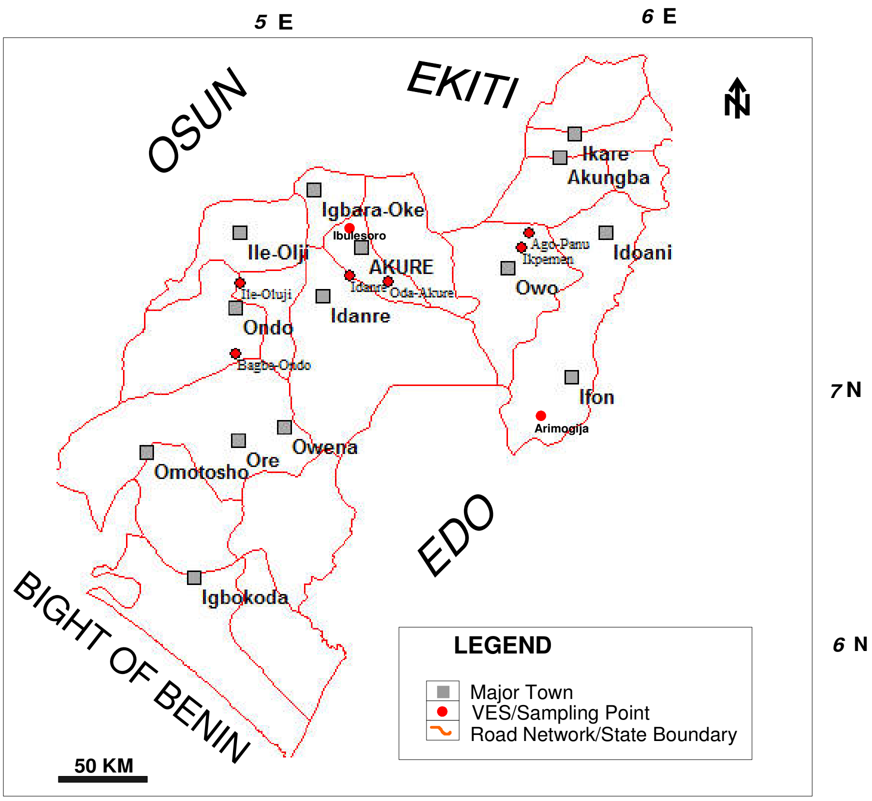

Figure 1: Map of Ondo State showing the Study Locations

2.3 *Geology and Soil*

The farm sites are underlain by the Precambrian Basement Complex except for Arimogija site in the sedimentary terrain of the Eastern Dahomey Basin, South-western Nigeria. The basement rock consists of the following dominant rock

3. Methods of Study

3.1 Field Survey/Data Acquisition Technique

Eight Schlumberger vertical electrical resistivity soundings (VES) were acquired at selected stations (Figure 1). The electrode spacing (AB/2) was varied from 1 – 65 m with maximum spread length of 130 m. The ABEM SAS 1000 Resistivity Meter was used for the measurement of the ground resistance. The product of the measured ground resistance (R) value and the geometric factor (G) of the electrode array for each set up gave the ground apparent resistivity values. A total of 24 holes were bored - 3 holes per site via the use of traditional tools. As the boring progressed, a careful record or logging of the holes was kept at 3 different depth levels (at surface 0 -0.15 m, 0.15 – 0.30 m and 0.30 –0. 45 m) but not greater than 1.0 m. The general physical properties of soil profile encountered as boring progressed enabled proper positioning of the sequence of occurrence of the lithologic units at these depth levels.

3.2 Data Processing/Analysis

The geoelectrical VES data obtained from each station were plotted on transparent bi-logarithms graph paper to obtain a smooth curve. The curves obtained were qualitatively assessed and the quantitatively interpretation by manual partial curve matching. The partial curve matching technique involved the matching of successive segments of the field curve by a set of two-layer theoretical Schlumberger curves (Orellana and Mooney, 1966) and the corresponding auxiliary curves. The geoelectric parameters obtained from the partial curve matching were refined by computer iteration technique using WinRESIST software (Vander Velpen, 1988). The computer assisted interpretation by forward and inverse modeling techniques was an interactive computer-graphic display system (Ghosh, 1974; Sharma, 2000). The system made use of a fast computer to calculate an apparent resistivity curve for a given layer sequence. From the above, the refinement of the results of the partial curve matching interpretation was obtained and found satisfactory with the root square mean (rsm) error of less than 10 percent.

4. Results and Discussion

The results of the data obtained from the field are presented as field curves ((Figure 2 a – c/Table 3)) and geo-electric sections/lithological logs ((Figure 3). The field or depth sounding curves show two distinct characteristics—a steeply rising segment due to the effect of high resistive materials and a falling terminal branch with depth at large electrode spacings due to the effect of low resistive materials. The type curves/occurrences include; H/50 %, K/37.5 % and KH/ 12.5 % (Table 3).

Typical curves with similar geoelectrical/geological features may be grouped as described below (Olorunfemi and Olorunniwo, 1985).

(i) Group 1: H-type curves: The H-type curve has a typical three-layer geoelectric sequence; the topsoil (alluvium, sand, lateritic clay or clay); (clay/sandy clay layer) and lastly the bedrock. The bedrock represents the weathered and possibly fractured basement which may be too thin to be identified as a unit.

(ii) Group 2: K and KH -types: The K-type is a three- layered sequence unit. The KH-type is a four-layered sequence layers include topsoil; hard sand/lateritic clay; clay/sandy clay and bedrock.

Generally, the geoelectric sections of the farm sites delineated three distinct subsurface geologic layers (Figure 3). These include the topsoil of variable moisture, the clay/sand/sandy clay/clayey weathered column and the bedrock.

(a) The Topsoil. This is generally composed of clay/sandy clay/clayey sand, sand with coarse/gravelly or oxidized quartz/dirty sands or lateritic column. It remains dry and hard in most places. Layer resistivity values range from 126 - 2306 ohm-m. The variation of the soil resistivity may be explained by the wide textural variation in the topsoil (Olorunfemi and Fasuyi, 1993; Mohammed, *et al.*, 2012). The resistivity value less than 100 ohm-m typifies clay while those in the range of > 100 and < 1000 ohm-m may indicate clayey sand, saturated sand while resistivity in the range of > 1000 ohm-m may represent lateritic sand (hard pan), sand and bedrock. The thickness of the topsoil ranges from 0.5 to 1.9 m with the mean thickness of 1.6 m. The variation may have been influenced by the local topographical highs and lows of the southwestern basement. The

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generally thin nature of the topsoil coupled with a very low degree of groundwater saturation makes the unit less hydrogeologically appeal.

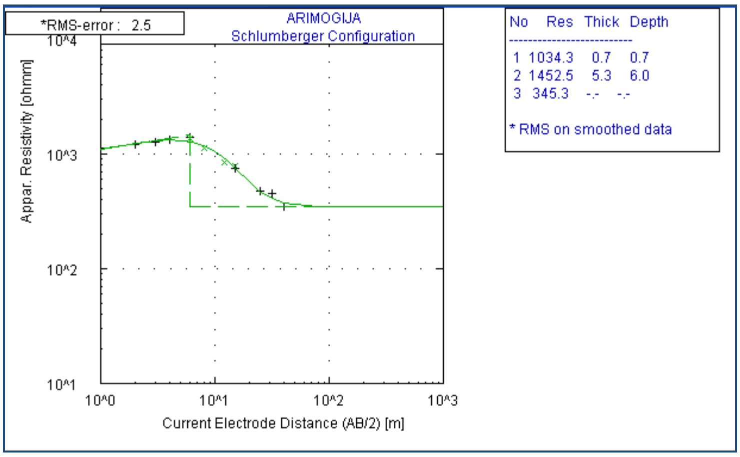

Figure 2 a: A Typical K - Type Curve

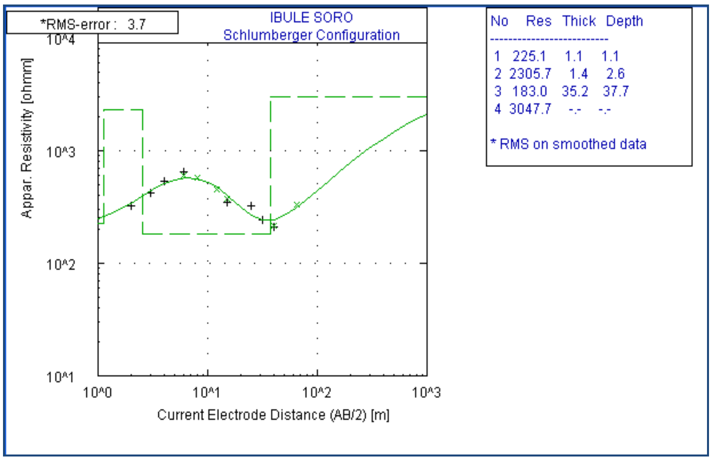

Figure 2 b: A Typical KH – Type Curve

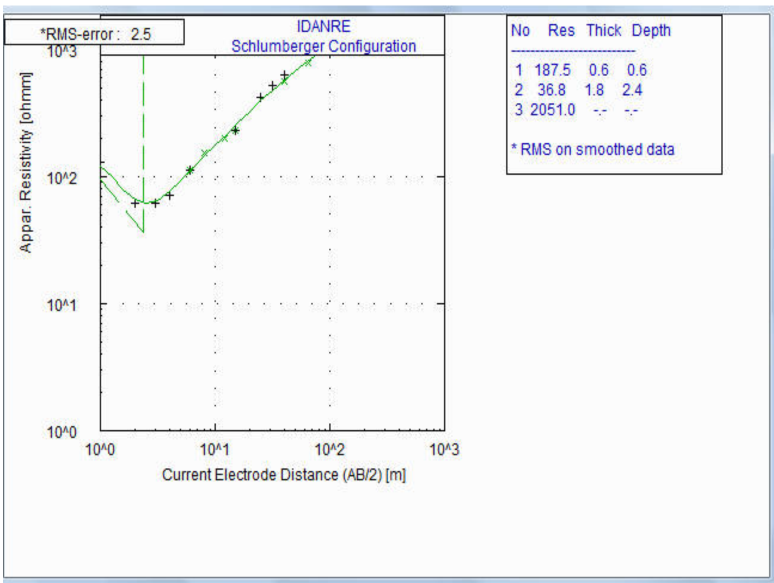

Figure 2 c: A Typical H – Type Curve

Table 3: VES Interpretation Results.

VES Station/ Farm site	Thicknesses (m) h_1	h_2	h_3	Resistivities (ohm-m) ρ_1	ρ_2	ρ_3	ρ_4	Curve Type
Ago Panu-Owo	1.9	7.5	-	126	37	∞	-	H
Arimogija	0.7	5.3	-	1034	1453	345	-	K
Ibulesoro-Akure	1.1	1.4	35.2	225	2306	183	∞	KH
Idanre	0.6	1.8	-	188	37	∞	-	H
Ikpemen-Owo	1.1	10.0	-	255	291	66	-	K
Ile-Oluji	1.7	15.5	-	362	557	289	-	K
Oda-Akure	0.8	8.4	-	444	85	∞	-	H
Ondo	1.4	19.8	-	511	105	∞	-	H

VES: Vertical Electrical Sounding

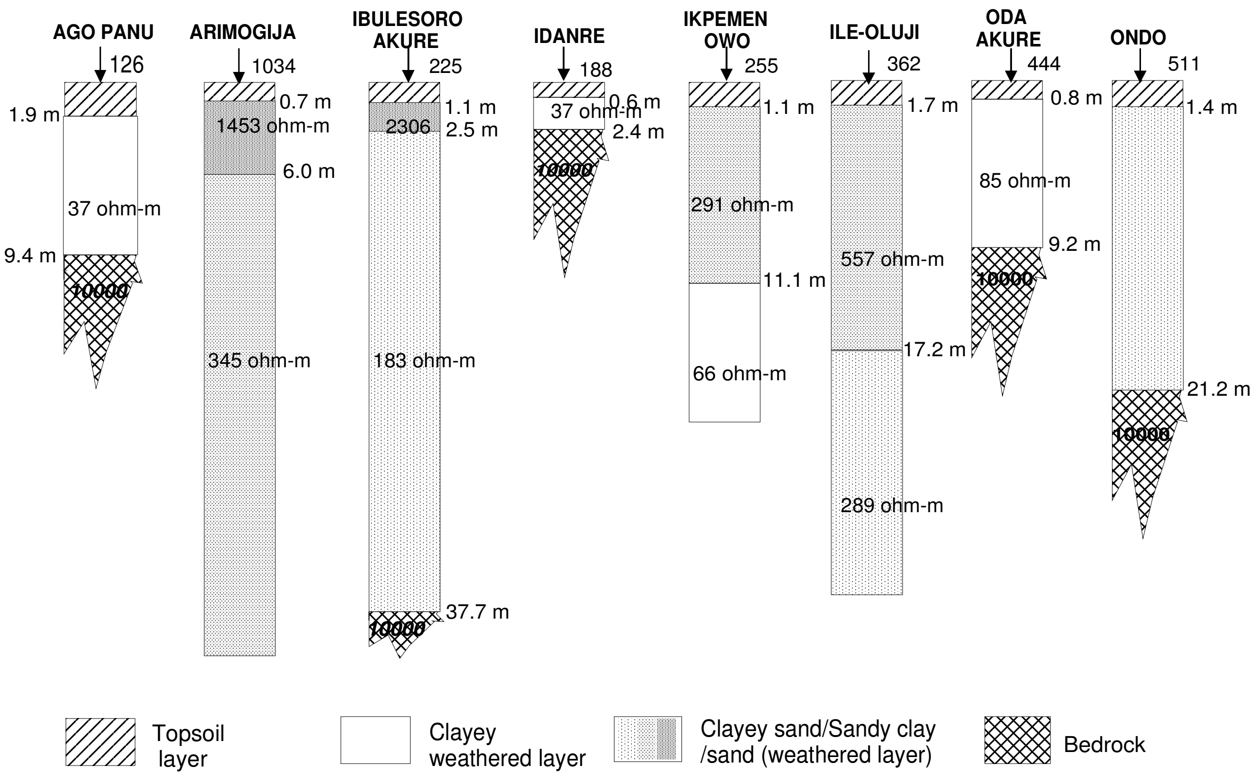

Figure 3: Geoelectric Sections of the Cocoa Plantations

(b) Clay/sandy clay/weathered/partially weathered basement. This unit is composed of varieties of clay materials i.e. reddish and pinkish clay with coarse/gravelly or oxidized quartz/dirty sands intercalations. The layer resistivity values range from 37 to 1453 ohm-m. Resistivity values less than 100 ohm-m range may suggest clay while values greater than 150 ohm-m may be typical of clayey sand/sand. The predominantly clayey zones suggest an impermeable medium with tendency for limited groundwater yielding capacity. The thickness of this layer varies from 1.9 – infinity metres. The wide spectrum of thicknesses observed is due to the uneven topography of the basement and the sedimentary terrains.
(c) Basement Bedrock: The third layer is the presumably fresh basement bedrock. The layer resistivity values are generally >1000 ohm-m and in most cases infinite.

5.0 Deductions from Results

Cocoa crop is a tap rooted plant and of the high forest. It requires a deep, fertile well-drained loam-clayey / clayey sand soil, 17 - 21°C temperature, 114 – 200 cm per annum of rainfall and a gentle slope to prevent water log (Opeke, 1997).

In the present study, while keeping other optimal meteorological factors constant, the evaluation of soil potential for optimum cocoa growth and production is based on two thresholds; resistivity and thickness of the upper two layers and the geology. However, the two strata/columns are considered most important zones as far as cocoa plant root penetration is concerned. The identification of areas/strata with relatively thick columns (not less than 2.4 m) of the sandy clay/clayey sand and resistivity range of between 37 and 511 ohm-m may have suggested a desirable site for cocoa soils. The areas with these features include Oda-Akure, Ibulesoro-Akure, Ondo, Ile-Oluji and Idanre.

The resistivity thresholds interpreted in terms of soil texture as sandy clay and clayey sand in these areas relate to the relative proportions of sand and clay in the soil. These areas consist of soils developed from grey gneiss or charnockitic rock lithologic units of the mineral rich and may have formed from the weathering and decomposition of these parent rock(s). The upper two layers have a well-defined horizon at a depth of 0.25 to 1.25 m with attendant good groundwater saturation/retention and required nutrients transport to sustain cocoa growth. These correspond to the typical profiles depth of 0.25 – 1.25 m of selected cocoa soils in Nigeria (Opeke, 1992). The results of the cocoa yield as published by the Ondo State corroborate the above findings with Akure, Ondo and Idanre axes ranked highest in cocoa production in the state.

In Arimogija, red soils developed on loose, leachable sandy sediments that do not contain weatherable minerals. The soil profile in particular nosedived into entirely sandy soil with overall low water/nutrient retention capability. As for Ikpemen and Ago Panu in Owo district, almost similar situation was observed. The red coarse – medium soils in the profile showed minimum saturation in the upper two layers. Report on short-stayed of cocoa plants after few years of overwhelming fruiting and bumper harvest in these farm sites may have corroborated the above findings that the base saturation is low and undesirable for optimal and sustainable growth/yield of cocoa.

The sustained cocoa plants of the few farm sites located within the upper two layers in the study areas is an indication of a saturation and good water retention capability of the units, while areas with predominantly sandy soil cover and/or shallow bedrock may suggest poor saturation and water retention..

It is, therefore, evident from the above that the yield of cocoa in the present study area depends largely on the composition and the saturated thickness of the upper two layers i.e topsoil and the underlying weathered/partially weathered columns. In the light of the above considerations, the upper two layers of weathering products of charnockitic/gray gneiss rocks remain the most important units for optimum production of cocoa in the study farm sites as found in Idanre, Akure and Ondo and other areas with same geologic setting..

6.0 Conclusion and Recommendations

The geoelectric survey for the evaluation of sub-soil for optimal production cocoa was undertaken. This is considered expedient considering a general decline in the production rate of the commodity crop in Ondo State in recent time. From the above findings, farm sites with relatively thick sandy clay/clayey sand and/or thin sand covers constitute the most probable sites for optimum cocoa yield. These sites are Idanre, Oda-Akure and Ondo farm sites with resistivity and thickness/depth thresholds of the topsoil and weathered layers between 37 - 511 ohm-m and 1.9 - 19.8 m respectively. Other farm sites that are not quite suitable for cocoa production include Arimogija, Ikpemen and Ago Panu – Owo. These sites graded into sandy substratum with resistivity and thickness/depth thresholds of the topsoil and weathered layers between 126 - 2306 ohm-m and 5.3 – 35.2 m respectively. Cocoa plants in these areas only thrived shortly after few years fruiting and later declined and died off. While other environmental/meteorological factors play essential roles in choosing a site for cocoa production, geology and sub-soil appraisal remain limiting factors for optimum cocoa production in the state and other areas with similar geologic settings.

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