Assessment of geoelectric properties and localized geology as indicators on cocoa (Theobroma cacao) yield in a part of southwestern Nigeria

Abayomi G. Osotuyi, Muraina Z. Mohammed, Isaac R. Ajayi, Adebayo O. Salako

1. Introduction

Nigeria ranks as the third highest producer of cocoa globally, behind Côte d’Ivoire and Ghana respectively. These countries are in West Africa where about 70% of global production is accounted for. The crop is grown in the southern part of Nigeria and predominantly in the South-west of Nigeria including Ondo, Ekiti, Ogun, Osun and Oyo states (Adelodun, 2017). Cocoa is one of the world's most important agricultural commodities which as well contributes to over half of Nigeria's non-oil export (Opeke, 2005; Voora et al., 2019).

The general dwindling yield in cocoa production in recent times gave the Nigerian government a major concern thereby calling on the governments of the cocoa producing regions to join in embarking upon the “Cocoa Rehabilitation Programme” (OSCDC, 2004). This was also initiated in Ondo State, which boasts as the crops' highest producing state in Nigeria. From available data from the Ondo State Ministry of Agriculture, from 2003 to 2007 (Table 1; Figure 1), Idanre has its peak production in 2004 and 2007, Ondo 2003 and 2006 while Akure South has its peak production in 2004. It is observed that there is a decline in production towards 2007 in these areas. When compared with other areas in the graph, the areas with relatively low production as Ose and Akoko North-west also have a decline in the same year. In Nigeria, Ondo, Osun and Cross River states are reported to contribute approximately 68% of Nigeria's annual cocoa output, which reached a high of 385,805T in 2014 when the Ministry of Trade and Industry also reported that Nigeria made $1.3 billion from cocoa export that year (www.factfish.com/statistics...
try/nigeria/cocoa%20beans,%20yield). The prevalence of tree crops, including cocoa, kola, coffee, rubber, oil palms and citrus, makes the vegetation of the state peculiar. Cocoa is the most prevalent of all the crops, and the state ranking as the highest cocoa producer in Nigeria (Ojo and Adhuze, 2006; Famuwagun et al., 2017).

Cocoa yield is observed to have varied with different soil types keeping other factors such as rainfall and temperature constant (Olujide and Adeogun, 2006; Ojo and Adhuze, 2006). Shortfall in chemical soil fertility may lead to suboptimal growth and corresponding low yield from cocoa trees. This condition also makes yield in many regions to fall below expected potentials (Zuidema and Leffelaar, 2002; FAOSTAT, 2015). Varying soil mineral requirements and chemical characteristics of soils interact not only with each other and with other soil properties, but with other factors including climatic conditions and shade management, which makes it difficult to set general standards. Thus, it has been submitted that environments in which the cocoa is to be grown needs to be assessed as a whole to adapt the method of cultivation to the local environment (Wood, 1985).

Soils in Ondo State vary in composition due to their rock parent materials. They are formed from the varying lithologic units of the mineral rich rocks constituting the Basement complex rocks. To the north-east is found a soil series under two associations which are skeletal mineral rich rocks constituting the Basement complex rocks. To the south, soils are of comparatively recent sedimentary origin of the Dahomey basin. The soil conditions in terms of soil water, porosity and permeability, soil texture, mineral aggregate etc. in different soil types differ and have a direct influence on the water and nutrient absorption by the cocoa plant and other similar tree crops (Ojo and Adhuze, 2006). Omotoso (1971), Sanchez (2002) and Hartemink (2006) have worked on the cocoa plant and other similar tree crops (Ojo and Adhuze, 2006). Differences and have a direct influence on the water and nutrient absorption by the cocoa plant and other similar tree crops (Ojo and Adhuze, 2006). Omotoso (1971), Sanchez (2002) and Hartemink (2006) have worked on the cocoa plant and other similar tree crops (Ojo and Adhuze, 2006). Differences and have a direct influence on the water and nutrient absorption by the cocoa plant and other similar tree crops (Ojo and Adhuze, 2006). Omotoso (1971), Sanchez (2002) and Hartemink (2006) have worked on the cocoa plant and other similar tree crops (Ojo and Adhuze, 2006).

2. Geographical and geological setting

Ondo State lies between latitudes 5°45'N and 7°52'N and longitude 4°20'E and 6°05'E. Its land area is about 15,500 km² (Balogun, 2000). Ondo State is bounded by Edo and Delta States on the east, Ogun and Osun State on the west, Ekiti and Kogi States to the North, and the Atlantic Ocean to the South. The studied farm sites are located in Ondo State (Figure 2) which is composed of lowlands and rugged hills of rock outcrops in several places. The climate of Ondo State is broadly of the

![Figure 1. Cocoa production data from 2003 – 2007 in study areas in Ondo State, Nigeria. *Cocoa production data from Tree Crop Unit, Agricultural Development Project (TCU-ADP), Ministry of Agriculture, Ondo State, Nigeria (Tree Crop Unit, 2008).*](image-url)
Soils form by the weathering and decomposition of rocks and mineral particles, with the addition of raw organic matters derived from plant and animal remains that are decomposed mainly by microbial activity. Plants contribute fresh organic material to the soil (Kang et al., 1977; Lal, 1989). Rocks and rock fragments are broken down into smaller particles without change in chemical composition by a variety of physical processes (Palacky and Kiyoshi, 1979). Weathering processes create superficial layers in the tropics and equatorial regions, with varying degree of porosity, permeability and electrical properties from the parent materials of the basement complex (Rahaman and Ocan, 1988; Mohammed and Olorumfemi, 2007 Salako et al., 2019; Oni et al., 2020), and sedimentary rocks. Generally, the main part of the tree crop belt in the state are underlain by the Precambrian Basement complex (Figure 4, Table 3) and the soils are usually derived in-situ from crystalline rocks or transported over small distances. The important tree crop producing areas of Nigeria are situated partly on ferrallitic soils and partly on ferruginous tropical soils (Ian and John, 1984).

3. Materials, methods and data processing

Different literature were reviewed to have a background understanding of the Agricultural aspects of the crop we are understudying, the soil types that aids its growth (Omomotsi, 1971; Sanchez, 2002; Hartemink, 2006; Ojo and Adhuze, 2006), and cocoa produce and output data for the different study areas between the period of year 2002–2007 (TCU-ADP). The produce data with respect to the active cocoa farmers in the cocoa producing belt of Ondo State (DRS-MEPB, 2010; Oladapo et al., 2012) was adopted to rank and guide on selection of study areas, and to correlate produce rate with the eventual findings from this study. In addition, selection of investigated farm sites was guided by community reports from local cocoa produce boards, reporting drop in yield or total death of cocoa trees over a period of years. Furthermore, the need to spread occupied sites objectively over the study area towards ensuring that the plant and site characteristics are adequately captured across the two geologic terrains where cocoa is the mainstay of the local agricultural economy in Ondo State.

Coupled with the reconnaissance survey, this helped us to make informed field and data acquisition plans ranging from selection of the farm sites, geophysical survey layout vs-a-vis spread length, whose scope were determined broadly by accessibility and logistics costs. The Geophysical equipment were stationed either within or at the edge of farm sites, and to achieve maximum energization of the subsoils underlying the farm sites, electrode spread were deployed perpendicular to the orientation of the regional strike in each farm site. Reconnaissance geological survey was conducted around the communities and the soils on each site were observed to ground truth and establish the rock lithologies constituting the local geology around the farms (Table 3, Figure 4). This is believed to have major contributing factors to the soil mineralogical make-up of the soil fauna diversities (Ololade et al., 2010a, b).

Geophysical investigation involving the electric resistivity survey method using the Vertical Electric Soundings (VES) technique was deployed. Due to costs and logistics, two representative stations were occupied on each site. The Schlumberger array, whose interest is in the scanning of the resistivity variation of soils with depth was adopted (Figure 5). The field procedure adopts a fixed centre of array with an expanding spread. Current was injected through current electrodes into
the earth subsoil through the current electrodes, thus measuring the potential difference with the potential electrodes. The inter-electrode spacing (AB/2) was varied from 1 - 100m with maximum spread varied between 150 - 200m, stationed within the farm sites or along the farm boundaries using ABEM SAS 1000 Digital resistivity meter to measure the ground resistivity.

The ground apparent resistivity values which was used for final data interpretation was obtained from the product of the value of observed earth resistivity (R) and a constant geometric factor (G) of the Schlumberger array for each set up (Telford et al., 1990). The apparent resistivity data were utilized in generating field curves. Apparent resistivity was manually plotted against the electrode separation on bi-log or log-log paper. Geoelectric parameters were obtained by manual inter-pretation of the obtained curves using partial curve matching technique of the appropriate set of two-layers Schlumberger theoretical master curves and the auxiliary curves corresponding to them (Orellana and Mooney, 1966). The values (geoelectric parameters) were imputed into the computer for iteration using Software algorithm, RESIST Version 1.0 (Vander Velpen, 1988) to obtain refined smoothed curves from a combined inverse and forward modelling technique, thus producing an iterative computer graphic display (Ghosh, 1971; Sharma, 1997; Ibitoye et al., 2013). The refined results of the interpreted partially matched curves

| S/No. | Location          | Longitude (E) | Latitude (N) | Vegetation          | Average Rainfall (mm) | Elevation (msl) (m) | Average Temp. (°C) |
|-------|-------------------|---------------|---------------|---------------------|-----------------------|---------------------|--------------------|
| 1     | Ipinen-Owo        | 7°15’04.9     | 5°35’57.8     | Savannah            | 1376                  | 393                 | 25.85              |
| 2     | Ago-Panu          | 7°17’19.6     | 5°36’59.6     | Woodland            | 1340                  | 393                 | 25.85              |
| 3     | Arimogija         | 6°49’19.3     | 5°41’40.2     | Tropical Rain Forest| 1784                  | 494                 | 27.23              |
| 4     | Ipele             | 7°03’18.8     | 5°40’53.5     | Humid Forest        | 1785                  | 393                 | 26.23              |
| 5     | Igbara-Oke        | 7°22’47.3     | 5°03’19.0     | Humid Forest        | 1465.5                | 418                 | 30.08              |
| 6     | Ibara-Mokin       | 7°20’41.5     | 5°06’7.00     | Humid Forest        | 1462.1                | 418                 | 30.08              |
| 7     | Ibuporo-Akure     | 7°19’4.10     | 5°06’49.4     | Humid Forest        | 1488.9                | 418                 | 29.9               |
| 8     | Uso               | 7°15’28.5     | 5°25’9.10     | Humid Forest        | 1487.6                | 393                 | 25.85              |
| 9     | Ogbese            | 7°14’3.00     | 5°25’57.7     | Humid Forest        | 1485.5                | 425                 | 27.34              |
| 10    | Oba-Akoko         | 7°22’2.20     | 5°43’21.3     | Humid Forest        | 1049                  | 325                 | 27.77              |
| 11    | Oke-Igbo          | 7°09’43.8     | 4°53’4.00     | Humid Forest        | 1395.7                | 455                 | 28.3               |
| 12    | Ondo              | 7°56’25.2     | 4°50’54.1     | Humid Forest        | 1503                  | 352                 | 28.5               |
| 13    | Ilu-Oluji         | 7°09’45.7     | 4°51’44.2     | Humid Forest        | 1502.8                | 361                 | 27.68              |
| 14    | Idenre            | 7°10’38.6     | 5°09’00.1     | Humid Forest        | 1505                  | 462                 | 28.13              |
| 15    | Oda-Akure         | 7°09’48.8     | 5°14’53       | Humid Forest        | 1488.6                | 420                 | 29.09              |

*Rainfall and temperature data modified from Eludoyin et al., 2017.
were obtained and found below error limit with Root Mean Square RMS error of <10%. The depth sounding curves are classified into type curves based on the layer resistivity combinations. The geoelectric layer parameters were determined from the results of the quantitative interpretation of the sounding curves. The relative response of the subsurface geologic units in the area may have depended on the sand to clay constituent ratio and the degree of water saturation (Mohammed and Olorunfemi, 2007; Salako et al., 2019; Oni et al., 2020).

4. Results and discussion

Five types of sounding curves have been identified from the study area (Table 4). There are however, striking similarities between some of these type curves with respect to the probable characteristic distinct geoelectric and geological successions. The resistivity relationship of the curves are presented as H, A, K, KH and HKH type curve geometry. The H and K–type curves predominate over all the other multi-layered curves (Figures 6a and 6b). The H and K – type curves account for 40 % and 20 % each of the total type curves respectively; the KH - type curve accounts for about 26.7 %, of the total sounding type curves, thus next in predominance. The typical three (3) layer H-type curve depicts the topsoil (aluvium, sand, lateritic clay or clay); (clay/sandy clay layer) and lastly the bedrock as its characteristic geoelectric sequence; weathered/fractured basement are identified as a unit when they are observed to be too thin. The K-type is a three (3) layered unit, while KH - type is a four (4) layered sequence comprising of topsoil; hard sand/lateritic clay; clay/sandy clay and bedrock.

A - type curve account for about 6.7 % of the total depth sounding curves, and HKH- type curve as well accounts for only 6.7 % of the total sounding curves (Figure 7). The geoelectric sections display and enable the delineation of the subsurface sequences and the basement bedrock structural altitude in line with the curve type features described previously.

These sections identify between three to four distinct subsurface lithologic layers from the geoelectric sequence. They are the topsoil, the clay to sandy clay or sand to clayey sand or alluvium units which makes up the weathered column, and the basal basement bedrock (Figures 8 and 9).

4.1. Topsoil

From field observations, the topsoil is widely composed of loam to clayey loam, clayey sand or sandy clay or sand, with coarse/gravely or oxidized quartz or dirty sands or lateritic column. It has resistivity values, which range from 68 to 1121 Ωm (Table 4). This indicates a wide compositional variation in the topsoil across different farm sites. The thickness of the topsoil ranges between 0.5 – 1.2 m, but is mostly greater than 1 m having average thickness of about 1.2 m. The variation in the topsoil thicknesses can be attributed to the differential erosional processes, weathering, organic matter decomposition, and the influence of the local topographical height variations of the southwestern Nigeria Basement Complex terrain (Mohammed and Olorunfemi, 2007). The relatively thin topsoil combined with a very low groundwater saturation would make the unit alone less hydrogeologically appealing to tree crop sustenance.

4.2. Cretaceous sediments and weathered/partially weathered layer

Weathered to partially weathered layer are widely ranging from clayey sand to sand, sandy clay to clay, sandy loam to loam, and sand making up the weathered to partially weathered Basement horizon. The subsoil in the sedimentary terrain is Cretaceous Alluviums or Alluvium sands which range in composition of varieties of clayey and sand materials (Table 4) i.e. reddish, pinkish, and or buff coloured clay with coarsely oxidized quartz or dirty sands intercalations. They are often well
drained soils, especially when they are oxidized tropical soils that are high in Iron (III) oxide (Lombin, 1986).

The resistivity ranges from 37 to 1835 Ωm for locations underlain by the Basement complex terrain, and 1500 Ωm for the only location that falls within Cretaceous sediment terrain. The weathered/partially weathered layers where the values tends to or exceeds 1000 Ωm could be diagnostic of lateritic hardpans, fresh boulders or dry sands (Mohammed and Olorunfemi, 2007). The thickness of these layers ranges from 1.1 to 60.8 m. The wide range of thicknesses may be due to the uneven basement topography and the sedimentary terrain. It is important to note that the predominantly clayey horizons suggest a highly porous but impermeable medium with tendency for limited hydraulic communication and high water retention. Where the plastic clay layer is thick and underlain by a less impermeable layer, the clay could retain water in excess quantities that could harm the roots of the plant. It could also serve as a water buffer for cocoa during dry and prolonged dry seasons if underlain by a fair to well drained or fractured stratum.

4.3. Basement bedrock

The infinitely continuous fresh basement bedrock is characterized as the third layer, observed with uneven basement topography as indicated by the geoelectric sections. Typically, the layer resistivity values are generally greater than 1000 Ωm, with infinite depth in most cases (Mohammed and Olorunfemi, 2005). The topsoil and weathered layer column sit on the bedrock.

5. Discussions

The depth and nature of the soil profile have obvious effects on the fertility of soil (Coulter, 1998; Opeke, 2005; Quinto and Moreno, 2015). Very shallow soils are generally unproductive for cocoa production since they provide little room for tree crop anchorage and extraction of water or hold too little moisture due to rapid percolation and draining down depth. A good depth of soil is of (Plummer et al., 2005; Coulter, 1998) importance in areas where rainfall is seasonal and unreliable for water to supply crops in a dry period. Annual crops rarely root below 1.5–2 m and therefore cannot use more than 2.0–2.3 m of soil, but some perennial crops and trees can root 4.5–6.0 m and beyond (Opeke, 2005; Prabhakaran Nair, 2010). Features of the nature, sequence, position and thickness of the soil horizons is of great importance for root proliferation. The illuviation of clay to form lower horizons of clay accumulation may be moderate and beneficial by increasing water storage capacity or excessive and thus having adverse effects on root development and the movement of air and water (Coulter, 1998).

Though, tree crop development and yield are not exclusively dependent on the resistivity, thickness and the underlying geology, it is well established that appropriate soil mineral mix of Nitrogen (N), Phosphorus (P) and Potassium (K) are have essential role in the proliferation of the tree. Deficiencies of this nutrient will lead to decreased yields (Vliet et al., 2015). The study sites with geoelectric parameters of thick lithology thickness of about 4.5 m and above, which are diagnostic of sandy clay or clayey sand layers with resistivity range of 37–651 Ωm, are suggestive of desirable site for cocoa development. These areas are marked with characteristic local geology having Charnokite and grey Gneiss. The areas that coincided with or mirrors these features are found in Idanre, Ile-oluji, Ondo, Oda-Akure, Ibulesoro-Akure, Ogbese, Ondo and Oloruntele – Okeigbo. The topsoil and layer thicknesses with their corresponding apparent resistivity values for these locations are respectively presented thus: Uso 599/868/378 Ωm and 1.1/3.3/23.9 m; Ogbese 479/102 Ωm and 1.5/21.3 m; Oda – Akure 470/87 Ωm and 0.7/9.2 m; Ilaramokin 868/564/611 Ωm and 1.2/14.3/60.8 m; Igbara – Oke 683/651/318 Ωm and 1.1/2.3/3.3/13.8 m; Ibulesoro 237/1475/156 Ωm and 1.1/2.2/32.5 m; Ille – Oluji 362/633/63 Ωm and 2.1/10.5 m; Ondo 68/534 Ωm and 1.8/1.5 m; Oloruntele – Oke 185/138/179 Ωm and 0.5/1.1/19.9 m; Idanre 188/37 Ωm and 0.6/1.8 m; Oba – Akoko 310/77 Ωm and 0.6/12.2 m (Table 4).

The local geology and lithologic units underlying the above mentioned areas include rocks of the Charnokitic group and Grey-Gneiss which are rich in minerals, and could have weathered and decomposed to develop the soil units on which the crops grow. This also give us on idea of the soil aggregates from the weathered rocks which make up for soil fertility, mineral content, soil structure, soil texture and soil drainage. The results of cocoa output in these areas validates and corresponds to the cocoa production data obtained from the Ondo State, Nigeria ministry of Agriculture archives and records (Figure 1). In the Owo axis.
comprising of Ago-Paanu, Ipemen and Ipele, it was reported by local cocoa farmers of the short stay and life span of cocoa crops that after few years of bumper harvests and excellent fruiting, the crops production begins to drop, the flourishing green leaves begins to turn yellow and fall off, hence, the cocoa crops begin to wilt. This condition makes the investigation in these locations to be of keen interest. The findings reveal the topsoil of the profile across the three sites, though rich in minerals and organic matter with thickness ranging from 1.1 to 1.8 m are thin. At Ipemen, the topsoil and its resistivity 1.8 m and 260 Ωm (Table 4 and Figure 9) are indicative of sand/lateritic sand; the underlying subsoil resistivity and thickness 294 Ωm and 10.3 m respectively are indicative of clayey substratum. These reveal a relatively homogenous profile which is indicative of poor soil water saturation and retention (Ololade et al., 2010a, b). This validates the report of cocoa farmers in the community about the short life span of cocoa plant.

At Ago-panu and Ipele, considerably thick subsoil underlying the topsoil with resistivity ranging from 37 to 77 Ωm (Table 4 and Figure 9) are suggestive of predominantly plastic clay known for high water retention, poor permeability and poor hydraulic communication. Cocoa plants in these locations may only thrive fairly well for few years as they develop and possibility for the crop to wilt and die off as the roots grows downwards into the second (clay) layer. These results scientifically give credence to and corroborate the observations of the local farmers. Also worthy of note is the local geology of this area which are predominantly Migmatite Gneiss of predominantly composed of Quartz and Feldspars which weathers into sands and clay materials which are evident on the resistivity profiles in the study locations. The only study location that lies in the sedimentary terrain is Arimogija. The topsoil thickness with its resistivity value is 1.3 m and 1121 Ωm respectively. While the weathered layer thickness with its resistivity is 3.9 m and 1500 Ωm respectively. The

**Table 4. Field data processed result, curve characterization and inferred lithology.**

| VES No. | Location   | Resistivity (Ωm) | Layer Thickness (m) h1, h2, h3 | Depth to Layer (m) d1, d2, d3 | No. of Layers | Curve Type | Geoelectric Lithology |
|---------|------------|------------------|---------------------------------|--------------------------------|---------------|------------|----------------------|
| 1       | Ago-Paanu  | 133, 37, 236     | 1.4, 4.2, ∞                      | 1.4, 5.6, ∞                    | 3             | H          | Topsoil, Weathered Layer, Bedrock |
| 2       | Ipemen    | 260, 294, 517    | 1.8, 10.3, ∞                    | 1.8, 12.1, ∞                   | 3             | K          | Topsoil, Weathered Layer, Bedrock |
| 3       | Ipele     | 458, 77, 4641    | 1.1, 3.7, ∞                     | 1.1, 4.8, ∞                    | 3             | H          | Topsoil, Weathered Layer, Bedrock |
| 4       | Arimogija | 1121, 1500, 371  | 1.3, 3.9, ∞                     | 1.3, 5.2, ∞                    | 3             | K          | Topsoil, Sand, Alluvium      |
| 5       | Uso       | 599, 868, 378, 1611 | 1.1, 3.3, 23.9, ∞           | 1.1, 4.4, 28.3                | 4             | KH         | Topsoil, Weathered Layer, Bedrock |
| 6       | Ogbese    | 479, 102, 1139   | 1.5, 21.3, ∞                    | 1.5, 21.8, ∞                   | 3             | H          | Topsoil, Weathered Layer, Bedrock |
| 7       | Oda, Akure | 470, 87, 2936   | 0.7, 9.2, ∞                     | 0.7, 9.9, ∞                    | 3             | H          | Topsoil, Weathered Layer, Bedrock |
| 8       | Ilaramokin | 868, 564, 611, 45818 | 1.2, 14.3, 60.8, ∞            | 1.2, 15.5, 76.4, ∞            | 4             | KH         | Topsoil, Weathered Layer, Bedrock |
| 9       | Igbara Oke | 683, 650, 1120, 318, 11576 | 1.1, 2.3, 3.0, 13.8, ∞      | 1.1, 3.4, 6.4, 20.2, ∞        | 5             | HKH        | Topsoil, Weathered Layer, Bedrock |
| 10      | Ilubesoro  | 273, 1475, 156, 18043 | 1.1, 2.2, 32.5, ∞             | 1.1, 3.3, 35.9, ∞             | 4             | KH         | Topsoil, Weathered Layer, Bedrock |
| 11      | Ille-Oluji | 362, 633, 301    | 1.8, 10.3, ∞                    | 1.8, 12.1, ∞                   | 3             | K          | Topsoil, Weathered Layer, Bedrock |
| 12      | Ondo      | 68, 534, 9662    | 1.8, 1.5, ∞                     | 1.8, 3.3, ∞                    | 3             | A          | Topsoil, Weathered Layer, Bedrock |
| 13      | Oloruntele, Oke-Igbo | 273, 1835, 179, 8549 | 0.5, 1.1, 19.9, ∞            | 0.5, 1.6, 21.5, ∞             | 4             | KH         | Topsoil, Weathered Layer, Bedrock |
| 14      | Idanre    | 186, 37, 2054    | 0.6, 1.8, ∞                     | 0.6, 2.4, ∞                    | 3             | H          | Topsoil, Weathered Layer, Bedrock |
| 15      | Oba Akoko | 310, 77, 908     | 0.6, 12.2, ∞                    | 0.6, 12.8, ∞                   | 3             | H          | Topsoil, Weathered Layer, Bedrock |

Note: ρnth, hnth and dnth correspond to Topsoil, Weathered layer and Bedrock for Nth layers respectively.

**Figure 6.** a: Computer assisted iterated curves for a H – type curve. b: Computer assisted iterated curves for a K – type curve.
Figure 7. Distribution of occurrence of curve types.

Figure 8. Geoelectric profile of cocoa farms in Idanre, Ibulesoro, Ilaramokin, Igbara-Oke, Ile-Oluji, Ondo, Oke-Igbo.
high resistivity of these two substratum signifies reddish, porous, permeable and highly leached lateritic soils with efficient air flow, but with poor water retention ability and organic matter content (Ololade et al., 2010a, b). The underlying substratum resistivity is 371 Ωm, and is indicative of alluvium sand of the Dahomey basin, probably directly overlying the Basement (Table 4 and Figure 9). Also, the soil profile shows entirely sandy soils, known to have poor capacity for water and nutrient retention. Knowing the tap rooted nature of cocoa crop, it thrives well in a relatively deep, well-drained fertile loamy-clay to clayey-sand soil. The temperature and rainfall were suggested to range between 25 – 35 °C, with 114 – 200 cm respectively per annum, and located on slightly sloping terrain to prevent water logging (Opeke, 2005; Famuwagun et al., 2017).

6. Conclusions

The use of geophysical Electrical Resistivity (ER) method in generating a geoelectric model for use in agriculture aimed at optimum yield of cocoa in parts of Ondo state was carried out. Schlumberger Vertical electric sounding (VES) technique was used for the data collection. Three distinct subsurface geologic layers comprising the topsoil, weathered layer/fractured basement, cretaceous sediment and basement bedrock were identified.

This study revealed that sites with geoelectric parameters of considerably thick strata, greater than 4.5 m of the clayey sand-sandy clay, with sandy loam topsoil and resistivity ranging from 37 – 651 Ωm, having characteristic local geology composed of Charnokite and Grey Gneiss rock units are suggestive of desirable sites for bumper cocoa development, which subsequently determines the output. Study sites located in Ogbese, Ondo, Oda-Akure, Ile-Oluji, Ibulesoro-Akure, Oloruntele-Okeigbo, Idanre, and Ilaramokin (Figures 8 and 9) coincide with these characteristics. The H-type curves characterize most of these locations that coincided with high yields.

Areas with thin soil cover and shallow thickness of the weathered layer to bedrock coincide with low output potential. Farm locations in Ipele-Owo, Ipen-Owo, Ago – Panu and Arimogija coincided with these characteristic, and ranked among areas of low yield. The short stay and life span of cocoa crops characterize some of these areas with few years of fruiting and yield, then production begins to drop, flourishing green leaves begins to turn yellow and fall off, hence, the cocoa crops wilt and die. The relatively thick portions of the sandy clay/clayey sand bodies are most optimum storage for water, hydraulic transmission and aeration that aids the growth, sustenance and attendant yield of cocoa plant (Coulter, 1998; Prabhakaran Nair, 2010; Ololade et al., 2010a, b, Famuwagun et al., 2017). Therefore, it is deduced that cocoa yield in the study areas may have depended on the products of the weathered materials from the local geology and saturated thickness of the topsoil/weathered/partially weathered/fractured basement columns of the soil profile that are made up of clayey sand/sandy clay. Thus, the thick columns of the topsoil and or weathered/partially weathered layer remain the most important units.
with the highest potential for optimum yield of cocoa in the areas of study. Areas with these characteristics fall as high-ranking zone in relation to yield of cocoa in the State (Table 1; Figure 1).

Though, some areas showing high yield from prior data does not reveal a thick topsoil/weathered/fractured basement spectrum, we sub-divided the results of the preliminary investigations into two sections: Arabica and Robusta. The initial data on yield and quality characteristics were obtained by the Department of Genetics and Breeding, National Research Institute for Agriculture, Nigeria. The data were based on the sample size of 30 cocoa trees per farm-site. Prior to starting the study, the soil of each farm-site was examined for its fertility and also keep track of crop performance over a time period, thus, observations should be carried out to minimize uncertainties, and cocoa produce data repository should be improved upon to ensure data integrity and also keep track of crop performance over a time period, thus, reducing uncertainties for future researches.

Declarations

Author contribution statement

OSOTUYI Abayomi G.: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

MOHAMMED Muraina Z.: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

AJAYI Isaac R.: Contributed reagents, materials, analysis tools or data.

SALAKO Adebayo O.: Analyzed and interpreted the data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors sincerely acknowledge the staff members of the Tree Crop Unit, Agricultural Development Project (TCU-ADP), Ministry of Agriculture, Alagbaka Akure Ondo State, Nigeria for providing relevant literature and advisory support in the course of this work. The meteorological information were provided by the Agroclimatological and Ecological Monitoring Unit, Akure, Ondo State, Nigeria. We also sincerely thank the reviewers for their constructive comments and suggestions that has made this manuscript better.

References

Adelodun, A., 2017. Cocoa production in Nigeria: a literature review. Anayis, food and agriculture. In: Centre for Public Policy Alternatives (CPPA) CPPAsearch org/nu-en-pl/cocoa-production-in-nigeria/#_ftn12.

Ameleko, A.A., Ogololo, C.E., Daramola, O.C., Babalola, A.O., 2020. Assessment of clay materials for drilling mud formulation from part of Ondo State, South-Western Nigeria. J. Petroleum. Explor. Prod. Technol.

Balogun, O.Y., 2000. Senior Secondary Atlas, second ed. Longman Nigeria Plc, Lagos Nigeria.

Burke, K.C.B., Dessauvagie, T.F.J., Whiteman, A.J., 1971. The opening of the gulf of Guinea and the geologic history of the benue depression and Niger Delta. Nat. Phys. Sci. (Lond.) 233 (38), 51–55.

Coulter, J.K., 1998. Tropical soils. In: Webster, C.C., Wilson, P.N.(Eds.), Agriculture in the Tropics, third ed.

Department of Research and Statistics, Ministry of Economic Planning and Budget (DRS-MEPB), 2010, 2010. Facts and Figures on Ondo State, pp. 21–26.

Ekanade, O., 2000. Ondo State in Nigeria: A people united, A future assured. In: Mamman, A.A., Oyebanji, J.O., Peters, S.W. (Eds.), Survey of States, Millennium Edition, 2 pp. 433–444.

Ehdoyn, A.O., Nevo, A.O., Abuloye, P.A., Ehdoyn, O.M., Awotoye, O.O., 2017. Climate events and impact on cropping activities of small-scale farmers in a part of southwest Nigeria. In: Weather, Climate, and Society. American Meteorological Society. Used with permission.

Famuwugbun, I.B., Agbe, S.O., Aiyelari, O.P., 2017. Shade effects on growth and development of cacao following two years of continuous dry season irrigation. Int. J. Fruit Sci.

FAOSTAT, 2015. Download Data. Food and Agriculture Organization of the United Nations. Cocoa, beans; All countries; 2012. http://faostat3.fao.org/download ad-0/j/QC8/ (Accessed 21 January 2015). Production Quantity.

Ghosh, D.P., 1971. The application of linear filter theory to the direct interpretation of geoelectric resistivity soundings measurements. Geophys. Prospect. 19 (2), 192-217.

Gonengah, R., Guiltinan, M., Maximo, S., Seguene, E., Iriarary, H., 2015. Yield performance and bean quality traits of cacao propagated by grafting and scion polyhedral cuttings. Hortscience 50 (3), 358–362, 2015.

Hartemink, A.E., 2006. Soil Fertility Decline: Definitions and Assessment. Encyclopedia of Soil Science, pp. 1618–1621.

Ian, M., John, L., 1984. Tropical field crops; Growing field crops, Cocoa. Evans Brothers (Nigeria Publishers) Ltd, Ibadan, pp. 11–12.

Ibitoye, F.P., Ipinmoroti, F.V., Salami, M., Akinlade, K.J., Taiwo, A.T., Adetunji, A.R., 2013. Application of geophysical methods to building foundation studies. Int. J. Geosci. 4, 1256–1266.

Kang, B.T., Dankoh, F., Moody, K., 1977. Soil fertility management investigations on benchmark soils in the humid low altitude tropics of West Africa: investigation on Egbida (Western Nigeria) Series. Agron. J. 69, 651–656.

Klumme, H.D., 1975. Geothermal gradient, heat flow and hydrocarbon recovery. In: Fischer, H.G., Judson, S. (Eds.), Petroleum and Global Tectonics. Princeton University Press, pp. 251–304.

Lal, R., 1989. The role of physical processes in maintaining productivity in the Tropics. In: Soil Physical Properties, pp. 3–5.

Lombi, G., 1986. In: Youdowow, A., Erdinem, F.O.C., Onazi, O.C. (Eds.), Introduction to Tropical Agriculture. Longman Group Ltd, pp. 34–52.

Mohammed, M.Z., Olorunfemi, M.O., 2007. Geoelectric investigation of the sedimentary/basement transition zone of parts of the river Jama are flood plain in the West Chad Basin, North-eastern Nigeria. Sci. Res. Ann. 3 (2), 44–60.

Ojo, A., Adhue, R., 2006. Cocoa Mirror Magazine, 1. Letado Agricultural Development Company Limited, Akure, Ondo State, Nigeria (1).

Oladapo, A., Shittu, A.M., Agboolah, M.U., Fapojouwo, O.E., 2012. Credit use and production efficiency of cocoa farms in Ondo state, Nigeria. J. Agri. Econ. (NJAE) 3 (1), 69–77, 2012.

Ololade, I.A., Ajayi, I.R., Gbadamosi, A.E., Mohammed, O.Z., Sunday, A.G., 2010a. A study on effects of soil physico-chemical properties on cocoa production in Ondo state. Mod. Appl. Sci. 4 (5).

Ololade, I.A., Ajayi, I.R., Gbadamosi, A.E., Mohammed, O.Z., Sunday, A.G., 2010b. A study on effects of soil physico-chemical properties on cocoa production in Ondo state. Mod. Appl. Sci. 4 (No. 5), May 2010.

Olujiude, M.G., Adeogun, S.O., 2006. Assessment of cocoa growers’ farm management practices in Ondo State, Nigeria, Spanish J. Agric. Res. 4 (2), 173–179.

Omotoso, T.I., 1971. Soil aspect of cocoa rehabilitation in Nigeria. In: Cocoa Research Institute of Nigeria (CRIN) Annual Report, 1971–72.

Ondo State Cocoa Development Committee, OSCDC, 2004. Guide to Good Quality Cocoa Production. Farmers Handbook, Ondo State Government of Nigeria. OSPDC, Office of the Deputy Governor, Akure, Ondo State.

Oni, A.G., Eniola, P.J., Olorunfemi, M.O., Okumobi, M.O., Osotuyi, A.G., 2020. The magnetic method as a tool in groundwater investigation in a basement complex terrain: modomo Southwest Nigeria as a case study. Appl. Water Sci.

Opeke, L.K., 2005. Tropical Commodity Tree Crops, Revised Edition. Spectrum books (Nigeria Publishers) Ltd, Ibadan, pp. 11–12.

Oreliana, E., Mooney, H.M., 1996. Two-Layer Master Curve for Vertical Electrical Sounding over Layered Earth Structures.

References
Palacky, G.J., Ryoishi, K., 1979. Effect of tropical weathering on electrical and electromagnetic measurements. Geophysics 44, 69–88.

Plummer, C.C., McGreary, D., Hanson, D.H., 2005. Physical Geology, tenth ed. McGraw-Hill, New York.

Prabhakaran Nair, K.P., 2010. The Agronomy and Economy of Important Tree Crops of the Developing World.

Quinto, M.H., Moreno, H.F., 2015. Precipitation effects on soil characteristics in tropical rain forests of the Chocó biogeographical region. Rev.Fac.Nac.Agron. 69 (1), 7813–7823, 2016.

Rahaman, M.A., Ocan, O.O., 1988. The nature of the granulite facies metamorphism in Ikare Area, South-western Nigeria. In: Precambrian Geology of Nigeria. GSN, pp. 157–162.

Rahaman, M.O., 2006. Nigeria’s solid minerals endowment and sustainable development. In: The Basement Complex of Nigeria and Its Mineral Resources.

Salako, A.O., Ootuyi, A.G., Adepelumi, A.A., 2019. Seepage Investigations of Heterogeneous Soils beneath Some Buildings Using Geophysical Approaches: Example from Southwestern Nigeria. Springer International Journal of Geo-Engineering.

Sanchez, P.A., 2002. Soil fertility and hunger in Africa. Science 295, 2019–2020.

Sharma, P.V., 1997. Environmental and Engineering Geophysics. Cambridge University Press.

Tree Crop Unit, 2008. 2003–2007 Report, Agricultural Development Project (TCU-ADP). Ministry of Agriculture, Ondo State, Nigeria.

Telford, W.M., Geldart, L.P., Sheriff, R.E., 1990. Applied Geophysics, second ed. Cambridge University Press, Cambridge.

Vander Velpen, B.P.A., 1988. RESIST Software Version 1.0. M. Sc. Research Project. ITC, Delft, Netherlands. Copyright © 2004, ITC, IT-RSG/DSG.

Vliet, J., Slingerland, M., Giller, K.E., 2015. Mineral Nutrition of Cocoa, A Review. Wageningen University and Research Centre, Wageningen, 57 pp.

Voora, V., Bermsider, S., Larrea, S., 2019. Global market report: cocoa. In: Sustainable Commodities Marketplace Series 2019. The International Institute for Sustainable Development isd.org.

Whiteman, A.J., 1982. Nigeria: its Petroleum Geology, Resources and Potential. Graham and Trotan, London, 394p.

Wood, G.A.R., 1985. In: Wood, G.A.R., Lass, R.A. (Eds.), Environment. Cocoa. Cadbury Schweppes, London.

Zuidema, P.A., Leffelaar, P.A., 2002. A Physiological Production Model for Cacao: Results of Model Simulations. Wageningen University, Department of Plant Sciences, Wageningen.