*Moor Journal of Agricultural Research 19, 69 - 83, 2018*

# Pedological Investigation of Edaphic Factors Limiting the Yield of Cocoa in Atakumosa West Local Government Area of Osun State

**Ajiboye[1] G. A., Jaiyeoba[2] J. O, Olutimi[3] M. S and Oyedepo, J. A.**

[1]*Department of Soil Science and Land Management*
*College of plant Science and Crop Production,*
*Federal University of Agriculture Abeokuta*
*Abeokuta Ogun State Nigeria.*
[2]*Nasarawa State University, Nassarawa.*
[3]*Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan.*
[4]*IFSERAR, Federal University of Agriculture Abeokuta, Abeokuta Ogun State Nigeria.*

## Abstract

The need to double cocoa production as a step towards the diversification of Nigeria's economy require an assessment of the edaphic factors limiting cocoa yield in the major cocoa-producing areas of the country. Field and laboratory studies were conducted to investigate the edaphic factors limiting the yield of cocoa in Atakumosa West Local Government Area (LGA) of Osun State. Soil samples were collected from the pedogenic horizons of eight profile pits dug in selected villages after a free survey covering about fourteen villages within the LGA. The physico-chemical properties of the soils were determined using standard laboratory procedures and the results were used to assess the suitability of the soils for cocoa production. The three major soil series from which samples were collected were Itagunmodi, Owena and Araromi. Overall actual suitability evaluation of the soil series showed that the soils of Itagunmodi series and Owena series were marginally (S3) suitable while those of Araromi series were currently not (N) suitable for cocoa production. Apart from the apparent effective cation exchange capacity (ECEC) which was lower than 16 cmol $kg^{-1}$ and the acid reaction of the soils, the major limitations of the soils were suboptimal rainfall and the dry seasons which are longer than the stipulated period. Also the slope gradient of the soils of Araromi series was a major limitation. Split application of Nitrogen/Phosphorus/Potassium (NPK) fertiliser at recommended rate for low fertility soils using non-acidifying fertiliser sources containing adequate quantities of Magnesium Oxide (MgO) or Calcium oxide (CaO) will upgrade the suitability status of the soils of Itagunmodi and Owena series to moderately suitable (S2) for cocoa production.

**Keywords:** Cocoa production, Edaphic factors, Fertiliser, Soils

## Introduction

Atakumosa West LGA of Osun State is among the LGAs with high per hectare yield of cocoa in Nigeria. In a recent survey however, the yield per hectare of cocoa in this LGA has reduced drastically. This has contributed to the observed decline in the export of cocoa in recent years. Several factors have been highlighted as probable causes of the observed decline. These include such factors as low yield arising from old and poor planting materials, depletion of humid rainforest, decline in soil fertility, poor agricultural practices in the management of cocoa plantation and the prevalence of malaria among farmers (Iremiren *et al*., 2012). The set goal for cocoa production in 2013 was to double its production within five years. To achieve this target, an urgent need for improvement in all the series of activities from site selection to primary processing was proposed. While efforts are now in place to distribute improved, high-yielding seeds and seedlings to farmers, efforts must also be put in place to select the best soils that are most suitable for cocoa production within this LGA. Where the soil is suboptimal, the constraining factors must be identified and appropriate solutions recommended.

This study appraised the suitability of the soils of Atakumosa West Local Government Area (LGA) of Osun state vis-a-vis identifying the most suitable soil series for the production of cocoa and to suggest possible management practices that could ensure high productivity and sustainability of cocoa production in this LGA.

## Material and Methods

### *Location and site characteristics*

Atakumosa West Local Government Area (AWLGA) lies within latitude 7° 25' and 7° 50'N and longitude 4° 20´ and 4° 50'E (Fig.1). The underlying geology is mainly fine-grained biotite gneiss and schists although Itagunmodi soil type is derived from variably migmatised gneiss, biotite-hornblende-gneiss and weathered amphibolites. However quartzite and quartz-schist rocks are common especially on slopes and ridges (Akintola, 1982). The major mineral resource found in AWLGA is gold (Awogboro, 2007). The area is drained by rivers Oni and Owena which flow in an approximately north-south direction. The drainage pattern is dendritic. The natural vegetation is the tropical rain forest which could only be found in patches all over the district but mainly on hills (Salami *et al.*, 2003).

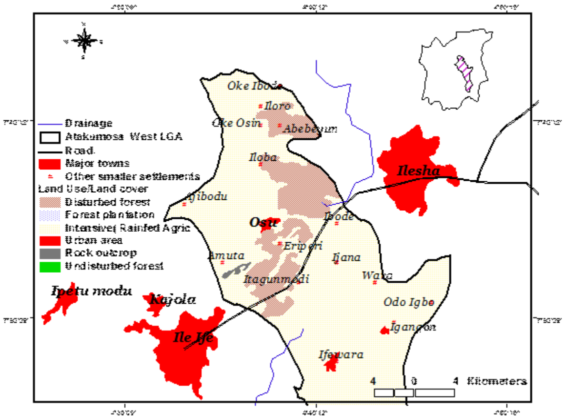


*Figure 1:* *Map of Atakumosa LGA study area and land use pattern*

## Rainfall

Atakumosa West LGA exhibits the typical tropical climate with definite wet and dry seasons. The rainy season commences mostly in late March and ends in late October while the dry season occurs between November and March.

The mean total monthly rainfall for Osu indicated that the Local Government Area has double maximal rainfall pattern with July and September having the highest average monthly precipitation of about 137mm and 169mm respectively and with a short break of about two weeks occurring in August (Fig 2). December and January have the least mean monthly precipitation of about 1mm and 6mm respectively. The average annual total rainfall ranges between 1100mm and 1300mm. The frequency of rainfall is highest in July and September with an average of 10 rainy days while the average total annual number of rainy days is about 55 days (Fig 3). The rainfall trend shows that the total annual rainfall is increasing indicating that both the mean monthly rainfall as well as the duration of the rainfall is expected to increase further from what is presently recorded (Alayaki, 2012).

## Temperature

Ambient minimum temperature in the area ranges between 22ºC and 24ºC; highest in February and March while the lowest minimum temperature occurs in January (Fig. 4). Mean maximum temperature ranges between 28ºC and 35ºC. Highest annual temperature reading occurs between March and April while the lowest annual temperature usually occurs in August. Both the minimum and maximum temperatures showed increasing trend. This may probably be in line with the general increase in global temperatures. As such, the temperature of the area is expected to increase further.

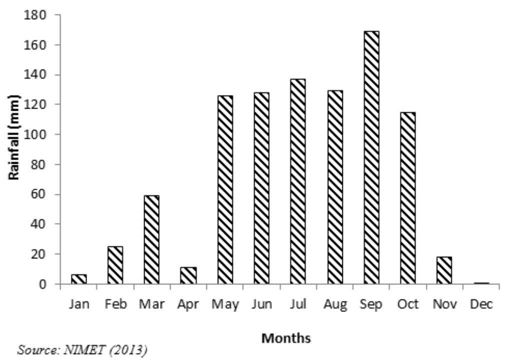


***Fig.2: Mean total monthly rainfall in Osu AWLGA***

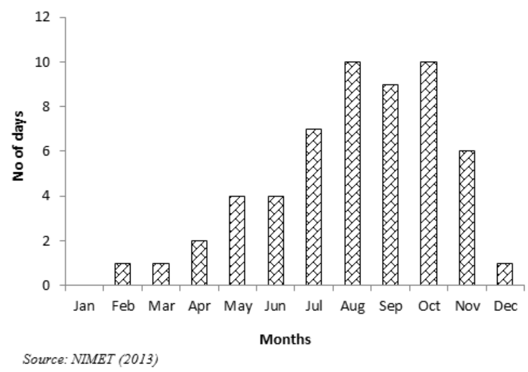


***Fig.3: No of rainy days per month in Osu AWLGA***

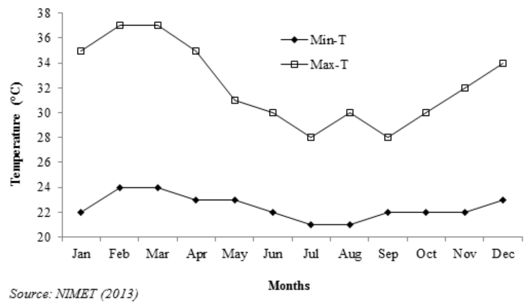


***Fig. 4: Mean monthly minimum and maximum temperatures in Osu AWLGA***

***Land use***

The communities in Atakumosa West Local Government Area are predominantly agrarian. The major crops produced in this area, in order of priority, include horticultural crops like Cacaoa (*Theobroma cacao*), Plantain (*Musa paradisiaca*) and Banana (*Musa spp*), Kolanut (*Cola acumulata* and *Cola nitida*) Pineapple (*Ananas sativa*) and African Walnut (*Tetracarpidium conophorum*). There are also root and tuber crops like cassava (*Manihot esculenta*) and sweet potatoes (*Ipomea batatas*). Other crops include cereals like maize (*Zea mays*), vegetables like pepper (*Caspicum spp*), egg plant (*Solanum spp*) as well as leafy vegetables like green (*Amaranthus spp*) and fruit trees like Mango (*Mangifera indica*) and Guava (*Guajava spp*). The shifting system of cultivation is predominant among the farmers of the area.

***Field Survey***

The major cocoa growing area of this LGA was selected with the assistance of two Agricultural Extension Officers attached to cocoa farmers in the LGA. Based on the information acquired from the Officers during the course of the exercise, the villages selected for the survey exercise are listed in Table 1.

**Table 1 : List and coordinates of village selected for sampling**

| Village | Northing | Easting |
|---|---|---|
| Olorombo village | 07.58936 | 004.65785 |
| Ibodi Village | 07.58752 | 004.68118 |
| Gada Village | 07.57043 | 004.65993 |
| Odoona-Aye village | 07.56650 | 004.66802 |
| Itagunmodi village | 07.51441 | 004.65531 |
| Araromi village 1 | 07.51965 | 004.63076 |
| Araromi village 2 | 07.51893 | 004.63002 |
| Osu village | 07.59764 | 004.62782 |
| Iwara-Oke village | 07.61232 | 004.63000 |
| Iloba village 1 | 07.63757 | 004.61894 |
| Iloba village 2 | 07.63808 | 004.61872 |
| Oke-Osin village 1 | 07.66914 | 004.62166 |
| Oke-Osin village 2 | 07.67043 | 007.62215 |
| Ijoka village | 007.67743 | 004.64591 |

In each of these villages, auger-hole samples were collected from the cocoa farm of at least five to seven farmers at 15cm interval from the soil surface to a depth of 120cm. Based on the morphological characteristics of the samples, eight soil profile pits were sited and dug in the selected villages (Table 2). The characteristics of the soil profiles were described according to the guidelines of FAO (2006) on soil profile description. Soil samples were collected from the pedogenic horizons into well labelled plastic bags and transported to the laboratory for analysis. Core samples were also collected using the core sampler. Each of the core samples were carefully labelled and sealed in plastic containers.

Except the core samples, all other samples were air-dried and passed through a 2mm sieve before analysis. Sample fractions larger than 2mm were assumed to be gravel and were collected, weighed and expressed as percentage gravel content of the soils.

The particle size distribution of the soils were determined using the hydrometer method after dispersion and mechanical shaking (Bouyoucos, 1962). Sodium hexametaphosphate was used as dispersing agent. The soil textures were determined using the USDA textural triangle.

The soil dry bulk density was determined using the core method while the total porosity was calculated using the relationship:

Soil core samples taken at delineated soil horizons were used for the determination of saturated hydraulic conductivity. The constant head method of Reynolds (1993) by transposed Darcy's equation for vertical flow of liquid was employed:

**Table 2: Selected village for soil profiling**

| Profile No. | Location | Land Use | Northing | Easting | Elevation |
|---|---|---|---|---|---|
| AW1 | Itagunmodi | Cocoa plantation | 07.51449 | 004.65528 | 333 |
| AW2 | Aye-Odona | Natural vegetation | 07.56656 | 004.66736 | 334 |
| AW3 | Ibodi | Cocoa plantation | 07.58742 | 004.68031 | 263 |
| AW4 | Olorombo | Cocoa plantation | 07.58926 | 004.65765 | 334 |
| AW5 | Iwaro-Oke | Cocoa plantation | 07.61228 | 004.62994 | 374 |
| AW6 | Iloba | Fallow land | 07.63810 | 004.61887 | 331 |
| AW7 | Oke-Osin | Cassava- maize | 07.67049 | 004.62209 | 333 |
| AW8 | Ijoka | Cocoa plantation | 07.67756 | 004.64593 | 334 |

$\%Tp = (1 - P_b/2.65) \times 10$

where Tp = Soil total porosity, $P_b$ = Soil bulk density.

$$Ks = \frac{Qw \times d}{h \times A \times t}$$

Where Qw is the volume of water ($cm^3$) that flowed through a cross-sectional area A ($cm^2$) in time (t), and h is the hydraulic head difference (cm) imposed across the sample length d (cm).

Soil pH was determined in water and $CaCl_2$, at 1:1 soil: water ratio using pH meter (FAO, 2008).

Exchangeable Ca, Mg, K and Na were extracted with 1N Ammonium acetate at pH 7 and subsequently analyzed. The K and Na were analyzed by flame photometer while the Ca and Mg content of the extract were determined by EDTA titration method (FAO, 2008).

Exchange acidity ($Al^{+3}$+ $H^{+}$) was extracted by KCl displacement method followed by titration with standard NaOH. The cation exchange capacity (CEC) was calculated by the summation of the exchangeable bases and total exchangeable acidity while the base saturation was evaluated by calculation. Exchangeable sodium percentage (ESP) was calculated (equation 1).

$$ESP = \frac{Na*100}{Ex\ bases} \quad \text{-------------} \quad (1)$$

Micro-nutrients (Mn, Zn, Cu and Fe) were analyzed using atomic absorption spectrophotometer after extraction with 0.04M EDTA. Boron was analyzed by photometric method following boiled water extraction (Haynes and Swift 1983).

**Table 3: Land Requirements for suitability evaluation of Cacao**

| Land, Soil and Climatic Characteristics | S1 | S2 | S3 | N1 | N2 |
|---|---|---|---|---|---|
| Climate (C) | | | | | |
| Annual Rainfall (mm) | 1400 – 2500 | 1400 – 1600<br>2500 – 3500 | 1200 – 1400<br>3500 – 4500 | < 1200 | - |
| Mean annual temperature (O°C) | 23 - 32 | 32 – 35 | 35 – 38 | > 38 | - |
| Length of Dry season (Months) | < 2 | 2- 3 | 3- 4 | > 4 | - |
| Relative humidity (driest month) | 40 – 65 | 65 – 75 | 375 – 85 | > 85 | - |
| Topography (T) | | | | | |
| Slope (%) | < 8 | < 16 | < 30 | - | - |
| Wetness (W) | | | | | |
| Flooding | Fo | Fo | F1 | F1 | Any |
| Drainage | WD | MD | ID | PD | VPD |
| Soil Physical Properties (S) | | | | | |
| Texture/Structure | C-60s to SC | C+60s to SCL | C+60s to Lfs | C+60s to Lfs | Cm to CS |
| Coarse fragment (%) | < 15 | < 35 | < 55 | > 55 | - |
| Soil depth (cm) | > 150 | > 100 | >50 | < 50 | - |
| Fertility Characteristics (F) | | | | | |
| Apparent CEC (Cmolc/kg) | > 16 | < 16 | - | - | - |
| Base Saturation | > 35 | > 20 | Any | Any | - |
| Organic matter (% OC 0 – 15 cm) | > 1.5 | > 0.8 | < 0.8 | - | - |
| pH in distilled water | 6.0 – 7.0 | 7.0 - 7.6 | < 5.5 | - | - |

C-60s = clay, blocky structure; C+60s = fine clay, blocky structure, SC= sandy clay; SCL = sandy clay loam; Lfs = loamy fine sand, Cm = massive clay; cS = coarse sand; S1 = Highly suitable; S2 = Moderately suitable; S3 = Marginally suitable; N1 = Currently not suitable; N2 = Permanently not suitable. Fo = No Flooding; F1= Susceptible to flooding; WD = well drained; MD = Moderately drained; ID = Imperfectly drained; PD = Poorly drained; VPD = very poorly drained

*Source: Ibiremo et al., (2011); Ritung et al., (2007) as modified by Ajiboye et al., (2015a)*

Organic Carbon was analyzed by wet oxidation method of Walkley and Black (1934) while the available P was extracted by Bray 1 method and the P concentration in the extracts determined by the vanado-molybdate blue method (Murphy and Riley, 1962). Total N was determined by micro-kjeldahl technique (FAO, 2008).

The suitability evaluation was done using the FAO Framework for Land suitability evaluation (FAO, 1976). Selected land qualities were climate, topography, drainage, soil physical and fertility status (Table 3). Soil fertility (f) was assessed using the soil reaction (pH), level of macro and micro nutrients (Ajiboye *et al*, 2015)

## Results

### The soils

The eight profile pits (AW1 – AW8) dug on the surveyed soils of Atakumosa West Local Government Area of Osun State were classified into three series (Table 4).

The first soil series (Itagunmodi series) comprises of profiles AW1, AW2 and AW3 and included the soils of Itagunmodi, Aiye-Odona and Ibodi villages.

The general landscape was gentle undulating with slope angles variation between 2% and 6%.The soils were deep, well drained with little Fe-Mn concretions in the subsurface horizons (mostly second or third horizons). The soils had moderate saturated hydraulic conductivity on the surface horizons and low saturated hydraulic conductivity at some subsurface horizons (Table 5). The bulk density of the soils was low – moderate (0.95 – 1.64 g $cm^{-3}$) and moderate - high total porosity (31.26 – 68.45 %).

In classifying the soils, we considered the textural B (Bt) horizon present in all the profiles (Table 5). Some of the profiles also had plinthites in the B (Btv) horizons (Table 5). All the Bt horizons also had ECEC (clay) (estimated as ECEC (soil) – ((3.5× %OC)/Clay %).) that were less than 16 cmol/kg (Kandic horizons). Most of the Bt horizon also had soil color hue that ranged between 2.5YR and 10R (Rhodic). The

**Table 4: Profile Locations and Classifications**

| Profile No. | Location | Land Use | Northing | Easting | Elevation M | Classification (Soil Survey Staff, 2010) | Classification (FAO, 2006b) |
|---|---|---|---|---|---|---|---|
| AW1 | Itagunmodi | Cocoa plantation | 07.51449 | 004.65528 | 333 | Rhodic Kandiudalf; | Lixisol, Rhodic Itagunmodi Series |
| AW2 | Aye-Odona | Natural vegetation | 07.56656 | 004.66736 | 334 | Plinthic Kandiudalf; | Lixisol, Rhodic Itagunmodi Series |
| AW3 | Ibodi | Cocoa plantation | 07.58742 | 004.68031 | 263 | Rhodic Kandiudalf; | Lixisol, Rhodic Itagunmodi Series |
| AW4 | Olorombo | Cocoa plantation | 07.58926 | 004.65765 | 334 | Typic Kandiudalf; | Lixisol, Eutric Owena Series |
| AW5 | Iwaro-Oke | Cocoa plantation | 07.61228 | 004.62994 | 374 | Rhodic Kandiudalf; | Lixisol, Rhodic Owena Series |
| AW6 | Iloba | Fallow land | 07.63810 | 004.61887 | 331 | Typic Kandiudalf; | Lixisol, Eutric Owena Series |
| AW7 | Oke-Osin | Cassava- maize | 07.67049 | 004.62209 | 333 | Arenic Kandiudalf; | Lixisol, Arenic Araromi Series |
| AW8 | Ijoka | Cocoa plantation | 07.67756 | 004.64593 | 334 | Rhodic Kandiudalf; | Lixisol, Rhodic Owena Series |

moisture regime of AWLGA was udic.

Pedons AW1 and AW3 were classified as Rhodic Kandiudalfs while pedon AW2 was classified as Plinthic Kandiudalf. Based on their morphogenetic properties the soils of this unit were classified further as Itagunmodi series. Pedons AW1 and AW3 classified as Rhodic Kandiudalfs were deep, well drained, dark reddish brown soils with sandy loam surface overlying red sandy clay loam, sandy clay to clay subsurface. While pedon AW1 had gravel contents >40% between 68 – 91 cm depth (endoskeletic), Pedon AW3 had no gravels. However, the gravel content of pedon AW1 was not as closely packed as those of Owena soil series. The soils of Itagunmodi series had moderate bulk density, moderate total porosity and low saturated hydraulic conductivity at some depths between the surface and 100 cm soil depth (Table 5). Soil reaction (pH in water) ranged from strong acid to neutral (4.85 – 6.35) both in the surface and subsurface horizons and the differences of soil pH in water and 0.01M calcium chloride was less than 10 % in most cases (Table 6). The cation exchange capacity and exchangeable bases were also low; generally below the critical requirements for Cocoa production in all the pedons except AW3 that had levels of Ca and K which were above the critical requirements (5 cmol $kg^{-1}$ and 0.30 cmol $kg^{-}$ respectively). Available Zn and Cu contents of the soils were very low, the level of B in the soils was moderate but the soil contents of Fe and Mn was toxic (Table 7).

The pedon AW2 classified as plinthic Kandiudalf had characteristics similar in all respect to those of Rhodic Kandiudalfs in Itagunmodi series but had very high concentration of Fe-Mn concretions in the third and last horizons. This pedon was deep with dark yellowish brown sandy loam surface overlying a dark red sandy clay loam to clay subsurface. The soil had low bulk density on the surface and a uniformly constant and higher (1.54 g $cm^{-3}$) bulk density in the subsurface horizons (Table 5). Total porosity of this pedon was moderate while the saturated hydraulic conductivity which was moderate on the surface decreased drastically in the plinthic horizons.

The second soil series (Owena series) included the soils of Olorombo, Iwaro-Oke,Iloba and Ijoka villages (profiles AW4, AW5, AW6 and AW8). The general landscape was gentle undulating with slope angles variation between 2% and 3%. The soils were deep, well drained with gravel contents >40 % mostly in the second or third horizons at some depths between 50 and 150 cm (endoskeletic). The soils had moderate saturated hydraulic conductivity on the surface horizons and slow – extremely rapid saturated hydraulic conductivity at some subsurface horizons. The bulk density of the soils was moderate (1.32 – 1.67 g $cm^{-3}$) and moderate total porosity (34.13 – 47.61 %). The soil reaction (pH in water) ranged from strong acid to neutral (5.55 – 7.20) both in the surface and subsurface horizon and the differences in soil pH in water and 0.01M calcium chloride was less than 10 % in most cases (Table 6). The cation exchange capacity and exchangeable K, Mg and Na were also low; generally below the critical requirements for Cocoa production in all the pedons. However, the value of exchangeable Ca was moderate in the surface horizons of all the pedons. Available Zn and Cu contents of the soils were very low, the level of B in the soils is moderate but the soil contents of Fe and Mn is toxic

**Table 5: Physical properties of the soil profiles**

| Profile | Depth cm | Sand (%) | Silt (%) | Clay (%) | Gravel (%) | Text | Colour | Ks $cmhr^{-1}$ | BD $^{3}$ $gcm^{-3}$ | Pore (%) | ECECc $Cmolkg^{-1}$ | BS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AW1-Ap | 0-18 | 72.4 | 12.8 | 14.8 | 0.0 | SL | 2.5YR ¾ | 1.25 | 1.25 | 45.00 | 4.19 | 97.85 |
| Bt1 | 18-68 | 50.4 | 10.8 | 38.8 | 2.26 | SC | 2.5YR 3/6 | 2.06 | 1.31 | 37.37 | 1.99 | 95.12 |
| Bt2 | 68-91 | 48.4 | 12.8 | 38.8 | 43.0 | C | 2.5YR 3/6 | 4.07 | 1.46 | 31.98 | 2.40 | 91.9 |
| B | 91-148 | 59.0 | 8.2 | 32.8 | 0.0 | SCL | 2.5YR 3/6 | 0.0 | 1.46 | 41.67 | 2.18 | 91.04 |
| B/C | 148-183 | 73.0 | 12.2 | 14.8 | 0.0 | SL | 5YR 8/3 | 1.56 | 1.35 | 42.49 | 1.49 | 87.09 |
| AW2-Ap | 0-32 | 79.0 | 6.2 | 14.8 | 0.8 | SL | 10YR 3/2 | 5.35 | 0.95 | 68.45 | 7.20 | 98.64 |
| Bt1 | 32-59 | 56.4 | 6.8 | 36.8 | 6.8 | SC | 1OYR 4/4 | 6.0 | 1.54 | 37.16 | 4.11 | 97.59 |
| Btv | 59-107 | 48.4 | 6.8 | 44.8 | 39.8 | C | 10YR 4/4 | 0.0 | 1.54 | 37.07 | 4.07 | 95.15 |
| Bv | 107-166 | 65.0 | 10.2 | 24.8 | 28.8 | SCL | 2.5YR 3/6 | 1.8 | 1.49 | 40.87 | 4.03 | 97.56 |
| AW3-Ap | 0-36 | 73.0 | 8.2 | 18.8 | 10.7 | SL | 5YR 3/2 | 30.7 | 1.12 | 46.08 | 10.06 | 99.04 |
| Bt | 36-55 | 61.0 | 4.2 | 34.8 | 9.2 | SC | 5YR 3/3 | 0.2 | 1.55 | 37.37 | 8.12 | 98.78 |
| B2 | 55-72 | 69.0 | 6.2 | 24.8 | 10.7 | SCL | 2.5YR ¾ | 3.5 | 1.35 | 41.48 | 18.87 | 98.95 |
| Bt | 72-111 | 51.0 | 4.2 | 44.8 | 0.0 | SC | 2.5YR ¾ | 3.2 | 1.64 | 31.26 | 9.14 | 97.83 |
| B/C | 111-189 | 42.4 | 4.8 | 52.8 | 2.5 | SC | 2.5YR 3/6 | 2.0 | 1.31 | 40.15 | 7.14 | 98.61 |
| AW4-Ap | 0-23 | 75.0 | 10.2 | 14.8 | 0.0 | SL | 10YR 3/3 | 5.2 | 1.1 | 43.74 | 12.65 | 99.24 |
| Bt1 | 23-41 | 61.0 | 10.2 | 28.8 | 34.5 | SCL | 5YR ¾ | 8.5 | 1.46 | 36.11 | 5.99 | 98.36 |
| Bt2 | 41-64 | 56.4 | 6.8 | 36.8 | 60.8 | SC | 5YR 4/6 | 104.7 | 1.4 | 30.59 | 5.04 | 94.14 |
| B3 | 64-113 | 52.4 | 8.0 | 39.6 | 36.0 | SC | 5YR 5/6 | 0.13 | 1.55 | 39.23 | 2.69 | 96.29 |
| B/C | 113-184 | 47.0 | 9.4 | 43.6 | 5.3 | SC | 10R 4/6 | 0.86 | 1.44 | 38.80 | 1.75 | 94.41 |
| AW5-Ap | 0-27 | 79.0 | 6.2 | 14.8 | 1.8 | SL | 10YR 3/3 | 0.6 | 1.51 | 34.13 | 6.38 | 98.52 |
| Bt | 27-118 | 38.4 | 8.8 | 52.8 | 3.7 | C | 2.5YR 3/6 | 0.5 | 1.67 | 35.38 | 4.25 | 97.66 |
| B2 | 118-170 | 48.4 | 4.8 | 46.8 | 61.2 | SC | 2.5YR 4/6 | 5.4 | 1.5 | 40.26 | 4.13 | 90.41 |
| B/C | 170-183 | 52.4 | 4.8 | 42.8 | 53.79 | SC | 2.5YR 3/6 | 5.6 | 1.32 | 39.43 | 3.49 | 97.18 |
| AW6-Ap | 0-29 | 81.0 | 6.2 | 12.8 | 3.03 | SL | 10YR 3/3 | 15.1 | 1.54 | 34.22 | 4.76 | 98.07 |
| Bt | 29-99 | 48.4 | 6.8 | 44.8 | 64.65 | SC | 5YR 4/6 | 7.8 | 1.45 | 36.20 | 4.15 | 97.62 |
| B2 | 99-161 | 61.0 | 5.4 | 33.6 | 62.79 | SCL | 5YR 4/6 | 0.9 | 1.46 | 41.59 | 2.26 | 95.71 |
| B/C | 161-183 | 58.4 | 4.8 | 36.8 | 60.18 | SC | 5YR 4/6 | 28.2 | 1.1 | 47.61 | 2.08 | 95.31 |
| AW7-Ap | 0-30 | 83.0 | 6.2 | 10.8 | 17.09 | LS | 10YR ¾ | 1.8 | 1.3 | 39.34 | 9.26 | 98.93 |
| Bt | 30-62 | 56.4 | 8.8 | 34.8 | 14.29 | SCL | 10YR 5/4 | 14.6 | 1.19 | 42.67 | 5.83 | 94.92 |
| B/C | 62-182 | 78.4 | 6.8 | 14.8 | 0.38 | LS | 2.5Y 5/4 | 1.8 | 1.62 | 37.82 | 4.59 | 95.74 |
| AW8-Ap | 0-23 | 77.0 | 8.2 | 14.8 | 1.49 | SL | 5YR ¾ | 1.07 | 1.38 | 37.46 | 7.64 | 98.79 |
| Bt1 | 23-71 | 42.4 | 6.8 | 50.8 | 4.7 | SC | 2.5YR ¾ | 0.3 | 1.45 | 49.49 | 4.12 | 97.6 |
| Bt2 | 71-100 | 40.4 | 8.8 | 50.8 | 73.57 | C | 2.5YR ¾ | 0.6 | 1.54 | 34.67 | 3.09 | 96.8 |
| B/C | 100-181 | 36.4 | 10.8 | 52.8 | 5.62 | C | 2.5YR 3/6 | 1.0 | 1.32 | 43.83 | 3.90 | 97.44 |

**Table 6: Soil chemical characteristics**

| Profile | Depth | pHw | OC (%) | TN (%) | TEA* | Mg* | Ca* | K* | Na* | ECEC* | BS (%) | ESP (%) | Avail-P (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AW1-Ap | 0-18 | 5.10 | 1.93 | 0.155 | 0.10 | 0.63 | 3.04 | 0.43 | 0.44 | 4.65 | 97.85 | 9.56 | 1.72 |
| Bt1 | 18-68 | 5.40 | 0.63 | 0.068 | 0.10 | 0.59 | 1.00 | 0.07 | 0.29 | 2.05 | 95.12 | 14.16 | 1.28 |
| Bt2 | 68-91 | 5.90 | 0.76 | 0.077 | 0.20 | 0.57 | 1.12 | 0.22 | 0.36 | 2.47 | 91.90 | 14.60 | 1.51 |
| B | 91-148 | 6.20 | 0.48 | 0.058 | 0.20 | 0.56 | 1.07 | 0.10 | 0.30 | 2.23 | 91.04 | 13.53 | 1.28 |
| B/C | 148-183 | 5.00 | 0.26 | 0.043 | 0.20 | 0.46 | 0.57 | 0.09 | 0.23 | 1.55 | 87.09 | 15.16 | 2.15 |
| AW2-Ap | 0-32 | 5.60 | 0.56 | 0.064 | 0.10 | 0.61 | 5.82 | 0.43 | 0.37 | 7.33 | 98.64 | 5.07 | 1.38 |
| Bt1 | 32-59 | 5.35 | 0.33 | 0.048 | 0.10 | 0.62 | 2.91 | 0.20 | 0.32 | 4.14 | 97.59 | 7.67 | 1.28 |
| Btv | 59-107 | 5.30 | 0.63 | 0.068 | 0.20 | 0.63 | 2.77 | 0.21 | 0.31 | 4.12 | 95.15 | 7.50 | 1.28 |
| Bv | 107-166 | 5.95 | 0.56 | 0.064 | 0.10 | 0.61 | 2.92 | 0.20 | 0.27 | 4.11 | 97.56 | 6.64 | 1.28 |
| AW3-Ap | 0-36 | 7.05 | 1.67 | 0.138 | 0.10 | 0.67 | 8.84 | 0.47 | 0.28 | 10.37 | 99.04 | 2.71 | 24.32 |
| Bt | 36-55 | 6.50 | 0.85 | 0.083 | 0.10 | 0.58 | 6.73 | 0.51 | 0.29 | 8.21 | 98.78 | 3.53 | 17.81 |
| B2 | 55-72 | 6.80 | 0.82 | 0.081 | 0.20 | 0.59 | 17.32 | 0.48 | 0.41 | 18.99 | 98.95 | 2.14 | 12.24 |
| Bt | 72-111 | 6.70 | 0.71 | 0.074 | 0.20 | 0.53 | 7.77 | 0.42 | 0.28 | 9.20 | 97.83 | 3.07 | 11.84 |
| B/C | 111-189 | 6.35 | 0.48 | 0.058 | 0.10 | 0.58 | 5.91 | 0.29 | 0.30 | 7.17 | 98.61 | 4.17 | 1.26 |
| AW4-Ap | 0-23 | 6.55 | 1.93 | 0.155 | 0.10 | 0.66 | 11.99 | 0.16 | 0.20 | 13.11 | 99.24 | 1.52 | 1.65 |
| Bt1 | 23-41 | 6.40 | 0.97 | 0.091 | 0.10 | 0.64 | 4.85 | 0.23 | 0.29 | 6.11 | 98.36 | 4.82 | 1.28 |
| Bt2 | 41-64 | 6.00 | 0.82 | 0.081 | 0.30 | 0.64 | 2.72 | 0.70 | 0.76 | 5.12 | 94.14 | 14.76 | 1.28 |
| B3 | 64-113 | 5.95 | | 0.026 | 0.10 | 0.62 | 1.31 | 0.33 | 0.33 | 2.69 | 96.29 | 12.11 | 1.28 |
| B/C | 113-184 | 5.95 | 0.48 | 0.058 | 0.10 | 0.60 | 0.64 | 0.15 | 0.30 | 1.79 | 94.41 | 16.69 | 1.28 |
| AW5-Ap | 0-27 | 5.85 | 1.6 | 0.133 | 0.10 | 0.60 | 5.56 | 0.18 | 0.32 | 6.76 | 98.52 | 4.77 | 1.78 |
| Bt | 27-118 | 6.10 | 0.33 | 0.048 | 0.10 | 0.60 | 2.97 | 0.36 | 0.24 | 4.27 | 97.66 | 5.67 | 1.28 |
| B2 | 118-170 | 7.20 | 0.52 | 0.061 | 0.40 | 0.56 | 2.31 | 0.59 | 0.31 | 4.17 | 90.41 | 7.47 | 1.28 |
| B/C | 170-183 | 6.60 | 0.59 | 0.066 | 0.10 | 0.55 | 1.98 | 0.62 | 0.29 | 3.54 | 97.18 | 8.29 | 1.28 |
| AW6-Ap | 0-29 | 5.60 | 1.52 | 0.128 | 0.10 | 0.53 | 3.99 | 0.27 | 0.29 | 5.18 | 98.07 | 5.66 | 1.65 |
| Bt | 29-99 | 5.55 | 0.71 | 0.074 | 0.10 | 0.60 | 2.96 | 0.19 | 0.36 | 4.21 | 97.62 | 8.49 | 1.28 |
| B2 | 99-161 | 5.60 | 0.63 | 0.068 | 0.10 | 0.59 | 1.10 | 0.10 | 0.44 | 2.33 | 95.71 | 19.02 | 1.28 |
| B/C | 161-183 | 5.55 | 0.48 | 0.058 | 0.10 | 0.62 | 1.17 | 0.09 | 0.16 | 2.13 | 95.31 | 7.37 | 1.28 |
| AW7-Ap | 0-30 | 6.55 | 0.26 | 0.043 | 0.10 | 0.67 | 7.89 | 0.42 | 0.26 | 9.34 | 98.93 | 2.74 | 2.12 |
| Bt | 30-62 | 5.55 | 0.78 | 0.078 | 0.30 | 0.66 | 4.34 | 0.33 | 0.28 | 5.91 | 94.92 | 4.66 | 1.28 |
| B/C | 62-182 | 5.70 | 0.45 | 0.056 | 0.20 | 0.69 | 3.17 | 0.32 | 0.31 | 4.70 | 95.74 | 6.59 | 1.28 |
| AW8-Ap | 0-23 | 6.65 | 2.67 | 0.205 | 0.10 | 0.70 | 6.90 | 0.27 | 0.30 | 8.27 | 98.79 | 3.69 | 1.28 |
| Bt1 | 23-71 | 5.70 | 0.71 | 0.074 | 0.10 | 0.62 | 3.03 | 0.12 | 0.31 | 4.17 | 97.60 | 7.33 | 1.28 |
| Bt2 | 71-100 | 5.95 | 0.56 | 0.064 | 0.10 | 0.61 | 2.13 | 0.12 | 0.17 | 3.13 | 96.80 | 5.41 | 1.28 |
| B/C | 100-181 | 5.90 | 0.04 | 0.029 | 0.10 | 0.63 | 2.64 | 0.17 | 0.35 | 3.90 | 97.44 | 9.02 | 1.28 |

* unit of measurement is cmol/kg

**Table 7: Soil micro nutrient status**

| Profile | Fe (mg/kg) | Mn (mg/kg) | Cu (mg/kg) | Zn (mg/kg) | B (mg/kg) |
|---|---|---|---|---|---|
| AW1-Ap | 271.8 | 450.68 | 21.41 | 6.9 | 6.01 |
| Bt1 | 136.59 | 387.09 | 4.39 | 2.4 | 2.14 |
| Bt2 | 188.3 | 368.05 | 4.37 | 1.3 | 2.31 |
| B | 87.94 | 277.98 | 2.83 | 1.1 | 2.11 |
| B/C | 20.83 | 86.33 | 0.96 | 2.7 | 1.58 |
| AW2-Ap | 169.98 | 421.88 | 7.56 | 5.9 | 2.08 |
| Bt1 | 160.13 | 369.24 | 4.58 | 7 | 1.92 |
| Btv | 126.08 | 347.23 | 3.68 | 1.6 | 1.46 |
| Bv | 65.73 | 226.48 | 1.6 | 2.9 | 1.72 |
| AW3-Ap | 146.08 | 351.87 | 16.27 | 12.8 | 2.82 |
| Bt | 157.82 | 368.01 | 9.62 | 10.8 | 2.15 |
| B2 | 130.56 | 348.75 | 10.19 | 15.4 | 2.38 |
| Bt | 93.23 | 289.2 | 6.75 | 5.7 | 2.33 |
| B/C | 44.7 | 198.31 | 2.76 | 1.7 | 2.6 |
| AW4-Ap | 143.55 | 456.82 | 8.75 | 4 | 6.53 |
| Bt1 | 148.85 | 418.99 | 4.25 | 4.6 | 6.53 |
| Bt2 | 58.09 | 212.88 | 3.06 | 0.5 | 3.08 |
| B3 | 53.1 | 310.9 | 1.48 | 0.6 | 3.21 |
| B/C | 32.81 | 119.04 | 0.71 | 1 | 3.53 |
| AW5-Ap | 163.01 | 481.21 | 24.11 | 9.9 | 1.87 |
| Bt | 89.47 | 360.1 | 3.72 | 1.1 | 2.46 |
| B2 | 45.77 | 157.92 | 1.06 | 0.4 | 2.33 |
| B/C | 34.18 | 83.92 | 0.83 | 0.4 | 1.99 |
| AW6-Ap | 269.02 | 485.01 | 10.66 | 4.7 | 2.88 |
| Bt | 151.67 | 431.82 | 3.89 | 2.5 | 2.17 |
| B2 | 95.22 | 278.27 | 1.62 | 1.2 | 2.76 |
| B/C | 46.42 | 182.24 | 0.92 | 0.5 | 3.38 |
| AW7-Ap | 157.12 | 471.19 | 4.87 | 6.4 | 3.44 |
| Bt | 170.41 | 451.14 | 2.86 | 1.6 | 2.66 |
| B/C | 62.56 | 232.97 | 0.02 | 0.8 | 2.85 |
| AW8-Ap | 251.79 | 495.34 | 40.26 | 17.6 | 2.45 |
| Bt1 | 322.77 | 490.48 | 12.02 | 4.6 | 2.3 |
| Bt2 | 222.35 | 478.53 | 6.49 | 1.7 | 1.98 |
| B/C | 162.13 | 449.96 | 4.19 | 1.1 | 0.9 |

(Table 7).

The Typic Kandiudalfs were also deep, well drained, dark brown sandy loam surface overlying yellowish red sandy clay loam to sandy clay subsurface horizons. The soils had moderate saturated hydraulic conductivity except at the second but last horizons where the saturated hydraulic conductivity were low. The bulk density and porosity are also moderate and increased with soil depth in profile.

The soils had moderate – slight acid (4.65 – 6.35) reactions with a narrow difference between the surface and subsurface pH values. Also the differences in the soil pH values in distilled water and 0.01M calcium chloride was less than 15 % in all cases. The cation exchange capacity was equally lower than critical requirements for Cocoa production. The levels of exchangeable bases as well as available Zn were deficient. Although the surface horizons of these soil contained adequate quantity of available Cu probably resulting from the residual effects of the application of Cu based fungicides, the subsurface horizons had inadequate quantity of Cu. The soil contents of Fe and Mn were very high and could be toxic (Table 6).

The third soil series (profile AW7) consisted of soils of Oke-osin village. This soil was developed on steep slope and subjected to sheet erosion. The soil was deep, well drained with dark yellowish brown sandy loam surface horizon merging into yellowish brown and yellowish red subsurface horizon. This pedon has Fe-Mn concretions in the B-horizon. This pedon had morphogentic properties different from those of Itagunmodi and Owena series that were predominant in AWLGA. However, the morphogenetic properties did not completely conform in textural class to those of Araromi series. The Fe-Mn concretion in the B-horizon resembled those of Itagunmodi series. However, because of the lower clay and higher sand contents of the soil, it was more convenient to classify this pedon as 'Araromi series. In actual fact, this soil has higher resemblance to the soils of Ibadan series in texture. The soil of this pedon was classified as Arenic Kandiudalf.

The pedon has moderate saturated hydraulic conductivity except at the second horizon, which has very fast saturated hydraulic conductivity while in the last horizons the saturated hydraulic conductivity was low. The bulk density and porosity were also moderate and increased with soil depth in profile.

The soil has strong – slight acid (5.55 – 6.55) reactions. The cation exchange capacity was equally lower than critical requirements for cocoa production. Also the levels of exchangeable Na, Mg as well as available Zn were deficient. The Ca, K, Cu and B were moderate in the surface horizon while the Fe and Mn contents of the soil could be toxic. Although the surface horizons of this soil contained adequate quantity of available Cu probably resulting from the residual effects of the application of Cu based fungicides, the subsurface horizons had inadequate quantity of Cu.

**Suitability evaluation**

In Atakumosa West Local Government Area (AWLGA) of Osun State, the average annual rainfall was rated as S2 (Table 8). This is because the mean annual rainfall which ranged from 1100 – 1300mm was lower than the optimum requirement according to Fasina *et al*., (2007). The dry season lasting about three months (S2), relative humidity ranging between 40 and 50% (S1) and mean annual temperature ranging from 28 – 35°C (S1) was considered to be moderately suitable for cocoa production. The drainage conditions of the soils, well drained soil condition (S1) and non susceptibility of the soils to flooding (S1) was also considered as highly suitable for cocoa production (Ritung et al., 2007). The slope, drainage and flooding conditions of two out of the three soil series (Itagunmodi and Owena) were rated as S1 (Table 8). However, the slope of the soils of Araromi series was rated as S2 while the drainage and flooding conditions were also rated as S1. The average soil rooting depth which was greater than 150 cm in all soil series is rated as S1 while the soil texture that ranged from sandy loam in the surface horizons to sandy clay loam, sandy clay or clay in the subsurface horizon is also rated as S1 for all the soil series. The coarse fragment content of the soils of Itagunmodi and Araromi series were rated as S1 while that of Owena series was rated as S2 been > 35% in the subsurface horizons.

The soil macronutrient contents of some of the pedons were grossly inadequate

**Table 8: Land Suitability ratings of the soils of Atakumosa West Local Government Area**

| Land, Soil and Climatic characteristics | Itagunmodi Series | Owena Series | Araromi Series |
|---|---|---|---|
| Climate (C) | | | |
| Annual Rainfall (mm) | 65 (S2) | 65 (S2) | 65 (S2) |
| Mean annual temperature (O°C) | 90(S1) | 90(S1) | 90(S1) |
| Length of Dry season (Months) | 67(2) | 67(2) | 67(2) |
| Relative humidity (driest month) | 95(S1) | 95(S1) | 95(S1) |
| Topography (T) | | | |
| Slope (%) | 95(S1) | 95(S1) | 65(S2) |
| Wetness (W) | | | |
| Flooding | 95(S1) | 95(S1) | 95(S1) |
| Drainage | 95(S1) | 95(S1) | 95(S1) |
| Soil Physical Properties (S) | | | |
| Texture/Structure | 90 (S1) | 90 (S1) | 90 (S1) |
| Coarse fragment (%) | 90(S1) | 60 (S2) | 90 (S1) |
| Soil depth (cm) | 95(S1) | 95(S1) | 95(S1) |
| Fertility Characteristics (F) | | | |
| Apparent CEC (Cmolc/kg) | 45 (S3) | 45 (S3) | 45 (S3) |
| Base Saturation | 95(S1) | 95(S1) | 95(S1) |
| Organic matter (% OC 0 – 15 cm) | 85 (S1) | 85 (S1) | 17 (N2) |
| pH in distilled water | 65 (S2) | 75 (S1) | 65 (S2) |
| Aggregate Suitability (Actual) | 45 (S3) | 45 (S3) | 17 (N2) |
| Aggregate Suitability (Potential) | 65 (S2) | 65 (S2) | 65 (S2) |

Although not used as part of the rating parameters, available Cu, B and Zn contents of the three soil series were rated as highly suitable for the production of cocoa. However the soil contents of Fe and Mn were extremely high.

The overall actual suitability evaluation of the soil series are Itagunmodi series (S3), Owena series (S3) and Araromi series (N). This shows that the soils of Itagunmodi and Owena series were marginally suitable for cocoa production while that of Araromi series was currently not suitable for cocoa production. The major limitations of the soils of Itagunmodi and Araromi series were sub-optima rainfall, the length of the dry season which was more than 90 days, the apparent ECEC which was lower than 16 cmol $kg^{-1}$ and the acid reaction of the soils. In addition to the limitations listed for the soils of Itagunmodi and Owena series, the soil of Araromi series is located on a steep slope and has low organic matter content. The evaluation of the potential suitability of the soils (assuming adequate management of the fertility of the soils) classifies all the soil into S2 suitability class as a result of the sub optima rainfall and length of the dry season in the soils of Itagunmodi and Owena series with addition of slope in the soils of Araromi series.

## Discussion

Ibiremo *et al*., (2011) quoting from different authorities indicated that the soil critical requirement for sustainable cocoa production were 0.9 g/kg N, 30.0 g/Kg OC, C/N ratio of 9; pH in water that range from 5 – 8; available phosphorus of 10.0 mg/Kg, 0.30 cmolc/ Kg K, 5 cmolc/Kg Ca, 0.9 cmolc/Kg Mg, base saturation of 60% and Ca/Mg ratio of 1 – 3. The fertility status of the soils were generally suboptimal for high yields of Cacao and fertiliser application should also be carefully done due to the low ECEC status of the soils. Federal Fertiliser Department (FFD, 2011) indicated that Zinc deficiency can affect Cacao seedling while Boron was only recommended at the rate of 30 g of Borax per plant in mature F3 Amazon. In terms of the physical characteristics of the soils required for optimum cocoa production, cocoa require a deep (> 100 cm), fine to medium textured soil (Sandy clay, clay, silty clay), well drained soils with high water holding capacity (Ritung et al., 2007). The soil physical conditions were highly suitable for the growth of cacao. However, the mean total annual rainfall and length of dry season were suboptimal for high yields of cacao.

## Conclusion

The nutrient holding capacities of the soils of Atakumonsa West Local Government Area as indicated by the CEC were very low. Also the soil macronutrient contents were lower than the minimum requirements for cocoa production. The soils will require supplementary addition of fertilisers having moderate amounts of CaO or MgO, P and K in addition to Cu, Zn and B. Therefore the recommended rate of N, P, K for low fertility soils could be adopted using non acidifying fertiliser sources with quantities of MgO and CaO that will be sufficient to raise the pH of the soils above 6.0 with good supply of Ca and Mg. In terms of application method, split application of the fertilisers is recommended because of the quantity and intensity of the rainfall in this region.

## References

Ajiboye G. A., Jaiyeoba J. O., Olaniyan J. O. and Olaiya, A. O (2015a). The characteristics and suitability of the soils of some major cocoa growing areas of Nigeria: Etung LGA of Cross River. *Agrosearch* 15(1): 101 – 116.

Ajiboye G. A., Jaiyeoba, J. O., Olaiya, A. O. and Hammed L. A. (2015b). Fertility baseline study of major cocoa growing soils of Nigeria and implication for cocoa production in Nigeria. *Nigerian Journal of Soil Science* 25:45-57

Akintola, F. A. (1982). 'Geology and Geomorphology'. Nigeria in maps. R.M. Bartours. Editors. Hodder and Stoughton. London,UK.

Alayaki, F. M. (2012). Water absorption properties of laterite soil in road pavement: A case study of Ife-Ilesa highway, Southwestern Nigeria. *Int. J. of Emerging Technology and Advanced Engineering,* 2 (11): 51-53

Awogboro S. (2007). Geotechnical evaluation of laterites in Illa Local Government Southwestern Nigeria. Unpublished B.Tech Thesis. Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

Bouyoucos, C. J. (1962). Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal* 54: 464 – 465.

FAO (1976). *A framework for land evaluation.* Soils Bulletin 32 Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (2006a).Guideline for soil description. Information Division, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy. ISBN 92-5-1055211-1. 109Pp.

FAO (2006b). World Reference Base for soil resources. A framework for international classification, correlation and communication.World Soil Resources Report 103. Information Division, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy. ISBN 92-5-105511-4. 145 Pp.

FAO (2008). Guide for Laboratory Establishment for Plant Nutrient Analysis. FAO Fertilizer and Plant Nutrition Bulletin. Information Division, FAO, Viale delle Terme di Caracalla, 00100 Rome, Italy. ISBN 978-92-5-105981-4, P. 33

Fasina, A. S.; Omolayo, F. O.; Ajayi, O. S. and Falodun, A. A. (2007). Influence of land use on soil properties of three mapping units in Southwestern Nigeria-Implications for sustainable soil management. *Research Journal of Applied Sciences,* 2(8): 879 – 883.

Haynes, R. J. and Swift, R. S. (1983). An evaluation of the use of DPTA and EDTA as extractants for micronutrients in moderately acid soils. *Plant Soil.* 74:111–122.

Ibiremo, O. S., Daniel, M. A., Iremiren, G. O. and Fagbola, O. (2011). Soil Fertility Evaluation for Cocoa Production in Southeastern Adamawa State, Nigeria. *World Journal of Agricultural Sciences* 7 (2): 218-223

Iremiren, G. O., Oduwole, O. O., Obatolu, B. O., Aigbekaen, E., Sanusi, R. A., Shittu, T. R., Emaku, L. E., Ibiremo, O. S., Aikpokpodion, P., Agbeniyi, S. O., Ndubuaku, T. C. N., Adeogun, S. and Olaiya, A. (2012). Cocoa Production Survey in Nigeria. Report published by Cocoa Research Institute of Nigeria. ISBN: 9789785065664. Pages: 84.

Murphy, J. and Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. Anal Chemical Acta.27: 31 – 36.

Reynolds W. D. 1993. Saturated hydraulic conductivity: Laboratory measurement, in: Soil Sampling and methods of analysis. Carter, M. R. (Ed.). Can. Soc. Soil Sci., Lewis Publ., Boca Raton, FL, 589–598.

Ritung S, Wahyunto, Agus F, Hidayat H. (2007). Land Suitability Evaluation with a case map of Aceh Barat District. Indonesian Soil Research Institute and World Agroforestry Centre, Bogor, Indonesia. Pp 42.

Salami, A. T., Jimoh, M. A. and Muoghalu , J. I. (2003). Impact of gold mining on vegetation and soil in Southwestern Nigeria. *Int. J. Environ. Stud.,* 60: 343-352.

Soil Survey Staff (2010). Keys to soil taxonomy. 11th Edition. USDA, Natural Resources Conservation Service, US Department of Agriculture, Washington DC. 306pp

Walkley, A. and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science, 37(1),* 29-38.