

Morphological Characterization and Soil Quality Assessment along a Toposequence in Obubra Cross Rivers State, Nigeria.

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Abstract: This study evaluated soil quality and landscape relationship in Obubra area, Cross River State using morphological, physical and land use characteristics. Soil Quality Morphological Index (SQMI) was used to assess soil health of arable farms on soils of the area. A total of fifty soil samples from three representative soil profiles and nine minipedons evenly distributed along a 10km toposequence from Apiapum to Obubra communities was studied. Three physiographic positions representing the crest, middle slope and toeslope were delineated and sampled. Samples were taken from genetic horizons in the three profiles while in the 9 minipedons sampling was at predetermined depths of 0-20, 20-40, 40-60 and 60-80cm. The colours of the soils vary between Reddish brown (5YR, 5/4) to Pale Yellow (5YR 6/4), while the texture ranged between Loamy sand to Sandy clay loam. The Crest and toeslope were classified as Fine, Kaolinitic, Thermic, Typic Kanduidult respectively while the middle slope was classified as coarse-loamy, isotic, frigid typic dystrudept. The soils are slightly acidic (5.10 – 6.80) while base saturation ranged between 16% – 88%. Bulk density ranged between 0.96-1.77g/cm³ with low Coefficient of Variability (0-17.3%) while Hydraulic conductivity (K_{sat}) ranged between 3.78-103.44cm/hr with low Coefficient of Variability (10.9-102.1%) The Toeslope had the best quality (SQMI = 3.42), followed by Middle slope (SQMI = 2.78) and least in the Crest (SQMI = 2.75). Soil quality had a good relationship with organic matter ($r = 0.87$; $r^2 = 0.76$; $1-r^2 = 0.24$; $p = 0.05$). This information may help in developing guidelines for agricultural soil management that are based on Topographic sequence of the soil and soil morphological properties.

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Introduction

Land is the pivot of man's absolute existence. Sheng (1989) stressed this by asserting that through the past, in the present, and through the foreseeable future, soil continues to be the foundation of our food supply chain, which is a vital recurrent and capital resource of any nation. However, the alarming rate at which prime and productive agricultural lands (soil) at the fringes of urban centres are being lost to physical development may have very significant implication for the future food security in the country (Oyekale, 2012).

Soil degradation is a topical issue in Nigeria especially among the peasant farmers. Soil degradation can be viewed as any act on soil that changes it from its natural ecological state and makes it unfit for effective use. If soil is degraded, its productivity is reduced and may be further reduced until steps are taken to stop further degradation and restore its productivity (Oyekale, 2012). Soil degradation includes irreversible losses due to soil sealing and erosion, contamination from local and diffuse sources, acidification, salinization and compaction (EEA, 2002).

Major causes of soil degradation include deforestation, burning of vegetation, increasing intensity of farming, tillage practices, low input agriculture, accelerated erosion by water and wind, road building and other construction works (Lal and Okigbo, 1990). Soil degradation has negative consequences on agriculture. (Olsson et al., 2005). About 40 – 75% of the world's agricultural land's productivity is reduced due to soil degradation (Baylis et al., 2012 UNCCD, 2003). The unhindered degradation of soil can completely ruin its productive capacity for human uses (Douglas, 1994).

In Nigeria, the issues of concern to sustainable agriculture include the problem of soil vis-à-vis human induced soil degradation, bush burning and soil compaction (FAO, 2000). The problem of resource degradation has been identified as the most crucial environmental challenge that faces the nation (World bank, 1990). These losses attached to soil degradation have sparked off interest in the concept of soil quality and its assessment (Karlen et al., 2001). The growing awareness that soil is an important component of the earth's biosphere especially in the production of food and fiber (Doran and Parkin, 1994) has caused

researchers to attempt definitions of soil quality (Seybold *et al.*, 1998; Doran and Safley, 1997). Seybold *et al.* (1998) used the word dynamic soil quality which they defined in terms of human use and management on soil functions. Doran and Safley (1997) defined soil quality as the 'continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries, sustain biological productivity, to promote the quality of air and water environments, and to maintain plant, animal and human health.

The relevance of soil quality in its capacity to function in several purposes calls for its quantitative assessment using reliable indices such as soil quality morphological index (SQMI). The index was developed out of the need to characterize the near-

surface attributes in detail for soil survey and to evaluate soil quality in the field using soil morphology. In this index, the higher the value, the better the soil quality (Seybold *et al.*, 2004). The need for putting land to optimum use through adequate and effective planning has never been greatly felt than at the present, when rapid population growth and urban expansion are making available agricultural land scarce (Akinbola, 1993).

Therefore, the soil of the study area was evaluated using SQMI as this will serve as baseline information for better soil management practices within the region and beyond.

Materials and Methods

Study Area

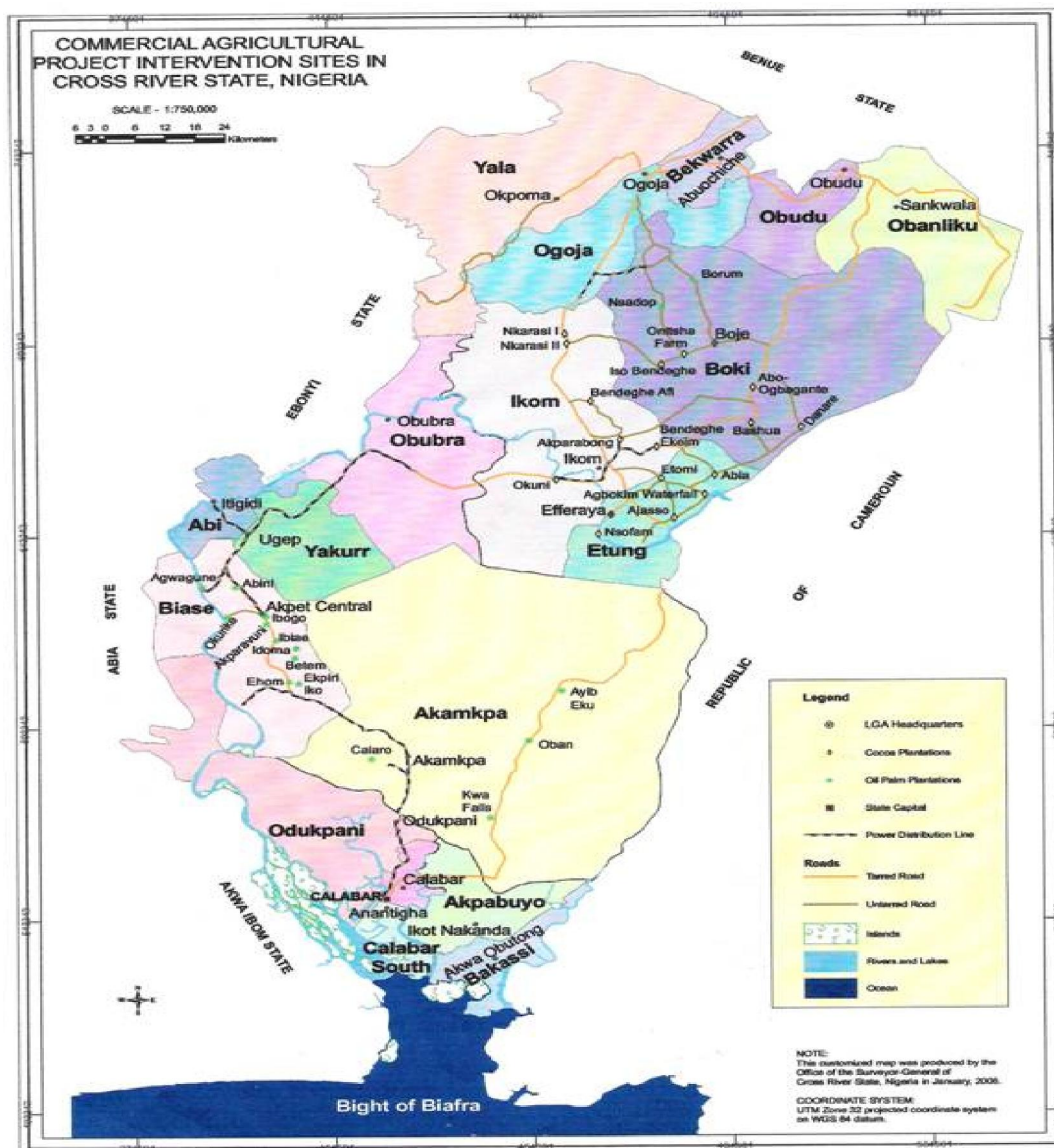


Fig 1: Map of Cross River State showing the Study Area (Adinya *et al.*, 2007).

The study area is located in Obubra Local Government Area of Cross Rivers State. Obubra lie on latitude 06.08°N and longitude 08.33°E, with elevation 109m (Handheld Global Positioning System Receiver readings- Garmin Ltd Kansas, USA). The soil is predominantly Sandy loam. The area has an annual rainfall distribution which ranges from 2500mm to 3000mm per annum, with an annual Temperature range of 25°C – 27°C (Adinya et al., 2007). The area is underlain by two major lithologic units namely: Crystalline basement and cretaceous sediments. The crystalline basement rock cover about 70% of the study area with about 30% gravels (Petters et al., 1987).

Field Work

The toposequence spans about 15km or more from Obubra community to Apiapum community of Cross River State. A hand held Global Positioning System was used to determine the coordinates of the various sample locations. Soil samples were collected from 9 minipeds at a dimension of 80cm X 60cm X 80cm and from three profile pits at a dimension of 2m X 1.5M X 2m along two transects. A total of 56 samples were collected.

Laboratory Analysis

Particle size distribution was determined using the hydrometer method as described by Bouyoucos (1962). Soil pH was determined in 1:1 (Soil: water) ratio using a glass electrode pH meter. Organic carbon was determined by the Wet oxidation method (Walkey and Black, 1934). Total Nitrogen was by the micro-Kjedahl digestion method. Available phosphorus was determined by Bray 1 method (Bray and Kurtz, 1945). Exchangeable bases (Ca, Mg, K and Na) were extracted in 1N NH₄OAC at pH 7 and determined with a flame photometer. Effective Cation Exchange Capacity was by summation of exchangeable bases and acidity. Percentage base saturation was calculated using: $\frac{TEB}{ECEC} \times 100$

Statistical Analysis

The range, mean, standard deviation (S.D) and coefficient of variation (C.V) were determined, C.V was calculated thus; $C.V = \frac{SD}{Mean} \times 100$. Average values of organic matter from soils sampled from minipedons were correlated with values of SQMI using SAS computer package (Little *et al.*, 1996)

Results and Discussion

The morphological properties of the three pedons studied are presented in Table 1. The soils occur on a landscape position that is gently sloping (0 to 4%) from the summit and gradually merge into gradients of 4 to 6% towards the backslope to footslope landscape positions. The pedon at the crest has a very deep

solum with tap root occurring beyond 113cm. This observation is similar to report of Eu et al. (2015).

At the surface, a combination of rock fragments (shale and basalt) were scatter all over from the summit to the foot slope. At the crest, soil colour changes from reddish black (2.5YR, 2.5/1) to very dark (7.5YR, 3/1) to reddish yellow (7.5YR, 7/8) to reddish brown (5YR, 5/4) and to red (2.5YR, 4/8) moist across the five horizons with few gleying at the BA horizon which is a sign of a moderately drained soil. Soil texture ranged from Sandy-loam for the first horizon to Clay-loam for Bt₁, Bt₂ and Bt₃ horizons and clay for Bt₄ horizon. Structure varies between weak sub-angular blocky to prismatic with a clear smooth horizon boundaries. Soil consistency varies from very friable in Ap horizon, friable in Bt₁, firm in Bt₂ and Bt₃; and were very firm in Bt₄.

Soil colour at the middle slope changed from brown (10YR, 5/8) to in Ap and red (10YR, 5/8) in BA horizon. The pedon at the middle slope had an impermeable layer chiefly composed of rock at a depth of 660cm. Horizon boundaries were clear and smooth with fine sand as the dominant soil texture. Soil structure is mainly granular.

Soils at the foot slope for the first two horizons had smooth horizon boundaries; while the last were noticeable. No roots were found in either of these horizons with soil structure that are mainly weak sub-angular blocky. Soil colour ranges from light grey (10YR, 6/1), white (10YR, 8/2), dark grey (5YR, 5/1) and pale yellow (5YR, 6/4) in all the four different horizon. The grayish and pale yellow colour of the foot slope suggests poor drainage and lower productivity. Obasi et al., (2011), reported the same in a similar work he conducted. Soil types that occur at the summit based on their morphological characteristics requires less efforts to be improved on, Lynn and Pearson, (2000). Some amount of organic matter should be added to improve on the fine-sand to loamy-fine-sand textures so as to increase nutrient holding capacity and improve on the CEC of the soil, Wojciech Majda (2014).

Particle Size Distribution

The percentage sand, silt and clay for the nine minipeds are presented in Table 4a. There was no particular trend in the sand fraction across the minipeds. The sand fraction dominates the entire soil ranging from 69.7 to 95.5%. The lowest sand was recorded in MP₆ (70.1 to 88.4%). MP₃ had the highest (70.7 to 95.5%). Sand fraction also varies considerable across the different horizons for all the micropeds ranging from 7.4 to 12.8% with MP₉ showing the lowest C.V (7.4) as against MP₅ which recorded the highest C.V (12.8%)

Table 1: Soil Morphological Properties for Pedons and Minipeds

| Sample I.D | Depth (cm) | Horizon | Colour (moist) | Mottling | Texture | Structure | Roots | Consistency |
|----------------------------------|------------|---------|----------------|----------|---------|-----------|---------|-------------|
| MP ₁ -A | 0-20 | AP | 2.5YR,3/2 | None | FS | Granular | Fibrous | Sticky |
| | 20-40 | BA | 10YR,8/6 | None | FS | Granular | None | N.S |
| | 40-60 | Bt1 | 7.5YR,6/6 | None | SL | Blocky | None | N.S |
| | 60-80 | Bt2 | 2.5YR,7/8 | None | LFS | Blocky | None | N.S |
| MP ₂ O-A | 0-20 | AP | 5YR,3/2 | None | FS | Granular | Fibrous | Sticky |
| | 20-40 | BA | 5YR,5/3 | None | FS | Granular | None | N.S |
| | 40-60 | Bt1 | 10YR,8/8 | None | FS | Granular | None | Sticky |
| | 60-80 | Bt2 | 10YR,8/8 | None | SL | Blocky | None | S.S |
| MP ₃ O-M ₆ | 0-20 | AP | 10R,3/2 | None | LFS | Platy | Fibrous | V.S |
| | 20-40 | BA | 2.5YR,6/8 | None | FS | Granular | Fibrous | V.S |
| | 40-60 | Bt1 | 2.5YR,6/8 | None | SL | Blocky | Fibrous | V.S |
| | 60-80 | Bt2 | 2.5YR,6/8 | None | LFS | SAB | None | V.S |
| MP ₄ O-M ₆ | 0-20 | AP | 7.5YR,2.5/1 | None | FS | Granular | None | Sticky |
| | 20-40 | BA | 7.5YR,5/8 | None | SL | Blocky | None | Sticky |
| | 40-60 | Bt1 | 7.5YR,5/8 | None | FS | Granular | None | N.S |
| | 60-80 | Bt2 | 7.5YR,5/8 | None | SL | Platy | None | S.S |
| MP ₅ O-A | 0-20 | AP | 10YR,2/1 | None | LFS | Blocky | Fibrous | S.S |
| | 20-40 | BA | 5YR,4/4 | None | LFS | Blocky | Fibrous | S.S |
| | 40-60 | Bt1 | 7.5YR,3/8 | None | SL | Blocky | Fibrous | N.S |
| | 60-80 | Bt2 | 7.5YR,3/8 | None | SL | Blocky | Fibrous | N.S |
| MP ₆ O-A | 0-20 | AP | 10YR,2/1 | None | LFS | Granular | Fibrous | S.S |
| | 20-40 | BA | 10R,4/4 | None | FS | Granular | Fibrous | S.S |
| | 40-60 | Bt1 | 5YR,5/8 | None | SL | Granular | None | N.S |
| | 60-80 | Bt2 | 10R,5/3 | None | SL | SAB | None | N.S |
| MP ₇ -A | 0-20 | AP | 2.5YR,2.5/1 | None | FS | Blocky | Fibrous | S.S |
| | 20-40 | BA | 10R,4/4 | None | FS | Blocky | Fibrous | N.S |
| | 40-60 | Bt1 | 10R,4/4 | Present | LFS | Platy | None | V.S |
| | 60-80 | Bt2 | 2.5YR,5/8 | None | SL | Platy | None | N.S |
| MP ₈ O-A | 0-20 | AP | 10R,4/3 | None | LFS | Granular | Fibrous | V.S |
| | 20-40 | BA | 2.5YR,4/8 | None | FS | Granular | None | V.S |
| | 40-60 | Bt1 | 2.5YR,4/8 | None | SL | Blocky | None | N.S |
| | 60-80 | Bt2 | 2.5YR,4/8 | None | SL | Platy | None | N.S |
| MP ₉ O-A | 0-20 | AP | 10R,3/2 | None | FS | Blocky | Fibrous | V.S |
| | 20-40 | BA | 10R,4/8 | None | LFS | Blocky | None | V.S |
| | 40-60 | Bt1 | 10R,4/8 | None | LFS | Platy | None | V.S |
| | 60-80 | Bt2 | 5YR,5/8 | Gleying | LFS | Blocky | None | V.S |
| PP ₁ A-OW (Summit) | 0-12 | AP | 2.5YR,2.5/1 | None | SL | SAB | Fibrous | VFr |
| | 12-35 | BA | 2.5YR,3/1 | None | CL | Granular | Fibrous | Fi |
| | 35-70 | Bt1 | 7.5YR,7/8 | None | CL | SAB | None | Fi |
| | 70-100 | Bt2 | 5YR,5/4 | None | CL | SAB | Tabroot | VFi |
| | 100-113 | Bt3 | 2.5YR,4/8 | None | C | SAB | Tabroot | VFi |
| PP ₂ O-OW (Middle) | 0-10 | AP | 10YR,5/3 | Present | FS | Granular | Fibrous | Sticky |
| | 10-60 | BA | 10R,5/8 | Present | FS | SAB | Tabroot | Sticky |
| PP ₃ O-OW (Foot) | 0-21 | AP | 10YR,6/1 | None | LFS | SAB | None | V.S |
| | 21-44 | BA | 10YR,8/2 | None | LFS | Platy | None | S.S |
| | 44-70 | Bt1 | 5Y,5/1 | None | LFS | Platy | None | N.S |
| | 70-111 | Bt2 | 5Y,6/4 | Present | LFS | Granular | None | Sticky |

FS: Fine sand, SL: Loamy sand, LFS: Loamy fine sand, SAB: Sub-angular blocky, Fbr: Fibrous root, Tb: Tap root, N.S: Non-sticky, S.S: Slightly sticky, V.S: Very sticky, H.N: Hardly noticed.

At the summit, from Table 4b the sand fraction decreases with increase in the soil depth across horizons Ap, BA, Bt₁ and Bt₂ and slightly increase in the Bt₃ horizon corresponding with the BA horizon. Ap horizon showed the highest sand content (90.2%), indicating that the sand fraction dominates the entire soils in the summit. The removal by illuviation of silty materials by rainwater or by erosion from the top slope and subsequent deposition down the slope could be the reason for the trend. These results are also in agreement with the findings of Voncir *et al.*, (2008) who worked on profile distribution of some physicochemical properties of soil along a toposequence. No particular trend was observed for the silt content. BA horizon had the highest silt content (9.4%) followed by the Bt₃ horizon which had the lowest % silt (3.4%). Clay content decreases with increase in depth for Ap and BA horizons and slightly increased in the Bt₁ (8.4%), Bt₂ (8.6%) and then decreased very slightly in the Bt₃ (8.4%) horizons; indicating the existence of definite clay bulge suggesting the occurrence of argillic horizon conforming with a similar work done by Esu *et al.*, (2015). Highest and lowest clay content were recorded in Bt₂ (8.6%) and BA (2.2%) horizons respectively.

At the middle slope, sand content increases with increase in the depth, this is possibly due to land cultivation. Sand content was highest at the BA horizon (90.4%) and lowest at the Ap horizon (88.4%). Silt content was highest at the upper horizon (9.4%) followed by 7.4% at the BA horizon, while clay content was fairly constant across the two horizons (2.2%). Sand content was highest at the BA horizon and lowest at Ap horizon, silt content were highest (17.4%) and lowest (1.4%) at the Ap and Bt₁ horizons respectively. Clay was constant at Bt₁ and Bt₂ horizons (10.2%). Generally, from Table 6, the mean values for sand was highest at the middleslope (89.4) lowest at the toeslope (84.9); silt was highest at middleslope (8.4) and lowest at the summit; clay was highest at the toeslope (7.7) and lowest at the middle slope (2.2).C.V across the physiographic positions vary from 1.6 to 4.3% at the summit, 16.8-93.6% at the middleslope and 42.2-49.2% and the footslope. This does not exactly correspond with a similar work conducted by Obasi *et al.*, (2011), which may possibly be due to the slope position of the toposequence. However, the regular clay increase with depth was in agreement with Eshett (1996), that soils of the region are friable and underlain by clay enriched sub-soil (argillic horizon).

Table 2: Soil Physical Properties for Minipeds

| Sample I.D | Depth (cm) | Horizon | B.D (g/cm ³) | K _{sat} (cm/hr) | % Sand | % Silt | % Clay | Porosity (%) |
|----------------------------------|------------|-----------------|--------------------------|--------------------------|--------|--------|--------|--------------|
| MP ₁ -A | 0-20 | AP | 1.58 | 50.22 | 87.4 | 10.4 | 2.2 | 40 |
| | 20-40 | BA | 1.43 | 13.44 | 88.6 | 4.9 | 6.5 | 46 |
| | 40-60 | Bt ₁ | 1.28 | 11.61 | 70.89 | 23.41 | 5.7 | 52 |
| | 60-80 | Bt ₂ | 1.24 | 4.89 | 80.2 | 16.7 | 3.1 | 53 |
| MP ₂ O-A | 0-20 | AP | 1.08 | 65.21 | 88.4 | 7.4 | 4.2 | 59 |
| | 20-40 | BA | 1.27 | 53.76 | 90.5 | 6.4 | 3.1 | 52 |
| | 40-60 | Bt ₁ | 1.29 | 40.26 | 89.6 | 5.6 | 4.8 | 51 |
| | 60-80 | Bt ₂ | 1.33 | 39.20 | 69.67 | 19.69 | 10.6 | 49 |
| MP ₃ O-M ₆ | 0-20 | AP | 1.38 | 8.55 | 87.6 | 5.6 | 6.8 | 48 |
| | 20-40 | BA | 1.77 | 7.00 | 95.5 | 2.2 | 2.3 | 33 |
| | 40-60 | Bt ₁ | 1.56 | 6.11 | 70.7 | 24.9 | 4.4 | 41 |
| | 60-80 | Bt ₂ | 1.38 | 3.78 | 80.9 | 16.1 | 3.0 | 48 |
| MP ₄ O-M ₆ | 0-20 | AP | 1.13 | 64.76 | 92.4 | 5.4 | 2.2 | 57 |
| | 20-40 | BA | 1.55 | 28.21 | 78.0 | 9.5 | 12.5 | 42 |
| | 40-60 | Bt ₁ | 1.61 | 15.31 | 88.4 | 5.8 | 5.8 | 39 |
| | 60-80 | Bt ₂ | 1.73 | 10.32 | 70.5 | 21.9 | 7.6 | 35 |
| MP ₅ O-A | 0-20 | AP | 1.56 | 36.32 | 88.4 | 4.0 | 7.6 | 41 |
| | 20-40 | BA | 1.49 | 32.61 | 80.1 | 15.5 | 4.4 | 44 |
| | 40-60 | Bt ₁ | 1.51 | 20.31 | 65.9 | 25.1 | 9.0 | 43 |
| | 60-80 | Bt ₂ | 1.48 | 15.31 | 71.8 | 19.2 | 9.0 | 44 |
| MP ₆ O-A | 0-20 | AP | 1.37 | 65.98 | 82.4 | 9.4 | 8.2 | 48 |
| | 20-40 | BA | 1.28 | 51.32 | 88.9 | 5.9 | 5.2 | 52 |
| | 40-60 | Bt ₁ | 1.52 | 40.52 | 70.7 | 22.6 | 6.7 | 43 |
| | 60-80 | Bt ₂ | 1.37 | 7.33 | 70.1 | 17.9 | 12.0 | 48 |
| MP ₇ -A | 0-20 | AP | 1.31 | 97.75 | 90.6 | 7.4 | 2.0 | 51 |
| | 20-40 | BA | 1.31 | 81.99 | 90.1 | 6.4 | 3.5 | 51 |
| | 40-60 | Bt ₁ | 1.05 | 78.81 | 78.8 | 13.1 | 8.1 | 60 |
| | 60-80 | Bt ₂ | 1.31 | 78.19 | 69.9 | 24.0 | 6.1 | 51 |
| MP ₈ O-A | 0-20 | AP | 1.54 | 49.55 | 80.4 | 17.4 | 2.2 | 42 |
| | 20-40 | BA | 1.28 | 38.40 | 90.5 | 6.7 | 2.8 | 52 |
| | 40-60 | Bt ₁ | 0.96 | 35.20 | 70.0 | 18.1 | 11.9 | 64 |
| | 60-80 | Bt ₂ | 1.21 | 28.71 | 78.9 | 8.3 | 12.8 | 54 |
| MP ₉ O-A | 0-20 | AP | 1.21 | 103.44 | 94.4 | 3.8 | 1.8 | 54 |
| | 20-40 | BA | 1.08 | 102.64 | 80.4 | 15.7 | 3.9 | 60 |
| | 40-60 | Bt ₁ | 1.33 | 53.54 | 81.8 | 11.4 | 6.8 | 50 |
| | 60-80 | Bt ₂ | 1.18 | 24.28 | 84.4 | 3.1 | 12.5 | 55 |

Bulk Density

Bulk density decrease with increase in the soil depth. This could be due to less compaction with increase in depth with slight increase in Silt/clay fraction. The values of bulk density for MPs 1, 3, 4 and 5 were slightly higher than the ideal (1.4g/cm^3), due to increased fraction caused by compaction and cultivation (USDA, 2008); while values of bulk density for MPs 2, 6, 7, 8 and 9 were lower than the ideal (1.4g/cm^3); probably due to higher accumulation of Organic matter.

Saturated Hydraulic Conductivity (Ksat)

C.V ranges from 10.9 to 102.1% indicating there was a wide variability in saturated hydraulic conductivity across the 9 micropeds along the catena. The soils of the study area showed high values of Ksat with range; $3.7 - 103.44\text{cm/hr}$ (Table 2), indicating that the soil are highly porous due to high percentage sand fraction, Brady (1999). It was observed that Ksat decreased with increased in soil depth due to a reduction in pore size distribution from sandy fraction to clay/silt fraction since sand contains large pore spaces (though fewer in number) when compared to clay or silt with smaller pore size thus holds water longer than sandy fractions of soil (USDA, 2008).

Porosity

The total porosity of the soils across all the 9 minipeds ranged from 40 to 64% with a greater portion above the ideal porosity for healthy soils (>50%), (Lawrence, 1977). Soils that fall below the ideal porosity were probably due to high bulk density and low soil organic matter content; this is similar to the report of Alemayahu (2014). High amount of total porosity (50 to 64%) is probably due to fine-textured and loamy-fine-sand texture of the soils as well as soil high organic matter content, Hallett et al., and Robinson et al., (2012).

Soil Type Classification of the Study Area

Soil types of the study area were classified based on USDA Soil Survey Staff, (1999). Fine, Kaolinitic, Thermic, Typic Kandiuult occurred at the crest and toeslope. One distinguishing characteristic of Ultisols is the presence of low base saturation and a bleached horizon throughout the soil profile with slightly higher Base contents in the upper soil horizon due to biocycling. In some soils, the low base status results from intense leaching of parent material initially high in content of weatherable minerals, while in others, a low base status and small quantities of weatherable minerals were initially of parent material characteristics. Typically, the cation exchange capacity (CEC) of Ultisols is low; this is because of their low base status. Most Ultisols are used for timber production but they are also used in agriculture, where liming and fertilization is important to decrease acidity

and increase soil fertility. Where adequate agricultural management is applied these Ultisols are quite productive.

Middleslope was classified as coarse-loamy, isotic, frigid typic dystrodept. The cambic subsurface diagnostic horizon of Inceptisols is composed of very fine sand, loamy fine sand or finer texture, with some weak indication of either an argillic or spodic horizon, but not enough to qualify as either. Typically, these soils have an ochric or umbric epipedon over a cambic horizon. Present use may be restricted by the shallowness of the solum (e.g. on steep slopes) or by poor drainage (e.g. in depression areas). Those Inceptisols are suited only to forestry and/or wildlife habitat.

Chemical Properties

Available Phosphorus (Avail P)

The results of available P in the study area are presented in Table 3. Avail P at the summit, middle and footslope was high ranging from $18.34-36.67\text{mg/kg}$ at the summit, $25.01-35.01\text{mg/kg}$ at the middleslope and $21.67-38.34\text{mg/kg}$ at the slope as against the critical limit P, $10 - 16\text{mg/kg}$; (Adeoye and agboola, 1985), across all the horizons. Avail P was highest at the footslope at Bt_2 horizon due to translocation and deposition of sediments from the summit to the footslope (Bray and Weil 2002). The trend of avail P was similar to the values reported by Amhaknian and Achimugu (2011) who worked on characteristics of soils on a toposequence in Kogi State, Nigeria. Avail P across the 9 minipeds ranged from $8.8-39.1\text{mg/kg}$ with MP_7 having the highest (39.1mg/kg) at the upper horizon while MP_6 recorded the lowest (8.8mg/kg) at Bt_2 horizon. No particular trend was observed for avail P across all the nine micropeds.

Total Nitrogen (TN), Organic Carbon (OC) and Carbon/Nitrogen (C/N) ratio

The following ranges of TN, OC & C/N were obtained in the study area. The content of N across the landscape positions decreases with increase in depth for the summit, middle slope and footslope. N was highest at the Ap horizon on the summit (0.712mg/kg) and lowest at the footslope on the Bt_2 horizon (0.101mg/kg), this trend is as a result of the geomorphological unit of the toposequence. Org C decreases across the landscape with increase in depth and was high at the crest (2.94%, Ap horizon) and lowest on the Bt_2 horizon (0.21%) at the footslope. However, the C/N ratio on the toposequence ranged from 2.1-17.1%. These values were below C/N ratio 25 being the separating index for mineralization and mobilization of N as established by Paul and Clark (1989). The trend of Total N, Organic Carbon, and C/N ratio are similar to the value reported by Ogeh

and Ukodo, (2012) who worked on profile distribution of physical and chemical properties of soils on a toposequence.

Total N across the micropeds ranges from 0.1-1.091mg/kg with no specific trend. MP₃ and MP₂ recorded the lowest (0.1-0.61mg/kg, lower and upper horizons) and highest (0.111-0.85mg/kg, lower and upper horizons) respectively. OC and OM decreases across the 9 minipeds with increase in depth and were highest (4.92% at the upper horizon) due to decomposition and lowest (0.21% at the Bt₂ horizon) for mapping units 3 and 6 respectively. CN ratio ranges from 1.0 – 47.7 across the miniped on the catena.

Soil Reaction (pH)

Soil pH (H₂O) generally reveal ranged from moderately to slightly acidic for all the profiles (crest, middlelope and toeslope) 5.0-6.0 respectively, (Schoeneberger et al., 2012). The pH values of the study area reveals that the soils of the area are generally slightly acidic, values of the soil at the upper horizons in all the pedons were similar (6.0) and this is in conformity with the finding of Babalola et al., (2007) who did similar work on soil properties and slope position in a humid forest and observed same trend of pH.

The pH values across all the minipeds ranged from 5.0-6.8 which indicates a slightly acidic soil, (Soil survey manual, 2014). MP₃ recorded the lowest pH value (5 to 6.2) while MP₇ showed the highest pH value (5.1-66.8).

Total Exchangeable Acidity

Total exchangeable acidity ranged from 0.32-2.60 Cmol/kg for all the three pedons across the

various geomorphological positions. This range is low when compared to the critical level of 2.1-4.0 Cmol/kg proposed by Holland et al., (1989). This is probably due to high H⁺ and Al³⁺ which tend to lower the soil pH. Ackley (2012), who worked on physico-chemical properties degradation rate and vulnerability potential of the soils in South-Eastern Nigeria reported the same findings.

Total Exchangeable Bases:

The data revealed that the total exchangeable bases varied greatly across the various horizons in all the profiles and the minipeds. The minipeds had the highest ECEC of 4.06 Cmol/kg at Ap horizon while the lowest was recorded in the Crest (1.67Cmol/kg) at Bt₃ horizon. ECEC were quite low across the profile and the mean value are 2.450Cmol/kg at the crest, 3.300Cmol/kg at the middlelope and 2.365Cmol/kg at the footslope. The low value of CEC across the physiographic position agreed with the works of Menzies and Gillman (1997) and Voundi, et al., (1997) (CEC = 3.0- 5.5 Cmol/kg). This is probably as a result of the heterogeneous nature of the parent materials during pedogenesis and domination of low activity components such as kaolinite, Fe, and Al (hydroxides) in soils.

Also, mean values of total exchangeable bases range from 2.780 -6.032 Cmol/kg across the 9 minipeds with MP₆ having the highest (7.53 Cmol/kg) while MP₄ showed the lowest value (2.05 Cmol/kg); both at Bt₂ horizons respectively. This observation is probably due to eluviation and illuviation processes at the argillic horizon.

Table 3: Chemical properties of the sampled Soil

| Sample ID | Depth (cm) | Horizon | pH (H ₂ O) | Avail P (mg/kg) | TOC | TN | C:N | Ca Cmol/kg | Mg | K | Na | TEB | TEA | ECEC | BS (%) |
|----------------------|------------|---------|-----------------------|-----------------|-------|-------|------|------------|------|------|------|------|------|-------|--------|
| MP ₁ -A | 0-20 | Ap | 5.5 | 39.05 | 3.151 | 0.950 | 3.3 | 0.69 | 1.00 | 1.01 | 0.56 | 3.26 | 3.3 | 6.56 | 50 |
| | 20-40 | BA | 6.1 | 20.61 | 2.111 | 0.805 | 2.6 | 0.90 | 0.55 | 1.12 | 0.76 | 3.33 | 2.6 | 5.93 | 56 |
| | 40-60 | Bt1 | 5.6 | 18.06 | 2.011 | 0.218 | 9.2 | 1.50 | 1.66 | 0.70 | 0.06 | 3.92 | 9.2 | 13.12 | 30 |
| | 60-80 | Bt2 | 5.4 | 30.71 | 1.021 | 0.200 | 5.1 | 0.99 | 0.54 | 1.30 | 1.00 | 3.83 | 5.1 | 8.93 | 43 |
| MP ₂ O-A | 0-20 | Ap | 6.7 | 9.08 | 1.976 | 0.850 | 3.2 | 0.85 | 0.89 | 1.00 | 0.48 | 3.22 | 3.2 | 6.42 | 50 |
| | 20-40 | BA | 6.0 | 12.45 | 1.561 | 0.350 | 4.5 | 1.80 | 0.22 | 0.88 | 0.33 | 3.23 | 4.5 | 7.73 | 42 |
| | 40-60 | Bt1 | 5.1 | 25.01 | 1.306 | 0.220 | 5.9 | 0.67 | 0.23 | 0.60 | 0.90 | 2.40 | 5.9 | 8.3 | 30 |
| | 60-80 | Bt2 | 5.9 | 38.60 | 0.516 | 0.111 | 4.6 | 0.61 | 1.50 | 1.11 | 0.56 | 3.78 | 4.6 | 8.38 | 45 |
| MP ₃ O-M6 | 0-20 | Ap | 5.0 | 14.80 | 2.851 | 0.611 | 4.7 | 1.00 | 0.27 | 0.99 | 0.56 | 2.82 | 4.7 | 7.52 | 38 |
| | 20-40 | BA | 6.2 | 35.65 | 2.112 | 0.512 | 4.1 | 1.20 | 0.80 | 0.55 | 0.34 | 2.89 | 4.1 | 6.99 | 41 |
| | 40-60 | Bt1 | 5.0 | 28.24 | 1.156 | 0.711 | 1.6 | 0.54 | 0.78 | 1.00 | 1.05 | 3.37 | 1.6 | 4.97 | 68 |
| | 60-80 | Bt2 | 5.5 | 16.16 | 1.011 | 0.101 | 10.0 | 0.45 | 0.99 | 1.01 | 0.61 | 3.06 | 10.0 | 13.06 | 23 |
| MP ₄ O-M6 | 0-20 | Ap | 6.8 | 29.06 | 1.171 | 0.185 | 6.3 | 0.97 | 0.53 | 0.98 | 0.73 | 3.21 | 6.3 | 9.51 | 34 |
| | 20-40 | BA | 6.5 | 30.01 | 1.001 | 0.214 | 4.6 | 0.87 | 1.12 | 0.12 | 0.90 | 3.01 | 4.6 | 7.61 | 40 |
| | 40-60 | Bt1 | 6.1 | 28.80 | 0.911 | 0.111 | 8.2 | 1.15 | 1.00 | 0.25 | 0.45 | 2.85 | 8.2 | 11.05 | 26 |
| | 60-80 | Bt2 | 5.9 | 18.45 | 0.600 | 0.106 | 5.7 | 0.10 | 0.05 | 0.89 | 1.01 | 2.05 | 5.7 | 7.75 | 27 |
| MP ₅ O-A | 0-20 | Ap | 6.0 | 36.69 | 0.815 | 0.911 | 1.0 | 0.82 | 0.16 | 0.87 | 0.66 | 3.51 | 1.0 | 3.51 | 72 |
| | 20-40 | BA | 6.0 | 25.20 | 0.611 | 0.105 | 5.8 | 0.88 | 0.85 | 0.76 | 0.23 | 2.71 | 5.8 | 8.51 | 32 |
| | 40-60 | Bt1 | 6.5 | 19.18 | 0.312 | 0.100 | 3.1 | 1.11 | 1.70 | 1.12 | 0.67 | 4.60 | 3.1 | 7.7 | 60 |
| | 60-80 | Bt2 | 5.9 | 30.00 | 0.104 | 0.101 | 1.0 | 0.97 | 0.77 | 1.12 | 0.56 | 3.42 | 1.0 | 4.42 | 77 |
| MP ₆ O-A | 0-20 | Ap | 5.7 | 38.67 | 0.991 | 0.196 | 5.1 | 0.84 | 0.87 | 1.07 | 0.67 | 3.45 | 5.1 | 8.55 | 40 |
| | 20-40 | BA | 5.6 | 21.00 | 0.510 | 0.181 | 2.8 | 0.90 | 1.66 | 1.90 | 0.87 | 5.33 | 2.8 | 8.13 | 66 |
| | 40-60 | Bt1 | 5.4 | 15.15 | 0.121 | 0.112 | 1.1 | 2.00 | 0.89 | 2.22 | 0.54 | 5.65 | 1.1 | 6.75 | 84 |
| | 60-80 | Bt2 | 6.4 | 8.80 | 0.100 | 0.103 | 1.0 | 1.90 | 1.66 | 2.41 | 1.56 | 7.53 | 1.0 | 8.53 | 88 |
| MP ₇ -A | 0-20 | Ap | 6.0 | 39.10 | 3.000 | 1.091 | 2.7 | 0.98 | 1.10 | 1.14 | 0.71 | 3.93 | 2.7 | 6.63 | 59 |

| Sample ID | Depth (cm) | Horizon | pH (H ₂ O) | Avail P (mg/kg) | TOC | TN | C:N | Ca Cmol/kg | Mg | K | Na | TEB | TEA | ECEC | BS (%) |
|------------------------------------|------------|---------|-----------------------|-----------------|-------|-------|------|------------|------|------|------|------|------|-------|--------|
| MP ₈ O-A | 20-40 | BA | 6.8 | 37.50 | 1.001 | 0.021 | 47.7 | 1.80 | 2.22 | 1.98 | 1.45 | 7.45 | 7.7 | 15.15 | 49 |
| | 40-60 | Bt1 | 5.9 | 33.40 | 0.197 | 0.210 | 1.0 | 1.70 | 1.89 | 1.55 | 1.00 | 6.14 | 1.0 | 7.14 | 86 |
| | 60-80 | Bt2 | 5.1 | 29.80 | 0.121 | 0.112 | 1.1 | 2.15 | 2.00 | 1.58 | 0.88 | 6.61 | 1.1 | 7.71 | 86 |
| | 0-20 | Ap | 6.1 | 20.50 | 0.861 | 0.811 | 1.1 | 1.07 | 0.74 | 1.00 | 0.70 | 3.51 | 1.1 | 4.61 | 76 |
| MP ₉ O-A | 20-40 | BA | 5.9 | 14.89 | 0.618 | 0.210 | 2.9 | 1.45 | 1.90 | 1.55 | 1.05 | 5.95 | 2.9 | 8.85 | 67 |
| | 40-60 | Bt1 | 5.6 | 16.10 | 0.401 | 0.105 | 3.8 | 0.98 | 0.88 | 1.23 | 0.90 | 3.99 | 3.8 | 7.79 | 51 |
| | 60-80 | Bt2 | 6.0 | 36.67 | 0.311 | 0.112 | 2.8 | 2.50 | 1.80 | 1.89 | 0.75 | 6.94 | 2.8 | 9.74 | 71 |
| | 0-20 | Ap | 5.9 | 25.21 | 0.411 | 0.121 | 3.4 | 1.12 | 0.98 | 0.89 | 0.54 | 3.53 | 3.4 | 6.93 | 51 |
| PP ₁ A-O (Crest) | 20-40 | BA | 5.6 | 25.21 | 0.312 | 0.186 | 1.7 | 0.55 | 0.45 | 0.81 | 1.00 | 2.81 | 1.7 | 4.51 | 62 |
| | 40-60 | Bt1 | 6.1 | 28.80 | 0.105 | 0.211 | 1.0 | 1.99 | 2.00 | 0.10 | 0.50 | 4.95 | 1.0 | 5.95 | 83 |
| | 60-80 | Bt2 | 6.7 | 15.90 | 0.100 | 0.107 | 1.0 | 0.50 | 1.11 | 0.45 | 0.82 | 2.88 | 1.0 | 3.88 | 74 |
| | 0-12 | Ap | 6.0 | 36.67 | 2.94 | 0.712 | 17.1 | 0.88 | 0.88 | 0.86 | 0.56 | 3.18 | 17.1 | 20.28 | 16 |
| PP ₂ O-OW (Middleslope) | 12-35 | BA | 5.7 | 18.34 | 1.60 | 0.139 | 11.5 | 0.74 | 0.77 | 0.65 | 0.60 | 2.16 | 11.5 | 13.66 | 16 |
| | 35-70 | Bt1 | 5.6 | 36.67 | 0.35 | 0.104 | 3.4 | 0.68 | 0.74 | 0.55 | 0.56 | 2.53 | 3.4 | 5.93 | 43 |
| | 70-100 | Bt2 | 5.9 | 36.67 | 0.38 | 0.105 | 1.0 | 1.15 | 0.18 | 0.70 | 0.72 | 2.75 | 1.0 | 3.75 | 73 |
| | 100-113 | Bt3 | 5.9 | 30.01 | 0.29 | 0.101 | 2.9 | 0.54 | 0.36 | 0.44 | 0.33 | 1.67 | 2.9 | 4.57 | 37 |
| PP ₃ O-OW (Toeslope) | 0-10 | Ap | 6.2 | 35.01 | 1.97 | 0.149 | 13.2 | 0.95 | 1.33 | 1.06 | 0.72 | 4.06 | 13.2 | 17.26 | 24 |
| | 10-60 | Bt1 | 5.9 | 25.01 | 0.30 | 0.104 | 2.9 | 0.73 | 0.70 | 0.55 | 0.56 | 2.54 | 2.9 | 5.44 | 47 |
| PP ₃ O-OW (Toeslope) | 0-21 | Ap | 6.0 | 28.34 | 1.17 | 0.109 | 10.7 | 0.79 | 0.58 | 0.98 | 0.51 | 2.86 | 10.7 | 13.56 | 21 |
| | 21-44 | BA | 5.5 | 30.01 | 0.92 | 0.185 | 5.0 | 0.64 | 0.58 | 0.53 | 0.66 | 2.41 | 5.0 | 7.41 | 33 |
| | 44-70 | Bt1 | 5.9 | 21.67 | 0.74 | 0.109 | 6.8 | 0.48 | 0.86 | 0.76 | 0.38 | 2.48 | 6.8 | 9.28 | 27 |
| | 70-111 | Bt2 | 5.9 | 38.34 | 0.21 | 0.101 | 2.1 | 0.44 | 0.54 | 0.46 | 0.27 | 1.71 | 2.1 | 3.81 | 45 |

TOC: Total Organic carbon, TN: Total Nitrogen, TEB: Total Exchangeable Bases, BS: Base Saturation, Avail. P: Available Phosphorus.

Variability In Soil Chemical Properties

Table 4: Variability Class

| Coefficient of Variation (%) | Variability Class |
|------------------------------|------------------------|
| ≤ 20% | Little variability |
| 20 – 50% | Moderately variability |
| ≥ 50% | High variability |

Source: Aweto, 1982

Avail P for the profiles were moderately variable and was highest at the summit (CV = 25.2%) and was almost the same at the middleslope and the footslope (CV = 23.4 and 23.2%) respectively (Table 4). For the minipeds, avail P ranges from little variability (12.6%) to highly variable (63.1%) across the 9 pedons. MP₇ has the lowest variability (12.6%) followed by MP₂ with the highest variability (63.1%). The variability of Soil pH was little at summit (2.8%), middleslope (3.5%) and at the footslope (3.88%). In the same vein, soil pH across the 9 minipeds showed a great degree of little variability with CV ranging from 3.7 to 11.7%, at minipeds 8 and 7 respectively. TEB across the profiles ranged from little to moderately variable. At the summit and footslope, CV was little variable 23.4% and 20.3% respectively, while at the middleslope, CV was moderately variable with 32.6 & minipeds also showed little to moderate variations across the 9 minipeds ranging from 8.0 to 31.8% at minipeds 3 and 8 respectively. Minipeds 5, 6, 7, 8 and 9 were moderately variable. TEA across the pedons ranged from little, moderate and highly variable. At the summit TEA was highly variable (CV = 58.2%), little variable at CV = 40%. Across the 9 minipeds, total exchangeable acidity ranged from moderately to

highly. Mapping units MP₄ to MP₉ were all moderately variable (CV = 50 to 79.1%). CN ratio ranged from moderately variable to highly variable across the minipeds and pedons. At the upperslope, middleslope and toelope CN was highly variable 95.1, 90.4 and 58.1 respectively. Also CV ranged from moderately to highly variable (24.2 to 176.3%) across the 9 minipeds. Percentage base saturation ranged from moderate to highly variable, at the summit BS was highly variable 63%, moderately variable at the middleslope and footslope; 46% and 33% respectively. BS also ranged from moderate (CV = 23%) to highly (CV = 8) variable across the 9 minipeds

This variability in soil properties agrees with Upchurch et al., (1998) that soil properties such as soil texture, soil thickness and colour are less variable while more dynamic and variable properties such as TOC TON, Avail P, and TEB are more variable as shown in Table & below. Also properties which are measured and closely calibrated to a standard such as texture, colour PH are less variable. The high variability of soil properties on the slope showed that the soil under investigation is a typical highly weathered soil of the tropical region in the southern Nigeria (Eshett, 1996, Onweremadu et al., 2007).

Table 5: Texture-weighting class criteria for SQMI (Source: Seybold et al., 2004)

| Texture Class | Criteria |
|---------------|-------------------------|
| A | Sand, loamy sand |
| B | Not A and Clay is < 18% |
| C | 18-40% Clay |
| D | ≥ 40% Clay |

Table 6: Criteria for placement of structure class in the soil quality morphological index (Source: Seybold et al., 2004)

| Structure Class | Criteria |
|-----------------|--|
| 1 | All structures with common or many stress irrespective of other features, massive, platy with firm or stronger horizontal rupture resistance, all weak structure except granular, moderate to very coarse prismatic, all columnar |
| 2 | All structure with few stress surface irrespective of other features, weak granular, moderate to very coarse and coarse blocky; coarse and medium prismatic, platy with friable horizontal rupture resistance; strong very coarse prismatic. |
| 3 | No stress surface, moderate to medium blocky, fine, fine and medium prismatic; platy with friable horizontal rupture resistance; strong very coarse and coarse blocky. |
| 4 | No stress surface, moderate to granular, moderate to very fine and fine blocky; strong fine |
| 5 | No stress surface, strong granular, strong very fine through medium blocky and very fine prismatic. |

Table 7: Rupture-resistance classes for the soil quality morphological index (Source: Seybold et al., 2004)

| Rupture Resistance | | | | | |
|--------------------|-------|--------------|---------|------|------------------------|
| Texture classes | Loose | Very friable | Friable | Firm | Very Firm and stronger |
| A | 2 | 3 | 3 | 2 | 1 |
| B | 3 | 4 | 3 | 2 | 1 |
| C | 4 | 5 | 3 | 2 | 1 |
| D | 5 | 5 | 4 | 1 | 1 |

Computation of Field Data

Soil quality morphological index was computed using the following formula:

$$SQMI = (4 SRI_{0-10} + 2 SRI_{10-20} + SRI_{20-30}) / 7$$

Where,

SRI = Structure-rupture resistance, 4, 2 and 7 = Weighting factors

Table 8: Soil quality morphological index (SQMI) value

| Physiography | Origin | SQMI |
|--------------|-----------|------|
| Upland | Minipedon | 2.53 |
| Middleslope | Minipedon | 2.78 |
| Toeslope | Minipedon | 3.42 |

Table 9: Relationship between SQMI and SOM

| Statistics | Values |
|--------------------|--------|
| R | 0.87 |
| r ² | 0.76 |
| 1 - r ² | 0.24 |
| P = 0.05, n = 9 | |

Soil on the toeslope have best quality having the highest index value (SQMI = 3.42) followed by those on the middleslope, 2.78 and the least being those on the Crest (upland). These results show that soils on the

Toeslope have least physical limitation for root growth, development and performance as well as in the soils ability to draw nutrients, air and water in the pedosphere (Table 8). It implies that soils of Toeslope

have the best soil physical fertility which according to Eneje et al (2005) is necessary on water status workability resistance to erosion and nutrient availability (Piccolo and Mbagwu, 1999).

SQMI values were correlated with Organic Matter at a probability of 5% and the result shows significant positive correlation (Coefficient $r = 0.87$, $P = 0.05$, $n = 9$) (Table 9). There was also a very good relationship between SQMI values and SOM ($r^2 = 0.76$, $P = 0.05$, $n = 9$). SOM is regarded as a very reliable and important soil quality parameter (Gregorich et al., 1994). If OM has correlated well with SQMI, it implies that both are good indicators of soil health status.

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