CHARACTERIZATION OF SOILS ALONG SOME TOPOSEQUENCES IN BEKWARRA LOCAL GOVERNMENT AREA, CROSS RIVER STATE, NIGERIA

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DOI No. 10.528 / zenodo 10558777

ABSTRACT

Soil characterization involve soil data acquisition and interpretation for crop production. This study was carried out to determine the morphological, physical and chemical properties of soils along toposequences in Bekwarra Local Government Area. Satellite imagery of Anyikang in Bekwarra was obtained from google earth, and the contour map and four profile graphs generated in the ArcGIS 10.2.1.3 environment which represented four spatially identified toposequences. Along each of the four toposequences, one profile pit was dug in the crest, middle slope and lower slope positions. A total of 12 profile pits were therefore studied from which 48 soil samples were obtained. The soils were very deep (>150 cm) with Ap horizons exceeding 20 cm and characterized by various shades of red (7.5 YR 3/3), black (5YR 2.5/1) and brown (7.5YR 4/4) colours with loamy sand and sandy loam surface textures. Sand content exceeded silt and clay at abundance of over 25 % in all depths, with clear clay bulges in the B horizons. Bulk density was within tolerable range of less than 1.6 Mg/m^3, while total porosity exceeded 30 % in all depths. Soil pH was within the range of 4.5 – 6.1, while organic carbon and available P were low to moderate in the entire studied soils. Low exchangeable Ca, K and Na and moderate Mg in the soils indicate active leaching process influencing the concentration of these bases, while exchangeable acidity was jointly caused by exchangeable Al^{3+} and H^+. The difficult-to-alter physical properties were relatively tolerable for crop production. The partly limiting chemical properties can easily be altered and managed for optimum crop production by the use of compost, plant residues and liming materials at recommended doses for optimum crop production.

Keywords: sandstone, toposequence, soil characteristics, southern guinea savannah, pedology

INTRODUCTION

Soil is dynamic and a collection of natural bodies occupying portions of the earth surface that can support crop production with properties that are influenced by climate, living organisms, parent materials, relief and time. Amongst these, parent materials and climate exert a strong influence on soil spatial variability but relief is most important in soil distribution. Akamigbo and Asadu (1982) as well as Esu (2010) and Ibanga (2006) observed the influence of parent materials on soil formation, especially when the soil is formed in-situ. Upon in-situ weathering, relief redistribute soils to regions to lower energy, resulting in toposequences.

In Cross River State, soils found over sandstone are fragile, acid, low in native fertility and have been reported to have been found to dominate Bekwarra, Yakurr (Ofem *et al*. 2020a, Ofem *et al*. 2022) and parts of Ogoja. However, the marginal soils are intensively cultivated by farmers (Udoh *et al*., 2003) and are often leached of basic cations which result in the low

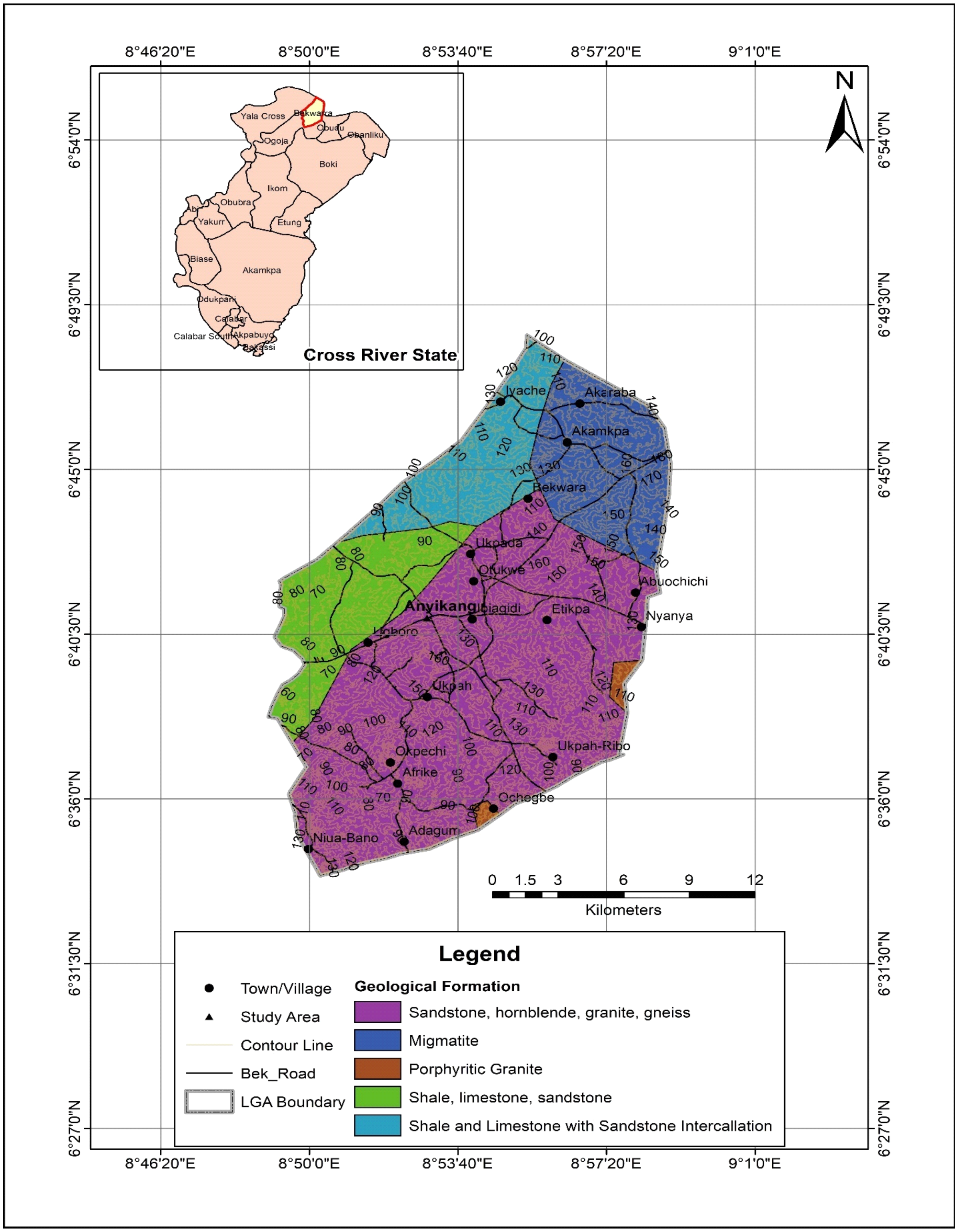

FIG. 1: Combined geology and contour map of Bekwarra LGA showing the study area

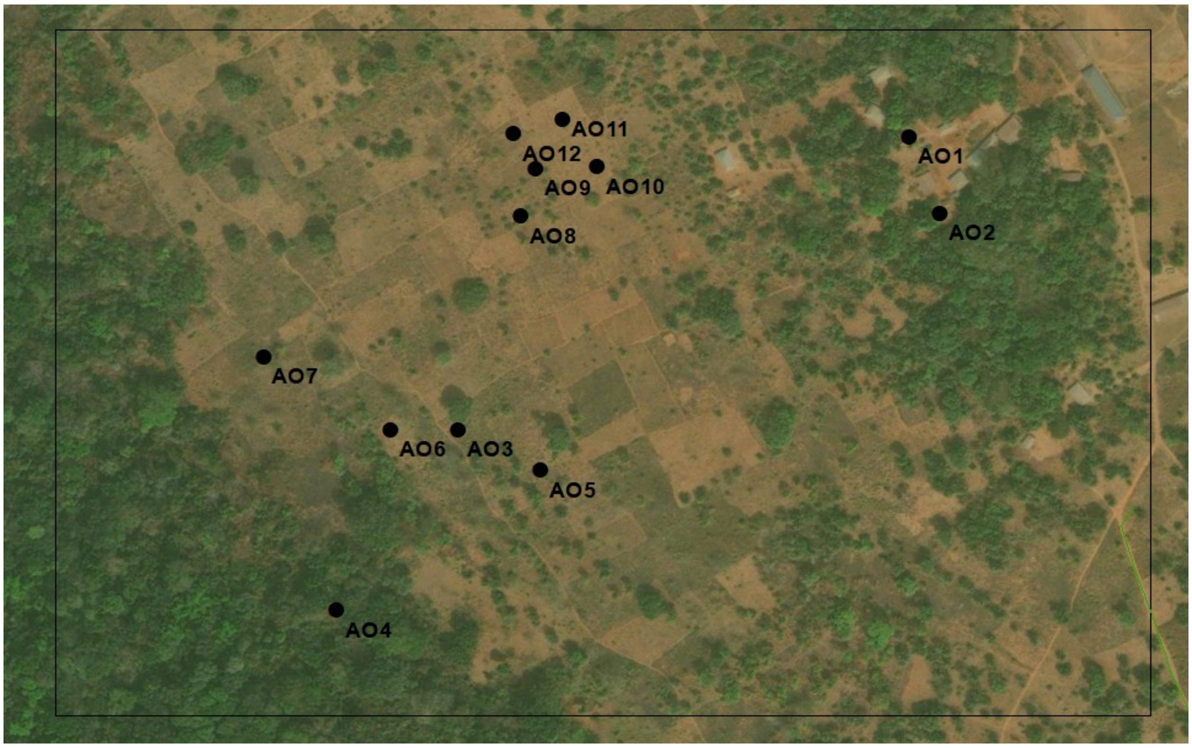

FIG. 2: Satellite imagery showing the map extent of Anyikang, Bekwarra LGA

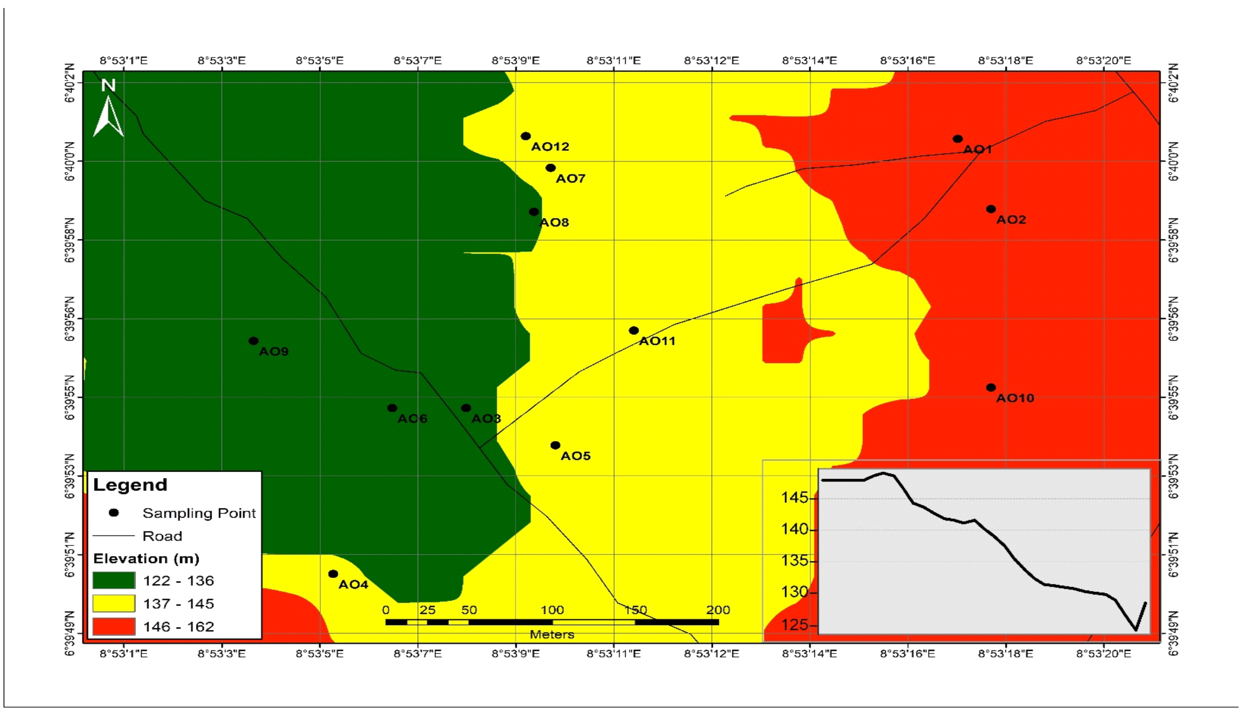

FIG. 3: Profile graph showing the soil profile positions in Anyikang, Bekwarra LGA

samples for analyses were collected from pedogenic horizons using the bottom – top approach into well labeled sampling bags and transported to the laboratory.

Laboratory studies

The fine-earth fraction was subjected to various laboratory analyses, following the procedures outlined by the Soil Survey Staff (2014). The Bouyoucos hydrometer method was employed to determine particle size distribution, whereas core method was used to measure bulk density where undisturbed core soil samples were oven-dried at 105°C to constant weight. The calculation of total porosity was carried out with the formula: {1 - (bulk density/particle density)} and expressed as a percentage, using 2.65 Mg/m^3 for particle density. Soil pH was determined electrometrically in soil-water ratio of 1:2.5 using a pH meter, whereas soil organic carbon content was determined by the modified Walkley-Black wet digestion and combustion method, while total nitrogen was analyzed via the macro Kjeldahl method. The titrimetric method was employed to determine basic cations (K^+, Ca^{2+}, Mg^{2+}, Na^+) using NH_4OAc as the extractant, and cation exchange capacity (CEC) was assessed using the NH_4OAc displacement method at pH of 7.0. Furthermore, exchangeable Al^{3+} and H^+ were determined by titration with 1 *M* KCl as the extracting agent, while available phosphorus was analyzed by the Bray-1 method. Finally, base saturation was calculated by expressing the sum of exchangeable basic cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) as a percentage of CEC, while CEC/clay was determined by dividing the CEC by percent clay and then multiplying by 100 %.

RESULTS AND DISCUSSION

Morphological properties

The morphological properties of the soils are presented in Tables 2, 3 and 4 to represent soils on the crest, middle slope and lower slope.

TABLE 1

Morphological properties of soils on the crest

Horizon	Depth (cm)	Soil colour (moist)	Texture	Structure	Consistence	Boundary	Other characteristics
PEDON AO1: N060 40' 001'', E 0080 53' 299'', 141m							
Ap	0-20	7.5YR 3/3 (Dusky Red)	LS	Wfgs	wns;mfr	Cs	Moderate fine pores, common medium roots, ants' holes.
Bt	20-67	5YR 3/6 (Dark Red)	SC	Sma	Wss.Mf	Gs	Moderate pores, common few roots, few moderate ants.
CB	67-130	7.5YR 3/4 (Dusky Red)	LS	Sma	Mvs:Mpf	Gw	Few fine pores, common medium roots.
Crt	130-188	7.5YR 5/6 (Red)	SC	Smbk	Vs:f		Few fine pores, Few moderate roots.
PEDON AO4: N060 39' 494", E0080 53' 02", 143m							
Ap	0-30	2.5YR ¾ (DRB)	SL	Mmsbk	wns.mfr	Gw	Common few pores, Moderate Fine roots.
Bt	30-98	2.5YR 2.5/4 (DRB)	SCL	Smbk	Wss:mf	Cs	Common few pores, few fine roots.
BC	98-150	10YR 3/6 (Dark Red)	SCL	Smbk	wns:ML	Gs	Few fine pores, few fine roots.
Crt	150-190	2.5YR 3/6 (Dark Red)	CL	Smbk	wss:mf:dh		Few fine pores, few fine roots
PEDON AO7: N060 39' 931", E 0080 53' 059", 137m							
Ap	0-37	5YR 2.5/1 (Black)	LS	Wfgs	wns:mf	Cs	Moderate fine pores, Medium fine roots.
Bt	37-106	7.5YR3/4 Dark Brown)	SCL	Mmsbk	wss:mf	Gs	Common medium pores, few medium roots.
BC	106-152	7.5YR4/4 (Brown)	SCL	Smsbk	wss:mf	CS	Few fine pores, few fine roots.
Crt	152-189	5YR4/6 (Yellowish Red)	SCL	Mmsbk	wss:mf		Common medium pores, few fine roots.
PEDON AO10: N060 40' 014", E0080 53' 153", 162m							
Ap	0-34	7.5YR2.5/3 (VDB)	LS	Wmsbk	Wns:mfr	Cs	Common medium pores, few fine roots, medium termites.
Bt	34-80	2.5YR4/6 (Dark Red)	SC	Smsbk	wss:mf	Gw	Few medium pores and roots, common moderate ants.
BC	80-150	2.5YR4/6 (Red)	SCL	Wfsbk	Wss.Mf	Gs	Few medium pores and roots, common moderate ants.
Crt	150-200	2.5YR4/6 (Red)	SC	Mmsbk	Wss:mf		Few medium pores, few fine roots.

Colour: DRB= Dark reddish brown, VDB= Very dark brown, texture: L = loam, S = sand, C = clay, STRUCTURE: 1,2,3 = weak, moderate and strong, f,m.c = fine, medium and coarse; gr. abk and sbk = granular, angular blocky structure and sub-angular blocky structure. CONSISTENCE: w = wet, m = moist, s = slightly sticky, fr = friable, fi = firm, v = very, BOUNDARY: cs = clear smooth, ds = diffuse smooth, gs = gradual smooth, cw = clear wavy, dw = diffuse wavy, gw = gradual wavy

ASL: Above sea level

TABLE 2
Morphological properties of soils in the middle slope

Horizon	Depth (cm)	Soil colour (moist)	Texture	Structure	Consistence	Boundary	Other characteristics
PEDON AO2: N060 40' 00", E0080 53' 299", 141m							
Ap	0-30	5YR4/2 (DRG)	LS	Wfgbk	wss.mfr	cs	common few pores, common fine roots.
Bt	30-85	10YR5/8 (Red)	SC	Smbk	wvss.mfm	Gw	Medium Moderate pores, few fine roots.
CB	85-140	10YR3/6 (Dark Red)	SL	Smsbk	wss.mfm	Gw	common moderate pores, common few roots
Cr	140-190	7.5YR4/8 (Red)	SC	Smsbk	wss.mfm		Common medium pores, Few fine root.
PEDON AO5: N060 39' 889", E0080 53' 157", 136m							
Ap	0-33	7.5YR3/2 (Dark Brown)	SL	Mmsbk	wns.mfr	Cs	Few medium pores, Moderate fine roots.
Bt1	33-87	2.5YR4/6 (Red)	SC	Smsbk	wss.mfr	Gw	Common medium pores, Few fine roots.
Bt2	87-150	2.5YR5/6 (Red)	CL	Smsbk	wss.mf	Dw	Moderate medium pores, Few fine roots
Cr	150-190	2.5YR4/6 (Red)	SC	Smsbk	wss.mfr		common medium pores, few fine roots.
PEDON AO8: N060 39' 983", E0080 53' 150",							
Ap	0-30	5YR2.5/2 (Very Dusky Red)	LS	Wmgs	wns.mfr	Gs	Common very few pores, moderate fine roots.
Bt	30-96	7.5YR3/6 (Dark Red)	SC	Smsbk	wss.mf	Gs	Few pores, few roots.
BC	96-146	7.5YR4/8 (Red)	SC	Mfsbk	wss.mf.dl	Dw	Common, few pores, fine roots.
Crt	146-186	10YR4/8 (Red)	SC	Smsbk	wss.mf.ds		moderate common pores.
PEDON AO11: N060 40' 014", E0080 53' 162", 44m							
Ap	0-50	5YR3/2 (DRB)	LS	Wmsbk	wns.ml	Gs	Few medium pores, moderate medium roots.
Bt1	50-107	10YR3/6 (Dark Red)	SCL	Sfsbk	wss.mfr	Dw	few medium pores, few fine roots quartz.
Bt2	107-163	2.5YR3/6 (Dark Red)	SC	Mfsbk	wss.mf	Gs	Few fine roots
Crt	163-190	2.5YR5/8 (Red)	SC	Wfsbk	ws.ml		few medium pores, few fine roots.

Colour = Dark reddish gray, DRB= Dark reddish brown, texture: L = loam, S = sand, C = clay, STRUCTURE: 1,2,3 = weak, moderate and strong, f,m.c = fine, medium and coarse; gr. abk and sbk = granular, angular blocky structure and sub-angular blocky structure. CONSISTENCE: w = wet, m = moist, s = slightly sticky, fr = friable, fi = firm, v = very, BOUNDARY: cs = clear smooth, ds = diffuse smooth, gs = gradual smooth, cw = clear wavy, dw = diffuse wavy, gw = gradual wavy
ASL: Above sea level

TABLE 3
Morphological properties of soils in the lower slope

Horizon	Depth (cm)	Soil colour (moist)	Texture	Structure	Consistence	Boundary	Other characteristics
PEDON AO3: N060 39' 904", E0080 53' 128", 128m							
Ap	0-34	5YR2.5/1 (Reddish Black)	LS	Wmsbk	wns.mfr	Cs	common medium pores, medium fine roots.
Bt1	34-93	10YR3/4 (Dusky Red)	SCL	Smsbk	wss.Mf.dh	Gs	Few medium pores, common medium roots.
Bt2	93-153	5YR4/6 (Yellowish Red)	C	Smsbk	wns.mf.dh	Cw	common medium pores, few fine roots.
Crt	153-198	7.5YR4/4 (Brown)	SCL	Mmsbk	wss.mf.dsh		common medium pores, few fine roots.
PEDON AO6: N060 39' 904", E0080 53' 104", 135m							
Ap	0-40	7.5YR3/2 (Dusky Red)	SL	Mmsbk	wns.mfr.dsh	Cs	Common medium pores, moderate fine roots.
Bt1	40-103	2.5YR4/6 (Red)	SCL	Smsbk	wss.mf.dh	Gs	Common medium pores, few fine roots.
Bt2	103-167	2.5YR4/6 (Red)	SCL	Smsbk	wss.mf.dh	Dw	Common medium pores, few fine roots.
Crt	167-194	10YR5/8 (Red)	SCL	Smsbk	Wss.mf.dh		Few medium pores, Few fine roots.
PEDON AO9: N060 40'014", E0080 53' 153", 162m							
Ap	0-37	5YR4/3 (Reddish Brown)	LS	Wmsbk	wss.ml	Cs	Few medium to coarse pores, common few roots.
Bt	37-100	10YR5/3 (Red)	SC	Smsbk	wss.mfr	Gw	few medium pores, few very fine roots.
BC	100-164	10YR3/6 (Dark Red)	SC	Mfsbk	wss.mf	Gw	few common pores, few very fine roots.
Crt	164-200	10YR4/8 (Red)	SC	Wfsbk	wss.mf		Few very fin e pores.
PEDON AO12: N060 40' 014", E0080 53' 153", 162m							
Ap	0-35	7.5YR3/4 (Dark Brown)	LS	Wmsbk	wns.mfr	Cs	Common, medium to coarse pores, and roots.
Bt	35-80	2.5YR6/8 (Light Red)	SCL	Mmsbk	wss.mf	Gs	Few medium pores, few fine roots, very few ants.
BC	80-132	2.5YR4/6 (Red)	SCL	Mmsbk	wss.mf	Dw	Few common pores.
Crt	132-170	2.5YR4/8 (Red)	SC	Mmsbk	wss.mufr		Common medium pores,few fine roots.

TEXTURE: L = loam, S = sand, C = clay, STRUCTURE: 1,2,3 = weak, moderate and strong, f,m.c = fine, medium and coarse; gr. abk and sbk = granular, angular blocky structure and sub-angular blocky structure. CONSISTENCE: w = wet, m = moist, s = slightly sticky, fr = friable, fi = firm, v = very, BOUNDARY: cs = clear smooth, ds = diffuse smooth, gs = gradual smooth, cw = clear wavy, dw = diffuse wavy, gw = gradual wavy
ASL: Above sea level

In the crest, Munsell colour in the surface soils ranged from dusky red (7.5YR 3/3), dark reddish brown (2.5YR 3/4) to very dark brown (7.5YR 2.5/3) and black (5YR 2.5/1) with dominant red, dark red or brown in the sub surface soils resulting from hues of 2.5YR, 5YR or 7.5YR. In the middle slope, the surface soils were very dusky red (5YR 2.5/2) to dark reddish grey (5YR 4/2), while the subsurface soils varied between dark red and red. Dusky red (7.5YR 3/2), reddish black (5YR 2.5/1), dark (7.5YR 3/4) or reddish brown (5YR 4/3) defined the surface soils of the lower slope. Irrespective of landscape position, reddish Munsell colour dominated the subsurface soils with alterations into dusky red, yellowish red, light red, dark red or dark reddish brown suggesting minimal variation in colour across landscape positions. Dominance of reddish soil colours in the subsurface soils is attributed to the presence of oxides and oxyhydroxides of iron, while the dark brown, dark gray or black colours common in the surface soils is likely to be connected to the state of organic matter decomposition and soil aeration. Well-drained soils are often brightly coloured and portray the presence of oxidized form of iron. The result of this study agrees with that of Akuhaemere *et al*. (2013) for similar soils in southern Nigeria, but contradict that of Ukut *et al*. (2014) who obtained brownish (7.5YR 3/4) and light brown grey (2.5YR 6/2) in the surface soils. Furthermore, Ofem *et al*. (2020b) reported similar findings with various shades of brown and gray colours in the surface soils, while reddish colours dominated the subsurface soils.

Soil texture was loamy sand and sandy loam in the surface soils, while subsurface soil textures varied from sandy clay, sandy clay loam and clay loam, irrespective of landscape position. Irrespective of the landscape positions, the sequence of textural variation between soil profiles appears very similar, and suggests greater vertical than lateral movement of fine particles. Vertically, clay particles have been eluviated from the surface horizons and subsequently illuviated in the Bt and Crt horizons. Similar textures were recorded by Akhuaemere *et al*. (2013) who reported loamy sand, sandy loam and sandy clay in the sandstone soils of Southern Nigeria. Ofem *et al*. (2020b) also observed very similar classes but with little lateral variation between landscape positions and reported loam with variable sand content giving rise to sandy loam and sandy clay loam. Also, Lafftan *et al*. (1998) obtained dominant sandy loam, loamy sand and clay loam in the sandstone soils of Northern Tasmania, New Zealand.

Soil structure was either granular or subangular blocky in the entire surface soils, with values that grade increasingly to dominantly subangular blocky structures in the subsurface soils. Result obtain from this study are similar to those obtained for similar soils by Bulktrade (1989) in the study area.

Plant roots in the entire studied soils extended beyond 170 cm indicating the absence of physical impediments such as hard pans or stone layers. This is important for crop production as it will encourage the proliferation of roots. Ants, worms and termites were nearly evenly distributed in the soil surface but decreased with soil depth irrespective of landscape position. Termite mounds were also observed in the environment. These are evidence of the presence of animals and their activities in the soil which encourage soil mixing.

Physical properties of the soils

The physical properties of the soils are presented in Tables 4, 5 and 6.

Particle size distribution was dominated by sand with values that exceed 50 % in the surface soils and 30 % in the subsurface soils irrespective of the landscape position. Generally, sand content decreased with soil depth, while clay increased in the Bt horizons. This suggests the ease with which clay particles are dislodged via surficial erosion and vertical movement of clay in suspension. This result agrees with Esu (2005) and Osedeke *et al*. (2002) that sand is the dominant fraction in sandstone derived soils and decrease with increase in soil depth. Similar result was obtained by Lawal *et al*. (2021) in lateritic soils of Minna, Nigeria, while Ofem *et al*. (2020b) reported sand content that exceed 50 % in similar soils. additionally, the studies of Ahukaemere *et al*. (2013) on false-bedded sandstone soils in southern Nigeria and Udoh (2015) in soils of Niger Delta recorded higher values than in the present study. High values of sand in the soils is a reflection of the sandstone lithology which underlies the studied soils. Such high values will increase infiltration rate, percolation and leaching leading to reduced soil fertility. Clay content was such that clay fluctuated with depth especially with the formation of clear clay bulges in the B- horizons giving rise to argillic horizons in the B and sparingly in the Cr horizon.

Bulk density of the soils was less than 1.6 Mg/m^3 irrespective of landscape position with slightly higher mean values obtained in the subsurface soils probably due to overburden. Also, surface soils are higher in organic matter content which have low density. This range of values indicate that the soils are not threatened by hardpans and will permit root proliferation. However, these values are within the range of 1.1 – 1.4 Mg/m^3 suggested for cultivated loams (Donahue *et al*.,

TABLE 4

Physical properties of soils in the crest

Horizon	Horizon Depth Cm	Sand	Silt %	Clay	Text. Class	BD	PD Mg/m³	TP %
AO1								
Ap	0-20	80	15	5	LS	1.30	2.0	35
Bt	20-67	52	13	35	SC	1.43	2.2	35
CB	67-130	52	27	21	SCL	1.35	2.5	46
Crt	130-188	52	7	41	SC	1.29	2.1	38.6
AO4								
Ap	0-30	70.6	24	5.4	SL	1.36	2.3	40.9
Bt	30-98	58.6	8	33.4	SCL	1.29	2.6	50.4
BC	98-150	52.6	16	31.4	SCL	1.38	2.6	46.9
Crt	150-190	44.6	20	35.4	CL	1.40	2.4	41.7
AO7								
Ap	0-37	76.0	17	7.0	LS	1.50	2.2	31.8
Bt	37-106	65.0	9	26	SCL	1.32	2.3	42.6
BC	106-132	64	12	24	SCL	1.48	2.4	38.3
Crt	132-189	67	12	21	SCL	1.39	2.1	33.8
AO10								
Ap	0-34	80	13	7	LS	1.35	2.2	38.6
Bt	34-80	54	10	36	SC	1.28	2.6	50.7
BC	80-150	54	11	35	SCL	1.60	2.6	38.5
Crt	150-200	51	7	42	SC	1.39	2.3	39.6
Mean of surface		76.7	17.3	6.1		1.38	2.18	36.7
Range of surface		70.6-80.0	13-24	5.0-7.0		1.3-1.5	2.0-2.3	31.8-40.9
Mean of subsurface		57.2	12.7	30.1		1.38	2.39	42.3
Range of subsurface		44.6-72.0	7-27	1.0-3.6		1.28-1.60	2.1-2.6	33.8-50.7

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TABLE 5
Physical properties of soils in the middle slope

Horizon	Depth cm	Sand	Silt %	Clay	Text. Class	BD Mg/m^3	PD	TP %
AO2								
Ap	0-30	77	17	6	LS	1.40	2.6	46.1
Bt	30-85	56	9	35	SC	1.45	2.6	44.2
CB	85-140	57	24	21	SCL	1.39	2.5	44.4
Cr	140-190	54	6	40	SC	1.48	2.4	38.3
AO5								
Ap	0-33	54.6	40	5.4	SL	1.51	2.3	34.3
Bt1	33-87	48.6	8	43.4	SC	1.46	2.2	33.6
Bt2	87-150	38.6	20	41.4	CL	1.36	2.1	35.2
Cr	150-190	44.6	14	41.4	SC	1.39	2.6	46.5
AO8								
Ap	0-30	78	14	8	LS	1.40	2.3	39.1
Bt	30-96	49	10	41	SC	1.50	2.4	37.5
BC	96-146	54	11	35	SC	1.65	2.6	36.5
Crt	146-186	54	5	41	SC	1.48	2.3	35.7
AO11								
Ap	0-50	84	11	5	LS	1.39	2.2	36.8
Bt	50-107	56	10	34	SCL	1.41	2.1	32.8
Bt2	107-167	56	8	36	SC	1.58	2.8	43.6

TABLE 6
Physical properties of soils in the lower slope

LS: Loamy sand, SC: Sandy clay, SL: Sandy loam, SCL: Sandy clay loam, CL: Clay loam, BD: Bulk density, PD: Particle density, TP: Total porosity

Horizon	Depth Cm	Sand	Silt %	Clay	Text. Class	BD Mg/m^3	PD	TP %
AO3								
Ap	0-34	76	15	9	LS	1.39	2.3	39.6
Bt1	34-93	63	8	29	SCL	1.50	2.1	28.6
Bt2	93-153	25	24	51	C	1.49	2.4	37.9
Crt	153-198	59	9	32	SCL	1.48	2.6	43.1
AO6								
Ap	0-40	68.6	26	5.4	SL	1.50	2.3	34.8
Bt1	40-103	58.6	12	29.4	SCL	1.48	2.5	40.8
Bt2	103-167	54.6	14	31.4	SCL	1.46	2.4	39.2
Crt	167-194	45.6	20	33.4	SCL	1.38	2.3	40
AO9								
Ap	0-37	79	14	7	LS	1.28	2.2	41.8
Bt	37-100	52	7	41	SC	1.42	2.5	43.2
BC	100-164	54	9	37	SC	1.29	2.3	43.9
Crt	164-200	53	6	41	SC	1.35	2.2	38.6
AO12								
Ap	0-35	83	11	6	LS	1.39	2.1	33.8
Bt	35-80	57	8	35	SCL	1.51	2.3	34.3
BC	80-132	53	13	34	SCL	1.45	2.5	42
Crt	132-170	53	10	37	SC	1.36	2.6	47.7
Mean of surface		76.7	16.5	6.9		1.39	2.2	36.8
Range of surface		68.6-83	11-26	6.0-9.0		1.28-1.50	2.1-2.3	33.8-41.8
Mean of subsurface		52.3	11.7	35.9		1.43	2.4	40.4
Range of subsurface		25-63	6-24	29-51		1.29-1.51	2.1-2.6	28.6-47.7

1983) and are less than 1.60 Mg/m^3 suggesting that air and water movement in the soils are optimum for plant growth (Esu, 2010).

Total porosity exceeded 25 % but was less than 55 % at all depths irrespective of landscape position. The values are high as the means were close to 50 % recommended for a silt-loam surface soil (Brady, 1974). Such values will result in extremely porous soils (Pagliai, 1988) which facilitate leaching and encourage high rate of infiltration. Rieu and Sposito (1991) reported that soil porosity of 45-50 % is good for agricultural soils. This description qualifies most of the studied soils as good agricultural soils as they are most likely to encourage water and air movement in the soils. These values are within the range obtained by Ahukaemere *et al*. (2013) in the false bedded sandstone derived soils in southern Nigeria.

Chemical properties of the soils

The chemical properties of the soils are presented in Tables 7, 8, and 9.

Soil pH ranged from 4.5 to 5.6 in the crest, 4.5 to 6.1 in the middle slope and 4.5 - 5.8 in the lower slope. The soils are rated as very strongly acid to strongly acid on the scale of Holland *et al*. (1989) and indicate that significant amounts of exchangeable Al^{3+} and H^+ are present to significantly affect plant growth (Esu, 2010). Such low values may affect the availability of plant nutrients and the activities of soil micro-organisms. The pH values of sandstone derived soils appear to be variable with location. For instance, Ahukaemere *et al*. (2013) obtained 4.18 - 4.55 in southern eastern Nigeria, Shigeo *et al*. (1991) obtained 2.76 - 5.12 in the Keranga forest of East Malaysia, Ofem *et al*. (2020b) obtained 5.0 – 6.0 in the Bekwarra sandstone soils, while Bulktrade (1989) obtained less than 5.0 in Bekwarra.

TABLE 7

Chemical properties of soils in the crest

Horizon	Depth cm	pH	Org. C g/kg	T.N	Avail. P mg/kg	Ca (Exch. Basic cations, cmol/kg)	Mg	K	Na	Al^{3+} (Exch. Acidity)	H^+	ECEC	CEC (NH_4OAc)	BS %
AO1														
Ap	0-20	5.0	9	0.8	5.37	2.6	1.2	0.11	0.08	0.0	1.84	5.83	19.0	68
Bt	20-67	4.6	5	0.4	1.12	1.4	2.0	0.10	0.08	1.52	1.20	6.30	18.0	57
CB	67-130	4.9	2	0.1	0.75	1.6	1.2	0.11	0.09	0.96	1.04	5.00	13.0	60
Crt	130-188	4.5	2	0.1	1.50	1.2	0.8	0.10	0.08	1.36	1.12	4.66	14.0	47
AO4														
Ap	0-30	5.2	7.1	0.6	2.87	2.2	0.4	0.09	0.07	0.2	0.2	3.16	14.0	87
Bt	30-98	5.6	2	0.1	0.37	1.4	0.8	0.09	0.06	1.36	0.12	3.82	11.0	61
BC	98-150	5.8	3.7	0.2	1.37	2.2	1.4	0.08	0.07	1.08	0.04	4.88	13.0	77
Crt	150-190	4.6	0.7	0.6	6.8	1.2	3.6	0.09	0.08	1.56	0.0	6.55	17.00	76
AO7														
Ap	0-37	5.1	7.0	0.6	3.25	1.0	0.6	0.10	0.08	0.0	2.40	4.18	20.0	43
Bt	37-106	5.1	3.8	0.2	2.12	0.8	0.4	0.10	0.06	1.2	0.88	3.42	15.0	39
BC	106-132	5.1	2.0	0.1	2.37	1.4	1.0	0.08	0.09	1.28	1.20	5.07	18.0	51
Crt	132-189	5.1	1.0	0.1	3.25	1.0	0.4	0.10	0.07	0.88	1.47	3.91	14.0	40
AO10														
Ap	0-34	5.6	5.6	0.4	3.37	1.2	0.6	0.10	0.09	0.24	1.36	3.99	15.0	60
Bt	34-80	5.2	4.2	0.3	2.50	1.6	0.6	0.10	0.08	2.20	0.24	4.82	15.0	49
BC	80-150	5.3	2.4	0.1	2.37	0.8	0.4	0.09	0.07	2.0	0.60	4.16	11.0	38
Crt	150-200	5.1	2.0	0.1	3.50	0.8	0.8	0.10	0.08	2.0	1.00	4.38	12.0	32
Mean of surface		5.2	7.2	0.6	3.72	1.75	0.70	0.10	0.08	0.11	0.15	4.3	17.0	64.5
Range of surface		5.1-5.6	5.6-9.0	0.4-0.8	2.87-5.37	1.0-2.6	0.40-1.2	0.09-0.11	0.07-0.09	0.0-0.24	0.2-2.4	3.16-5.83	14-20	43-87
Mean of subsurface		5.0	2.4	0.2	2.34	1.28	1.12	0.10	0.08	1.45	0.74	4.8	14.3	52.3
Range of subsurface		4.5-5.5	1-5	0.1-0.6	0.75-6.8	0.8-2.2	0.4-2.0	0.08-0.11	0.06-0.09	0.88-2.2	0-1.47	3.42-6.55	11-18	32-77

TABLE 8

Org C: Organic carbon, T.N: Total nitrogen, Avail. P: Available phosphorus, ECEC: Effective cation exchange capacity, CEC: Cation exchange capacity, BS: Base saturation

Horizon	Depth Cm	pH	Org. C g/kg	T.N	Avail.P mg/kg	Ca (Exch. basic cations, cmol/kg)	Mg	K	Na	Al^{3+} (Exch. Acidity)	H^+	ECEC	CEC (NH_4OAc)	BS %
AO2														
Ap	0-30	4.8	9	0.8	8.37	2.0	0.6	0.11	0.09	0.0	1.60	4.40	20.0	64
Bt	30-85	5.0	3	0.2	1.50	2.4	1.2	0.10	0.09	0.96	1.60	6.35	18.0	60
CB	85-140	5.5	2	0.1	1.25	2.0	1.8	0.10	0.07	0.64	1.16	4.78	15.0	83
Cr	140-190	4.7	2	0.1	0.87	1.4	0.8	0.11	0.07	0.88	1.36	4.60	17.0	51
AO5														
Ap	0-33	5.5	12.1	1.0	3.0	2.2	2.4	0.11	0.08	0.24	0.2	5.22	21.00	92
Bt1	33-87	5.6	6.9	0.5	6.25	2.2	2.4	0.10	0.09	1.6	0.16	6.56	13.00	73
Bt2	87-150	4.5	3.7	0.2	0.5	1.4	1.8	0.11	0.06	1.86	0.14	5.34	18.0	62
Cr	150-190	5.7	2.0	0.1	0.25	1.2	1.2	0.08	0.06	1.88	0.12	4.53	14.00	56
AO8														
Ap	0-30	5.5	7.4	0.6	2.25	1.0	0.8	0.10	0.08	0.40	1.20	3.58	14.0	53
Bt	30-96	5.1	5.0	0.4	0.87	1.4	0.4	0.10	0.08	2.50	0.32	4.80	27.0	41
BC	96-146	5.3	2.8	0.1	1.25	0.8	0.4	0.09	0.08	1.52	1.20	4.09	13.0	35
Crt	146-186	5.4	3.0	0.2	1.25	0.8	0.4	0.08	0.06	1.20	1.68	4.22	31.0	32
AO11														
Ap	0-50	6.1	7.8	0.6	5.50	1.2	2.0	0.10	0.07	0.0	0.80	2.97	10.0	73
Bt	50-107	5.5	3.2	0.2	2.12	0.8	0.6	0.09	0.07	1.24	1.36	5.56	21.0	53
Bt2	107-167	5.1	2.4	0.1	2.62	0.8	0.6	0.08	0.06	1.50	1.20	4.24	14.0	36
Crt	167-190	5.1	3.8	0.2	0.87	0.8	0.6	0.09	0.07	1.70	0.90	4.16	14.0	37
Mean of surface		5.5	9.1	0.8	4.8	1.60	1.45	0.11	0.08	0.16	0.95	4.04	16.3	70.5
Range of surface		4.8-6.1	7.4-12.1	0.6-1.0	2.25-8.37	1.0-2.2	0.6-2.4	0.10-0.11	0.07-0.09	0.24-0.4	0.2-1.6	2.97-5.2	10.0-21.0	53-92
Mean of subsurface		5.2	3.3	0.2	1.63	1.33	1.01	0.09	0.07	1.46	0.93	4.9	17.9	51.6

Soil organic carbon was 5.6 - 9.0, 7.4 – 12.1, and 2.0 – 6.9 gkg^{-1} in the surface soils of the crest, middle slope and lower slope, respectively with values that generally decreased with soil depth in all the soils and decrease with a rise in elevation. Organic carbon is low in the surface soils of the crest and middle slope positions and moderate in the lower slope position on the scale of Holland *et al*. (1989) probably because of active surficial erosion process in the crest and middle slope positions. Low values of organic carbon in the soils may be attributed to organic matter mineralization and subsequent loss to leaching, while Ofem *et al*. (2020b) attributed the low values to bush burning, especially during hunting periods. Higher values of organic carbon were obtained by ogunwale and Ashaye (1975) and Laffan *et al*. (1998) in similar soils, and lower values of 1.2 gkg^{-1} by Ovie *et al*. (2013) in the sandstone soils of Makurdi – North central,

TABLE 9

Chemical properties of soils in the lower slope

Org C: Organic carbon, T.N: Total nitrogen, Avail. P: Available phosphorus, ECEC: Effective cation exchange capacity, CEC: Cation exchange capacity, BS: Base saturation

Horizon	Depth	pH	Org. C	T.N	Avail.P	Ca	Mg	K	Na	Al^{3+}	H^+	ECEC	CEC	BS
	Cm		g/kg		mg/kg	←				cmol/kg			→	%
						Exch. Basic cations				Exch. Acidity			NH_4OAc	
AO3														
Ap	0-34	4.5	9	0.8	2.37	1.4	1.0	0.09	0.08	0.0	2.4	4.97	14.0	52
Bt1	34-93	4.8	4	0.3	3.25	1.8	1.4	0.09	0.08	1.04	0.64	5.06	18.0	67
Bt2	93-153	4.7	2	0.1	4.50	2.0	1.0	0.10	0.09	0.16	2.04	5.39	15.0	54
Crt	153-198	4.5	2	0.1	2.12	1.8	0.8	0.10	0.07	0.88	1.36	5.00	18.0	55
AO6														
Ap	0-40	4.6	20.5	1.7	9.5	2.4	1.2	0.07	0.07	0.0	0.48	4.24	10.0	89
Bt1	40-103	5.2	9.9	0.8	1.87	1.2	1.2	0.09	0.06	1.44	0.40	4.38	19.0	58
Bt2	103-167	5.3	10.3	0.9	4.5	1.8	2.8	0.08	0.09	1.56	0.12	6.47	15.00	74
Crt	167-194	5.0	9	0.6	0.75	1.8	4.6	0.10	0.08	1.8	0.08	8.46	12.0	78
AO9														
Ap	0-37	5.7	8.8	0.7	3.12	1.4	1.0	0.09	0.07	1.42	1.04	5.02	15.0	51
Bt1	37-100	5.5	3.6	0.2	1.62	1.0	0.8	0.10	0.09	0.80	1.20	3.99	20.0	50
BC	100-164	5.5	3.0	0.2	1.25	1.4	1.0	0.11	0.08	1.04	1.36	4.99	13.0	52
Crt	164-200	5.8	2.0	0.1	3.0	1.0	0.8	0.10	0.07	0.88	1.28	4.13	18.0	48
AO12														
Ap	0-35	5.4	5.8	0.4	3.62	1.4	0.6	0.08	0.07	0.0	1.44	3.59	16.0	60
Bt1	35-80	5.1	2.8	0.1	1.25	1.8	0.4	0.08	0.06	2.0	1.60	5.94	11.0	39
BC	80-132	5.2	4.2	0.3	1.50	1.8	0.6	0.09	0.07	1.80	1.40	5.76	21.0	44
Crt	132-170	5.3	2.8	0.1	3.75	1.8	0.6	0.09	0.07	1.40	1.20	5.16	22.0	50
Mean of surface		5.1	11	0.9	4.7	1.65	0.95	0.08	0.07	0.36	1.34	4.5	13.8	63.0
Range of surface		4.5-5.4	5.8-20.5	0.4-1.7	2.37-9.50	1.4-2.4	0.6-1.2	0.07-0.09	0.07-0.08	0.0-1.42	0.48-2.4	3.59-5.02	10.0-16.0	51-89
Mean of subsurface		5.2	4.7	0.4	2.5	1.6	1.33	0.09	0.08	1.2	1.06	5.4	16.8	55.8
Range of subsurface		4.7-5.8	2-10.8	0.1-0.9	0.75-4.5	1.0-2.0	0.4-4.6	0.08-0.11	0.06-0.09	0.16-2.0	0.08-2.04	3.99-8.46	11-22	39-78

Total nitrogen had ranges of 0.4 – 0.8, 0.6 - 1.0 and 0.4 – 1.7 g/kg in the surface soils of the crest, middle slope and lower slope respectively and concentration regularly decreasing with increasing soil depth. Irrespective of landscape position, the entire soils were low to very low in total nitrogen. Low values of total nitrogen may be attributed to leaching, due mainly to the porous nature of the soils and relatively high rainfall in the study area. However, Eshett (1985) attributed the low nitrogen to crop removal and rapid mineralization of organic matter. In Northern Tasmania, New Zealand and Makurdi, in Nigeria low values of total nitrogen was obtained by Laffan *et al*. (1998) and Ovie *et al*. (2013), respectively, while Olaniyan *et al*. (2012) observed a range of values comparatively higher than that obtained in this study.

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