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Assessing Properties of the Lower Niger Flood Plain Alluvial Soils in Bayelsa State, Nigeria for Sustained Food Security

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Abstract: ***Alluvial soils from different river plains in Bayelsa State, Southern Nigeria were characterized and relationship between soil properties assessed. Pedogenic soil samples from the levee crest, middle slope, lower slope and recent alluvial soils from the channels of present active rivers were analyzed for physical and chemical properties using standard methods and the soils properties relationship evaluated using principal component and correlation analyses. Plant nutrients availability in the soils depended strongly on soil acidity as Principal Component Analysis (PCA) revealed the eight most important contributions of soil properties (PC1, PC2, PC3, PC4, PC5, PC6, PC7, and PC8) explaining 83% of the total variability, each component representing a series of variables that simplified the analysis and interpretation. Soil acidity, exchangeable Al and ECEC dominated PC1 positive factor loading contribution, emphasizing the dominance of soil acidity in dictating nutrient retention and availability in the soils. Clay gave a negative loading in PC5 while organic matter gave a positive loading in PC2, implying that organic matter contributed more to plant nutrients availability than clay. The correlation between organic matter and N (r=0.366, p<0.001) and available P (r = - 0.310, p<0.01) were positive and highly significant, confirming the PCA results, that N and P availability were function of the amount of organic matter present. Biomass accumulation contributed greatly to improvement of soil fertility and soil structure. Therefore, soil organic matter improvement and maintenance should be given priority for sustained food security.***

Keywords: Alluvial soils, Bayelsa State, Principal Component Analysis, Nutrient availability, Organic matter

1. Introduction

Univariate statistical methods have limitations and are not effective in developing better understanding and assessment of soil processes due to complexity, large amounts and variance of environmental data. Multivariate statistical methods are better able to detect similarities between variables and allow a more profound interpretation of relevant data [1], [2]. According to [3], multivariate data analysis is beneficial in that large amounts of data can be processed for exploring and understanding relationships between different parameters, achieved through the procedures of pattern recognition, classification and prediction techniques; Principal Component Analysis (PCA) being one of the most common pattern recognition method used in multivariate analysis. PCA is a multivariate statistical data analysis technique which reduces a set of raw data into a number of principal components which retain the most variance within the original data to identify possible patterns or clusters between objects and variables. The utility of principal component analysis in selecting the most appropriate parameters for evaluating soil quality under long term wastewater irrigation was demonstrated by [4]. Also, [5] used PCA to assess chemical and microbiological data from shallow groundwater and to relate to the density of on - site wastewater treatment systems.

The handling of large data is a major challenge for the floodplain soils of the lower Niger River with its unique soil characteristics with materials sorted from the northern part of Nigeria, transported to the south and discharged. The Niger River traverses Nigeria in a north - western to Southern direction with the attendant sediment load ensuring that the delta platform ends up as flat terrain, making it a unique geologic environment. The soils in this unique geologic environment include levee soils (levee crest or upper slope, lower slope or middle slope and floodplain or lower slope) fringing the river channels or abandoned river channels, back swamp soils and clay pan soils that are seasonally flooded. But information on these soils, especially the relationship between soil characteristics is scanty. This study therefore, characterizes soils from different river systems in Bayelsa State, Nigeria and the soils properties relationship evaluated using principal component analysis (PCA) and correlation studies.

2. Materials and Methods

2.1 Location and Description of the Study Area

The study was carried out within Bayelsa State from the Niger Delta region, Southern Nigeria. The study locations lie between latitude 05° 22' 03.9" N and 04° 59' 08.9"N and longitude 006°30' 21.1" E and 006° 06' 54.1" E. The Niger River traverses Nigeria in a north - western to Southern direction with the attendant sediment load ensuring that the delta platform ends up as flat terrain, making it a unique geologic environment. The Niger River flows southward and breaks up into Forcados and Nun Rivers: The Nun River, running north and south down the middle of the Bayelsa State, which remains the most direct tributary of the Niger while Forcados River demarcates the western borders of the state. From Bayelsa State's territory issues several rivers into the Atlantic Ocean, namely the Ramos, Dodo, Pennington, Digatoru, Middleton, Koluama, Fishtown, Sangana, the Nun, Brass, St. Nicholas, Santa Barbara and Sombreiro (Fig.1). The annual rainfall of the study area ranges from 2000 to 4000mm, spread over 8 to 10 months of the year. Relative humidity is comparatively uniform (average over 80%) all over the state due to proximity to the Atlantic Ocean. Temperature is fairly constant with a maximum of 30^{o}C. The natural vegetation is tropical rainforest but much of the original vegetation is presently degraded or altered. Food crop production is carried out on the levee crest, levee slope, back slope and on recent alluvial soils on channels of present active rivers. Levee crest soils are no longer flooded while most flood plain soils and alluvial soils in the channels of present active rivers are flooded yearly by the Niger River floods.

The designations of the soil mapping units are ELM1, ELM2 and ELM3 for Elemebiri, ODN1, ODN2 and ODN3 for Odoni, TFN1, TFN2 and TFN3 for Trofani, ODI1, ODI2 and ODI3 for Odi, KRM1, KRM2 and KRM3 for Koroama and NDU1, NDU2 and NDU3 for Niger Delta University Teaching and Research Farm. Details of the soil mapping units and the area covered are presented in Table 1.

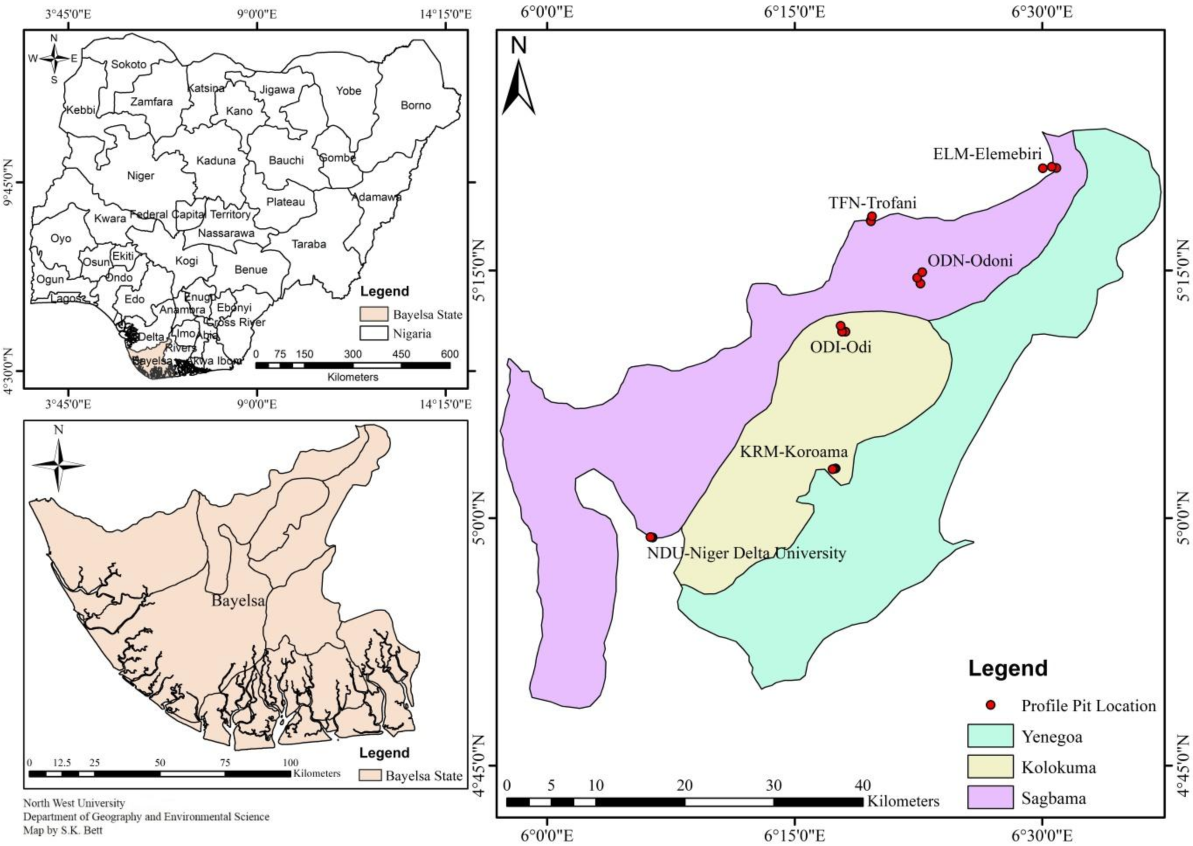

Figure 1: Map of Bayelsa State showing Sampling Points

2.2 Soil sampling and analyses

Detailed soil survey was conducted on agricultural lands from Elemebiri, Trofani, Odoni, Odi, Koroama, and Niger Delta University Teaching and Research farm using rigid sampling method. The designation of the soil mapping units (SMUs) of 0 – 200 cm depth were ELM1, ELM2 and ELM3 for Elemebiri; TFN1, TFN2, and TFN3 for Trofani soils, ODN1, ODN2 and ODN3 for Odoni soils; ODI1, ODI2 and ODI3 for Odi soils; KRM1, KRM2 and KRM3 for Koroama soils and NDU1, NDU2 and NDU3 for Niger Delta University farm soils. Details of the soil mapping units and the land area are presented in Table 1. Soil sampling procedures followed the methods prescribed by the USDA Soil [6] and the [7]. Three representative soil pedons were dug per location, one each on the levee crest, levee slope, lower slope for Odi, Koroama and Niger Delta University farm soils and in recent alluvial soils in the channel of the present active river for Elemebiri and Trofani soils, giving priority to where farming is concentrated. The soils were morphologically described *in - situ* and samples collected from the different horizons for physico - chemical properties determination following standard procedures. Soil samples collected were air - dried, crushed and sieved to pass through a 2 mm mesh. Analyses were carried out in the Green River Project Laboratory of the Nigerian Agip Oil Company and Zadell Laboratory, Port Harcourt, Nigeria. Standard laboratory methods were used to determine the physical and chemical properties of the soils as reported in [8].

Table 1: Soil Sampling Units, Profile Pit Location and Land Area

Study Location	Sampling Unit	Geo - reference of Profile Pit	No. of Profile Pits	Land Area (Ha)	Land Area (%)
Elemebiri	ELM1	N 05° 21′ 11.5″ E 006° 30′ 02.2″	1	29.08	2.4
	ELM2	N 05° 21′ 12.4″ E 006° 30′ 51.3″	1	21.25	1.7
	ELM3	N 05° 21′ 22.6″ E 006° 30′ 51.3″	1	162.14	13.3
Odoni	ODN1	N 05° 14′ 12.4″ E 006° 22′ 37.2″	1	89.94	7.4
	ODN2	N 05° 14′33.3″ E 006° 22′ 25.5″	1	52.10	4.3
	ODN3	N 05° 14’ 53.3″ E 006° 22′ 43.4″	1	90.57	7.4
Trofani	TFN1	N 05° 18′ 01.5″ E 006° 19′ 36.0″	1	87.61	7.2
	TFN2	N 05° 17′ 58.6″, E 006° 19′ 37.1″	1	51.50	4.2
	TFN3	N 05° 18′ 17.1″, E 006° 19′ 41.2″	1	148.51	12.2
Odi	ODI1	N 05° 11′ 17.4″ E 006° 18′ 04.6″	1	142.49	11.7
	ODI2	N 05° 11′ 17.1″, E006° 17′ 52.3″	1	65.06	5.3
	ODI3	N 05° 11′ 38.7”″ E 006° 17′ 47.0″	1	138.65	11.4
Koroama	KRM1	N 05° 02′ 59.9″, E 006° 17′ 28.8″	1	13.18	1.1
	KRM2	N 05° 02′ 59.2″, E 006° 17′ 26.9″	1	10.65	0.9
	KRM3	N 05° 02′ 58.1″, E 006° 17′ 14.0″	1	21.43	1.8
Niger Delta University	NDU1	N 04° 58′ 49.1″ E 006° 06′ 23.7″	1	24.05	2.0
	NDU2	N 04° 58′ 49.9″, E 006° 06′ 17.5″	1	7.53	0.6
	NDU3	N 04° 58′ 50.5″, E 006° 06′ 15.7″	1	60.53	5.0
Total Hectares			**18**	**1, 216.26**	

2.3 Statistical Analysis

Data were subjected to Principal component analysis (PCA) to detect the most prominent soil parameters that influence the fertility of the soils. Pearson's correlation analysis was performed to determine the relationship between the selected soils properties. All statistical analyses were performed using SPSS version 21.

3. Results and Discussions

3.1 Soil Physical Properties

Particle size distribution of the soils revealed that silt fraction dominated except ELM3 and TFN3 (Tables 2 and 3) which are recent alluvial deposits on the channels of presently active Lower Niger River and Forcados Rivers. The sand fraction dominated ELM3 and TFN3. The average silt content in the surface 40 cm of the soils of Elemebiri ranged from 23% in ELM3 to 64% in ELM2 and in the subsurface, from 18% in ELM3 to 65% in ELM1. Sand contents were 19% in ELM1 to 73% in ELM3 in the surface 40 cm and 18% in ELM1 to 74% in ELM3 in the subsurface. Similarly, in the Trofani soils, the average silt content varied from 26% in TFN3 to 61% in TFN1 and 22% in TFN3 to 61% in TFN1 in the subsurface. For the sand fraction, the average concentration ranged from 19% in ELM1 to 70% TFN3 in the surface 40 cm and 20% in TFN1 to 71% in TFN3 in the subsurface layers.

Hazelton and Murphy [9] rating for sand, silt and clay contents in soils was ≥40% (high), 25 - 40% (moderate) and 10 - 25% (low). In this regard, silt was rated high in both layers of the pedons except ELM3 and TFN3. Sand was rated high in ELM3 and TFN3 but low to moderate in the other soils. Clay was rated low to moderate in the soils. Abua [10] associated silt fraction of soil with good aggregation and high absorptive capacity, suggesting that soils with high sand fraction (exceeding 70%), may mean silt content below 15% and such soils are likely to have weak surface aggregation. The report further stated that soils with less than 15% silt may lack adsorptive capacity for basic plant nutrients and might be susceptible to erosion. Soils with silt fraction greater than 15% for both surface and sub soils on the other hand, indicated strong surface aggregation and might not be vulnerable to erosion hazard. Thus, the soils investigated have strong surface aggregation and might not be vulnerable to erosion hazard. According to [11], silt/clay ratios of below 0.15 in soil indicated that the soils are of old parent material, while those above 0.15 are of young parent materials with low degree of weathering. All the soils recorded average silt/clay ratio of 1 and above which indicated that the soils were young and could further undergo weathering to release plant nutrients.

3.2 Soil Chemical Properties

The pH values at the surface 40 cm level were lower than those of the subsurface soils except for ELM3 from Elemebiri and ODI1 from Odi. The average pH (H_2O) of the surface 40 cm ranged from 5.62 in ELM1 to 6.30 in ODI1 while the subsurface layers pH ranged from 5.74 in ELM3 to 6.40 in TFN2. Bray and Weil [12] and [13] established the pH range of 5.5 to 7.0 as preferred for most crops and optimal for the overall satisfactory availability of plant nutrients. Again, some available nutrients are deficient in soils with pH < 6.0. Most food crops cultivated in Bayelsa State have their roots within the surface 40 cm. When the mean pHs of the surface 40 cm were compared to the preferred pH range, the pHs were suitable for cultivation of crops.

ΔpH values are used to estimate the level of negative charges in soil colloids [14]. Usually, the value of ΔpH could be positive, zero or negative, depending on the net surface charge of soil. A positive ΔpH indicated the presence of negative charges on soil colloids [6]. According to [15] and [14] highly positive ΔpH values for A - horizon indicated presence of appreciable amount of negatively charged clay colloids. In this study, ΔpH values were all positive which corroborated the silt/clay ratio results revealing that the soils were relatively young.

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Table 2: Summary of Physicochemical Properties of the surface 40 cm

Soil properties	P*	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	TFN1	TFN2	TFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Sand (%)	R	15 - 23	18 - 31	68 - 78	22 - 25	21 - 35	19 - 25	21	15 - 79	68 - 71	31	41 - 42	21 - 35	20 - 24	19 - 27	10 - 30	10 - 20	13 - 22	16 - 17
	M	19	23	73	24	29	22	21	36	70	31	42	28	22	23	25	15	18	16
Silt (%)	R	54 - 67	57 - 68	18 - 28	65	53 - 60	53 - 65	60 - 62	17 - 60	25 - 27	56	45 - 47	57 - 63	61 - 64	53 - 67	60 - 64	61 - 73	59 - 61	69
	M	61	64	23	65	56	61	61	45	26	56	46	59	63	61	62	67	60	69
Clay (%)	R	10 - 31	12 - 16	4	12 - 13	12 - 19	12 - 22	17 - 19	4 - 28	2 - 7	13	11 - 14	8 - 16	14 - 15	9 - 28	9 - 16	7 - 29	18 - 28	14 - 15
	M	20	14	4	13	15	18	18	19	4	13	13	13	15	16	13	18	22	15
Silt/ clay ratio	R	1.7 - 6.7	4.1 - 5.2	4.5 - 7.0	5.0 - 5.4	3.2 - 4.4	2.4 - 5.4	3.2 - 3.6	2.0 - 4.3	3.6 - 14.0	4.3	3.2 - 4.3	3.9 - 7.1	4.1 - 4.6	1.9 - 7.4	4.0 - 6.0	2.1 - 10.4	2.1 - 3.3	4.6 - 4.9
	M	3.9	4.7	6.22	5.2	3.8	3.7	3.4	2.9	8.0	4.3	3.8	5.0	4.4	5.4	5.4	6.3	2.9	4.7
pH - H_2O	R	5.46 - 5.77	5.44 - 6.61	5.52 - 7.00	5.75 - 5.76	5.38 - 6.70	5.67 - 6.45	5.64 - 5.75	5.98 - 6.16	5.55 - 5.98	6.30	5.70 - 6.08	5.67 - 6.30	5.48 - 5.79	5.55 - 6.39	5.67 - 6.09	5.58 - 5.69	5.64 - 6.07	5.42 - 5.90
	M	5.62	5.96	6.22	5.76	5.91	6.04	5.70	6.10	5.76	6.30	5.89	5.95	5.64	6.01	5.88	5.64	5.88	5.68
pH - $CaCl_2$	R	5.17 - 5.36	5.20 - 5.37	5.30 - 5.42	5.17 - 5.33	5.18 - 5.32	5.18 - 5.51	5.12 - 5.25	5.06 - 5.35	4.98 - 5.24	5.24	4.78 - 5.31	5.37 - 5.40	5.02 - 5, 30	4.27 - 5.00	5.51 - 5, 52	4.53 - 5.54	5.40 - 5.49	5.20 - 5.53
	M	5.26	5.23	5.34	5.25	5.24	5.34	5.19	5.19	5.13	5.24	5.05	5.39	5.16	4.64	5.52	4.99	5.45	5.39
ΔpH	R	0.21 - .60	0.09 - 1.24	0.10 - 1.70	0.42 - 0.43	0.20 - 1.38	0.30 - 0.94	0.50 - 0.52	0.81 - 1.09	0.50 - 0.82	1.06	0.39 - 1.30	0.30 - 0.90	0.18 - 0.77	0.89 - 1.83	0.16 - 0.57	0.13 - 1.16	0.19 - 0.66	0.22 - 0.37
	M	0.36	0.67	0.88	0.43	.67	0.70	0.51	0.90	0.63	1.06	0.85	0.70	0.48	1.37	0.37	0.65	0.43	0.29
Org. C (%)	R	1.52 - 2.25	0.16 - 1.03	0.78 - 0.84	0.58 - 1.07	0.20 - 2.13	0.31 - 2.33	0.45 - 1.60	0.35 - 1.28	0.55 - 1.20	0.95	0.46 - 1, 58	0.38 - 5.25	1.76 - 1.84	0.43 - 1.30	0.31 - 1.29	1.48 - 1.51	0.93 - 2.06	1.23 - 2.81
	M	2.00	0.42	0.81	0.83	1.22	1.36	1.03	0.74	0.82	0.95	1.02	2.27	1.80	0.76	0.80	1.50	1.41	2.22
Org. M (%)	R	2.62 - 3.88	0.27 - 1.77	1.35 - 1.45	1.00 - 1.84	0.35 - 3.68	0.53 - 4.02	0.78 – 2.76	0.60 - 2.20	0.94 - 2.07	1.64	0.80 - 2.72	0.65 - 9.05	3.03 - 3.18	0.74 - 2.24	0.54 - 2.22	2.56 - 2.60	1.61 - 3.56	2.12 - 4.84
	M	3.46	0.71	1.40	1.42	2.10	2.35	1.77	1.27	1.42	1.64	1.76	3.92	3.15	1.32	1.38	2.58	2.44	3.82
Total N (%)	R	0.08 - 0.25	0.01 - 0.09	0.03 - 0.06	0.05	0.04 - 0.21	0.30 - 0.2	0.06 - 0.13	0.05 - 0.06	0.05 - 0.10	0.04	0.04 - 0.14	0.03 - 0.45	0.1 - 0.11	0.03 - 0.06	0.02 - 0.06	0.06	0.05 - 0.10	0.06 - 0.22
	M	0.15	0.04	0.04	0.05	0.11	0.12	0.10	0.06	0.07	0.04	0.09	0.18	0.11	0.04	0.04	0.06	0.07	0.14
C/N ratio (%)	R	9 - 20	8 - 21	13 - 28	12 - 21	5 - 15	12	8 – 12	12 - 21	11 - 12	24	11 - 12	12 - 24	17 - 18	14 - 22	16 - 22	25	19 - 21	13 - 22
	M	16	13	21	17	10	12	10	17	12	24	12	16	18	18	19	25	20	18
Avail P mg/kg	R	9 - 18	10 - 17	9 - 18	12 - 15	8 - 16	14 - 22	8 – 12	10 - 17	3 - 15	13	16 - 19	7 - 21	20 - 21	16 - 22	18 - 20	5 - 11	1 - 2	0.9 - 3
	M	14	14	14	14	13	17	10	14	9	13	18	12	21	19	19	8	2	2
Ca^{2+} $cmolkg^{-1}$	R	0.74 - 1.26	0.80 - 1.95	0.72 - 0.84	0.75 - 1.25	0.70 - 0.79	0.69 - 1.95	0.75 - 0.78	0.75 - 1.83	0.75 - 1.24	0.77	0.74 - 0.78	0.71 - 0.83	0.75 - 1.35	0.81 - 0.93	0.75 - 0.86	0.75 - 1.25	0.57 - 1.25	0.50 - 0.69
	M	0.93	1.10	0.76	1.00	0.74	1.15	0.77	1.27	0.93	0.77	0.76	0.77	1.05	0.88	0.81	1.00	0.63	0.63
Mg^{2+} $cmolkg^{-1}$	R	0.43 - 0.64	0.09 - 0.79	0.45 - 0.97	0.58 - 0.99	0.28 - 0.86	0.32 - 0.70	0.12 - 0.42	0.12 - 0.89	0.34 - 0.93	0.28	0.22 - 0.25	0.17 - 0.52	0.02 - 0.15	0.07 - 0.82	0.09 - 0.53	0.99 - 1.63	0.12 - 0.55	0.10 - 0.39
	M	0.55	0.43	0.73	0.79	0.53	0.49	0.27	0.44	0.65	0.28	0.24	0.31	0.09	0.41	0.31	1.31	0.37	0.29
K^+ $cmolkg^{-1}$	R	0.53 - 1.65	0.43 - 0.66	0.18 - 0.58	0.24 - 0.53	0.10 - 0.48	0.18 - 0.68	0.15 - 0.65	0.14 - 0.53	0.46 - 0.94	1.51	0.73 - 0.77	0.19 - 0.52	0.33 - 0.73	0.09 - 0.41	0.12 - 0.24	0.16 - 0.35	0.24 - 0.43	0.15 - 0.44
	M	0.91	0.57	0.40	0.39	0.33	0.53	0.35	0.37	0.64	1.51	0.75	0.20	0.53	0.24	0.18	0.26	0.36	0.29
Na^+ $cmolkg^{-1}$	R	0.06 - 0.09	0.03 - 0.13	0.06 - 0.08	0.07 - 0.09	0.07 - 0.08	0.04 - 0.13	0.07	0.07 - 0.08	0.07 - 0.09	0.07	0.07 - 0.08	0.07 - 0.08	0.07 - 0.12	0.04 - 0.08	0.05 - 0.07	0.05 - 0.09	0.04 - 0.9	0.03 - 0.05
	M	0.08	0.07	0.07	0.08	0.07	0.08	0.07	0.08	0.08	0.07	0.08	0.07	0.10	0.06	0.06	0.07	0.06	0.04
TEB $cmolkg^{-1}$	R	1.80 - 4.14	1.54 - 2.57	1.70 - 2.47	2.05 - 2.45	1.47 - 1.81	1.36 - 3.39	1.09 - 1.92	1.09 - 2.91	2.06 - 2.72	2.63	1.81 - 1.83	1.22 - 1.62	0.57 - 1 95	1.14 - 2.04	1.03 - 1.68	2.14 - 3.13	1.45 - 1.81	0.97 - 1.57
	M	3.12	2.17	1.96	2.25	1.68	2.97	1.51	2.05	2.29	2.63	1.82	1.36	1.76	1.53	1.36	2.64	1.65	1.25
Exch. acid. $cmolkg^{-1}$	R	1.50 - 2.50	0.90 - 2.7	1.20 - 1.90	1.9 - 2.2	1.5 - 2.9	1.6 - 2.3	1.70 - 1.80	1.80 - 3.30	1.60 - 1.80	1.8	1.7 - 2.5	2.0 - 2.8	1.3 - 1.5	1.7 - 5.4	1.7-1.8	2.3 - 4.0	1.8 - 3.4	1.5 – 2.3
	M	2.13	1.85	1.43	2.1	2.2	1.9	1.75	2.57	1.70	1.8	2.1	2.4	1.4	3.37	1.8	3.2	2.7	1.8
Exch. Al $cmolkg^{-1}$	R	0.8 - 1.1	0.6 - 1.2	0.7 - 1.2	1.0 - 1.4	0.9 - 1.9	0.8 - 1.5	1.0 - 1.4	1 - 1.9	0.9 - 1.2	1	0.9 - 1.3	1.0 - 1.7	0.7	0.8 - 3.8	0.7	1.0 - 2.3	0.7 - 2.0	0.8 - 1.0
	M	1.0	0.9	1.1	1.2	1.2	1.1	1.2	1.5	1.0	1	1.1	1.3	0.7	2.0	0.7	1.8	1.5	0.9
ECEC $cmolkg^{-1}$	R	3.99 - 5.62	2.44 - 5.07	2.91 - 4.37	4.25 - 4.35	2.97 - 4.71	3.66 - 4.99	2.89 - 3.62	2.89 - 6.29	3.66 - 4.52	4.43	3.53 - 4.31	3.22 - 4.24	2.87 - 3.58	2.84 - 6.80	2.83 - 3.38	4.44 - 7.14	3.50 - 5.21	2.90 - 3.27
	M	4.60	4.02	3.40	4.30	3.88	4.15	3.26	4.62	3.99	4.43	3.92	3.76	3.16	4.89	3.11	5.79	4.35	3.08
Al sat. (%)	R	14 - 28	16 - 28	24 - 34	23 - 33	30 - 40	16 - 41	35 – 39	31 - 35	26 - 27	23	25 - 30	31 - 38	20 - 24	28 - 59	21 - 25	23 - 32	20 - 44	26 - 31
	M	22	23	28	28	37	28	37	33	26	23	28	35	22	38	23	28	34	28
BS (%)	R	43 - 62	47 - 63	57 - 59	52 - 56	38 - 49	37 - 68	38 – 53	38 - 47	55 - 60	59	42 - 52	34 - 38	55 - 57	21 - 40	36 - 50	44 - 48	33 - 49	30 - 51
	M	55	55	58	54	44	53	46	43	57	59	47	36	56	34	43	46	4.35	41

*P= Pedon; R=Range; M=mean

Table 3: Summary of Physicochemical Properties of the subsurface Layers

Soil Properties	P*	ELM1	ELM2	ELM3	ODN1	ODN2	ODN3	TFN1	TFN2	TFN3	ODI1	ODI2	ODI3	KRM1	KRM2	KRM3	NDU1	NDU2	NDU3
Sand (%)	R	14 - 24	12 - 28	66 - 88	29 - 41	27 - 48	21 - 33	11 - 39	17 - 41	54 - 91	11 - 41	15 - 35	15 - 37	16 - 21	18 - 19	16 - 18	13 - 17	15 - 19	14 - 15
	M	18	21	74	33	39	26	20	30	71	30	26	22	18	18	15	15	17	15
Silt (%)	P	56 - 73	58 - 72	10 - 21	52 - 55	38 - 58	48 - 51	50 - 66	49 - 60	8.0 - 36	41 - 67	51 - 69	53 - 65	60 - 69	53 - 70	54 - 67	59 - 72	57 - 70	66 - 69
	R	65	65	18	53	47	49	61	56	22	57	60	63	64	65	61	64	61	67
Clay (%)	M	10 - 30	12 - 18	2 - 15	6 - 18	12 - 15	19 - 29	11 - 29	10 - 23	1 - 12	12 - 22	12 - 18	110 - 20	15 - 19	12 - 29	16 - 30	10 - 30	14 - 28	16 - 19
	P	17	15	8	14	14	25	20	15	8	17	16	15	18	17	29	21	22	18
Silt/clay ratio	R	1.9 - 7.0	3.6 - 5.3	1.3 - 10.0	2.9 - 8.8	2.7 - 4.4	1.7 - 2.5	2.1 - 4.5	2.6 - 5.3	1.4 - 8.0	2.1 - 5.3	3.4 - 4.8	3.3 - 5.3	3.2 - 4.6	1.8 - 5.8	1.8 - 2.3	2.0 - 7.2	1.9 - 5.0	3.5 - 4.3
	M	4.7	4.4	4	4.73	3.5	2.1	3.4	4.3	4	3.63	4.02	4.3	3.7	4.4	2.1	3.9	3	3.8
pH - H_2O	P	5.72 - 6.55	5.74 - 6.18	5.31 - 5.98	5.33 - 6.48	6.11 - 6.41	5.91 - 6.62	5.30 - 5.95	6.15 - 6.80	5.79 - 6.11	5.60 - 6.40	6.00 - 6.10	5.90 - 6.20	5.77 - 6.18	6.15 - 6.49	5.72 - 6.35	5.92 - 6.32	6.01 - 6.15	6.03 - 614
	R	5.94	6.04	5.74	6.04	6.27	6.3	5.75	6.4	5.97	6	6.03	6.03	5.98	6.28	6.11	6.13	6.08	6.09
pH - $CaCl_2$	M	4.94 - 5.37	5.17 - 5.32	5.19 - 5.64	5.17 - 5.72	5.27 - 6.19	5.27 - 5.70	5.09 - 5.39	4.90 - 5.25	5.15 - 5.33	5.07 - 5.55	5.13 - 5.47	5.11 - 5.32	5.05 - 5.55	5.04 - 5.52	4.15 - 5.40	4.28 - 5.49	4.22 - 5.50	5.25 - 5.55
	P	5.21	5.23	5.35	5.37	5.54	5.41	5.23	5.07	5.26	5.3	5.34	5.22	5.37	5.36	5.07	4.79	4.88	5.42
ΔpH	R	0.49 - 1.18	0.54 - 1.01	0.04 - 0.68	0.16 - 1.02	0.22 - 1.10	0.55 - 1.30	0.21 - 0.74	1.09 - 1.55	0.51 - 0.96	0.38 - 1.17	0.55 - 0.97	0.67 - 0.97	0.33 - 0.73	0.63 - 1.45	0.32 - 2.09	0.43 - 1.99	0.57 - 1.93	0.58 - 0.75
	M	0.73	0.81	0.43	0.67	0.74	0.88	0.52	1.38	0.73	0.7	0.7	0.83	0.62	0.94	1.04	1.34	1.2	0.64
Org. C (%)	P	0.70 - 1.50	0.11 - 0.16	0.53 - 0.59	0.01 - 0.41	0.37 - 0.73	0.31 - 0.99	0.21 - 1.04	0.19 - 0.31	0.08 - 0.68	0.11 - 0.93	0.11 - 0.20	0.21 - 0.34	0.37 - 1.03	0.23 - 0.45	0.14 - 0.45	0.29 - 0.50	0.23 - 0.59	0.59 - 0.92
	R	1.04	0.13	0.56	0.19	0.61	0.71	0.54	0.24	0.35	0.34	0.17	0.25	0.75	0.36	0.29	0.38	0.46	0.75
Org. M (%)	M	1.21 - 2.59	0.19 - 0.28	0.91 - 1.02	0.02 - 0.71	0.63 - 1.26	0.53 - 1.70	0.37 - 1.80	0.32 - 0.54	0.14 - 1.18	0.19 - 1.60	0.19 - 0.35	0.36 - 0.58	0.64 - 1.78	0.40 - 0.78	0.20 - 0.77	0.50 - 0.87	0.40 - 1.01	1.02 - 1.58
	P	1.8	0.23	0.97	0.32	1.04	1.22	0.94	0.41	0.6	0.59	0.29	0.43	1.29	0.63	0.49	0.66	0.79	1.29
Total N (%)	R	0.02 - 0.09	0.01 - 0.03	0.02 - 0.07	0.01 - 0.04	0.03 - 0.06	0.03 - 0.09	0.02 - 0.04	0.02 - 0.03	0.01 - 0.06	0.01 - 0.04	0.01 - 0.02	0.02 - 0.03	0.02 - 0.05	0.02 - 0.03	0.01 - 0.02	0.02 - 0.03	0.01 - 0.03	0.03 - 0.04
	M	0.06	0.02	0.04	0.02	0.05	0.06	0.03	0.03	0.03	0.02	0.02	0.02	0.04	0.03	0.02	0.03	0.02	0.04
C/N ratio (%)	P	12 - 21	5 - 11	13 - 28	10 - 12	11 - 12	10 - 11	8 - 26	10 - 12	08 - 11	6 - 28	10 - 17	11 - 13	19 - 21	12 - 17	14 - 23	14 - 17	18 - 23	19 - 23
	R	17	7	15	11	12	11	16	11	10	15	12	12	20	15	19	16	20	21
Avail P mg/kg	M	3 - 10	10 - 17	5 - 10	3 - 9	2 - 4	1 - 5	4 - 6	2 - 15	4 - 10	6 - 19	6 - 13	2 - 12	5 - 14	4 - 15	6 - 14	0.6 - 1	1 - 3	3 - 4
	P	6	14	7	7	3	3	9	7	7	11	9	7	9	9	10	1	2	4
Ca^{2+} $cmolkg^{-1}$	R	0.71 - 1.22	0.63 - 0.90	0.56 - 1.28	0.72 - 0.91	0.74 - 0.83	0.73 - 1.22	0.56 - 0.78	0.78 - 1.83	0.74 - 0.95	0.63 - 0.75	0.44 - 1.13	0.65 - 0.85	0.30 - 0.85	0.60 - 1.53	0.70 - 2.05	0.70 - 1.10	0.58 - 0.75	0.75 - 0.92
	M	0.93	0.81	0.93	0.81	0.78	0.97	0.72	1.17	0.8	0.71	0.76	0.75	0.65	0.91	1.28	0.9	0.67	0.85
Mg^{2+} $cmolkg^{-1}$	R	0.10 - 1.22	0.13 - 0.48	0.08 - 0.74	0.15 - 0.93	0.38 - 0.89	0.39 - 0.92	0.20 - 0.98	0.40 - 0.66	0.06 - 1.01	0.23 - 1.26	0.48 - 1.12	0.02 - 0.87	0.37 - 1.02	0.35 - 1.24	0.53 - 1.12	0.10'1.35	0.51 - 0.90	0.13 - 0.32
	M	0.49	0.35	0.31	0.43	0.57	0.53	0.43	0.51	0.49	0.56	0.78	0.3	0.52	0.79	0.76	0.77	0.64	0.22
K^{+} $cmolkg^{-1}$	R	0.18 - 1.42	0.18 - 0.70	0.12 - 1.81	0.17 - 1.12	0.15 - 0.82	0.58 - 2.13	0.16 - 0.62	0.28 - 1.88	0.19 - 0.88	0.11 - 1.44	0.10 - 1.44	0.11 - 0.73	0.16 - 1.51	0.12 - 0.27	0.18 - 0.52	0.09 - 0.43	0.15 - 0.32	0.44 - 0.60
	M	0.6	0.4	0.61	0.56	0.43	1.22	0.41	0.81	0.55	0.59	0.7	0.5	0.66	0.21	0.35	0.27	0.21	0.53
Na^{+} $cmolkg^{-1}$	R	0.07 - 0.08	0.04 - 0.08	0.03 - 0.08	0.03 - 0.09	0.05 - 0.08	0.07 - 0.80	0.03 - 0.07	0.05 - 0.07	0.07 - 0.08	0.03 - 0.07	0.06 - 0.08	0.04 - 0.08	0.03 - 0.08	0.04 - 0.11	0.04 - 0.08	0.04 - 0.09	0.04 - 0.07	0.05 - 0.08
	M	0.07	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.05	0.07	0.07	0.06	0.07	0.07	0.06	0.06	0.06
TEB $cmolkg^{-1}$	R	1.59 - 2.75	1.29 - 2.16	0.99 - 3.91	1.07 - 2.99	1.55 - 2.02	1.97 - 4.34	0.97 - 2.07	1.74 - 3.24	1.10 - 2.67	1.14 - 2.96	1.48 - 3.77	0.82 - 2.25	1.93 - 2.29	1.11 - 3.03	1.71 - 3.32	0.93 - 2.48	1.54 - 1.70	1.53 - 1.90
	M	2.09	1.61	1.91	1.87	1.83	2.79	1.61	2.56	1.91	1.9	2.3	1.61	2	1.47	2.45	2	1.61	1.66
Exch. acid. $cmolkg^{-1}$	R	1.40 - 2.40	0.70 - 2.30	0.50 - 3.40	1.10 - 2.80	1.40 - 6.20	2.0 - 3.4	1.90 - 5.40	0.80 - 1.80	1.40 - 4.60	1.50 - 2.50	0.90 - 2.70	1.80 - 5.00	1.00 - 4.90	0.70 - 2.10	1.00 - 2.10	1.10 - 3.30	0.90 - 4.50	1.70 - 1.80
	M	1.88	1.55	1.78	1.9	2.83	2.5	3.1	1.2	2.43	1.81	1.9	2.6	2.83	1.5	1.8	2	3.07	1.7
Exch. Al $cmolkg^{-1}$	R	0.70 - 1.80	0.50 - 1.30	0.30 - 1.90	0.70 - 1.80	0.70 - 3.60	1.20 - 2.00	0.80 - 2.40	0.50 - 1.10	0.70 - 2.20	0.80 - 1.20	0.40 - 1.40	0.90 - 3.00	0.60 - 2.40	0.30 - 0.90	0.50 - 1.00	0.60 - 1.80	0.40 - 2.40	0.70 - 0.80
	M	1.1	0.9	1	1.2	1.6	1.5	1.4	0.7	1.2	0.9	1	1.3	2.4	0.7	0.8	1.1	1.6	0.8
ECEC $cmolkg^{-1}$	R	3.99 - 4.74	2.21 - 3.77	1.49 - 6.11	2.47 - 4.75	3.42 - 8.06	4.07 - 6.84	3.66 - 6.37	2.79 - 5.04	3.05 - 5.70	2.74 - 4.56	2.38 - 5.87	3.32 - 5.82	2.93 - 6.43	2.71 - 5.13	3.96 - 4.52	2.03 - 5.78	2.48 - 6.20	3.23 - 3.70
	M	3.97	3.16	3.69	3.72	4.66	5.29	4.71	3.76	4.34	3.72	4.2	4.17	4.83	3.47	4.2	4	4.67	3.39
Al sat. (%)	R	15 - 46	23 - 34	16 - 34	17 - 45	20 - 45	23 - 35	18 - 38	14 - 23	20 - 39	20 - 34	17 - 30	20 - 51	20 - 37	10 - 30	11 - 25	18 - 31	16 - 39	22 - 25
	M	29	29	26	33	30	29	29	19	26	26	23	30	29	22	19	26	31	23
BS (%)	R	41 - 59	39 - 68	40 - 66	41 - 73	23 - 59	40 - 63	15 - 48	64 - 77	19 - 57	36 - 65	42 - 64	14 - 51	24 - 66	41 - 77	40 - 78	43 - 63	27 - 64	47 - 51
	M	53	52	55	66	45	52	37	68	47	50	55	41	46	56	58	50	40	49

*P= Pedon; R=Range; M=mean

The single most important indicator of soil fertility and in the assessment of soil quality in the tropical regions is soil organic matter (SOM). The mean SOM in the surface 40 cm ranged from 0.71 % in ELM2 to 3.82 % in NDU3 and 0.23% in ELM2 to 1.29 in NDU3 in the subsurface. Similarly, the mean total N (TN) ranged from 0.04 % in ELM2 to 0.18 % in ODI3 in the surface 40 cm and 0.02 % in ELM2 to 0.06 % in ELM1 in the subsurface. The results indicated organic matter as the main source of T - N in the soils, which indicated the close relationship between organic C and total N. Report by [16] revealed that soils with less than 0.07% total N have limited N mineralization potential, whereas those higher than 0.15% are expected to mineralize sufficient N during the succeeding crop cycle. From the results, the studied soils may require N applications for each crop cycle as only ELM1 andODI3 met this condition. The relationship between carbon and nitrogen has been established in ratios. Bray and Weil [12] established (8:1–15:1) as the common C/N ratio range for arable soils. Tisdale *et al.* [17] reported that the C/N ratio of the undisturbed topsoil in equilibrium with its environment is about 10 or 12, narrowing in the subsoil because of lower amounts of C. Considering the C/N ratio of undisturbed topsoil (10:1–12:1), 33% of the soils were within the range which means oxidation and loss of organic matter in the plow layers was not very rapid which is safe considering the prevailing high temperature and rainfall.

Available P in the surface 40 cm was relatively higher than the available P values in the subsurface. The average available P in the surface 40 cm ranged from 2 ppm in NDU2 to 21 ppm in KRM1 and 1 ppm in NDU1 to 11 ppm in ODI1 in the subsurface. There seems to be a close relationship between available P and soil organic matter in these soils and P availability is dictated by soil pH. Alemayelu *et al.* [14] considered high soil available P as a reflection of slightly acid to neutral soil reaction and low contents of exchangeable Al. and low P availability in tropical soils has been attributed to the nature of the chemical forms of soil P and the high content of oxides of Fe and Al associated with high P fixation. Though the available P levels in the surface 40 cm of the soils was medium based on the critical P values reported by [18] for southern Nigeria soils, P might be readily available only for the first crop and P availability in the subsequent cropping seasons could be a challenge due to high concentration of Al.

Exchangeable cations (Ca, Mg and K) in the subsurface were generally higher than those of the surface 40 cm. The average exchangeable Ca in the surface 40 cm ranged from 0.63 cmolkg^{-1}in NDU2 to 1.27 cmolkg^{-1} in TFN2 and 0.65 cmolkg^{-1} in KRM1 to 1.28 cmolkg^{-1} in KRM3 in the subsurface. Mean exchangeable Mg in the surface 40 cm ranged from 0.09 cmolkg^{-1} in KRM1 to 1.31 cmolkg^{-1} in NDU1 and 0.22 cmolkg^{-1}in NDU3 to 0.79 cmolkg^{-1} in KRM2 in the subsurface while exchangeable K in the surface 40 cm ranged from 0.18 cmolkg^{-1} in KRM3 to 1.51 cmolkg^{-1} in ODI1 and 0.21 cmolkg^{-1} NDU2 to 1.22 cmolkg^{-1} in ODN3 in the subsurface. The average ECEC in the surface 40 cm ranged from 3.08 cmolkg^{-1} in NDU3 to 5.79 cmolkg^{-1} in NDU1 and 3.16 cmolkg $^{-1}$ in ELM2 to 5.29 cmolkg^{-1} in ODN3 in the subsurface. When compared to [13] ratings for Ca and Mg, exchangeable Ca in these soils were very low, exchangeable Mg low to medium, exchangeable K in KRM and NDU soils low to medium K, while K in the others soils (ELM, ODN, TFN and ODI) were medium to high K. Low exchangeable bases in soils (Ca, Mg and K) have been attributed to acidifying properties of organic matter, high aluminum concentration and leaching loss of exchangeable bases [17]. The low exchangeable Ca and Mg in these soils was attributed to inherently low concentration of ferromagnesian minerals, low nutrient retentive capacity and the moderate to high exchangeable Al.

Effective cation exchange capacity (ECEC) values were generally low. However, 50% of the soils from the surface 40 cm and 56% from the subsurface layers had ECEC values of 4 cmolkg^{-1} and above which is the value considered as having the ability to withstand heavy leaching loss of nutrients for tropical soil [19].

The mean exchangeable acidity in the surface 40 cm ranged from 0.7 cmolkg^{-1} in KRM1 to 3.37 cmolkg^{1} in KRM2 and 1.20 cmolkg^{-1} in TFN2 to 3.10 cmolkg^{-1} in TFN1 in the subsurface while mean exchangeable Al in the surface 40 cm ranged from 0.7 cmolkg^{-1} in KRM1 to 2.0 cmolkg^{-1} in KRM2 and 0.7 cmolkg^{-1} in TFN2 to 2.4 cmolkg^{-1} in KRM1 in the subsurface. Theoretically, soil acidity is quantified on the basis of hydrogen (H^+) and Aluminum (Al^{3+}) concentrations of soils. Increased soil acidity causes solubilization of Al, which is a principal source of toxicity to plants at pH below 5.5 [20]. Exchangeable acidity in the soils varied from low to high. The exchange acidity of 50 % of the soils was 2.0 cmolkg^{-1} and above suggesting that the soils were slightly to strongly acid [21]. This probably contributed to the low concentration of exchangeable basic cations in the soils. Since the soils were of sedimentary origin and are yet to go through long period of weathering and leaching loss of nutrients, the parent materials from which these soils originated were probably acid in nature.

Aluminum, though, not a plant nutrient and not useful to plant growth, could be a good indicator for acidity and weathering status of soils [22]. Aluminum mostly exist as exchangeable Al^{3+} under very acidic conditions (pH ‹4.5) and aluminum - hydroxyl ions at higher pH (pH 4.5 - 6.5). Aluminum toxicity restricts and disturbs seedling growth [23]. Exchangeable Al is also known to inhibit Ca and Mg uptake [24], [25], reduce root growth and causes nutrient imbalances in soils [26]. The Al concentration in the soils was moderately high. Given the pH values recorded for the soils (pH 5.62 - 6.40), Al may exist in the form of aluminum - hydroxyl ions in these soils and might not be toxic. However, Al toxicity is reported to be most prevalent in the humid tropics and acid savannas soils [27] and high Al concentration correlates with low nutrient capital reserves.

3.3 Identification of the important soil properties in relation to soil fertility.

Presented on Table 4 are the important soil properties relating to soil fertility which principal component analysis (PCA) identified while Pearson's correlation analysis of selected soil properties is presented in Table 5. The PCA revealed the eight most important contributions of the selected soil physical and chemical properties. The results revealed positive factor loading contribution in all the components and negative factor loading contribution in PC1, PC4, PC5, PC7 and PC8. Soil acidity (including exchangeable Al and H), Al saturation and nutrient retention capacity (effective CEC) dominated the positive factor loading contribution in PC1. Correlation analysis showed clay has very highly significant, positive relationship with silt (r=0.396***), ECEC (r=0.350***), and highly significant positive relationship with exchangeable acidity (r=0.332**) as well as with exchangeable Al (r=0.246**). The relationship between clay and sand (r=-0.675***), ECEC (r=-0.263**) and P (r=-0.216*) was inverse. Similarly, the relationship between silt and sand was inverse and very highly significant (r=-0.942***).

The eight components (PC1, PC2, PC3, PC4, PC5, PC6, PC7, and PC8) recorded in this study explained 83 % of the total variability. Each of the components represents a series of variables which made the analysis and interpretation straightforward. The dominance of soil acidity in PC1 factor loading corroborated the results of physical and chemical analyses as most of the soils fell into the acid pH range. Exchangeable Al in PC1 suggested that this cation significantly influence soil quality in the pedons which agreed with [22] results for degraded tropical rainforest soils of Malaysia. Lu *et al.* [28] reported the chemical components of Ca and Ale in soil as having strong negative correlations. High amounts of Ca and Mg were associated with low amount of Al leading to a rise in pH value while low amounts of Ca and Mg were accompanied by high amount of Al resulting in low pH, causing soils acidity. The Al concentration in the soil mapping units was moderate to high. Neither very high nor very low pH values are appropriate for good vegetative growth. ECEC's presence in PC1 was due to contribution of soil acidity to ECEC. Soil organic matter, organic carbon, total nitrogen and electrical conductivity dominated PC2 with high positive factor loading, reflecting the strong positive relationship between organic matter and total nitrogen. This explains the fact that total nitrogen in these soils is a function of organic matter as N is stored in organic matter. Organic matter in soils is connected to nutrient availability, soil structure, air and water infiltration, and water retention [29]. In PC3, Ca, Mg, Na and TEB gave high positive factor loading indicating that this component is contributed by exchangeable bases. High amounts of Ca, Mg, and K are helpful to vegetation growth while high Al limits vegetation growth [28]. Silt gave a high positive factor loading for PC4 and silt/clay ratio for PC5 while sand and clay gave negative factor loading in the respective PCs. Clay's negative factor loading for PC5 showed organic matter contributed more to nutrient retention in these soils than clay. PC6, PC7 and PC8 component scores showed K, pH ($CaCl_2$) and pH (H_2O), contributing high positive factor loading for the respective PCs while P and C/N ratio negative factor loading for PC7 and PC8, respectively. The fact that P gave negative factor loading in PC7 may mean that P availability is negatively affected by Al in these soils as Al is known to complex P, reducing availability [12].

The positive relation between silt and clay may mean that weathering of the silt fraction adds to the clay fraction while the sand fraction contributed nothing to the clay fraction. Also, the relationship between clay and silt may mean that the two soil separates were influenced by similar climatic, pedogenic and biotic factors and the reverse for sand. Furthermore, owing to the clay's negatively charged sites, clay contributed to exchange acidity, Al and ECEC hence the significant positive correlation between clay and these properties. Angelica *et al.* [26] reported that negatively charged sites from clay bond Al cations, assist reducing exchangeable Al. The relationship between clay and available P was inverse but significant (r=-0.216*) implying that clay contributed negatively to P availability. Aluminum and Fe which are part of the clay structure fix P in these soils hence the negative relationship. The relationship between clay and Ca, Mg and K, was positive though not significant indicating that clay contributed partly to the availability of these nutrients. The correlation between organic matter and total nitrogen was positive and very highly significant (r=0.366***) confirming the PCA results which revealed that total N content in the soils was a function of the amount of organic matter present. Similar results were reported by [30] for Odukpani soils, Cross River State in southern Nigeria. The higher the organic matter the higher the potential N released in the soil. This is understandable because organic matter and total N primarily are sourced from the accumulation of biomass in soils. The correlation between organic matter and available P was also positive and highly significant (r=-0.310**) indicating that organic matter contributed positively to the accumulation and availability of P.

4. Conclusions

The PCA results allowed the process of developing specified pointers that could represent more complex variability of the soil chemical and physical properties in the Lower Niger River floodplain soils. The availability of many of the plant nutrients in the soil mapping units depended strongly on soil acidity. Generally, the concentrations of exchangeable Ca and Mg were low due to inherently low ferromagnesian minerals, low clay activity and low nutrient retentive capacity coupled with high Al concentration. The PC1 factor loading indicated the importance of soil acidity in dictating chemical reactions in the soils while PC2 factor loading results and correlation analysis amplified organic matter contributions to soil N and P accumulation and availability of P. Correlation results also showed that the silt fraction weather and add to the clay fraction.

Table 4: Soil Parameters used for PCA and results of PCA of the Soil Mapping units

Factor loadings Soil mapping units	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
+	Exch. Al Soil acidity ECEC Al Sat.	SOM TOC T - N ECe	Ca^{2+} Mg^{2+} Na^{+} TEB	Silt	Silt/clay ratio	K^{+}	pH - $CaCl_2$	pH - H_2O
-	Base sat.	-	-	Sand	Clay	-	P	C/N ratio
Contribution	Soil acidity, Cation retentive capacity	Soil organic matter, TN, ECe	Cation retention capacity	Silt, sand	Silt/clay ratio, clay	K^{+}	pH, P	pH, C/N ratio
Total	3.858	3.412	2.878	2.341	1.705	1.646	1.226	1.216
Variance (%)	17.537	15.507	13.081	10.639	7.750	7.483	5.575	5.527
Cumulative (%)	17.537	33.044	46.125	56.765	64.515	71.998	77.572	83.099

Table 5: Pearson's Correlation matrix of soil properties

	pH - H_2O	**ECe**	**T - N**	**Org. C**	**Org. M**	**P**	**Ca**	**Mg**	**K**	**Na**	**TEB**	**Acidity**	**Al**	**ECEC**	**Al sat**	**BS**	**Sand**	**Silt**	**Clay**
pH - H_2O	1.000																		
ECe	- 0.081	1.000																	
T - N	- 0.224*	0.325**	1.000																
Org. C	- 0.307**	0.366***	0.924***	1.000															
Org. M	- 0.307**	0.366***	0.924***	1.000	1.000														
P	- 0.152	0.114	0.326**	0.310**	0.310**	1.000													
Ca	- 0.088	0.087	0.048	0.010	0.009	0.060	1.000												
Mg	0.118	0.010	- 0.073	- 0.068	- 0.068	- 0.056	0.223*	1.000											
K	- 0.056	- 0.106	0.012	- 0.062	- 0.062	- 0.008	- 0.002	0.058	1.000										
Na	- 0.142	0.099	0.174*	0.103	0.102	0.222*	0.506***	0.219*	0.248**	1.000									
TEB	- 0.019	- 0.015	- 0.002	- 0.063	- 0.064	- 0.003	0.579***	0.650***	0.644***	0.523***	1.000								
Acidity	0.010	- 0.055	0.105	0.109	0.109	- 0.065	- 0.098	0.052	- 0.063	- 0.156	- 0.069	1.000							
Al	0.004	- 0.039	0.119	0.115	0.115	- 0.048	- 0.056	0.062	- 0.080	- 0.130	- 0.059	0.927***	1.000						
ECEC	- 0.014	- 0.064	0.082	0.054	0.054	- 0.051	0.250**	0.416***	0.322**	0.169	0.518***	0.812***	0.757***	1.000					
Al salt	- 0.027	0.008	0.164	0.173	0.173	0.001	- 0.278**	- 0.264**	- 0.335**	- 0.307**	- 0.482***	0.651***	0.809***	0.267**	1.000				
BS	0.002	0.009	- 0.144	- 0.198*	- 0.198*	0.032	0.399***	0.316**	0.341**	0.397***	0.565***	- 0.775***	- 0.689***	- 0.343**	- 0.731***	1.000			
Sand	0.018	- 0.179*	0.001	- 0.054	- 0.054	0.067	- 0.087	- 0.079	0.027	0.088	- 0.059	- 0.178*	- 0.093	- 0.165	0.002	0.191*	1.000		
Silt	- 0.024	0.208*	0.044	0.094	0.095	0.013	0.053	0.091	- 0.083	- 0.064	0.018	0.065	- 0.003	0.044	- 0.045	- 0.110	- 0.942***	1.000	
Clay	0.007	0.009	- 0.116	- 0.074	- 0.075	- 0.216*	0.142	0.035	0.095	- 0.097	0.132	0.332**	0.246**	0.350***	0.073	- 0.263**	- 0.675***	0.396***	1.000

*. = Correlation significant at 5% level; **. = Correlation significant at 1% level; *** = Correlation significant at 0.1% level

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