A MULTIVARIATE APPROACH TO ASSESSING VARIABILITY IN SOME SOILS OF THE NIGERIAN SAVANNA

[1*]SOLOMON, R. I., [2]ABDULKAREEM J. H., AND [3]MAMZING D.,

[1]Department of Soil Science, Faculty of Agriculture, Modibbo Adama University, Yola, Nigeria.
[2]Department of Soil Science, Institute for Agricultural Research/Faculty of Agriculture, Ahmadu Bello University, P.M.B 1044, Zaria, Nigeria.
[3]Department of Pest Management Technology, Plateau State College of Agriculture, Garkawa, Plateau State, Nigeria.
*rejoice605@gmail.com, solomonri@mautech.edu.ng

ABSTRACT

Multivariate analysis is a vital tool for investigative data analysis as it permits grouping of samples based on similarity and at the same time allows the selection of the most important variables that differentiates them. The study was conducted with a multivariate approach to determine the soil properties that account for soil variability in selected soils of the Nigerian Savanna. To achieve this, soil samples were collected from twelve (12) different locations where they were analyzed for various soil physical and chemical properties using standard laboratory procedures. Twenty-one soil properties were subjected to principal component analysis (PCA). Results revealed that only six principal components (PCs) were found to have eigenvalue of >1 out of the twenty-one. Principal component (PC) 1 with an eigenvalue of 6.35 was the most influential and accounted for 28.86 % of the cumulative variance. Similarly, PC 2, 3, 4, 5 and 6 have eigenvalues of 5.17, 2.55, 1.41 and 1.29 respectively and together with PC 1 accounted for a cumulative variation of 83.55%. Clay content, field capacity water (FCW), soil porosity, total nitrogen, available nitrogen, nitrate, exchangeable bases, ECEC, EC, pH in $CaCl_2$, H + Al, organic carbon and sulphate were the main soil properties influencing soil variability in this study and are related to water and nutrients retention as well as soil salinity and reaction. Therefore, management of these properties through the incorporation of organic residues can enhance in minimizing their variability.

***Keywords:* Principal component analysis (PCA); Nigerian Savanna; soil properties; variability**

INTRODUCTION

Evaluating soil properties is a vital means of providing economic and environmentally sustainable agricultural practices (Oliveira *et al*., 2017). Soil being an indispensable natural resource for crop production, is a product of climate, topography, parent materials, disturbance history and a number of soil forming processes (Ezeaku, 2013). Soil properties vary from place to place, however, these variations are not by chance, but are influenced by five (5) key factors known as the factors of soil formation (Benjamin, 2017; Balasubramanian, 2017). Generally, soils are very similar where all elements of the five factors are the same. Under similar environments in different places, soils are similar. This uniformity permits prediction of the location of many different kinds of soil (Benjamin, 2017; Balasubramanian, 2017).

Soils of the Nigerian Savanna are naturally low in fertility except for Vertosols and hydromorphic soils found in some pockets throughout the Savanna region (Jones, 1973). Different cultural practices coupled with diverse landscape features are responsible for variations of soil property both laterally and vertically in most agricultural sites in the Savanna ecology. This resultant variability in soil fertility presents huge challenge to land management and results in varying output in farmlands (Maccarthy *et al*., 2013). However, failure of the soil quality indicators to perform optimally in terms of increasing productivity, especially in Savanna agroecology, has been related mostly to soil degradation (Ezeaku and Salau, 2005). Therefore, assessment of soil properties and productivity in various agricultural management systems is vital and should be on a continuous basis (Lal, 1994). Although, there has been increased interest in assessing soil variability by examining the physical and chemical properties, through univariate approaches, this is an expensive process due to large sample size and variables (Silva *et al*., 2010).

Multivariate analysis is an important tool for investigative data analysis of soil as it permits grouping of samples based on similarity and at the same time allows the selection of the most important variables that differentiate them. Ferre (1995) opined that this analysis of components should explain more than 70 to 80 % of the total variance and which should constitute the selected attribute variables for principal component analysis (PCA). This study therefore, employed a multivariate approach to determine the driving soil properties that account for soil variability in some soils of the Nigerian Savanna.

MATERIALS AND METHODS

Bulk soil samples were collected from cultivated fields in twelve (12) different locations across the Nigerian Sudan, Northern guinea and Southern guinea Savanna agroecological zones. Vertisols were collected from Numan (9° 27' 14.081 "N - 9° 27' 56.011" N, 12° 0' 35.188" E - 12° 0' 55.168" E), Shelleng (9° 53' 42.520 "N ˉ 09^{o} 56\` 32.71\`\` N, 12° 0' 37.615" E - 12^{o} 3’ 15.96” E) and Guyuk (9° 49' 26.483" N - 9^{o} 38’ 59” N, 11° 55' 48.953" E – 11^{o} 54’ 57” E) Local government areas of Adamawa State (Zata *et al.*, 2013). While Alfisols were collected from Modibbo Adama University of Technology (MAUTECH) Yola teaching and research farm (9° 20' 26.708" N – 09^{o} 51’ 49.26” N, 12° 30' 6.006" E – 12^{o} 4’ 12.82” E) in Adamawa State, Federal College of Land Resources Technology (FECOLART) Kuru (9^{o} 44’ 30.74” – 9^{o} 44’ 45.56” N, 8^{o} 48’ 55.36” – 8^{o} 49’ 3.28” E), Jos in Plateau State and Institute for Agricultural Research (IAR) Research Farm (11^{o} 10’ 37.26” N – 11^{o} 10’ 38.18” N, 7^{o} 36’ 38.51 E -7^{o} 37’38.20”E), Samaru, Zaria in Kaduna State. Similarly, Ultisols were collected from Akko Local Government Area (10° 6' 13.530" N – 10^{o} 4’ 40.53” N, 11° 1' 22.999" E – 11^{o} 6’ 30.81” E) of Gombe State, Farmers' fields behind Area F Residential Quarters (11^{o} 10’ 20.33” N – 11^{o} 10’ 17.80” N, 07^{o} 37’ 33.44” E – 07^{o} 37’ 34.30” E), ABU Zaria (Bawa, 1997) and Barkin Ladi (9° 33' 55.868" N – 09^{o} 34’ 0.73” N, 8° 55' 6.209" E – 08^{o} 58’ 7.87” E) in Plateau State (Kparmwang, 1993). Inceptisols were collected from Kadawa (11° 37' 46.762" N - 11^{o} 4’ 22.76” N, 8° 26' 9.975" E – 08^{o} 30’ 3.96” E) in Kano State (Aliyu, 1999), Lake

Geriyo Irrigation Project (9° 17' 39.319'' N – 0 9º 34' 0.73'' N, 12° 25' 30.667'' E – 12° 35' 30.667'' E) (Usman, 2005) and Loko flood plains (9° 46' 35.865'' N – 0 9º 18' 18.60'' N, 12° 35' 15.270'' E - 12º 25' 56.99'' E) (Musa, 2016) in Adamawa State as shown in Figure 1.

Stratified random sampling was employed to sample soils using soil auger. At each sampling site, soil samples were collected from 20 points at 0-15 cm depth. The collected samples were bulked together to make a composite sample for each of the sampling location, air-dried, passed through 2 mm mesh sieve while samples for organic carbon and total N were further passed through 0.5 mm mesh sieve. Similarly, undisturbed soil samples were collected from as many as ten (10) points in each location using core samplers of about 5 cm long and 5 cm diameter for determination of bulk density.

Figure 1: Map of Nigeria showing Selected States and Sampling Points

Source: Map Gallery, Geography Department, ABU Zaria

Soil Physical and Chemical Analysis

Standard laboratory methods were adopted in the determination of soil physical and chemical properties. The soil particle size analysis was determined as described by Jaiswal (2003). Bulk density was determined using the undisturbed soil samples and calculated using the expression as described by Blake and Hartge (1986).

The Bulk density $= \frac{M1 - M2}{V}$ ……………. (1)

where; M_1 = mass of core plus oven dry soil at 105 ^oC.

M_2 = mass of the empty core, and

V = Volume of the core.

Similarly, percentage porosity was calculated by assuming a particle density of 2.65 Mg m^{-3} and then using the below expression:

Total Porosity $= \left(1 - \frac{Bulk\ density}{Particle\ density}\right)$… (2)

Field capacity water (FCW) was determined from undisturbed soil sample by weighing known weight of dry soil, the soil was then saturated with water and allowed to drain for twenty (24) hours under gravity. The soil was re-weighed and the difference in weight was amount of water at field capacity. The soil pH (soil reaction) was measured using a glass electrode pH meter in a 1: 2.5 soil to water ratio and in 0.01M $CaCl_2$ as described by Jaiswal (2003). The organic carbon was determined by Chromic acid wet oxidation method of Walkley and Black (1947). Total soil nitrogen was determined by wet digestion using the macro Kjeldahl digestion and distillation procedure as described by Jaiswal (2003). Similarly, available nitrogen content of the soils was extracted using 2 M KCl as described by Jaiswal (2003). The available phosphorus (Available P) was determined using Bray 1 method as described by Bray and Kurtz (1945). The exchangeable bases were extracted in neutral 1N ammonium acetate (NH_40Ac). Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrophotometer while, K^+ and Na^+ were determined with a flame photometer (Jaiswal, 2003). Electrical Conductivity (EC) was determined in a 1: 2.5 (soil: water) suspension as described by Jaiswal (2003). Effective cation exchange capacity (ECEC) was determined by the summation method (Juo, 1978). The soil nitrate was determined using spectrophotometry by nitration of salicylic acid. Phosphate was extracted with sodium bicarbonate at pH of 8.5 as described by Jaiswal (2003). Sulphate in soil samples was extracted with 500 ppm of $K_2H_2PO_4$, turbidity was developed using gelatin- $BaCl_2$ solution, and the optical density was measured using a spectrophotometer.

Data Analysis

Pearson correlation was used to determine relationship between soil parameters. To study the multivariate structure of the data, Principal components analysis (PCA) was employed to remove redundant variables and determine the driving soil properties that account for the variability in the soil samples. This was achieved by identifying similarities among the different soil samples in an effort to group them in relation to physical and chemical attributes. Scree-plot which is a graph of eigenvalues was produced to establish the number of components that should be removed. This graph arranges the eigenvalues according to the main components, by plotting the variance percentage by each attribute. Having established the components to be adopted, PCA was carried out to obtain a fewer set of variable in linear combinations that would retain most of the information provided by the original ones (Smith, 2002). The basis for selecting the number of components were an eigenvalue greater than 1.00 and a cumulative variance of over 70 to 80 % (Ferre, 1995). Also, Varimax rotation was adopted to simplify interpretation. This method transforms the factor coefficient such that the correlation values among factors and *n* original variables are between zero and 1 (Ferre, 1995).

RESULTS AND DISCUSSION

Characteristics of soil in the study area

The summary statistics of the soil physical and chemical properties of the study area are presented in Table 1. Maximum sand, silt and clay contents of 78%, 48% and 35% respectively were recorded with mean values of 56.1%, 24.6% and 19.2 % for sand, silt and clay respectively. Higher sand content recorded compared to those of silt and clay is in line with the reports of Sonneveld (2005), Jibrin *et al*. (2008), and Adamu and Aliyu (2012) reported that soils of Nigeria's Savanna are mostly sandy with little silt and clay contents. Highest and lowest soil bulk density of 1.64 and 1.39 M gm^{-3} respectively was recorded with a mean value of 1.44 M gm^{-3} (Table 1). This mean bulk density value is optimum for root development. Hunt and Gilkes (1992) reported critical bulk density values of 1.6 M gm^{-3} for restricting root growth.

Mean soil pH values of 6.0 and 5.2 in water and $CaCl_2$ respectively were observed. This soil pH fall within the slightly to moderately acidic range based on the classification by Black (1965). Mustapha *et al*. (2011) and Sonneveld (2005) reported similar pH range for soils of the Savanna and associated it to the high sand contents of Savanna soils which resulted in leaching of basic cations. Soil EC values were low and ranged from 0.07 to 0.10 dS m^{-1}. This is an indication of low salt concentration of the soil suggesting that there is no salinity problem.

Results on soil organic carbon content of the sampling locations revealed highest and lowest organic carbon content of 16.60 and 2.60 g kg^{-1} respectively. These values reflected low organic carbon according to the classification of Beernaert and Bitondo (1992) and Esu (1991). They reported critical organic carbon values of 10-20 g kg^{-1}. Similarly, Mustapha and Nanlee (2007) reported similar organic carbon contents and linked the result to scanty vegetation and high decomposition rate typical of Savanna climate. Also, Raji and Mohammed (2000) reported that more than 80 % of Nigerian Savanna soils are low in organic carbon and only about 20 % of these soils have organic carbon content of greater than 10 g kg^{-1}. They attributed the result to high sand contents and scanty vegetation of the soils. Similar rating was reported by Marx *et al*. (1999).

Total and available nitrogen contents of the areas are generally low with mean values of 0.58 and 0.04 g kg^{-1} for total and available nitrogen respectively. These low nitrogen contents may be attributed to the low organic carbon contents of the soils (Table 1). Beernaert and Bitondo (1992) reported a critical N value of 0.5 to 1.25 g kg^{-1} for optimum crop production. Available P contents ranged from 3.33 to 24.80 mg kg^{-1}

with a mean value of 14.65 mg kg^{-1}. This falls between medium to low Available P content based on the classification of Marx *et al*. (1999) and Esu (1991). Highest and lowest effective cation exchange capacity (ECEC) of 25.65 and 4.17 cmol (+) kg^{-1} were observed (Table 1). These values are rated medium to low based on the ratings of Black (1965).

Relationship among Soil Properties

The Pearson's correlation matrix between soil properties is presented in Table 2. Results revealed little or low correlation between most of the soil properties. However, significant negative correlation was observed between sand and clay content as well as sand and silt content (*r*=-0.64, -0.82 respectively). This implies that an increase in sand fraction of these soils resulted in reduction in clay and silt fractions of the soils.

TABLE 1: SUMMARY STATISTICS OF SOIL PROPERTIES

Soil property	Unit	Minimum	Maximum	Mean	Standard deviation
Sand	%	30.00	78.00	56.10	14.10
Silt	%	10.00	48.00	24.62	10.82
Clay	%	6.00	35.00	19.23	8.18
FCW		0.18	0.32	0.24	0.04
Bulk density	kg m^{-3}	1.39	1.64	1.44	0.18
Porosity	%	38.00	50.00	45.00	3.50
pH (H_2O)		5.05	7.46	6.04	0.58
pH ($CaCl_2$)		4.26	6.57	5.17	0.64
EC	dS m^{-1}	0.07	0.10	0.09	0.01
Organic C	g kg^{-1}	2.60	16.60	9.37	6.72
Total N	g kg^{-1}	0.17	1.72	0.58	0.31
Available N	g kg^{-1}	0.01	0.20	0.04	0.04
$NO3^-$	g kg^{-1}	0.00	0.09	0.02	0.02
Sulphate	mg kg^{-1}	3.53	740.57	141.45	173.64
Available P	mg kg^{-1}	3.33	84.18	14.65	14.76
Ca	cmol (+) kg^{-1}	1.51	24.80	9.34	5.22
Mg	cmol (+) kg^{-1}	0.23	4.13	1.48	1.01
K	cmol (+) kg^{-1}	0.09	2.20	0.61	0.60
Na	cmol (+) kg^{-1}	0.05	2.55	0.78	0.68
H+Al	cmol (+) kg^{-1}	0.40	3.60	1.32	0.52
ECEC	cmol (+) kg^{-1}	4.17	25.65	13.53	6.94

TABLE 2: CORRELATION MATRIX OF SOIL PROPERTIES

Soil property	Clay	Silt	Sand	FCW	BD	Porosity	pH (H_2O)	pH ($CaCl_2$)	EC (dSm^{-1})	OC	TN	AVN	NO_3	Sulphate	Available P	Ca	Mg	K	Na	H+Al
Silt	0.08	**1**																		
Sand	**-0.64**	**-0.82**	**1**																	
FCW	**0.90**	**0.50**	**-0.90**	**1**																
BD	**-0.65**	-0.09	**0.45**	**-0.59**	**1**															
porosity	**0.96**	0.24	**-0.75**	**0.93**	**-0.65**	**1**														
pH (H_2O)	**0.48**	0.21	**-0.44**	**0.51**	**0.43**	**0.52**	**1**													
pH ($CaCl_2$)	**0.50**	**0.45**	**-0.64**	**0.63**	**0.39**	**0.58**	**0.83**	**1**												
EC	-0.13	-0.14	0.19	-0.18	0.23	-0.12	0.09	0.04	**1**											
OC	-0.09	-0.24	0.24	-0.18	0.05	-0.16	-0.26	-0.07	0.21	**1**										
TN	0.29	0.02	-0.18	0.25	**-0.34**	0.22	-0.17	-0.18	-0.23	0.10	**1**									
AVN	0.03	**-0.34**	0.25	-0.11	-0.03	-0.04	-0.04	0.13	-0.03	-0.10	0.15	**1**								
NO_3	0.03	**-0.34**	0.24	-0.11	-0.03	-0.04	-0.04	0.14	-0.03	-0.11	0.16	**1.00**	**1**							
Sulphate	0.31	-0.22	-0.01	0.19	**-0.33**	0.22	-0.05	-0.16	0.25	0.30	0.20	-0.06	-0.06	**1**						
Available P	**-0.35**	**-0.35**	**0.48**	**-0.46**	0.26	**-0.48**	**0.46**	**0.55**	0.06	0.23	0.11	0.22	0.21	-0.02	**1**					
Ca	0.22	**-0.39**	0.17	0.01	-0.09	0.18	-0.29	-0.08	-0.01	0.23	-0.01	**0.45**	**0.45**	0.11	-0.01	**1**				
Mg	0.20	**-0.48**	0.25	-0.03	-0.02	0.11	-0.21	0.03	0.12	0.26	-0.22	**0.58**	**0.58**	0.23	0.08	**0.79**	**1**			
K	0.08	**-0.55**	**0.38**	-0.16	-0.09	-0.02	**-0.37**	-0.03	0.13	0.27	0.01	**0.73**	**0.73**	0.10	0.13	**0.64**	**0.75**	**1**		
Na	-0.26	**-0.59**	**0.61**	**-0.47**	0.17	**-0.35**	0.10	**0.39**	0.05	0.19	0.15	**0.71**	**0.71**	0.00	**0.37**	**0.50**	**0.56**	**0.70**	**1**	
H+Al	0.03	-0.06	0.03	0.03	0.02	0.04	**-0.34**	-0.27	**0.34**	0.07	0.01	0.02	0.01	0.03	-0.14	0.08	0.07	0.31	0.08	**1**
ECEC	0.17	**-0.47**	0.26	-0.05	-0.06	0.12	-0.30	-0.04	0.05	0.26	-0.03	**0.56**	**0.55**	0.12	0.04	**0.98**	**0.86**	**0.76**	**0.62**	0.18

Values in bold are different from 0 with a significance level of 5%

and vice versa. Significant positive correlation was observed between field capacity water (FCW) and clay content (*r*= 0.90) as well as FCW and silt content (*r*=0.5). This suggests that an increase in clay and silt fractions of the soils resulted in a corresponding increase in FCW and may not be unconnected to higher number of micropores of these soil fractions. Adamu and Aliyu (2012) recorded high water holding capacity in Loamy sand soil with a high amount of soil organic matter content and attributed the result to fine texture. However, a very high but negative correlation between FCW and sand content (*r*=-0.9) as well as between FCW and bulk density (*r*=-0.59) was observed and may be due to the many macropores present in sand which allow free drainage. Shehu *et al*. (2015) linked low water retention of the Savanna soils of Shanono and Bunkure Local Government Areas of Kano State, Nigeria to the low level of organic carbon with a high proportion of sand particles.

Pearson's correlation coefficient revealed significant (P<0.05) negative correlation between bulk density and clay content as well as bulk density and porosity (*r*=-0.65). This may be due to the weightless nature of pore spaces as well as the lighter weight of clay particles compared to their larger sand counterpart. However, highly significant (P<0.01) correlation was observed between porosity and clay as well as porosity and FCW (*r*=0.96) and (*r*=0.93) respectively. Significant (P<0.05) positive correlation between soil pH with clay, FCW and porosity may due lower leaching of basic cations with increasing clay content. Similarly, negative correlation between pH and sand content may be due to leaching of the basic cations from the soils which result in the soil becoming more acidic (Table 2). A highly significant (P<0.01) positive correlation was observed between NO_3^- and available nitrogen (r= 1.00). This implies that an increase in available nitrogen of the soils will result in a corresponding increase in soil nitrate concentration. Highly significant positive relation was observed between AVN and NO_3^- with K and Na (Table 2). Similarly, there is a highly significant positive correlation between ECEC with all the basic cation. This is anticipated as the exchangeable bases accounted for almost all ECEC.

Principal Components Analysis

The suitability of using principal component analysis (PCA) was assessed by determining the Kaiser- Mayer-Olkin (KMO). This helps to determine if the samples are adequate to perform PCA. Result revealed a KMO value of 0.597 (Table 3) suggesting that the sample are sufficient for PCA. Abdulkareem *et al*. (2019); Smith (2002) reported that if KMO value is ≥ 0.5, PCA can be carried out on the data.

Selection of Principal Components

Twenty-one (21) soil properties were subjected to PCA where 21 principal components (PCs) were identified (Table 4). However, scree plot (Fig. 2) shows that only six (6) PCs were most valuable as they have eigen value of >1 and a cumulative variance of 83.55 % (Table 4). These six PCs were selected and retained. The most influential among the PCs is PC 1 with an eigenvalue of 6.35 and accounted for 28.86 % of the cumulative variance. Similarly, PC 2, 3, 4, 5 and 6 have eigenvalues of 5.17, 2.55, 1.41 and 1.29 respectively with variability of 23.48, 11.58,7.37 and 5.88 % for PC 2, 3, 4,5 and 6 respectively (Table 4). After varimax rotation, PC 1 has strong positive loading of clay, FCW and porosity (0.936, 0.934 and 0.955 respectively) (Table 5 and 6). Similarly, strong but negative loading of sand with an Eigen value of -0.775 and bulk density (-0.708) were recorded. These properties are related to water movement and holding capacity of the soils and indicates that the moisture characteristics of these soils are significant contributors to the soil variability. Strong positive correlation observed between clay, FCW and porosity with PC 1 (Table 6) suggests that increase in this soil properties will lead to a corresponding increase in moisture retention and movement within these soils. While strong but negative correlation observed between sand and bulk density (Table 6), indicates that high sand and bulk density will lead to a reduction in the water holding capacity of these soils. Adamu and Aliyu (2012) reported increased water holding capacity in soils with finer texture and linked it to high clay and organic matter content of the soils.

TABLE 3 KAISER-MEYER-OLKIN (KMO) MEASURE OF SAMPLING ADEQUACY

Soil property	KMO values
Clay	0.609
Silt	0.565
Sand	0.666
FCW	0.887
Bulk density	0.699
Porosity	0.633
pH (H_2O)	0.616
pH ($CaCl_2$)	0.625
EC (dSm^{-1})	0.423
OC	0.646
TN	0.197
AVN	0.506
NO_3	0.503
Sulphate	0.383
Available P	0.770
Ca	0.506
Mg	0.591
K	0.868
Na	0.787
H+Al	0.425
ECEC	0.568
KMO	0.597

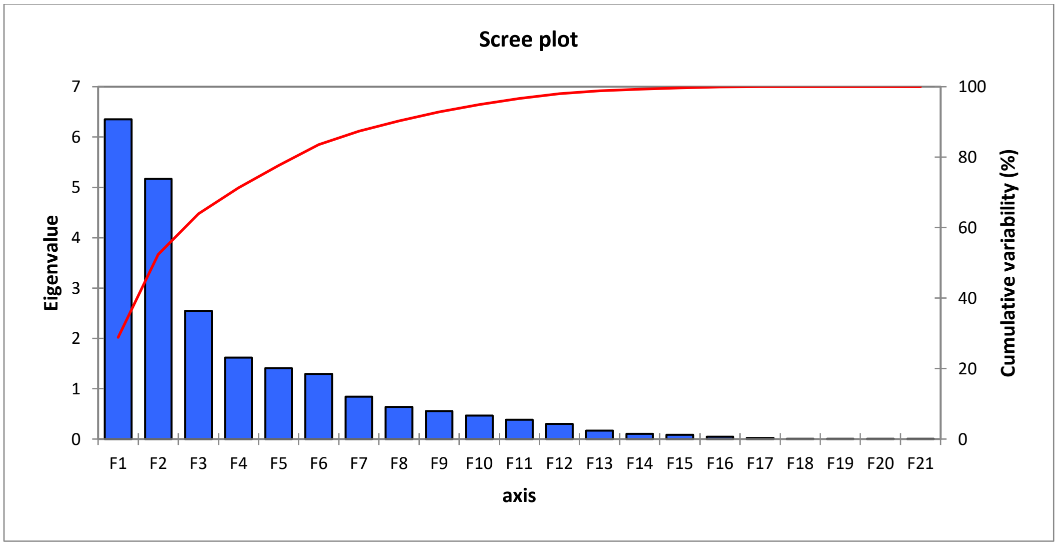


Figure 2: Scree plot of extracted PCs or factors (factors with Eigenvalue ≥ 1 are considered the most significant)

TABLE 4: EIGENVALUE, VARIABILITY AND CUMULATIVE PERCENTAGE OF EXTRACTED PCs

PC	Eigen value	Variability (%)	Cumulative (%)
PC 1	**6.349**	**28.860**	**28.860**
PC 2	**5.166**	**23.482**	**52.342**
PC 3	**2.547**	**11.579**	**63.921**
PC 4	**1.621**	**7.366**	**71.287**
PC 5	**1.406**	**6.389**	**77.676**
PC 6	**1.293**	**5.878**	**83.554**
PC 7	0.843	3.832	87.387
PC 8	0.640	2.909	90.296
PC 9	0.554	2.520	92.816
PC 10	0.465	2.116	94.932
PC 11	0.385	1.749	96.681
PC 12	0.298	1.356	98.037
PC 13	0.169	0.769	98.806
PC 14	0.106	0.481	99.287
PC 15	0.086	0.389	99.676
PC 16	0.048	0.218	99.894
PC 17	0.019	0.089	99.983
PC 18	0.004	0.016	99.999
PC 19	0.000	0.001	99.999
PC 20	0.000	0.000	100.000
PC 21	0.000	0.000	100.000

Values in bold represents PCs with Eigen value ≥ 1

TABLE 5: FACTOR LOADINGS AFTER VARIMAX ROTATION

Soil property	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Clay	0.936	0.133	-0.042	-0.038	0.093	0.069
Silt	0.299	-0.570	-0.124	-0.350	-0.395	-0.071
Sand	-0.775	0.361	0.119	0.291	0.250	0.018
FCW	0.934	-0.125	-0.078	-0.195	-0.096	0.040
Bulk density	-0.708	-0.056	0.160	0.043	-0.166	-0.292
Porosity	0.955	0.044	-0.038	-0.124	-0.004	-0.020
pH (H_2O)	-0.428	-0.202	0.085	0.805	-0.163	-0.026
pH ($CaCl_2$)	-0.550	0.091	-0.002	0.724	-0.049	-0.014
EC	-0.092	0.022	0.968	0.001	0.066	-0.077
OC	-0.210	0.122	0.106	-0.262	0.775	0.107
TN	0.215	0.006	-0.203	-0.080	0.122	0.837
AVN	-0.035	0.836	-0.009	0.089	-0.381	0.295
NO_3	-0.033	0.833	-0.012	0.091	-0.382	0.296
Sulphate	0.371	0.063	0.339	0.214	0.586	0.219
Available P	-0.470	0.146	0.012	0.422	0.151	0.364
Ca	0.128	0.808	-0.094	-0.109	0.268	-0.270
Mg	0.108	0.869	0.084	0.037	0.207	-0.285
K	-0.079	0.892	0.127	-0.223	0.078	0.112
Na	-0.396	0.780	0.002	0.108	0.019	0.255
H+Al	-0.072	0.124	0.454	-0.600	-0.041	0.120
ECEC	0.061	0.896	-0.013	-0.130	0.237	-0.201
Eigen value	6.349	5.166	2.547	1.621	1.406	1.293
Variability (%)	22.759	25.483	10.678	10.017	7.969	6.649
Cumulative (%)	22.759	48.241	58.919	68.936	76.905	83.554

TABLE 6: CORRELATIONS BETWEEN VARIABLES AND FACTORS AFTER VARIMAX ROTATION

Soil property	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Clay	0.936	0.133	-0.042	-0.038	0.093	0.069
Silt	0.299	-0.570	-0.124	-0.350	-0.395	-0.071
Sand	-0.775	0.361	0.119	0.291	0.250	0.018
FCW	0.934	-0.125	-0.078	-0.195	-0.096	0.040
Bulk density	-0.708	-0.056	0.160	0.043	-0.166	-0.292
Porosity	0.955	0.044	-0.038	-0.124	-0.004	-0.020
pH (H_2O)	-0.428	-0.202	0.085	0.805	-0.163	-0.026
pH ($CaCl_2$)	-0.550	0.091	-0.002	0.724	-0.049	-0.014
EC	-0.092	0.022	0.968	0.001	0.066	-0.077
OC	-0.210	0.122	0.106	-0.262	0.775	0.107
TN	0.215	0.006	-0.203	-0.080	0.122	0.837
AVN	-0.035	0.836	-0.009	0.089	-0.381	0.295
NO_3	-0.033	0.833	-0.012	0.091	-0.382	0.296
Sulphate	0.371	0.063	0.339	0.214	0.586	0.219
Available P	-0.470	0.146	0.012	0.422	0.151	0.364
Ca	0.128	0.808	-0.094	-0.109	0.268	-0.270
Mg	0.108	0.869	0.084	0.037	0.207	-0.285
K	-0.079	0.892	0.127	-0.223	0.078	0.112
Na	-0.396	0.780	0.002	0.108	0.019	0.255
H + Al	-0.072	0.124	0.454	-0.600	-0.041	0.120
ECEC	0.061	0.896	-0.013	-0.130	0.237	-0.201

Principal component 2 contains a strong positive loading of available nitrogen, nitrate, Ca^{2+}, Mg^{2+}, K^+, Na^+ and ECEC (Table 5). These properties are related to the nutrient holding capacity of the soils which is a reflection of soil fertility. Strong loading of available nitrogen, nitrate, Ca^{2+}, Mg^{2+}, K^+, Na^+ and ECEC observed (Table 5 and 6) suggests that variation in nutrients holding ability of these soils is a factor contributing to their variability. Strong positive relationship observed between these factors and PC 2 implied that the higher the available nitrogen, nitrate, Ca^{2+}, Mg^{2+}, K^+, Na^+ and ECEC of these soils, the higher the soil fertility. Dai *et al*. (2018); Arit (2016) reported that soil cation exchange capacity reflects the retention and supply capacity of soil nutrients. They opined that it is an important indicator for evaluating soil fertility and the higher the ECEC the higher the soil fertility.

Similarly, PC 3 has a strong positive loading of EC (Table 5). This suggests that the soil EC has strong influence in determining the variability of these soils and the PC is associated with soil salinity. This may be attributed to the quality of irrigation water as some of these locations have been under dry and wet season farming for a long period. Also, high positive correlation observed between this PC and EC (Table 7) indicates that as the EC increases, the salinity of the soil increases and vice versa. Kwaghe *et al.* (2017) linked higher EC in their study area to increasing soluble salts concentration from irrigation water.

PC 4 shows a strong positive loading of pH in water and $CaCl_2$ had a moderate negative loading of H + Al (Table 5). The positive moderate loading of pH in water and $CaCl_2$ and moderate negative loading of H + Al is related to soil reaction and indicates the contribution of these variables to the variability of these soils. This correlation of the factors with PC 4 revealed a high positive relationship between pH in $CaCl_2$ and PC 4 while moderate but negative correlation was observed between H + Al and PC 4 (Table 6). Barreto *et al.* (2006) reported lower pH with increasing potential acidity (H + Al) and linked it to leaching of the basic cations.

Also, PC 5 was reported to have a strong positive loading of organic and a moderate loading of sulphate (Table 5). High loading of organic carbon is an indication of the variable organic matter content of these soils due to differences in vegetation cover and high temperature associated with the Savanna climate. It may also be due to the alternate wet and dry seasons obtainable in this region. Similarly, moderate loading of sulfur may be due to the fact that significant quantity of sulfur is being contributed by organic matter. Oldham (2021) reported that Organic matter is the source of organic sulfur compounds and is the main source of soil sulfur in most soils.

PC 6 has a strong positive loading of total nitrogen (Table 5). This may be related to the contribution of organic carbon to the soil variability. This PC is associated with organic matter which relates to soil fertility. Mustapha *et al.* (2011), Yang *et al*. (2013), and Uzoho *et al*. (2014) reported increasing N contents with the higher organic carbon content.

CONCLUSION

Results from this study highlighted that multivariate analysis is appropriate for studying large datasets to determine soil variability contributors among soils of the study area. Results revealed that clay content, FCW, soil porosity, total nitrogen, available nitrogen, nitrate, exchangeable bases, ECEC, EC, pH in $CaCl_2$, H + Al, organic carbon and sulphate were the main soil properties influencing soil variability under this study. Therefore, soil properties that are key contributors to soil variability in the Nigerian Savanna are those related to water and nutrients retention as well as those of soil salinity and reaction. Management of these properties through the incorporation of organic residues is key for economic and environmentally sustainable agricultural practices in the Nigerian Savanna.

REFERENCES

Abdulkareem, J. H., Umar, D. A., Gabasawa, A. I., Anyika, C., and Jamil, N. R. (2019). Long-Term Water Quality Assessment in a Tropical Monsoon. *Science and Technology*, *27*(4), 1955–1959.

Adamu, G. K., & Aliyu, A. K. (2012). Determination of the Influence of Texture and Organic Matter on Soil Water Holding Capacity in and Around Tomas Irrigation Scheme , Dambatta Local Government Kano State. *Research Journal of Environmental and Earth Sciences*, *4*(12), 1038–1044.

Arit, E. (2016). The Soils Cation Exchange Capacity and its Effect on Soil Fertility. *Permaculture News*.

Balasubramanian, A. (2017). *Soil Taxonomy and Classification* (Issue April). https://doi.org/10.13140/RG.2.2.15832.08964

Barreto, A. C., Lima, F. H. S., Freire, M. B. G. S., Araújo, Q. R. and Freire, F. J. (2006). Chemical and physical characteristics of soil under forest, agroforestry system and pasture in the south of Bahia. *Caatinga Magazine*, *19*(4), 415–425.

Beernaert, F. and Bitondo, D. (1992). *Simple and practical methods to evaluate analytical data of soil profiles*. 66 pp.

Benjamin, E. S. (2017). USDA Soil Taxonomy : Soil Orders and their Major Characteristics. In *Environment* (p. 13 pp).

Black, C. A. (1965). *Methods of soil analysis Part I and II*. American Society of Agronomy Inc. Publisher, Wisco 1572 PP.

Blake, G. R., & Hartge, K. H. (1986). Bulk density. *Methods of soil analysis: Part 1 Physical and mineralogical methods*, *5*, 363-375.

Bray, R.H. and Kurtz, L. (1945). Determination of total organic and available forms of phosphorus in soils. *Soi l Science Jounal of America*, *59*, 39–45.

Dai, y., Qiao, X. and Wang, X. (2018). Study on Cation Exchange Capacity of Agricultural Soils. *IOP Conference Series: Materials Science and Engineering*, *392*(042039). https://doi.org/10.1088/1757-899X/392/4/042039

Esu, I. E. (1991). *Detailed Soil Survey of NIHORT Farm at Bankure, Kano State Nigeria*.

Ezeaku, P.I. and Salau, E. S. (2005). Indigenous and scientific soil classification systems: Acase of differences in criteria in some soils of northcentral Nigeria. *Production Agriculture and Technology Journal*., *1*(1), 54–66.

Ezeaku, P. I. (2013). Evaluating the Spatial Variability of Soils of Similar Lithology under Different Land Uses and Degradation Risks in a Guinea Savanna Agro-Ecology of Nigeria. *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, *5*(5), 21–31.

Ferre, L. (1995). Selection of components in principal component analysis : A comparison of methods. *Computational Statistics and Data Analysis*, *19*, 669–682.

Hunt, N., and Gilkes, R. (1992). *Farm Monitoring Handbook. The University of Western Australia*.

Jaiswal, P. (2003). *Soil, PlanT and Water Analysis*. Kalyani Publishers Ludhiana, New Delhi – Norda Hyderabad, India.450 pp.

Jibrin, J.M., Abubakar, S.Z. and Suleiman, A. (2008). Soil fertility status of the Kano river irrigation project area in the Sudan Savanna of Nigeria. *Journal of Applied Science*, *8*, 692–696.

Jones, M. J. (1973). The Organic Matter Content of the Savanna. *Journal of Soil Science*, *24*(I), 42–53.

Juo, A. S. R. (1978). *Selected methods for soil and plant analysis*. Manual series No. 1, Ibadan, Nigeria: IITA, p. 57.

Kwaghe, E. K., Saddiq, A. M., & Solomon, R. I. (2017). Integrated Nutrient Management on Soil Properties and Nutrient Uptake by Red Onion. *Turkish Journal of Agriculture - Food Science and Technology*, *5*(5), 471–475.

Lal, R. (1994). .Methods and guidelines for assessing sustainability use of soil and water resources in the tropics. *Soil Management Support Services Technical Monograph*, *#21*, 1–78.

Maccarthy, D. S., Agyare, W. A., Vlek, P. L. G. and, & Adiku, S. G. K. (2013). Spatial Variability of Some Soil Chemical and Physical Properties of an Spatial Variability of Some Soil Chemical and Physical Properties of an Agricultural Landscape. *West African Journal of Applied Ecology*, *21*, 47–61.

Marx, E.S. Hart, J. and Stevens, R. G. (1999). *Soil Test Interpretation Guide* (Issue Oregon State University; and Bob Stevens, Extension soil scientist, Washington State University).

Mustapha, S., Voncir, N. and Umar, S. (2011). Content and Distribution of Nitrogen Forms in some Black Cotton Soils in AkkO LGA, Gombe State, Nigeria. *International Journal of Soil Science*, 1–7.

Mustapha, S. and Nanlee, C. C. (2007). Fertility and salinity/sodicity status of some fadama soils in Jos, Plateau state Nigeria. *Journal of Sustainable Development, Agriculture and Environment*, *3*, 96–103.

Oldham, L. (2021). Secondary Plant Nutrients: Calcium, Magnesium, and Sulfur, Calcium,. *Mississippi State University Extension Service*, 2 pages. http://extension.msstate.edu/publications

Oliveira, I. A. De, Júnior, J. M., César, M., and Campos, C. (2017). Multivariate technique for determination of soil pedoenvironmental indicators in Southern Amazonas. *Acta Scientiarum Agronomy*, *39*(1), 99–108.

https://doi.org/10.4025/actasciagron.v39i1.30763

Raji, B.A. and Mohammed, K. K. (2000). Nature of acidity in Nigerian Savanna soils . *Samaru Journal of Agricultural Research*, *16*(January 2000), 15–24.

Shehu, B. M., Jibrin, J. M., & Samndi, A. M. (2015). Fertility Status of Selected Soils in the Sudan Savanna Biome of Northern Nigeria. *International Journal of Soil Science*, *10*(2), 74–83. https://doi.org/10.3923/ijss.2015.74.83

Silva, A. S., Lima, J. S. S., Xavier, A. C., and Teixeira, M. M. (2010). Variabilidade espacial de atributos químicos Com, um Latossolo Vermelho-Amarelo húmico cultivado café. *Revista Brasileira de Ciência Do Solo*, *34*(1), 15–22.

Smith, L. I. (2002). *A tutorial on principal components analysis introduction*.

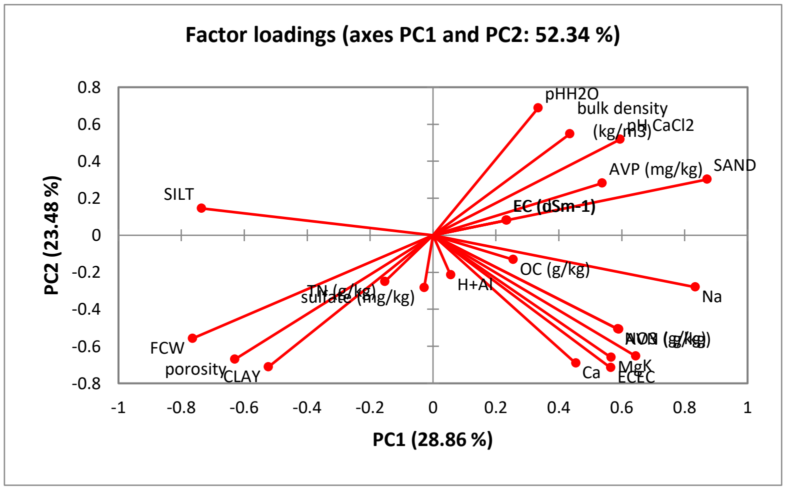
Sonneveld, B. (2005). *Dominant soils of Nigeria. Amsterdam: Stichting onderzoek werelvoedelvoorziening van de vrije universiteit (SOWVU).* (p. World soil information data base.). World soil information data base.

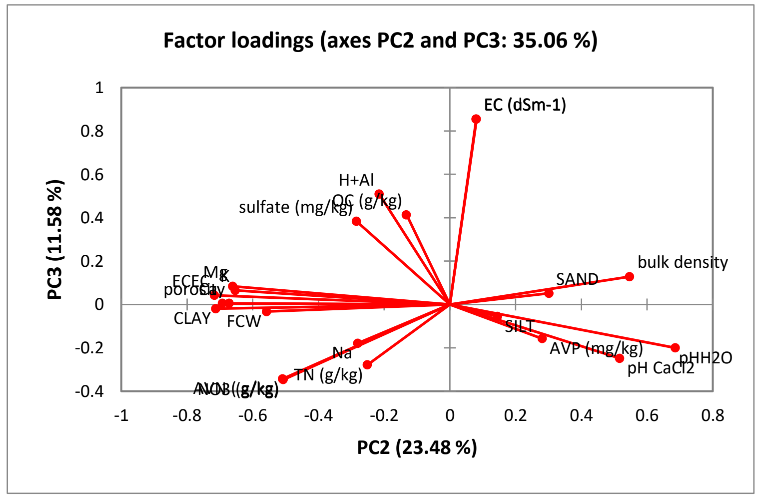
Uzoho, B.U., Ekpe, I. I., Ahukaemere, C. M., Ndukwu, B.N., Okoli, N.H., Osisi, F.A. and Chris- Emenyonu, C. M. (2014). Nitrogen Status of Soils of Selected Land-uses of Two Cropping Systems in the Humid Tropical Rainforest , Southeastern Nigeria. *Advances in Life Science and Technology*, *25*, 24–34.

Walkley, A., & Black, I. A. (1947). Determination of organic matter in the soil by chromic acid digestion. *Soil Sci*, *63*, 251-264.

Yang, X., Zhu, B., & Li, Y. (2013). Spatial and Temporal Patterns of Soil Nitrogen Distribution under Different Land Uses in a Watershed in the Hilly Area of Purple Soil , China. *Journal of Meteological Science*, *10*, 410–417. https://doi.org/10.1007/s11629-013-2712-7

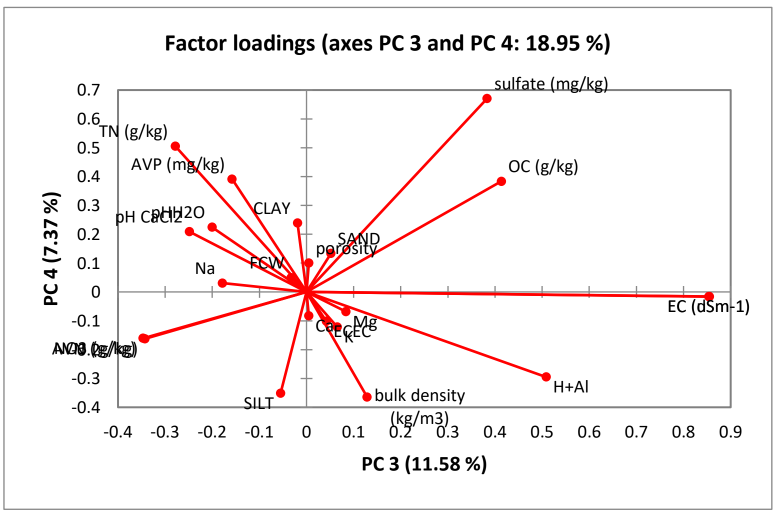
APPENDICES

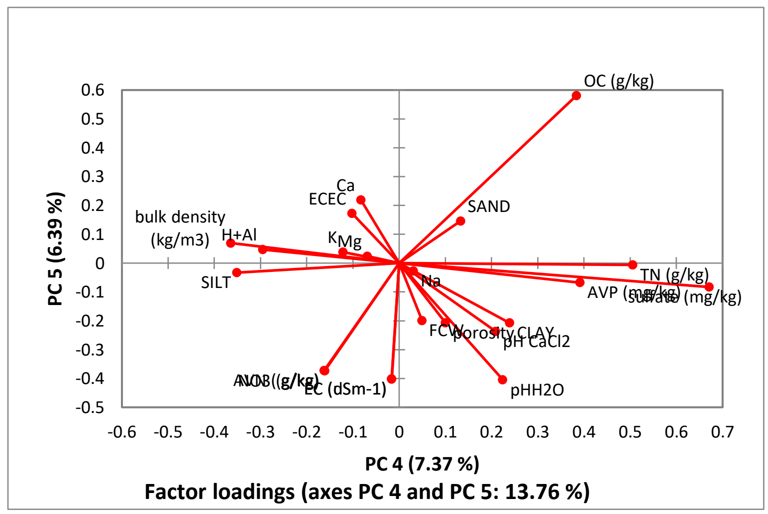




(a) (b)

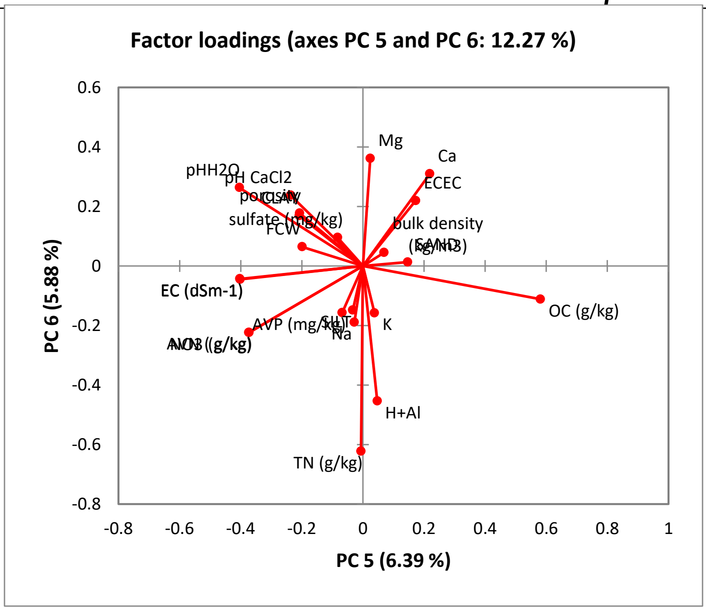
Appendix I: Graphical presentation of factor loadings between (a) PC 1 and PC 2 (b) PC 2 and PC 3





(a) (b)

Appendix II: Graphical presentation of factor loadings between (a) PC 3 and PC 4 (b) PC 4 and PC 5



Appendix III: Graphical presentation of factor loadings between PC 5 and PC 6