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Research Paper

Determination of Soil Nutrients Management Zones using Principal Component and Clustering Analysis in Bade LGA, Yobe State, Nigeria

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ABSTRACT: *Determination soil nutrients management zone will define site specific management strategies for enhanced crop productivity. Soils samples were taken through multi-staged sampling method from the five geographical zones (Dagona, Gashua, Gwiokura, Sugum-Tagali and Usur-Dawayo) in the Local Government Area (LGA) with the aim of determining the level of variability between the zones. Nineteen soil physico-chemical properties were analyzed from the samples and Principal Component and clustering analysis was used to classify the soils into similarity zones. Results indicate that higher coefficient of variation (CV) with EC, calcium, magnesium, sodium and exchangeable sodium percentage and low to moderate CV for the other soil properties. There was no consistency in the status of soil physical properties between the zones. Sand fraction was high in Gwiokura, clay at Usur-Dawayo, bulk density in Gashua and saturated hydraulic conductivity in Gwiokura. Total nitrogen was the only chemical property significantly higher in Gashua than other zones. The first four principal components (PC1, PC2, PC3 and PC4) together explained 100% of the total variance of soil physico-chemical properties. The PC1 was significantly correlated with clay, magnesium, potassium, whereas significant correlation between pH, Available P, potassium, BS, ESP and PC2 was observed. PC3 significantly correlated with OC, nitrogen, pH, sodium and ESP. EC and Fe positively correlated with PC4. Clustering analysis indicated that Sugum-Tagali and Usur-Dawayo zones are closely similar in their soil properties, while Dagona and Gashua clustered together and Gwiokura is simplicifolious. Therefore consideration should be given soil management according to their clustering.*

KEYWORDS: *Gashua, nutrient, PCA, soils, Yobe*

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I. INTRODUCTION

Knowledge of soil properties variability in relation to locations requires techniques to demarcate areas for optimized site specific soil management [1, 2]. Assessment of many soil properties for soil quality determination is very cumbersome and time consuming. Moreover, the observed variables tend to have many dimensions and not all of them are as important as others, as such certain reduced key variables are selected through some statistical techniques for spatio-temporal soil evaluation [3]. Soil fertility across an area s not always homogeneous, the heterogeneity is caused by both inherent soil properties and anthropogenic variability on soils having different management practices. Multivariate analysis such as principal component analysis (PCA) which is concerned with condensing the observed variables into smaller set of variables (factors) for soil quality assessment without losing much of the necessary information needed from the large data gathered [4]. PCA is a useful tool in determining the variation in soils [5]. PCA can be applied for dimension reduction on predictor variables that have a strong correlation so that the principal components formed has no significant correlation. PCA has been applied to many research fields including soil science. PCA has been used to determine the levels and metal variations in the soil of the mining zones, and to examine the distribution of the metals across the mining sites in Kebbi State, Nigeria [6]; it was also employed to determine the driving soil properties that account for soil variability in some soils of the Nigerian Savanna [7, 8]. PCA was also used to delineate areas into nutrient management zones in the maize-based cropping system in Nigeria [9]. It then becomes very important to study the variability of the soil properties that are geographically related, so as to develop sustainable site specific soil management strategies in the study area. Thus, this study evaluated the soil physico-chemical properties of the soils of the five agricultural zones in the LGA to be able to understand their status and apply appropriate management practices.

II. MATERIALS AND METHODS

Study site

The study was conducted in Bade Local Government Area (LGA) of Yobe State, Nigeria. The LGA is located in the northern part of the State on latitude and longitude (Figure 1). The area is Sahel savanna, with an average altitude of 299m above sea level. The dominant soils type in the area are Inceptisols, Alfisols and Oxisols with mostly sandy clay loam to sandy loam texture. Rainfall is unimodal with mean annual amount of a little above 400 mm, the rainy season is usually between Junes to September. Mean annual minimum and maximum temperatures are 12 and 40 °C, respectively.

Soil Sampling and Laboratory Analyses

A stratified random sampling procedure was used for soil sampling. The LGA was divided into five (5) management zones (Dagona, Gashua, Gwiokura, Sugum-Tagali and Usur-Dawayo). Soils were sampled at the depth of 0 – 20 cm using a soil auger from eight (8) randomly selected points in each of above listed management zones. The sampling points' geographic coordinates were recorded using GPS device.

The collected soil samples were processed and taken to laboratory for physico-chemical analysis using standard routine procedures as described in [10]. Particle size distribution (sand, silt and clay fractions) were determined by the Bouyoucos Hydrometer method. Soil pH and EC were determined in 1:2.5 soil: water mixture using pH and conductivity meter. Soil organic carbon (OC) was determined by Walkley and Black wet oxidation method and total nitrogen (TN) by micro-Kjeldahl method, while available phosphorus was analyzed by Olsen's method. Exchangeable bases were determined using ammonium acetate method, calcium and magnesium were measured from the extract using AAS, while potassium and sodium were measured using Flame photometer. The CEC was determined by the summation methods. Zinc and Iron were determined using DTPA soil test method and Boron by Hot water method).

Statistical Analysis

Descriptive statistics and analysis of variance for soil variables data were computed, where significant differences were detected the means were separated using LSD. The principal component analysis (PCA) and cluster analysis using Euclidean distance and Ward's clustering methods for the data.

III. RESULTS AND DISCUSSIONS

Table 1 presents the summary statistics of the physico-chemical properties of the soils of the study area. The soil properties were rated according to Esu [15] for physico-chemical properties; Ryan et al. [10] for micro nutrients and Pawar [11] for hydraulic conductivity. The soil textural class for the study locations is sandy loam with slight coefficient of variation (8.22% for sand fraction and 14.04% for silt, while clay fraction indicated moderate variability (25.62%)). Bulk density was marginally high (1.60 – 1.67 g cm-3) across the sampled locations with slight CV (0.91%). The Saturated hydraulic conductivity of the soils was moderately variable (31.54%) and ranged between 7.31 mm hr-1 (moderately slow) to 55.79 mm hr-1 (moderate) according to Pawar [11] rating. Soil pH ranged from slightly acidic (6.00) to slightly alkaline (8.70). The Electric conductivity (EC) was highly variable (109.50%) with a mean value 0.25 dSm-1 considered to be non-saline [12], while the wider variability will require close monitoring to prevent salinity problem. Organic carbon (OC) range from low (6.91 g kg-1) to slightly moderate (11.91 g kg-1) with moderate CV (32.24%) across the sampled sites. The mean soil total nitrogen content was moderate (0.19 g kg-1) with moderate level of variability (26.61%). The mean available phosphorus level is rated low (9.13 mg g-1) with slight coefficient of variation (13.48%). the average concentration of calcium (3.89 cmol kg-1) and magnesium (0.67 cmol kg-1) were moderate with high CV (38.46% and 42.71% respectively). Sodium content was highly variable (87.92%) and rated very high (0.61 cmol kg-1). This high sodium concentration in the soils will require serious management to prevent and correct sodicity problem most likely to effect the soils, most especially in areas with alkaline pH. The potassium content in the soils was also high (0.36 cmol kg-1) and moderately variable (28.85%). The average CEC was generally low (5.50 cmol kg-1) and varied moderately (27.35) across the area.

Table 1. Descriptive statistics of the selected soil variables

Soil variables	Mean	Minimum	Maximum	SD $\pm$	CV (%)	Shapiro
Sand (g kg^{-1})	577.51	473.50	794.70	68.02	8.22	0.0001
Silt (g kg^{-1})	287.49	101.50	352.20	41.25	14.04	0.0001
Clay (g kg^{-1})	135.00	55.10	215.10	56.01	25.62	0.1951
Bulk Density (g cm^{-3})	1.64	1.60	1.67	0.02	0.91	0.3487
SHC (mm hr^{-1})	25.12	7.31	55.79	16.90	31.54	0.5878
pH	6.74	6.00	8.70	0.76	11.30	0.0013
EC (dSm^{-1})	0.25	0.07	1.42	0.29	109.50	0.0001
OC (g kg^{-1})	11.90	6.90	19.10	4.10	32.24	0.2684
TN (g kg^{-1})	0.19	0.08	0.29	0.06	26.61	0.7915
AP (mg g^{-1})	9.13	7.07	12.09	1.21	13.48	0.1125
Ca (cmol kg^{-1})	3.89	1.14	6.52	1.46	38.46	0.3236
Mg (cmol kg^{-1})	0.67	0.20	1.08	0.29	42.71	0.1356
Na (cmol kg^{-1})	0.61	0.12	1.88	0.52	87.92	0.0018
K (cmol kg^{-1})	0.36	0.16	0.51	0.10	28.85	0.0033
CEC (cmol kg^{-1})	5.54	2.22	8.51	1.45	27.35	0.4194
ESP (%)	11.48	1.80	32.40	9.62	85.31	0.0026
Zn (mg g^{-1})	0.96	0.79	1.18	0.11	11.58	0.0968
Fe (mg g^{-1})	7.33	3.55	9.88	2.04	27.60	0.0561
B (mg g^{-1})	0.33	0.23	0.42	0.05	15.92	0.3498

The soil physical properties presented in table 2 showed that sand and clay fractions significantly differ within the study sites with Gwiokura area having highest sand content (660.39 gkg-1) and lowest at Usur Dawayo (519.06 gkg-1) and the sand content slightly varied (8.22%) across the five locations. Clay content moderately varied (25.62%) with higher content in Usur Dawayo and minimum at Gwiokura. Soil bulk density was slightly higher at Gashua area (1.66 gcm-1) and lowest at Gwiokura (1.61 gcm-1). Saturated hydraulic conductivity was generally higher at Gwiokura (32.89 mm h-1) and Sugum Tagali (23.00 mm h-1), which is an indication of moderate conductivity but, moderately slow in Gashua (14.64 mm h-1), Dagona (15.16 mm h-1), and Usur Dawayo (14.64 mm h-1) according to Pawar [11] ratings.

Table 2. Mean soil physical properties comparison between the study locations

Zones	Sand gkg^{-1}	Silt gkg^{-1}	Clay gkg^{-1}	TC	Bulk Density gcm^{-3}	SHC mm h^{-1}
Dagona	574.86bc	308.460	116.67c	SL	1.64b	15.16c
Gashua	599.55b	265.100	135.35bc	SL	1.66a	10.68c
Gwiokura	660.39a	277.380	62.24d	SL	1.61c	32.89a
Sugum Tagali	533.69cd	298.500	167.81ab	SL	1.63b	23.00b
Usur Dawayo	519.06d	288.020	192.91a	SL	1.64b	14.64c
CV	8.220	14.040	25.620		0.910	31.540
SE	23.730	20.190	17.290		0.007	3.960
Pr (> F)	0.0001	0.2448	0.0001		0.0001	0.0001

TC = Textural class, SHC = Saturated hydraulic conductivity, CV = Coefficient of variation, SE = Standard error

Table 3 presents results for some chemical properties. Soil pH of sites ranged between very slightly acidic to neutral (6.41 – 7.16) with slight level of variability (11.30%) and fall within the acceptable limit for good crop production [13]. The Electric conductivity (EC) level have shown very high coefficient of variability (109.50%), but falls within the very low level and is a characteristics of mostly sandy soils with low organic carbon as found in the study area. It is also an indication of low level of nutrients and non-saline [14]. Soil organic carbon (SOC) and total nitrogen were moderately variable (32.24 and 26.61% respectively). Total nitrogen (TN) was significantly different within the study locations, where Gashua (0.169 gkg^{-1}), Dagona (0.116 gkg^{-1}) and Usur Dawayo (0.106 gkg^{-1}) have moderate levels of TN, while Gwiokura and Sugum Tagali were rated low [15]. Available phosphorus was generally low all over with slight level of variability (13.48%).

Table 3. Mean soil chemical properties comparison between the study locations

Zones	pH	EC dSm^{-1}	SOC gkg^{-1}	TN gkg^{-1}	AP $mgkg^{-1}$
Dagona	6.700	0.136	1.420	0.116ab	8.950
Gashua	7.160	0.323	1.330	0.169a	9.430
Gwiokura	6.410	0.144	0.890	0.069c	9.340

Sugum Tagali	6.730	0.191	1.090	0.087bc	9.340
Usur Dawayo	6.680	0.471	1.220	0.106ab	8.600
CV	11.300	109.500	32.240	26.610	13.480
SE	0.380	0.139	0.192	0.025	0.616
Pr (> F)	0.4166	0.0974	0.0692	0.0123	0.6353

CV = Coefficient of variation, SE = Standard error

Soil exchangeable bases results as presented in table 4 showed that calcium, magnesium, sodium and potassium as well as cation exchange capacity (CEC) and exchangeable sodium percent (ESP) were all not significantly different within the study sites. Calcium and Magnesium concentration in the soils were moderate, highly variable within the location (CV was 38.46% and 42.71% respectively). Although there was no significant difference in sodium content between the locations, but the concentrations were generally rated high [15] and highly varied (87.92%). CEC was rated low and moderately varied across the sites (27.35%). The ESP was highly variable (85.31%) and ranged between the minimum in Gwiokura (8.79%) to the maximum in Gashua area (15.59%) which is above the threshold (15%) that soil water infiltration problem and crusting would be expected to occur due to clay dispersion by the action high sodium concentration in relation to other cations in the soil [16].

Table 4. Mean soil exchangeable bases content, CEC and ESP within the study locations

Zones	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CEC	ESP
	cmol kg^{-1}					%
Dagona	3.940	0.715	0.640	0.353	5.650	11.670
Gashua	3.520	0.634	0.813	0.369	5.340	15.590
Gwiokura	4.490	0.497	0.442	0.307	5.730	8.790
Sugum Tagali	3.550	0.730	0.639	0.413	5.330	12.390
Usur Dawayo	3.980	0.798	0.524	0.353	5.660	8.940
CV	38.460	42.710	87.920	28.850	27.350	85.310
SE	0.749	0.144	0.269	0.052	0.758	4.900
Pr (> F)	0.6984	0.2976	0.7059	0.3881	0.9708	0.9269

CV = Coefficient of variation, SE = Standard error

The critical values of the micro nutrients assessed in the different farming zones in Bade LGA were presented in table 5. The results showed that zinc (Zn) content of the soils across the zones was marginal (< 1.00 mg kg-1) and slightly varied (11.58%), while iron (Fe) is rated high (> 4.5 mg kg-1) according Ryan et al. [10] and moderately varied across the zones. Boron (B) was low across the study areas with moderate level of variation (15.92%).

Table 5. The mean values of some micro nutrients in the different locations in Bade LGA

Zones	Zn	Fe	B
		mg g^{-1}	
Dagona	0.920	6.930	0.336
Gashua	0.920	7.600	0.309
Gwiokura	0.990	7.420	0.355
Sugum Tagali	0.980	6.320	0.308
Usur Dawayo	1.010	8.370	0.338
CV	11.580	24.600	15.920
SE	0.056	1.010	0.026
Pr (> F)	0.3413	0.3521	0.3198

CV = Coefficient of variation, SE = Standard error

Principal Component Analysis

Principal component analysis was conducted for some soil properties for the five management zones with regard to level of variability. The results showed that, the four principal components (PC1, PC2, PC3, and PC4) accounted for 100.00% of the total variation in the selected soil properties that had the Eigen values greater than one. PC1 contributed 48.96% of the total variation whereas PC2, PC3, PC4 contributed 25.54%, 13.38% and 12.12% respectively to the total variation (Table 6).

Table 6. Proportion of variability and Eigen values accounted by the Principal Components (PC).

Statistics	PC1	PC2	PC3	PC4	PC5
Standard deviation	3.1293	2.2601	1.6357	1.5568	0
Proportion of Variance	0.4896	0.2554	0.1338	0.1212	0
Cumulative Proportion	0.4896	0.7450	0.8788	1.0000	1
Eigen Values	9.7928	5.1081	2.6755	2.4237	0

Scree plot

Scree plot presented the percentage of variance associated with each principal component obtained in a graph between Eigen values and principal component. The maximum variation was observed in PC1 and decreased gradually in comparison to other next 4 PCs (Fig. 2).

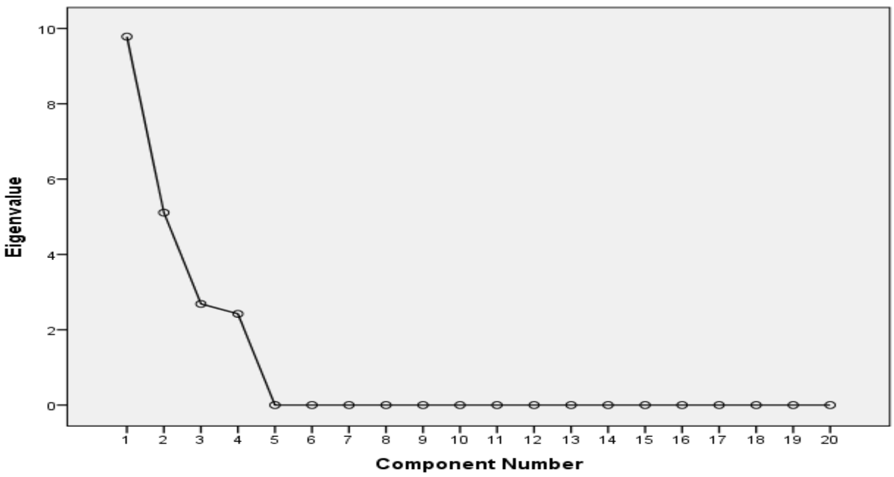

Figure 2. Scree plot of the Eigen values and principal components

Soil variables contribution to principal components (PC)

There were strong positive correlations between Clay content (r = 0.947), Magnesium (r = 0.965), potassium (r = 0.639) and moderate with EC (r = 0.565), while sand content (r = -0.992) and saturated hydraulic conductivity (r = -0.923) indicated negative strong correlations with principal component 1. The correlations between the other soil properties and the first component are very low (Table 7). Component 2 has a high positive correlations with base saturation (BS), available P, potassium (K).

Table 7. Rotated Component Matrix

Soil Variables	Unit	PC1	PC2	PC3	PC4
Sand	gkg^{-1}	-.992	-.075	-.092	.036
Silt	gkg^{-1}	.494	-.378	.045	-.782
Clay	gkg^{-1}	.947	.212	.088	.225
Bulk Density	gcm^{-3}	.307	.412	.765	.388
Sat. Cond.	mm h^{-1}	-.923	-.221	-.299	-.094
pH		.121	.601	.721	.325
EC	dSm^{-1}	.565	-.018	.056	.823
org. C	gkg^{-1}	.352	-.086	.932	-.020
Total N	gkg^{-1}	.308	-.026	.934	.178
Avail. P	$mgkg^{-1}$	-.648	.733	-.053	-.200
Ca^{++}	cmol kg^{-1}	-.477	-.731	-.487	.047
Mg^{++}	cmol kg^{-1}	.965	-.069	.252	-.030
Na^{+}	cmol kg^{-1}	.211	.586	.767	-.158

K^+	cmol kg^{-1}	.639	.689	.171	-.296
CEC	cmol kg^{-1}	-.135	-.931	-.333	-.060
BS (%)	%	-.435	.846	-.306	.033
ESP (%)	%	.185	.681	.701	-.106
Zn	$mgkg^{-1}$	.272	-.198	-.905	.261
Fe	$mgkg^{-1}$	.073	-.438	.029	.895
B	$mgkg^{-1}$	-.360	-.855	-.367	.068

Cluster Analysis

Three main cluster groups were used in a Dendrogram (Figure 3). The results revealed that cluster I consist of two zones (Usur Dawayo and Sugum Tagali), cluster II consist of two zones also (Dagona and Gashua) and cluster III of only one zone (Gwiokura).

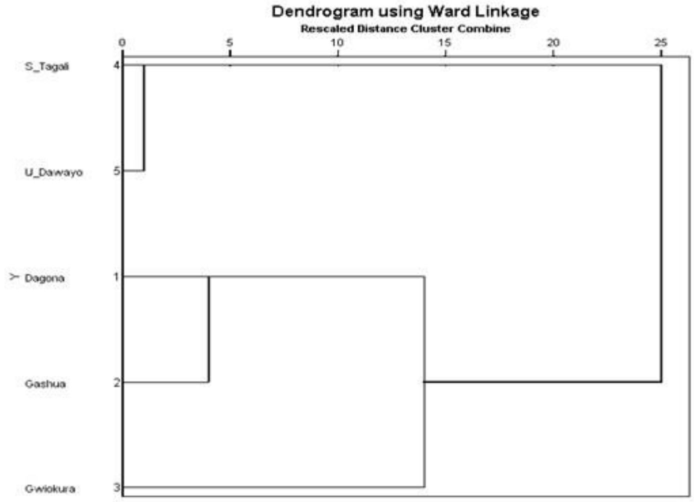

Figure 3. Classification of the five management zones in a Dendrogram

IV. CONCLUSION

Spatial variability was observed in some soil properties between the farming zones in the study sites. These variations were contributed by variables such as clay, magnesium, potassium, pH, Available P, BS, ESP, OC, nitrogen, EC and Fe and are considered as likely indicators in determining the different soil groupings in the study area. PC1 to PC5 explained 100% of the total variance of soil physico-chemical properties and clustering analysis showed that Sugum-Tagali and Usur-Dawayo zones are closely similar in their soil properties, while Dagona and Gashua were clustered together and Gwiokura was on its leaf. Proper nutrient management strategies considering the spatial variability of the soil properties should be adopted for the area.

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