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Identification of Soil Fertility Indices of Inland Valley Soils of Nifor Using Factor Analysis

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Abstract: Principal Component Analysis (PCA) or Factor analysis used to reduce the dimensionality of a data set was applied to soils of the NIFOR Inland Valley to identify the soil fertility indices. The soils were sampled from profile pits and analyzed for particle sizes (Sand, Silt and Clay), free oxides (Fe_d, Fe_o, Al_d and Al_o), micronutrients (Zn, Fe, Cu, Mn and Cl), exchangeable bases (K, Ca, Na and Mg), exchangeable acidity (H^+ and Al^{3+}), total nitrogen, available phosphorus, organic carbon and soil pH using standard laboratory methods. Effective Cation Exchange Capacity (ECEC) and Base saturation percent (B.S.) were also computed and extracted using Principal Component Analysis (PCA). Factors with eigenvalues > 1 explained more total variation in the data than individual soil properties. Retained factors were then subjected to varimax rotation. The results showed that the original twenty five soil properties/variables could be reduced to seven soil properties without any loss of information. Fe_d, sand, clay, Base Saturation %, Organic Carbon, Soil pH and total Nitrogen were variables with the highest loading in each of the components indicating the relative importance of these elements to the understanding of the factors to be considered in managing the soils of the NIFOR Inland Valley for improved cultivation of Raphia palms (*Raphia spp*).

Key words: Factor analysis · Inland Valley · NIFOR · Principal Component Analysis (PCA) · Soil properties

INTRODUCTION

Wetland is an area of land in which the soils are saturated with water either permanently or seasonally [1]. Wetlands or hydromorphic soils have also been defined as soils saturated with water for most parts of the year, such that the morphology of their profile horizons is influenced by the continuous presence of water; poor drainage resulting in gleying and mottling of the profile [2]. Wetland occurs in various categories namely inland valleys (IVs), inland basins, river flood plains and coastal plains [3]. Wetlands have great potentials for sustainable increase in food production because of their inherent high fertility status and their occurrence in the flat or near flat landscapes where soil erosion is not a major constraint to crop production [4, 5] in his evaluation of wetland soils in Akwa Ibom state reported that the land was suitable for maize production. The soils of wetland have received over-whelming acceptance for agriculture [6]. Wetlands are currently underutilized in Nigeria and little studies have been made of their utilization in general [7]. This under-utilization might be as a result of the complexities in chemical properties which are the major determinants of nutrient status of soils [8]. Aquic moisture regime is a characteristic of wetland soils and this makes them chemically dynamic. This dynamic situation of the chemical nature of wetland soils makes the factors that contribute to their fertility status numerous and diverse, there is therefore the need to device ways of identifying these factors for effective management and use. One of such ways of identifying these factors is the use of factor analysis. The use of factor analysis

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facilitates reduction of large number (p) of correlated variables to $m < p$ uncorrelated factors that are linear functions of the original variables. Each factor is responsible for the correlation among the group of soil properties that comprised it [9]. The knowledge of major contributors to soil variability especially at a single plot scale should be complemented with the establishment of minimum data set that could enhance management decision processes for optimum output [10]. The enormous problems of crop production and management systems associated with sub-Saharan Africa ranging from unavailability of inputs, poverty, low soil fertility and resilience and technology creates the need to establish some soil management factors that will facilitate reduction in the dimensionality of parameter indicative of capacity of soils to give optimal crop yield and at the same time adaptive for site-specific management [10, 11]. This approach which has extensively been applied to upland soils has not been applied to hydromorphic or wetland soils.

The objective of this study therefore was to identify the soil physical and chemical properties which influenced the overall fertility status of NIFOR Inland Valley Bottom soils from a set of the physical and chemical properties documented frequently as components of routine and mineralogical analysis.

MATERIALS AND METHODS

Study Area: The study was carried out at the NIFOR Inland Valley located at NIFOR main station. It lies within Latitude 6° 34' N and Longitude 5° 43'E. It is located in the rain forest zone of Nigeria characterized by rainy season (February/March-November) and dry season (November-February/March. There is a short break in the rains in August, known as 'August break.' Rainfall ranges from 2000mm to 3000mm while minimum and maximum temperature ranges are 20°C to 36°C with a mean annual temperature of 25°C.The dominant vegetation of the NIFOR Inland Valley was Raphia *hookeri* and Raphia *vinifera* palms. The Raphia *hookeri* palms are occasionally tapped for palm wine bottling by the Palm wine Bottling Unit of the Nigerian Institute for Oil Palm Research (NIFOR).

Soil Sampling and Laboratory Analysis: Soils samples were obtained from profile pits sunk at the Inland Valley Bottom (IVB) of the NIFOR Inland valley. Though six profile pits were sunk at the study site, only the three that were sited at the bottom of NIFOR Inland was used for this study. Collected soil samples were stored in polythene bags and accurately labelled for further processing in the laboratory. The soil samples were air-dried under shade for seven days, ground with mortar and pestle and sieved with a 2-mm mesh sieve for the determination of physical and chemical properties of the soils. Soil samples used for the determination of organic carbon was further passed through a 0.05mm sieve. The other physical and chemical properties were determined as follows: Particle size distribution was determined using disturbed soil samples by the hydrometer method as described by Bouyoucous [12]. Soil organic carbon was determined by the Walkley and Black method [13]. Total nitrogen (TN) was determined by micro Kjeldahl [14] method. Soil pH was determined using a pH meter [15]. Available phosphorus was extracted by the Bray-1 extractant [16]. Soil exchangeable bases were extracted by the ammonium acetate method buffered at pH 7 [17]. Calcium and magnesium were read with the aid of a UV2100 Spectrophotometer while potassium and sodium were read with a flame photometer. Total exchangeable acidity, hydrogen and aluminium ($H^+ + Al^{3+}$) was by titration method [18] while effective cation exchange capacity (ECEC) was determined by summation of exchangeable cations and exchangeable acidity [19]. The base saturation was calculated as the ratio of exchangeable bases to the effective cation exchange capacity (ECEC) expressed in percentage. Aluminium saturation was calculated as the ratio of exchangeable acidity to the effective cation exchange capacity. The crystalline iron and aluminium oxides designated as Fe_d and Al_d respectively were determined by dithionite-citrate buffered with sodium bicarbonate solution [20]. The content of ammonium oxalate soluble iron and aluminium oxides also designated as Fe_o and Al_o respectively were determined by Mckeague and Day [21] method. The essential micronutrients copper, zinc, manganese and iron were extracted with 1% EDTA, the filtrate was aspirated into an air-acetylene flame of an atomic absorption spectrophotometer and Cu, Zn, Mn and Fe were read at 324.7nm, 213.9nm, 279.5nm and 248.3nm respectively [22] while soluble chloride in soil was obtained by silver nitrate titration [22].

Statistical Analysis (Descriptive Statistics and Principal Component Analysis): The soil properties were analyzed using classical statistical methods to obtain descriptive statistics such as mean, median and coefficient of variation [23] using SPSS version 20. Factor analysis was then used to group the twenty five (25) soil properties into statistical factors based on their correlation structure using SPSS version 20. Factor analysis as a generic term includes principal component analysis and common factor analysis. While the two techniques are functionally very similar and are used for the same purpose (data reduction), they are quite different in terms of underlying assumptions [9]. The term “common” in common factor analysis describes the variance that is analyzed. It is assumed that the variance of a single variable can be decomposed into common variance that is shared by other variables included in the model and unique variance that is unique to a particular variable and includes the error component. Common factor analysis (CFA) analyzes only the common variance of the observed variables [9, 24] while principal component analysis (PCA) considers the total variance and makes no distinction between common and unique variance [9, 11, 25]. Principal component analysis was used as the method of factor extraction because it does not require prior estimates of the amount of variation in each of the soil properties explained by the factors. Factor (principal component) analysis was performed on standardized variables using correlation matrix to eliminate the effect of different measurement units on the determination of factor loadings [26, 27]. Factor loadings are the simple correlation between properties and each factor [28]. Factors with eigenvalues > 1 explained more total variation in the data than individual soil properties. Therefore, only factors with eigenvalues > 1 were retained for interpretation. Retained factors were subjected to varimax rotation. A varimax rotation redistributed the variance of each factor to maximize relationships between the inter-dependent soil properties [29].

RESULTS AND DISCUSSION

There exists a degree of interrelationship among the variables revealing association among soil properties. The correlation matrix is quite complex such that the direction of association among the different soil properties at the NIFOR Inland Valley is not quite clear (Table 1). In order to overcome the problem, we convert this correlation matrix to principal components in order for us to determine which among all the variables are best for representing the structure of the data so that the maximum amount of information measured in terms of its variability is retained in the smallest number of dimension [11]. Ranking of coefficient of variation (CV) of soil properties into different classes including least (< 15%), moderately (15-35%) and highly (>35%) variable according to Wilding [30] indicated that among the twenty five (25) soil properties measured, only sand, soil pH and Na were least variable, they had coefficient of variation less than 15% while silt, Al_d, Zn, Mn, ECEC, BS and CNR were moderately variable as they had CV >15$\leq$ 35% (Table 2). The remaining soil properties which are organic carbon, total nitrogen, exchangeable Mg, Ca, K, acidity, Fe_d, Fe_o, Al_o and phosphorus were highly variable (CV > 35%), (Table 2). Table 3 shows the number of components retained in the analysis. Using the Kaiser criteria according to [24], only principal component having eigen values greater than one are considered as essential, only seven components with eigen values > 1 were retained in the analysis. The first seven components accounted for 19.46, 18.66, 17.55, 12.38, 10.20, 8.83 and 7.39 with about 94.46% cumulative of the total variation in the soil properties correlation matrix with 5.54% explained by the remaining 18 variables (Table 3).

Table 1: Correlation Matrix of physico-chemical properties of soils of NIFOR Inland Valley

	Sand	Silt	Clay	Fe_d	Fe_o	Al_d	Al_o	Zn	Fe	Cu	Cl	Mn	ECEc
Sand	1												
Silt	0.4	1											
Clay	-0.9**	-0.8*	1										
Fe_d	0.6*	0.6	-0.7**	1									
Fe_o	-0.4	0.0	0.0	0.3	1								
Al_d	-0.4	-0.5	0.5	-0.2	0.2	1							
Al_o	0.6*	-0.2	-0.4	0.2	0.3	-0.3	1						
Zn	0.4	0.0	-0.3	0.1	0.2	0.1	0.3	1					
Fe	-0.0	0.0	0.0	0.3	1.0**	0.2	0.3	0.2	1				
Cu	-0.6*	-0.3	0.6	-0.2	0.4	0.9**	-0.6*	-0.0	.04	1			
Cl	0.1	-0.6	0.7	-0.2	0.1	0.4	0.3	0.5	0.1	0.2	1		
Mn	-0.4	-0.5	0.5	-0.2	0.2	1.0**	-0.3	0.1	0.2	0.9**	0.4	1	
ECEc	0.2	-0.3	0.0	-0.4	-0.1	0.3	0.5	0.2	-0.1	-0.0	-0.2	0.1	1

*Correlation sig at the 0.05 level. **Correlation sig at the 0.01 level.

Fe_d = Dithionite extractable iron, Fe_o= oxalate extractable iron, Al_d = Dithionite extractable Aluminium, Al_o= Oxalate extractable aluminium,ECEC = Effective Cation Exchange Capacity,

Table 1: Correlation Matrix of physico-chemical properties of soils of NIFOR Inland Valley contd

	Snd	Slt	Cly	Fe_d	Fe_o	Al_d	Al_o	Zn	Fe	Cu	Cl	Mn	ECE	Bs	pH	OC	TN	C/N	P	Ca	Mg	Na	K	EA	Al.S
BS	0.5	0.3	-0.5	0.1	-0.2	-0.1	0.4	0.1	-0.1	-0.3	-0.2	0.1	0.58*	1											
pH	0.2	-0.0	-0.1	0.2	-0.1	0.3	-0.1	0.2	-0.1	0.3	-0.2	0.3	0.0	0.5	1										
OC	0.6*	0.7**	-0.8**	1.0**	0.2	-0.3	0.1	0.2	0.2	-0.2	-0.2	-0.3	-0.3	0.1	0.1	1									
TN	0.7*	0.3	-0.6*	0.2	0.3	-0.4	0.6*	0.6	0.3	-0.5	0.3	-0.4	0.2	0.4	0.1	0.2	1								
C/N	-0.2	0.2	-0.6	0.3	-0.2	0.1	-0.4	-0.5	-0.2	0.3	-0.4	0.1	-0.1	-0.1	-0.1	0.3	-0.8**	1							
P	0.6	0.3	-0.6	0.4	-0.3	-0.3	-0.0	0.5	-0.3	-0.2	0.2	-0.3	-0.2	-0.1	-0.0	0.5	0.2								
Ca	0.3	0.1	-0.3	-0.2	-0.3	0.2	0.3	0.1	-0.3	-0.0	0.2	0.1	0.8**	0.8**	0.2	-0.1	0.4								
Mg	-0.1	-0.4	0.2	-0.1	0.2	0.0	0.5*	0.0	0.2	-0.2	-0.1	0.0	0.4	0.0	-0.1	-0.2	-0.3								
Na	-0.1	0.2	-0.1	-0.3	-0.2	0.2	-0.2	0.0	-0.2	0.2	-0.2	0.2	0.4	0.6*	0.4	-0.2	0.2								
K	0.5	-0.1	-0.3	-0.1	-0.2	-0.1	0.5	0.1	-0.1	-0.2	0.1	-0.1	0.7*	0.8**	0.3	-0.2	0.5								
EA	-0.6	-0.8**	0.8**	-0.5	-0.1	0.5	-0.1	-0.1	-0.0	0.5	0.5	0.5	0.4	-0.5	-0.4	-0.6*	-0.6								
Al.S	-0.6*	-0.5	0.7*	-0.3	0.1	0.2	-0.4	-0.2	0.1	0.4	0.3	0.2	-0.4	-0.9**	-0.5	-0.3	-0.6*								

*Correlation sig at the 0.05 level. **Correlation sig at the 0.01 level. Snd= Sand, Slt = Silt, Cly = Clay. ECE= Effective cation exchange capacity, BS= Base saturation, OC = Organic carbon, C/N = Carbon to nitrogen ratio, TN = Total nitrogen, EA = Exchange acidity, Al. Sat = Aluminium

Table 2: Descriptive statistics of properties of Inland Valley Bottom Soils of NIFOR

Variable	SE	SD	CV	MEAN	MEDIAN	MINIMUM	MAXIMUM
Sand	0.304	1.054	1.11	94.71	94.50	93.00	96.50
Silt	0.201	0.697	32.44	2.15	2.15	1.40	3.50
Clay	0.430	1.490	47.43	3.142	3.60	1.00	5.60
Fe_d	13.06	47.00	109.56	42.900	21.3	5.86	151.4
Fe_o	0.845	2.929	79.54	3.682	3.385	0.660	9.640
Al_d	0.909	3.149	25.75	12.228	12.040	8.200	19.470
Al_o	0.465	1.611	66.58	2.419	2.090	0.320	5.600
Zn	0.167	0.579	26.710	2.167	2.135	1.290	3.140
Fe	0.295	1.023	79.490	1.288	1.185	0.230	3.370
Cu	0.312	1.081	40.330	2.680	2.735	0.980	5.170
Cl	64.100	222.1	45.78	485.200	497.000	142.000	852.000
Mn	0.248	0.861	25.760	3.341	3.290	2.240	5.320
ECEC	0.212	0.734	33.580	2.188	2.095	1.310	3.600
BS	3.430	11.890	15.360	77.410	76.380	60.780	98.060
pH	0.085	0.294	5.200	5.664	5.585	5.350	6.810
OC	3.071	10.640	72.050	14.767	11.200	3.500	35.500
TN	0.713	2.469	159.810	1.545	0.760	0.190	9.200
CNR	1.490	5.170	33.580	15.410	16.630	1.53	23.000
P	1.01	3.50	49.73	7.04	6.04	2.960	15.310
Ca	0.217	0.753	69.08	1.09	0.84	0.16	2.48
Mg	0.113	0.392	94.94	0.41	0.30	0.08	1.52
Na	0.00796	0.02758	13.91	0.198	0.19	0.16	0.25
K	0.0052	0.018	46.97	0.038	0.030	0.020	0.080
EA	0.0628	0.2174	43.48	0.500	0.45	0.02	0.08
Al.Sat	2.90	10.06	41.82	24.05	23.62	6.83	39.21

Al. Sat = Aluminium saturation, EA = Exchange acidity, CNR = Carbon to nitrogen ratio, OC = Organic carbon, BS= Base saturation, ECEC = Effective Cation Exchange Capacity, Al_o= Oxalate extractable aluminium, Al_d = Dithionite extractable Aluminium, Fe_o= oxalate extractable iron, Fe_d = Dithionite extractable iron

Table 3: Eigenvalues and the proportion of Total variance Explained by the Seven Components

Component	Total	% of Variance	Cumulative %
1	4.865	19.460	19.460
2	4.665	18.661	38.121
3	4.387	17.550	55.671
4	3.094	12.375	68.046
5	2.550	10.200	78.246
6	2.207	8.827	87.073
7	1.846	7.385	94.458

Extraction Method: Principal Component Analysis.

Table 4: Eigenvectors of Principal Components Representing a Linear Combination of the Original Variables

	Component						
Component Matrix[a]	1	2	3	4	5	6	7
Sand	.893	.010	.177	.033	-.173	.312	-.123
Silt	.660	-.448	-.353	.198	.084	-.094	.351
Clay	-.941	.202	.040	-.116	.084	-.177	-.077
Fed	.550	-.521	.101	.468	.101	.338	-.026
Feo	-.007	-.178	.680	.437	.490	-.200	.172
Ald	-.593	.418	.027	.655	-.055	.166	-.005
Alo	.527	.342	.625	-.299	.188	.240	-.112
Zn	.301	.201	.505	.361	-.482	.003	-.067
Fe	-.007	-.178	.680	.437	.490	-.201	.172
Cu	-.687	.193	-.233	.643	-.121	.035	.042
Cl	-.213	.381	.613	.071	-.555	.121	.138
Mn	-.593	.418	.027	.656	-.055	.166	-.005
ECEC	.103	.858	.094	-.151	.111	.363	.209
BS	.658	.589	-.301	.087	.309	.095	-.094
pH	.229	.332	-.297	.536	.000	-.136	-.663
C	.589	-.555	.005	.431	.022	.347	.131
TN	.753	.262	.433	.026	-.164	-.360	.116
CNR	-.270	-.352	-.502	.081	.250	.658	.175
P	.398	-.321	-.004	.024	-.735	.306	-.018
Ca	.398	.809	-.222	.007	-.074	.058	.306
Mg	-.183	.131	.371	-.255	.518	.498	-.284
Na	.203	.613	-.527	.193	.097	-.220	.271
K	.475	.734	-.041	-.118	.093	.059	.055
EA	-.815	.274	.220	-.204	-.068	.368	.144
Alsat	-.808	-.363	.195	-.171	-.210	.018	.126

Extraction Method: Principal Component Analysis. Fe_d = dithionite extracted iron; Fe_o= oxalate extracted iron; Al_d= dithionite extracted aluminium; Al_o = oxalate extracted aluminium.
a. 7 components extracted.

The implication of this is that the 25 soil properties of the NIFOR Inland Valley Bottom soils can be reduced to 7 with minimal loss of information. Table 4 shows the loadings of the twenty five variables on the seven extracted components. The seven components identified seven clear groups. Soil properties mainly associated with the first components are sand, silt, clay, Fe_d, Al_d, Al_o, Cu, Mn, Base saturation, organic carbon, total nitrogen, exchangeable acidity and aluminium saturation percent. Sand, silt, Fe_d, Al_o, Base Saturation percent, organic carbon and total nitrogen had positive loadings or correlations while clay, Al_d, Cu, Mn, exchangeable acidity and aluminium saturation percent had negative loadings or correlations. The second component is associated with the following seven variables: Fe_d, ECEC, Base saturation percent, organic carbon, Ca, Na, K. Similarly, ECEC, Base saturation, Ca, Na and K had positive loadings while Fe_d and organic carbon had negative loadings. Component 3 is associated with six variables namely

Fe_o, Al_o, Zn, Fe, C/N and Na. Fe_o, Al_o, Zn and Fe had positive loadings or correlations while C/N ratio and Na had negative correlations. Component 4 is associated with four variables which are Al_d, Cu, Mn and soil pH. They all had positive loadings or correlations. Component 5 is associated with three variables which are Cl, P and Mg. Only Mg had a positive loading. Components 6 and 7 are associated with two variables only which are C/N ratio and soil pH respectively. Only C/N ratio had a positive loading in component 6 (Table 4) while soil pH had a negative loading in component 7. Given that seven groups have been identified, it is probable that soil properties with significantly high loadings are eventually saying the same thing or closely related. The first group for instance described the importance of weathering in soils as evidenced in the particle sizes having higher correlations or loadings. It also defines the importance of organic matter (organic carbon) at the Inland Valley Bottom soils. Component two seemed to emphasize the findings in components 1. Components two had earlier identified Fe_d, ECEC, BS%, Organic carbon, Ca, Na and K. Fe_d can be used to determine the extent of weathering in soils such that the higher the amount of Fe_d the more advanced the weathering [31]. Component 3 describes the association of micronutrients with amorphous oxides in the soils as it identifies Fe_o, Al_o, Zn, Fe, C/N and Na (Table 4). Component4 describes the role of soil pH in the occurrence of crystalline aluminium oxides and some of the micronutrients. Component 5 identifies magnesium while component 6 identifies the C/N ratio as important in Inland Valley soils of NIFOR. Component 7 simply identifies soil pH. It is however argued that each principal component is a mathematical number without a defined biological meaning, the relative contribution of each soil properties to the components is an indication of their relative importance.

CONCLUSION

The Principal Component Analysis (Factor analysis) has shown that soil properties can be reduced from 25 to 7 components which should guide the farmer in managing soils of the Inland Valley for crop cultivation. The analysis retained about 94.46% of the total variability and identified crystalline iron oxide (Fe_d), Sand, Clay, Base Saturation percent, Organic Carbon soil pH and total nitrogen as variables with the highest loading in each of the components thus indicating the relative importance of these elements to the understanding of the factors to be considered in managing the soils of the NIFOR Inland Valley. Sand and clay are two components of particle size distribution of a soil that affect such properties as drainage and nutrient retention. This means that provision of drainage will help in organic matter decomposition at the NIFOR Inland Valley while the crystalline iron oxides (Fe_d) clearly defined the extent of weathering.

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