Variability of Some Soil Physicochemical Properties on Lithosequence in Funtua, North - Western Nigeria

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Abstract: ***Variability of some physicochemical properties on Lithosequence in Funtua, Northwestern, Nigeria were studied to determine the extent of variation in physical and chemical properties within and between soils developed on basement complexes, loess over basement complexes and loess parent materials. Variability was more pronounced in chemical than in physical properties. Particle density (CV = 0.23%) and exchangeable sodium percentage (CV = 2.23) were the least variable physicochemical properties. Physicochemical properties with highest variability are Si/C ratio (CV =88.29%) and AP (CV = 149%). Less variability (CV ≤ 15%) irrespective of soils were recorded in particle density, bulk density and pH, and therefore required similar management for all the soils. Silt, AWHC, CEC, CEC clay and base saturation were consistently moderately variable (CV: >15 ≤ 35%). Silt/clay ratio, K, OC, TN, AP and AS were consistently highly variable CV > 35%). Large proportion of properties of the soils were highly variable in all the soils with 10 (42%) of physicochemical properties of soils on BC, 9 (38%) on LBC and 13 (54%) on LS. The highly variable status was attributed to difference in land use types, management and cultural practices occurring within the study area. Properties significantly influenced by Lithosequence include available water holding capacity, magnesium, potassium, CEC and TEA. They were significantly highest in soils on loess and contributed to variation in pattern of nutrient and exchangeable bases retention.***

Keywords: Variability, lithosequence, physicochemical properties, coefficient of variability.

1. Introduction

Soil as a natural body is inherently heterogeneous because of the many factors that contribute to soil formation and the complex interactions of those factors. Thus soils are varied on a macro-scale on landscape and on a micro-scale in farmer's field. Variation in soil properties has been found to significantly influence soil management and crop production [1]. Variability of soil properties may be attributed to several sources. Apart from inherent soil differences, variation in soil properties are due to soil forming factors (climate, parent materials, organisms, relief and time) and differences in weathering rates [2], [3]. Man has contributed to soil variability through various forms of land use, fertilizer application and different management practices [4], [5], [1].

Variation in soils from appropriate sampling methods can be described by simple statistical procedures such as range, mean, standard deviation, kurtosis and coefficient of variability (CV). In the use of CV, soil properties with CV of ≤15% are considered less variable, 15 – 35% moderately variable and >35% highly variable [6 – 8], [3]. The extent of soil heterogeneity estimated by analysis of variance (ANOVA) was used to indicate differences within and between field plots [3]. The results indicates significant difference in mean values of N, P, K and OM between field plots studied, and emphasized urgent need for soil testing for fertilizer recommendation to ensure balanced nutrient application. Semivariogram is an essential component of kriging in geostatistics which have been in use to examine soil spartial variability [8 – 10]. The system is effective in bringing out spartial variability patterns but requires collection of large number of soil samples across landscape at close intervals. Thus, the procedure for soil sampling and laboratory analysis are time consuming and costly. The use of semivariograms has contributed to understanding of many aspects of soil variability, genesis, proper land use and site specific farm management [2], [11], [12].

Despite several studies on soil variability in other parts of the world, in Nigeria information is more in Southwest and Forest regions. There is scanty information on soil variation in Northwestern Nigeria [7] and none related to influence of Lithosequence (difference in parent materials). Therefore, the objective of this study was to examine variation in physical and chemical properties within and between soils developed on basement complex rocks, loess over basement complexes and loess deposit.

2. Materials and Methods

2.1 Study Area

The study area is located between latitude 11° 33' 07.4" to 11° 33' 54.2" N and longitude 07° 14' 08.6" to 07° 14' 16.8" E**.** on Northwest of Funtua town in Katsina State, Nigeria. The area is underlain by undifferentiated basement complex and overlying it is aeolian material referred to as Loess deposit [13]. The land forms include a series of plains with scattered inselbergs [14].

Funtua is situated in northern guinea savanna region. The area has mean annual rainfall of about 1051mm and last from May to October [15], [16]. The mean monthly temperature is high reaching 28.8 ^{o}C in April and lowest in December (21.7 ^{o}C).

Land use of the area includes cultivation of cotton, millet, cowpea, soybean, groundnut, maize, and sorghum. The dry season (October to May) experience soil cultivation for irrigated agriculture to produce sugar cane, maize, tomato, onion, pepper, and vegetables [15], [17].

2.2 Field Studies

Total of twenty seven (27) soil samples were collected for the study; seven (7) samples were from soils on basement complex (BC), twelve (12) from soils on loess over basement complex (LBC) and eight (8) on soils on loess deposits (LS). Soils were sampled following standard procedure as described in the USDA Soil Survey Manual [18]. Undisturbed soil samples were collected on the field using core samplers.

2.3 Laboratory Analysis

Soil samples collected were air-dried, ground and sieved to remove materials larger than 2mm. Soil particles of less than 2mm fraction were used for the laboratory analyses. Particle size distribution was determined by hydrometer method [19]. Available water holding capacity (AWHC) was determined by calculating the difference in moisture content at field capacity (33kPa) and permanent wilting point (1500kPa) pressure [20] using pressure plate method as described by Klute [21]. Bulk density was determined by oven drying the undisturbed samples [22]. Particle density was determined using pycnometer method as described by Blake and Hartge [23].

Soil pH was determined in a 1:1 soil/water ratio and the saturation extract was also used to obtain electrical conductivity. Exchangeable bases (Ca, Mg, K, Na) were determined using NH_4OAc saturation method and exchange acidity was obtained by methods described by Thomas [24]. Cation exchange capacity (CEC) was determined by neutral (pH 7.0) NH_4OAc saturation method [25]. Base saturation percentage (BSP) and exchangeable sodium percentage (ESP) estimated by calculation, using proportion of exchangeable bases and exchangeable Na respectively to CEC in percentage. Organic carbon was determined by Walkley-Black dichromate wet oxidation method [26] and total nitrogen (TN) micro-Kjeldahl technique as described by Bremner and Mulvaney [27]. The content of available phosphorus (AP) and available sulphur (AS) were determined by methods described in IITA [28] laboratory manual.

2.4 Statistical Analysis

Each soil property was assessed in terms of descriptive statistics, *ie* mean, maximum and minimum, standard deviation, and coefficient of variability (CV), skewness and kurtosis to assess variability within the soils. The data were analysed using Statgraphic Centurion XV soft-ware package [29]. Variation of soil physicochemical properties between soils developed on the three (3) parent materials were analysed using one way analysis of variance (ANOVA) [30].

3. Results and Discussions

3.1 Soil Fertility Status and Variability within Soils

The descriptive statistical results summarizing data of the physical and chemical properties of the three soils were presented in Table 1. Soil pH ranged between 4.9 and 5.8 and was rated as very strongly to moderately acid [18], [31]. The soils were rated non saline and non sodic as the electrical conductivity (EC) and ESP values were all less than 2 dSm^{-1} and 15% respectively. Exchangeable Mg, K, Na and CEC were rated low to high [32], [33] in the soils. Exchangeable Ca, organic carbon and available phosphorus (AP) were rated as low to medium [32], [33], whereas total nitrogen (TN) was rated low in all the soils as their values were <1.5 gkg^{-1}. From the mean values of available sulphur (6.83 – 11.84 $mgkg^{-1}$) all the soils were rated as adequate. These soils will require high doses of N fertilizer for crop requirement and low to moderate P and K application. Farm yard manure and crop residue incorporation will increase organic matter content thereby improving soil condition and retention of nutrients and water. The extents of variability of the 24 physicochemical properties determined in the study area were presented in Table 1 and 2. Variability of soil properties within the soils were generally more pronounced in chemical properties than in physical properties. The least varied physical property was found to be particle density (CV = 0.23%), and ESP (CV = 2.23 had least variability in chemical properties (Table 2). The physical and chemical properties that had the highest variability within the soils are Si/C ratio (CV =88.29%) and AP (CV = 149%) respectively.

In all the properties, only particle density, bulk density and pH had less variability (CV ≤ 15%) irrespective of the soils. Hence soil management related to compaction and porosity may be handled in similar pattern within all the soils. Silt, AWHC, CEC, CEC clay and base saturation were consistently moderately variable (CV: >15 ≤ 35%). Silt/clay ratio, K, OC, TN, AP and AS were consistently highly variable CV > 35%). The highly variable nutrient status of these soils may be attributed to differences in land use types, management and cultural practices occurring within the study area and the socio-economic status of the farmers as it contribute to input (fertilizer) application in their farms.

Table 1: Descriptive statistics of physical properties of soils of the study area

Soil Properties	Unit	Mean	Range Min.	Max.	SD (σ)	CV (%)	Skewness	Kurtosis
Soils on Basement Complexes								
Sand	%	41.57	25	53	11.59	27.88	-0.64	-1.32
Silt	%	31.71	22	50	9.41	29.68	-0.09	-0.19
Clay	%	22.57	8	37	10.33	45.77	-0.22	-0.82
Si/C	-	2.22	0.88	6.25	1.96	88.29	1.87	3.30
Bulk density	Mgm^{-1}	1.53	1.41	1.67	0.09	5.88	0.45	-0.80
Part. Density	Mgm^{-1}	2.60	2.54	2.65	0.02	0.23	-0.81	-1.17
Total porosity	%	41.23	35.76	46.39	3.65	8.85	-0.16	-0.87
AWHC	%	10.77	6.4	15.9	3.49	32.40	0.69	-0.77
Soils on Loess over Basement Complexes								
Sand	%	30.83	15	41	7.55	24.49	-0.87	0.23
Silt	%	37.75	22	51	8.09	21.43	-0.03	0.33
Clay	%	30.92	12	43	9.29	39.05	-1.06	0.70
Si/C	-	1.49	0.71	4.25	1.11	74.50	2.05	3.25
Bulk density	Mgm^{-1}	1.45	1.26	1.55	0.10	6.90	-0.84	-0.65
Part. Density	Mgm^{-1}	2.58	2.43	2.74	0.09	3.49	-0.06	-0.56
Total porosity	%	43.88	39.92	52.09	3.67	8.36	1.32	1.11
AWHC	%	12.27	6.3	17.2	3.14	25.59	-0.26	-0.44
Soils on Loess								
Sand	%	8.5	3	17	4.87	57.29	0.62	-0.32
Silt	%	56	50	65	5.63	10.05	0.47	-1.21
Clay	%	35.5	18	45	10.09	28.42	-0.80	-0.72
Si/C	-	1.79	1.16	3.61	0.87	48.60	1.55	2.05
Bulk density	Mgm^{-1}	1.45	1.40	1.49	0.04	2.76	-0.29	-1.81
Part. Density	Mgm^{-1}	2.55	2.50	2.59	0.03	1.22	-0.06	-1.06
Total porosity	%	43.1	40.4	45.1	1.48	3.43	-0.63	0.47
AWHC	%	14.8	10.3	18.3	2.86	19.32	-0.06	-1.06

SD = Standard deviation, CV= Coefficient of variability

Large proportion of properties of the soils were highly variable in all the soils (Table 1 and 2) with 10 (42%) of physicochemical properties of soils on BC, 9 (38%) on LBC and 13 (54%) on LS. Five (21%) properties in each of the soils were less variable (CV ≤ 15%). Nine (38%) of the properties for soils on BC were moderately variable (CV: >15 ≤ 35%). Soils on LBC had 10 (42%) properties and LS had 6 (25%) properties to be moderately variable. The moderate and high extent of variability of properties of soils on the lithosequence was attributed to variation in land use types, management and cultural practices applied within the study area. The properties with mostly moderate or high variability include soil separates, AWHC, exchangeable Ca, Mg, K, Na, TEB, CEC, base saturation (BS), OC, TN, AP and AS. These are mostly properties which can easily be altered by varied land use types, cultural and management practices as cropping systems, weeding, fertilizer applications, fallowing and bush burning. Similarly, Ogunkunle and Erinle [4], Fasina [1], Tabi and Ogunkunle [8] and Udo et al. [3] have reported significant variability in some soil physicochemical properties due to influence of land use, cultural and management practices. Therefore for sustainable land use and appropriate management, there is need for thorough understanding of the factors and extent of variability of soil properties within any area of the region of this study. Shi et al. [34] also observed high variability of AP and attributed it to site-to-site differences in mineralization, uneven distribution of fertilizers in past seasons and yield dependent differences in crop AP uptake.

3.2 Variability between Soils

Results for comparison of physicochemical properties of the soils are presented in Table 3. Particle sizes (sand, silt and clay) were significantly different between the soils formed on the different parent materials. Sand was significantly highest in soils on BC followed by LBC and was significantly lowest in LS. Similarly, several researchers have reported sand to be the dominant particle in soils on BC [36, 37, 38]. Silt was significantly highest in soils on LS than BC and LBC, indicating their origin as loessial deposit [13]. The significantly higher clay (Table 3) in LS and LBC compared to soils on BC may be attributed to weathering of materials from silt to clay as indicated by the lower values of Si/C ratio in LS and LBC compared to soils on BC.

Table 2: Descriptive statistics of chemical properties of soils of the study area

Soil Properties	Unit	Mean	Range Min.	Max.	SD (σ)	CV (%)	Skewness	Kurtosis
			Soils on Basement Complexes					
pH	-	5.40	4.9	5.8	0.38	7.09	-0.57	-2.37
Exch Ca.	cmol(+)kg^{-1}	2.05	1.16	2.7	0.52	25.27	-0.85	0.31
Exch Mg.	cmol(+)kg^{-1}	0.41	0.21	0.56	0.12	29.27	-0.62	-0.06
Exch K.	cmol(+)kg^{-1}	0.19	0.1	0.5	0.14	72.63	2.45	6.24
Exch Na.	cmol(+)kg^{-1}	0.09	0.07	0.15	0.03	35.23	1.72	2.36
TEB	cmol(+)kg^{-1}	2.75	1.7	3.48	0.66	23.82	-0.74	-0.75
TEA	cmol(+)kg^{-1}	0.69	0.3	1.2	0.6	51.88	0.64	-1.28
CEC	cmol(+)kg^{-1}	6.23	3.7	8.8	1.81	29.05	-0.03	-1.23
CECc	cmol(+)kg^{-1}	19.53	13.9	28.3	5.02	25.70	0.77	0.17
BS	%	45	36	59	7.26	16.13	1.14	2.29
ESP	%	1.49	1	2.2	0.43	2.89	0.75	-0.36
EC	dScm^{-1}	0.04	0.02	0.06	0.02	42.86	0.32	-0.01
OC	gkg^{-1}	4.70	1.8	8.18	2.36	49.72	0.43	-1.15
TN	gkg^{-1}	0.55	0.35	0.88	0.21	38.91	2.49	6.38
Avail. P	mgkg^{-1}	3.60	0.50	15.6	5.37	149.08	2.49	6.38
Avail. S	mgkg^{-1}	11.84	2.50	25.6	9.02	76.14	0.53	-1.38
			Soils on Loess over Basement Complexes					
pH	-	5.39	5.10	5.60	0.16	2.97	-0.45	-0.80
Exch Ca.	cmol(+)kg^{-1}	2.38	1.05	3.38	0.62	26.05	-0.63	0.87
Exch Mg.	cmol(+)kg^{-1}	0.55	0.19	0.94	0.20	36.80	-0.01	0.58
Exch K.	cmol(+)kg^{-1}	0.13	0.09	0.26	0.05	37.21	2.09	5.14
Exch Na.	cmol(+)kg^{-1}	0.07	0.05	0.09	0.01	16.67	0.80	0.90
TEB	cmol(+)kg^{-1}	3.13	1.41	4.66	0.79	25.15	-0.32	1.96
TEA	cmol(+)kg^{-1}	0.38	0.20	0.70	0.13	34.30	1.14	2.64
CEC	cmol(+)kg^{-1}	8.28	6.50	10.7	1.31	15.81	0.32	-0.81
CECc	cmol(+)kg^{-1}	20.33	15.5	33.4	4.70	23.12	2.14	5.72
BS	%	37.92	20.0	48.0	7.27	19.17	-1.37	2.71
ESP	%	1.43	0.60	8.00	2.08	145	3.39	11.62
EC	dScm^{-1}	0.03	0.01	0.06	0.01	2.23	1.27	2.03
OC	gkg^{-1}	4.89	1.00	11.57	3.02	61.76	0.81	0.74
TN	gkg^{-1}	0.63	0.18	1.23	0.30	48.25	0.41	-0.31
Avail. P	mgkg^{-1}	3.02	0.50	9.60	2.88	95.59	1.85	2.32
Avail. S	mgkg^{-1}	10.36	3.20	24.8	7.48	72.21	1.05	-0.05

SD = Standard deviation, CV= Coefficient of variability

Silt/Clay ratio, BD, PD, and total porosity were not significantly different between the soils; however soils on BC were highest in mean values except for total porosity which was lowest. Soils on BC tend to be more compacted, whereas soils with loessial material deposition (LBC and LS) were more porous. All the soils were rated adequate for AWHC as their mean values were > 9.5% critical limits of moisture retention [39]. Soil AWHC was significantly different, with highest water retention in loess soils and was significantly higher than soils on BC. The highest moisture retention in LS may be attributed to the high total porosity and considered to have high proportion of micropores as clay content was highest in soils on LS (Table 1).

Most chemical properties were not significantly different between the soils developed on the three different parent materials; however trends of variation indicated that LS had higher mean values of exchangeable bases and TN than soils on LBC and BC. Available phosphorus and sulphur were highest in soils on BC. These trends indicated influence of Lithosequence on the variation of soil nutrients.

Exchangeable bases (Mg and K) significantly varied between the soils with significantly highest mean value in LS (Table 3).and was not significantly different between soils on BC and LBC. Similarly, TEA, CEC and CEC clay were significantly highest in soils on loess.

Table 2 Continued: Descriptive statistics of chemical properties of soils of the study area

Soil Properties	Unit	Mean	Range Min.	Max.	SD (σ)	CV (%)	Skewness	Kurtosis
			Soils on Loess					
pH	-	5.33	5.10	5.70	0.23	4.32	0.79	-0.75
Exch Ca.	cmol(+)kg^{-1}	2.48	1.58	4.31	0.99	39.92	1.00	-0.11
Exch Mg.	cmol(+)kg^{-1}	0.84	0.52	1.08	0.20	23.81	-0.01	-1.66
Exch K.	cmol(+)kg^{-1}	0.29	0.48	0.59	0.17	58.62	0.57	-0.51
Exch Na.	cmol(+)kg^{-1}	0.20	0.80	0.85	0.27	135	2.35	6.56
TEB	cmol(+)kg^{-1}	3.81	4.32	6.62	1.42	38.32	1.05	0.59
TEA	cmol(+)kg^{-1}	0.85	2.05	2.15	0.68	80	0.92	0.79
CEC	cmol(+)kg^{-1}	10.59	6.00	13.7	2.44	23.04	-0.17	-1.88
CECc	cmol(+)kg^{-1}	27.16	12.6	30.8	4.53	16.68	-1.33	-1.88
BS	%	36.13	31.0	55.0	10.8	29.98	0.51	-0.47
ESP	%	1.78	0.50	7.00	2.18	122	2.50	6.43
EC	dScm^{-1}	0.02	0.01	0.50	0.01	60	1.85	3.57
OC	gkg^{-1}	4.21	1.40	10.6	3.12	74.10	1.44	-1.60
TN	gkg^{-1}	0.64	0.35	1.05	0.23	35.94	0.91	-0.21
Avail. P	mgkg^{-1}	3.39	1.10	11.5	3.75	111	1.90	2.99
Avail. S	mgkg^{-1}	6.83	2.10	19.9	7.27	106	1.43	0.23

SD = Standard deviation, CV= Coefficient of variability

Table 3: Ranking of means of physicochemical properties of soils of the study area

Parameter	Unit	Basement Complex	Loess over Base. Complex	Loess	SE±	LOS
Sand	%	41.57a	30.83b	8.50c	1.16	***
Silt	%	35.71b	37.75b	56.00a	1.55	***
Clay	%	22.57b	30.92ab	35.50a	1.93	*
Si/C	-	2.22	1.49	1.79	0.26	NS
Bulk density	Mgm^{-1}	1.53	1.45	1.45	0.02	NS
Part. Density	Mgm^{-1}	2.60	2.58	2.55	0.02	NS
Total porosity	%	41.23	43.88	43.10	0.63	NS
AWHC	%	10.77b	12.27ab	14.80a	0.62	*
pH	-	5.40	5.39	5.33	0.50	NS
Exch Ca.	cmol(+)kg^{-1}	2.05	2.38	2.48	0.14	NS
Exch Mg.	cmol(+)kg^{-1}	0.41b	0.55b	0.84a	0.04	***
Exch K.	cmol(+)kg^{-1}	0.19ab	0.13b	0.29a	0.02	*
Exch Na.	cmol(+)kg^{-1}	0.09	0.07	0.20	0.03	NS
TEB	cmol(+)kg^{-1}	2.75	3.12	3.81	0.20	NS
TEA	cmol(+)kg^{-1}	0.69ab	0.38b	0.85a	0.08	*
CEC	cmol(+)kg^{-1}	6.23c	8.28b	10.59a	0.36	***
CECc	cmol(+)kg^{-1}	19.53b	20.33b	27.16a	0.94	**
BS	%	45.00	37.92	36.13	1.67	NS
ESP	%	1.49	1.43	1.78	0.37	NS
EC	dScm^{-1}	0.04	0.03	0.02	0.00	NS
OC	gkg^{-1}	4.70	4.88	4.21	0.57	NS
TN	gkg^{-1}	0.55	0.63	0.64	0.05	NS
Avail. P	mgkg^{-1}	3.60	3.02	3.39	0.77	NS
Avail. S	mgkg^{-1}	11.84	10.36	6.83	1.55	NS

LOS (P): NS > 0.05, * ≤ 0.05, ** ≤ 0.01
Note: Means followed by the same letters in the rows are not significantly different at 5% LOS.

4. Conclusion

Variability of properties within the soils studied were generally more pronounced in chemical than in physical properties. The least varied physical property was found to be particle density (CV = 0.23%) and ESP (CV = 2.23 was least variable in chemical properties. The physical and chemical properties that had the highest variability within the soils are Si/C ratio (CV =88.29%) and AP (CV = 149%) respectively.

Irrespective of the soils, particle density, bulk density and pH had less variability (CV ≤ 15%) and soil management related to these properties were expected to be handled in similar pattern within all the soils. Silt, AWHC, CEC, CEC clay and base saturation were consistently moderately variable (CV: >15 ≤ 35%). Silt/clay ratio, K, OC, TN, AP and AS were consistently highly variable CV > 35%). The highly variable nutrient status of these soils was attributed to differences in land use types, management and cultural practices occurring within the study area.

Larger proportion of properties of the soils were highly variable in all the soils with 10 (42%) of physicochemical properties of soils on BC, 9 (38%) on LBC and 13 (54%) on LS. Lithosequence significantly influence soil particles (sand, silt and clay) attributing to the trend in variation of physicochemical properties. Properties significantly influenced by Lithosequence include; AWHC, Mg, K, TEA, CEC and CEC of clay, and were significantly highest in soils on loess. These have contributed to variation in pattern of nutrient and exchangeable bases retention.

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