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Profile Distribution of Physical and Chemical Properties in Soils of a Toposequence in Benin, Rainforest of Nigeria

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ABSTRACT: The experiment was carried out along a toposequence to study some physical and chemical properties of soils from three pedons at three topographic positions representing, Rhodic Paleuults (pedon 1) in the Upper Slope (US), Typic Udipsamment (pedon 2) in the Middle slope (MS) and Typic Psammaquents (pedon 3) in the Bottomland (BL). Soil samples collected were analyzed for pH, organic carbon content, total nitrogen, available phosphorus, exchangeable cations (Ca, Mg, Na and K) and particle size distribution. The trend of change and difference in soil properties down the profiles and across the landscapes position were also studied. Results showed that BL had the highest organic carbon content with a range values of (6.00 – 30.30g/kg) and US had the lowest organic carbon content (5.40 - 9.70g/kg). The variation of the soil chemical properties showed that available phosphorus varied highly across the landscape with MS having highest P value of 14.72mg/kg and highest CV of 137.47%. CEC is low across the landscape, The trend of change and difference in soil properties across the slope shows that soil properties differs at these three positions, it was observed that soils of the bottomland were more fertile than those of the Upper slope. The results generated in this study could provide useful information for effective land use planning and land management.
Keywords: Toposequence, profile distribution, soil physical and chemical properties, rainforest.

INTRODUCTION

Managing soil resources for food security and sustainable environment is quite apt and deserves great attention considering the increasing pressure on our soil due largely to population increase and intensive agricultural production. In the past farmers relied mainly on shifting cultivation through which the land is allowed to fallow for well over five to eight years to allow organic matter and plant nutrients build up before another cropping will begin on such land again, (Udoh *et al*., 2010). But this fallow period have now reduced drastically to one or two years. This practice could create serious drawback such as decrease in soil fertility, increase in soil erosion and invasion by weed species (Rumpel *et al*., 2006). Farmers are beginning to crop on marginal lands including farming on slopes in many tropical countries. It is important to know that different soils occur at different positions on the landscape (Nuga *et al*., 2006). This various positions can have effect on yield of crops. Depending on the location on a slope physical and chemical properties of the soil will also vary either minimally or maximally. Soil physical and chemical properties are necessary to define and evaluate soil types, slopes, existing land use or natural cover under given condition of management. Soil variation occurs naturally from pedogenic factors and across multiple geographic scales ranging from small fields to very large fields. For example, in a forest or agricultural field, soil properties vary from the summit of a hill down to the bottom slope.

Many approaches have been used to examine soil variation. The application of new crop management technique, such as precision farming in which inputs are applied where they are needed may need to be fine-tuned to local variable conditions. New methodological developments better enables us to separate out these different sources of variation by examining soil variability over a range of scales, which is important for linking soil properties with soil processes (Xuemen *et al*., 2001). These linkages have important predictive capacities, such as forecasting crop yields based on soil characteristics, or understanding where micro-organism live in the soil and how human alteration to certain soil properties affects their livelihood.

Thus, evaluating agricultural land management practices require the knowledge of soil spatial variability and understanding the relationship of soil properties in a toposequence. Spatial variability could allow prediction or estimation of values of un-sampled locations within the region (Xuewen et al, 2001) and can also make a basis for defining different management zones on a field or an area. Based on the above the objective of this work was to examine the variability of some soil physical and chemical properties from three (3) pedons, in a toposequence in the University of Benin, Edo State, Nigeria.

MATERIALS AND METHODS

Description of the Experimental Area

The study site was located at the University of Benin, along a toposequence. The area lies between Lat. 6° 30' and 6° 58' N and Long 5° 30' and 6° 10' E and it is situated in the forest zone of South Western Nigeria. The rainfall has a characteristic bimodal distribution with peaks occurring in June/July and September and a period of lower precipitation around August known as August break. The dry season lasts from November to March. The annual rainfall ranges between 788mm and 1884mm. The bimodal character of rainfall distribution enables two distinct cropping seasons. First planting season starts from April to early August while the second shorter season starts from late August to November. The length of the cropping season is about 211-270 days. Cloud cover is high (above 89%) during the rainy season and 50-60% in the dry season. Mean annual temperature is about 26.2^{0}C and ranges from an average minimum of 21.3^{0}C to an average maximum of 31.2^{0}C. Relative humidity is directly influenced by rainfall and temperature but uniformity in temperature compels the relative humidity to follow the pattern of rainfall (NIFOR, 2008).

Soil Sampling and Analysis

The three (3) pedons located along the toposequence are Rhodic Paleudult (Pedon 1): Upper Slope (US), Typic Udipsamment (Pedon 2): Middle slope (MS), Typic Psammaquents (Pedon 3): Bottomland (BL). The area where the pedons were located was cleared and profile pits were dug. Soil samples were collected from each identified horizon in each profile, air dried, pass through a 2mm sieve, properly labeled before laboratory analyses.

Laboratory Analyses

Particles size distribution was determined using the hydrometer method as described by Bouyoucos (1951). Soil pH was determined in 1:1 (soil:water) ratio using a glass electrode pH meter. Organic carbon was determined by the wet oxidation method (Walkley and Black, 1934). Total Nitrogen was by the micro-Kjeldhal digestion method. Available phosphorus was determined by Bray 1 method (Bray and Kurtz, 1945). Exchangeable bases (Ca, Mg, K and Na) were extracted in 1N NH_40AC at pH 7. Sodium and K were determined with a flame photometer while Ca and Mg were determined with the atomic absorption spectrophotometer. Effective Cation Exchange Capacity was by summation of exchangeable bases (Ca, Mg, K and Na). From the results of the laboratory analysis and field work the pedons were classified following the USDA Soil Taxonomy (Soil Survey Staff, 1999)

Statistical Analysis

The differences among soils in the toposequence were determined statistically using the nested analysis of variance (ANOVA) (Wahua, 1999) and descriptive statistics.

RESULTS AND DISCUSSION

Chemical Properties

The results in Table 1 show data on some soil chemical properties. Soil pH was generally slightly acidic with values 4.7 – 5.7. While the values along the toposequence were similar but that of the middle and valley bottom were slightly higher than that of the upper slope. The trend of soil pH obtained in this toposequence is an evidence of chemical weathering. This is in conformity with the findings of Babalola *et al*. (2007) who did similar work on soil properties and slope position in a Humid forest and observed same trend of pH. Organic carbon which has direct relationship with organic matter was high at the valley bottom. However, the C/N ratio in the toposequence ranged between 1.30 - 4.7. These values were below C/N ratio of 25 being the separating index for mineralization and mobilization of nitrogen as established by Paul and Clark (1989). The available P values at the upper slope (pedon 1) was low ranging from 0.64 – 4.29 mgkg^{-1} in the profile as against the critical level of 10 – 16 mgkg^{-1} (Adeoye and Agboola 1985) but at the middle slope (pedon 2) available P was above critical level at 0 – 7cm depth and at the bottomland soil (pedon 3) at 21 – 125 cm depth. Ca values along the toposequence were low ranging from 0.64 – 2.83 cmol+kg^{-1} based on the critical values of 5.0 cmol+kg^{-1} (Amalu, 1997). Na values along the toposequence were high ranging from 0.30 – 0.38 cmol+kg^{-1} based on the critical values of 0.02 cmol+kg^{-1} (Amalu, 1997). Mg values along the toposequence were high ranging from 2.13 – 6.74 cmol+kg^{-1} based on the critical values of 0.50 cmol+kg^{-1} (Onyekwere *et al*., 2003). The K values in the toposequence were low ranging from 0.02–0.16 cmol+kg^{-1} in the profile as against the critical level of 0.16–0.25 cmol+kg^{-1} (Akinrinde and Obigbesan 2000). The ECEC values in the toposequence ranged from 3.13 – 10.60 cmol+kg^{-1} in the profile which are quite low. The low ECEC have been attributed to the fact that soils in this region are strongly weathered, have little or no content of weathered materials in sand and silt fractions and have predominantly Kaolinite in their clay fractions. This finding is also in agreement with that of Korieocha *et al*. (2010) who worked on inland valley soils of south eastern Nigeria and observed low ECEC.

Particle - Size Distribution

The results in Table 2 show data on particle size distribution at each slope position. The sand fraction generally dominated the soils along the toposequence. Within the horizons, the sand content decreased with depth in all the profiles, silt content increased with depth in all the profile. The removal by illuviation of silty materials by rainwater or by erosion from the top slope and subsequent deposition down the slope could be the reason for the trend. These results are also in agreement with the findings of Voncir *et al*. (2008) who worked on profile distribution of some physicochemical properties of soil along a toposequence.

Table 1: Some soil chemical properties in the pedons along the toposequence

Soil Depth	pH H_2O	Org C gkg^{-1}	TN gkg^{-1}	C/N ratio	Av.P $mgkg^{-1}$	Ca ←-	Mg cmol+kg^{-1}	Na -----	K ----	ECEC →
Upper Slope (Rhodic Paleudult)										
0 – 20 cm	4.9	9.7	2.4	4.04	4.29	1.16	3.68	0.33	0.04	5.21
20 – 40 cm	5.0	5.4	1.3	4.15	0.64	1.08	3.45	0.35	0.02	4.90
40 – 90 cm	4.8	6.4	1.5	4.27	1.90	1.10	3.95	0.32	0.04	5.41
Middle Slope (Typic Udipsamment)										
0 – 7 cm	5.6	13.6	3.4	4.00	14.72	2.18	7.96	0.31	0.15	10.60
7 – 13 cm	4.9	7.2	1.7	4.24	3.90	1.56	4.48	0.30	0.05	6.39
13 – 30 cm	5.7	7.0	1.7	4.12	1.02	1.16	4.44	0.30	0.03	5.93
30 – 111 cm	4.9	3.4	0.8	4.25	1.41	0.64	2.23	0.33	0.03	3.23
Bottomland (Typic Psammaquents)										
0 – 4 cm	4.7	6.0	4.6	1.30	1.15	0.91	3.10	0.32	0.04	4.37
4 – 10 cm	5.2	9.7	2.4	4.04	0.51	0.67	2.13	0.33	0.02	3.15
10 – 21 cm	5.7	12.6	3.1	4.06	6.53	0.73	2.88	0.35	0.07	4.03
21 – 125 cm	5.7	30.3	7.3	4.15	15.47	2.83	6.74	0.38	0.16	10.11

Table 2: Particle size distribution in the pedons along the toposequence

Profile	Particle size (gkg^{-1})			Textural Class
	Sand	Silt	Clay	
Upper Slope (Rhodic Paleudult)				
0 – 20 cm	832	34	134	Loamy Sand (LS)
20 – 40 cm	632	34	334	Sandy Clay Loam (SCL)
40 – 90 cm	722	44	234	Sandy Clay Loam (SCL)
Middle Slope (Typic Udipsamment)				
0 – 7 cm	946	34	20	Sand (S)
7 – 13 cm	906	54	40	Sand (S)
13 – 30 cm	766	34	200	Sandy Clay Loam (SCL)
30 – 111 cm	746	34	220	Sandy Clay Loam (SCL)
Bottomland (Typic Psammaquents)				
0 – 4 cm	546	74	380	Sandy Clay (SC)
4 – 10 cm	826	94	80	Loamy Sand (LS)
10 – 21 cm	626	114	260	Sandy Clay Loam (SCL)
21 – 125 cm	766	94	140	Sandy Loam (SL)

The clay content increased with depth in the top and middle slope, while at the bottom slope the clay content was higher at the top soil than the subsoil. The trend in the clay content at the upper horizon maybe as a result of processes like pedoturbation and in situ weathering in the middle horizon, while the movement of clay down the profile through illuviation may have contributed higher content in the top slope. Noma *et al* (2011) also reported similar results in a chrono-toposequence studies of soils in Sokoto State, Nigeria. The textural classes along the toposequence is typical of soils derived from coastal plain sands parent material. This is also in agreement with the findings of Udoh *et al*., (2010). The soils based on the Soil Survey Staff, (1999) belong to

Rhodic Paleudult at the TS, Typic Udipsamment (MS) and Typic Psammaquent at the BS.

Variation in the Physical and Chemical Properties of the Soils

The results in Table 3 show the variation of the physical and chemical properties of the soil along the slope. Among the three pedons, the coefficient of variation of soil pH among these three pedons was between 2.04% and 9.45%. Upper Slope was least with a value of 2.04% with that of the bottomland as 9.45%. pH is a "master variable" and it regulates almost all biological and chemical reactions in soils (Brady and Weil, 1996). Organic carbon content coefficient of variation ranged between 31.38% (in Upper Slope), 90.29% (in Middle Slope) and 73.58% (in Bottomland). Upper Slope were most variable along the slope. Organic carbon content had a mean value of 14.65 gkg^{-1}. Bottomland has the highest mean value for total nitrogen 4.35 gkg^{-1} while Upper slope had the lowest 1.73gkg-^{1}. Nitrogen content in bottomland was high due to high organic carbon content while Total Nitrogen in upper slope and middle slope were low. The Available phosphorus was high at the upper slope horizons across the slope except bottomland. The CV were also high along the toposequence with the middle slope having the highest value of 137%. The low level of Available P down the slope could have been due to fixation as either aluminum or iron phosphate. Menzies and Gillman (1997) also established this kind of trend under different land use for various humid forest zone topsoil of Cameroon.

Among the basic cations measured, results shown in Table 3 reveals that at the Upper Slope Ca, Mg, Na were least variable and K moderately variable. At the Middle Slope, Na was least variable, while Ca, Mg and K are highly variable. In Bottomland Na is least variable while Mg and K were highly variable. The mean CEC of US was 6.16 $cmo1kg^{-1}$, MS was 7.37 $cmolkg^{-1}$ and that of BL was 6.85 $como1kg^{-1}$. The reason for low CEC values of soils across the landscape also corroborates the works of Menzies and Gillman (1997) and Voundi, *et al*. (1997) that low and variable character of the CEC within humid forest zone could be due to the domination of low activity components such as Kaolinite, Fe and Al (hydroxides) in these soils which resulted from higher degree of weathering of the parent rock.

Table 3: Variation in the physical and chemical properties of the soils in Pedon 1 (Rhodic Paleudult), Pedon 2 (Typic Udipsamment) and Pedon 3 (Typic Psammaquents)

	Pedon 1 (Rhodic Paleudult),			Pedon 2 (Typic Udipsamment)			Pedon 3 (Typic Psammaquents)		
Soil Properties	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)
pH (H_2O)	4.8-5.0	4.9	2.04	4.9-5.7	5.28	8.14	4.7-5.7	5.33	9.45
*C (gkg^{-1})	5.40-9.70	7.17	31.38	3.40-13.60	7.80	90.29	6.00-30.30	14.65	73.58
**N (gkg^{-1})	1.30-2.40	1.73	33.53	0.80-3.40	1.90	57.37	2.40-7.30	4.35	57.46
**P ($mgkg^{-1}$)	0.64-4.29	2.28	131.58	1.02-14.72	5.26	137.47	0.51-15.49	4.42	117.06
Ca ($cmolKg^{-1}$)	1.08-1.16	1.11	3.60	0.64-2.18	1.39	46.76	0.67-2.83	1.29	20.23
Mg ($cmolKg^{-1}$)	3.45-3.95	3.69	6.78	2.23-7.96	4.78	49.58	2.13-6.74	3.71	39.90
Na ($cmolKg^{-1}$)	0.32-0.35	0.32	6.06	0.30-0.33	0.31	3.23	0.32-0.38	0.35	8.57
K ($cmolKg^{-1}$)	0.02-0.04	0.03	33.33	0.03-0.15	0.07	89.69	0.02-0.16	0.07	85.71
CEC ($cmolKg^{-1}$)	5.69-6.79	6.16	9.42	4.00-11.38	7.37	43.01	4.13-12.89	6.85	59.42
Sand	632-832	729	21.09	746-946	841	10.47	546-826	691	18.19
Silt	34-44	37	15.46	34-54	44	13.11	74-114	94	17.32
Clay	134-334	234	81.84	20 – 220	125	78.79	80-380	215	61.88

* Organic Carbon ** Total Nitrogen ***Available Phosphorus

The CV (%) of the particle size fractions are presented in Table 3. Clay content appears to be highly variable at all the three slope positions. Silt and Sand fractions were moderately variable. However the high amount of clay at BL is as a result of fine materials that have been transported from upper and middle slopes to bottomland which is a characteristic of soils in depression hence, making the water holding capacity of the soils to be high, likewise the accumulation of clay fraction, such soils are good for off season cropping.

CONCLUSION

This study has shown the relationship between soil properties and slope position and how slope position can affect the physical and chemical properties of soil across a landscape. The low effective cation exchange capacity has shown that Kaolinite is predominant in the clay fraction. So for any land management to be affective it must put into consideration soil properties that affect agricultural practice in that area. Maintenance of satisfactory organic matter level is essential for most of the nitrogen and phosphorus to be utilized by crops.

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