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Effect of Slope Positions on some Properties of Soils under a *Tectona grandis* Plantation in Minna, Southern Guinea Savanna of Nigeria

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Abstract: *Topography influence soil erosion and consequently has impact on the properties of soils. This study assessed some properties of basement complex rocks derived soils under a young Teak (Tectona grandis) plantation in Minna, southern Guinea savanna of Nigeria. Three soil profiles sited at the upper, middle and lower slope positions along a toposequence were studied. Soil samples collected from their genetic horizons were analysed. Results have shown that the color of surface horizon differed. The upper had very dark gray (10YR3/1), the middle had very dark brown (10YR2/2) while the lower slope position was characterized by dark yellowish brown (10YR3/4) coloration. Also, the texture of surface horizon differed; the upper slope had sandy clay loam, while the middle and lower slope positions had sandy loam. Soil pH slightly increased down the slope with mean values of 6.7, 6.8 and 7.4 for upper, middle and lower slopes respectively. Surface horizon had the highest soil organic carbon (SOC) content, 15.3, 8.7 and 8.5 g kg^{-1} and the SOC values decreased down the slope. Total nitrogen (N) was low for all slope positions, with middle slope had the lowest value of 0.1 g kg^{-1}. Available phosphorus (P) was rated low at the upper and middle slopes, 8 mg kg^{-1}, and medium in lower slope, 15 mg kg^{-1}. Calcium (Ca), magnesium (Mg) and sodium (Na) were rated high in all slope positions; potassium (K) was rated low to medium. Effective cation exchange capacity (ECEC) ranged from 6.92 to 20.77 cmol kg^{-1} and was rated medium to high. Irrespective of slope position, base saturation was rated high with values > 84 %. Despite variation in some properties as influenced by topography, the studied soils have potentials to sustain the current land use type.*

Keywords: *Soil properties, classification, toposequence*

1. Introduction

Productivity of a soil is a function of its physical and chemical properties. These properties are as a result of the interaction among the soil forming factors [1] and processes [2], hence, making soil to be heterogeneous. As a factor of soil formation, topography, for instance, may hasten or delay the work of climatic factors. It has influence on soil morphological, chemical and physical properties and also affects the pattern of soil distribution over landscape [3] even when the soils are derived from the same parent material. Studies have shown that the extent of variability in soil properties may be significant even for a simple change in topography [4]. Consequently, soils on hill slopes exhibits remarkable difference in properties from those on the summits because of percolating water which tends to move laterally across a profile instead of vertically [5]. According to [6] water velocity on a slope affect deposition of materials in suspension, sand drops out of suspension first, while clay size particles can be carried further away from the base of the slope before they are deposited. This kind geological sorting brings about variation in soil in relation to landscape.

The physical features around Minna, north-central Nigeria, consist mainly of gently undulating high plains developed on basement complex rocks [7]. Predominantly, soils developed on basement complex rocks of Minna, have impervious subsurface horizons due to plinthization processes [8]. The plinthites (mostly aggregated and cemented) do limits vertical water flow and encourage horizontal flow of water in soils [9]. This phenomenon may affect the distribution of soil properties in a predominantly rolling landscape of Minna. Studies on soil-landscape relationships in the rolling terrain around Minna, Nigeria are rare. Therefore, this study was undertaken to assess the effect of slope position on morphological, physical and chemical properties of soils of a toposequence under a teak (*Tectona grandis*) plantation in Minna.

2. MATERIALS AND METHODS

2.1 The Study Area

The study site is a 10 year-old Teak (*Tectona grandis*) plantation of the Federal University of Technology, Minna, Nigeria. Geographic location was on latitude 09° 31′ 18.2″ N and longitude 6° 27′ 39.6″ E and elevation ranged from 229.7 to 250.2 m above sea level. The study area fall under the southern Guinea savanna ecological zone of Nigeria, underlain by rocks of the pre-Cambrian Basement Complex. Climate of the study area was designated by 'Koppen Aw' as sub-humid with mean annual rainfall of 1338 mm, dry season of about 5 months and mean annual temperature >30 ^{o}C [10] [7].

Along the dominant slope, the study site was partitioned into three, designated as the upper, middle and lower slopes. In each segment a representative profile pit was dug and described according to Food and Agriculture Organization (FAO)'s guidelines for soil profile descriptions [11]. Soil samples were collected from natural horizons for laboratory analysis. Soil samples for bulk density determination were collected using soil core rings.

2.2 Soil Analysis and Data Interpretation

Soil samples for routine analysis were air-dried, gently crushed and passed through a 2-mm sieve to obtain fine earth separates. Part of the samples used for the determination of organic carbon (OC) and total nitrogen (N) were further passed through a 0.5-mm sieve. Samples were analysed for some physical and chemical properties following standard laboratory procedures. Briefly, soil texture was determined by Bouyocous hydrometer method using sodium hexametaphosphate as dispersing agent [12]. The textural classes of the soils were then determined using IUSS soil Textural Triangle. Soil pH was determined using a glass electron pH meter in soil: water ratio of 1:1. The OC was determined by Walkley-Black method of wet combustion involving oxidation of organic matter with potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4) [13]. Total N was determined by micro Kjeldahl method [14]. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were extracted with 1N neutral ammonium acetate (NH_4OAc) solution and amounts of K and Na in solution measured using a Flame Photometer while Ca and Mg was by atomic absorption spectrophotometry [15]. Effective cation exchange capacity (ECEC) was determined by summation of basic cations and exchangeable acidity. Percent base saturation was by calculation method, i.e., by dividing the ∑(Ca, Mg, K, Na) by their ECEC, then multiplied by 100. Exchangeable acidity (H^+ and Al^{3+}) was determined by titrimetric method. Samples for bulk density determination were oven-dried at 105 ^{O}C for 24 hours after taking their initial volume. The oven-dried weight of each sample was then divided by its initial volume [16].

3. RESULTS AND DISCUSSION

3.1 Morphological and Physical Properties

Results on some morphological and physical properties of the soils are shown in Table 1. The upper slope was characterized by very dark gray (10YR3/1) color at Ah-horizon overlain dark yellowish brown (10YR4/4) at BA-horizon and grayish brown (10YR5/2) at B- and C-horizons. The Ah- and BA-horizons were mottled-free implying that the surface horizon was well-drained [17]. The grayish color of B- and C-horizons with mottles of different shades of colors may be attributed to poor internal drainage condition [1]. The middle slope had very dark brown (10YR2/2) at Ah-horizon overlain various grades of yellowish brown. Similarly, the Ah-horizon was mottled-free while subsurface horizons had dark brown (7.5YR4/4) to reddish yellow (7.5YR6/8) mottles. The lower slope had dark yellowish brown (10YR3/4) at Ah-horizon overlain various shades of yellowish brown and gray to very dark grayish brown. Surface horizons, especially the upper and middle slope positions had weak sub-angular blocky structure while the lower slope had weak to moderate crumb structure. All the profiles had in common one or more subsurface horizons poorly structured either due to high illuvial accumulation of clay and / or decaying rock which contributed to their poor internal drainage characteristics. According to [9], presence of impediments in subsurface horizon may restrict vertical water flow and induce horizontal flow of water in soil.

Table 1. *Some Morphological Properties of the Soils*

Horizon	Depth (cm)	Colour (moist)		Str*	Sand	Silt	Clay	TC†	SCR‡	BD‡
		Matrix	Mottling		⟵	(g kg^{-1})	⟶			(g/cc)
Upper Slope										
Ah	0 – 19	10YR3/1	-	1sbk	607	144	249	SCL	0.58	1.62
BA	19 – 56	10YR4/4	-	1sbk	497	134	369	SC	0.36	1.67
Btg	56 – 103	10YR5/2	Mottled	0ms	417	144	439	C	0.33	1.68
BC	103 – 147	10YR5/2	Mottled	0ms	397	164	439	C	0.37	1.78
C	147 – 200	10YR5/2	Mottled	0ms	457	184	359	SC	0.51	1.82
Middle Slope										
Ah	0 – 19	10YR2/2	-	1sbk	764	100	136	SL	0.74	1.66
Btg1	19 – 30	10YR4/6	7.5YR4/4	1sbk	656	90	254	SCL	0.35	1.69
Btg2	30 – 100	10YR5/8	7.5YR5/6	2sbk	649	87	264	SCL	0.33	1.77
Btg3	100 – 165	10YR5/6	Mottled	0ms	616	70	314	SCL	0.22	1.97
Lower Slope										
Ah	0 – 20	10YR3/4	-	1cr	835	43	122	SL	0.35	1.52
AB	20 – 39	10YR4/6	7.5YR5/8	2cr	755	110	135	SL	0.81	1.63
Btg1	39 -82	10YR5/4	7.5YR6/8	2sbk	678	77	245	SCL	0.31	1.69
Btg2	82 -120	10YR5/1	7.5YR6/8	3sbk	661	87	252	SCL	0.35	1.74
BC	120 - 177	10YR3/2	Mottled	0ms	681	100	219	SCL	0.46	1.79

*Str = structure; 0 = structureless; 1 = weak, 2 = moderate, 3 = strong, g = granular; ms = massive, cr = crumb, abk = angular blocky, sbk = sub-angular blocky.

†TC = Textural class; C = clay, SL=sandy loam, SCL = sandy clay loam, SC = sandy clay.

‡SCR = Silt/clay ratio; BD = Bulk density

Sand ranged from 397 to 607, 616 to 764 and 661 to 815 g kg^{-1} for the upper, middle and lower slopes respectively and decreased with soil depth in a regular trend. The trend of distribution was in the following order, lower slope > middle slope > upper slope, probably due to the effect of slope which accelerated movement of sand particles by run-off water, wind and gravity. According to [3] topography has influence on pattern of soil distribution over landscape. Silt ranged from 134 to 184, 70 to100 and 43 to110 g kg^{-1} and except in the middle slope, its distribution within the soil profiles was irregular. Unlike sand, silt decreased down the slope, upper slope > middle slope > lower slope. Clay ranged from 249 to 439, 136 to 314 and 122 to 259 g kg^{-1} and increased with soil depth in all the profiles. The observed increase may be linked to argilluviation processes [1]. Like silt, clay also decreased with slope, upper slope > middle slope > lower slope due to reasons earlier stated [3]. Silt/clay ratio ranged from 0.33 to 0.58, 0.22 to 0.74 and 0.31 to 0.81 respectively for upper, middle and lower slope positions. With exception of Btg3 horizon of the middle slope which had silt/clay ratio < 0.22, other horizons irrespective of slope positions had values > 0.25, a critical limit [18] used in defining the intensity of weathering of parent materials. The results therefore implied that the studied soils still have considerable amount of weatherable minerals in them. Bulk density of the soils ranged from 1.62 to 1.82, 1.66 to 1.97 and 1.52 to 1.77 g cm^3 for the upper, middle and lower slope positions respectively and increased with soil depth. [19] had established bulk density values of > 1.75 g cm^3 (for sandy soils) and > 1.63 g cm^3 (for silty and clayey soils) as critical to cause hindrance to root penetration. The implication of the result from the present study was that the surface horizon of the upper slope, being clayey soil, was rated marginally suitable, while those of middle and lower slopes were rated moderately suitable. However, the subsurface horizons in all the studied profiles were rated unsuitable and may limit root penetration. The textural class of the surface horizon was sandy clay loam at the upper slope and sandy loam at middle and lower slope positions respectively. Surface erosion and depositional processes by run-off influenced by topography might have been responsible for the differences observed in textural classes of the surface horizon in the three slope positions studied. Similarly, the subsurface horizons which had textural class graded from sandy clay to clay at the upper and sandy clay loam at middle and lower slope positions respectively may be attributed to effect of eluviations-illuviation processes encouraged by water soil water movement. It has been established that water movement in landscapes is the major process responsible for soil development [20].

3.2 Chemical Properties of the Soils

Results on some chemical properties of the soils are presented in Table 2. Interpretation of results was based on the fertility ratings of [21] and [22] established for Nigerian soils. Soil reaction was slightly acidic to slightly alkaline with pH values ranged from 6.4 to 7.6. The pH of the study soils may imply low level of leaching of non acid cations [23]. However, the pH values were higher than those reported by [23] [8] [24] for similar soils of Minna. The variation may be linked to the effect of land use, teak (*Tectona grandis*) plantation. According to [25] teak has the ability to act as cation pump, and this probably accounted for the higher pH level of the studied soils relative to those reported by [23] [8] [24]. Organic C ranged from 2.1 to 15.3 g kg^{-1} and was rated low in all soil profiles except the upper horizons (Ah and Bt) of the soil profile at the upper slope. In all profiles, OC decreased with increasing soil depth, probably due to decreased faunal activities in the underlying horizons as suggested by [26]. It may also be an indication of the maturity of the profile developed on a very stable platform [24]. Organic C in the surface horizon decreased down the slope, upper slope > middle slope > lower slope. Total N was also rated low in the studied soils and its contents ranged from 0.1 to 0.3 g kg^{-1}. Organic matter content of soil supplies about 85 to 90 % of soil nitrogen in unfertilized soils [27]. Although N is associated with organic matter, its distribution in surface horizon was not in tandem with the OC along the slope sequence. Available P ranged from 5 to 8 mg kg^{-1} at upper and middle slope positions and was rated low, while it values ranged from 11 to 15 mg kg^{-1} at lower slope position was rated medium. For similar reason stated for low total N, organic matter was identified as principal source of soil phosphorus for many soils [28]. Irrespective of soil depth, P levels was higher in lower slope position than the upper and middle slopes probably due to weathering of P-rich parent rock releasing phosphorus into the soil.

Table 2. *Some Chemical Properties of the Soils*

Soil Depth (cm)	pH (H_2O)	OC	N	P (mg kg^{-1})	Exchangeable Bases				EA	ECEC	BS (%)
		(g kg^{-1})			Ca^{2+}	Mg^{2+}	K^+	Na^+			
					← (cmol kg^{-1}) →						
Upper slope											
0-19	6.9	15.3	0.3	8	6.50	3.50	0.15	0.41	1.8	12.36	85
19-56	6.6	10.3	0.1	7	7.00	4.00	0.15	0.39	1.2	12.74	91
56-103	6.4	5.3	0.1	6	6.40	3.10	0.46	0.40	1.2	11.52	90
103-147	6.9	4.3	0.1	7	7.20	2.85	0.35	0.38	1.4	12.14	87
147-200	6.8	2.1	0.1	7	10.20	4.28	0.33	0.29	1.2	16.30	93
Middle slope											
0-19	6.9	8.7	0.1	8	2.53	2.53	0.08	1.08	0.7	6.92	90
19-30	6.9	5.5	0.1	7	4.02	4.10	0.11	0.52	1.7	10.45	84
30-100	7.1	3.4	0.1	5	3.06	6.17	0.19	0.60	1.1	11.12	90
100-165	6.4	2.9	0.1	5	7.84	6.58	0.22	0.60	1.1	16.34	93
Lower slope											
0-20	7.3	8.5	0.2	15	5.70	3.70	0.18	0.47	1.1	11.15	90
20-39	7.4	7.3	0.3	11	7.73	4.74	0.19	0.55	0.8	14.01	94
39-82	7.3	4.9	0.1	15	9.54	5.86	0.31	0.54	1.0	17.25	94
82-120	7.2	3.8	0.1	15	10.60	6.32	0.34	0.60	0.9	18.76	95
120-177	7.6	1.5	0.1	14	12.20	6.65	0.25	0.67	1.0	20.77	95

* OC = organic carbon; N = total nitrogen; P = available phosphorus; EA = exchangeable acidity; ECEC = effective cation exchange capacity; BS = base saturation

Calcium ranged from 2.53 to 12.20 cmol kg^{-1} and was rated medium to high in the soils. Calcium was higher in the subsurface horizons in all the profiles probably due to eluviations-illuviation processes. However, since the study site is under tree plantation, Ca accumulated at the subsurface horizons may be accessible to the tree species. According to [25] teak has the ability to act as cation pump and can recycle nutrients to surface horizons. Magnesium ranged from 2.53 to 6.65 cmol kg^{-1} and was rated high in all the slope positions and soil depth. In terms of plant nutrition, Mg may not be a constraint in the studied soils, but its accumulation in soil may have negative impact on soil structure, lower water intake rates and may affect the chemical and biological properties of soil [29]. Potassium ranged from 0.03 to 0.46 cmol kg^{-1} and was rated low at the surface horizon of the upper and middle slopes, and medium at lower slope position. In the subsurface, K was rated medium for middle slope and high, at the upper and lower slope positions respectively. Sodium ranged from 0.39 to 1.08 cmol kg^{-1} and was rated high in all positions and soil depths, hence, making the soils to be potentially sodic [8]. Distribution of Ca, Mg, K and Na down the slope was irregular. Effective cation exchange capacity (ECEC) ranged from 6.92 to 20.77 cmol kg^{-1} and was rated medium to high. Base saturation ranged from 84 to 95 % and was rated high. High base saturation in the studied soils reflects dominance of non-acid cations on their exchange sites.

4. CONCLUSION

The result affirmed that topography had effect on the soil color and particle size distribution of the soils, especially the in the surface horizon. Also affected were the bulk density and drainage characteristics of the soils. Surface horizons were well drained while the subsurface were poorly drained. On the basis of some morphological and physical properties assessed, the major management limitations of the studied soils were poor internal drainage and unfavourable bulk density, both capable of causing hindrance to root penetration. Although, the study site is currently under teak plantation, measures that will enhance internal drainage of the soil and roots penetration should be explored. Organic C, N and P are low and therefore require build-up of these nutrients in the soils. Measures to improve their replenishment may include prevention of burning of litters and encourage practices of incorporating organic residues. Exchangeable bases (Ca, Mg, K and Na) in the studied soils are presently adequate to sustain the current land use.

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