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Content and Profile Distribution of Extractable Zinc (Zn) and Some Physicochemical Properties of Soil Along a Toposequence at Bauchi, Northern Guinea Savanna of Nigeria

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Abstract: The content and distribution of extractable zinc within profiles along a toposequence at the Abubakar Tafawa Balewa University, Research Farm Bauchi, Nigeria was studied. Soil samples were collected from each identified horizon of five profile pits dug at the crest, upper slope, middle slope, lower slope and valley bottom positions and subjected to laboratory analysis. The soils were sandy loam at the top and sandy clay loam or clay loam in the subsoil. Clay content was generally higher in the subsoil than in the topsoil with the pH values ranged between 5.98 and 6.18. Organic carbon although generally low was higher in the topsoil than in the subsoil and not markedly different with position along the toposequence while CEC (although generally low 3.28-5.26 cmol kg⁻¹) was higher in the subsoil than in the topsoil. The available phosphorus was also low in all the profiles and not markedly different between the profiles. Available zinc distribution followed the pattern of organic matter distribution and it was also low with no marked difference along the toposequence.

Key words: Extractable zinc, physicochemical properties, toposequence

INTRODUCTION

In many areas of the world where shifting cultivation is the method practiced in agriculture, nutrient recycling helps in minimizing the deficiency of major and minor elements (Osiname *et al.*, 1973). The need for increased food production for increasing populations has brought land under intensive use with the consequence of depleting both macro and micro nutrients faster than they could be replenished; even when nutrients are supplied by man to improve the fertility of the soil attention is given to macro nutrients only, forgetting the micronutrients (Swaine, 1955). Pam (1990) noted that factors like weathering, leaching and the introduction of high-yielding varieties also help in depleting the soils of its micronutrient reserves.

Soil micronutrient study was neglected in both soil science and crop production in Nigeria and Africa as a whole and even other developing countries (Pam, 1990). Recently, micronutrient studies have received some attention from scientists. Kang and Osiname (1972) reported that deficiency symptoms were not apparently shown in the past because depleted micronutrients were replenished from the soil organic matter during the long fallow periods that followed cultivation.

In Nigeria, most work on soil has been on soils developed on crystalline basement complex rocks, metamorphic rocks and on sedimentary rock (Lombin, 1983; Kparmwang *et al.*, 1995). Generally, studies have been related to ecological zones with most of the investigations done on soils of the southwestern zone (Lombin, 1983). Most savanna soils are reported to have low clay contents, low organic matter and cation exchange capacities (Lombin, 1983). There is very little or no much research work on micronutrient distribution within soil profiles in the savanna region of Nigeria. Zinc occurs in basic ferromagnesian minerals such as olivine and biotite through isomorphous substitution

of Zn^{2+} for Fe^{2+} and Mg^{2+} . According to Krauskopf (1989), zinc occurs in limestone rock and shales through a similar phenomenon. Zinc may also be found in the form of sphalarite (ZnS), zincite (ZnO) and smithsonite ($ZnCO_3$). According to Udo and Fagbami (1979), rocks of igneous origin contain more zinc than their sedimentary counterparts with zinc being more concentrated in basalt than granite.

The total zinc content of soils Nigeria has been reported by many scientists: Chude *et al.* (1985) who reported values between 12 and 92 ppm in western Nigeria; Udo and Fagbami (1979) reported values of 67 and 80 ppm for soils at Dogon Gaba and Vom, respectively in north central Nigeria and Pam (1990) reported values between 6 and 84 ppm for upland soils of northern Nigerian savanna and 21.6 ppm for one site in Bauchi State (Pam, 1977).

This study was therefore conducted to determine variation in content and profile distribution of zinc and other physico-chemical properties of soils along a toposequence.

MATERIALS AND METHODS

The study was conducted at Bauchi in the northern guinea savanna zone of Nigeria ($10^{\circ}22'N$ and $9^{\circ}47'E$). The area is characterized by two distinct seasons, the rainy season lasting from May to October and the dry season from November to April. The mean annual rainfall is 1014.70 and the mean daily maximum temperature is $26^{\circ}C$. The geology of the area is made up of basement complex rocks (Kowal and Knabe, 1972).

Five profile pits representing the crest, upper slope, middle slope, lower slope and valley bottom positions along the toposequence were dug and soil samples were collected from each identified horizon of the five pits and subjected to laboratory analysis.

Particle size distribution was determined using the hydrometer method as described by Bouyoucos (1951). Soil pH was determined in 1:1 soil water suspension with a glass electrode pH meter. Organic carbon was determined by the wet oxidation method (Walkley and Black, 1934). Cation Exchange Capacity (CEC) was determined by sodium acetate ($NaOAc$) saturation and neutral ammonium acetate.

Extractable zinc was determined by the Mehlich I method using the atomic absorption spectrophotometer to determine the zinc concentration in the extract. Analysis of variance of the data obtained was carried out using a nested design.

RESULTS AND DISCUSSION

Soil pH and Particle Size Distribution

The result in Table 1 indicated that although the soils are generally slightly acid with values between 5.98 and 6.15 the topsoils generally have higher pH values than the subsoils. While the values along the toposequence were similar even though the middle and lower slope positions had slightly higher values. The lower pH values in the subsoil may be due to the presence of aluminosilicate clay minerals, which undergo isomorphous substitution releasing Al^{3+} and/or H^+ into the soil solution. This is in conformity with the views of Tisdale *et al.* (1985).

The plinthite content of the soil was observed to increase along the slope appearing at very close to the surface at the lower slope position. The middle and lower slope positions were more acidic than the other positions and this condition might have contributed to the insolubility of iron as stated by Tisdale *et al.* (1985) and the Hamdan *et al.* (1998) leading to intense plinthization.

Particle Size Distribution

The sand fraction generally dominated the soils along the toposequence. Within the horizons, the sand content decreased with depth in all the profiles while along the toposequence the sand content

Table 1: Soil pH and particle size distribution

Profile	Horizon	Textural class	Depth (cm)	pH	Particle size (%)		
					Sand	Silt	Clay
1 (C)	Ap	SL	0-8	6.12	71.0	10.0	19.0
	AB	SCL	821	6.10	69.0	8.0	23.0
	Bt1	SCL	29-21	6.07	60.0	9.0	31.0
	Bt2	CL	50-38	6.08	59.0	10.0	31.0
	Bt3	CL	88-43	6.02	55.0	8.0	37.0
			Mean	6.08	63.0	9.0	28.0
2 (US)	Ap	SL	0-6	6.10	70.0	12.0	18.0
	BA	SCL	6-9	6.09	68.0	10.0	23.0
	Bt1	SCL	15-10	6.10	68.0	8.0	24.0
	Bt2	SCL	25-19	6.04	66.0	12.0	28.0
	Bt3	SCL	44-17	6.03	64.0	10.0	26.0
	BC	CL	61-23	5.99	48.0	16.0	36.0
			Mean	6.08	64.0	11.0	25.0
3 (MS)	Ap	SL	0-6	6.15	75.0	10.0	15.0
	Bt1	SCL	6-10	6.10	69.0	10.0	21.0
	Bt2	SCL	16-32	6.13	71.0	8.0	21.0
	Bt3	CL	32-46	6.14	51.0	11.0	26.0
			Mean	6.13	66.5	9.8	20.8
4 (LS)	Ap	SL	0-5	6.18	67.0	18.0	15.0
	B	SL	5-21	6.15	71.0	12.0	17.0
			Mean	6.17	69.0	15.0	16.0
5 (VB)	Ap	SL	0-16	6.13	65.0	20.0	15.0
	Bt1	SL	16-25	6.09	71.0	12.0	17.0
	Bt2	SL	25-31	6.09	75.0	8.0	17.0
	Bt3	SL	31-52	6.14	61.0	14.0	19.0
	Bt4	SL	52-79	6.03	65.0	15.0	21.0
	Bt5	SCL	79-110	5.98	63.0	14.0	23.0
			Mean	6.08	66.7	13.8	18.7

C = Crest; US = Upper Slope; MS = Middle Slope; LS = Low Slope; VB = Valley Bottom

increased down the slope with the lower slope position having the highest value (mean 69%) and the crest having the lowest amount (62.8%). The silt content just like the sand content increased down the slope with the lower slope position having the highest amount of silt (mean 15.0%). The removal either by erosion or alluviation of silty materials by rainwater from the upper portions of the toposequene and subsequent deposition down the slope may be the reason for the trend. According to Fanning and Fanning (1989), soil differences across a catena are the results of drainage conditions, differential transportation of eroded material and leaching, translocation and redeposition of mobile chemical constituents.

The clay content distribution within the profiles increased with depth which could be the result of eluviations/illuviation. The clay content was higher in the subsoil than in the topsoil averaging 24.6 and 16.4%, respectively. Fitzpatrick (1986) observed that the increase in clay with depth is a result of three processes (translocation, destruction of clay in the upper horizon and *in situ* weathering in the middle horizon) which may proceed singly, simultaneously or successively. The clay content however decreased along the slope with the crestal position having the highest amount of clay (mean 28.2%). Higher clay content at the crest and upper slope positions is attributable to the slower rate of removal of materials by water due to position and probably also because of the relative stability of the soil constituents up slope. The movement of clay down the profile through eluviation also contributed to its mean higher amount at the higher slope positions.

Organic Carbon

The organic carbon content of the soils is included in Table 2. The soil were generally low in organic carbon with higher values in the topsoil than in the subsoil averaging 5.9 and 2.77 g kg⁻¹,

Table 2: Chemical properties of the soils

Profile	Horizon	Depth (cm)	Organic C (g kg ⁻¹)	Avail. P (mg kg ⁻¹)	CEC (cmol kg ⁻¹)
1 (C)	Ap	0-8	5.18	0.567	3.28
	AB	8-21	3.19	0.315	4.46
	Bt1	29-50	3.79	0.161	4.85
	Bt2	50-88	2.95	0.108	4.45
	Bt3	88-131	2.20	0.338	3.86
	Mean		3.46	0.298	4.18
2 (US)	Ap	0-6	5.19	0.338	3.93
	BA	6-15	1.20	0.215	3.91
	Bt1	15-25	2.79	0.269	4.29
	Bt2	25-44	2.40	0.362	4.59
	Bt3	44-61	2.29	0.458	4.79
	BC	61-84	2.39	0.377	4.90
Mean		2.71	0.337	4.40	
3 (MS)	Ap	0-6	4.39	0.243	3.64
	Bt1	6-16	4.39	1.151	4.17
	Bt2	16-32	3.45	0.319	4.44
	Bt3	32-46	2.39	0.208	4.48
	Mean		3.66	0.480	4.18
4 (LS)	Ap	0-5	9.78	0.243	3.99
	B	5-21	3.99	1.151	4.17
	Mean		6.89	0.697	4.08
5 (VB)	Ap	0-16	5.18	0.319	3.36
	Bt1	16-25	3.19	0.208	4.05
	Bt2	25-31	2.39	0.154	4.36
	Bt3	31-52	1.16	0.110	4.99
	Bt4	52-79	0.30	0.084	5.26
	Bt5	79-110	0.80	0.096	5.26
Mean		2.17	0.162	4.47	

C = Crest; US = Upper Slope; MS = Middle Slope; LS = Low Slope; VB = Valley Bottom

respectively. Organic carbon is a product of organic matter decomposition. Soil organic matter is obtained from the remains of plants and animals, which are mostly found in the topsoil than in the subsoil. The decomposition of soil organic matter is undertaken by soil microorganisms especially bacteria. These soil organisms are found more in the topsoil due to favourable living conditions. When organic matter is decomposed many substances including organic carbon are released into the soil, hence the higher amount of organic carbon in the topsoil.

The distribution of organic carbon along the toposequence was not regular. The highest amount (mean 6.89 g kg⁻¹) was obtained at the lower slope position followed by the middle slope position (mean 3.66 g kg⁻¹) and the least at the valley bottom position. The lower slope position was only about 21 cm deep due to the plinthite layer encountered. The mean value obtained at that position therefore was mainly for the topsoil as opposed to the means of the other profiles, which had higher numbers of horizons. The lower value of organic carbon at the valley bottom position may be due to slower rate of organic matter decomposition due to long periods of continuous wetness.

Available Phosphorus

The phosphorus content was very low both within and between the profiles ranging between 0.162-0.697 mg kg⁻¹ (Table 2). The P content decreased with depth at the crest, upper slope and valley bottom positions while at the middle slope and lower slope positions, it increased with depth. Soil pH has been reported to have a profound influence on the amount and manner in which soluble phosphorus becomes fixed. Adsorption of phosphorus by iron and aluminum oxides declines with increasing pH.

According to Tisdale *et al.* (1985), phosphorus availability in most soils is at a maximum in the pH range 6.0 to 6.5. The pH values of the middle and lower slope positions are slightly higher than the other positions.

Table 3: Available zinc in the soil

Profile	Horizon	Depth (cm)	Available zinc (mg kg ⁻¹)
1 (C)	Ap	0-8	2.12
	AB	8-29	2.02
	Bt1	29-50	2.02
	Bt2	50-88	1.41
	Bt3	88-131	1.09
	Mean		1.73
2 (US)	Ap	0-6	2.01
	BA	6-15	1.86
	Bt1	15-25	1.19
	Bt2	25-44	0.77
	Bt3	44-61	1.81
	BC	61-84	1.42
Mean		1.51	
3 (MS)	Ap	0-6	1.13
	Bt1	6-16	1.21
	Bt2	16-32	1.06
	Bt3	32-46	1.28
	Mean		1.17
4 (LS)	Ap	0-5	3.14
	B	5-21	1.82
	Mean		2.48
5 (VB)	Ap	0-16	1.92
	Bt1	16-25	2.28
	Bt2	25-31	1.68
	Bt3	31-52	2.45
	Bt4	52-79	1.56
	Bt5	79-110	1.11
Mean		1.83	

C = Crest; US = Upper Slope; MS = Middle Slope; LS = Low Slope; VB = Valley Bottom

The available phosphorus content distribution along the toposequence followed similar pattern as the organic carbon with the lower slope position having the highest amount (mean 0.697 mg kg⁻¹) and the valley bottom position having the lowest amount (mean 0.162 mg kg⁻¹). A substantial portion of soil phosphorus is obtained from organic matter and therefore the trend observed is not surprising because the lower slope position having had more organic matter might contain more phosphorus.

Cation Exchange Capacity

The cation exchange capacity of the soils was low both within and between profiles along the toposequence (Table 2) with values ranging between 3.28 and 5.25 cmol kg⁻¹. The distribution trend within profiles is similar to that of the clay fraction. The mean distribution of CEC along the topoposition also follows the pattern of clay distribution with the upper slope position having the highest value (mean 4.40 cmol (+) kg⁻¹) and the lower slope position having the lowest value (mean 4.08 cmol (+) kg⁻¹). According to Tisdale *et al.* (1985), the soil fraction that are seats of iron exchange are a portion of silt and all the clay fraction (< 2 nm) as well as colloidal organic matter. In this mineral soils, the bulk of the CEC might have been contributed by the clay fraction hence the similarity in the distribution trend.

Extractable Zinc

The zinc content was generally low in the soils. However, within profiles, extractable zinc generally decreased with depth. Along the toposequence, the zinc distribution although not regularly distributed was highest at the lower slope position (mean 2.48 mg kg⁻¹) corresponding to the position with the highest amount of organic carbon and the lowest value (mean 1.17 mg kg⁻¹) at the middle slope position (Table 3). The total zinc concentration of soil is known to vary greatly. Earlier findings by other researchers have indicated that soil layers rich in organic matter, such as upper soil

horizons have higher zinc concentrations (Audbert and Pinta, 1977). It has also been noted that although there is variability in the distribution of total zinc in soil profiles, extractable or available zinc accumulates in the topsoil (Follett and Lindsay, 1970). Consequently, removal of topsoil through grading or erosion can increase the likelihood of zinc deficiency in crops (Grunes *et al.*, 1961).

Lombin (1983) and Pam (1990) reported that low zinc levels in the savannah soils of Nigeria was due to low levels of the element in the parent material, absence of the micronutrient in fertilizer programme, soil pH and leaching intensities.

CONCLUSION

The soils along the toposequence were generally low in fertility and available zinc and there was no marked difference between the properties along the toposequence probably because the processes of soil formation are at equilibrium within this environment since the soils are formed from the same parent material under the same climatic conditions.

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