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Assessment of some Micronutrients in Profiles of Typic Plinthustalfs in Minna, Southern Guinea Savanna, Nigeria

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ABSTRACT

A study was carried out to assess the distribution and relationship of some micronutrients in profiles of Typic Plinthustalfs, the dominant soil unit in the Teaching and Research Farm of the Federal University of Technology, Minna, Nigeria. Two related soil profiles designated as NM-1 and NM-2 respectively were evaluated for their copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn) contents. Also, the relationship of these micronutrients with sand, silt, clay, pH and organic carbon (C) were determined. The two soil profiles had surface texture of sandy loam with subsurface characterized by presence of concretionary layers. The pH of the soil was rated strongly acid to moderately acid in both profiles. Organic C and available phosphorus (P) were low in both pedons while total nitrogen was rated high except in the C-horizons. Calcium (Ca) was low in the surface horizons and high in the subsurface of NM-2. Magnesium (Mg) and sodium (Na) were rated medium to high while potassium (K) was high irrespective of horizons in both profiles. All the micronutrients were sufficient in the soil for crops. Only Zn correlated significantly ($P < 0.01$) with organic carbon ($r = -0.81$). The relationships of the other micronutrients with texture, pH and organic C were not significant. For adequate supply of essential micronutrients, the soil may require liming to raise the pH to favourable range for optimal availability of micronutrients. Incorporation of organic residues is required to improve the soil organic C and soil structure induced by the plinthites.

Keywords: Micronutrients, Plinthustalfs, Basement Complex Rocks, savanna ecosystems

INTRODUCTION

Micronutrients are chemical elements required in very small amounts by plants. They are usually of relatively low abundance in soils but play key roles in the growth and development of crop plants, hence, essential for plant growth (Brady and Weil, 2010; Mustapha *et al.*, 2010). In the past, little attention was paid to the study and/ or use of micronutrients, especially in developing countries such as Nigeria, probably due to low intensity agriculture being practiced. Low intensity farming permitted the recuperation of soils, hence, replenishing its macro- and micronutrients that were hitherto lost (Mustapha *et al.*, 2010). Also, studies have shown that micronutrients were not applied regularly to the soil along with major fertilizer elements, despite the fact that mounts of up to six fold in quantity of these micronutrient elements were removed annually from the soil than were applied to it (FAO, 1983). This trend in micronutrients exploitation from soil called for more studies on micronutrients, especially in developing countries such as Nigeria.

Studies on the micronutrients status of soils of Nigeria are well documented, especially in the savanna ecosystem (Udo *et al.*, 1979; Lombin, 1983a, 1983b, 1985; Kparmwang *et al.*, 1998; Mustapha and Singh, 2003; Mustapha *et al.*, 2010; Oyinlola and Chude, 2010; Ibrahim *et al.*, 2011; Lawal *et al.*, 2012a). Severally, Lombin (1983a, 1983b, 1985) reported deficiencies of micronutrients in some soils of the Nigeria savanna. Also, Enwezor *et al.* (1990) reported low levels of available zinc (Zn) and boron (B) and sufficient levels of copper (Cu) and manganese (Mn). Mustapha *et al.* (2010) reported low content of Zn, low to medium for Cu and high for Fe and Mn in Haplustults of north eastern Nigeria. Similarly, Biwe (2012) observed low level of Zn, medium level and sufficient amount of iron (Fe) and Mn in some soils in Northern Guinea savanna in Bauchi State of Nigeria.

Rapid urbanization encouraged high influx of people into Minna. Consequently, the surrounding land, are being cleared and intensively cultivated to a variety of food and tree crops, such as maize, cowpea, yams, mango, citrus, apple, banana and plantain (Lawal *et al.*, 2012b). The implication of extensive cultivation of land does not permit the land to fallow and regain its fertility naturally, hence its inability to recuperate lost nutrients, especially micronutrients (Kparmwang *et al.*, 1998; Mustapha *et al.*, 2010). The dominant soils around Minna have been classified as Typic Plinthustalfs (Lawal *et al.*, 2012b), that were derived from intensive weathering of basement complex rocks, with some soil types having gravelly or concretionary layers developed from irreversible hardening of plinthites in their surface or subsurface layers (Ojanuga, 2006). These properties created some management problems which included low fertility attributed to strong weathering and leaching of nutrients, hindrance to root penetration, poor internal drainage and occasionally, shallow depth which limits their water storage capacity. In addition, information about the micronutrients status of soils around Minna has not been well documented. This study therefore, was conducted to, assess the status of some extractable micronutrients, particularly, zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) in the profiles of the dominant soil types around Minna, and determine the relationship between these micronutrients and sand, silt, clay, pH and organic C.

MATERIALS AND METHODS

The study site was the Teaching and Research Farm of the Federal University of Technology, Minna, Gidan Kwano Campus, located at latitude 09° 31' 09.7" N and longitude 06° 36' 26.2" E. The study site is underlain predominantly by igneous and metamorphic rocks of the pre-Cambrian Basement Complex and lies within the Tropical Hinterland Climate region designated by 'Koppen Aw' sub-humid with mean annual rainfall of 1284 mm, and a dry season of about 5 months and mean annual temperature greater than 30 °C (Ojanuga, 2006). Arable crops mainly yam, maize and upland rice were major crops grown in the study site.

Two soil profiles designated as NM-1 and NM-2 respectively were dug in section of the farm covered by Typic Plinthustalfs (Lawal *et al.*, 2012b). Soil samples were collected from each identified genetic horizons and taken to the laboratory for analysis.

Soil analysis and data interpretation

The samples were air-dried, gently crushed using porcelain mortar with pestle and passed through a 2-mm sieve to obtain the fine earth separates and the samples used for the determination of organic carbon (C) and total nitrogen (N) were further ground and passed through a 0.5-mm sieve. Processed samples were analysed following the procedures outlined by the International Soil Reference and Information Centre and Food and Agricultural Organization (ISRIC/FAO, 2002). Particle size distribution was determined by Bouyocous hydrometer method using sodium hexametaphosphate as dispersing agent. Soil pH in 1:2.5 soil-0.1m calcium chloride suspensions was determined using a digital glass electrode pH meter. Organic C 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). Total nitrogen (N) was determined by micro Kjeldahl method. Available phosphorus (P) was by Bray P-1 method. 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 was measured using a Flame Photometer while Ca and

Table 1: Particle size distribution of the soils

Pedon	Horizon	Soil Depth (cm)	Sand	Silt	Clay	Textural class*
				($g\ kg^{-1}$)		
NM-1	Ap	0-23	807	110	83	SL
	BA	23-46	667	120	213	SCL
	Btg	46-89	547	90	363	CL
	Btv1	89-117	687	50	263	GSCL
	Btv2	117-158	557	110	333	GSCL
	C	158-192	627	110	263	SCL
NMA-2	Ap	0-19	827	80	93	SL
	Btg1	19-47	697	70	233	SCL
	Btg2	47-117	627	110	263	SCL
	Btv	117-143	657	70	273	GSCL
	C	143-167	777	70	153	SCL

*SL=sandy loam, SCL=sandy clay loam, CL=clay loam, GSL=gravelly sandy loam, GSCL= gravelly sandy clay loam

Mg was by atomic absorption spectrophotometry (AAS). ECEC was by summation of exchangeable bases and exchangeable acidity. Base saturation was by calculation (dividing the sum of exchangeable bases by their ECEC then multiplied by 100). Exchangeable acidity (H^+ and Al^{3+}) was determined by titrimetric method. Available zinc (Zn), copper (Cu), manganese (Mn) and iron (Fe) were extracted with 0.01 N HCl and amount in extract determined using atomic absorption spectrophotometry.

Pearson correlation analysis was carried out to determine the relationship between the micronutrients and sand, silt, clay, pH and organic C using the computer software, SPSS Statistics 17.0. Data interpretation was made by comparing the results with the critical limits recommended for each parameter (Table 1).

RESULTS AND DISCUSSION

Physical properties

Results on particle size distribution of the studied profiles designated as NM-1 and NM-2 are shown in Table 1. Sand fraction ranged from 547 to 807 g kg^{-1} in NM-1 and 757 to 867 g kg^{-1} in NM-2. Although both profiles were derived from the same Parent Material, sand content NM-2 was higher than NM-1 probably due to differences in their elevation. The study had shown that topography had influenced the soil physical properties and also on pattern of soil particle size distribution over the landscape (Esu *et al.*, 2008). Silt ranged from 50 to 120 g kg^{-1} in NM-1 and 60 to 110 g kg^{-1} in NM-2, but distribution in both profiles were irregular. Clay was next to sand in dominance and its content ranged from 83 to 363 g $kg^{-1}$and 93 to 273 g kg^{-1} in NM-1 and NM-2 respectively. The two profiles showed remarkable differences in clay content with depth probably due to eluviation and illuviation processed which has led to formation of argillic horizons.

Chemical properties of the soils

Results of the chemical properties of the studied soil are presented in Table 2. Soil reaction was strongly to moderately acid with pH values ranging from 5.1 to 5.8 and 5.2 to 5.8 for NM-1 and NM-2 respectively. Lake (2000) had reported soil pH of 5.2 to 8.0 as favourable range for most agricultural crops, particularly for optimum availability of micronutrients. Organic carbon (C) content in the soils ranged from 0.63 to 4.08 g kg^{-1} and 0.41 to 3.27 g kg^{-1} in NM-1 and NM-2 respectively and was rated low in both profiles, irrespective of soil depth. These results implied that the amount of residues returned to the soil from vegetation was low. Nartey *et al.* (1997) attributed low level of organic C to the low biomass turnover from the predominantly grass vegetation and the destructive bush fires characteristic of the savanna environment. Total nitrogen (N) ranged from 0.11 to 0.88 g kg^{-1} in NM-1 and 0.04 to 0.32 g kg^{-1} in NM-2. Except in the C-horizon (a mass of decomposing rock) of NM-1, where total N was rated low, its

Table 2: Some chemical properties of the soils

Pedon	Horizon	Soil Depth (cm)	pH	Organic C	Total N	Avail. P (mg kg^{-1})	Ca	Mg	K	Na	Exch. Acidity	ECEC	Base Saturation (%)
				(g kg^{-1})			← (cmol kg^{-1})					→	
NM-1	Ap	0-23	5.6	4.08	0.80	7	1.12	0.72	0.48	0.51	1.12	3.95	72
	BA	23-46	5.1	2.25	0.41	6	1.40	1.16	0.33	0.16	0.32	3.37	91
	Btg	46-89	5.5	1.23	0.46	8	4.24	1.76	0.57	0.24	0.32	7.13	96
	Btv1	89-117	5.3	1.43	0.88	6	3.68	1.12	0.53	0.30	0.32	5.95	95
	Btv2	117-158	5.6	0.82	0.48	7	7.44	0.88	0.45	0.49	0.32	9.58	97
	C	158-192	5.8	0.63	0.11	8	6.80	1.44	0.34	0.62	0.24	9.44	97
NM-2	Ap	0-19	5.6	3.27	0.08	8	1.52	0.56	0.41	0.15	0.32	2.96	89
	Btg1	19-47	5.7	2.25	0.04	6	2.24	0.24	0.31	0.20	0.28	3.27	91
	Btg2	47-117	5.8	1.84	0.18	10	2.96	1.84	0.69	0.30	0.72	6.51	89
	Btv	117-143	5.2	1.43	0.13	7	3.84	1.20	0.38	0.34	1.52	7.28	79
	C	143-167	5.7	0.41	0.32	7	3.52	0.56	0.29	0.36	1.12	5.85	81

concentration in other horizons was rated high. In NM-2, total N content was very low with surface horizon down the profile. Since organic matter was low in NM-1 and NM-2, application of inorganic N fertilizers by farmers might have contributed to the high level of total N observed, especially in NM-1 which was cropped to maize at the time of the study. Available phosphorus (P) was rated low in NM-1 and NM-2 irrespective of soil depth with values that ranged from 6 to 8 and 6 to 10 mg kg^{-1} respectively.

The values for calcium (C) ranged from 1.12 to 7.44 cmol kg^{-1} in NM-1 and 1.52 to 3.84 cmol kg^{-1} in NM-2. While Ca content was rated low in surface horizon, its concentration increased irregularly with soil depth. Magnesium (Mg) ranged from 0.72 to 1.76 cmol kg^{-1} in NM-1 and 0.24 to 1.84 cmol kg^{-1} in NM-2. In both profiles, Mg was rated low in the surface and medium to high in the subsurface horizons. Potassium (K) ranged from 0.33 to 0.57 cmol kg^{-1} in NM-1 and 0.29 to 0.69 cmol kg^{-1} in NM-2 and was rated high in both profiles except in the C-horizon of NM-2 where it was rated medium. Sodium (Na) was rated medium to high and the values ranged from 0.16 to 0.62 cmol kg^{-1} in NM-1 and 0.15 to 0.36 cmol kg^{-1} in NM-2. Values for ECEC ranged from 3.37 to 9.58 cmol kg^{-1} in NM-1 and 2.96 to 7.28 cmol kg^{-1} in NM-2 was rated low to medium. Base saturation was rated medium to high with values $\geq$ 72 %, implying the presence of soluble forms of non-acid cations in the soil solution and if fertilizers are applied to these soils, the nutrients would readily be in available forms for crop uptake (Akpan-Idiok *et al.*, 2013).

Amounts and distribution of micronutrients in the soil profiles

Extractable copper

Data on micronutrients are shown on Table 3. The content of available copper (Cu) ranged from 3.60 to 5.20 mg kg^{-1} and 4.20 to 5.00 mg kg^{-1} in NM-1 and NM-2 respectively. These values were rated high in all horizons. The content of Cu in the studied soil was higher than 1.7 to 2.0 mg kg^{-1} reported for some hydromorphic soils of Minna (Lawal *et al.*, 2012a). These results therefore implied that deficiency of Cu in the studied soil may not occur in the nearest future. Also, the finding of this study corroborated with that of Lombin (1983a) which indicated that the content of available Cu in soils of Northern Nigeria savanna are adequate and poses no fertility problem. High Cu content may be due to the low pH of the soils and sandy loam and sandy clay loam texture of the soils. However, Enwezor, *et al.* (1990) had reported that Cu deficiencies are common in sandy soils or soils with high pH.

Table 3: Micronutrients content of the soils

Pedon	Horizon	Soil Depth (cm)	Cu	Zn	Fe	Mn
			←	(mg kg^{-1})	→	
NM-1	Ap	0-23	4.00	3.60	77	37
	BA	23-46	4.40	4.40	63	8
	Btg	46-89	4.60	9.40	130	13
	Btv1	89-117	3.60	7.40	48	40
	Btv2	117-158	5.20	17.00	53	31
	C	158-192	4.00	23.00	256	55
NMA-2	Ap	0-19	4.20	3.80	135	30
	Btg1	19-47	5.00	4.60	39	9
	Btg2	47-117	4.20	7.80	39	8
	Btv	117-143	4.60	8.60	184	50
	C	143-167	4.80	18.20	256	42

Extractable zinc

Extractable zinc (Zn) ranged from 3.60 to 23.00 mg kg^{-1} and 3.80 to 18.20 mg kg^{-1} in NM-1 and NM-2 respectively. The values were all rated high in both profiles irrespective of soil depth and the studied soil could therefore be regarded as being adequate in extractable Zn. The relatively high values in all the horizons may be attributed to the relatively high clay content in the studied soils. Soils with high clay content have been reported to be rich in Zn (Lombin, 1983a). Furthermore, Zn content was highest in the C-horizons, implying that the parent materials may be a major source of this nutrient. Therefore, increase in Zn content observed with soil depth may not be associated fully to leaching, more so that Zn has low mobility in soils (Chesworth, 1991).

Extractable iron

The content of iron (Fe) ranged from 48 to 256 mg kg^{-1} and 39 to 256 mg kg^{-1} in NM-1 and NM-2 respectively. In both profiles, Fe content was rated high for all horizons. High contents of Fe in the studied soils probably induced complex chemical reactions which led to the formation of plinthites in some horizons (Sombroek, 1987; Biwe, 2012). The pattern of distribution of Fe within the profiles differed. In NM-1, Fe was irregularly distributed within the profile and it showed a bimodal maxima distribution pattern. Its highest concentration of 256 mg kg^{-1} was at the C-horizon. On the contrary, in NM-2, Fe decreased with soil depth, and the trend was reversed from Btv horizon to C-horizon where its value peaked at 256 mg kg^{-1}. The distribution pattern of Fe within the profiles suggested that the nutrient element was not tied to specific soil properties or pedogenic processes (Shittu *et al.*, 2010). Also, higher amount of Fe in surface horizon of NM-2 may be attributed to pedoturbation process, particularly by roots of plants. Some researchers had established that deep-rooted crops extract micronutrients from deeper layers and deposited them on the surface layers after decomposition of such crops (Harmsen and Vlek, 1985).

Extractable manganese

Extractable manganese (Mn) in the profile of NM-1 ranged from 8 to 55 mg kg^{-1} and was rated high in all horizons except in BA horizon where it was rated medium with value of 8 mg kg^{-1}. Similarly, in NM-2, Mn ranged from 8 to 50 mg kg^{-1} and like in NM-1, it was rated medium to high. These results agreed with those reported for some other northern Nigeria savanna soils (Kparmwang *et al.*, 2000; Oyinlola and Chude, 2010). Medium to high values of Mn in the profiles of the studied soil may be due to acidity of the soil which was rated strongly acid to moderately acid. The soil investigated could be said to be sufficient in Mn and the prospect of Mn deficiency problems may not arise in the nearest future. In both profiles, the distribution of Mn was irregular with soil depth. Also, high amount of Mn in the surface horizon of both profiles may be linked to pedoturbation as explained for Fe.

Table 4: Critical limits for interpreting levels of analytical parameter of soils

Parameter	Low*	Medium	High	Source
pH:				
Strongly Acid	5.0 – 5.5			Chude *et al.* (2011).
Moderately Acid	5.6 – 6.0			"
Slightly Acid	6.1 – 6.5			"
Neutral	6.6 – 7.2			"
Slightly Alkaline	7.3 – 7.8			"
Org. C (g kg^{-1})	< 10	10 – 15	> 15	Esu (1991).
TN (g kg^{-1})	< 0.1	0.1-0.2	> 0.2	"
Av. P (mg kg^{-1})	< 10.0	10.0-20.0	> 20.0	"
Ca^{2+} (cmol kg^{-1})	< 2	2 – 5	> 5	"
Mg^{2+} (cmol kg^{-1})	< 0.3	0.3 – 1	> 1	"
K^{+} ($cmol^{kg-1}$)	< 0.15	0.15-0.3	> 0.3	"
Na^{+} (cmol kg^{-1})	< 0.1	0.1-0.3	> 0.3	"
CEC (cmol kg^{-1})	< 6.0	6.0-12.0	> 12.0	"
Micronutrients:				
Cu (mg kg^{-1})	<0.2	0.2 - 1.0	>1.0	"
Zn (mg kg^{-1})	<0.8	0.8 - 2.0	>2.0	"
Fe (mg kg^{-1})	<4.5	4.5 - 10.0	>10.0	"
Mn (mg kg^{-1})	<5	5 – 10	>10	"

*Except for pH, values for other soil parameters were rated as low, medium or high

Table 5: Pearson's Correlation coefficient of the micronutrients with some soil properties

Parameter	Extractable micronutrients			
	Cu	Zn	Fe	Mn
Sand	-0.30 NS	-0.37 NS	0.15 NS	0.22 NS
Silt	0.05 NS	0.13 NS	-0.13 NS	-0.26 NS
Clay	0.30 NS	0.35 NS	-0.12 NS	-0.16 NS
pH ($CaCl_2$)	0.12 NS	0.41 NS	0.19 NS	0.02 NS
Organic C	-0.32 NS	-0.81*	-0.46 NS	-0.27 NS

*Significant at 5 %
NS = Not significant

Relationship between micronutrients and some soil properties

The relationship between micronutrients and soil texture, pH and organic carbon are shown in Table 5. All the micronutrients had no significant relationship with the soil sand, silt and clay particles, pH and organic carbon, except Zn which had significant negative correlation with organic carbon (r = -0.81). These results implied that soil properties under consideration do not have control on the amount of the micronutrients in both profiles except Zn. Previous works on some savanna soils have shown significant relationships between extractable Cu and Zn with pH, clay and organic carbon (Iyaka and Kakuku, 2009); Zn with clay and organic carbon (Adeboye, 2011), Mn with pH (Ibrahim *et al.*, 2011). The lack of significant relationship between the other micronutrients and other soil properties suggest that their availability in the study soil might be controlled by some undefined soil properties, most likely the soil parent material.

CONCLUSION

The soils investigated had pH values marginally favourable for optimal availability of macro- and micronutrients for most crops. Liming may be necessary to increase the availability of the micronutrients. Organic carbon was low in the studied soil and as such, it is suggested that all measures that will encourage return and incorporation of plant and animal residues should be adopted, not only to improve the nutrient status of the soil but also to improve the soil structure in these poorly structured soils due to the occurrence of plinthites. In addition, high status of Fe and low pH of the studied soil may accelerate the plinthization process, which is a potential threat to sustainable use of the soil for cropping. Hence, incorporation of organic matter should be accorded a high priority. The studied soil currently have sufficient amount of Zn, Fe, Cu and Mn and their deficiencies are not likely to occur quickly with the current use and management of the soil.

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