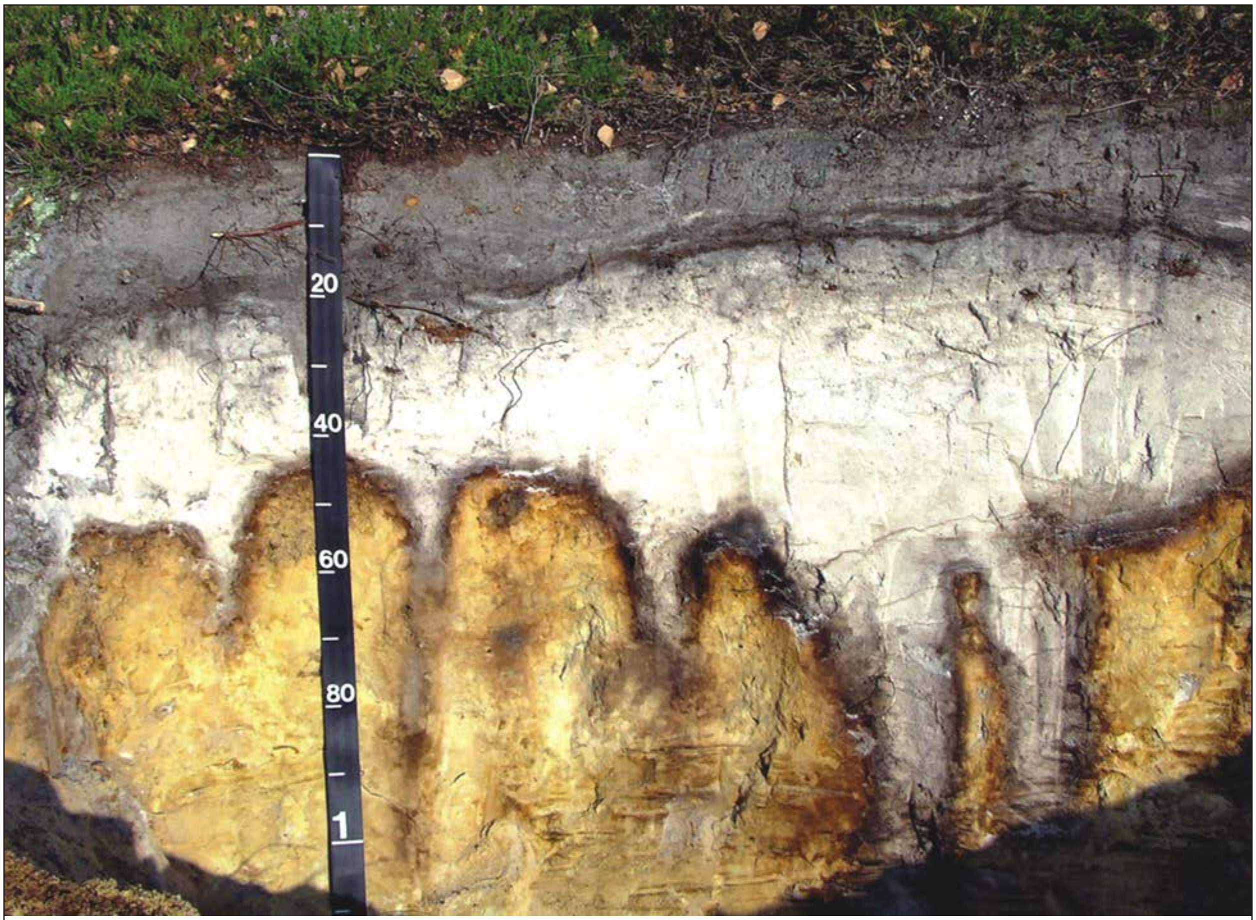

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Status and Distribution of some Available Micronutrients in the *Haplic usterts* of Akko Local Government Area, Gombe State, Nigeria

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ABSTRACT

This study has been conducted to assess the status and distribution of available Zinc (Zn), Copper (Cu), Iron (Fe) and Manganese (Mn) in soils of Akko Local Government Area (LGA), Gombe State, Nigeria. Sixty composite soil samples were collected from 0-15 and 15-30 cm depths from 15 purposively selected representative locations in the LGA and analyzed in the laboratory using standard procedures. Results obtained showed that the soils were generally clayey to sandy clay loams, slightly to moderately acid (pH range = 5.77 -6.5; mean = 6.1), low in organic carbon (mean = 0.83 g kg^{-1}) and low to medium in exchangeable bases. Zinc was generally 'low' in all the locations (range = 0.13 to 0.37; mean = 0.22 mg kg^{-1}), Cu ranged from 'low' (66.7%) to 'medium' (33.3%) while Fe (mean = 10.80 mg kg^{-1}) and Mn (mean = 34.0 mg kg^{-1}) were generally 'high' in content. Depth significantly ($p<0.05$) influenced the distribution of all the micronutrients studied except Fe that did not significantly vary with depth. For sustainable crop production, it is recommended that the pH be improved to near neutral. Crops grown in all the locations will benefit from Zn and organic matter application while areas identified 'low' for Cu should have Cu included in their fertilization programme.

Key words: Fertilization, vertisols, micronutrients, soil pH, organic matter

INTRODUCTION

Micronutrients are metallic chemical elements necessary for plant growth in only extremely small amounts. Although required in minute quantities however, micronutrients have the same agronomic importance as macronutrients and play vital roles in the growth of plants (Nazif *et al*., 2006). These metallic chemical elements include Zinc (Zn), Iron (Fe), Copper (Cu) and Manganese (Mn), amongst others. Most micronutrients are associated with the enzymatic systems of plants. For instance, Zn is known to promote the formation of growth hormones, starch and seed development, Fe is important in chlorophyll formation, Cu in photosynthesis and Mn activates a number of important enzymes and is important in photosynthesis and metabolism (FFTC, 2001).

The origin and sources of micronutrients in soils are as diverse as they are variant. However, the major sources include: parent materials, sewage sludge, town refuse, farm yard manure and organic matter (Nazif *et al*., 2006). It is reported (Brady and Weil, 2005) that Fe and Mn are common in silicate minerals such as biotite and horneblende. Zinc may also replace some of the major constituents of silicate minerals including clays and be found therein, while Cu and Mn are often tightly held by organic matter.

In Nigeria, micronutrient deficiencies were quiet rare, owing in part to the extensive system of agriculture practiced that permitted the recuperation of soils over a fairly long period of fallow. This tended to replenish the soil macro- and micro-nutrients that were hitherto lost. However, with the increasing human and animal population in Nigeria in general and in Gombe State in particular and the country's drive to attain food security, the abandonment of the traditional extensive agricultural system, to a more scientific intensive one has become imperative. This, coupled with the use of new high yielding crop varieties which are nutrient demanding and the realization of the concept of balanced nutrition by farmers have unraveled micronutrient deficiencies in some Nigeria Savanna soils (Mustapha and Loks, 2005).

As a pre-requisite to the successful implementation of the scientific agricultural practice, the evaluation of the nutrient status of the soils, including the micronutrients becomes necessary. This will ensure a more economic utilization of the soil resources by the resource-poor Nigeria farmers (Mustapha, 2003) and also help in the Government's drive towards food sufficiency.

With this view this study was undertaken with the objective of determining the status and distribution of available zinc, copper, iron and manganese, in the cultivated *Haplic usterts* of Akko LGA, Gombe State, Nigeria as a case study for soils with similar characteristics in other agro-ecologies.

MATERIALS AND METHODS

The study area: The study was conducted between May and August, 2010 in Akko LGA; located along Gombe-Adamawa road, about 30 km away from Gombe town. It is situated 12°30'N and 11°45'E, within the northern Guinea Savanna Zone of Nigeria. The geology of the area is said to be of tertiary continental sandstone to the west of the Keri-Keri escarpment, clays and siltstones. The climate is characterized by two distinct wet (May to October) and dry April) seasons. The annual rainfall is about 800 to 900 mm per annum with mean annual temperature ranging from 30° to 32°C (BSADP, 1982).

Soil sampling and handling: A total of 60 composite soil samples were collected at 0-15 and 15-30 cm depths from 15 different, purposively selected representative locations in Akko LGA of Gombe State, Nigeria. Each composite soil sample was made of five sub-samples.

The collected soil samples were properly labeled and stored in polythene bags and taken to the laboratory. In the laboratory, each sample was separately dried in air and then ground using porcelain pestle and mortar. The ground soil samples were sieved with 2 mm sieve and the fine earth fractions, collected in separate bags, were used for all the laboratory analyses.

Laboratory analyses: The processed soil samples were analyzed for some physico-chemical properties including the micronutrients (Zn, Cu, Fe and Mn) under investigation following procedures described by Page *et al.* (1982). Particle size distribution was determined by the hydrometer method after dispersing in sodium hexametaphosphate solution (Bouyoucos, 1951). The soil pH was determined in 1:1 soil/water suspension using a glass electrode pH meter while organic carbon in the soil was determined by the wet combustion method of Walkley and Black (1934). Cation exchange capacity was estimated using the NH_4O Ac saturation (pH 7) method, while the leachate was used to determine the exchangeable bases. The extractable micronutrients: Zn, Cu, Fe and Mn were extracted with 0.1M HCl solution (Osiname *et al.*, 1973) and determined on an atomic absorption spectrophotometer at appropriate wave lengths.

For the purpose of micronutrient fertility ratings, the limits given by Esu (1991) were employed. For Zn, values <0.8, 0.81-2.0 and >2.0 mg kg^{-1} were respectively rated 'low', 'medium' and 'high' while for Cu, the respective fertility category rating limits were <0. 2, 0.21-2.0 and >2.0 mg kg^{-1}. Iron was regarded as 'low' if <2.5, 'medium' if 2.51-5.0 and 'high' if >5.0 mg kg^{-1}. Manganese was low if the values were <1.0, 'medium' if 1.1-5.0 and 'high' if >5.0 mg kg^{-1}.

Data analysis: Data generated were subjected to simple descriptive statistics, including range and means (Harry and Steven, 1995). Computer Minitab software was employed for analysis of variance to determine significant differences between means. Means that were statistically different were separated using the Least Significant Difference (LSD).

RESULTS AND DISCUSSION

Physico-chemical properties: Results of some physico-chemical properties of the soils studied are presented in Tables 1 and 2. The particle size distribution of the soils as shown in Table 1 indicates that the soils have relatively high sand (mean = 46.9%) and clay (mean = 30.1%) contents; giving the soils a generally sandy clay to clay texture. Clay content significantly (p<0.05) increased with soil depth. This is expected as some of the increase with depth in clay may be as a result of removal of the fraction by surface run-off and also by illuviation. This is a common phenomenon in soil in this agro-ecology as was also reported by Voncir *et al.* (2008). The results also indicate that

Table 1: Particle size distribution in the *Black cotton* soils in Akko LGA, Gombe state, Nigeria

Location	Sand (%)	Silt (%)	Clay (%)	pH (in H_2O)	Org. C. (g kg^{-1})
L. Mango	40.5	23.6	35.7	6.2	0.39
Zange	28.8	23.8	47.4	6.4	0.61
Lamba	25.5	24.6	49.9	6.3	0.87
Kumo	29.9	28.8	49.0	6.5	0.61
Tsamiya	35.1	19.1	45.4	6.2	0.87
M. Bakari	46.9	20.9	32.7	5.9	1.00
G. Wakili	45.0	30.8	24.0	6.0	0.76
A. Bose	50.9	20.3	27.4	6.1	0.62
W. Bappa	62.0	19.3	18.5	6.2	0.12
W. Yola	54.4	18.1	27.4	5.9	1.56
Kembu	60.4	22.4	21.5	5.8	1.22
S. Gari	54.4	19.8	25,5	6.1	0.94
Gamawa	47.7	29.3	23.0	5.9	0.83
Y. Shehu	55.2	26.3	18.5	6.1	1.09
W. Abba	66.9	15.1	17.9	5.7	0.90
Mean	46.9	22.8	30.1	6.1	0.83
Level of significance	***	***	***	*	*
LSD (p<0.05)/SE±	9.64	4,58	7.90	0.14	0.14
Depth (cm)					
0-15	48.3	23.5	28.7	5.8	0.99
15-30	44.4	22.0	33.1	6.4	0.75
Level of significance	NS	NS	*	***	NS
LSD(p<0.05)/ SE±	7.21	3.42	12.14	0.72	0.40

NS: Not significant

Table 2: Exchangeable bases (in cmol(+)kg^{-1}) of some soils in Akko LGA, Gombe State, Nigeria

Location	Ca	Mg	K	Na
L. Mango	6.7	0.43	0.01	0.02
Zange	4.7	0.60	0.24	0.05
Lamba	5.3	0.53	0.24	0.01
Kumo	4.3	0.72	0.66	0.02
Tsamiya	5.2	0.53	0.17	0.01
M. Bakari	4.7	0.72	0.20	0.02
G. Wakili	5.0	0.62	0.32	0.02
A. Bose	5.0	0.67	0.32	0.02
W. Bappa	7.2	0.33	0.38	0.03
W. Yola	7.0	0.44	0.27	0.02
Kembu	4.7	0.39	0.21	0.02
S. Gari	3.7	0.58	0.22	0.02
Gamawa	5.1	0.53	0.27	0.02
Y. Shehu	3.9	0.42	0.22	0.02
W. Abba	3.8	0.39	0.26	0.02
Mean	5.1	0.53	0.27	0.02
Significance	NS	NS	NS	*
LSD (p<0.05)/SE±				
Depth (cm)				
0-15	4.9	0.52	0.54	0.02
15-30	5.3	0.53	0.26	0.02
Significance	NS	NS	*	NS
LSD (p<0.05)/SE±	1.4	0.17	0.65	-

NS: Not significant

all the fractions varied significantly ($p<0.05$) between the locations indicating wide variability in the fractions between soils from different parts of the LGA. Except for clay, however, all the other fractions did not vary significantly ($p>0.05$) with depth probably indicating the importance of illuviation as a pedogenic process in this area as also reported by Uzoije and Onunkwo (2011) elsewhere in south-eastern Nigeria.

The soil reaction ranged from pH 5.7-6.5 (mean = 6.1) indicating slightly to moderately acidic reaction. Though generally acidic, the pH values varied significantly ($p<0.05$) between the locations and depths considered. The upper 0-15 cm was more acidic (pH = 5.8, moderately acidic) than the lower 15-30 cm (pH = 6.4, slightly acidic). This could be attributed to the removal of basic cations from the surface of the soils to the lower depths (Mustapha and Loks, 2005; Voncir *et al.*, 2008; Kolo *et al.*, 2009) and/or the use of acid-forming fertilizers such as urea for agricultural purposes.

Results in Table 1 show that organic carbon content ranged from low to medium (Esu, 1991) across the locations; with values ranging from 0.12 to 1.56 (mean = 0.83) g kg^{-1}. Even though the surface 0-15 cm soils contained more organic carbon (0.99 g kg^{-1}) than the lower 15-30 cm (0.75 kg^{-1}), the differences were not statistically significant ($p>0.05$). Similar low organic carbon values have been reported by Yaro *et al.* (2006) for the Nigeria Savannah soils, Mustapha and Nnalee (2007) and Mustapha *et al.* (2007) for soils in the northern guinea Savanna zone of Nigeria.

The exchangeable bases (Ca, Mg, K and Na), except for Na, did not significantly ($p<0.05$) vary with location and depth (except for K) (Table 2). The Ca varied from medium to high (range = 3.7-7.2; mean = 5.1 mg kg^{-1}), Mg (range = 0.33-0.72; mean = 0.53 mg kg^{-1}) was medium,

Table 3: Some exchangeable micronutrients (in mg kg^{-1}) of some soils in Akko LGA, Gombe State, Nigeria

Location	Zn	Cu	Fe	Mn
L. Mango	0.13	0.26	6.9	33.3
Zange	0.21	0.23	7.3	29.9
Lamba	0.19	0.09	10.3	46.4
Kumo	0.19	0.15	10.1	38.2
Tsamiya	0.21	0.16	6.9	34.3
M. Bakari	0.26	0.25	10.4	30.1
G. Wakili	0.19	0.28	8.3	33.4
A. Bose	0.22	0.12	12.3	32.1
W. Bappa	0.21	0.09	13.2	32.2
W. Yola	0.17	0.15	5.7	32.7
Kembu	0.22	0.18	12.5	37.8
S. Gari	0.24	0.15	13.2	25.9
Gamawa	0.37	0.24	14.9	29.9
Y. Shehu	0.32	0.19	12.2	29.9
W. Abba	0.22	0.09	18.3	43.7
Mean	0.22	0.18	10.8	34.0
Significance	NS	***	NS	NS
LSD (p<0.05)/SE±	0.02	0.05	1.3	2.7
Depth (cm)				
0-15	0.27	0.22	9.9	27.6
15-30	0.17	0.13	11.8	40.4
Significance	***	***	NS	***
LSD (p<0.05)/SE±	0.21	0.16	3.8	27.2

NS: Not significant

while K (range = 0.01-0.66; mean = 0.27 mg kg^{-1}) and Na (range = 0.01-0.05; mean = 0.02 mg kg^{-1}) were low to high and low, respectively.

Zinc status: Results in Table 3 show that Zn in the soils studied ranged from 0.13 to 0.37 (mean = 0.22) mg kg^{-1} between the locations; placing it in the 'low' category. This indicates that soils in all the locations studied were deficient in the nutrient as the values were below the critical 0.80 mg kg^{-1} reported by Esu (1991). Except for some locations such as L. Mango (0.13 mg kg^{-1}), Gamawa (0.37 mg kg^{-1}) and Y. Shehu (0.32 mg kg^{-1}), Zn was fairly uniformly distributed in the area studied. The values obtained in the present study are indeed lower than the 0.48-0.75 (mean = 0.58) mg kg^{-1} obtained for the soils elsewhere in the State (Mustapha *et al.*, 2010).

Depth significantly ($p<0.001$) influenced the distribution of zinc in the soils studied. Soils from the top 0-15cm contained significantly ($p<0.05$) more (0.27 mg kg^{-1}) Zn than soils from the lower 15-30cm (0.17 mg kg^{-1}). The implication here is that plants may not have a Zn 'store' in the lower soil strata which plants could exploit especially if same obtains even at lower depths. Similar decrease with depth was also observed by Mari *et al.* (2006) in soils in Pakistan.

Copper status: Table 3 shows that Cu in the soils studied ranged from 0.09 to 0.28 (mean = 0.18) mg kg^{-1}, putting it in the 'low' to 'medium' fertility rating. These results obtained are lower than the results obtained by Mustapha and Singh (2003) for soils elsewhere in Galambi, Bauchi State, Nigeria in similar agro-ecology but are similar to the 0.81 to 0.26 (mean = 0.21) mg kg^{-1} obtained by Mustapha *et al.* (2010) in other area in Gombe State. It is pertinent to note that Cu significantly

($p<0.05$) varied with locations. Most (66.7%) of the soils studied were classed 'low' in Cu fertility while about 33.3% were in the 'medium' category. Consequently, crops grown on most of the soils in the LGA will benefit from supplementary Cu application.

Between the depths considered, Cu varied rather significantly ($p<0.05$). The upper 0-15 cm contained significantly higher (0.22 mg kg^{-1}) amounts of Cu than the lower 15-30 cm (0.13 mg kg^{-1}). This indicates that while the upper soils contain sufficient amounts of Cu for crop production, the lower soils may not serve as a reservoir for replenishing lost Cu taken up by plants and/lost through other means.

Iron status: Iron contents in the soils studied ranged from as low as 5.7 at W. Yola to a high of 14.9 mg kg^{-1} at Gamawa (Table 3). Even though the soils contained Fe above the critical 2.5 mg kg^{-1} given by Esu (1991), the values recorded for the soils (mean = 10.80 mg kg^{-1}) are below those recorded (range = 18.40-21.91; mean = 19.96 mg kg^{-1}) for soils elsewhere in Gombe State, Nigeria (Mustapha *et al.*, 2010) and the 12.40-45.10 mg kg^{-1} reported for Ustults in the neighbouring Bauchi State, Nigeria (Mustapha and Singh, 2003).

The contents indicate that with values above the critical limits for crop production, Fe deficiency is very unlikely for any crop grown on these soils. This is especially so when viewed against the backdrop of reports (Mengel and Geurtzen, 1986) that Fe deficiency is very unlikely in acid soils; as it is known to be soluble under relatively acid and reducing conditions (Chesworth, 1991).

Although there was an apparent increase in the Fe content with depth from 9.9 in the 0-15 cm depth to 11.8 mg kg^{-1} in soils within 15-30 cm, the increase was not statistically significant ($p<0.05$).

Manganese status: Manganese in the soils (Table 3) according to the ratings by Esu (1991), was 'high' ranging from 25.9 to 43.7 (mean = 34.0) mg kg^{-1}. These values suggest that the soils contain sufficient Mn for successful agriculture in the area studied as they are above the critical limits of 3-5 mg kg^{-1} reported by Lindsay and Norvell (1978) and 1-5 mg kg^{-1} reported by Esu (1991). The values obtained are higher than the 7.89-12.00; mean = 9.10 mg kg^{-1} obtained by Mustapha (2003) for the Ustults in Bauchi State, Nigeria.

It is pertinent to note that Mn distribution was significantly ($p<0.05$) influenced by depth with the lower 15-30 cm depths containing significantly more (40.40 mg kg^{-1}) Mn than the upper 0-15 cm (27.60 mg kg^{-1}). The high Mn contents may not be unconnected to the acidic nature of the soils. Sillanpaa (1982) reported that above soil pH of 7.5, the availability of Mn is very low because of the formation of hydroxides and chelates. Worthy of note is that the high contents of Fe and Mn in the soils studied could lead to the formation of complexes which could lead to serious drainage and infiltration problems.

CONCLUSION

Results from the present study indicate that the soils were generally clays to sandy clay loams in texture, slightly to moderately acidic (5.7-6.5) and low in organic carbon (matter) with low to medium contents of exchangeable bases. Zinc was generally 'low' in all the locations while Cu content ranged from low to medium with about 66.7 and 33.3% of the soils falling in the 'low' and 'medium' categories, respectively. Equally worthy of note is that the soils contained Fe and Mn above the critical limits for crop production and categorized 'high'. This, may be a potential environmental problem as they may, upon complex reactions, result in the formation of plinthites and petroplinthites leading to hard pan formation; restricting rooting depth and causing infiltration and drainage problems in the soil.

Owing to the aforementioned observations, it is recommended that for successful crop production in the area studied; concerted efforts should be geared towards improving the pH to near neutral especially for locations at Wuro Yola, Kembu, Gamawa and Wuro Abba. Application of organic matter to improve the overall fertility of the soil and to reduce the possible development of plinthic/petroplinthic layers is further recommended. Crops grown in all the locations will benefit from Zn and organic matter application while areas identified 'low' for Cu should have Cu included in their fertilization programme.

REFERENCES

BSADP, 1982. Zonal and Development Area Statistics Bauchi State Agricultural Development. BSADP., Bauchi, Nigeria, pp: 90-100.

Bouyoucos, C.A., 1951. A re-calibration of the hydrometer for making mechanical analysis of soils. Agron. J., 31: 510-513.

Brady, N.C. and R.R. Weil, 2005. The Nature and Properties of Soil. 13th Edn., Macmillan Publishing Co., New York, USA., pp: 976.

Chesworth, W., 1991. Geochemistry of Nutrients. In: Micronutrients in Agriculture, 2nd Edn., Mortredt, J.J., L.M. Shuman and R.M. Welch (Eds.). Soil Science Society of America Inc., Madison, Wisconsin, USA., pp: 427-476.

Esu, I.E., 1991. Detailed soil survey of NIHORT farm at Bunkure, Kano State, Nigeria. Institute of Agricultural Research, Zaria, pp: 72.

FFTC, 2001. The functions and critical concentrations of micronutrients in crop production. Food and Fertilizer Technology Center. http://www.agnet.org/library/bc/51001/.

Harry, F. and C.A. Steven, 1995. Statistics: Concepts and Applications. Cambridge Univ. Press, Great Britain, pp: 853.

Kolo, J., S. Mustapha and N. Voncir, 2009. Profile distribution of some physic-chemical properties of Haplustults in Gaba District, Central Nigeria. J. League Res. Nigeria, 10: 71-77.

Lindsay, W.L. and W.A. Norvell, 1978. Development of DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am. J., 42: 421-428.

Mari, A.H., R.N. Panhwar, G.M. Kaloi, M. Chohan, A.A.Y. Zai, M.A. Brohi and M.A. Bhutto, 2006. Assessing Zinc status of sugarcane in taluka nawabshah through soil and plant analysis. J. Applied Sci., 6: 206-210.

Mengel, K. and G. Geurtzen, 1986. Iron chlorosis on calcareous soils. Alkaline nutritional conditions as the cause of chlorosis. J. Plant Nutr., 9: 161-173.

Mustapha, S., 2003. Fertility status and productivity constraints of the basement complex-derived Ustults in Bauchi State, Nigeria. J. Agri. Technol., 11: 11-19.

Mustapha, S. and B.R. Singh, 2003. Available zinc, copper, iron and manganese status of the basement complex rock-derived Ultisols in Bauchi State, Nigeria: A case study. Nig. J. Soil Res., 4: 35-40.

Mustapha, S. and N.A. Loks, 2005. Distribution of available zinc, copper, iron and manganese in the fadama soils from two distinct agroecological zones in Bauchi State, Nigeria. J. Environ. Sci., 9: 22-28.

Mustapha, S. and C.C. Nnalee, 2007. Fertility and salinity/sodicity status of some fadama soils in Jos, Plateau State, Nigeria. J. Sustain. Develop. Agric. Environ., 3: 96-103.

Mustapha, S., S.I. Yerima, N. Voncir and B.I. Ahmed, 2007. Contents and distribution of phosphorus forms in some haplic plinthaquults in bauchi local Government area, bauchi state, Nigeria. Int. J. Soil Sci., 2: 197-203.

Mustapha, S., H.K. Mamman and N.A. Abdulhamid, 2010. Status and distribution of exchangeable micronutrients in Haplustults in Yamaltu-Deba Local Government Area, Gombe State, Nigeria. J. Soil Sci. Environ. Manag., 1: 200-204.

Nazif, W., S. Perveen and I. Saleem, 2006. Status of micronutrients in soils of District Bhimber (Azad Jammu and Kashmir). J. Agri. Biol. Sci., 1: 34-40.

Osiname, O.A., E.E. Schulte and R.B. Corey, 1973. Soil tests for available copper and zinc in soils of western Nigeria. J. Sci. Food Agric., 24: 1341-1349.

Page, A.L., R.H. Miller and D.R. Keeney, 1982. Methods of Soil Analysis. 2nd Edn., Amercen Society of Agronomy, Madison, WI., USA.

Sillanpaa, M., 1982. Micronutrients and the nutrient status of soils. A Global Study FAO Soils. Bulletin, No: 48, FAO, Rome, Italy.

Uzoije, A.P. and A.A. Onunkwo, 2011. Soil quality modeling of a highly acidic Eutric-tropofluvent soil Int. J. Soil Sci., 6: 164-175.

Voncir, N., S. Mustapha, V.A. Tenebe, A.L. Kumo and S. Kushwaha, 2008. Content and profile distribution of extractable zinc (Zn) and some physicochemical properties of soil along a toposequence at Bauchi, Northern guinea savanna of Nigeria. Int. J. Soil Sci., 3: 62-68.

Walkley, A. and C.A. Black, 1934. Acid extractable Zn in soil in relation to the occurrence of Zn deficiency symptoms of corn: A method of analysis. Soil Sci. Society Am. Proc., 12: 143-148.

Yaro, D.T., T. Kparmwang, B.A. Raji and V.O. Chude, 2006. The extent and properties of plinthite in a landscape at zaria, Nigeria. Int. J. Soil Sci., 1: 171-183.