Journal of Forestry Research and Management. Vol. 17(1).46-54; 2020, ISSN 0189-8418
www.jfrm.org.ng

Heavy metal status in soils formed on a Toposequence underlain by Mica Schist in Ife Southwestern Nigeria

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ABSTRACT

Heavy metals application as supplements in form of fertilizer to enhance soil productivity are not only considered as one of the major sources of pollution, but also result to various adverse effect on parameters relating to plant yield and soil contamination. The study therefore assessed the heavy metal status in soils formed on a toposequence underlain by mica schist in Ife area Southwestern Nigeria through the assessment of the soils physical and chemical properties. Five (5) soil profile pits were established along the toposequence and samples were collected from the horizons established on each pit. The concentrations of Mn, Co, Fe, Cu and Zn in the soils varied. The results indicated that Cu values ranged from 0.2 to 7.7 mg/kg, Fe from 80.0 to 520.0 mg/kg, Zn was 0.36 to 1.52 mg/kg, Co from 0.12 to 13.46 mg/kg and Mn was 0.90 to 7.1 mg/kg. The concentration of Fe and Cu was found to be higher in all the profiles examined and are responsible for the occlusion of some of the plants nutrient, and lower exchangeable cations recorded from the soils. With adequate soil management system, this can be taken care of. Apart from these two elements, the soil is presumed to have adequate level of Mn, Co and Zn for plant growth. The study therefore, provide evidence of gradual accumulation of Fe in the area, while the concentration levels of the other heavy metals evaluated do not appear to be of serious concern at the moment. The sources of the metals in farmlands are suspected to be either from the weathering of the bedrock, the use of nutrient replenishing materials traffic and aerial deposition and thus required proper monitoring to avoid increased level of the elements.

Keywords: Heavy metals, Toposequence, Underlain, Mica Schist

Introduction

The prevalence of soil contamination by heavy metals from both natural (geogenic) and anthropogenic sources has raised a lot of concern in agricultural produce and its effects on human health particularly with people living in urban environment who are more likely to be exposed to this threat. Natural and anthropogenic sources of soil contamination are widely spread and varies (Tahir *et al*, 2007). Heavy metals occur naturally in rocks, but most of the heavy metals occurrences in urban soils tend to originate from anthropogenic sources such as industrial, urban development and transport activities (Charlesworth *et al.*, 2003, Strivastava and Jain, 2007). Agricultural activities practiced by most farmers such as the application of micronutrient fertilizer, animal manure, sewage sludge, pesticides and atmospheric deposition (IPNI, 2008; Tracy and Baker, 2010; Wuana and Okieimen, 2011), has also been attributed to the high levels of heavy metals encountered in most soils.

Supplementing soil with essential minerals, nutrients and organics fluxes in arable agricultural land is on the increase in a bid to enhance (Drechsel and Gyiele, 1999; Akinrinde, 2006) soil productivity and crop yield. This is because nutrient regeneration processes such as weathering of soil minerals, nitrogen fixation, and atmospheric deposition in rain and dust are unable to meet up with the rate of nutrient depletion. Although trace elements and heavy metals occur naturally in all agricultural soils (Alloway, 1990; IPNI, 2008), elevated levels of some of this elements have been reported, Which can result in phyto-toxicity (Chang and Page, 2000; Alloway, 2004). The ubiquitous character and the increase of heavy-metals which flows through the soil system may also cause serious problems for soil fertility, ground water quality, and food chains (Keller *et al*., 2001).

The build-up of heavy metals in soils occurs at a slow rate, but on large areas (Keller *et al*., 2001). There may be spatial variability and geographical heterogeneity in heavy metals levels in arable soils, and this may be small and localized in same soil type within an ecosystem community, or regional involving large scale differences (Du Feng *et al*., 2008). This, however, depends on the physicochemical properties of the farmland soil ecosystems, and their impact on physical and biological factors including soil origin, structure, topography, vegetation cover and soil exposure, soil microclimate, various land use systems and land management (Lipiec *et al*., 2004; Ithier-Guzman, 2010). Detailed knowledge about the concentration of heavy metals, trends of heavy metals fluxes, soil withholding capacity/release potential and the stability of heavy metals within soil mineral aggregates in many farmlands in Africa and especially Nigeria is lacking. Adequate and comprehensive information such as these is essential in order to achieve sustainable use and management of heavy metal regimes for preservation of the soil resources against heavy metal build-up. This will constitutes an important means of access to precise and quantitative information, essential for environmental evaluation of soil quality, risk of soil pollution and retro-gradation of soil characteristics. The information obtained from the study can further be extrapolated to many other soils that are closely related in genesis, taxonomic group and geography specifically.

This study was carried out to investigate heavy metal status in soils formed on a toposequence underlain by mica schist in Ife, South West Nigeria with a view to suggesting management practices to promote the sustainable management of the soils in the area for improved agricultural productivity.

Materials and methods

The study area

The study was conducted in Ife, Osun State. It is located approximately between latitudes 7^o 32´N and 7^o 33´N and longitudes 4^o 39´E and 4^o 40´E. The study site is about 2.5 km away from Kajola village, a suburb of the Obafemi Awolowo University (O.A.U.) Teaching and Research Farm (T&R-F) and is located within the schist belt of southwestern Nigeria (Rahaman, 1988). The area is in the same ecological zone (tropical rainforest) as Ile-Ife with hot, humid tropical climate having distinct dry and bimodal rainy seasons. The mean annual rainfall is about 1527mm and the mean monthly air temperature is approximately 31^{o}C (Soil Survey Staff, 2006).

Guided by the geological map of the study area produced by the Department of Geology, O.A.U. Ile-Ife, a toposequence underlain by mica schist was selected for the study. The toposequence is slightly undulating with relatively flat top and approximately 500 m long from the valley bottom to the crest with an elevation of 295.9 m above mean sea level (amsl) at the crest and 268.6 m amsl at the valley bottom.

Five (5) soil profile pits were established along the toposequence at different physiographic positions. All the pedons were described following the procedures in the guidelines for soil profile description (FAO, 2001) and horizon designations of the Soil Survey Staff (2006). Soil samples were collected from each of the identified genetic horizons for physical and chemical analyses in the laboratory. Undisturbed core soil samples were collected and used for bulk density determination.

Laboratory analyses

The soil samples meant for physical and chemical analysis were air dried, gently crushed in ceramic mortal with pestle and passed through 2-mm sieve to separate materials that were greater than 2-mm which was used for the laboratory analyses aside bulk density.

Physical analyses

The bulk density was determined by the core method (Blake, 1965) as reported by (Blake and Hartge, 1986). The particle size distribution was evaluated by the modified Bouyoucos hydrometer method (Bouyoucos, 1965) as reported by (Gee and Or., 2002) using 5% w/v sodium hexametaphosphate (calgon) as the dispersing agent.

Chemical analyses

The soil pH was determined in 1.0 M KCl (1:1 soil: solution ratio) using glass electrode pH meter (Kent model 720) after equilibration for 30 minutes (Thomas, 1996). The exchangeable bases (Ca, Mg, K and Na) were extracted with 1.0 M ammonium acetate (NH_40AC) solution at pH 7.0 (Thomas and Throp, 1985). Calcium, Ca^{2+}, sodium, Na^+, and potassium, K^+ ions in the extract were determined with the use of flame photometer (Gallenkamp Model FH 500), while magnesium (Mg^{2+}) ion in the extract was determined by titration. The exchangeable acidity was determined by extraction with 1.0 M KCl solution and titrated with NaOH and HCl solutions to measure total acidity (Al^{3+} and H^+) concentrations respectively (McLean, 1965) as reported by (Bertsch and Bloom, 1996). The organic carbon was determined by the Walkley Black method (Allison, 1965) as reported by (Darrell *et al.*, 1994), and the available phosphorous by Bray No. 1 method as reported by Kuo, (1996). Heavy metals (Mn, Co, Fe, Cu and Zn) were determined by the use of about 2 g each of the <2 mm sieved soil samples that were acid digested by the method of Onianwa (2001), and the digests dissolved in dilute HNO_3. The heavy metals (Mn, Co, Fe, Zn, and Cu) in the digests were determined by atomic absorption spectrophotometer (AAS). Data were analyse using descriptive statistics and results presented in mean table.

Results and discussions

The results of the physical, chemical and the concentrations of the heavy metals (Mn, Co, Fe, Cu and Zn) along the landscape in the study area are presented in Table 1. The sand content ranged from 29 to 67% and decreased with increasing depth except at certain depths where the BC-horizon contained more of sand as in Pedons 03 and 04. The silt content ranged from 11 to 25%, although the value fluctuated within all the pedons with increasing depth. Generally, the silt content is low, a characteristic which the soils shared with most Nigerian soils (Ojanuga, 1975). The clay values ranged from 18 to 59% in the Bt horizons. The clay content increased generally with increasing depth to a maximum (probably due to illuviation/ eluviation interplay or possibly clay migration) and then decreased in the BC horizons. Similar trend was observed by Ojanuga (1978) in soils of Ife and Ondo areas of southwestern Nigeria. The lower clay content in the surface horizons could be due to the sorting of soil materials by biological and/or agricultural activities, clay migration or surface erosion by run-off or a combination of these (Ojanuga, 1978; Ogban *et al*., 1999).

The bulk density values obtained ranged from 0.74 g cm^{-3} in the Ap horizons to 1.7 g cm^{-3} in the Bt horizons. The higher values in surface soils are due to compaction (for instance pedons 02 and 03). Usually, root penetration becomes a problem when bulk density exceeds 1.6 g cm^{-3} (Payne, 1988). Generally, the bulk density value increased with increasing depth to a maximum and then decline with increasing soil depth. The exception to this trend was observed in Pedon 04 with their values fluctuating. However the higher values at depth have not created any hindrance to plant root penetration as evidenced by deep rooting of plants into greater depth in Pedon 02.

Chemical properties of the soils

The soils studied fall within the neutral to very strongly acidic class (Ojanuga, 1975; Landon, 1991; Soil Survey Staff, 2003). The pH (1M KCl) ranged from 4.4 to 5.7. The value decreased as the soil depth increased except in Pedon 03 where no definite pattern was observed. Generally, there was higher accumulation of bases in the surface horizons 6.59 - 12.57 cmol(+)kg^{-1} of the soil, and the total exchangeable bases decreased with soil depth except in some cases owing to nutrient biocycling (Ajiboye and Ogunwale, 2010), and could also be due to differential weathering that had taken place or as a result of plant uptake and leaching losses. Like in most tropical soils, the exchangeable sites of the soils studied were dominated by exchangeable calcium and magnesium that fluctuated irregularly with soil depth and across the slope. Exchangeable sodium (Na^+) and potassium (K^+) are low with values ranging from 0.08 to 0.26 cmol(+)kg^{-1} and 0.15 to 0.30 cmol(+)kg^{-1} soil for Na^+ and K^+ respectively. These low values indicated that the soils under investigation developed from materials that are either low in K^+ and Na^+ content or have been exhausted by plant uptake or leaching due to their mobility within the soil. The higher values obtained at the surface horizon of the pedons could be attributed to higher organic matter content (Ano, 1991). However, the values fluctuated irregularly down the soil profile.

The organic matter content of the surface horizons of the pedons under examination ranged from 1.54 to 2.55% and decreased with increasing soil depth. The organic matter content of the entire soils studied was generally low, mostly less than 2% except in the surface horizon of Pedon 01. In all the pedons examined, pH and organic matter contents were slightly higher in the surface horizons than in the sub-soils in general. Probable reason is that the surface horizons, although the most exposed to leaching and runoff, are indeed continuously recharged by phytocycling (Amusan and Ashaye, 1991). Available phosphorous (P) contents of the soils varied from 2.6 to 11.2 ppm in all the horizons in the profiles with the highest values at the surface horizons, The relatively high concentration of the available P and organic carbon in the surface horizons may imply significant organic or biocycled P in the soils and also an indication that organic matter contributes significantly to the available phosphorus in these soils. The available P values are considered low at some horizons as they were below or only slightly above the 10 ppm critical limit recommended for most commonly cultivated crops in the area (Uponi and Adeoye, 2000; Aduayi *et al*., 2002).

The metal content of the soils

Heavy metals occur at measurable concentration across the toposequence. The concentrations of Mn, Co, Fe, Cu and Zn in the soils varies. The distributions of the metals does not follow any definite pattern. The results indicated that Cu values ranged from 307.37 to 521.1 mg/kg, Fe from 124.00 to 523.01 mg/kg, Zn was 0.11 to 3.00 mg/kg, Co from 1.00 to 19.00 mg/kg and Mn was 3.90 to 16.49 mg/kg (Table 1). The distribution of these elements down the soil profiles was irregular. The concentration of Fe and Cu was found to be higher in all the profiles examined, this could either be due to the mineral composition of the underlying rock and/ or of the transported materials, uptake of essential nutrients by plant, leaching of exchangeable cations through heavy rainfall or by erosion or a combination of these factors. The higher values observed could be responsible for the occlusion of some of the plants nutrient like phosphorus, thereby making it unavailable for plant uptake and could also be responsible for the lower exchangeable cations recorded from the soils under examination. With adequate soil management system, this can be taken care of. Apart from these two elements, the soil is presumed to have adequate level of other heavy metals for plant growth.

The detected concentration levels were geochemically indexed in comparison to the European Economic Community (EEC) recommended maximum allowable concentration (MAC) threshold in agricultural soils, in order to ascertain whether the investigated soils contain metal levels that may be of concern. The measured concentration levels of the heavy metals were below the EEC MACs The concentration levels of the metals in the surface and subsurface farmland soils were within the normal range of values in unpolluted soils as reported for different countries of the world (Brady and Weil, 2002). Values recorded in top soil were slightly higher than that recorded in subsurface soils. Thus, it can be suggested that the heavy metal concentrations of soil samples from the study areas do not indicate heavy metal contamination of the soils. According to Fennessy and Mitsch (2001), total nutrient of soil may decrease due to prolonged usage, hence the need to enhance the essential nutrients and minerals quality of arable farmlands. Although, the use of fertilizer in the study area was common, the observed levels were apparently a product of the natural background and inputs from diffused sources which are not readily ascertained. The prevention and/or rational management of heavy metal contamination through the application of fertilizer, sewage sludge, manures and other soil nutrient supplement in the area, requires the use of flux balancing technique.

Conclusion

Results obtained from the study show that the concentration levels of heavy metals in the study area soils do not appear to be of major concern at the moment, except for Fe and Cu which requires monitoring on a regular basis to avoid larger accumulation in the long run. The study provide evidence of gradual accumulation of Fe and Cu in the area, while the concentration levels of the other heavy metals evaluated do not appear to be of serious concern. The sources of the metals in farmlands are suspected to be either from the weathering of the bedrock, the use of nutrient replenishing materials (such as fertilizer), traffic and aerial deposition. The result also indicate a low contamination of the area of study from anthropogenic sources. Effort should therefore be intensified to guide against pollution of the area because of the agricultural activities that is their major occupation in the area for long term sustainability.

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Journal of Forestry Research and Management. Vol. 17(1).46-54; 2020, ISSN 0189-8418
www.jfrm.org.ng

Table 1: Physical and Chemical Properties and concentrations of the heavy metals of the soils under investigation

Horizon	Depth (cm)	Total Sand (%)	Silt (%)	Clay (%)	Bulk density g/cm^3	pH KCl	Exch. Bases cmol (+) kg^{-1} Ca^{2+}	Mg^{2+}	Na^+	K^+	Exch. Acidity cmol (+) kg^{-1} Al^{3+}	H^+	OC (%)	Avail. P. (ppm)	Mn (ppm)	Co (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)
									Profile 1										
Ap	0-18	49	21	30	1.06	6.0	7.2	4.86	0.21	0.30	0.4	0.2	2.55	11.2	12.60	19.00	396.12	393.05	1.80
AB	18-24	47	25	28	1.54	5.4	6.6	4.86	0.26	0.26	0.2	0.3	1.61	7.4	8.70	17.00	296.48	436.06	3.00
B	24-51	31	11	58	1.62	5.0	6.7	4.10	0.25	0.30	0.3	0.3	1.21	3.4	9.66	3.00	292.02	517.27	1.20
BC	51-70	29	13	58	1.59	4.6	5.8	3.20	0.20	0.24	0.7	0.3	1.07	3.2	10.21	14.00	342.02	500.61	3.00
									Profile 2										
Ap	0-18	55	17	28	1.01	5.3	5.3	4.86	0.19	0.24	0.4	0.2	1.68	6.3	14.66	10.00	523.01	399.82	0.60
AB	18-28	51	11	38	1.57	5.0	4.9	4.05	0.19	0.22	0.4	0.3	1.14	8.2	16.49	14.00	506.81	528.1	1.70
B21	28-72	39	13	48	1.63	5.0	5.5	1.62	0.21	0.28	0.1	0.4	0.87	4.1	9.68	8.00	298.59	456.88	1.30
B22	72-132	33	13	54	1.68	5.0	5.3	5.67	0.19	0.26	0.4	0.3	0.67	3.3	7.64	6.00	274.69	448.77	0.40
BC1	132-185	35	17	48	1.73	4.9	5.3	4.05	0.20	0.26	0.1	0.3	0.60	3.0	6.20	1.00	179.70	457.3	0.30
BC2	185-210	43	15	42	1.48	4.8	5.0	4.86	0.17	0.26	0.2	0.2	0.07	2.6	3.90	1.00	100.50	449.8	1.20
									Profile 3										
Ap	0-18	55	17	28	1.34	5.6	4.0	7.29	0.14	0.22	0.4	0.3	1.54	8.4	12.11	10.00	322.64	333.15	2.00
BA	18-33	51	15	34	1.42	5.5	4.9	4.05	0.19	0.24	0.3	0.3	0.94	10.5	11.90	8.00	329.81	432.73	3.00
B21	33-65	34	13	53	1.45	5.5	5.3	1.62	0.21	0.30	0.2	0.2	0.94	7.0	9.21	6.00	288.22	422.73	1.10
B22	65-120	30	11	59	1.65	5.5	4.1	6.48	0.14	0.20	0.2	0.3	0.87	5.8	7.08	4.00	216.43	516.86	1.50
BC	120-200	39	15	46	1.40	5.7	3.1	10.53	0.11	0.22	0.3	0.2	0.40	3.2	5.33	2.00	124.00	452.3	ND
									Profile 4										
Ap	0-20	57	15	28	1.54	5.2	4.7	4.05	0.23	0.24	0.2	9.22	1.74	7.7	11.89	19.00	338.26	383.58	0.50
BA	20-40	39	13	48	1.48	4.8	3.2	5.67	0.12	0.22	0.2	9.21	0.93	8.4	10.24	11.00	332.22	398.34	0.22
BC1	40-71	31	11	58	1.30	4.8	2.2	5.67	0.08	0.24	0.2	8.19	0.67	5.8	9.24	11.00	298.72	444.24	0.32
2BtC1	71-115	31	13	56	1.71	4.6	2.1	4.05	0.10	0.24	0.3	6.49	0.60	6.2	10.1	5.00	226.12	498.22	0.11
2BC2	115-170	39	13	48	1.40	4.4	2.8	3.24	0.16	0.26	0.2	6.46	0.40	4.5	10.98	1.00	308.92	504.78	ND
									Profile 4										
Ap	0-18	67	15	18	0.74	6.7	1.5	4.86	0.08	0.15	0.2	6.59	1.74	6.9	9.56	18.00	257.28	332.36	ND
AB	18-40	65	13	22	1.21	5.2	1.9	4.86	0.08	0.24	0.3	7.08	0.74	8.9	6.22	18.00	212.44	311.22	ND
B	40-60	67	11	22	1.31	5.0	0.6	2.43	0.08	0.22	0.2	3.33	0.40	5.4	4.39	18.00	135.40	307.37	0.80
Btg	60-75	65	15	20	1.13	5.0	1.5	2.43	0.08	0.21	0.2	4.22	0.13	5.2	6.11	2.00	190.60	459.80	0.20