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Effect of changes in land use pattern on selected soil properties In Northern Guinea Savannah of Nigeria

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Abstract

Land use change is an essential driver of global environmental change, yet the extent and nature of global land use practices are still poorly understood. A study was conducted under four different land uses (Pasture, fertilized cropland, vegetable garden treated with municipal waste in Zaria and Afaka forest). Forty samples from surface soils (0 - 20cm) and profile pits were collected to determine soil physical and chemical properties. Soil properties determined include particle size distribution, bulk density, pH, exchangeable bases, cation exchange capacity (CEC), organic carbon (OC), total nitrogen (TN), and available phosphorus (AP). Results of the analysis showed that surface soils are predominantly sandy loam in all the land uses. At the same time, the texture of profile soils ranged from sandy loam, sandy clay loam, and clay loam depending on the land use and horizon. The pH at both the surface soils and down the horizons is slightly acidic (6.03-6.80) in all the four land uses. Exchangeable calcium ranged from low down the profile, to moderate at the surface in all land uses except Sabo where it was found high. Potassium and sodium were both found low at 0 -20 cm and various depths in the pedons. CEC under Sabo land use recorded the highest value (13.90 $cmol_{(+)}$/kg) on the surface soil as opposed to other land uses which recorded moderate values. OC was found low in all the soils with the lowest value of 0.50 g/kg found on the surface soil in IAR and the highest value of 1.43 g/kg found in Afaka soil. TN mean ranged from 0.47 g/kg for Afaka soil to 3.03 g/kg for Sabo soil. AP was observed to decrease with depth, while high values were obtained on surface soils. The results showed that different land uses affect the physical and chemical composition of soils.

Keywords: soil properties; land use; agriculture; northern guinea savannah; Afaka

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1.0. Introduction

Land use for agriculture causes significant changes in the natural properties of soil, particularly in the humid tropics. Land-use changes have a significant impact on soil geochemical properties (Townsend *et al*., 2002) since highly weathered soils with low inherent fertility, firm acidity, and a high proportion of iron (Fe) and aluminum (Al) oxides prevail (Nortcliff, 2010). Land use refers to man's activities and the varied uses, which are carried out overland (Keshava and Raghu, 2015). Land use affects soil by altering the soil environment. The characteristics of soil can vary significantly across the entire urban landscape, including not only highly disturbed but also relatively undisturbed soils that are modified by management and urban environmental factors (Schleu*et al.,* 1998; Pouyat *et al.,* 2003).

Depending on the land use, climate and vegetation, soil characteristics such as soil organic matter (SOM), aggregation and aggregate stability (Shretha *et al*., 2007), bulk density, and water retention (Lal, 2003), pH and nutrient status (Benbi and Brar, 2009), and soil biota (Islam and Weil, 2000) tend to change. Any change in land use has important consequences for many biological, chemical, and physical processes in soils and so, indirectly, the environment (Goulding *et al.,* 1995;). Therefore due to changes in the land use pattern over the last few decades (Adriano, 2001), the knowledge of trace elements geochemistry for different land-use types, which has scarcely been investigated, is critical in assessing human impact on soil geochemistry.

The spatial distributions of elements are controlled primarily by natural geochemical processes, such as the formation of soils from parent materials of varying composition, and by climate-driven processes that establish soil moisture regimes and levels of organic matter in the soil. According to Duo and Li (2015), how elements are spatially distributed in a region were conditioned by the regional environmental, geological conditions and influenced by human activities. Anthropogenic influences such as industrialization, urbanization, waste disposal, mining, and agriculture are regularly superimposed on these natural, or background geochemical distributions.

Patterns of natural soil variability provide the starting point for understanding and measuring differences between natural concentrations of elements and anthropogenic effects. The inherent characteristics of soil which are mainly the result of parent material and climate undergo subtle change due to different land management practices (Girma and Endalkachew, 2013). Also, overexploitation (or degradation) of soils could diminish their ability to function for critical ecological and economic purposes.

The Nigerian savannah region is currently witnessing an increase in the intensity of agricultural land use to meet the demand of an ever-increasing population (Waniyo *et al.,* 2013). Also, urbanization is placing a greater demand on land in and around cities, and the geochemistry of soils in these areas can mirror the shifting patterns of land use (Wilson *et al.,* 2008). Currently, there is limited information available to regulatory authorities with a mandate to manage soils under different land use. Analysis of the effects of land use on soil physical and chemical properties is, therefore, critical for the making of policies aimed at reducing the loss of soil fertility and guaranteeing the maintenance or even improvement of soil functions. Because of this, a study was conducted to determine the physical and chemical composition of soils under four different land-use patterns in the northern guinea savannah zone of Nigeria. Furthermore, the physical and chemical properties were compared among the four chosen land use patterns.

2.0 Materials and methods

2.1 Site description

The soil samples for the study were collected from four different land-use patterns (forest soil, vegetable garden soil treated with municipal waste, pastureland, and soil under long-term fertilizer treatment). The forest soil was collected from Afaka forest, Kaduna, the soil under pasture was collected from National Animal Production Research Institute (NAPRI), Zaria, and vegetable garden soil was collected from Sabon Gari, Zaria. In contrast, the soil under long-term fertilizer treatment was collected from the Institute for Agricultural Research farm (IAR), Zaria.

The Afaka Forest Reserve Kaduna lies between latitude 10^0 33' and 10^0 40'N and longitude 07^0 15'E while Zaria is located between latitude 11^0 00' and 11^0 30'N and longitude 07^0 30' and 08^0 00 E both in the Northern Guinea Savanna ecological zone of Nigeria. The climate of Zaria is characterized by an average rainy season of about six months, lasting from May to October with its peak in August and a dry/harmattan season of also about six months, lasting from November through April as well as the highest day temperature of about 38^0C during April/May. The mean annual rainfall of Zaria is approximately 1,000mm while the Afaka forest has a long-term mean annual rainfall of 1270mm.

2.2 Soil Profile Sampling

For each land use, a profile pit of approximately 1m wide was excavated to a depth of below 1.5 m. The surface of the pit was cleaned with a sharp knife, and different genetic horizons were delineated, and subsamples were collected in duplicate from each identified horizon. Care was taken to minimize the potential of cross-contamination of samples and the introduction of external contaminants during sample transportation and preparation by cleaning and decontaminating (acid-washed with 1 N nitric acids) of sampling equipment before sampling. For bulk-density determination, additional undisturbed core samples were collected using a hand-held hammer and driven cylindrical core sampler (Soil Moisture Equipment Co., CA, USA)

2.3 Soil Preparation and Analyses

2.3.1 Preparation of Soil Samples

The soil samples were air-dried, crushed, and then passed through a 2-mm diameter mesh after which standard laboratory techniques were used to determine some soil physical and chemical properties. All the analyses were carried out in the laboratory of the Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University Zaria.

2.3.2 Particle-size distribution

Particle size distribution was determined by the Bouycous hydrometer method, according to Gee and Bauder(1986). Fifty grams of the soil was shaken with 100mL of 5% Calgon (sodium hexametaphosphate) for 30 minutes for complete dispersion. The suspension was transferred into a 1000mL measuring cylinder and made to mark with water. Hydrometer readings were taken at 40seconds and 2 hours. A blank containing no soil was carried through the same procedures to correct the readings taken in the soil suspension.

2.3.3 Bulk Density (BD)

The bulk density was determined using the procedures described by Blake and Hartge (1986). The mass of the soil after drying in an oven for 24hours at 105^0C was calculated and divided by the volume of soil (volume of the cylindrical core sampler). Note that the volume included both solids and soil pores. The soil volume was obtained by using the formula for the volume of a cylinder ($\pi r^2 h$).

2.3.4 Soil Reaction (pH)

The soil pH was determined in both water and 0.01M $CaCl_2$ solution in the soil to water ratio 1:2.5. Ten (10) grams of the soil samples were weighed, and twenty (20) mL of distilled water were added and stirred. The pH of the suspension was read using a pH meter after 30 minutes. The same procedure was repeated using 0.01M $CaCl_2$.

2.3.5 Exchangeable Bases

Exchangeable bases which include Calcium (Ca), Potassium (K), Sodium (Na), and Magnesium (Mg) were extracted with 1.0 N ammonium acetate (NH_4OAC) at pH 7.0. Potassium and Na contents of the extract were determined by reading with 410 Sherwood flame photometry, while Ca and Mg were determined with AA 500 PG Instrument atomic absorption spectrophotometer (AAS).

2.3.6 Cation Exchange Capacity (CEC)

The CEC of the soil was determined by leaching the soil with 1N NH_4.AOC (Rhoades, 1982). The soil was soaked overnight in 1N NH_4OAC and subsequently leached with 1N NH_4Cl and washed with ethanol. After washing with 1N $NaCl_2$, the leachate was distilled and titrated with 0.1N HCl using boric acids for trapping NH_4^+ions.

2.3.7 Total Nitrogen (TN)

Total N was determined by the Kjeldahl steam distillation method (Bremmer and Mulvaney, 1982). One gram of the soil was digested with 10mL of concentrated sulphuric acid, and the digest was diluted with 100mL of distilled water. 10mL of the aliquot was distilled with sodium hydroxides. The distillate was titrated with 0.01N $H_2SO_4$to pink endpoint.

2.3.8 Available Phosphorous (AP)

Available phosphorus was determined using Bray 1 extraction method. The available P was extracted from 10g of the soil using ammonium fluoride in hydrochloric acid, and the P in the solution was measure calorimetrically (Bray and Kurtz, 1945).

2.3.9 Organic Carbon (OC)

Organic carbon was determined by the dichromate wet oxidation method of Walkley-Black as described by Nelson and Sommers (1986). One gram of the soil was digested with potassium dichromate using concentrated tetraoxosulphate (VI) acid for 30 minutes after which 100mL of water was added. This was back titrated with ferrous ammonium sulphate using barium diphenylamine sulphate as an indicator.

3.0. Results and Discussion

3.1 Effect of Land use on Soil Texture and Bulk Density

The data for the particle size distribution of surface soils and that of various horizons are presented in Tables 1 and 3, respectively. The results showed no variation with changes in land use. Silt and sand recorded higher values for the surface soils [(193.33 - 233.33 g/kg), (661 – 741 g/kg) respectively] compared to the profile soils with values of 153 – 235 g/kg and 516 – 656 g/kg respectively. The reverse is the case for the horizon clay content with a value of 159 - 244 g/kg and surface soils with a clay content of 65.67 - 105.67 g/kg, indicating possible clay translocation from the top layer to the layer below. These findings were in line with others (Habtamu e*t al*., 2014 and Moges *et al*., 2013) who showed high clay fraction with increasing depth. The soil texture is sandy loam at the surface and sandy clay loam at the lower horizons except in the case of IAR fertilized farm. This is an indication of the homogeneity of soil-forming processes and similarity of parent materials (Forth, 1990). However, over a very long period, pedogenesis processes such as erosion, deposition, eluviation, and weathering can change the soil texture (Forth, 1990; Brady and Weil, 2002).

The bulk density values are presented in Tables 1 and 3 for horizon and surface soils, respectively. The bulk density for horizon soils ranges from a mean of 1.36 kg/m^3 in Afaka forest to 1.65 in Sabo vegetable garden. While for surface soils, IAR fertilized farm recorded the highest value (mean 1.51 kg/m^3) which is statistically similar to the NAPRI pasture field (mean 1.44 kg/m^3). The values observed for the Sabo vegetable garden (1.27kg/m^3) although similar to that obtained in the pasture field was not statistically different from that of the Afaka forest (1.18kg/m^3) which is the least. The highest bulk density observed for Sabo vegetable garden despite its high content of organic matter, and IAR fertilized farm might be attributed to the fact that more intensive cropping (year-round cultivation) give rise to higher bulk density as frequent tilling increases compaction.

Table 1: Mean values of selected physical properties of surface soils under different land use pattern

Land use types	Depth (cm)	Clay ←	Silt g/kg	Sand →	Textural class	Bulkdensity (mg/m^3)	
NAPRI	0 – 20	99-119 105.7^a	180-220 193.3	681-721 701^{ab}	Sandy loam	1.3-1.7	1.4^{ab}
IAR	0 – 20	99-119 105.7^a	200-260 233.3	641-661 661^b	Sandy loam	1.4-1.6	1.5^a
SABO	0 – 20	79-99 85.7^{ab}	180-220 206.7	681-741 707.7^b	Sandy loam	1.2-1.3	1.3^{bc}
AFAKA	0 - 20	59-79 65.7^b	180-200 193.3	721-761 741^a	Sandy loam	1.1-1.2	1.2^c
LSD		2.23*	4.48^{NS}	4.35*		0.20*	

Numbers in bold are means, means followed by the same letters are not significantly different

Table 3: Mean values of selected physical properties of profile soils under different land use pattern

Site	Depth (cm)	Clay	Silt	Sand	Textural class	Bulk density (mg/ m^3)
			g/kg			
NAPRI	0-27	139	200	661	Sandy loam	1.21
	27-69	219	200	581	Sandy clay loam	1.43
	69-120	119	240	641	Sandy loam	1.61
		159^b	213	627.7		1.42mg/g
IAR	0-20	239	200	561	Sandy clay loam	1.64
	20-44	219	240	541	Sandy clay loam	1.33
	44-110	279	280	441	Clay loam	1.73
	110-182	239	240	521	Sandy clay loam	1.44
		244^a	235	516		154
SABO	0-10	119	160	721	Sandy loam	1.82
	10-30	139	180	681	Sandy loam	1.61
	30-47	259	120	621	Sandy clay loam	1.40
	47-70	199	200	601	Sandy clay loam	1.78
		179^{ab}	165	656		1.65
AFAKA	0-17	139	140	721	Sandy loam	1.47
	17-69	219	140	641	Sandy clay loam	1.14
	69-97	279	180	541	Sandy clay loam	1.47
		212^a	153	634.3		1.36
LSD		796^{NS}	17.79^{NS}	22.53		0.29^{NS}

Numbers in bold are means, means followed by the same letters are not significantly different

3.2 Effect of land use pattern on chemical properties of soils.

Results of soil pH (H_2O) for surface soils and horizons are presented in Table 2 and 4 respectively and were both higher than pH in $CaCl_2$. For the horizon soils, the highest pH was observed in Sabo vegetable garden (6.8) and Afaka forest (6.6) while the fertilized IAR farm recorded the least (6.28), although IAR values are statistically not different from the NAPRI pasture field NAPRI (6.30). High pH values observed in Sabo vegetable garden may be due to high organic matter content of municipal waste, which buffer the soil and prevent excessive pH change while for Afaka forest, it might be due to high litterfall from trees which on decomposition add organic matter to the soil. Lower pH observed for the fertilized IAR farm maybe because the long-term application of chemical fertilizer reduced the soil pH (Chu *et al*., 2007; Liu *et al*., 2010; Xie and Zhou, 2008). This contradicted the findings of Buba (2015) and Duguma *et al.*(2010) in Nigeria and Ethiopia respectively, but the values are within the pH level of 4.8 - 6.9 reported by Raji *et al.* (2015) in some soils of the Nigerian savanna.

Exchangeable $Ca^{2+}$and Mg^{2+} showed significant variation with land use (Table 2 and 4). Higher exchangeable bases (Ca^{2+}, Mg^{2+}, $K^{+,}$ and Na^+) were recorded in the surface soils than the horizon soils. Higher Ca, Mg and Na observed in Sabo vegetable garden is associated with the fact that municipal waste (garbage from households, markets, and industries) used as organic manure releases exchangeable cations during mineralization. In contrast, the high K in the NAPRI pasture field is associated with the dominant mineral (muscovite, phlogopite, and chrysotile) in the land use as K is derived from the interlayer of feldspars and micas. The main problem with high sodium concentration in soil is its effect on soil structural stability which makes it weak and easily dispersed, and the surface is prone to surface capping (Malgwi, 2001).

Sabo vegetable garden soil although similar to fertilized IAR farm (2.70 $cmol_{(+)}$/kg) and NAPRI pasture field (2.51 cmol $_{(+)}$/kg) but significantly different from Afaka forest (1.73 $cmol_{(+)}$/kg) recorded the highest CEC values (2.71 $cmol_{(+)}$/kg) reflecting the high exchangeable bases observed for this location. Compared to horizon soils, higher CEC values were recorded for the surface soils; this may be attributed to the high organic matter content at the surface compared to the lower horizons.

Afaka forest soil has the highest OC content of 1.43 g/kg while Sabo vegetable garden soil and fertilized IAR farm soil recorded the least with a value of 1.24 g/kg, which is significantly not different from what was obtained in the NAPRI pasture field (1.27 g/kg) (Table 1). The high OC in the forestland may be attributed to high organic matter content. For the surface soil (Table 2), Sabo vegetable garden (1.6 g/kg) although similar to Afaka forest (1.4 g/kg) had the highest OC values which are not different from NAPRI pasture field (1.0 g/kg) while fertilized IAR farm (0.5 g/kg) had the least. However, the NAPRI pasture field and fertilized IAR farm are significantly not different. These values are consistent with the findings of Wuddivira (1998) for savanna soils due to their low organic matter status caused by the rapid decomposition of organic materials (Jones and Wild, 1975).

The TN showed no variation with land use and its mean value ranged from 0.47 g/kg for Afaka forest soil to 3.03 g/kg for Sabo vegetable garden soil (Table 2), while for the surface soils, Sabo vegetable garden soil has a mean value of 6.5 g/kg, which is higher than the values (3.7 g/kg) for Afaka forest soil. NAPRI pasture field (2.8 g/kg) is statistically similar to Afaka forest while the fertilized IAR farm had the least. The least TN observed for fertilized IAR farm might be attributed to N lost through either plant uptake, leaching, and or volatilization while the highest TN content recorded for Sabo vegetable garden maybe because organic wastes contain a high concentration of total N (Mbagwu and Piccolo, 1990). It was also reported by Adediran et al. (1999) that in every ton of municipal wastes added to soils, 16.5kg N, 21.4 kg P, 17.3kg K, and 120. 6kg Ca were supplied.

Sabo vegetable garden observed the highest available P content with a mean of 4.07 mg/kg, which is not statistically different from fertilized IAR farm with a mean of 2.15 mg/kg and Afaka forest having a mean of 2.10 mg/kg (Table 1). NAPRI pasture field, although similar to fertilized IAR farm had the least AP content of 1.25 mg/kg. However, the different land use did not affect the AP content of the soil. Surface soils (Table 2), recorded higher values with fertilized IAR farm having the highest P concentration of 10.15 mg/kg and Sabo vegetable garden soil had the least P concentration of 4.61 mg/kg. NAPRI pasture field with P concentration of 4.79 mg/kg and Afaka forest soil with a concentration of 5.43 mg/kg were significantly not different from values obtained from Sabo vegetable garden soil. The AP was observed to decrease with depth, although Iris *et al.* (2009) had reported that mineral P fertilization resulted in the building up of plant-available P in the topsoil compared to non-fertilized plots and decreased with increasing soil depth.

Table 2: Mean values of selected chemical properties of surface soils under different land use pattern

Site	Depth	PH		Ca	Mg	K	Na	CEC	OC(g/	TN	AP
	(cm)	H_2O	$CaCl_2$	←		Cmol/kg		→	kg)	(%)	(mg/kg)
NAPRI	0-20	6.0-6.1	5.3-5.5	3.0-4.0	1.1-1.7	0.04-0.04	0.0-0.1	4.9-5.5	0.8-1.4	1.4-5.6	3.2-6.1
		6.03^{ab}	5.4^{b}	3.6^{b}	1.4^{b}	0.04^{ab}	0.03^{b}	5.2^{b}	1.0^{ab}	2.8^{ab}	4.8^{b}
IAR	0-20	5.7- 5.8	5.0-5.5	3.0-3.2	0.4-0.9	0.02-0.02	0.0-0.01	4.0-4.2	0.4-0.6	1.4-2.8	8.6-12.6
		5.8^{b}	5.3^{b}	3.1^{b}	0.7^{b}	0.02^{b}	0.01^{b}	4.1^{b}	0.5^{b}	1.9^{b}	10.2^{a}
SABO	0-20	5.7- 5.8	5.7-6.7	4.2-11.6	3.5-7.1	0.02-0.08	0.1-0 2	8.1-19.2	1.2- 1.9	4.2-8.4	3.7-6.3
		5.7^{a}	6.3^{a}	7.9^{a}	5.6^{a}	0.05^{a}	0.14^{a}	13.9^{a}	1.6^{a}	6.5^{a}	4.6^{b}
AFA-KA	0-20	6.2-6.3	5.9-5.9	2.8-4.2	1.7-2.2	0.02-0.06	0.0-0.01	5.0-6.3	1.0-1.6	2.8-4.2	3.5-7.4
		6.3^{ab}	5.9^{a}	3.6^{b}	2.0^{b}	0.04^{ab}	0.01^{b}	5.8^{b}	1.4^{a}	3.7^{ab}	5.4^{b}
LSD		0.07^{NS}	0.42^{**}	2.95^{*}	1.75^{**}	0.03^{NS}	0.05^{**}	4.60^{*}	0.7^{*}	3.23^{NS}	3.40^{*}

Numbers in bold are means, means followed by the same letters are not significantly different

Table 4: Mean values of selected chemical properties of profile soils under different land use pattern

Site	Depth (cm)	pH H_2O	pH $CaCl_2$	Ca	M	K	Na	CEC	OC g/kg	TN (%)	AP mg/kg
NAPRI	0-27	6.40	5.90	1.73	0.35	0.03	0.03	2.24	1.33	2.80	1.29
	27-69	6.30	5.80	1.97	0.41	0.21	0.04	2.82	1.21	2.10	1.23
	69-120	6.20	5.70	1.46	0.43	0.17	0.10	2.46	1.28	0.00	1.23
		6.30^{b}	5.80	1.72^{a}	0.40^{a}	0.14^{a}	0.06	2.51^{a}	1.27^{b}	1.63	1.25^{b}
IAR	0-20	6.10	5.20	0.95	0.32	0.03	0.04	2.13	1.35	2.10	4.73
	20-44	6.00	5.90	1.97	0.40	0.03	0.04	2.94	1.19	0.70	1.23
	44-110	6.40	5.90	1.90	0.42	0.03	0.07	2.93	1.19	0.70	1.23
	110-182	6.60	6.00	1.65	0.43	0.04	0.08	2.80	1.22	2.80	1.40
		6.28^{b}	5.80	1.62^{a}	0.39^{a}	0.03^{b}	0.06	2.70^{a}	1.24^{b}	1.60	2.15^{ab}
SABO	0-10	6.30	5.40	1.85	0.32	0.02	0.06	2.55	1.27	6.30	9.63
	10-30	6.70	5.60	2.04	0.35	0.03	0.08	2.81	1.21	0.70	1.93
	30-47	6.70	5.40	2.00	0.38	0.04	0.13	2.95	1.19	2.10	2.28
	47-70	7.00	5.70	1.80	0.38	0.05	0.07	2.51	1.27	0.00	2.45
		6.80^{a}	5.53	1.92^{a}	0.36^{a}	0.04^{b}	0.09	2.71^{a}	1.24^{b}	3.03	4.07^{a}
AFA1.42	0-17	6.50	5.90	1.16	0.33	0.02	0.06	1.77	1.42	0.70	2.98
1.42KA	17-69	6.60	5.30	0.45	0.18	0.30	0.05	1.60	1.46	0.00	1.58
	69-97	6.70	5.50	0.33	0.18	0.70	0.05	1.83	1.41	0.70	1.75
		6.60^{a}	5.57	0.65^{b}	0.23^{b}	0.13^{ab}	0.05	1.73^{b}	1.43^{a}	0.47	2.10^{ab}
LSD		0.306^{*}	0.42^{NS}	0.58^{**}	0.09^{**}	0.10^{NS}	0.04^{NS}	0.35^{**}	0.07^{**}	2.42^{Ns}	2.23^{NS}

Numbers in bold are means, means followed by the same letters are not significantly different

4.0 Conclusion

The results showed that pH ($CaCl_2$), Ca, Mg, Na, CEC, OC, AP, clay, sand and bulk density significantly varies ($p < 0.05$) across the land uses for surface soils while only pH (H_20), Ca Mg, CEC, and OC showed variation for pedon soils ($p < 0.01$). Thus, it can be concluded that land uses can significantly affect soil physical and chemical properties.

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