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SOIL PROPERTIES AFFECTING SOIL ORGANIC CARBON STOCK OF DIFFERENT LAND USE TYPES IN TWO AGRO-ECOLOGICAL ZONES OF NIGERIA

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ABSTRACT
Soil organic carbon (SOC) stock is the carbon proportion that is of biological origin stored with respect to soil depth. It is more prone to loss than soil inorganic carbon. High sequestration of SOC in soil is germane to the improvement of soil quality and mitigating impact of climate change. Thus, this study was carried out to evaluate soil properties affecting SOC stock in the two agro-ecological zones, namely Upland Rainforest (Ado-Ekiti) and southern Guinea Savanna (Kabba) agro-ecological zones of Nigeria, with respect to three selected land use types; arable, oil palm and wetland. Random collection of soil samples was carried out at four varying depths (0-15, 15-30, 30-45, and 45-60 cm) for evaluation of soil properties. The SOC stock regression models for the two agro-ecological zones showed that land use, SOC, pH, SOM (soil organic matter), Ex-K, Ex-Ca, Ex-Mg (exchangeable potassium, calcium, magnesium, respectively), BD (bulk density), and gravel content would predict variation in SOC stock in the two agro-ecological zones with coefficient of determination (R^2) values of 0.952 and 0.996 for Kabba and Ado-Ekiti respectively. Principal component analysis identified that in the soil of the southern Guinea Savanna agro-ecological zone, SOC, CEC, EA, Ex-Na, land use, clay content, and soil depth with Eigenvalues > 1 explained 80.58% of sample variance while in the soil of the Upland Rainforest agro-ecological zone, Ex-Ca, SOC, Ex-Na, EA, sand and silt contents with Eigenvalues > 1 explained 78.81% of sample variance as potential determinants of SOC stock.

Key words: soil organic carbon, carbon stock, land use types, agro-ecological zones, soil management

INTRODUCTION
Soil carbon sequestration is the process through which carbon is stored in the soil and protected from decomposition and emission into the atmosphere as carbon dioxide. Soil organic carbon (SOC) stock refers to the amount of organic carbon stored in soil (with respect to depth). Soils take thousands of years to form as rocks are broken down and colonized by soil biota, resulting to the formation of soil organic matter (SOM), which primarily contains carbon (C) and other nutrient elements that are essential for plant growth such as nitrogen (N), phosphorus (P), sulphur and micronutrients (Reynaldo *et al.*, 2012). Soil organisms decompose SOM to make these nutrients available (Brussaard *et al.,* 2007). The rate of SOM decomposition and turnover mainly depends upon the interaction between soil biota, temperature, moisture and a soil's physical and chemical composition (Taylor *et al.,* 2009).

Basically, the quantity of SOC stored in a given soil is ascertained by the balance of C entering the soil, majorly through plant residues and exudates, and C exiting the soil through mineralization as carbon dioxide (CO_2), greatly by microbial processes, and less by leaching out of the soil as dissolved organic carbon. Locally, C can also be gained or lost through deposition or soil erosion, leading to a change in distribution of soil C at local, landscape and regional scales. Generally speaking, for a given pedo-climatic condition, more levels of plant residue inputs will tend to support more SOC stocks, and vice versa. Carbon contents of many soils are also influenced by addition of fertilizer (FAO and ITPS, 2015).

Climatic factors, such as soil temperature and water content significantly influence soil C storage by their effect on microbial activity. Generally, higher soil temperatures lead to increased microbial decomposition of SOM. Temperature is, thus, taken as main control of SOM storage in soil C cycle models (Conant *et al.*, 2011). Soil water influences soil C storage through several processes. Moist but well-aerated soils are most favourable for microbial activities and decomposition rates therefore decrease as soils become drier. By contrast, flooded soils have lower rates of organic matter decomposition due to restricted aeration (e.g., oxygen (O_2) depletion due to limited O_2 diffusion in water) and hence may often yield soils with large amounts of soil C (e.g., peat and muck soils). High rainfall may also lead to transportation of C down the soil profile as dissolved and/or particulate organic matter. During drought, SOM decomposition may decrease only to increase after rewetting (Borken and Matzner, 2008). Fire may initially decrease soil C storage, but over time may increase it by positive effects on plant growth and by input of very stable pyrogenic C (Knicker, 2007).

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The amount and composition of SOC in mineral soils also depends on soil type, with clay content influencing both the amount and the composition of soil C. Clay rich soils may be characterised by higher organic matter content and a higher concentration of O-alkyl C derived from polysaccharides, while sandy soils are characterised by low C and high alkyl C concentrations (Rumpel and Kögel-Knabner, 2011). Bioturbation which refers to the reworking of soils by animals or plants may further influence the content as well as the chemical nature of soil C. It may highly influence the heterogeneity of soils by creating hotspots. On biologically active sites, organic compounds transformation and incorporation into soil is usually enhanced by bio-turbation, leading to organo-mineral interactions and increase of soil C storage (Wilkinson *et al*., 2009).

Maintaining improved land use and management practices help to increase SOC stocks and counteract increasing atmospheric CO_2 concentrations (Paustian *et al*., 1998, Smith *et al*., 2007; Whitmore *et al*., 2014). From the foregoing, many soil forming factors and properties contribute to the amount of SOC being stored in the soil, thus in order to add to the body of knowledge, the primary scope of this article is to identify some soil properties affecting SOC stock of three different land use types in two agro-ecological zones of Nigeria.

MATERIALS AND METHODS

Site Description

This study was carried out on soil of two agro-ecological zones of Nigeria: the Upland Rainforest and southern Guinea Savanna. The location of study for the upland rainforest was the Teaching and Research Farm of Ekiti State University, Ado Ekiti, Ekiti State, while that of the southern Guinea Savanna was the Teaching and Research Farm of Kabba College of Agriculture, Kabba, Kogi State (Figure 1). The experiment was carried out on three land use types (LUTs) viz; arable (LU1), oil palm (LU2) and wetland (LU3) located on latitude and longitude 7° 42.810" N and 5° 014.759" E, 7° 42.694" N and 5° 014.60" E and 7° 42.726" N and 5° 014.781" E, respectively at Ado-Ekiti site and 7° 51.568" N and 6° 04.201" E, 7° 51.630" N and 6° 04.270" E and 7° 51.692" N and 6° 04.393" E, respectively at Kabba site. Ado-Ekiti lies between latitude 7° 31' N and 7° 49' N and longitude 5° 14' E and 5° 23' E. It has distinct dry and wet seasons, which come up between November and April and between May and October, respectively, with double maxima rainfall occurring in July and September. Mean annual rainfall is 1575.8 mm (NASA Power, 2020). Ado-Ekiti's annual mean temperature is about 25°C, the range being 12-39°C. The mean annual relative humidity is 77% (NASA Power, 2020). Cultivated arable crops in the area

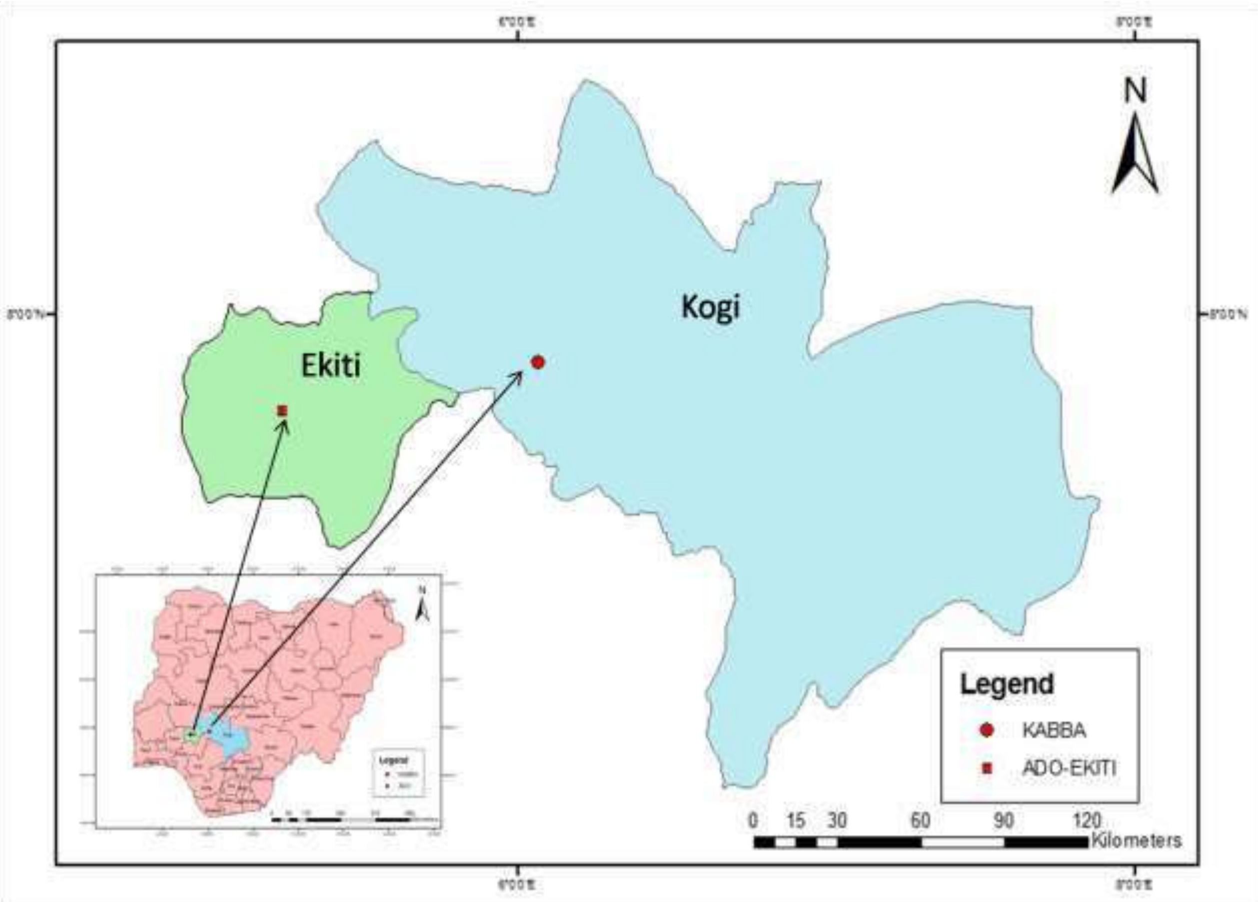

Figure 1: Map of Ado-Ekiti (Upland Rainforest) and Kabba (southern Guinea Savanna) agro-ecological zones

include yam (*Dioscorea* spp.), cassava (*Manihot esculenta*), maize (*Zea mays*) and vegetables. The major tree crops include cashew, oil palm, mango and citrus. Others include teak (*Tectona grandis*), gmelina (*Gmelina arborea*) and iroko (*Teminalia superba*). Kabba is located in the southern part of Kogi State and lies between latitude 7° 52' N and 7° 34' N and longitude 6° 02' E and 7° 42' E. The mean annual rainfall is 1230 mm, and it spreads from the month of April to November with the peak in June to September (NASA Power, 2020). The mean annual temperature of the area is 31°C. Mean annual relative humidity is 72% (NASA Power, 2020). The area is cultivated with arable crops like maize, yam, cassava, cowpea (*Vigna unguiculata*) and tomato (*Lycopersicon lycopersicum*). Trees grow in clusters and are up to 6 m tall, interspersed with grasses which grow up to about three metres. The trees include locust bean (*Parkia biglobosa*), shea butter (*Vitellaria paradoxum*) and isoberlinia (*Isoberlinia doka*) trees.

Soil Survey and Sampling

One hectare of land was marked out for each of the three land use types (LUTs). Then, five soil samples were randomly taken at four different depths (0-15, 15-30, 30-45 and 45-60 cm) to obtain 20 soil samples from each of the three LUTs. Auger and undisturbed core soil samples were taken in each case for laboratory analysis.

Laboratory Analysis

Sixty soil samples collected from the three LUTs were air-dried in the laboratory, processed and used for laboratory analyses using standard procedures. Particle size distribution was determined as described by Bouyoucous (1951) and bulk density (BD) was obtained by using method of Blake and Hartge (1986). Soil pH (water) was determined using pH meter (Thomas, 1996), total nitrogen (TN) was determined using macro-Kjeldahl method (Black, 1965), available phosphorus (AP) was determined as described by IITA (1979) using the Bray-P1 extraction procedure (Bray and Kurtz, 1945), while SOC was determined using wet oxidation method (Walkley and Black, 1934). Exchangeable cations including exchangeable potassium (Ex-K), exchangeable sodium (Ex-Na), exchangeable calcium (Ex-Ca), and exchangeable magnesium (Ex-Mg) were extracted with 1-M neutral ammonium acetate (1N NH_4OAc pH 7.0) (Thomas, 1982). Then, Ex-K and Ex-Na in the filtered extracts were determined with flame photometer while Ex-Ca and Ex-Mg were determined with atomic absorption spectrophotometer. Exchangeable acidity (EA) was determined by titration of the extract with standard sodium hydroxide (NaOH) solution (Thomas, 1982). Other soil properties obtained were cation exchange capacity, defined here as the sum of exchangeable bases (CEC_{bases}) (IITA, 1979), and effective cation exchange capacity (ECEC) which is the sum of CEC_{bases} and EA. Base saturation (BS) percentage was calculated by the formula:

$$\%\ \mathrm{BS} = \frac{CEC_{bases}}{\mathrm{ECEC}} \times \frac{100}{1};$$

while exchangeable sodium percentage (ESP) was obtained by the formula:

$$ESP = \frac{Exchangeable\ sodium}{\mathrm{CEC}} \times \frac{100}{1}$$

According to Anikwe (2010) and Obalum *et al.* (2012a), the SOC stock of the three LUTs was calculated by the following formula:

$$SOC\ stock = \frac{SOC\ (\%)}{100} \times BD \times A\ (ha) \times d\ (cm);$$

where A is area, and d is soil depth.

Statistical Analysis

The data obtained for soil properties were analysed using descriptive statistics of mean, minimum and maximum, coefficient of variation, skewness, kurtosis, correlation and regression analyses. The data obtained were fitted into the randomised complete block design and analysed using analysis of variance (ANOVA). Principal Component Analysis (PCA) was performed using soil attributes representing soil physical and chemical properties to group the correlated soil properties to the smallest possible subsets representing the majority of variation. Total variance of each factor was defined as Eigenvalue (Swan and Sandilands, 1995). Factors with Eigenvalues ≥ 1 (Brejda *et al*., 2000) and those that explained at least 5% of the variation in the data (Wander and Bollero, 1999) were retained. Soil properties from each factor were picked out using the correlation coefficients or factor loadings between soil properties and each factor (Johnson and Wichern, 1992; Sharma, 1996). Principal components with Eigenvalues > 1 were retained and then subjected to varimax rotation, which maximizes the sum of variance, to identify potential determinants of SOC stock using a factor procedure in SPSS. The factor loading, based on rotated scores and communality estimates, was used as a criterion to determine the effects of soil properties on SOC stock. SPSS IBM Statistics 19.0 (SPSS, 2010) software was used for the statistical analysis.

RESULTS AND DISCUSSION

Soil Chemical and Physical Properties

Tables 1 and 2 show the summaries of soil physico-chemical properties from the two agro-ecological zones among the three land use types; arable - LU1, oil palm - LU2 and wetland - LU3, denoted with K - LU1, K - LU2, K - LU3 and A - LU1, A - LU2, A - LU3 for southern Guinea Savanna (Kabba site) and Upland Rainforest (Ado-Ekiti site) agro-ecological zones, respectively.

Table 1: Physico-chemical soil properties of Ado-Ekiti, Upland Rainforest agro-ecological zone

	pH	SOC	SOC_{stock}	SOM	TN	AP	Ex-K	Ex-Na	Ex-Ca	Ex-Mg	EA	CEC	ECEC	BS	ESP	BD	SND	SLT	CLY	GRV
$A\text{-}LU_1$	5.80	0.69	14.83	1.18	0.08	11.46	0.52	0.59	2.40	1.05	2.82	4.55	7.37	63.85	13.20	1.48	525.50	160.00	314.50	17.24
$A\text{-}LU_2$	5.60	0.56	12.64	0.96	0.15	4.36	0.48	0.48	2.36	1.08	2.52	4.38	6.91	64.60	11.06	1.52	572.00	166.00	262.00	1.76
$A\text{-}LU_3$	5.20	0.35	7.75	0.60	0.04	6.84	0.44	0.51	1.41	0.64	2.72	3.02	5.74	56.10	16.78	1.48	572.00	145.00	283.00	24.89
LSD	0.46**	0.21**	4.89**	0.36**	NS	7.11*	NS	0.11*	0.95**	0.41**	NS	1.36**	1.17*	NS	2.15**	NS	NS	NS	NS	15.48*
SDT_a	5.60	0.87	18.17	1.48	0.20	11.79	0.58	0.58	2.07	0.91	2.53	4.14	6.67	64.78	14.26	1.41	576.00	152.00	272.00	10.20
SDT_b	5.60	0.54	11.79	0.93	0.08	7.58	0.45	0.51	1.99	0.91	2.30	3.86	6.16	63.59	13.65	1.46	579.30	154.70	266.00	15.24
SDT_c	5.50	0.38	8.86	0.65	0.04	4.82	0.46	0.51	2.02	0.95	3.15	3.98	7.14	58.53	13.36	1.54	548.70	157.30	294.00	16.47
SDT_d	5.50	0.34	8.15	0.59	0.04	6.02	0.43	0.50	2.13	0.92	2.78	3.95	6.73	59.17	13.46	1.57	522.00	164.00	314.00	16.61
LSD	NS	0.20**	6.38**	0.34**	0.13**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.11*	NS	NS	NS	NS
Mean	5.50	0.53	11.74	0.92	0.09	7.55	0.48	0.53	2.05	0.92	2.69	3.98	6.67	61.52	13.68	1.49	556.50	157.00	286.50	14.63
Min.	4.30	0.08	2.09	0.13	0.01	1.24	0.23	0.21	0.90	0.40	1.08	2.02	3.40	26.88	8.06	1.09	330.00	80.00	210.00	0.41
Max.	6.40	1.69	33.19	2.91	1.02	54.00	1.12	0.97	4.00	1.50	8.84	6.54	12.09	81.95	24.14	1.76	650.00	240.00	510.00	67.91
SD	0.52	0.33	6.84	0.57	0.15	8.69	0.17	0.15	0.64	0.29	1.58	1.01	1.94	12.46	4.01	0.13	87.50	33.50	77.30	19.94
CV	9.44	62.00	58.21	62.12	169.33	115.08	35.36	28.19	31.22	31.76	58.62	25.31	29.09	20.26	29.3	8.71	15.72	21.35	27.00	136.27
Skewness	-0.40	1.38	1.10	1.41	4.41	3.42	1.40	0.60	0.31	0.03	1.76	0.05	0.74	-0.71	0.68	-0.17	-1.61	-0.05	1.79	1.56
Kurtosis	-0.26	2.35	1.29	2.43	23.75	14.34	2.97	1.40	0.32	-0.91	3.64	-0.22	0.25	0.11	-0.45	0.54	1.54	-0.18	2.31	1.25

LSD - least significant difference, NS - not significant, * - significant at 5% probability, ** - significant at 1% probability, $A\text{-}LU_1$ - arable land use (7°42.81" N and 5°014.75" E), $A\text{-}LU_2$ - oil palm land use (7°42.69" N and 5° 014.60" E), $A\text{-}LU_3$ - wetland land use (7°42.72" north and 5°014.781" east), SDT_a - soil depth of 0-15 cm, SDT_b - soil depth of 15-30 cm, SDT_c - soil depth of 30-45 cm, SDT_d - soil depth of 45-60 cm, SD - standard deviation, Min. - minimum, Max. - maximum, CV - coefficient of variation (%), CV ≤ 15 - low variation, CV 15 ≤ 35 - moderate variation, CV > 35 - high variation, SOC - soil organic carbon (%), SOC_{stock} - soil organic carbon stock (*t* ha^{-1}), SOM - soil organic matter (%), TN - total nitrogen (%), AP - available phosphorus (mg kg^{-1}), Ex-K - exchangeable potassium (cmol kg^{-1}), Ex-Na - exchangeable sodium (cmol kg^{-1}), Ex-Ca - exchangeable calcium (cmol kg^{-1}), Ex-Mg - exchangeable magnesium (cmol kg^{-1}), EA - exchangeable acidity (cmol kg^{-1}), CEC - cation exchange capacity (cmol kg^{-1}), ECEC - effective cation exchange capacity (cmol kg^{-1}), BS - base saturation (%), ESP - exchangeable sodium percentage (%), BD - bulk density (g cm^{-3}), SND - sand (g kg^{-1}), SLT - silt (g kg^{-1}), CLY - clay (g kg^{-1}), GRV - gravel (%)

Table 2: Physico-chemical soil properties of Kabba agro-ecological zone (southern Guinea Savanna)

	pH	SOC	SOC_{stock}	SOM	TN	AP	Ex-K	Ex-Na	Ex-Ca	Ex-Mg	EA	CEC	ECEC	BS	ESP	BD	SND	SLT	CLY	GRV
$K\text{-}LU_1$	6.30	0.49	9.15	0.84	0.08	11.29	0.19	0.27	2.62	1.21	0.92	4.28	5.20	82.10	6.50	1.39	595.00	148.00	257.00	29.24
$K\text{-}LU_2$	5.80	0.91	16.93	1.56	0.27	4.10	0.30	0.29	2.57	1.12	1.14	4.29	5.43	80.12	7.00	1.27	604.00	134.00	262.00	30.98
$K\text{-}LU_3$	5.70	0.75	15.02	1.24	0.21	6.81	0.24	0.39	2.64	1.12	0.94	4.40	5.34	81.92	8.89	1.35	609.00	137.00	254.00	10.97
LSD	0.55**	0.42**	5.87*	0.73**	0.13**	4.48**	0.11**	NS	NS	NS	NS	NS	NS	NS	NS	0.08*	14.00**	NS	NS	18.27**
SDT_a	5.80	0.93	15.95	1.59	0.28	11.19	0.36	0.27	2.60	1.13	1.05	4.35	5.40	82.06	6.33	1.23	601.30	148.00	250.70	21.60
SDT_b	6.10	0.82	15.91	1.41	0.20	7.35	0.23	0.30	2.62	1.11	1.00	4.27	5.27	81.00	7.17	1.32	601.30	140.00	258.70	24.66
SDT_c	6.00	0.62	12.72	1.02	0.15	5.50	0.19	0.30	2.46	1.15	1.03	4.11	5.14	79.22	7.86	1.38	609.30	129.30	261.30	22.50
SDT_d	5.90	0.48	10.21	0.84	0.11	5.54	0.19	0.40	2.76	1.21	0.91	4.56	5.47	83.25	8.51	1.42	598.70	141.30	260.00	26.14
LSD	NS	0.31*	NS	0.57**	NS	5.66*	0.13**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	5.90	0.72	13.70	1.21	0.18	7.40	0.24	0.32	2.61	1.15	1.00	4.32	5.32	81.38	7.47	1.34	602.70	139.70	257.70	23.73
Min.	0.54	0.43	8.09	0.72	0.18	5.63	0.14	0.20	0.65	0.21	0.53	0.78	0.98	6.41	3.83	0.13	15.60	24.00	25.00	15.26
Max.	4.92	0.21	2.25	0.36	0.02	0.31	0.09	0.20	0.32	0.60	0.48	2.11	3.07	52.34	4.03	1.08	568.00	80.00	212.00	3.53
SD	6.90	2.72	53.04	4.69	0.80	34.61	0.70	1.80	3.60	1.60	4.48	5.58	9.40	89.14	32.55	1.65	62.80	18.00	31.20	63.47
CV	9.09	60.49	59.10	59.48	97.90	76.09	55.81	63.75	24.76	18.33	52.71	17.95	18.34	7.88	51.27	9.65	2.58	17.19	9.70	64.31
Skewness	0.22	2.13	2.39	2.21	1.68	2.51	1.91	6.87	-0.58	-0.06	5.19	-0.43	1.04	-2.40	4.98	0.29	-0.16	-0.64	0.68	0.53
Kurtosis	-0.91	7.07	9.08	8.14	2.44	9.23	4.07	50.85	1.15	0.04	33.15	-0.28	3.92	7.36	31.74	-0.29	-0.30	0.50	-0.18	-0.63

LSD - least significant difference, NS - not significant, * - significant at 5% probability, ** - significant at 1% probability, $K\text{-}LU_1$ - arable land use (7°51.56" N and 6°04.20" E), $K\text{-}LU_2$ - oil palm land use (7°51.63" N and 6°04.27" E), $K\text{-}LU_3$ - wetland land use (7°51.69" north and 6°04.39" east), SDT_a - soil depth of 0-15 cm, SDT_b - soil depth of 15-30 cm, SDT_c - soil depth of 30-45 cm, SDT_d - soil depth of 45-60 cm, SD - standard deviation, Min. - minimum, Max. - maximum, CV - coefficient of variation (%), CV ≤ 15 - low variation, CV 15 ≤ 35 - moderate variation, CV > 35 - high variation, SOC - soil organic carbon (%), SOC_{stock} - soil organic carbon stock (t ha^{-1}), SOM - soil organic matter (%), TN - total nitrogen (%), AP - available phosphorus (mg kg^{-1}), Ex-K - exchangeable potassium (cmol kg^{-1}), Ex-Na - exchangeable sodium (cmol kg^{-1}), Ex-Ca - exchangeable calcium (cmol kg^{-1}), Ex-Mg - exchangeable magnesium (cmol kg^{-1}), EA - exchangeable acidity (cmol kg^{-1}), CEC - cation exchange capacity (cmol kg^{-1}), ECEC - effective cation exchange capacity (cmol kg^{-1}), BS - base saturation (%), ESP - exchangeable sodium percentage (%), BD - bulk density (g cm^{-3}), SND - sand (g kg^{-1}), SLT - silt (g kg^{-1}), CLY - clay (g kg^{-1}), GRV - gravel (%)

Soil Chemical Properties

Mean values of soil pH at the two sites under the three LUTs and across the soil depths ranged from 5.2 to 6.3. They were rated to be strongly acidic (pH 5.1-5.5), moderately acidic (pH 5.6-6.0) and slightly acidic (pH 6.1-6.5) (FAO, 2004). The pH range between 5.50 and 6.50 of the two sites has been reported to be optimum mineral soil pH range for best plant growth (Jones, 2012) because most nutrient elements are readily available at the pH range of 5.5-6.5 (Motsara and Roy, 2008). Low variability in soil pH across all LUTs was reported by previous researchers and this indicates that soil pH is uniform or homogenous within the two study areas (Omotoso and Akinbola, 2007; Obalum *et al*., 2013; Tegha and Sendze, 2016).

Mean SOC stock ranged between 7.75 and 18.17 t ha^{-1} at both agro-ecological zones under the three LUTs and across the four soil depths. The highest SOC stock was recorded on 0-15 cm soil depth at Ado-Ekiti, Upland Rainforest agro-ecological zone. This may be attributed to adoption of better soil management practices, which involved addition of organic and inorganic fertilizers (Onah *et al*., 2021). Mean SOC contents at both sites under the three LUTs and across the soil depths ranged from 0.34 to 0.93%. According to FAO (2004) rating, SOC mean values were between very low (< 0.4%) to low (0.4-1.0%) ratings. Highest SOC content in the topsoils (0-15 cm) at the two sites may be attributed to the relative intensity of litter accumulation and recycling (Igwe, 2001; Obalum *et al*., 2012a; Oguike *et al*., 2022).

Lowest mean SOC was observed on A - LU3 at Ado-Ekiti. This may be attributed to frequent wetting-drying cycles in waterlogged soils which facilitates SOC decomposition, thus lowering of its content in the soil (Nwite *et al*., 2017; Nnadi *et al*., 2021). At the two sites, the range of mean SOM among the LUTs and across the four soil depths ranged between 0.60 and 1.56% and 0.59 and 1.59% respectively. According to Adepetu (1990), the values of mean SOM on soils of Kabba and Ado-Ekiti LUTs were rated between low (< 1.5%) and medium (1.5-2.5%) on soil fertility classification scale. These were below the critical value of 2.0% reported for Nigerian soils (Adepetu, 1990). Crop residue management and soil fertility practices will increase SOM content of these soils (Jones, 2012; FAO and ITPS, 2015). Mean values of TN obtained ranged from 0.04 to 0.28% among LUTs and across the depths at both sites. The mean TN values were below the critical level of 0.2% (Adepetu, 1990) recommended for tropical soils. This indicates high N deficiencies. Thus, the low N values signify that the soils will respond to N fertilization. The cause of N deficiency in the soils may be related to intense leaching and erosion due to rainfall and high mineralization rate and crop exports (Enwezor *et al*., 1989).

At both sites, arable land use (LU) recorded the highest AP (11.29 and 11.46 mg kg^{-1}), followed by wetland (6.81 and 6.84 mg kg^{-1}) and oil palm LU (4.10 and 4.36 mg kg^{-1}) at Kabba and Ado-Ekiti sites, respectively. According to Adepetu (1990) rating of AP for Nigerian soils, the mean values of AP of LUTs of the two sites were rated within the range of low (< 8.00 mg kg^{-1}) and medium (8.00-20.00 mg kg^{-1}). Most mean values of AP were below the reported critical values of 8.00-12.00 mg kg^{-1} for tropical soils (Enwezor *et al*., 1989) indicated that the soils are P deficient. Phosphorus deficiency in tropical soils has been related to leaching by intense rainfall, high weatherability of the soils, presence of kaolinitc clay as the dominant mineral (Enwezor *et al*., 1989) and adsorption reaction by soil constituents (Bubba *et al*., 2003). This suggests that most of the AP in these soils was in inorganic form (Obalum *et al*., 2012b).

Ex-Ca mean (range, 1.41-2.64 cmol kg^{-1}) values of the three LUTs on Kabba and Ado-Ekiti soils were rated between very low (< 2.00 cmol kg^{-1}) and low (2.00-5.00 cmol kg^{-1}) according to FAO (2004). Low Ex-Ca content in soil has been attributed to loss by leaching from rainfall or irrigation in acid sandy soils (Jones, 2012). At both sites, Ex-Ca mean values obtained for all the LUTs were above reported critical value of 2 cmol kg^{-1} for Nigerian soils (Adepetu, 1990), except on LU3 (wetland LU) at Ado-Ekiti site. This indicates that these soils have presence of adequate Ex-Ca nutrient for crop use. The mean Ex-Mg values (0.64-1.21 cmol kg^{-1} range) at both sites among the three LUTs were rated between low (0.30-1.00 cmol kg^{-1}) and moderate (1.00-3.00 cmol kg^{-1}) (FAO, 2004). Generally, lowest mean values of Ex-Mg were observed on wetland (K - LU3 and A - LU3) at both sites. This may be attributed to leaching loss (Jones, 2012). Critical value of 0.28 cmol kg^{-1} has been reported for Nigerian soils (Adepetu, 2000). Ex-Mg values of these soils were mostly above the critical limits, indicating that these soils have presence of adequate amounts of Mg nutrient for crop use.

Among the LUTs and across the soil depths, mean Ex-K values (0.19-0.58 cmol kg^{-1} range) on soils of Kabba and Ado-Ekiti sites were between low (< 0.15 cmol kg^{-1}) and high (> 0.30 cmol kg^{-1}) according to Adepetu (2000) fertility classes for Nigerian soils. This implies that values of exchangeable K were mostly above the critical value of 0.20 cmol kg^{-1} has been reported for Nigerian soils by Adepetu (1990). This indicated that the soils have presence of adequate K nutrient for crop use. Mean Ex-Na values (0.27-0.59 cmol kg^{-1} range) at both sites among the three LUTs were rated between low (0.10-0.30 cmol kg^{-1}) and moderate (0.30-0.70 cmol kg^{-1}) (FAO, 2004). Mean EA ranged from 0.19-2.82 cmol kg^{-1} among LUTs and across the depths at both sites. It was higher at Ado-Ekiti site indicating loss of exchangeable bases to leaching.

Soil CEC mean values among the three LUTs and across the soil depths ranged between 3.02 and 4.56 cmol kg^{-1} at both sites. The exchange sites were dominated with Ca, followed by Mg, probably because of the soil's affinity for these cations (Idoga, 2008). The mean CEC values were rated between very low (< 5.00 cmol kg^{-1}) and low (5.00-15.00 cmol kg^{-1}) (FAO, 2004). Any CEC value of < 5.00 cmol kg^{-1} indicates a level of infertility normally unsuitable for irrigated agriculture; such soil has extremely poor capacity to retain applied nutrient in the root zone. This indicates that soils of the two study locations are poor in organic matter due to high leaching problems causing decline in exchangeable bases and depletion of SOM (Alarima *et al*., 2020). Thus, they may require careful management of the fertilization process (Adepetu, 2000).

Mean ECEC among the LUTs and across the soil depths ranged from 5.14 to 7.37 cmol kg^{-1} and 5.14 cmol kg^{-1} and 7.14 cmol kg^{-1}, respectively for both sites. The mean ECEC at both locations were rated between very low (< 6.00 cmol kg^{-1}) and low (6.00-12.00 cmol kg^{-1}) (FAO, 2004). Low ECEC values of these soils may be attributed to weathering processes and low SOM contents of the soil (Alarima *et al*., 2020). Mean BS of all the three LUTs and across soil depths at Kabba and Ado-Ekiti locations ranged from 56.10 to 83.25%. According to Landon (1984) and Adepetu (2000) ratings, these soils' mean BS values were rated between less fertile soils (20-60%) and fertile soils (> 60%). Mean BS of these soils was more of clay colloid contributions (Idoga and Azagaku, 2005) as a result of low SOM contents. Thus, better soil management practices will improve the soil fertility and enhance SOC sequestration at both sites. The two sites ESP mean values of soils of the three LUTs and across the soil depths ranged between 6.50 and 16.78%; and 6.33 and 14.26% respectively. The highest value of ESP (16.78%) at Ado-Ekiti site was above the critical value of 15% that is reported for sodic soil, indicating that the soil of Ado-Ekiti wetland (A - LU3) is sodic. The soil contains sufficient soluble salts to interfere with growth of most crops (Landon 1984; Adepetu, 2000). Thus, there is need for improvement of the soil against sodicity.

Soil Physical Properties under the Three Land Use Types in the Two Agro-Ecological Zones

Mean soil BD values among the three LUTs and across the soil depths ranged between 1.27 g cm^{-3} and 1.48 g cm^{-3}, and 1.23 g cm^{-3} and 1.57 g cm^{-3} at both sites respectively. Soil BD variability was low (< 15%), 8.71% and 9.65% at Ado-Ekiti and Kabba sites respectively. Similar result was recorded by Zhang and Shao (2014), indicating that BD was not very variable throughout the study sites. BD increased with increasing soil depth at both sites. This result is consistent with the previous observation of other workers (Agboadoh, 2011; Bessah *et al*., 2016). The increase in bulk density with increasing soil depth may be due to absence of tillage activities below the soil surface. Average soil textural classes at Kabba and Ado-Ekiti sites were sandy clay loam among the LUTs and across the four soil depths. High proportion of sand in the soils may be attributed to the genesis of the soils (Uzoh *et al*., 2020).

Values of mean sand proportion of soils under the three LUTs and across the soil depths ranged between 525.50 g kg^{-1} (A - LU1) and 609.00 g kg^{-1} (K - LU3) and 522.00 g kg^{-1} (A, 45-60 cm depth) and 609.30 g kg^{-1} (A, 30-45 cm depth) at both sites. Mean silt proportion values among the three LUTs and across the soil depths ranged from 129.30 g kg^{-1} and 166.00 g kg^{-1} at both sites. Among the three LUTs at Kabba and Ado-Ekiti sites, mean clay proportion of soils ranged from 250.70 g kg^{-1} and 314.50 g kg^{-1}. Mean gravel content values among the three LUTs and across the soil depths ranged from 1.76% and 30.98% at both sites. The non-significant difference in the particle size distribution of the soils of different LUTs of Kabba agrees with the findings of Amana *et al*. (2012) and Osayande *et al*. (2014) that LU had no significant effect on the texture of soil. Texture is largely determined by parent material (Obi, 1999).

Influence of Land Use Type and Soil Depth on Soil Physicochemical Properties of the Two Agro-Ecological Zones

At both sites effect of LU was significant on soil pH, SOC concentration, SOC stock, SOM and AP, while soil depth significantly influenced SOC and SOM. At Ado-Ekiti and Kabba sites, coefficient of variation (CV) was high (> 35%) for SOC, SOC stock, SOM, TN, AP, Ex-K, EA and gravel content; and moderate (15 ≤ 35%) for Ex-Ca, Ex-Mg, CEC and ECEC.

Relationship between SOC and Other Soil Chemical and Physical Properties on different LUTs within the Two Agro-ecological Zones

Results in Tables 3 and 4 show the correlation between soil physical and chemical properties. The SOC stock was observed to have positive and significant correlation ($p < 0.01$) with SOM ($r = 0.94^{**}$ and 0.99^{**}) and TN ($r = 0.88^{**}$ and 0.48^{**}) at Kabba and Ado-Ekiti sites, respectively. This indicates that increases in SOM and TN were associated with increased SOC stock. Jung and Lal (2011) reported similar observation that there is a positive correlation between rates of nitrogen and SOC stock due to increase in N fertilization rate. This is attributed to the fact that SOC stock and TN are largely associated with SOM (Kparmwang and Esu, 1995). Significant negative correlation ($p < 0.01$) was observed between SOC stock and soil pH ($r = -0.34^{**}$) at Kabba site. However, significant positive correlation ($r = 0.37^{**}$) existed between soil pH and SOC stock at Ado-Ekiti site. This may be attributed to better land use management effect on Ado-Ekiti soil, involving application of organic/inorganic fertilizers (Alarima *et al*., 2020).

At Ekiti site, AP, Ex-K, Ex-Na, Ex-Ca, Ex-Mg, CEC and BS were significantly and positively related ($p < 0.01$) to SOC stock ($r = 0.52^{**}$; 0.37^{**}; 0.33^{**}; 0.33^{**}; 0.39^{**}; 0.45^{**}; and 0.41^{**} respectively), indicating that increase in AP, Ex-K, Ex-Na, Ex-Ca, Ex-Mg, CEC and BS were connected with increase in SOC stock. However, no significant correlation was obtained at Kabba site. This may be due to the high influence of SOM on soil chemical properties as reported by Agbede (2009). Ibrahim and Idoga (2013)

Table 3: Correlation matrix on physico-chemical soil properties of Kabba agro-ecological zone (southern Guinea Savanna)

	SOC_{stock}	SOC	LU	Depth	pH	BD	SOM	TN	AP	Ex-K	Ex-Na	Ex-Ca	Ex-Mg	EA	CEC	ECEC	BS	ESP	SND	SLT	CLY
SOC	0.96**																				
LU	030*	0.25																			
Depth	–0.28*	–0.40**	0.00																		
pH	–0.34**	–0.39**	–0.49**	0.07																	
BD	–0.32*	–0.47**	–0.11	0.56**	0.21																
SOM	0.94**	0.99**	0.23	–0.41**	–0.38**	–0.48**															
TN	0.88**	0.91**	0.30*	–0.34**	–0.46**	–0.43**	0.90**														
AP	–0.07	–0.07	–0.33*	–0.38**	0.22	0.08	–0.05	–0.16													
Ex-K	0.15	0.23	0.15	–0.43**	–0.27*	–0.34**	0.25	0.27*	–0.05												
Ex-Na	–0.12	–0.13	0.27*	0.21	–0.08	0.01	–0.14	–0.06	–0.14	–0.12											
Ex-Ca	–0.14	–0.15	0.01	0.06	0.19	0.07	–0.13	–0.12	0.14	0.04	0.00										
Ex-Mg	–0.15	–0.16	–0.16	0.15	0.19	0.11	–0.15	–0.14	–0.03	–0.02	–0.09	0.33*									
EA	0.05	0.06	0.02	–0.09	–0.06	–0.14	0.07	–0.00	–0.11	0.34**	–0.02	0.02	0.07								
CEC	–0.16	–0.16	0.06	0.07	0.14	0.03	–0.15	–0.11	0.07	0.17	0.22	0.93**	0.52**	0.09							
ECEC	–0.10	–0.10	0.06	0.01	0.08	–0.05	–0.08	–0.09	–0.01	0.32*	0.16	0.75**	0.45**	0.61**	0.84**						
BS	–0.10	–0.09	–0.01	0.03	0.11	0.11	–0.10	–0.01	0.19	–0.14	0.08	0.42**	0.22	–0.83**	0.40**	–0.13					
ESP	–0.08	–0.09	0.26*	0.21	–0.13	–0.00	–0.11	–0.04	–0.20	–0.19	0.91**	–0.37**	–0.28*	–0.04	–0.18	–0.16	–0.11				
SND	0.29*	0.24	0.37**	0.00	–0.19	0.07	0.21	0.17	–0.19	–0.03	–0.14	–0.24	0.07	–0.07	–0.22	–0.21	–0.09	–0.03			
SLT	–0.04	–0.02	–0.19	–0.14	0.11	–0.04	0.01	0.01	0.16	0.09	–0.03	0.21	0.15	0.16	0.22	0.26*	–0.01	–0.11	–0.26*		
CLY	–0.15	–0.13	–0.05	0.14	0.01	–0.00	–0.14	–0.12	–0.03	–0.07	0.11	–0.05	–0.18	–0.11	–0.08	–0.12	0.07	0.12	–0.37**	–0.80**	
GRV	–0.00	0.01	–0.49**	0.09	0.20	0.19	0.02	–0.02	–0.02	0.13	–0.19	0.06	0.10	–0.02	0.05	0.02	0.08	–0.24	–0.11	0.10	–0.03

* - significant at 5% probability, ** - highly significant at 1% probability; LU - land use, SOC - soil organic carbon (%), SOC_{stock} - soil organic carbon stock (t ha^{-1}), SOM - soil organic matter (%), TN - total nitrogen (%), AP - available phosphorus (mg kg^{-1}), Ex-K - exchangeable potassium (cmol kg^{-1}), Ex-Na - exchangeable sodium (cmol kg^{-1}), Ex-Ca - exchangeable calcium (cmol kg^{-1}), Ex-Mg - exchangeable magnesium (cmol kg^{-1}), EA - exchangeable acidity (cmol kg^{-1}), CEC - cation exchange capacity (cmol kg^{-1}), ECEC - effective cation exchange capacity (cmol kg^{-1}), BS - base saturation (%), ESP - exchangeable sodium percentage (%), BD - bulk density (g cm^{-3}), SND - sand (g kg^{-1}), SLT - silt (g kg^{-1}), CLY - clay (g kg^{-1}), GRV - gravel (%)

Table 4: Correlation matrix on physico-chemical properties of soils in Ado-Ekiti, Upland Rainforest agro-ecological zone

	SOC_{stock}	SOC	LU	Depth	pH	BD	SOM	TN	AP	Ex-K	Ex-Na	Ex-Ca	Ex-Mg	EA	CEC	ECEC	BS	ESP	SND	SLT	CLY
SOC	0.99**																				
LU	–0.43**	–0.42**																			
Depth	–0.54**	–0.59**	0.00																		
pH	0.37**	0.33*	–0.54**	–0.13																	
BD	–0.18	–0.31*	–0.02	0.47**	0.13																
SOM	0.99**	1.00**	–0.42**	–0.58**	0.32*	–0.31*															
TN	0.48**	0.49**	–0.10	–0.40**	0.23	–0.17	0.46**														
AP	0.52**	0.53**	–0.22	–0.26*	0.21	–0.11	0.54**	0.17													
Ex-K	0.37**	0.40**	–0.21	–0.27*	0.01	–0.20	0.40**	0.20	0.48**												
Ex-Na	0.33**	0.34**	–0.24	–0.20	0.26*	0.04	0.34**	0.12	0.49**	0.70**											
Ex-Ca	0.33**	0.29*	–0.63**	0.04	0.46**	0.14	0.29*	0.14	0.06	0.16	0.21										
Ex-Mg	0.40**	0.35**	–0.58**	0.03	0.43**	0.12	0.34**	0.24	0.03	0.14	0.18	0.92**									
EA	–0.17	–0.20	–0.03	0.12	0.05	0.16	–0.20	–0.10	–0.12	0.11	0.10	0.06	0.07								
CEC	0.45**	0.41**	–0.62**	–0.05	0.44**	0.11	0.41**	0.20	0.19	0.41**	0.46**	0.95**	0.92**	0.08							
ECEC	0.09	0.05	–0.35**	0.07	0.27*	0.19	0.05	0.02	0.01	0.30*	0.32*	0.54**	0.54**	0.86**	0.59**						
BS	0.41**	0.42**	–0.26*	–0.20	0.22	–0.10	0.42**	0.18	0.24	0.08	0.19	0.34**	0.31*	–0.86**	0.36**	–0.51**					
ESP	–0.15	–0.12	0.37**	–0.08	–0.16	0.01	–0.12	–0.10	0.21	0.26*	0.55**	–0.63**	–0.64**	0.01	–0.46**	–0.23	–0.12				
SND	0.07	0.09	0.22	–0.25	–0.15	–0.17	0.09	0.12	–0.04	0.09	–0.05	–0.24	–0.14	0.01	–0.19	–0.09	–0.09	0.13			
SLT	0.11	0.08	–0.18	0.13	0.15	0.16	0.08	0.10	0.15	0.04	0.21	0.31*	0.36**	0.12	0.35**	0.28*	0.03	–0.14	–0.48**		
CLY	–0.12	–0.14	–0.17	0.22	0.10	0.12	–0.14	–0.18	–0.02	–0.12	–0.04	0.13	0.01	–0.07	0.06	–0.03	0.09	–0.09	–0.93**	0.11	
GRV	0.00	–0.01	0.16	0.12	–0.00	0.08	–0.01	–0.09	0.16	0.07	0.41**	–0.09	–0.05	0.17	0.03	0.15	–0.08	0.44**	–0.03	0.17	–0.04

Abbreviations are as defined in Table 3.

also reported that SOM contributes greatly to soil N, P, CEC and exchange-able cations and where SOM is lacking; these soils properties will be adversely affected. At both sites no correlation was observed between EA, ECEC, ESP, proportion of silt and clay and gravel content and SOC stock and concentration. In related studies, no significant correlation of SOC with clay content was reported (McDaniel and Munn, 1985; Lugo and Brown, 1993; Percival *et al*., 2000). Negative significant correlation existed between BD and SOC stock and concentration (r = 0.32* and 0.47**) at Kabba site; at Ado-Ekiti site, BD significantly correlated negatively (r = –0.31*) with SOC concentration only. Soil bulk density often decreases with increases in SOC probably due to the effect by the low-density organic compounds (Blanco-Canqui and Lal, 2007; Obalum and Obi, 2014).

Correlation between SOC stock with sand proportion was significant (r = 0.29*) at Kabba site while there was no significant correlation with SOC stock at Kabba site. This opposed report of Zhang and Shao (2014) that significant correlations were observed between SOC and soil physical properties, i.e., stone, sand, silt, and clay contents because the studied soil was desert soil, derived from gravelly diluvial-alluvial materials of the denuded monadnock, which implies that SOC may be related to clay colloid contribution. In a previous article on this study, Fasina *et al*. (2021) reported that at Kabba and Ado-Ekiti sites, soil depth was negatively correlated with SOC stock (r = –0.28* and –0.40**, respectively) and concentration (r = –0.54** and –0.59**, respectively), indicating that increase in soil depth is associated with decrease in SOC stock and concentration. The LU was significantly negatively correlated with SOC stock (r = –0.43**) at Ado-Ekiti site but significantly positively correlated at Kabba site. Zinn *et al*. (2007) reported that there was a clear soil depth effect on the correlation with SOC concentration. The apparent effect of depth on SOC concentration suggests that for a textural range of soils, SOC retention for a specific soil depth is proportional to the < 20 μm (clay; < 2 μm and silt; 2-20 μm) portion. The fact that SOC concentrations decrease in the subsoil indicated not only the occlusion of clay surfaces by SOC, but also the input of organic matter to a specific soil depth is the primary factor affecting SOC retention, followed by texture. Storage of SOC is a function of climate, vegetation, drainage, and management interactions, and also of intrinsic soil properties such as texture, structure and mineralogy (Zinn *et al*., 2007).

At Kabba site, negative correlation was observed between BD and TN (r = –0.43*), which agreed with the report of Shrestha and Lal (2011) that the correlation may be due to a gradual and simultaneous decrease in SOC and increase in BD with increase in soil depth, in undisturbed soil. Other soil properties which include -BD, SOM, TN, AP, Ex-K, Ex-Na, Ex-Ca, Ex-Mg, EA, CEC, ECEC, BS, ESP, proportion of sand, silt, clay, and gravel content, exhibited significant positive and negative correlation among them. SOM which is the sink of SOC, has positive significant correlation with TN, AP, Ex-K, Ex-Na, Ex-Ca, Ex-Mg, CEC and BS (r = 0.46**; 0.54**; 0.40**; 0.34**; 0.29*; 0.34**; 0.41** and 0.42**, respectively) in Ado-Ekiti site, but correlated with only TN (r = 0.90**) in Kabba site. As earlier mentioned, this may be due to high influence of SOM on soil chemical properties (Agbede, 2009).

The data of soil properties from this study were fitted to a multiple linear regression model (Table 5) for SOC stock at Kabba and Ado-Ekiti sites. The regression models showed that LU, SOC, pH, SOM, Ex-K, Ex-Ca, Ex-Mg, BD, and gravel content predict SOC stock in similar positive and negative trends at both sites, while other properties; soil depth, TN, AP, Ex-Na, EA, CEC, BS, ESP, proportion of silt and clay predict SOC stock in different trend at both sites. Coefficient of determination (R^2) of 0.952 and 0.996 at Kabba and Ado-Ekiti, respectively (Table 5), shows that 95.2% and 99.6% of the variations in the SOC stock (dependent variable) can be explained based on the soil properties (independent variables), which include LU, soil depth, soil pH, SOC, BD, SOM, TN, AP, Ex-K, Ex-Na, Ex-Ca, Ex-Mg, EA, BS, ESP, proportion of sand, silt, clay and gravel content. For southern Guinea Savanna agro-ecological zone soils, SOC stock regression coefficient (Table 6) shows that SOC (p < 0.01) and BD (p < 0.05) were significant; for Ado-Ekiti soils (Table 7), land use (p < 0.05) and BD (p < 0.01) were significant. This confirms significant influence of better land use management on SOC stock at Ado-Ekiti location. The two sites, soil properties - SOC, BD, land use and soil pH (Kabba, 1.13; 0.11; 0.11 and 0.09; and Ado-Ekiti, 1.21; 0.14; 0.04 and 0.03) are the predictors that contribute more to the model since they have larger absolute standardised coefficient. Others include TN (0.10), depth (0.09), EA (0.05) and AP (0.05) at Kabba location and CEC (0.12) and Ex-Na (0.03) at Ado-Ekiti location.

Table 5: Regression analytical models for soil organic carbon stocks in Kabba (southern Guinea Savanna) and Ado-Ekiti (Upland Rainforest) agro-ecological zones

Site	Regression models	R^2
Kabba	SOC_{stock} = –26.21 + 1.03 (land use) + 0.61 (depth) + 1.33 (pH) + 21.07 (SOC) – 1.93 (SOM) + 4.41 (TN) + 0.07 (AP) – 1.16 (Ex-K) – 2.50 (Ex-Na) – 0.12 (Ex-Ca) – 0.50 (Ex-Mg) + 0.80 (EA) + 0.02 (BS) + 0.08 (ESP) + 7.03 (BD) + 0.08 (SND) – 0.04 (CLY) + 0.00 (GRV)	0.952
Ado-Ekiti	SOC_{stock} = –9.62 + 0.32 (land use) – 0.03 (depth) + 0.36 (pH) + 25.11 (SOC) – 2.05 (SOM) – 0.80 (TN) – 0.01 (AP) – 1.10 (Ex-K) + 1.20 (Ex-Na) – 0.88 (Ex-Ca) – 0.87 (Ex-Mg) – 0.18 (EA) + 0.82 (CEC) – 0.03 (BS) – 0.13 (ESP) + 7.33 (BD) – 0.02 (SLT) + 0.00 (CLY) + 0.00 (GRV)	0.996

SOC - soil organic carbon (%), SOC_{stock} - soil organic carbon stock (t ha^{-1}), SOM - soil organic matter (%), TN - total nitrogen (%), AP - available phosphorus (mg kg^{-1}), Ex-K - exchangeable potassium (cmol kg^{-1}), Ex-Na - exchangeable sodium (cmol kg^{-1}), Ex-Ca - exchangeable calcium (cmol kg^{-1}), Ex-Mg - exchangeable magnesium (cmol kg^{-1}), EA - exchangeable acidity (cmol kg^{-1}), CEC - cation exchange capacity (cmol kg^{-1}), BS - base saturation (%), ESP - exchangeable sodium percentage (%), BD - bulk density (g cm^{-3}), SND - sand (g kg^{-1}), SLT - silt (g kg^{-1}), CLY - clay (g kg^{-1}), GRV - gravel (%)

Principal Component Analysis of Soil Properties Related to SOC Stock

In Kabba, Southern Guinea Savanna zone, each of the first seven factors had Eigenvalues > 1.00 which were retained for interpretation (Table 8) while in Ado-Ekiti, Upland Rainforest zone, each of the first six factors had Eigenvalues > 1.00, and were retained for interpretation (Table 9). Extraction communalities estimates (EC) at Kabba site (Table 8) were all high (> 0.50) except for pH (0.48) and Ex-K (0.47) while at Ado-Ekiti site EC was similar to Kabba site except that only pH (0.38) was low (< 0.50). These seven factors explained cumulative sample variance of 80.58%. The first and the most important factor explained, 20.50% of the variation, had high factor loading (> 0.50) for three properties SOC, SOM and TN (0.94, 0.94 and 0.94, respectively). Factor 2 had high loading from CEC, Ex-Ca, ECEC and Ex-Mg (0.99, 0.91, 0.87 and 0.56, respectively) collectively explained 16.32% of the sample variance. The highly weighted variable under factor 3 was EA (–0.96). For factor 4, Ex-Na and ESP had high factor loading (0.94 and 0.91) explaining 10.09% of the sample variance and for factor 5 land use (–0.80) was selected as highly weighted variables and explained 8.17% of the sample variance. Factor 6 had high loading from clay content (–0.97) which explained 7.58% of the sample variance and factor 7 had high loading from soil depth (0.745) which explained 6.02% of the sample variance. The SOC concentration was selected as a representative from factor 1 because it had the highest factor loading of 0.940. Under factors 2, 3, 4, 5, 6 and 7; CEC, EA, Ex-Na, land use, clay content and soil depth with the highest factor loading (0.99, –0.96, 0.94, –0.80, –0.97 and 0.75, respectively) were selected to represent factors 2, 3, 4, 5, 6 and 7, respectively.

Table 6: Regression coefficients for soil organic carbon stock of Kabba agro-ecological zone (southern Guinea Savanna)

	Un-standardized coefficients		Standardized coefficients		
Model 1	β	Standard error	β	t	Sig.
(Constant)	–26.21	29.332		–0.89	0.38
Land use	1.03	0.563	0.11	1.83	0.08
Depth	0.61	0.404	0.09	1.52	0.14
pH	1.33	0.674	0.09	1.97	0.06
Soil organic carbon	21.07	4.737	1.13	4.45	0.00
Soil organic matter	–1.93	2.666	–0.17	–0.73	0.47
Total nitrogen	4.41	4.172	0.10	1.06	0.30
Available phosphorus	0.07	0.069	0.05	1.06	0.30
Exchangeable potassium	–1.16	3.028	–0.02	–0.38	0.71
Exchangeable sodium	–2.50	11.540	–0.06	–0.22	0.83
Exchangeable calcium	–0.12	1.217	–0.01	–0.10	0.92
Exchangeable magnesium	–0.50	1.961	–0.01	–0.25	0.80
Exchangeable acidity	0.79	2.386	0.05	0.33	0.74
Base saturation	0.02	0.213	0.02	0.10	0.92
Exchangeable sodium percentage	0.08	0.666	0.04	0.12	0.91
Bulk density	7.03	3.205	0.11	2.20	0.03
Sand	0.08	0.255	0.02	0.32	0.75
Clay	–0.04	0.130	–0.01	–0.30	0.77
Gravel	0.00	0.025	0.00	0.03	0.98

Dependent variable: SOC stock

Table 7: Regression coefficients for soil organic carbon stock of Ado-Ekiti agro-ecological zone (Upland Rainforest)

Model 1	Un-standardized coefficients		Standardized coefficients		
	β	Standard error	β	t	Sig.
(Constant)	–9.62	2.113		–4.56	0.00
Land use	0.32	0.141	0.04	2.26	0.03
Depth	–0.03	0.102	–0.01	–0.28	0.78
pH	0.36	0.199	0.03	1.82	0.08
Soil organic carbon	25.11	14.298	1.21	1.76	0.09
Soil organic matter	–2.05	8.094	–0.17	–0.25	0.80
Total nitrogen	–0.80	1.534	–0.02	–0.52	0.60
Available phosphorus	–0.01	0.013	–0.01	–0.51	0.61
Exchangeable potassium	–1.10	1.447	–0.03	–0.76	0.45
Exchangeable sodium	1.20	3.073	0.03	0.39	0.70
Exchangeable calcium	–0.88	1.114	–0.08	–0.79	0.43
Exchangeable magnesium	–0.87	1.459	–0.04	–0.60	0.56
Exchangeable acidity	–0.18	0.175	–0.04	–1.00	0.33
Cation exchange capacity	0.82	1.265	0.12	0.65	0.52
Base saturation	–0.03	0.025	–0.06	–1.23	0.23
Exchangeable sodium percentage	–0.13	0.100	–0.08	–1.34	0.19
Bulk density	7.33	0.755	0.14	9.71	0.00
Silt	–0.02	0.026	–0.01	–0.66	0.51
Clay	0.00	0.010	0.00	0.27	0.79
Gravel	0.00	0.006	0.01	0.48	0.63

Dependent variable: SOC stock

Table 8: Factor analysis on physical and chemical soil properties of Kabba, southern Guinea Savanna agro-ecological zone

Factors	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	EC
Eigenvalue	4.30	3.43	2.50	2.12	1.72	1.59	1.27	
Percent variance	20.50	16.32	11.90	10.09	8.17	7.58	6.02	
Cumulative variance	20.50	36.82	48.72	58.81	66.98	74.56	80.58	
Factor loading								
Land use	0.28	0.09	–0.01	0.19	–0.80	–0.07	0.18	0.81
Depth	–0.41	0.06	0.11	0.19	0.08	–0.10	0.75	0.79
pH	–0.50	0.09	0.11	–0.11	0.42	0.10	–0.15	0.48
Soil organic carbon	0.94	–0.11	0.00	–0.09	–0.04	0.06	–0.02	0.91
Bulk density	–0.56	–0.00	0.20	–0.09	0.10	0.07	0.45	0.57
Soil organic matter	0.94	–0.10	–0.01	–0.10	–0.02	0.07	–0.04	0.91
Total nitrogen	0.94	–0.06	0.05	–0.01	–0.06	0.05	0.03	0.89
Available phosphorus	–0.19	0.01	0.21	–0.15	0.13	0.12	–0.70	0.62
Exchangeable potassium	0.40	0.24	–0.42	–0.12	–0.03	–0.05	–0.24	0.47
Exchangeable sodium	–0.05	0.12	0.06	0.94	–0.13	–0.01	0.11	0.93
Exchangeable calcium	–0.08	0.91	0.15	–0.08	0.04	0.01	–0.09	0.88
Exchangeable magnesium	-0.15	0.56	0.06	–0.27	0.05	0.20	0.25	0.51
Exchangeable acidity	0.02	0.16	–0.96	–0.00	0.01	0.08	0.02	0.95
Cation exchange capacity	–0.05	0.99	0.08	0.08	0.01	0.05	–0.03	0.99
Effective cation exchange capacity	–0.03	0.87	–0.45	0.06	0.01	0.08	–0.01	0.98
Base saturation	–0.00	0.35	0.90	0.00	0.04	–0.05	–0.10	0.94
Exchangeable sodium percentage	–0.06	–0.27	–0.00	0.91	–0.16	–0.02	0.14	0.94
Sand	0.14	–0.23	0.08	–0.36	–0.56	0.22	0.40	0.73
Silt	0.00	0.19	–0.09	0.10	0.23	0.87	–0.21	0.90
Clay	–0.09	–0.04	0.04	0.13	0.13	–0.97	–0.05	0.98
Gravel	0.11	0.05	0.03	–0.19	0.78	0.04	0.28	0.74

EC - extraction communality estimate

Table 9: Factor analysis on physical and chemical soil properties of Ado-Ekiti agro-ecological zone (Upland Rainforest)

Factors	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	EC
Eigenvalue	5.61	3.64	2.73	2.18	1.36	1.03	
Percent variance	26.74	17.31	13.01	10.39	6.49	4.88	
Cumulative variance	26.74	44.05	57.06	67.44	73.93	78.81	
Factor loading							
Land use	–0.73	-0.15	–0.14	0.01	0.22	0.13	0.64
Depth	0.07	-0.79	–0.12	0.03	–0.14	0.16	0.68
pH	0.52	0.20	0.08	–0.02	–0.11	0.22	0.38
Soil organic carbon	0.34	0.81	0.26	–0.18	0.05	0.02	0.88
Soil organic matter	0.34	0.80	0.27	–0.18	0.04	0.01	0.86
Total nitrogen	0.15	0.67	–0.10	–0.04	0.16	0.28	0.58
Available phosphorus	0.07	0.42	0.58	–0.14	–0.12	0.11	0.56
Exchangeable potassium	0.20	0.26	0.77	0.14	0.06	–0.22	0.76
Exchangeable sodium	0.21	0.09	0.91	0.03	0.01	0.21	0.91
Exchangeable calcium	0.97	–0.01	0.00	–0.00	–0.06	0.04	0.94
Exchangeable magnesium	0.94	0.06	–0.06	0.02	0.05	0.14	0.92
Exchangeable acidity	0.06	–0.11	0.06	0.98	0.03	0.08	0.98
Cation exchange capacity	0.94	0.07	0.25	0.02	–0.00	0.09	0.95
Effective cation exchange capacity	0.54	–0.06	0.18	0.81	0.02	0.11	0.99
Base saturation	0.34	0.17	0.13	–0.89	–0.04	0.00	0.96
Exchangeable sodium percentage	–0.65	–0.08	0.66	–0.03	0.06	0.17	0.89
Bulk density	0.19	–0.57	–0.01	0.02	0.01	0.39	0.51
Sand	–0.16	0.12	0.02	0.02	0.95	–0.22	0.98
Silt	0.28	0.06	–0.00	0.11	–0.30	0.68	0.65
Clay	0.06	–0.16	–0.02	–0.06	–0.94	–0.05	0.93
Gravel	-0.16	–0.14	0.45	0.09	0.09	0.59	0.61

EC - extraction communality estimate

Meanwhile, at Ado-Ekiti site, Table 9 reveals the six factors that explained 78.81% cumulative sample variance, the first and most important factor, which explained 26.74% of the variation, had high factor loading (> 0.50) for six soil properties; Ex-Ca, Ex-Mg, CEC, ESP, ECEC and pH (0.97, 0.94, 0.94, –0.65, 0.54 and 0.52, respectively). Factor 2 had high loading from SOC, SOM, depth, TN and BD (0.81, 0.80, –0.79, 0.67 and –0.57, respectively), they collectively explained 17.31% of the sample variance. The variables with high factor loading under factor 3 include Ex-Na, Ex-K, ESP, and AP (0.91, 0.77, 0.66 and 0.58) explained 13.01% of the sample variance. The highly weighted variable under factor 4 was EA (0.98). For factor 5, sand content was selected being the highly weighted variable, which explained 6.49% and factor 6 had highest factor loading to be silt proportion (0.68). The highest factor loading in factor 1, Ex-Ca was selected. The SOC concentration was selected to represent factor 2 being the highest factor loading (0.81). Under factors 3, 4, 5 and 6; Ex-Na, EA, sand and silt contents with highest factor loading (0.91, 0.98, 0.95 and 0.68, respectively) were selected to represent factors 3, 4, 5 and 6 respectively. At Kabba and Ado-Ekiti sites, SOC, EA and Ex-Na were similar factors with high loading that were identified as potential determinants of SOC sequestration, while other potential determinants were not similar but related. They include CEC, clay content, land use and soil depth at Kabba site, and Ex-Ca, sand and silt contents at Ado-Ekiti site.

CONCLUSION

Generally, at both sites i.e., southern Guinea Savanna (Kabba) and Upland Rainforest (Ado-Ekiti) agro-ecological zones, SOC, EA and Ex-Na are similar factors with high loading that were identified as potential determinants of SOC stock, while others are Ex-Ca, soil texture (sand, silt and clay contents), land use and soil depth. Thus, for optimum SOC stock storage at the two agro-ecological zones under the different LUTs, land use management practices geared towards sustainable soil and crop management should be adopted. These include appropriate land development strategies, conservation tillage, crop rotation involving legumes, organic manures and biosolids, slash and char, agroforestry and irrigation for soil water management.

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