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Article

Land use effects on soil properties and carbon stocks of agricultural and agroforestry landscapes in a rainforest zone of Nigeria

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Abstract: This study examined the impacts of land use on the physical and chemical properties of soils of land use types along agroforestry and agricultural landscapes in a rainforest zone of Nigeria. The land use systems are forest, agroforestry, fallow, and ornamental plant fields in addition to permanent crop fields (cocoa, oil palm, and citrus) and annual crop fields (maize). Profile pits were dug on the land use types and samples were collected 0–20 cm and 20–50 cm for laboratory analysis. Soil samples were collected from undisturbed soil and profile pits for bulk density and moisture content determination following standard analytical procedures. Among the land use types, physical properties (sand, clay, soil bulk density) and chemical properties (soil pH, SOC, total N, P, K, Ca, Mg, and CEC) differed significantly. Bulk density, pH, SOC, total, and stocks of SOC and N differed statistically for 0–20 and 20–50 cm soil depths with downward increases in N and SOC stocks along sampling depth. Permanent croplands (forest and agroforestry fields) had higher soil pH, SOC, total N, and CEC, while arable crop fields had relatively lower pH, SOC, TN, P, K, Ca, Mg, and CEC. Arable fields had significantly lower C and N stocks within 50 cm compared with permanent crop fields, which may be attributed to continuous tillage by the smallholder farmers and soil erosion-enhanced SOC and N removal from top soil. For both permanent and annual crop fields, SOC and total N stocks ranged from 5.75 to 3.12 kg/m^2 for 0–20 cm depths and 2.44 to 1.93 kg/m^2 for deeper (20–50 cm) layers. Relative to forest soil, stocks of SOC in the surface soils (0–20 cm) decreased in the order: agroforestry > ornamental plant field > cocoa > fallow land > citrus > oil palm > annual cropping system. Following this decreasing order, soil deterioration indices are equivalent to 27% > 28% > 30% > 31% > 32% > 34% > 38% compared with forest soil, respectively. Strong significant correlations ($p < 0.05$) were observed between SOC and TN stocks and some soil properties (bulk density, clay contents, pH, and CEC) with R^2 values ranging from 1.0 to 0.85. It is concluded that the soil's physical and chemical properties and carbon storage potential differed among the land uses of the study site.

Keywords: land use; vegetation cover; biogeochemistry; degradation; ecosystem; rainforest; sustainability

1. Introduction

Agriculture is a major source of food, raw materials for industries and livelihoods, and overall economic development of Sub-Saharan Africa (SSA). In Nigeria, agriculture contributes about 30% of the GDP to the economy, offers employment for up to 70% of the labor force, contributes over 70% of non-oil exports, and provides over 80% of the food requirements for citizens [1,2]. Of the over 98 million hectares of land, about 74 million hectares is useful for agriculture [2,3]. Cultivated lands occupy 45% of the land area, of which 37.3% and 7.4% are cultivated to arable and permanent crops, forest cover occupies 10%, and 13% is for other land uses [2,4].

In West Africa, land use types are mostly forest, agroforestry, fallow, permanent (plantation) and arable crop cultivation and grazing lands especially by smallholder farmers. Land use and management practices have influence on physical, chemical and biological properties of soils [5–8]. Such influence may be attributed to anthropogenic activities such as tillage, livestock trampling, harvesting, planting, application of agrochemicals. Thus, land use produces changes in soil properties, climate, and socio-economic opportunities [6,8]. Land use systems impact temporal and spatial variations of soil processes with consequences on the distribution of water, sediments and organic materials in the soil [9–11] and organic matter stabilization [12–14]. Changes in land use and land cover transform landscapes and alter ecosystem processes (nutrient cycling, water use, evaporation, evapotranspiration and heat) and microclimate. Literature reports that ecosystem processes of carbon, water balance and energy fluxes in landscapes can change or affect land use, land cover, and vegetation dynamics [15–17]. Land use and agricultural practices impact the environment including biogeochemical processes and climate modifications [17–19]. Land use and management practices have potential to resolve adaptation challenges to climate change and variability of weather through provision of ecosystem services and functions. Knowledge of land use effects on vegetation cover and biogeochemistry of landscapes is important to design practices to promote sustainability of ecosystems, improve performance of agriculture and strategy for climate change mitigation (adaptation and resilience building). There is inadequate information from the rainforest agroecology, the influence of land use practices (agroforestry, fallowing, plantation and arable/annual cropping) on vegetation land cover along agricultural and agroforestry landscapes. The continual evaluation of dynamics of soil properties under different management practices will foster the development of strategies for improving soil and crop productivity and sustainability.

Land is an important natural resource and a spatial carrier of human socio-economic activities. The activities have implications for ecosystem functions and services [20,21]. Land use and associated changes in soil and ecosystem properties and functions reflect the impact of human activities on the natural environment and the modification of surface structure (i.e., water bodies, climate, and ecology) and ecosystem services [22,23]. There is growing concerns for environment degradation by human activity including land use and the quality of life of citizens. Therefore, it becoming increasing important to continuously monitor and assess land use changes and associated effects on ecosystem services. This exercise is crucial to sustainable planning, management of soil and vegetation resources and to avert accelerated degradation of the environment [21]. Sustainable land use planning and management is fundamental instrument for socioeconomic development. It fosters prosperity of the people and nation, especially, the quality of life of local inhabitants and can arrest social imbalances and spatial inequalities [22,24]. Sustainable land use planning may positively impact the environment by preserving natural resources, enhancing ecosystem resilience [22,25]. Unsustainable land use practices result in the destruction of natural resources, reduced quality of life of local population as well as climate resilience. The role of policy and regulatory frameworks to development of strategies and approaches for sustainable ecosystem cannot be over emphasized. Poorly developed and implemented policy would lead to unsustainable use and management of natural resources, changes in natural land surfaces and ecosystem structure, function and services.

Various studies had highlighted the capacities of tropical soils to store carbon and nitrogen, the potentials of rainforest soils for carbon sink and sequestration under various land use systems are poorly reported [19,22,26]. Information is also limited from the rainforest agroecology with respect to the influence of land use practices (agroforestry, fallowing, plantation and arable/annual cropping) on vegetation cover patterns, soil physical and chemical properties, stocks of soil N and organic carbon and fertility deterioration along agricultural and agroforestry landscapes from the rainforest zone of Nigeria.

Studies on changing dynamics of land use systems will provide information important to guide decision makers to factor in such changes for developing strategies and approaches to attain sustainable ecosystem [27,28], and to evaluate the footprint of human activities on ecosystem services and function [21,24]. Such information is paramount to the design of sustainable strategies and planning for ecosystem management [21,23].

The objectives of the present study are to evaluate the effects of land use and vegetation cover patterns on soil properties, stocks of soil N and organic carbon and fertility deterioration of agricultural and agroforestry landscapes in the rainforest zone of Nigeria. The study provided information on the changes in soil properties under some widely practiced smallholder land use and management practice in the rainforest zone of Nigeria. The findings will foster development of strategies for improving soil and crop productivity, ecosystem sustainability and potentials and relevance of land use practices to resolve adaptation challenges to climate change.

2. Materials and Methods

2.1. Site of study and conditions

The site of study, Akure, a rainforest zone of southern Nigeria, is geo-referenced on 734393 E, 808614 N coordinate lines, western flank of meridians. **Figure 1** presents the research methodology chart while **Figure 2** is the map of Nigeria showing Ondo State and experiment site as insert.

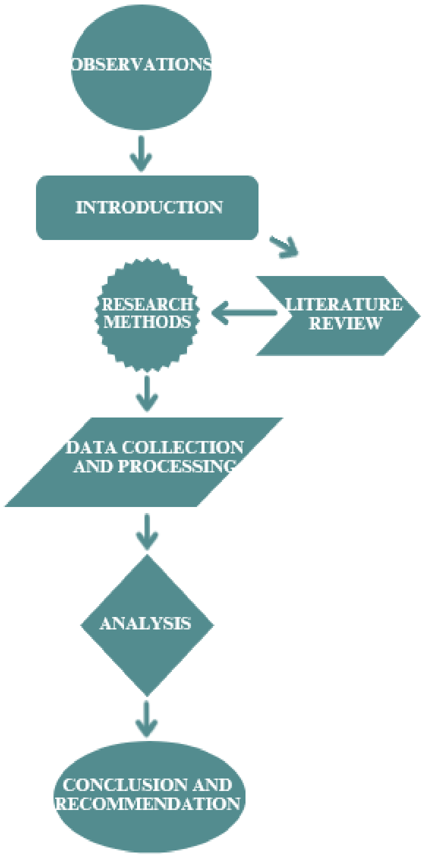

Figure 1. Research methodology chart.

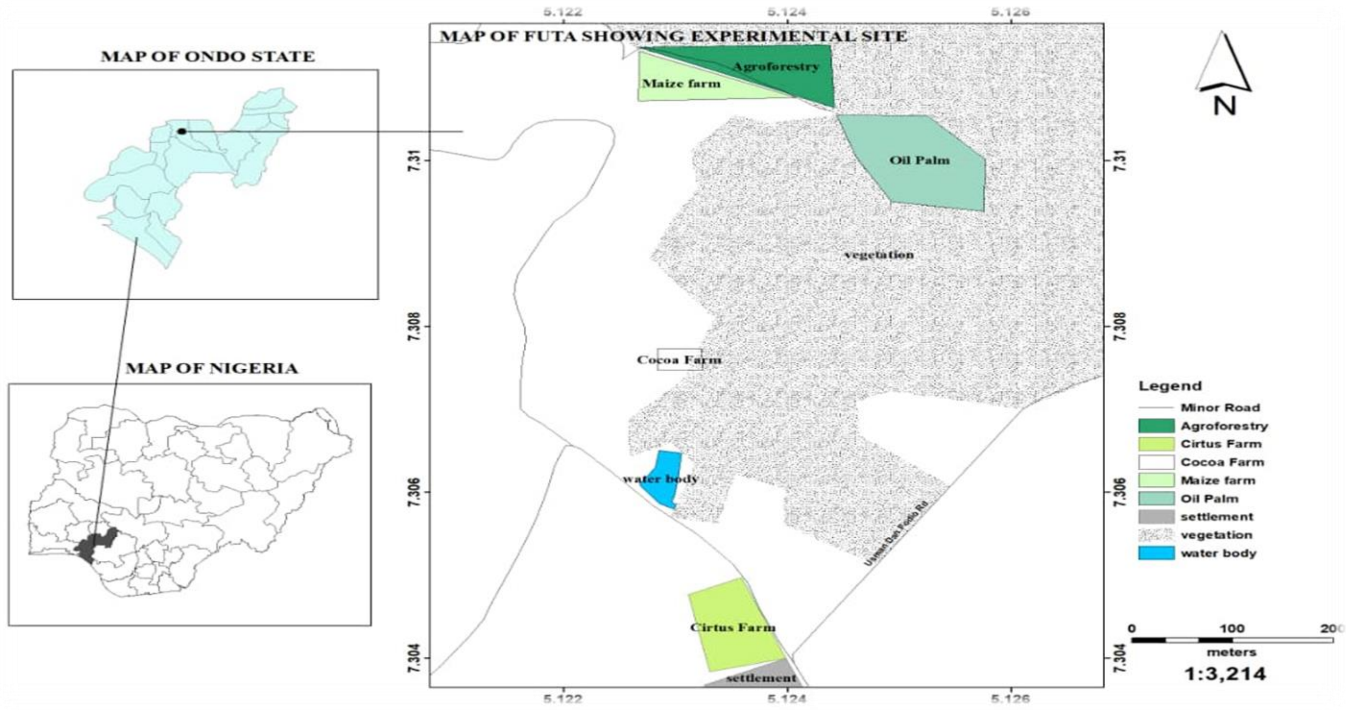

Figure 2. Map of Nigeria showing Ondo State and experiment site as insert.

In the study site, land use systems constituted by forest, agroforestry, fallow and ornamental plant field in addition to permanent crop fields constituted by cocoa, oil palm and citrus and annual crop (arable crop: maize) field were evaluated for impacts on soil texture, bulk density, pH, CEC, stocks of SOC and total N.

2.2. Soil analysis

Soil profile pits were dug on the land use types from which samples were collected at two depths (0 to 20 and 20–50 cm) for physical and chemical analysis. Soil sample were collected by drill insertion of core samplers into walls of pits. Samples were collected from the lowest point followed by top in order to reduce contamination of the two layers. Approximately, 1 kg of sample was collected from each soil depth, air-dried at room temperature, sieved (2 mm and 0.5 mm sieves) and subjected to laboratory analyses

Total nitrogen was determined by Kjeldahl method [29] and available phosphorus using Olsen et al. [30] method from sample extracts using 0.5 M sodium bicarbonate extraction solution (pH: 8.5). Exchangeable cations (K^+, Ca^{2+}, Mg^{2+} and Na^+) were determined from sample extracts using 1 M ammonium acetate at pH (7.0) and cation exchange capacity (CEC) from ammonium acetate saturated extracts. The exchangeable cations (Ca^{2+} and Mg^{2+}) were determined using atomic absorption spectrophotometry (AAS) while K^+ and Na^+ were determined by flame photometer. Soil pH was measured using a glass pH meter in supernatant solution of 1:2.5 soil to water solution. Soil organic carbon was determined following the wet oxidation method of Walkley and Black [31]. Particle size distribution was determined by hydrometer method. Soil water content was determined by the gravimetry method after oven drying to a constant weight at 105 ℃. Bulk density and moisture contents of soil were determined from undisturbed soil samples from soil 0–20 and 20–50 cm depths and calculated as the ratio of weight of oven-dried soil and volume of corer. Soil hydrological properties were calculated using soil water characteristic equations derived by Saxton et al. [32] modified by Saxton and Rawls [33]. The variables of soil texture and soil organic matter were deployed based on the relationships of tension and conductivity using the predictive system of soil water characteristics for agricultural water management and hydrologic analyses [32]. The program based on graphical computerized model of predictive system for rapid solutions was adopted (http://hydrolab.arsusda.gov/soilwater/Index.htm).

2.2.1. Soil organic carbon stocks

Soil carbon stocks of the land use types were calculated following method of Wairiu and Lal [34].

$$\text{Carbon stock (kg} \cdot \text{m}-2) = [\%\ C \times BD \times \text{Depth (m)} \times 10\ 4\ m^2\ ha^{-1}] / 100 \tag{1}$$

where BD is bulk density (g/cm^3) of each sample depth, percentage C is Walkley-Black carbon. Subsequently, SOC and TN contents were summed to determine total SOC and TN stocks for the land use types.

Carbon to nitrogen ratio (C:N) was calculated using the formula:

$$\text{C:N ratio} = \text{SOC (\%)} \times \text{TN (\%)} \tag{2}$$

where C:N is the ratio of carbon to nitrogen, SOC is concentration of carbon (%) in the soil and TN is the concentration of total nitrogen (%) in the sample.

Bulk density, the density of the fine soil component is calculated as:

$$\text{Bulk density} = \frac{\text{Bulk mass (g)} - \text{coarse fragment (g)}}{\text{Bulk soil volume (cm}^3\text{)} - \text{coarse fragment volume (cm}^3\text{)}} \quad (3)$$

2.2.2. Soil deterioration index (SDI)

Soil deterioration indices were calculated on the assumption that the status of individual soil properties under a particular land use types (permanent crop fields, agroforestry fallow, and cropland) were once the same as adjacent soils under natural forest before conversion to present land uses. Differences in mean values of soil properties of the land use types were compared with values under well-stocked natural forest taken as 100%. Soil deterioration index (SDI) was thus computed as percentage of the means of individual soil properties under the land uses. Thus, soil deterioration index of the land uses was determined following the method of Adejuwon and Ekanade [35].

$$\text{SDI (\%)} = [P_{\text{SL}} - P_{\text{RL}}] \times 100 \quad (4)$$

where P_{SL} is mean value of individual soil property (P) under specific land use (SL), P_{RL} is the mean value of individual soil property (P) under reference land use (RL). The cumulative sum obtained is the SDI for the identified land-use types. The higher the total value, the better the soil quality and/or health of for a particular land-use system.

2.3. Statistical analysis

Data collected on soil physical and chemical properties and carbon and total N stocks of the land use types were subjected to analysis of variance (ANOVA) test while significant treatment means were separated for pair wise comparison using Tukey Honestly Significance Difference (THD) test at 5% level of probability. Pearson correlation coefficient was used to test the relationship among soil properties of the land use types (clay, bulk density, pH, SOC and TN).

3. Results

3.1. Effect of land use on soil physical and hydrologic properties

The land use type affected particle size classes (Sand, Clay and Silt), the textural class is generally sandy-clay-loam (**Table 1**). Cocoa field had the highest sand percentage, followed by oil palm, maize, ornamental plant field, agroforestry, citrus and fallow land. Bulk density range around 1.40 to 1.47 while lowest values were found for permanent crop fields and values were recorded for MF and OPF. Soil porosity values above 50% were found for OPF and MF and approximately 50% for most others. The highest porosity was recorded for oil palm followed by citrus, cocoa, agroforestry, fallow land and maize. Porosity values would have followed from soil compaction indicated by bulk density (**Table 2**). Field capacity (Fc) moisture was highest for oil palm followed by Maize, Ornamental, citrus, Cassava and Cocoa and agroforestry while the least values was obtained for fallow. High field capacity (FC) water content (0.47) was recorded for OPF closely followed by MF land use (0.36). lower values ranging between 0.22 and 0.27 were recorded for other land use types.

Permanent wilting point (PWP) was highest for oil palm followed by Maize, Citrus, Cassava, Cocoa, Agroforest and fallow fields. Permanent wilting percentage of the soil under the land use types range between 0.13 to 0.34. highest value was obtained for oil palm followed by maize with lowest under agroforestry (**Table 2**). Plant available water (AW) value was lowest for forested and agroforestry and oil palm and values were close for other land use types. The permanent crop fields had lower bulk density values compared with arable crop field in addition to hydraulic conductivity which had implications for PWP and FC moisture contents and thus plant available water contents of the land use types (**Figure 3**). Hydraulic conductivity (Ks) values was highest for fallow land followed by agroforestry, Cocoa, Citrus, Ornamental, Oil palm and Maize field respectively. The available water (AW) in soil was highest for Oil palm followed by ornamental plant field, Agroforestry, Maize, Cocoa and Citrus field (**Figure 3**). Highest values of hydraulic conductivity (indicator of soil water transmission property) above 70% were for four of the land use types and lowest for MF and OF (less than 30%).

Table 1. Soil physical properties of land use types.

Land use	Sand (%)	Clay (%)	Silt (%)	Textural Class
GFF	16.80	63.20	20.00	Clay loam
OPF	56.80	27.20	16.00	Sandy clay loam
CF	58.00	27.00	15.00	Sandy clay loam
CTF	52.20	27.80	20.00	Sandy clay loam
AF	54.80	25.20	20.00	Sandy clay loam
MF	36.80	43.20	20.00	Clay loam
CSF	56.80	27.20	16.00	Sandy clay loam
OF	56.80	27.20	16.00	Sandy clay loam

Note: GFF: Grass fallow; OPF: oil palm; CF: cocoa; CTF: citrus; AGF: agroforestry; MF: maize; CSF: cassava; OF: ornamental plant field.

Table 2. Soil hydrological properties of the land use classes.

Soil hydrological properties						
Land Uses	**Porosity**	**PWP**	**FC**	**Ks**	**AW**	**BD**
CTF	0.469	0.150	0.257	0.563	0.107	1.407
CF	0.461	0.136	0.245	0.786	0.109	1.430
MF	0.512	0.244	0.355	0.163	0.111	1.294
OPF	0.542	0.337	0.469	0.226	0.132	1.215
AF	0.460	0.131	0.244	0.836	0.113	1.432
GFF	0.446	0.127	0.220	0.937	0.094	1.470
CSF	0.465	0.135	0.251	0.727	0.117	1.418
OF	0.476	0.155	0.267	0.458	0.112	1.389
LSD (0.05)	0.053	0.013	0.008	0.035	0.003	0.026

Note: GFF: Grass fallow; OPF: oil palm; CF cocoa; CTF: citrus; AGF: agroforestry; MF: maize; CSF: cassava; OF: ornamental plant field.

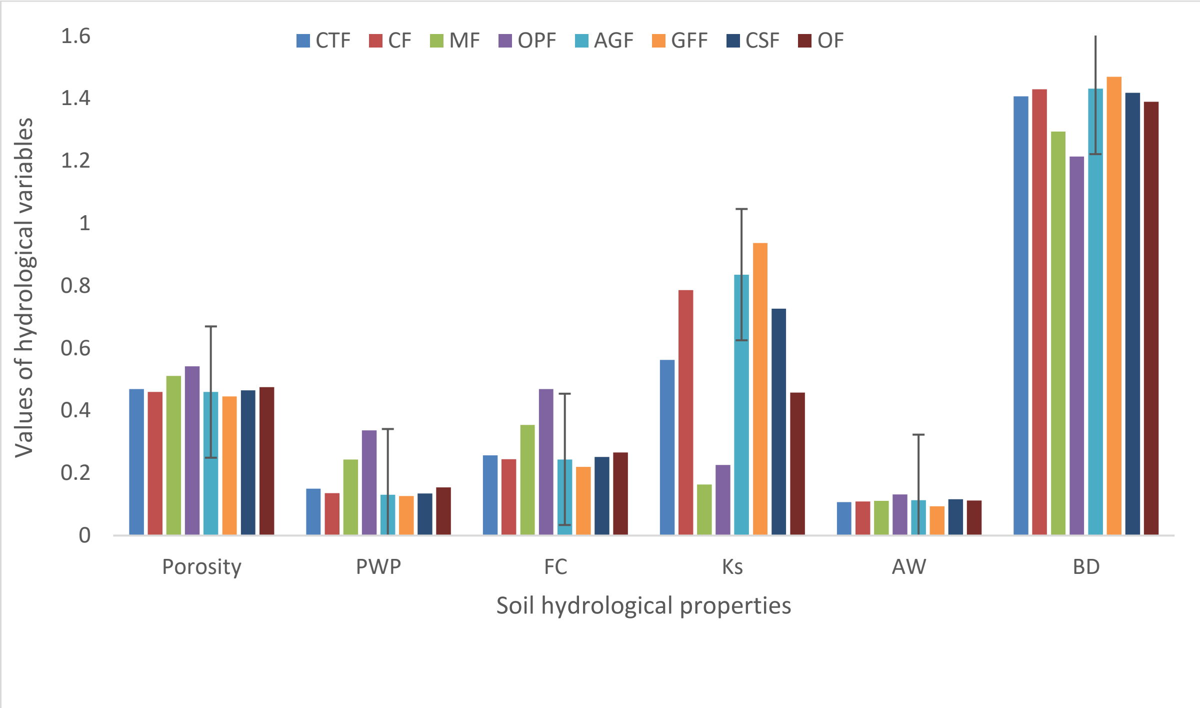

Figure 3. Hydrological properties of soils of the land use types. PWP (permanent wilting percentage), FC (field capacity moisture), KS (hydraulic conductivity), AW (available water), BD (bulk density).

3.2. Effect of land use on soil chemical properties

The differences among the land uses for soil pH were not significant ($P \geq 0.05$) although highest soil pH value was recorded for ornamental plant field followed by cocoa, agroforestry, maize, citrus, cocoa and oil palm fields respectively while the least mean value was recorded for grass fallow (**Table 3**). Among the land use types, total N was highest for Citrus followed by Ornamental, Maize, Cocoa field, Agroforestry, Cassava and Oil palm fields had the least N value. The highest value of K was recorded on Ornamental field followed by Maize, Grass fallow, Cassava, Citrus, Cocoa and Agroforestry respectively while the least mean value was recorded on Oil palm tree (**Table 3**). The highest *P* value was recorded on Citrus followed by Agroforestry, Ornamental, Maize and cassava, Cocoa and oil palm field respectively while the least mean value was recorded on grass fallowed field. Cocoa field had highest Ca followed by Citrus field, Ornamental field, Grass fallowed field, Maize field, Agroforestry and Cassava field respectively. Oil palm field had the least mean value (**Table 3**). Cocoa field also had highest Mg in soil followed by Citrus field, Agroforestry, Grass fallowed field, Ornamental field, Maize field and Citrus field respectively. However, Citrus field had highest value, followed by Cocoa field, Maize field, Grass fallow, Cassava field, Ornamental and Agroforestry plots respectively while the least mean value was recorded on Oil palm field (**Table 3**) Soil pH differed significantly among land use types, soil pH were highest for OF, CSF MF and AF and lowest values for GFF and close values for OPF and CF. soil organic matter (SOM) values also differed significantly among land use types. CTF, MF. And OF recorded highest SOM whereas lowest values were found for OPF and CF. Similar trends was observed for SOM, total N in soils differed among land use types. CTF recorded highest values followed by OF, MF and CF while lowest were found for GFF and OPF. The records of soil K values differed from those of SOM, significantly higher K was obtained for OF, values were close for CF, CTF and AF and lowest for oil palm field. Total P in soil were differed significantly. Significantly higher values were recorded for cocoa, agroforestry and oil palm which had close values while lowest soil P were found for oil palm field. Calcium contents of soil under the land use types differed, CF and CTF were not different, OF, GFF and MF which were not different while lowest Ca values were recorded for OPF and CSF. Soil contents of Mg differed among land uses, CF and CTF were not different in values and lowest were recorded for oil palm. Highest CEC values were found for CTF while values were close for agroforestry, cocoa and maize fields (**Table 3**).

The effect of season was significant on chemical properties of the land uses. In the rainy season, pH of soil under the land uses was lower significantly compare with values for the dry season. SOM follow the observations on soil pH for the seasons while values for soil N, K and P, Ca and Mg and CEC occurred in contrast to those of soil pH and SOM, the rainy season recorded higher values compare with the dry season for these nutrient elements. Soil pH, OC, SOM and total N were higher in values for permanent cultivation compared to arable (annual crop) fields. however, soil K was higher for arable fields. Other measured chemical variables had higher values for permanent cultivation.

Table 3. Chemical properties of soils of land use types.

Chemical properties										
Land use	**pH (1:2 in $H_2$0)**	**OC (%)**	**OM (%)**	**N (%)**	**K (cmol/kg)**	**P (mg/kg)**	**Na (cmol/kg)**	**Ca (cmol/kg)**	**Mg (cmol/kg)**	**CEC (cmol/kg)**
GFF	5.296[a]	0.94[a]	1.632[a]	0.182[a]	0.556[a]	8.680[a]	0.411[a]	3.650[a]	1.381[a]	8.999[a]
OPF	5.471[a]	1.04[a]	1.805[a]	0.232[a]	0.343[a]	9.240[a]	0.4219[a]	3.004[a]	1.098[a]	8.189[a]
CF	5.453[a]	1.52[a]	2.627[a]	0.385[a]	0.448[a]	10.090[a]	0.430[a]	3.892[a]	1.618[a]	9.848[a]
CTF	5.504[a]	1.79[a]	3.094[a]	0.472[a]	0.487[a]	12.440[a]	0.455[a]	3.813[a]	1.532[a]	12.260[a]
AF	5.738[a]	1.54[a]	2.671[a]	0.346[a]	0.445[a]	12.090[a]	0.441[a]	3.417[a]	1.415[a]	8.840[a]
MF	5.672[a]	1.68[a]	2.909[a]	0.407[a]	0.604[a]	11.069[a]	0.539[a]	3.621[a]	1.249[a]	9.522[a]
CSF	5.812[a]	1.58[a]	2.729[a]	0.308[a]	0.518[a]	10.530[a]	0.507[a]	3.242[a]	1.166[a]	8.921[a]
OF	5.886[a]	1.68[a]	2.906[a]	0.434[a]	0.671[a]	11.940[a]	0.513[a]	3.730[a]	1.332[a]	8.897[a]
LSD (0.05)	0.095	0.214	0.242	0.026	0.113	0.723	0.009	0.057	0.07	0.4268

Note: [a] Values bearing same letters along the column are not significantly different ($P < 0.05$).

3.3. Soil carbon and total nitrogen of land use types

Agroforestry recorded the highest SOC stocks followed by Maize, Oil palm, Citrus, Cocoa, fallow land and maize. Significantly higher SOC values were obtained for agroforestry, ornamental plant and oil palm fields compared with cocoa, citrus and fallow land. Maize field recorded significantly higher SOC compared with citrus, cocoa, cassava and grass fallow. Soil organic carbon values were higher significantly for agroforestry and oil palm while maize field recorded significantly higher value compared with citrus, cocoa, cassava and grass fallow. The stocks of SOC and total N differed significantly among land uses: forest based and permanent crop fields compared with the annual (maize) field and between 0–20 cm and 20–50 cm soil depths (**Table 4**). Between permanent and annual crop fields, the stocks of SOC and total N at 0–20 cm depth ranged from 5.75 to 3.12 kg/m^2 and 2.44 to 1.93 kg/m^2 for 20–50 cm depth (**Table 4a**). Trends in nitrogen stocks for the subsoil (20–50 cm depths) were similar to observations for 0–20 cm depth. The permanent land uses had highest total N stocks compared to annual crops and highest values were recorded for 0–20 compared with 20–50 cm soil. Forest, fallow land, agroforestry and permanent crop fields had highest stocks of organic carbon and total nitrogen compared with annual cropland (**Table 4b**).

Table 4a. Soil chemical properties at 20 and 20–50 cm depths of land use types.

Land uses	Soil depth (cm)	Soil organic carbon (%)	Carbon stocks (kg/m^2)	Total N (%)	Total N stocks (kg/m^2)	Soil pH (water)	Clay	Bulk density (g/cm^3)
Forest soil	0–20	2.33	8.14	0.28	8.51	6.53	28.4	1.20
	20–50	0.01	3.67	0.14	5.13	6.13	35.8	1.31
Fallow land (Grass spp. dominant)	0–20	1.07	6.12	0.16	7.22	5.62	33.2	1.28
	20–50	0.59	2.83	0.06	3.84	5.21	42.4	1.33
Oil palm	0–20	1.04	5.75	0.25	6.33	5.48	30.2	1.32
	20–50	0.56	2.44	0.12	3.05	5.11	41.5	1.43
Cocoa	0–20	0.93	4.25	0.12	6.53	5.53	30.3	1.30
	20–50	0.42	2.11	0.74	2.84	5.15	40.4	1.42
Citrus	0–20	0.95	4.46	0.15	6.71	5.51	37.1	1.33
	20–50	0.46	2.14	0.78	3.08	5.08	44.2	1.44
Agroforestry	0–20	1.73	6.52	0.18	7.91	5.74	31.3	1.29
	20–50	0.68	3.33	0.08	4.32	5.27	38.6	1.41
Crop land	0–20	1.21	3.12	0.10	4.13	5.45	34.3	1.37
	20–50	0.53	1.93	0.63	1.82	5.06	40.4	1.45
Ornamental field	0–20	1.71	6.44	0.19	8.12	5.89	32.2	1.33
	20–50	0.65	3.31	0.08	4.44	5.33	37.8	1.44

Table 4b. Soil properties of land use types (means of 0–20 and 20–50 cm depths).

Soil depth (cm)	SOC (%)	Carbon stocks (kg/m^2)	Total N (%)	Total N Stocks (kg/m^2)	Soil pH (water)	Clay	Silt	Sand	Bulk density (g/cm^3)
0–20	1.25	8.14	0.21	7.18	6.47	17.65	19.3	60.27	1.28
20–50	0.11	3.67	0.13	4.13	6.27	22.34	21.6	51.34	1.43

Regression analysis showed significantly strong correlations between SOC stocks and some soil physical (clay and bulk density) and chemical (pH and CEC) properties. Strong but negative relationship was obtained between bulk density and SOC (0.63; p = 0.05) while positive relationships between SOC and clay content, pH and CEC were positive and highly significant (**Table 5**).

Table 5. Correlation equations and coefficients of some soil physical and chemical properties.

Variables	Equations	r^2
SOC vs Clay	$y = 0.3689x - 9.1896$	0.92
SOC vs TN	$y = 0.8449x - 0.4857$	0.91
SOC vs CEC	$y = 1.9833x - 14.703$	0.92
SOC vs pH	$y = 5.5791x - 25.987$	0.95
TN vs pH	$y = 5.4477x - 24.086$	0.85
SOC vs BD	$y = -18.208x + 28.88$	0.50
TN vs BD	$y = 18.703x - 19.829$	0.41

3.4. Soil deterioration indices

Relative to forest soil, soil organic carbon stocks for surface soils (0–20 cm) decreased in the order: agroforestry > ornamental plant > cocoa > fallow land > citrus > oil palm > annual cropping system (**Table 4b**). Soil deterioration indices of were 0%, −27%, −28%, −30%, −31%, −32%, −34% and −38% for forest, agroforestry, ornamental plant, cocoa, fallow land, citrus, oil palm and maize crop fields. Hence, stock of SOC within 0 to 50 cm soil were 73%, 72%, 70%, 69%, 68%, 66% and 62% for the respective land use types (**Figure 4**).

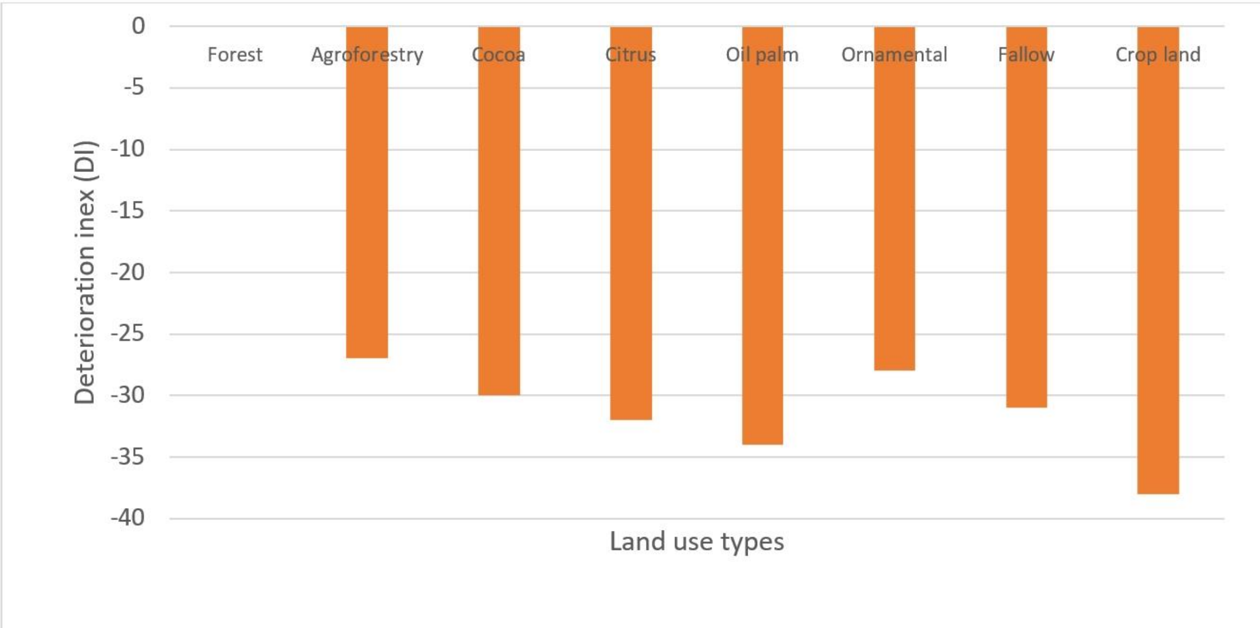

Figure 4. Deterioration Indices (0–20 cm) of land use types.

4. Discussion

4.1. Land use and soil physical properties

The analysis of particle sizes showed that soil of the land use types were predominantly sandy clay loam in texture. This result is consistent with those of Omotade and Alatise [36] and Agele et al. [37]. Soil texture is influenced by the parent material and topography from which the soil is derived. The soil of the study area is characterized by high sand fractions which can be attributed to the nature of parent material. The study area is characterized by high rainfall which is known to promote illuviation or leaching of soil particles (silt and clay particles) which might have contributed to the high sand fractions of soils of the land use types.

4.2. Land use and soil hydrological properties

Soil hydrological properties are parameters that determine soil quality and its capacity to sustain plant growth and ecosystem services [37]. The results showed that soil porosity differed among land use types, permanent crop fields had higher values compared with arable crop field. The observation supports the findings of Mefin and Mohammed [38], Theobald et al. [39] and Nnaji et al. [40]. Field capacity, available water, permanent wilting point and hydraulic conductivity were higher in values compare with the cultivated/agricultural land uses. These results confirmed the findings of Oguike and Onwuka [41] on permanent land uses which had higher soil moisture contents and hydraulic conductivity. Our results contradicted those of Mandel et al. [42] who reported that cultivated land uses were better in hydrological properties compared with forest, agroforestry and permanent crop fields. The contradictions can be attributed to differences in soil type and climatic conditions of sites of study. Bulk density of soils showed that the permanent land uses had lower values compared with annual crop field, observation that is consisted with those of Ryan et al. [43] who obtained lower bulk densities for soils of forest and agroforestry compared with annual (arable) crop field. Management practices of the land use types differed and can explain differences in bulk density, total porosity and moisture contents of the soils [44].

Soil hydrological properties are important parameters that determine soil quality and function within the ecosystem [37]. The higher values of hydraulic conductivity (K) recorded for permanent land uses can be linked to lower disturbance, improved soil structure (high microporosity), organic matter contents as well as microbial activities [45]. High microporosity is known for ability to improve hydraulic conductivity (K); lower k value for arable crop field may be due to the loose, less coherent nature of soil caused by disturbance during land/seedbed preparation [46,47]. However, Mander and Meyer [48] reported that cultivated land had better hydrological properties compared to agroforestry and crop-based permanent land uses.

Bulk density is an indicator of soil compaction. Kakaire et al. [49] reported the influence of bulk density on soil water infiltration ad water holding/retention properties. The bulk density of soil of forest, agroforestry and crop-based permanent land uses were lower compared with annual crop field. Ryan et al. [43] obtained lower bulk density for forested soils compared with crop land. High bulk density of soil under arable land use can be attributed to compaction from tractorization activities due to machinery heavy weight [45]. In addition, crop cultivation exposes surface soil to agents of erosion which promote washing away and removal of fine soil particles [46,47]. Agricultural activities differ on the land uses and may explain the observations on soil moisture, porosity and bulk density. In addition, crop cultivation exposes surface soil to agents of erosion which promote washing away and removal of fine soil particles [50,51]. Agricultural activities differ on the land uses and may explain the observations on soil moisture, porosity and bulk density. Bulk density values among the land use types were not above 1.63 g/cm^{-3} and such value would not constitute severe hindrance to root penetration, seed germination and plant growth [49–51] It is therefore important to report that soil under more stable permanent land uses such as agroforestry, cocoa and oil palm fields have good properties which can be adduced to minimal disturbance and higher soil organic carbon [52–54]. The significantly higher bulk density of soil of annual crop field compared to forest, and permanent crop-based land uses may stem from intensities of ploughing plus harrowing/ridging and raindrop-enhanced soil water erosion [51]. Bulk density values were higher in subsoils compared to the topsoil of the land uses. The redistribution of soil carbon during tillage operation and increased soil evaporation from arable crop land may produce upward movement of dissolved inorganic C from the subsoil to the surface soil [55,56]. Bulk density of soils has influence on other physical properties and processes such as soil-water dynamics, aeration, mechanical resistance to root growth and development.

4.3. Chemical properties of soils of land uses

Land use types especially agroforestry, cocoa. citrus and oil palm including fallow land, had higher values of soil pH, exchangeable bases and CEC compared with arable land use. This can be attributed to differences in soil water erosion, litter retention, biological population and activities. Smallholder farmers in the study area commonly use fertilizers (including livestock manure and plant residues, domestic wastes (ash from firewood and bush burning) and other biodegradable materials. Ash serves as liming material and thus, the high soil pH recorded in arable crop field and the enhanced exchangeable bases of this land use. Soil pH values across the land uses for this study showed that the soil is slightly acidic. This result agreed with the findings of Olubanjo and Ayoola [57] reported soil pH of soils of the study area range from 5.65 and 5.72. Hassan et al. [58] reported that favorable pH enhances availability of nutrients in the soil. Soil pH for most crops lies within 6.0 and 7.0 within which nutrient availability in soil is enhanced. This result showed that the study area was fairly suitable for plant growth as the pH values fall around the optimum value of 6.0. The organic matter of soils of the land use types differed This result confirmed the findings of Olubanjo and Ayoola [57]. The organic matter of the study site varied from 2.88% to 3.97%. The cultivated crop fields tend to produce lower organic matter compare to permanent crop land uses an observation also conformed to those of Biernbaum [59] that the organic matter of loam soil ranges from 1% (low) to average of 2% to 4%. Kazilkaya [60] and Panwar et al. [61] opined that organic matter modifies water retention capacity and other physical properties which contribute to carbon accretion into soil pool.

Nitrogen, phosphorus, potassium, calcium and cation-exchange capacity did not differ significantly among the land use types. This observation agreed with the findings of Biernbaum [59] and Akintokun and Owoeye [62] that soil chemical properties of soil cultivated for arable crop production are lower than under permanent land uses. The land use types had undergone different practices involving engagement of tractorized operations for tillage, sowing and agrochemical application. White [63] and Haddaway et al. [64] reported the effects of such activities on the mineralization of organic materials in the soil. Citrus field had highest value of organic matter, N and

P in addition to high cation exchange capacity compared with other permanent land uses. The high contents of nutrient elements of citrus soil can be adduced to the abundance of elephant grass (*Pennisetum purpureum* Schum.) on the field. Elephant grass has been known for soil erosion prevention and enhancement of soil fertility [65,66]. Results showed that soil acidity is higher in dry season than the wet season which would influence soil nutrients availability for crop use [67,68]. The seasons differed in soil nutrient status: higher nutrient availability was found for wet season compared with dry season. This observation conforms with those of Guizani et al. [69] that rain remove significant amount of salts that accumulate in the soil during previous cultivation period from the soil. Hence the low nutrient status of soils during the rainy season (leaching losses). From this study, it is observed that permanent land uses recorded higher values of the essential nutrient elements for plant growth enhancement compared with arable crop field [70–72].

4.4. Land use and stocks of soil organic carbon and nitrogen

The use types differed in stocks of SOC and total N. Agroforestry and oil palm fields had highest SOC stock. Oladoye et al. [73] reported that forest soil had high carbon stocks and will thus sequester higher carbon compared with than other land uses especially arable crop land. However, Nyawira et al. [74] reported high SOC stocks of land use with good soil management such as reduced or no tillage soil management. The permanent crop lands (cocoa, citrus, oil palm) including agroforestry ecosystem are associated with high biodiversity and ability to sequester carbon in the soil than frequently cultivated (arable crops) crop lands [75]. The mechanisms of SOC stabilization appear to differ among land uses an observation attributable to soil and crop management intensity. Soil management practices is significant to SOC dynamics and global carbon [76].

Soil organic carbon (SOC) stocks were obtained from the product of organic carbon concentration (g/kg) and soil bulk density [77]. The land uses differed in SOC stocks: agroforestry and oil palm fields had highest SOC stock. Oladoye et al. [73] reported that forest land soil sequester higher carbon than other land use. Nyawira et al. [74] opined that SOC stocks can be increased for agricultural land uses with good soil management such as reduced/minimum or no tillage soil management practice. Maize field from this study had high SOC stocks not significantly different from other land uses. This can be attributed to soil management practiced over the years [78,79]. Agroforestry is an example of ecosystem with high biodiversity has ability to sequester more carbon in the soil than those with reduced biodiversity [73]. Therefore, understanding mechanisms of SOC build up of land uses and management intensity adopted are relevant for understanding their carbon sequestration and contributions to global C cycle [76]. Forest and permanent crop fields had significantly higher stocks of SOC and total nitrogen compared with annual crop field. Soil carbon concentration influences the retention of nutrients, buffer pH, microbial activity, structure (formation of micro-aggregate and water infiltration and retention. Higher litter accumulation promotes build up in permanent crop fields which can be attributed to high above and below-ground biomass (root biomass) and lower litter breakdown (decomposition) rate [80–82]. Tillage enhance oxidation of organic materials and expose surface soil exposure increases water erosion and washing away of nutrients including organic matter, this can explain the low SOC and total N in arable crop field. In addition, the susceptibility of micro-aggregate held organic carbon to microbial degradation due to seasonal shift in moisture and temperature regimes would have promoted SOC loss on arable lands. In the forest, the favorable micro-climate would have enhanced nutrient transformation and accelerated decomposition of organic matter. Delegan et al. [82] reported that fine root biomass from forest and crops are primary source of carbon and nitrogen to soil making huge contributions to the stocks of SOC and total N. High plant root and shoot biomass turnover and decomposition by soil microbes and exudates from mycorrhizal fungi in the rhizosphere of forest ecosystem is known [82,83]. This process contributes to nutrient build-up in soils in forest and permanent crop fields.

The SOC and total N stocks in the topsoil of the land use types (forest, permanent and annual croplands) decreased with depth. The larger N stock in forest and permanent crop fields can be adduced to deep root systems of tree crops which may promote porosity and nutrient transfer processes in soil [82,83]. The differences observed for stocks of SOC and total N of the land uses may be attributed to the length of fallow [17,84,85]. Soil organic carbon plays important for provision of ecosystem services such as carbon sequestration, climate regulation, nutrient cycling, and provision food, fiber, fuel, and water [85]. The stabilization of stocks of SOC and TN in landscapes is affected by land use, geographical area, climate and dominant vegetation composition [86,87]. Factors such as climate and vegetation are important soil-forming factors influencing C and N storage in agroecologies [88]. The high stocks of SOC and total N for forest and permanent crop lands compared with annual (arable) cropland can be attributed to high litter decomposition, and carbon turnover which may serve as carbon sinks

4.5. Relations of land use, SOC and total nitrogen concentration and stocks

The relations between SOC stocks and soil physical (clay and bulk density) and chemical (pH and CEC) properties were negative (bulk density and SOC, total N concentrations and stocks with bulk density) and positive (SOC and clay content, pH and CEC). These relationships indicated the influence of bulk density on high clay content and SOC accumulation [89]. These observations are consistent with the findings of Tsui et al. [86], Yu et al. [89] and Seifu et al. [90]. These authors opined that bulk density enhanced soil compaction is detrimental to SOC and soil organic matter accretion. Bulk density promotes reduction in soil water infiltration and drainage capacity consequent causing aeration-related challenges in soil.

4.6. Soil deterioration index (SDI)

The land uses influenced soil quality properties (physical and chemical) which deteriorated more for arable crop field compared with forest and permanent crop lands in particular, the. degradation of SOC and TN stocks and essential nutrients. Soil deterioration index (SDI) values for the land use types compared with forest soil showed net degradation of soil C and N stocks. Low SDI observed from annual cropland compared to permanent cropping systems affirmed that most smallholder farmers practice results in soil quality degradation [90,91]. Land use change alters the stocks of vegetation biomass and plant species diversity with consequences on input of organic residues and hence soil SOC stock and carbon storage potential [92]. Land use differ in potential to sequester and/or capture atmospheric carbon. Carbon sequestration is important for climate mitigation in the long term [17,73]. Adoption of sustainable land use practices especially incorporating climate-smart options can enhance the potential of smallholder land use systems to sequester carbon, and reduce emissions to the atmosphere [93]. Adoption of sustainable land use practices will enhance smallholder farmers' adaptation capacity in the frame of climate change. Such practices may include soil re-carbonization (enhancing soils capacity for carbon storage) using restoration strategies to reintegrate smallholder agricultural activities into the global produce and carbon market [2,3]and for policymakers at local, national and international levels.

5. Conclusions

The effects of land use and associated changes in vegetation and biogeochemistry were analyzed in a rainforest zone of southern Nigeria and the results discussed in relation to similar works with respect to land use changes, patterns and trends of vegetation cover from other parts of the world. There were differences between the permanent land use types (forest land, agroforestry, fallow land, cocoa, citrus, oil palm, ornamental plant field) and arable (annual) crop fields for soil organic matter, available nitrogen, bulk density and clay content. Among the land use types, differences were found for values of SOC, total N, P, K, Ca, Mg. Soil pH was highest for forest and permanent crop fields and the soils under forest and permanent crop fields had higher SOC, total nitrogen, available P, carbon and nitrogen stock compared to annual crop field. Soil organic carbon and total nitrogen contents of the land use types differed within soil depths: higher values of soil organic carbon and total nitrogen contents and stocks were found for upper soil layers (0–20 cm) compared with 20–50 cm depths. Generally, the permanent land use systems (agroforestry and permanent crop lands) had more favorable soil biophysical and chemical properties, while annual (arable) crop field had degraded the soil physical and chemical properties. Decreasing order of SOC and total N stocks were: forest > agroforestry > fallow > ornamental plant field > cocoa, citrus > oil palm > maize field. Lower SOC and TN were found for maize field indicate soil fertility depletion, whereas compared with higher soil nutrients and stocks of SOC and total nitrogen under forest and permanent land use types which suggests relevance of these land use types for addressing soil nutrient depletion and carbon storage in soil.

Strategies for restoration of degraded lands or avert trends of soil degradation may benefit from findings from this study. The low input continuous cultivation of annual crops (such as maize), would require soil conservation and fertility management measures to address the trends of soil degradation and nutrient depletion. Practices for mitigating loss of nutrients and degradation of soil properties under continuous annual cropping may include crop residues retention, manure use, crop rotation. These practices would enhance soil pH, SOC and N stocks and carbon sequestration. The carbon stocks of the land uses can be traded in the frame of carbon markets for ecosystem services, for additional income and incentives to resource-poor farmers to invest in sustainable soil management. Trends obtained for carbon stocks of land uses can serve as baseline for establishing large-scale inventory of SOC for while the carbon sequestration potentials of forest-based land use systems can serve as useful input for emission reduction targets for Nigeria.

The study advance understanding of the interplay of human activities and environment which has important implications for land use decisions and sustainability of the environment, functions and services. The findings will be pivotal to address barriers and opportunities to foster sustainable land use practices, build recommendations and guidelines for planning, and create policy frameworks for sustainable use and management of natural resources in the study area. Recommended are innovative policy frameworks, science, knowledge, and practice to protect, preserve, and conserve ecosystem services and functions in landscapes in the different regions of the country. Sustainable use of natural resources is crucial for achieving the target and vision for development and growth.

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