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Assessment of Soil Quality under Different Agricultural Land Use Systems: A Case Study of the Ibadan Farm Settlement

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Authors' contributions

This work was carried out in collaboration among all authors. All the authors contributed to the conception of the idea. Author BOA designed the study, performed the statistical analysis, managed the literature search and wrote the first draft of the manuscript. Authors AOA and KO supervised and reviewed the article. All authors read and approved the final manuscript.

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ABSTRACT

Soil quality in an agroecosytem is considerably influenced by land use and management practices. Twenty two potential soil quality indicators were used to assess the effects of five different land use types (arable land, plantation, agroforestry, marginal land and native forest) on soil quality in Akufo and Atan farm settlements in Ibadan, southwestern Nigeria. A total of sixty-two fields were selected from which soil samples were taken at a depth of 0-15 cm and subjected to laboratory analysis. Majority of the evaluated physicochemical properties varied significantly among the land uses and whereas native land performed relatively better for most of the observed attributes, arable and marginal lands performed worse. Due to the moderate to strong significant correlation among the potential indicators, they were subjected to principal component analysis and only seven indicators were selected to compute the soil quality index (SQI). In both Akufo and Atan, native land had the highest SQI (0.8250 and 0.860 respectively) which was significantly different (P = .05) from all the

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agricultural land uses, except plantation (0.739 and 0.750 respectively). Whereas marginal field in Atan was most degraded (SQI = 0.455), it was closely followed by arable fields in both locations. This study indicates that the current agricultural land use and soil management practices in Akufo and Atan farm settlements have negatively impacted soil quality; however, the degree of degradation was strongly influenced by the concentration of soil organic carbon in the understudied land use systems. It also emphasizes the need to promote the use of sustainable management practices among agricultural land users, so as to increase soil organic carbon stock, and improve soil quality and land productivity.

Keywords: Akufo; Atan; farm settlement; land use; PCA; soil quality assessment.

1. INTRODUCTION

Soil quality, as defined by Acton and Gregorich [1] is the "soil's capacity or fitness to support crop growth without resulting in soil degradation or otherwise harming the environment." Soil quality decline is one of the most critical constraints to food security, especially in sub-Sahara Africa (SSA), where about 65% of the total arable lands have already lost their ability to support viable food production [2]. In Nigeria, the menace of soil degradation has severely affected the productivity of about 62.76% of the total agricultural lands [3]. This may be largely attributed to demographic pressure and the consequent conversion of native lands to agricultural use, as well as prevalent use of unsustainable soil management practices among agricultural land users [4–7]. Between 1950 and 2000, Ibadan, a city in southwestern Nigeria, experienced rapid expansion of urban areas from 40 km^2 to 400 km^2, with consequent shrinkage of rural arable lands [8]. This reduction is however being offset with the increasing conversion of native lands to agricultural use, a practice which expose fertile top soils to the erosive effect of both water and wind [9,10].

The effect of land use and soil management (LUSM) practices on soil quality can be evaluated through the periodic assessment and monitoring of soil physical, chemical and biological attributes [11–13]. However, in the absence of periodic soil data, comparing soils under specific LUSM systems with those under native vegetations has been reported to provide an estimate of the change in soil quality [14,15]. The concern for soil sustainability has necessitated diverse studies on the effect of land use on soil quality across the world [16–21]. Several of such studies have also been carried out in Nigeria [22–25], however, many agroecosystems have never been assessed [26] and because of the complex spatial and temporal variability of soil properties, there is need for site-specific soil quality assessment that adequately represents a given local condition [27,28].

Farm settlements were set up in Ibadan in order to promote efficient utilization of land resources among indigenous farmers [29]. However, despite their relevance to agriculture and food security in the region, current studies conducted to evaluate the impact of agricultural land use and management practices on the quality of soils in the settlements are scarce. This study was therefore carried out to evaluate the extent to which soil quality has degraded as a result of agricultural use in comparison with soils under native lands, using Akufo and Atan farm settlements as case studies.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was conducted at Akufo and Atan farm settlements in Ido and Akinyele local government areas respectively, Ibadan. Ibadan is located in a rainforest zone of south-western Nigeria and lies between latitudes 7° 02’ 49″ and 7° 43′ 21″ N and longitudes 3° 31′ 58″ and 4° 08′ 20″ E and at a mean altitude of 183 m above sea level. It is characterized by mean annual minimum and maximum temperatures of 21.9°C and 35.5°C respectively; and mean annual rainfall of about 1,205 mm, which is bimodal in distribution, with two rainfall peaks in June and September [30]. These climatic conditions favor agriculture, which has been the mainstay of the economy of Ibadan from prehistoric times.

Based on the FAO soil classification system, soils of Akufo and Atan are predominantly luvisols and regosols respectively, formed from crystalline basement complex rocks mainly made up of magmatites and some grained granite gneiss and schists [31].

2.2 Selection of Sampling Units and Soil Sample Collection

Reconnaissance and questionnaire surveys were first carried out to assess the number of farm settlers, existing LUSM practices and farm history. Five LUSM systems, arable farms (AL), agroforestry (AF), plantation (PL), marginal land (ML) and native forest (NL), were identified. Based on the observed variability among the identified systems, sixty-two fields were selected (thirty in Akufo and thirty-two in Atan) as sampling units (Table 1). The selected arable lands had been in use for varied period of time, ranging from 6 to 20 years, but had been continuously cropped for an average of about 6 to 10 years. The fields were mainly used for rainfed cultivation of two or more annual crops such as maize, cassava, okra, tomato and "ewedu." Lands under plantation and agroforestry had average age of about 11-20 years. The marginal lands were uncultivated but contained sparse grasses and other natural vegetations and were sometimes used as grazing fields for nomadic livestock. Dominant plantation crops were cocoa, oil palm and plantain. The native land had fallowed for over 20 years and had diverse natural trees and shrubs, including African mahogany (*Khaya grandifolia*), African star apple (*Chrysophyllum albidum*), gmelina (*Gmelina arborea*), teak (*Tectona grandis*), iroko (*Milicia excelsa*), among others. Due to the long fallow period and the minimum human impact on soils under native lands, they were assumed to represent the most idea condition, hence, were used as benchmark for comparing the other land use systems.

Based on the size and homogeneity of each field, about 4 to 6 representative soil core samples were randomly collected per hectare at a depth of 0-15 cm and then bulked to form a composite sample. Andrews et al. [32] remarked that 0-15 cm depth was appropriate for soil quality assessment as it is where most soil quality changes are expected to occur due to long-term land use and soil management practices. The composite soil samples were then air dried, sieved with a 2 mm mesh and subjected to laboratory analysis to determine twenty-two potential physical, chemical and biological soil quality indicators.

2.3 Laboratory Analysis

Soil analysis was conducted at the soil laboratory of the University of Ibadan, Ibadan using standard procedures. Soil particle size distribution was determined using the hydrometer method [33]. Bulk density (BD) was determined using the undisturbed core method and total porosity was calculated mathematically using the equation: (1-BD/PD) x 100, where PD= particle density (2.65 g cm^{-3}) [34]. The percentage water stable aggregate (WSA) was determined using the wet sieve method, following the procedure described by Cambardella and Elliot [35]. Soil structural index (SSI) was computed mathematically using the equation [36]:

$$SSI = \frac{1.724\ x\ \%SOC}{\%Silt + \%Clay}\ x\ 100$$

Where SOC= soil organic carbon.

Soil pH was measured in a 1:1 soil-water suspension using a glass electrode meter. Organic carbon content was determined using the Walkley and Black wet digestion method [37] and total nitrogen was determined by the Kjeldahl distillation method [38]. Available phosphorus was determined using the Bray P-1 method [39]. Exchangeable acidity (H^+ and Al^{3+}) was measured by extraction and titration using 1N KCl and 0.01N NaOH solutions respectively [40]. Exchangeable Ca, Mg, K and Na were extracted with 1N ammonium acetate and then analyzed using Atomic Absorption Spectrophotometer (AAS) [41]. Cation exchange capacity (CEC) was calculated as the sum of exchangeable acidity, Ca, Mg, K and Na. Micronutrients (Fe, Mn, Zn and Cu) were extracted using 0.1N HCl and analyzed with AAS [42].

2.4 Soil Quality Assessment

Soil quality indexing was done using the framework of Andrews et al. [32]. The 22 potential indicators were first subjected to principal component analysis (PCA) to determine the most representative minimum data set (MDS). The corresponding PC weight of the selected MDS was noted and normalized. The values obtained from soil laboratory analysis of the selected indicators were then transformed into unitless scores using the linear scoring function [43] as described in Table 2. For indicator described as "more is better," the highest observed value was assigned a score of 1 and the other observations were divided by the highest observed value to obtain scores less than 1. However for those described as "less is better," the lowest observed value was divided by each observation, such that the lowest observed value received a score of 1. Soil pH, total porosity, micronutrients and percentage sand were classified as optimum because they have positive influence up to a certain level beyond which they could be considered detrimental, hence they were scored up to a threshold value as "more is better," but above the threshold values, were scored as "less is better."

The soil quality index (SQI) was computed by integrating the normalized MDS weight and the calculated scores using the weighted index equation:

$$\mathrm{SQI} = \sum_{i=1}^{n} W_i S_i$$

SQI = soil quality index; W_i = normalized weight derived from the PCA results; S_i = score for individual indicator in the MDS.

2.5 Statistical Analysis

Data obtained for soil quality indicators and integrated indices under the different land use systems were subjected to analysis of variance using SAS (version 9.3, 2012) and significant differences among the treatment means were separated using least significant difference (LSD) at 5% level of probability. The relationship among the potential soil quality indicators was evaluated using correlation analysis and PCA was used to select the minimum data set.

Table 1. Characteristics of the sampling units selected for soil quality assessment

S/N	Land use	No of fields (Akufo/Atan)	Description of land use and soil management practices
1.	Arable (AL)	*13 **8	○ Land in use for about of 6 to 20 years. ○ Maize, cassava, okra, tomato and vegetables were dominant crops. ○ Generally characterized by mixed cropping. ○ Slash and burn as the predominant means of land preparation. ○ Mineral fertilizers as the main source of soil fertility improvement as the use of organic manures was generally limited. ○ Highly intensive with high human interference on soil.
2.	Plantation (PL)	*7 **13	○ Average land age of 11 to 20 years. ○ Cocoa, oil palm and plantain as dominant crops. ○ Mechanical tillage for land preparation. ○ Periodic application of fertilizers. ○ Accumulation of organic litter on soil surface. ○ Relatively less intensive.
3.	Agro-forestry(AF)	*3 **5	○ Land in use for an average of about 11 to 20 years. ○ Simultaneous cultivation of both tree crops and arables on the same land. ○ Arables sown either between rows of trees with uncovered canopy, or the trees served as hedgerows around the arable crops. ○ Periodic application of fertilizers. ○ Periodic pruning of trees to prevent shading of companion arable crops. ○ Moderate to high human impact on soil.
4.	Native land (NL)	*4 **3	○ Native forest ○ Fallow period of over 20 years. ○ Multi-storey vegetations comprised of native trees and shrubs including teak, gmelina, iroko, African star apple, etc. ○ Uncultivated and unprotected. ○ Minimal human interference on soil.
5.	Marginal land (ML)	*3 **3	○ Uncultivated, with little agricultural value. ○ Sparse natural shrubs and grasses. ○ Occasionally serve as roaming and grazing zone for nomadic livestock.

*Total number of sampled fields = 62 (30 in Akufo and 32 in Atan); * and ** = number of sampled fields in Akufo and Atan respectively*

Table 2. Soil indicators, scoring curve, optimum limits used for evaluating the under studied land uses

Indicators	Scoring curve	Optimum limit	Sources of limit
Chemical			
pH	Optimum	7	[18]
Available P	More is better	-	-
Total nitrogen	More is better	-	-
Copper	Optimum	2.5	Native land
Zinc	Optimum	5	[45]
Manganese	Optimum	500	[44]
Iron	Optimum	250	[44]
Exch. acidity	Less is better	-	-
Calcium	More is better	-	-
Magnesium	More is better	-	-
Potassium	More is better	-	-
Sodium	More is better	-	-
CEC	More is better	-	-
Base saturation	More is better	-	-
Physical			
Silt	More is better	-	-
Clay	More is better	-	-
Sand	Optimum	80	Native land
Bulk density	Less is better	-	-
Porosity	Optimum	50	[18]
SSI	More is better	-	-
WSA	More is better	-	-
Biological			
SOC	More is better	-	-

P = phosphorus; Exch.=exchangeable; CEC= cation exchange capacity; WSA= water stable aggregate; SSI= soil structural index; SOC = soil organic carbon

3. RESULTS

3.1 Effect of Land Use on Soil Chemical Properties

Akufo: Majority of the soil attributes were significantly influenced by land use (Table 3). Although soil pH ranged from 6.13 (both NL and PL) to 6.85 (ML), it was not significantly different (P = .05) among the land uses. The assessed soils had considerably moderate to high concentration of available phosphorus, ranging from 28.13 (ML) to 99.27 mg kg^{-1} (AL), with cultivated lands (AL, PL and AF) having considerably higher values than uncultivated ones (ML and NL). Soil organic carbon (SOC) progressively declined from native to arable lands. Although native land had the highest concentration of SOC (1.77%), it was not statistically different (P = .05) from the other land uses except arable land which had the least (1.11%). Furthermore, total nitrogen, which ranged from 0.12% (AL) to 0.2% (PL and AF) did not vary significantly (P = .05) among the land use systems. However, PL and AF, which are cultivated lands, had higher nitrogen concentration than NL.

There was significant variation in soil exchangeable cations among the land use types. Exchangeable acidity (H^+, Al^{3+}) was relatively low, ranging from 0.52 (ML) to 0.62 cmol$_c$ kg^{-1} (AL). The highest CEC (21.46 cmol$_c$ kg^{-1}) was observed for NL, primarily due to the contribution of Ca (14.95 cmol$_c$ kg^{-1}), Na (3.54 cmol$_c$ kg^{-1}) and K (0.65 cmol$_c$ kg^{-1}). Marginal land, however, had the least CEC value (7.68 cmol$_c$ kg^{-1}) which was mainly due to the low concentrations of Mg and Na (0.72 and 0.24 cmol$_c$ kg^{-1}). Because of the low soil exchangeable acidity observed for the land use systems, base saturation was high, ranging from 97.21 to 92.23% (NL and ML respectively).

Except for Zn, all the analyzed micronutrients were significantly different among the land use types. Cultivable lands (PL, AF, and AL) contained higher Mn, Cu and Fe than uncultivated lands (NL and ML). The concentrations of Mn and Fe in ML (81.85 and

17.65 mg kg^{-1} respectively) were significantly lower (*P* = .05) than the other land uses, howbeit, all the micronutrient levels were within the moderate ranges. Soils under AF had the highest Mn and Cu values (461 and 2.75 mg kg^{-1} respectively) whereas Fe was highest for AL (306.33 mg kg^{-1}). There was no significant variation in the concentration of Zn, which ranged from 5.81 (PL) to 36.47 (ML).

Atan**:** Soil pH was significantly affected (P = .05) by land use and ranged from 5.83 (AL) to 7.10 (NL). Cultivated lands (PL, AF and AL) had high concentrations of available P ranging from 118.13 (PL) to 123.35 mg kg^{-1} (AL), which were all significantly higher (P = .05) than those observed for NL (9.20 mg kg^{-1}) and ML (0.8 mg kg^{-1}). Soil organic carbon ranged from 1.78 (NL) to 0.6% (ML), but significant difference (P = .05) was only observed between NL and ML. Similarly, total nitrogen was highest for NL (0.17%) and was only significantly different from ML which had the least value (0.07%).

Exchangeable cations differed significantly among the land use systems. As was the case in Akufo, all the assessed soils had low exchangeable acidity, ranging from 0.39 (NL) to 0.58 (PL and AL). Exchangeable Ca, Mg and K were highest in NL (3.67, 3.7 and 0.67 $cmol_c$ kg^{-1} respectively) which resulted in the highest CEC (11.94 $cmol_c$ kg^{-1}). In contrast, marginal soils had the lowest concentrations of Ca (0.47 $cmol_c$ kg^{-1}), Mg (0.44 $cmol_c$ kg^{-1}), K (0.21 $cmol_c$ kg^{-1}) and Na (0.16 $cmol_c$ kg^{-1}), and consequently, the significantly lowest CEC (1.72 $cmol_c$ kg^{-1}). Furthermore, percentage base saturation was highest for NL (96.74%) but was only significantly different from ML which had the least value (74.67%).

Land use had no significant effect on the concentrations of Mn, Fe, Cu and Zn, however, all the micronutrient levels were relatively moderate among the understudied land uses.

3.2 Effect of Land Use on Soil Physical Properties

Akufo: The effect of land use on soil physical attributes is shown in Table 4. Soil textural composition (silt, clay and sand) was not statistically different (P = .05) among the LUMS, however, other physical parameters significantly improved from marginal to native lands. Marginal land showed significantly highest bulk density (1.65 g cm^{-3}), as well as the least total porosity (37.74%) and water stable aggregate (WSA) (38.91%). In contrast, native land recorded the lowest bulk density (1.35 g cm^{-3}), highest total porosity (48.98%) and the highest WSA (67.99%). Soil structural index, which ranged from 16.48 (PL) to 9.20% (AL), was not significantly affected by land use.

Atan: Soil particle size distribution was not significantly different among the land use types, except for percentage clay which was significantly higher in ML (15%) than the others. However, bulk density was observed to increase from NL (1.34 g cm^{-3}) to ML (1.63 g cm^{-3}). As total porosity is inversely related to bulk density, NL had the highest value (50.57%) whereas ML had the least (38.49%). Similarly, SSI and WSA were highest for NL (13.13 and 65.14% respectively), whereas ML had the lowest values (3.68 and 38.58% respectively).

3.3 Computation of Soil Quality Index

3.3.1 Selection of indicators for soil quality assessment

There was moderate to strong correlation (0.99<r>0.5) among many of the soil attributes (Table 5). In order to minimize redundancy among the data set, the potential indicators were subjected to PCA, which resulted in twenty-two principal components (PCs), but only the first five contributed at least 5% to the total variance, and were therefore selected. The selected PCs explained 93.68% of the total variability in the data set (Table 6).

Principal component 1 solely explained 39.25% of the total variation and this was mainly due to the higher loadings of pH, bulk density, total porosity, total N, SOC, clay and SSI. However, SOC was selected due to its strong positive correlation (0.98<r > 0.7) with pH, total N and SSI and its high communality effect. Because bulk density was negatively correlated with SOC (r = -0.97) it was also retained. Principal component 1 is the "organic matter component."

Exchangeable K, Ca and CEC were highly weighted in PC 2, but CEC was selected due to its strong correlation with the others ($r \geq 0.70$) and its relatively higher communality. PC 2 is identified as the exchangeable cations component. Copper and Mn had the highest factor loadings for PC 3 but because they were strongly correlated (r = 0.85), Cu was retained because it had higher loading. This PC is the micronutrient component.

Table 3. Chemical soil attributes as influenced by land use in Akufo and Atan farm settlements

Land use	pH	Av .P	O.C	T.N	Mn	Fe	Cu	Zn	Ex A (H^+Al^{3+})	Ca	Mg	K	Na	CEC	BS
	(H_20)	(mg kg^{-1})	(%)		(mg kg^{-1})				(cmol$_c$ kg^{-1})						%
								Akufo							
Native land	6.13	69.08	1.77	0.17	201.60	172.97	1.35	8.41	0.58	14.95	1.75	0.65	3.54	21.46	97.21
Plantation	6.13	81.25	1.74	0.20	409.67	274.33	2.11	5.81	0.56	0.67	2.21	0.44	6.02	10.01	94.40
Agroforestry	6.60	72.56	1.75	0.20	461.00	185.00	2.75	32.44	0.53	2.35	2.42	0.62	4.11	10.02	94.68
Arable	6.17	99.27	1.11	0.12	348.33	306.33	2.57	21.61	0.62	1.69	1.86	0.63	5.44	9.23	93.30
Marginal	6.85	28.13	1.46	0.14	81.85	17.65	1.41	36.47	0.52	4.71	0.72	1.49	0.24	7.68	93.23
LSD (*P* = .05)	ns	33.19	0.63	ns	167.94	175.55	0.65	ns	ns	9.21	1.02	0.90	2.57	7.26	2.40
								Atan							
Native land	7.10	9.20	1.78	0.17	207.00	125.00	2.49	5.62	0.39	3.67	3.70	0.67	3.52	11.94	96.74
Plantation	6.37	118.13	1.64	0.12	229.33	245.00	1.50	3.31	0.58	1.14	1.89	0.37	6.38	10.37	94.31
Agroforestry	6.63	117.47	1.24	0.13	166.00	129.50	0.83	2.60	0.45	0.54	1.50	0.64	8.05	11.10	95.97
Arable	5.83	123.35	1.07	0.13	198.00	225.00	1.87	3.16	0.58	0.66	1.80	0.27	6.41	9.73	93.79
Marginal	6.90	0.85	0.60	0.07	219.35	318.92	1.42	6.07	0.44	0.47	0.44	0.21	0.16	1.72	74.67
LSD (*P* = .05)	1.00	31.10	0.87	0.08	ns	ns	ns	ns	0.18	2.06	1.61	0.56	2.98	5.27	4.36

Av P = available phosphorus; OC = organic carbon; TN = total nitrogen; Mn = manganese; Fe = iron, Cu = copper; Zn = zinc; Ca = Calcium, Mg = magnesium, Na = sodium, K = potassium; CEC= cation exchange capacity; BS = base saturation; LSD = least significant difference; ns = not significantly different

Table 4. Land use effects on soil physical properties

Land use type	Silt	Clay	Sand	Bulk ρ	Porosity	SSI	%WSA
		%		(g cm^{-3})		(%)	(>250 μm)
			Akufo				
Native land	12.73	5.80	83.40	1.35	48.98	16.47	67.99
Plantation	12.40	5.40	83.87	1.39	47.73	16.85	65.58
Agroforestry	15.40	4.00	80.60	1.40	47.08	15.55	54.18
Arable	14.73	6.07	79.23	1.53	42.31	14.03	44.68
Marginal	12.90	5.80	81.30	1.65	37.74	13.49	38.91
LSD (*P* = .05)	ns	ns	ns	0.06	2.274	ns	12.76
			Atan				
Native land	14.40	6.70	78.90	1.34	50.57	13.13	65.14
Plantation	10.07	6.53	83.40	1.36	48.68	11.75	55.75
Agroforestry	10.07	6.47	83.47	1.43	46.04	12.00	50.75
Arable	13.40	6.47	80.13	1.55	41.51	10.45	39.45
Marginal	8.40	15.00	76.60	1.63	38.49	3.68	38.58
LSD (*P* = .05)	ns	5.12	ns	0.13	5.075	ns	4.03

ρ = density; SSI= structural stability Index; WSA= water stable aggregate; LSD = least significant difference; ns = not significantly different

Table 5. Correlation among soil attributes in the understudied land uses types

	pH	**AvP**	**OC**	**TN**	**Mn**	**Fe**	**Cu**	**Zn**	**ExA**	**Ca**	**Mg**	**K**	**Na**	**CEC**	**BS**	**Silt**	**Clay**	**Sand**	**Bulk**	**TP**	**SSI**	**WSA**
pH	1.00																					
AvP	-0.75*	1.00																				
OC	0.70*	0.34	1.00																			
TN	0.71*	0.32	0.98**	1.00																		
Mn	0.37	0.23	0.64	0.72	1.00																	
Fe	-0.31	0.39	-0.13	-0.11	0.55*	1.00																
Cu	0.31	0.20	0.70	0.70	0.85*	0.29	1.00															
Zn	0.16	0.02	0.42	0.36	0.08	-0.34	0.36	1.00														
ExA	0.85**	0.73*	0.40	0.28	0.12	0.39	0.28	0.23	1.00													
Ca	-0.15	-0.40	-0.01	-0.12	-0.53	-0.56	-0.27	0.56	-0.01	1.00												
Mg	0.65	0.07	0.63*	0.68*	0.67	-0.06	0.64*	-0.18	-0.09	-0.41	1.00											
K	0.34	-0.88*	0.29	0.23	-0.34	-0.78*	-0.09	0.72*	-0.06	0.78*	-0.13	1.00										
Na	0.50	0.62**	0.16	0.25	0.22	0.14	0.00	-0.48	0.15	-0.79*	0.63	-0.88*	1.00									
CEC	0.49	0.29	0.67*	0.29	-0.39	-0.79*	-0.19	0.41	0.11	0.70*	0.95*	0.84*	-0.16	1.00								
BS	-0.45	0.48	0.79*	0.69*	-0.27	-0.26	-0.07	0.49	-0.27	0.82*	0.95*	0.48	-0.99*	0.22	1.00							
Silt	0.29	0.16	0.58	0.53*	0.34	-0.20	0.71*	0.43	0.27	-0.08	0.49	0.20	0.12	0.18	-0.15	1.00						
Clay	-0.84	-0.50	0.77*	0.76*	-0.23	0.44	-0.30	-0.28	-0.36	0.07	-0.53	-0.40	-0.52*	-0.60*	0.95*	-0.54	1.00					
Sand	0.79	0.49	0.51	0.52	0.02	-0.38	-0.15	0.01	0.25	-0.04	0.29	0.32	0.56	0.59	-0.51	-0.04	-0.82	1.00				
Bulk	-0.61	-0.35	-0.97*	-0.98*	-0.43*	-0.02	-0.32	0.43	-0.24	0.51	-0.80*	0.30	-0.69	-0.86	0.71*	-0.30	0.80*	-0.59	1.00			
TP	0.60	0.35	0.97*	0.98*	0.43*	0.03	0.32	-0.43	0.24	-0.51	0.80*	-0.30	0.69	0.87*	-0.71*	0.30	-0.78*	0.58*	-0.99**	1.00		
SSI	0.72	0.41	0.93*	0.92*	0.52	-0.14	0.44	0.28	0.40	-0.01	0.96*	0.29	0.27	0.44	0.97*	0.28	-0.91*	0.74	-0.97*	0.96*	1.00	
WSA	0.62	0.09	0.99**	0.91*	0.45	-0.03	0.17	-0.30	-0.03	-0.14	0.68	-0.10	0.27	0.25	0.76	-0.14	-0.41	0.57	-0.95*	0.71*	0.97*	1.00

** and ** represent significant at P = .05 and .01 respectively*

Table 6. Principal component analysis using 22 potential soil quality indicators showing principal components (PC) with their Eigen values and proportion of variances

Soil attributes	PC1	PC 2	PC 3	PC 4	PC 5	Communality
pH	**0.81**	0.30	-0.21	-0.03	-0.05	0.80
Available P	0.57	-0.19	-0.09	**0.74**	0.13	0.93
SOC	**0.81**	0.40	0.35	0.01	0.10	0.95
Total nitrogen	**0.84**	0.33	0.33	-0.06	0.08	0.94
Manganese	0.63	-0.23	0.65	-0.21	0.16	0.94
Iron	0.03	-0.73	0.40	0.25	0.42	0.93
Copper	0.54	0.02	**0.82**	-0.06	-0.09	0.98
Zinc	-0.06	0.70	0.47	0.34	-0.09	0.84
E.A	0.36	0.02	0.17	**0.75**	0.30	0.82
Calcium	-0.45	**0.82**	-0.03	0.00	0.20	0.91
Magnesium	0.78	-0.05	0.17	-0.53	-0.15	0.95
Potassium	-0.06	**0.91**	-0.10	0.09	-0.14	0.87
Sodium	0.66	-0.47	-0.42	0.19	-0.27	0.94
CEC	0.18	**0.87**	-0.38	0.03	-0.01	0.93
Base saturation	-0.69	0.51	0.35	-0.25	0.20	0.97
Silt	0.45	0.23	0.49	0.12	**-0.62**	0.89
Clay	**-0.84**	-0.40	0.19	-0.18	0.21	0.98
Sand	0.69	0.30	-0.59	0.15	0.15	0.97
Bulk density (ρ)	**-0.87**	0.19	0.21	0.22	0.01	0.89
Porosity	**0.87**	-0.19	-0.21	-0.22	-0.01	0.89
SSI	0.81	0.37	0.05	0.04	0.31	0.90
WSA	0.05	0.05	-0.21	-0.52	**0.48**	0.54
Eigen value	9.03	5.95	3.04	2.17	1.36	-
Proportion (%)	39.25	25.86	13.23	9.43	5.91	-
Cumulative (%)	39.25	65.11	78.34	87.77	93.68	-
Weight	0.393	0.259	0.132	0.094	0.059	-

P= phosphorus; SOC= soil organic carbon; EA=exchangeable acidity; CEC= cation exchange capacity; ρ=density; SSI= soil structural index; WSA= water stable aggregate; wt = weight.
***Boldfaced values** under each PC correspond to the indicators considered for computing the SQI.*
SQI = 0.393SOC + 0.393Bulk ρ + 0.259CEC + 0.132Cu + 0.0948EA + 0.059Silt + 0.059WSA
Normalized SQI = 0.283SOC + 0.283Bulk ρ + 0.186CEC + 0.095Cu + 0.068EA + 0.042Silt + 0.042WSA

Exchangeable acidity and available phosphorus were highly weighted in PC 4 but were also strongly correlated (r = 0.73). Exchangeable acidity was preferred and retained because of its higher factor loading. PC 4 is the acidity component. Silt had the highest negative loading in PC 5, followed by WSA. However, both variables were retained because of their low correlation coefficient (r = 0.21). Principal component 5 is the soil physical attribute component.

Soil organic carbon, bulk density, CEC, Cu, exchangeable acidity, silt and water stable aggregate were therefore chosen as minimum data set for the assessment of soil quality in the understudied land use systems. The variance for the components were normalized to obtain their weight and resulted in PC 1 having the highest weight (0.283), whereas PC 5 had the least (0.042).

3.3.2 Indicator scoring and integration

Soil quality index was computed by the integration of the normalized weight and indicator scores. Soil quality was significantly affected by land use both in Akufo and Atan (Table 7). In Akufo, native land had the highest SQI value (0.825) and this was primarily due to the high scores contributed by WSA (0.99), bulk density (0.98), Cu (0.89), CEC (0.84) and SOC (0.72). This SQI value was statistically higher (*P* = .05) than those obtained for the other land use

Table 7. Mean scores of the selected indicators and soil quality index of the understudied land uses

Land use	Mean Scores							SQI
	SOC	Bulk ρ	CEC	Cu	Ex. Acidity	Silt	WSA	
				Akufo				
Native land	0.92	0.98	0.84	0.89	0.53	0.62	0.99	0.825
Plantation	0.90	0.96	0.38	0.57	0.54	0.62	0.96	0.739
Agroforestry	0.90	0.95	0.38	0.45	0.66	0.89	0.79	0.734
Arable	0.49	0.87	0.34	0.47	0.49	0.85	0.65	0.589
Marginal	0.65	0.81	0.64	0.85	0.60	0.74	0.57	0.710
LSD	0.28	0.03	0.29	0.15	ns	0.27	0.19	0.09
				Atan				
Native land	0.91	0.97	0.69	0.77	0.83	0.74	0.97	0.860
Plantation	0.85	0.98	0.59	0.32	0.55	0.52	0.83	0.750
Agroforestry	0.64	0.92	0.64	0.41	0.87	0.52	0.76	0.710
Arable	0.55	0.85	0.55	0.40	0.57	0.69	0.59	0.627
Marginal	0.31	0.81	0.08	0.30	0.77	0.43	0.58	0.455
LSD	0.43	0.07	0.32	ns	0.26	ns	0.06	0.14

SOC = soil organic carbon; ρ = density; CEC = cation exchange capacity; Cu = copper; Ex. acidity = exchangeable acidity; WSA = water stable aggregate; SQI = soil quality index; LSD = least significant difference (P = .05); ns = not significantly different

systems, except PL. Soils under arable use, however, had significantly lowest SQI value (0.589), which was mainly due to the low scores obtained for organic carbon (0.49) and CEC (0.34).

In Atan, there was considerable decline in SQI in the order: native lands (0.860) > plantation (0.750) > agroforestry (0.710) > arable farms (0.627) > marginal fields (0.455). Except for PL, the SQI observed for NL was significantly higher (*P* = .05) than the other land use systems. Whereas the SQI scores varied significantly between marginal lands and the others, there was no statistical difference (*P* = .05) in the values observed for PL, AF and AL.

4. DISCUSSION

Soil physical, chemical and biological attributes varied among the understudied land use and soil management systems. In both locations, organic carbon in soils under native land was higher than, but not statistically different from those under plantation and agroforestry. This may be due to the consistent addition, accumulation and decay of organic tree litter which form a protective layer over the soil surface [21,46]. In contrast, arable farms had significantly lower soil organic carbon than native lands. This may be attributed to the exposure of soil surface to erosion and fertility decline as a result of the prevalent practice of continuous cropping, nutrient mining via the removal of crop residues, as well as bush burning among the indigenous arable farmers. Various studies have reported low soil organic carbon in arable lands across the agroecological zones of Nigeria [7,25,47]. However, marginal lands in Akufo had higher SOC than arable fields. This may be because they occasionally serve as grazing fields for nomadic cattle due to the presence of grasses and natural shrubs and the addition of animal dung may have resulted in the buildup of organic matter. This corresponds with the findings of Panday et al. [20] who assessed soil quality in the Dang district of Nepal and observed higher soil organic matter in agroforestry and grasslands than arable lands. This was however attributed to the reduction in soil erosion occasioned by the presence of natural vegetations, plant litter as well as minimal soil disturbance associated with grasslands. Similarly, Gelaw et al. [18] and Muche et al. [19] also observed higher SOC for grazing lands than cultivated fields in Mandae and Alket-Wonzi watersheds respectively, in Northern Ethiopia. Higher SOC has also been reported for grasslands than agroforestry [46]. This indicates that with the buildup of organic matter over time coupled with innovative and sustainable production systems, the agricultural viability of marginal lands could be restored [48].

Native land, plantation and agroforestry with high SOC also showed corresponding high concentrations of nitrogen, possibly due to the mineralization of organic tree litter. However for cultivable lands (plantation, agroforestry and arable), the observed nitrogen (and even phosphorus) values may also be due the continuous use of mineral fertilizers. The use of chemical fertilizers, especially urea and NPK, has been reported to be one of the most commonly adopted soil management practices among farmers in Nigeria [49–52].

Cation exchange capacity consistently declined from native, agroforestry, plantation, to arable and marginal land use systems. Using the criteria of Landon [44], the CEC of the understudied soils was moderate for native land in Akufo and relatively low for the others. Low CEC is not peculiar to the study areas, but has been widely reported for tropical soils [3,53–55]. This has been attributed due to the prevalent high temperatures and rainfall which enhance weathering of parent materials, decomposition of organic matter and leaching of nutrients [56,57], the presence of 1:1 clay which has less ability for cation sorption [58], as well as the extensive use of unsustainable land management practices which depletes soil natural fertility [7,59].

As to be expected, land use did not alter the textural classification of the assessed soils, which was loamy sand. The lower bulk density and corresponding higher total porosity and aggregate stability observed for native lands, agroforestry and plantation may be due to the strong significant relationship that exist between these variables and organic carbon. Litter fall associated with these land use types promote microbial activities and enhance soil aeration, hence, bulk density is reduced [21,46]. In addition to low SOC contents, the high bulk density and lower total porosity observed for arable and marginal lands may be partly due to impacts of continuous tillage operations and trampling pressure from livestock respectively. This results aligns with the findings of Muche et al. [19] and Panday et al. [20] who observed higher bulk densities for arable and marginal lands than native land or agroforestry, which they attributed to low organic matter and high soil compaction. Increased bulk density resulted in a corresponding reduction in soil aggregate stability and structural index, in line with the findings of Khan et al. [60] and Mada et al. [61]. Whereas water stable aggregate measures the soil's ability to resist water erosion, soil structural index (SSI) is an indication of the soil's ability to resist structural degradation. According to the SSI rating by Reynold et al. [36], marginal lands in Atan are structurally degraded, with greater risk of surface runoff and soil erosion, and this is as a result of its very low soil organic carbon. Shehu et al. [46] also observed low SSI values for soils with low SOC contents. Reynold et al. [36] opined that SSI of less than 7% indicates that organic carbon is not sufficient to maintain soil structural stability, hence the risk of soil degradation is increased.

Compared to baseline condition of native lands in both Akufo and Atan, agricultural land use have resulted in a decline in soil quality, but the degree was dependent on the intensity of soil disturbance and the associated management practices. Plantation farming and agroforestry which are relatively less intensive had the least impact on soil quality, but the former performed relatively better. However, from the indicators used for computing the SQIs, the superior performance may be due to its SOC content which was relatively close to baseline conditions as a result of the continuous addition and accumulation of tree litter. Furthermore, SOC showed moderate to very strong significant correlation with majority of the selected indicators, hence, may have been largely influenced the quality of the understudied soils. Higher SQI ratings have been commonly reported for soils with higher SOC [18,21,62]. On the other hand, marginal and arable lands had significantly lower SQI ratings than native lands and were most degraded. The higher level of soil quality degradation, especially for arable lands, may be due to the prevalent use of continuous cropping and other unsustainable practices among arable farmers, which deplete soil organic matter and reduce land productivity [7,59,63]. This result validates the assertion that soil organic carbon is the single most important soil attribute affecting soil quality and functioning [64]. It can therefore be inferred that the quality of agricultural soils can be improved through concerted effort geared towards improving soil organic carbon stock.

5. CONCLUSION

As to be expected soil quality was highest in native forest but declined under agricultural land use at a rate dependent on the intensity of soil disturbance and management practices. However, among the agricultural land uses, those associated with tree farming (either sole as in plantation, or combined with arable cropping as in agroforestry) performed better in terms of the selected soil indicators, especially soil organic carbon and resulted in the least degradation of soil quality. In contrast, marginal and arable lands were most degraded.

This study underscores the need to promote the use of sustainable practices like organic manuring, agroforestry, mulching, crop rotation and proper residue management among agricultural land users, especially arable farmers, so as to enhance soil organic carbon pools, improve soil quality and increase land productivity.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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