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Evaluation of agro-ecological approach to soil quality assessment for sustainable land use and management systems

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Long-term cultivation of crops has been found to cause soil physico-chemical and biological quality (SQ) degradation for sustainable agricultural production practices in Akwanga, Nigeria. Understanding the dynamics of SQ change under different land use types is desired. The present study was carried out to assess soil physico-chemical indicators (based on land evaluation approach) and biological SQ (based on agro-ecological approach) for sustainability of cereal, arable and plantation land uses and management systems. Quantitative and qualitative indicators were defined based on chronosequence of soils under different land use types: 3-month cereal cropping of Rice); 7-month root cropping (yam/cassava/vegetable intercrop); 10-year plantation (orange/pineapple orchard); and >22-year oil palm plantation. Their respective management practice is Tillage + NPK fertilization; Tillage + NPK fertilizers + Organic manure; No tillage + mulch; and no tillage + Farm yard manure + Legume cover as live mulch. Each age class was replicated at least three times and their sensitivity to change was sought. The statistical mean values of the bio-physical and chemical properties of soil quality indicators (SQI) under the various types of land use (LUT) show that the most sensitive soil quality indicators ($P \leq 0.001$) were soil pH, total organic C, available phosphorus (P), CEC, bulk density, total porosity, and PWAC, and earthworm population. Moderately sensitive indicators ($0.001 < P \leq 0.01$) include total N, P and K, and exchangeable K. Weaker indicators of SQ ($0.01 < P \leq 0.05$) include percentage BS. Soil texture and clay/silt ratio were of no value as soil quality indicators (SQI) for these soils. SQI improvements were related to their management practices; hence LUT4 had the best SQ, followed by LUT3. The worst management was that in LUT1. Qualitative assessments based on farmers' perception of SQ showed the following order of importance for their cropping systems: Soil organic matter, fertility, topsoil thickness, soil structure, moisture retention, earthworm abundance, compaction, soil erosion, and the incidence of weeds. Farmer observations of SQ changes were generally in good agreement with the quantitative assessments. To ensure adoption of improved management practices for more sustainable production system, qualitative soil quality information obtained from on-farm surveys should be used to supplement the quantitative data obtained through soil analyses. These would serve as effective diagnostic tools for evaluating soil quality for long-term sustainability of crop productivity

Key words: Soil quality indicators, land evaluation, agro-ecological approach, guinea savanna, Nigeria.

INTRODUCTION

In Guinea savanna agro-ecology of Nigeria, arable, cereal and perennial cash crop production are dominant land uses. Their production system is undergoing major changes in response to population pressure upon land resources to meet their food and fibre demand. As a consequence, there has been an increase in both land use intensity and soil degradation (Ezeaku and Salau, 2005).

Intensive land use causes important changes in soil physico-chemical and biological characteristics, and can rapidly diminish soil quality and soil fertility. This follows Amana et al. (2012) report that ecologically sensitive components of tropical soils are not able to buffer effect of intensive agricultural practices. Thus, severe deterioration of soil quality (SQ) may lead to a permanent degradation of land productivity.

Initially planted crops remain productive for long periods but yields tend to decline in later years, especially plantation crops. This drop in productivity is traditionally associated to natural ageing of the plants (Do, 1980), while low yield from other land uses may reflect a loss in soil quality (SQ) due to the type of intensive land use involved in the production. Moreover, because crop growth and productivity are a reflection of SQ (Penning de Vries et al., 1995a), any degradation of the soil can be expected to adversely affect the stability of soil system in the tropics (Ezeaku, 2013). The spatial distribution of any soil has a marked influence on its agricultural productivity (Obasi et al., 2011), while the extent and impact of soil degradation can also lead to the reduction of biological and economic productivity potentials of rain-fed or irrigated croplands, pasture and forested land, including social and political instability (Adaikwu et al., 2012; Ezeaku and Iwuanyanwu, 2013).

The foregoing revives the issue of sustainability; hence it was deemed that an evaluation of SQ changes could enhance the sustainability of crop production in guinea savanna agro-ecology of Nigeria.

Awareness that soil is vital to both production of food and fibre and global ecosystem functions generated interest in the quality and health of soil for environmental sustainability (Bouma, 2002). Hence, during the last decade a soil quality concept emerged, necessitating several SQ definitions and quantifications (Piarce and Larson, 1993; Doran and Parkin, 1994; Karlen et al., 1997; Mausbach et al., 1998; Nortcliff, 2002). The summary of these authors' definitions is that soil quality is "*the capacity of a specific kind of living soil to function, within ecosystem boundaries to sustain biological productivity (plant and animal), maintain environmental (air and water) quality, and support/promote plant and animal health and habitation".* Some bio-physicochemical indicators that determine a soil's quality to function have been identified (USDA, 1993) and include: Soil depth, water-holding capacity, bulk density, nutrient availability, potential capacity, organic matter, microbial biomass, carbon and nitrogen content, soil structure, water infiltration, and crop yield. These determine soil's two distinct but interconnected parts (Mausbach et al., 1998): i) inherent quality (that is, innate properties) of soils as determined by the factors of soil formation-climate, topography, vegetation, parent material, and time. An example is water holding capacity that determines inherent quality for storing water; and ii), dynamic quality, which results from the changing nature (health or condition) of soil properties as influenced by human use and management decisions. Management practices and uses of the land either result in a net positive (e.g. increased organic matter contents of soils under irrigation) or negative (e.g. compaction from tillage or acidification from fertilizer application) impact on the health of the soil (Mausbach et al., 1998). This dynamic aspect of soil quality is the focal point of the concern for assessing and maintaining healthy soil resources, a point of emphasis in this study.

As soil quality integrates the biological, chemical, and physical components and processes of the soil interconnected with its surroundings in the landscape (Arshad and Coen, 1992), much remains to be known concerning the complex relationships between specific soil property measurements and overall soil quality (Gomez et al., 1996). Therefore, a methodology for assessing and monitoring soil quality whether the setting is a research plot, a field, watershed, or earth from space (global) is necessary (Seybold et al., 1998).

Several minimum data sets of indicators have been proposed (Ezeaku, 2013; Raji, 2011; Doran and Jones, 1996; Gregorich et al., 1994; Larson and Pierce, 1994). An example minimum data set is presented in Table 1 (Seybold et al., 1998). However, for indicators to be useful in assessing soil quality, a standard or reference condition must be established as a baseline from which to assess the current state of soil quality (Karlen et al., 1997). This determines whether soil quality, from environmental viewpoint, is improving, stable, or declining with changes in land use (Sanchez-Maranon et al., 2002). If the change in a soil quality indicator is positive and more is of better quality, then the soil can be regarded as improving or aggrading in quality. Conversely if the trend line is negative, then soil quality is degrading. Therefore, use of the reference condition in conjunction with trend analysis to monitor change in soil quality could be better.

Qualitative (descriptive) and quantitative (analytical) approaches have been most commonly used for

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monitoring and assessing soil quality changes (Ezeaku and Iwuanyanwu, 2013; de la Rosa et al., 2009; Harris et al., 1996). Input variables or diagnostic indicators expressed in the traditional land evaluation (quantitative and qualitative approaches) for soil quality assessment include land characteristics such as soil physic-chemical properties, climate and crop/management factors as well as soil degradation processes (Tables 1 to 3) (Seybold et al., 1998; de la Rosa et al., 2004; Ezeaku, 2005), but these parameters are mainly capable of indicating different end-point values in a soil retrospective (Filip, 2002). Therefore, it appears appropriate to develop soil-quality assessment that incorporates biological soil indicators in order to assess the total sustainability of soil (agro-ecology) functions under different uses.

Akwanga located in guinea savanna agro-ecology of Nigeria has various natural environments containing native and managed soils with different land uses and management systems. Therefore, the study was carried out to assess soil quality indicators based on land evaluation approach (physical/chemical properties) and to explore agro-ecological approach (biological property) for sustainability of land use and management systems in the study area.

MATERIALS AND METHODS

Study site description

The study was conducted for two years (2005-2006 cropping seasons) in Akwanga location (6° 15'N and 9° 30' E and 11° 00' E, with altitude about 600 m above sea level) at Nasarawa state belonging to guinea savanna agroecology of Nigeria. It is an agricultural area generally characterized by gentle, undulating plains and upland-inland continuum. The general climate is humid tropical, having distinct rainy with clear and dry seasons. The mean temperature ranges between 23.5 and 30.9°C, while mean annual rainfall ranges between 1270 and 1530 mm with a 3 to 4 month dry season. The dominant land uses are plantation, cereal and arable cropping systems (Ezeaku and Salu, 2005; Amana et al., 2012).

The study was based on chronosequence approach which represents an ecological time series of soil where the differences in age or time of land use are selected but not differences in environmental conditions (Dyck and Cole, 1994). This method is often used to define the degree of soil degradation or improvement by comparing soil properties under the same or different land use patterns but having different land use periods (Karlen et al., 1994). Based on such approach and for the purpose of this study, field sites were randomly selected based on dominant land uses, age/time and management for soil sampling, that is, 3-month (cereal cropping: Rice); 7-month (root cropping: Yam/Cassava/Vegetable intercrop) as short-term crop cultivation; 10-year (plantation: Orange/Pineapple orchard); and >22-year (plantation: Oil palm) as long-term crop production. Their respective management is Tillage + NPK fertilization; Tillage + NPK fertilizers + Organic manure; No tillage + mulch; and No tillage + farm yard manure + Legume cover as live mulch. Each age class was replicated at least three times.

Due to the beneficial effects of permanent vegetation cover on soil physical, chemical, and biological properties (Burger et al., 1998), natural vegetation areas adjacent to the various land use types was expected to provide optimal values (reference conditions) to compare the current state of soil characteristics of the sites with various land uses. If the change in a SQI is positive, then the SQ is improving, but if the trend line is negative, then the SQ is degrading.

Quantitative approach (soil analysis)

Soil sampling procedures

Physical analyses (particle size distribution, plant available water-holding capacity- Plant available water-holding capacity (PAWC), bulk density) and total porosity were conducted, respectively, using composite and undisturbed samples (n = 24) collected using cylindrical cores (at the 0-20 cm depth only) from three grids (7 × 10 m) within each field.

Soil samples analyzed for chemical were collected with auger samplers at two depths (0-20 cm surface soil; 20-40 cm subsurface soil). Each depth increment was composited and analyzed separately for the following soil properties: pH; Organic carbon; total N; exchangeable cations - Ca, Mg, Na, K; available P; total P and K with CEC and Base saturation calculated. Total soil P and K were analyzed to understand their accumulation in soils. Earthworm populations, representing biological indicators, were monitored monthly throughout the rainy season (June-October, 2006). Five core (15 cm diameter) soil samples were randomly collected from each land use type soil (25 × 25 × 20 cm, even though earthworms have been shown to be primarily in the surface 15 cm of soil profile (Pankhurst, 1997) to determine the earthworm population.

Laboratory methods

The analytical characteristics of the soil samples were determined in the following manner. A particle size analysis was determined by Gee and Bauder (1986) method. Soil pH was obtained in 1:2.5 soil/water extract of the composite samples according to McLean (1982) method. Organic carbon (OC) was determined by the potassium dichromate method (Nelson and Sommers, 1982); Organic matter was obtained by multiplication of OC with a factor 1.72. Exchangeable cations (Ca, Mg, Na and K) were estimated using 1M NH_4 OAC extractant method (Thomas, 1982) where Ca and Mg were obtained on an Atomic Absorption Spectrometer; Na and K by flame photometer; Cation exchange capacity (CEC) was obtained as a summation of exchangeable bases and acidity (Rhoades, 1982a). Total N was determined by Macro-Kjeldhal method (Bremmer and Mulvaney, 1982). Available phosphorus (P) was obtained by Bray I extractant (Olsen and Sommers, 1982) method. Total soil P and K were extracted using H_2SO_4-H_2O_2 digestion (Thomas et al., 1967). Phosphate in the digests was measured colorimetrically using a Technicon autoanalyzer; K in the extracts was determined using absorption spectrometry (AES). Bulk density was estimated by core method described by Blake and Hartge (1986). Plant available water-holding capacity (PAWC) was calculated as the difference between field capacity and the permanent wilting point–determined using a pressure chamber apparatus (Anderson and Ingram, 1993) and the values expressed on percent volumetric basis. Total porosity was estimated from the particle and bulk density and value expressed on percentage basis. For the earthworm populations' determination the core samples were passed through a 10mm sieve to hand-sort the earthworms. Earthworm data represents the cumulative number of each monthly sampling.

Qualitative approach (farmer interviews)

A survey was conducted at the same time and the same place where soil samples were taken in order to explore indigenous

Table 1. Proposed minimum data set of physical, chemical and biological indicators for screening the condition, quality, and health of soil.

Indicators of soil condition	Relationship to soil condition and function; Rationale as a priority measurement.
Physical	
Texture	Retention and transport of water and chemicals; Modeling use, soil erosion and variability estimate.
Depth of soil, topsoil, and rooting	Estimate of productivity potential and erosion; Normalizes landscape and geographic variability.
Infiltration and bulk density	Potential for leaching, productivity, and erosivity; SDB needed to adjust analyses to volumetric basis.
Water holding capacity	Related to water retention, transport and erosivity; Available H_2O, calculate from SDB, texture and OM.
Chemical	
Soil organic matter (SOM)	Defines soil fertility, stability and erosion extent; use in process models and for site normalization.
Soil pH	Defines biological and chemical activity thresholds; Essential for process modeling.
Electrical conductivity	Defines plants and microbial activity thresholds; Presently lacking in most process model.
Extractable N, P and K	Plant available nutrients and potential for N loss; Productivity and environmental quality indicators.
Biological	
Microbial biomass C and N	Microbial catalytic potential and repository for C and N; Modeling: early warning of management effects on OM.
Potentially mineralizing N	Soil productivity and N supplying potential; process modeling (surrogate indicator of biomass.
Soil respiration, water content and temperature	Microbial activity measure (in some plants), Process modeling; estimate of biomass activity.

Source: Seybold et al. (1998)

Table 2. List of land productivity and degradation related issues, the input land characteristics required and their modeling procedures.

Input land characteristics required	Issues evaluated			
	Soil	Climate	Crop/management	Modeling procedure
Land productivity-related				
General land capability	+	+	_	Qualitative
Agricultural soil suitability	+	-	-	Qualitative
Forestry land suitability	+	+	-	Qualitative
Natural soil fertility	+	-	-	Qualitative
Soil productivity	+	-	-	Statistical
Bioclimatic deficiency	+	+	+	Parametric
Land degradation related				
General soil contamination	+	+	+	Expert system
Specific soil contamination	+	+	+	Expert system
Water and wind erosion	+	+	+	Expert system
Soil plasticity/Workability	+	-	-	Statistical system
Subsoil compaction	+	+	+	Statistical system
Erosion/ impact/mitigation	+	+	+	Expert system/neural network

+, Required; -, not required. Source: de la Rosa et al. (2004).

knowledge of the farmers. Farmers approach is descriptive using words as descriptors, and hence, is inherently subjective. A questionnaire was developed based on the soil quality survey proposed by Garlynd et al. (1994). The questionnaire was used as an interview guide, in which the questions were structured in a way that was understood easily by the farmers. This is akin to the soil health card proposed by USDA Soil Quality Institute (Romig et al., 1995). The questionnaire guide was pre-tested and corrected to be sure the research objectives were satisfied.

The survey included 22 farmers chosen at random from the community. Only heads of household who have at least 20 years working experiences in farms were interviewed. These heads of household had some types of formal education, with approximately 23% having completed a high school level education, 42% at a secondary school level, and only 35% at a primary school level. Household heads were selected and interviewed as representative of the four main cropping systems sampled.

Statistics

Differences between the different land use practices based on the several soil biophysical and chemical properties were determined (Hoshmand, 1994). Significant differences between means were identified using sensitivity analysis (t-test). For the purpose of this study, a given soil property was considered to be a sensitive indicator of soil quality if the probability of a greater F-value (P>F) was ≤ 0.05. Moreover, the smaller the probability value, the greater the sensitivity of the indicator variable. Conversely, a given soil property was considered to be a poor indicator of soil quality if the probability of a greater F-value was >0.05. The use of t-test was to verify if there were statistically significant differences. Changes in these indicators can be used to determine whether soil quality is improving, stable or declining with changes in land use.

RESULTS AND DISCUSSION

Quantitative soil quality indicators (Sensitivity analysis)

Potential soil quality indicators assessed in this study included a variety of soil physical, chemical, and biological properties. To be useful as an indicator of soil quality, variations in soil properties associated with management practice must be distinguishable from those associated with natural soil variability (Burger and Kelting, 1998).

The statistical mean values of the bio-physical and chemical properties of soil quality indicators (SQI) under the various types of land use (LUT) are presented in Table 4. The results show that the most sensitive soil quality indicators ($P \leq 0.001$) were soil pH, total organic C, available phosphorus (P), CEC, bulk density, total porosity, and PWAC, and earthworm population. Moderately sensitive indicators ($0.001 < P \leq 0.01$) include total N, P and K, and exchangeable K. Weaker indicators of soil quality ($0.01 < P \leq 0.05$) include percentage BS. Soil properties such as soil texture and clay/silt ratio exhibited little change with cultivation history and, consequently, were of no value as soil quality indicators for these soils.

Assessment of dynamic SQI under different land uses

To fully assess the impact of cultivation on soil quality, it is necessary to have a baseline against which cultivation induced differences can be measured (Burger and Kelting, 1998). The reference condition for this study was native vegetation nearby the crop fields. Reference was also made to the critical values of soil properties established for the tropics (Ojanuga and Awojuola, 1981) and as well used in discussing data in Table 4 and contrasted LUT values of the reference conditions (natural vegetation fallow soils) as shown in Table 5. The statistical results showing the direction of change in population mean are presented in Table 6 as > (increase), < (decrease) and = (no change or static).

The result (Table 4) shows that texturally the soils are generally uniform in clay content and the silt/clay ratio is less than unity, suggesting high weatherability of the soils and pedogenesis under land uses (Nwaka and Kwari, 2000).

Bulk density of 3-month LUT (1.33 mgm^{-3}) was higher than that of 7-month (1.30 mgm^{-3}) and this may be related to the physiographic position of the LUT soils. Upland Rice/Maize (3-month) LUT was cultivated in slightly lower land than Yam/Cassava (7-month) LUT located in the upper landscape. It is expected that colluviation and seasonal flooding of soils, resulting to continued wetting and drying of soils (Areola, 1982), may have contributed to the increased bulk density. Caron et al. (1992) and Swartz et al. (2003) reported increases in bulk density due to decreases in aggregate stability leading to collapse of soil pores (decreased macro-porosity) and production of finer particles and macro-aggregates. Similarly, high soil bulk density observed in 7-month LUT relative to reference condition (Table 4) may be associated to poor vegetal cover, soil surface crusting and compaction by raindrop impact.

High percentage porosity observed across the LUTs may be due to decreased bulk density (Table 4) and could be the cause of increased availability of water (PAWC) relative to reference conditions. Thus increase in bulk density of the reference fallow condition may be due to compaction that could inhibit water conductance and availability, oxygen movement to the root zone and especially; the erosive vulnerability of macro-aggregates (Karlen et al., 1997). These are in further agreement with the report that structural decline due to compaction, typical of some agricultural systems; specifically affect the transmission and drainage pores (Caron et al., 1992).

Adaikwu et al. (2012) reported that a typical characteristic of savanna soils is that pH of the soil in water is predominantly moderate to slight acid condition. The mean soil pH values obtained across the LUTs ranges from 6.2 to 6.8 (Table 4). These values could be considered reasonably well for plant growth and development in the area. The pH values obtained accords the range (6.2 to 6.5) reported for soils in southern guinea savanna of Nigeria (Adaikwu et al., 2012; Amana et al., 2012; Akinrinde and Obigbesan, 2000). The increased pH of the soils may be associated to incorporated vegetation biomass that has the capacity to retain and release enough base forming cations. Value of 17.4 gkg^{-1} organic-C content (OC) is suggested as critical limit level for the soils of northern Nigeria (Akinrinde and

Table 3. Main soil characteristics and qualities considered in land evaluation.

Grouping type	Soil physico-chemical parameters**
Visible attributes	Surface ponding of water, surface runoff, forms of rill, sheet or gully, exposure of subsoil, sub-soil compaction, retarded/poor growth.
Physical attributes	Soil texture, bulk density, porosity, aggregate strength and stability, soil crusting, soil compaction, water retention, drainage, hydraulic conductivity, infiltration rate, stoniness, soil depth.
Chemical attributes	Clay content, soil reaction, colour, organic matter content, carbonate content, base saturation, cation exchange capacity, sodium saturation, electrical conductivity, soil fertility status.
Land qualities*	
Land Productivity	Nutrient availability, water holding capacity/ availability, oxygen availability that is, water and air-filled pores), plant root penetration, plant- water- use efficiency, crop growth.
Land Degradation	Soil structure, cover protection, runoff, soil erodibility, sub-soil compaction, soil workability, leaching potential, toxic absorption and mobility, pesticide degradation.

Sources: de la Rosa et al. (2004)*; Ezeaku (2005)**.

Table 4. Soil quality data (mean and standard deviation) among the fallow and age of the various land use types (LUT).

Indicator	Fallow (n=6)	3-month (n=4)	7-month (n=4)	10-year (n=5)	>22-year(n=5)	Sig. level
Soil physical indicators						
Clay gkg^{-1}	22(8.3)	24(8.0)	22(6.9)	21(7.1)	23(7.6)	*
Si/Clay ratio	0.84	0.80	0.77	0.81	0.87	ns
Bd Mgm^{-1}	1.37(3.9)	1.33(3.1)	1.30(3.4)	1.28(2.7)	1.26(3.8)	***
Tp (%)	52.7(10.3)	54.3(10.9)	55.1(10.3)	57.9(9.1)	60.0(8.7)	***
PAWC(% V)	9.1(3.1)	9.7(3.4)	9.4(3.6)	10.5(3.4)	13.1(3.6)	***
Soil chemical indicators						
Soil pH (H_2O)	6.8(0.03)	6.2(0.04)	6.4(0.02)	6.5(0.03)	6.6(0.02)	***
Total C gkg^{-1}	10.8(0.6)	4.2(0.01)	2.9(0.03)	17.6(7.8)	21.0(9.2)	***
Total N gkg^{-1}	2.6(1.2)	0.9(0.1)	1.2(0.1)	2.4(0.6)	4.1(0.5)	**
Av.P mgkg^{-1}	24.0(5.2)	22.4(3.4)	19.0(3.2)	23.8(5.7)	24.5(5.3)	***
Exch.K cmolkg^{-1}	13.4(2.2)	11.3(3.1)	12.7(2.6)	13.3(1.9)	13.9(1.7)	ns
Total P kgha^{-1}	320(52)	262(67)	247(91)	338(76)	360(89)	**
Total K kgha^{-1}	263(56)	164(40)	179(24)	256(53)	262(58)	**
CEC cmolkg^{-1}	5.4(4.1)	5.3(2.8)	4.7(3.8)	8.6(2.5)	10.3(1.4)	*
BS (%)	96(22)	94(21)	92(22)	97(23)	96(23)	ns
Bio-indicators						
Ew count m^{-3}	10	2	3	7	9	***

[a] = significant at 0.05 (*), 0.01 (**) and 0.001(***) level of probability; ns = not significant; Cc = clay content; Si/Cl = silt/clay; Bd = bulk density; Tp(%) = total porosity percent; PAWC (%v) = plant available water capacity on volumetric percent; C = carbon; N = nitrogen; av.P = available phosphorus; Exch. K = exchangeable potassium; CEC = cation exchange capacity; BS(%) = base saturation percent; Ew = earthworm.

Obigbesan, 2000). The result (Table 4) shows that total OC contents of the 3-month (4.2 gkg^{-1}) and 7-month (2.9 gkg^{-1}) soils are below the critical limit; an indicative of very high biological degradation. Low soil organic matter content (SOM) may be due to crop uptake exacerbated by continuous cropping without adequate measures of nutrient replacement either through the use of inorganic fertilizer or other forms of soil conservation measures (Adaikwu et al., 2012). They also reported that low SOM is a process associated with the savanna soils, which could be due to high temperature that rapidly breakdown organic matter and inhibit nitrogen fixation by rhizo-bacteria. Asadu et al. (2004) associated low SOM with use of inappropriate farming practices, frequent changes in land uses (over cultivation) and erosion. These could result to decline in crop performances.

Table 5. Statistical level (P>F) for contrasts among land use type (LUT) study soils.

Indicator	Fallow Vs 3-month	3-month Vs 7 month	Fallow Vs 10-year	10-year Vs 22 year
Soil physical indicators				
Bd Mgm^{-1}	0.000	0.002	0.008	0.212
Tp (%)	0.001	0.001	0.003	0.241
PAWC(% V)	0.002	0.006	0.009	0.073
Soil chemical indicators				
Soil pH (H_2O)	0.001	0.056	0.001	0.051
Total C gkg^{-1}	0.000	0.004	0.010	0.143
Total N gkg^{-1}	0.001	0.001	0.008	0.092
Av.P $mgkg^{-1}$	0.002	0.002	0.000	0.006
Exch.K $cmolkg^{-1}$	0.000	0.001	0.003	0.042
Total P $kgha^{-1}$	0.000	0.000	0.002	0.000
Total K $kgha^{-1}$	0.000	0.012	0.000	0.038
CEC $cmolkg^{-1}$	0.002	0.000	0.009	0.027
Bio-indicators				
Ew count m^{-3}	0.000	0.000	0.001	0.003

Bd = bulk density; Tp (%) = total porosity percent; PAWC (%v) = plant available water capacity on volumetric percent; C = carbon; N = nitrogen; Ext. P = extractable phosphorus; Exch. K = exchangeable potassium; CEC = cation exchange capacity; BS(%) = base saturation percent; Ew = earthworm. Only dynamic soil properties were selected.

Table 6. Changes in soil quality indicators in response to crop cultivation.

Indicator	Fallow Vs 3-month	3-month Vs 7 month	Fallow Vs 10-year	10-year Vs 22 year
Soil physical indicators				
Bd Mgm^{-1}	<	<	<	<
Tp (%)	>	>	>	>
PAWC(% V)	>	<	>	>
Soil chemical indicators				
Soil pH (H_2O)	<	<	<	=
Total C gkg^{-1}	<	<	=	>
Total N gkg^{-1}	<	<	=	=
Av.P $mgkg^{-1}$	<	=	>	>
Exch.K $cmolkg^{-1}$	<	<	<	=
Total P $kgha^{-1}$	<	<	<	<
CEC $cmolkg^{-1}$	<	<	>	>
Bio-indicators				
Ew count m^{-3}	<	<	>	>

> increase; < decrease; = no change or stable; Vs. = versus; mth = month; yr = year; Bd = bulk density; Tp(%) = total porosity percent; PAWC (%v) = plant available water capacity on volumetric percent; C = carbon; N = nitrogen; Ext. P = extractable phosphorus; Exch. K = exchangeable potassium; CEC = cation exchange capacity; Ew = earthworm. Only dynamic soil properties were selected.

The LUTs of 10 and >22 years have higher values of total OC relative to the reference soil. This may be associated to management practices. Soil quality maintenance and improvement in the savanna soils of Nigeria would depend on sequestration of organic matter high in humic substances (Raji, 2011).

The values of soil properties presented in Table 4 is used to compare with critical limits reported by Ojanuga and Awojuola (1981), Akinrinde and Obigbesan (2000) and Ezeaku and Iwuanyanwu (2013).

Soil nitrogen as a soil quality is one of the key nutrients in plant production. Most important of all 16 essential plant elements needed for growth, development and reproduction and also the most easily limiting or deficient in the tropics (Adaikwu et al., 2012). The values of total N in the 3 and 7 month LUTs are less than 0.15% or 1.5 g kg^{-1} total N at which response to N fertilization is not expected in the soils of the tropics. Low percentage soil N (0.15%) as obtained 3 and 7 month LUTs requires 200 kg ha^{-1} Urea in guinea savanna agroecology (Agbede, 2009) as cited by Adaikwu et al., (2012).

Available P is the second most critical element influencing plant growth and production. It is taken up by plants from soil solution as orthophosphate anion $H_2PO_4^-$ or HPO_4^-. In Table 4, the available P in 3-month and 7-month LUT is 4.2 and 2.9 mg kg^{-1}, implying low available P contents. For such LUTs in guinea savanna, 225 $kgha^{-1}$ of P is recommended for maize production if available P is low (<8.0 ppm) (Agbede, 2009) as cited by Adaikwu et al. (2012). However, across the plantation LUTs the values of P are greater than 8 to 12 mg kg^{-1} critical limit for the tropics, suggesting non-limiting P availability.

Exchangeable K values are higher than the critical values of 0.16 to 0.20 Cmol kg^{-1}. Cation exchange capacity (CEC) is a key component of any minimum data set to be used for assessing SQ and sustainability of agricultural management systems (Raji, 2011). This is because it determines the soil's capacity to hold and exchange natural and artificial sources of cationic plant nutrients. CEC is classified as low (< 6 Cmol kg^{-1}), medium (6-12 Cmol kg^{-1}) and high (> 12 Cmol kg^{-1}). Based on these limits, the amounts of CEC across all LUTs are generally low to medium (Table 4), suggesting high nutrient deficiencies that may be related to intense leaching and erosion due to rainfall, high mineralization rate and crop exports. The low levels signify response to N, P and K fertilization for the crops.

Contrast analysis results in Tables 5 and 6 shows that traditional lands use have modified the soil properties, especially in 3-month and 7-month LUTs. This indicates that change in soil quality indicators occurred and it is in synchrony with the observation that chemical, physical, and biological indicators of soil quality generally decline in response to intensive cultivation (Pandey, 1996). The soil characteristics most sensitive to 3-month and 7-month LUTs, showing significant differences at 0.05 probability level (t-test) with respect to the reference conditions were organic carbon, CEC, total porosity and PAWC. Even though these dynamic soil attributes could be used for biocycling, partitioning, storage and release of water and buffering of soil solution (Karlen et al., 1997), their amounts in the soil are generally low. This may be related to degradation resulting from land misuse and soil management. Soil degradation is the lowering of soil fertility to a threshold that cannot maximize agricultural productivity (Ezeaku et al., 2012).

On the other side of the spectrum, the observed soil properties of 10-year and >22-year LUTs were relatively unaffected because of probable suitable conditions. The result in Table 5 generally show that the contrasted 10-year and >22-year LUTs SQI were within the original reference levels, suggesting thus, it is unlikely that the soils are functioning much below their potentials, which indicate a high level of soil resilience and a greater ability of the soils to return to their original dynamic equilibrium after disturbance (Seybold et al., 1999).

Results indicate that bulk density, when contrasted to reference soil conditions, consistently decreased with relative increase in nutrient elements and volume of water in plantation LUT, an indicative improvement in SQ due to management. These phenomena may be associated to length of cultivation, increased microbial processes occasioned by added organic inputs and mulch management. These are expected to reduce compaction and favor infiltration over surface runoff, a probable justification for the decrease in bulk density (Tables 5 and 6) and a further suggestion that biological activity occurred, and storage and release of water can be altered. Increased microbial activities could be an induced change due to organic material management.

Lower bulk density (Bd) and earthworm number were deemed level 1 indicators of a soil's ability to accommodate water entry for prolonged periods during high-intensity rainfall and frequent irrigation events (Karlen et al., 1997). Furthermore, number of earthworms can indicate the extent of macropores (earthworm burrows) able to quickly drain surface water hence low bulk density indicates a high volume of water. Based on baseline and threshold values for earthworms (determined from population counts in the 10-year and >22-year orchards and related to the fallow), Table 6 show that the level of microbial activity and thus nutrient cycling may increase more in >22-year LUT relative to the 10-year land use because of the number of earthworms observed. However, the total number of earthworms is below the baseline of 50 or 100 for integrated plots (Werner, 1996).

Conversely, the increase in nutrient elements and especially total-P in plantation LUTs is a result of long-term supply of organic matter applications and represents a management-induced enhancement of soil quality. The increases may be beneficial as phosphorus plays critical role in plantation growth and fruit productivity, although at high levels, however it may interfere with uptake of Ca by trees, and to be more susceptible to loss of surface water runoff (Sharpley, 1996).

Recovery of SOM after the cessation of human activity would seem to be favored more in plantation LUTs than cereal and arable LUTs because of probable higher average OC contents, less erosion and cold (pseudo-temperate) climate condition occasioned by mulch and plant canopy formed. Presence of soil organic matter may impact on physical and chemical properties of plantation soils and thus may likely play a crucial role in their resiliency. Again, the high sequestered organic carbon in the plantation LUTs raises potentials for SQ improvement, which consequently may serve to mitigate the effect of climate change. This can be catalogued as

Table 7. Diagnostics of soil quality indicators (SQI) based on farmers experiences.

Soil indicators	Qualitative SQI used by farmers
SOM	Dark color and good aromatic smell.
Fertility	Based on yield and plant growth (Biomass). Lush green leaves indicate high fertility, stunted growth suggests poor fertility.
Compaction	Hard and dry when touched or feeled.
Structure	Observed soil crumbs during cultivation is a good structure.
Consistence	Stickiness on hoes when cultivating.
Moisture	Observed moist feels and dews on leaves at morning periods
Surface soil thickness	Observing the depth of dark colored soil during hoeing.
Soil erosion	Observing soil surface after rainfall event; comparing yearly variations in topsoil depth during ploughing.
Weed incidence	Presence of weed species in the field.
Earthworm population	Observing number of earthworm casts at the soil surface.

sustainable land use.

Qualitative soil quality indicators

Most of the farming operations (e.g., weeding, fertilizer application and harvesting) involved in the different land uses was carried out manually. There were no reports of serious labour shortages in the crop production areas but could be costly during peak demands. In any case, the farmers had performed farm works by themselves. As working in their crop production fields for a long-time farmers know their soil indicator best. The criteria farmers used to assess changes in soil quality are described in Table 7. Farmers commonly assess soil quality in terms of visual properties of the soil, such as appearance, feel or taste. For example, observed changes in soil color (darkness) are used by farmers to evaluate changes in organic matter content. Likewise, soil water content is assessed by feeling the soil. Plant growth and crop yield were used for fertility criteria. Many farmers perceived that their soils were still fertile if crop yields were comparable to those achieved in previous years with the same management level.

Farmers considered that drop in productivity following long-term cultivation could be attributed to degradation of the soil quality. This is because the yield potential of the crop plants remained good even after years of cultivation, provided an adequate supply of plant available nutrients was maintained through adequate fertilization to the crop land uses. The occurrence of some wild plant species in the crop fields was a useful indicator of some soil properties. Experienced farmers linked the presence of certain weed species (e.g., *Mimosa pudica* and *Eupatorium odoratum* L.) to increased acidity. Likewise, species such as Spear grass; C*hrysopogon aciculatus* R. etc. were used as indicators of poor nutrient status (soil fertility) and dryness of the soil, both of which are indicators of soil degradation. However, the use of wild plant indicator to judge soil acidity may have some limitation whereas occurrence of some species (e.g. *E. odoratum* L) may be due to not only soil acidity, but also the changes of other soil properties (that is, soil moisture and soil fertility) and/or the changes of crop canopy with time (Ezeaku and Salau, 2005).

Farmers were asked to comment on ten indicators of soil quality (Table 7). Most recognized that organic matter content, soil fertility, soil moisture storage, soil structure, earthworm population, and weed incidence decreased over time, while soil compaction increased as a result of long-term cultivation. It is apparent that these soil indicators were well recognized and easily assessed by farmers, hence could serve as soil health card (Romig et al., 1995; Mausbach et al., 1998).

In contrast, changes of other soil indicators such as thickness of topsoil, and soil erosion were not well recognized by many farmers and their answers varied from farmer to farmer (e.g. 29% of interviewed farmers indicated that soil erosion increased along with time of cultivation, while 58% considered soil erosion decreased) (Table 8). The response of many farmers about changes of these soil quality indicators do not agree with scientific approach such as the use of USLE or EPIC models. This is possibly because these soil indicators were not easily recognized by observation, and the criteria used to assess changes of these soil quality indicators were too complicated and unsuitable with farmers' knowledge. This may be a limitation of farmer approach to evaluate soil quality.

Each farmer was asked to rank generally the relative importance of the various soil quality indicators as it relates to their crop production. They ranked the SQI in the following increasing order of importance (Table 9): Soil organic matter content, soil fertility, topsoil thickness, structure, moisture, earthworm, compaction, soil erosion, and weed incidence. The last three SQ indicators are

Table 8. Farmer perceptions of change in soil properties with crop cultivation (expressed as a percentage of 22 farmers).

Indicator	Increase	Decrease	No change	No idea
SOM	30	57	13	0
Fertility	26	54	18	2
Compaction	42	14	31	3
Structure	14	66	20	0
Consistence	24	53	17	6
Moisture	38	44	18	0
Surface soil thickness	22	61	17	0
Soil erosion	29	58	6	7
Weed incidence	26	57	14	3
Earthworm population	4	9	86	1

SOM = soil organic matter; pop. = population.

Table 9. Ranking of soil quality indicators based on farmers' perceptions.

Indicator	Total SQI points**	Overall rank
SOM	90	1
Fertility	104	2
Topsoil thickness	136	3
Structure	178	4
Moisture	193	5
Earthworm	208	6
Compaction	235	7
Soil erosion	271	8
Weed incidence	294	9

Each farmer ranked the SQI on a scale from 1 to 9, with 1 being the most important indicator, and 9 being the least important. Soil quality points for each indicator were then totaled, and an overall ranking assigned to each soil variable.

considered the least important but are important in conservation programs for soil protection and productivity enhancement.

Conclusion

The study revealed that depletion of the soil nutrients, particularly N, P and K, due to continued cultivation with imbalanced fertilization caused a degradation of SQ in short-term (3-month and 7- month) land uses. Opposite was the case for 10-year and 22-year plantation LUTs. The statistical mean values of the bio-physical and chemical properties of SQIs under the various LUTs show that soil pH, total organic C, available phosphorus (P), CEC, bulk density, total porosity, and PWAC, and earthworm population were the most sensitive soil quality indicators ($P \leq 0.001$). Moderate sensitive indicators were total N, P and K. Percentage BS showed weaker indicators of SQ, while soil texture and clay/silt ratio were of no value as soil quality indicators for these soils. In terms of SQI improvements with applied management practices, LUT4 had the best SQ followed by LUT3, while LUT1 had the worst management. Qualitative assessments based on farmers' perception of SQ showed that farmers considered organic matter, inherent fertility, topsoil thickness, structure, PAWC and biochemical processes (earthworm activities) as important soil quality indicators for increased crop production. Consequently, soil conservation programs targeted at crop growers should address all the factors identified. Evaluating SQ using bio-indicator (earthworm count as biological factor) underlines the importance of process-related microbial and physicochemical parameters in evaluating ecological SQ indicators. The methodological approach presented and discussed in this study should further strengthen national, regional and an international attempt in harmonizing of procedures for the monitoring and evaluation of soil quality. Farmer observations of SQ changes were generally in good agreement with the quantitative assessments. To ensure adoption of improved management practices for more sustainable production system, qualitative soil quality information obtained from on-farm surveys should be used to supplement the quantitative data obtained through soil analyses. Both assessment methods provided important information that could be used as entry point for wider geospatial application. Using both assessment methods could also serve as effective diagnostic tools for evaluating soil quality for long-term sustainability of crop productivity. This would equally allow the development of soil quality standards and control techniques, and subsequently the design of sustainable land management systems.

Conflict of Interest

The authors have not declared any conflict of interest.

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