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Comparison of qualitative and quantitative approaches to soil quality assessment for agricultural purposes in South-western Nigeria

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Abstract: There has been a major challenge on how to develop soil quality standards to assess changes which are practical and useful to farmers. This study assesses soil quality using qualitative and quantitative indicators and established the relationship between the two methods of assessment. Two locations (farmer's fields) were chosen for the study in each of three states (Oyo, Osun and Ekiti) in south-western Nigeria. In each of the farmlands, soil quality was assessed qualitatively on the field using soil health cards for visual indicators produced by natural resources conservation services of United State Department of Agriculture, and quantitatively by laboratory analysis of measured properties. The values of indicators by each of the methods of assessment were separately integrated into quantitative index using soil management assessment framework. The relationship between qualitative and quantitative methods was established using correlation analysis at $\alpha_{0.05}$.Qualitative soil quality index ranged from 65 to 90%. Quantitatively, the indices ranged from 64 to 87%. Significant positive relationships (r = 0.64 to 0.93) exist between qualitative and quantitative methods. From the results, the two methods can be used interchangeably for soil quality assessment but where fund is limiting as with peasant farmers, the qualitative approach is preferable.

Subjects: Agriculture; Agriculture and Food; Environment & Agriculture

Keywords: soil quality; qualitative method; quantitative method; soil quality index

ABOUT THE AUTHORS

Olateju Dolapo Adeyolanu is a research scientist and holds a PhD in soil survey and land evaluation with specialization in soil quality. She has conducted studies on conventional soil survey, soil quality concept and sustainable land use.

Ayoade Olayiwola Ogunkunle is a lecturer/research professor and a land evaluation expert at Agronomy Department, University of Ibadan. He is an erudite scholar who has conducted studies and published in almost every aspect of soil science. This study is very important because of challenge on how to develop soil quality standards to assess changes which are practical and useful to farmers. Linking soil quality measurement with farmers' perception will bridge the gap in the interpretation of complex data-sets and permit interaction between farmers, researchers, extension and policy personnel. It will also ensure adoption of improved management practices.

PUBLIC INTEREST STATEMENT

Soil quality is the capacity of the soil to function on a sustainable way without causing any havoc to the environment, animal and human health. Periodic assessment of soil quality is necessary in the tropics because of the fragile nature of tropical soils. Soil quality assessment can be done using farmers methods or perspective or using laboratory analysis. Both methods have their merits and demerits. Farmer's method is subjective, and can provide very little information although it is relatively cheap and quick. Laboratory method on the other hand is detailed, accurate to a reasonable extent, but it is expensive. This study assesses soil quality of some farmers' farms using both methods and established the relationship between the two methods. This study showed that the two methods can be used interchangeably. The method to use will depend on the kind of information required and the soil function of interest.

1. Introduction

In the last two decades, assessments of soil quality and measurement of the impact of management practices aimed at improving it have been the topic of considerable discussion in agricultural circles (Andrews, Karlen, & Cambardella, 2004). Efforts to assess dynamic soil quality (qualitatively or quantitatively) have been complicated with establishing a consensus on a set of standard conditions to be used for the assessment. Clearly, what is considered good soil quality in one farming context may not be so good in another and this makes soil quality assessment a big task.

Since time immemorial, traditional farmers have used descriptive terms to assess the quality of soil for sustainable crop production. In south-western Nigeria, for instance, farmers recognized clay content as a measure of soil quality for cocoa production. They believed that the higher the clay content, the higher the quality of the soil for cocoa production. Similarly, farmers have also used soil colour as a measure of soil organic matter. The darker the soil colour, the higher the organic matter content for crop production. However, this approach is highly subjective (Romig, Garlynd, & Harris, 1996). Very little information could be derived from it, it requires several years of experience for accuracy, although it is relatively cheaper and less time-consuming. Over the years, with the advent of soil and crop sciences and the advancement in analytical procedures, there has been a progressive shift from descriptive to analytical properties for soil quality assessment. This approach is quantitative; it is more specific and more accurate, though more expensive and time-consuming.

However, descriptive soil quality or health information play some roles in the development and application of technical and non-technical tools for assessing and monitoring soil quality for user groups of diverse background and interests (Aikore, 2002). On-farm assessment of soil quality is recommended to assist farmers evaluate the effects of their management decisions on soil productivity (Andrews & Carroll, 2011). Also, this approach permits interaction between researchers, extension and policy personnel when providing interpretation to link on-farm knowledge to soil quality information (Andrew & Carroll 2011). For instance, linking soil quality measurement with farmers' perception can bridge the gap in the interpretation of complex data-sets. Adoption of improved management practices is ensured when qualitative soil quality information is used to supplement the quantitative data obtained through laboratory analyses. In Africa, several studies show that by using local knowledge, small holder farmers are able to accurately predict soil quality differences of productive and non-productive fields (Barrios et al., 2006; Murage, Karanja, Smithson, & Woomer, 2000). The main challenge is to develop soil quality standards to assess changes which are practical and useful to farmers. Thus, whether by qualitative of quantitative method, the results should give similar impression about the quality of the soil in question, otherwise, the methods cannot be said to be doing the same thing.

This study therefore aims to conduct qualitative and quantitative assessments of soil quality and compare their results to establish the degree of similarity in the two approaches.

2. Materials and methods

2.1. Study sites

The study was conducted in three states (Oyo, Osun and Ekiti) in south-western Nigeria (Figure 1). In Oyo State, it was carried out in Idi Ayunre (Oluyole local government area). The study locations fall within longitudes 3° 45′ E and 3° 55′ E and latitudes 7° 10′ N and 7° 20″ N of the equator. In Osun State, the study was carried out in Iwo (Egbedore local government area). The sites are within longitudes 4° 10′ E and 4° 30′ E and latitudes 7° 30″ N and 7° 45′ N. The study was conducted in Ikole (Ikole local government area), Ekiti State between longitudes 5° 25′ E to 5° 30′ E and latitudes 7° 47′ N and 7° 51′ N of the equator.

The climate of the study sites can be described as humid to sub-humid tropical with distinct dry and wet seasons. The dry season runs from early November to the end of March or early April, while the wet season is from end of March or early April to about middle of November. There are two

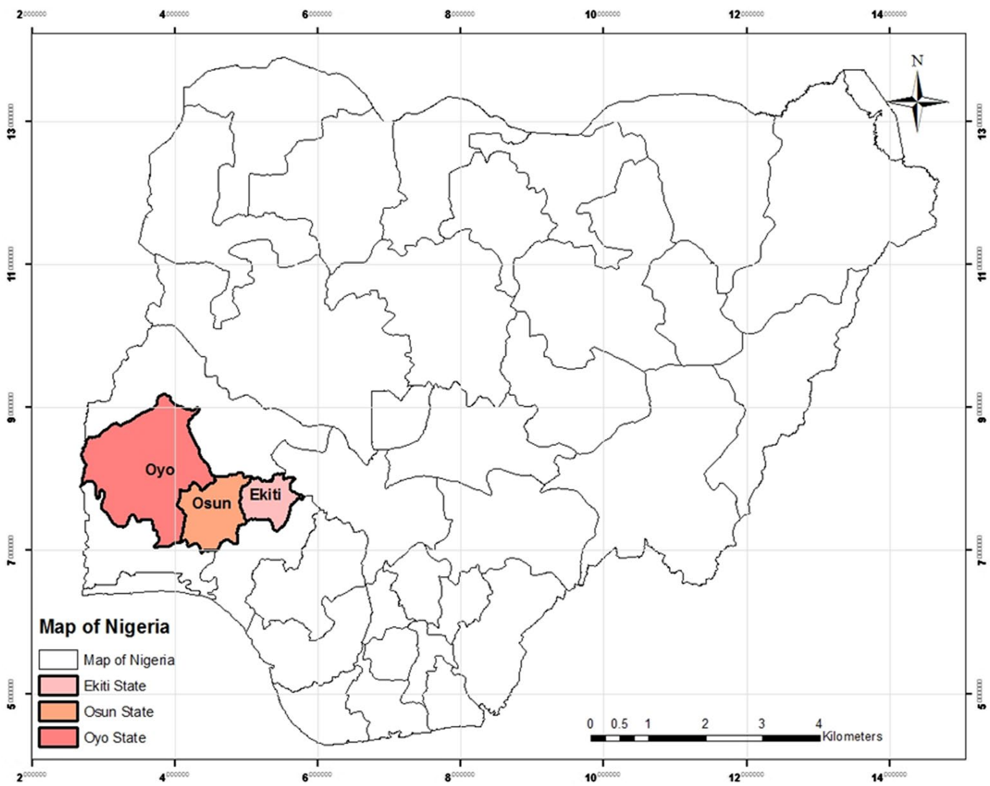

Figure 1. Map of Nigeria showing the study states.

rainfall peaks in June and September with dry spell in August (August break) which produces the bimodal rainfall pattern in south-western Nigeria. The average annual rainfall for Oyo, Osun and Ekiti States are 1,279, 1,282 and 1,576 mm, respectively. The mean annual temperature ranged between 26 and 32 C, relative humidity is high and ranged between 60 and 90% at 16.00 h.

The soils of the study sites are formed on crystalline basement complex rocks with granite gneiss as the dominant parent rock. There is a very strong geological and geomorphological influence on the pattern of soil distribution in the study sites. The soils encountered at the sites belong to three main associations: Iwo, Egbeda and Ondo associations (Smyth, & Montgomery, 1962) and the summary of their properties is as follows:

Iwo Association: The soils of this association are derived from coarse-grained granites, granitic gneisses and pegmatite. The fine earth fraction of the soils usually contains a high proportion of coarse sand and a most marked stone/gravel layer is present between depths of 10 and 48 inches. The upper horizons of the soils, above a depth of 10 inches are usually sandy in texture and brownish grey in colour. The deeper horizons show a variety of textures but mostly very clayey with colour ranging from pale brownish grey to brownish red. The soils are usually well drained.

Egbeda Association: The soils are derived from fine-grained biotite gneisses and schist which are easily weathered giving rise to very deep soils. They occupy an undulating to rolling topography and are characteristically very fine in texture with pronounced gravel layer between depths of 10–48 inches. They are very clayey in texture between 10 and 20 inches to the surface with colour variation of pale brownish grey to brownish red. The soils are also usually well-drained.

Ondo Association: The soils of this association are derived from medium-grained granitic gneisses and, to much lesser extent, from fine to medium-grained, scarcely foliated, granitic rocks. The characteristics of these soils and their parent rocks are intermediate in nature between those of the coarse textured Iwo association and the fine-textured Egbeda association. They are also very clayey in texture between 10 and 20 inches to the surface with colour variation of orange brown to brownish red. The soils are also usually well drained.

The vegetation of south-western Nigeria can be divided into three broad zones: forest, savanna and derived savanna zones with locations in Oyo and Ekiti States having forest vegetation, while those of Osun State are derived savanna.

2.2. Field study

Two farmlands of about one hectare were chosen for the study in each state making a total of six farmlands. The soil map of south-western Nigeria prepared by Smyth and Montgomery (1962) was used to identify the soil types of the experimental sites. Auger soil examination was done to ascertain the information on the map. One soil profile was dug on each soil type, described and sampled to further ascertain the soil type and for laboratory analysis.

In each of the locations, the quality of the soil was assessed qualitatively and quantitatively using soil health card (Natural Resources Conservation Service. USDA [NRCS], 1999) and laboratory data, respectively. The soil health card is a qualitative tool designed for land users. It contains selected soil quality indicators and associated ranking description typical of local producers. The ranking on the soil health card ranges from low to high and is based on specific criteria from NRCS Guidelines for Soil Quality Assessment (NRCS, 1999). A sample of the soil health card is shown in Table 1. Five sampling points were randomly located on each mapping unit (soil type) and soil samples were collected at 0–15 cm depth which is the peak of biological activities in the soil. The samples were assessed qualitatively on the field using soil health cards, and taken to the laboratory for quantitative assessment.

Table 1. Farmer-produced soil health card

Indicators	Low	Moderate	High	Methods of determination
Earthworm	Few worms (1–4) per shovel, no casts or holes	More worms (5–8) per shovel, some casts and holes	Many worms (>8) per shovel, many casts and holes	Use of quadrant and counting the number of earthworms or casts. (Five quadrant throws per site)
Organic matter content	No visible roots or residues	Some plant residues and roots	Lots of roots/residues in many stages of decomposition	Presence and abundance of visible residues or roots, Colour
Subsurface compaction	Hard layers, tight soil, restrict wire penetration, Obvious hardpan, roots turned awkwardly	Firm soil, moderate shovel resistance, penetration beyond tillage layer	Loose soil, unrestricted wire penetration, no hardpan, mostly vertical root plant growth	Degree of resistance to a stick (100 cm × 1 cm in diameter) when inserted into the soil
Erosion	Obvious soil deposition, large gullies joined, obvious soil drifting	Some deposition, few gullies, some coloured run-off, some evidence of soil drifting	No visible soil movement, no gullies, clear or no run-off, no obvious soil drifting	Presence of gullies, rills or any evidence of run-off
Water holding capacity	Plant stress immediately following rain or irrigation, soil has limited capacity to hold water, soil requires frequent irrigation	Crops did not easily suffer from dry spell in the area, soil requires moderate irrigation	Soil holds water well for long time, thick topsoil for water storage, crops do well in dry spells, soil requires little irrigation	Rate at which water runs out after a good rain, with or without puddling
Drainage	Excessive wet spots on the field, ponding, root disease	Some wet spots on the field and profile, some root diseases	Water is evenly drained through field and soil profile no evidence of root disease	Degree of wetness or dryness, ponding or run-off
Crop condition	Stunted growth, uneven stand, discolouration, low yield	Some uneven or stunted growth, slight discolouration, signs of stress	Healthy, vigorous, and uniform stand	Leaf colour and rate of crop growth throughout season

Source: Natural Resources Conservation Services (NRCS) (1999).

2.3. Selection of indicators

Indicators used for soil quality assessment were selected by modifying the approach of Cameron, Beare, McLaren, and Di (1998) and Gugino et al. (2007) for selecting soil quality indicators for crop production function.

2.4. Soil quality assessment

In each of the locations, the quality of the soil was assessed qualitatively and quantitatively using soil health card (Table 1) and standard laboratory procedures, respectively. The values of indicators for both methods of assessment were then combined into a quantitative index separately using the framework for evaluating indicators of soil quality by Andrews et al. (2004) called soil management assessment framework. This technique uses the principle that soil quality can only be assessed by a combination of different properties or indicators (i.e. no single indicator can represent the condition of the soil). The combination was based on the critical values of the indicators and the soil processes relevant to crop productivity. In this case, the soil processes relating to crop productivity were identified; weights were also assigned based on their relative levels of importance.

Soil quality indicators relating to each process were identified and also given weights based on their level of importance to the process. The soil quality indicators for each of the six processes and their relative weights are shown in Tables 2 and 3.

All weights within each level summed up to 1.0 and 100% equivalent. To combine the different processes and indicators, all indicators affecting a particular process were grouped together, given scores and relative weights based on their critical values and relative importance to crop production. For farm 1 in Oyo State, under nutrient availability, the indicators were scored as follows: active carbon = 0.85, available p = 0.4, pH 0.9, base saturation = 0.9 and moisture content = 0.75. These scores were determined based on the values of the indicators relative to their critical values. After scoring each indicator, the value was multiplied by the appropriate weight producing an equation which arrives at the soil quality index for each process.

$$\text{S.Q.I}_{\text{nutrient availability}} = 0.85 \times 0.25 + 0.4 \times 0.15 + 0.9 \times 0.2 + 0.9 \times 0.2 + 0.75 \times 0.20 = 0.78(78\%) \quad (1)$$

Table 2. Soil processes, quantitative soil quality indicators and their relative weights

Soil processes	Relative weights	Quantitative soil quality indicators	Relative weights
Nutrient availability	0.20	Active carbon	0.25
		Available phosphorus	0.15
		pH	0.20
		Base saturation	0.20
		Moisture content	0.20
Nutrient retention	0.20	Cation-exchange capacity (CEC)	0.35
		Organic matter	0.35
		Texture	0.30
Root penetration	0.15	Bulk density	1.0
Biotic environment	0.10	Potentially mineralizable Nitrogen	1.0
Water entry capacity	0.15	Porosity	1.0
Ability to resist degradation	0.20	Aggregate stability	1.0

Table 3. Soil processes, qualitative soil quality indicators and their relative weights

Soil Processes	Relative Weights	Qualitative Soil Quality Indicators	Relative Weights
Nutrient Availability	0.2	Organic Matter Content	0.60
		Crop Condition	0.40
Nutrient Retention	0.2	Water holding capacity	1.0
Root Penetration	0.15	Subsurface compaction	1.0
Biotic Environment	0.10	Earthworm count	1.0
Water Entry Capacity	0.15	Drainage	1.0
Ability to resist degradation	0.20	Erosion rate	1.0

Soil quality index for each process was also multiply by the appropriate weight and the resulting matrix summed to provide the overall soil quality index for crop productivity as follows:

$$Q = \sum_{1}^{n} (q.wt) \tag{2}$$

where Q = Overall soil quality index for crop productivity; q = soil quality rating for soil process; w = relative weight; n = nth soil process.

Example: For farm 1 in Oyo State, nutrient availability = 78%, nutrient retention = 80%, root penetration = 90%, biotic environment = 92%, water entry capacity = 86% and degradation resistance = 92%.

$$\mathrm{Q} = 0.78 \times 0.2 + 0.80 \times 0.2 + 0.90 \times 0.15 + 0.92 \times 0.1 + 0.86 \times 0.15 + 0.92 \times 0.2$$

$$Q = 0.853(85.3\%)$$

The relationship between qualitative and quantitative methods of assessing soil quality was established using correlation analysis.

3. Results and discussion

3.1. Qualitative soil quality

Table 4 shows the estimates of the qualitative soil quality indicators in the three states. In Oyo State, earthworm count and organic matter were rated high in both farms, while others were rated moderate to high indicating that the qualitative soil quality indicators assessed were high in the state. In Osun State, all the indicators were rated high to moderate. Ekiti State follows the same trend as Oyo State indicating high values of soil quality indicators in the state. Qualitative soil quality index range was 65–90%.

3.2. Quantitative soil quality

Table 5 shows the values of quantitative soil quality indicators in the three states. In Oyo State, the soils are moderately acidic to near neutral with pH (H_2O) ranging from 5.7 to 6.9, so acidity may not pose a problem to crop production. Active carbon which is the fraction of organic matter that is readily available as a carbon and energy source for the soil micro-organisms is high to moderate. This is an indication that there is enough food for the soil microbial community. The potentially mineralizable nitrogen (PMN) is high to moderate indicating that the soil microbial community has a moderate capacity to convert tied up nitrogen into plant available form of ammonium. Available phosphorus is low indicating need for addition of P-based fertilizers. Total carbon and total nitrogen are both high to moderate. Base saturation is high indicating that the exchange sites have very large amount

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Table 4. Estimates of qualitative soil quality indicators in the three states

Indicators	Oyo State		Osun State		Ekiti State	
	Farm 1 (Typic Dystrudept)	Farm 2 (Aquic Dystrudept)	Farm 1 (Vertic Eutrudept)	Farm 2 (Dystric Eutrudept)	Farm 1 (Typic Kanhapludalf)	Farm 2 (Aquic Kanhapludalf)
Earthworm count	High	High	High	High	High	High
Organic matter	High	High	High	High	High	High
Subsurface compaction	Moderate	High	Moderate	High	Moderate	High
Erosion	Moderate	High	Moderate	High	Moderate	Moderate
Water holding capacity	Moderate	High	Moderate	High	High	High
Drainage	Moderate	High	Moderate	High	High	High
Crop condition	Moderate	High	Moderate	High	High	High

Note: Soil classification was done using Keys to Soil Taxonomy (USDA, 2010).

of basic cations. Cation exchange capacity (CEC) is high. All the physical parameters assessed—bulk density, water holding capacity, aggregate stability, texture and porosity are all at optimum level indicating that the physical quality of the soil is good. In Osun State, the soil is moderately acidic with pH 5.4–6.0, active carbon is moderate to high (ranging from 2.40 to 11.62), PMN is high to moderate (0.54–2.54). Available phosphorus is low ranging from 0.82 to 3.34 mg/kg. Total carbon and nitrogen both ranged from high to moderate, base saturation is high to moderate. CEC is high indicating that ion exchange will not pose a problem. Just like in Oyo State, all the physical parameters are in good condition indicating good physical quality of the soils. The conditions of the soil quality indicators assessed in Ekiti State are similar to that of Oyo state. The soil is near neutral (pH 6.5–6.9), active carbon and PMN are moderate to high, available phosphorus is low, total carbon and nitrogen

Table 5. Average values of quantitative soil quality indicators in the three states

Indicators	Oyo State		Osun State		Ekiti State	
	Farm 1 (Typic Dystrudept)	Farm 2 (Aquic Dystrudept)	Farm 1 (Vertic Eutrudept)	Farm 2 (Dystric Eutrudept)	Farm 1 (Typic Kanhapludalf)	Farm 2 (Aquic Kanhapludalf)
pH (H2O)	6.9	5.9	5.4	5.6	6.8	5.5
pH (KCl)	6.2	5.6	5.1	4.9	5.9	4.6
Active C (g/kg)	10.1	17.5	11.6	2.7	12.3	7.5
PMN (g/kg)	1.1	1.5	2.5	1.0	2.3	1.1
Avail.P (mg/kg)	0.8	3.1	3.3	4.6	2.3	1.9
Total C (g/kg)	19.0	24.3	24.4	7.9	20.5	6.5
Total N (g/kg)	2.0	2.5	2.5	2.5	2.1	1.1
Base Sat. (%)	97.5	99.0	93.5	96.0	81.7	94.2
CEC (cmol/kg)	12.8	18.7	7.3	3.5	1.8	2.9
Bulk density(g/cm3)	1.3	1.3	1.38	1.3	1.35	1.4
WHC	0.4	0.4	0.3	0.3	0.4	0.3
Aggt. Stab. (%)	86.4	81.5	68.5	75.9	75.5	80.5
Texture	SL	LS	LS	LS	SL	SCL
Porosity(m3/m3)	0.6	0.5	0.5	0.5	0.5	0.5

Note: Soil classification was done using Keys to Soil Taxonomy (USDA, 2010).

Key: PMN = Potentially Mineralizable Nitrogen, WHC = Water Holding Capacity, CEC = Cation Exchangeable Capacity, Aggt. Stab = Aggregate Stability, Active C = Active Carbon, Total C = Total Carbon, Total N = Total Nitrogen, Base Sat = Base Saturation, Avail. P = Available Phosphorus.

are both high to moderate, base saturation is high. Unlike Oyo State however, CEC is low indicating low capacity for ion exchange and the need to enhance the CEC through the use of organic fertilizers. All the physical parameters assessed are in good state. The percentage quantitative soil quality index ranged from 64 to 87%. The moderate to high values (65–90%) of qualitative soil quality index (Table 6) is a reflection of the values of qualitative soil quality indicators which are moderate to high. This may be due to the high level of organic matter which helps in improving the levels of some of the soil quality indicators. For instance, organic matter is improved, and will positively influence aggregate stability, water holding capacity, and compaction, reduce erosion (Pagliai et al., 1998). Wakene (2001) and Solomon, Fritzsche, Tekalign, Lehmann, and Zech (2002) also reported that a change in organic matter content of the surface soil significantly influence other key soil properties. Similarly, soil organic matter plays a key role in soil function, determining soil nutrient status, water holding capacity and susceptibility of soil to degradation (Feller, Balesdent, Nicolardot, & Cerri, 2001; Giller & Cadisch, 1997). It is also the principal reserve of nutrients such as *N* in the soil and some tropical soils may contain large quantities of mineral *N* in the top 2 m depth (Havlin, Beaton, Tisdale, & Nelson, 2005).

The percentage quantitative soil quality indices follow the same trend as for the qualitative and the same explanation holds for both. The indices are generally moderate to high and ranged from 64 to 87%. Values of the qualitative indicators also ranged from moderate to high. Apomu soil series (Aquic Dystrudept and Dystric Eutrudept) have relatively higher soil quality indices than all other soil types in each of the states. This could be due to the fact that Apomu series is usually located at the lower slope of the toposequence which makes it a constant recipient of organic matter and other nutrient-containing materials from the upper slope regions, resulting into high nutrient level, low bulk density, good tilth and water-holding capacity (Oluwatosin, Adeyolanu, & Idowu, 2003).

The differences in the magnitude of the values of the two methods of assessment could be due to the fact that the qualitative method is highly subjective and requires long-term frequent practices for accuracy. Quantitative method on the other hand involves laboratory analysis and is more accurate to a reasonable extent. Aikore (2002) obtained different soil quality values by the qualitative approach for the same soil type but under different land use. Another reason for the difference in their magnitude could be seen in the number of parameters or indicators involved in each of the two approaches. Qualitative method uses fewer indicators than the quantitative, so more information about soil quality may be lost. This agrees well with the view of Harris and Bezdicek (1994) that reported: “less information would be gotten with descriptive properties”. This notwithstanding, no method of soil quality can be said to be perfect or the best, the method to choose depends on the level of information required and the soil function being considered (Chen, 1999; Oluwatosin et al., 2003).

There has been a high dependence of estimation on laboratory accuracy because human judgement is subjective. However, the laboratory method could be costly and time-consuming, hence there is a need for the qualitative, farmer-friendly method.

Table 6. Average aggregate qualitative and quantitative soil quality index for each of the farms

Type of quality index	Oyo State		Osun State		Ekiti State	
	Farm 1 (Typic Dystrudept)	Farm 2 (Aquic Dystrudept)	Farm 1 (Vertic Eutrudept)	Farm 2 (Dystric Eutrudept)	Farm 1 (Typic Kanhapludalf)	Farm 2 (Aquic Kanhapludalf)
Qualitative index (%)	71	90	65	90	75	87
Quantitative index (%)	85	87	64	84	76	80

3.3. Relationship between qualitative and quantitative soil quality

Significant positive relationship has been established between qualitative and quantitative methods of soil quality assessment with r values ranging between 0.64 and 0.93. These values ranged from moderate to high and this implies that any of the two methods could be used for soil quality assessment. The relationship is linear in most of the cases indicating that the two methods can be used interchangeably depending on available fund, the level of education and information required from soil quality assessment and the soil function of interest (Aikore, 2002; Oluwatosin et al., 2003).

4. Conclusions

Establishing a standard procedure which is farmer oriented for soil quality assessment has been a major challenge. This study assessed soil quality of some agricultural lands using qualitative and quantitative methods and established the relationship between the two methods. From the results, the followings were deduced:

- Organic matter is a highly sensitive indicator of soil quality that positively influences the levels of other indicators.
- Qualitative method of soil quality assessment requires long-term frequent practice for accuracy.
- Depending on the level of information required and the soil function of interest, both qualitative and quantitative methods can be used interchangeably for soil quality assessment. Where fund is limiting as with the case of peasant farmers, qualitative method could be used.

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