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Soil Quality Evaluation and Classification System: Criteria for Determining Fertility Classes for Agricultural Production

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ABSTRACT
Soil functions are numerous and diverse considering the different uses and roles played by the soil in both managed and natural environments. An evaluation system was developed and applied to three soil units or sites in a mangrove (*Rhizophora* spp.) forest ecosystem by reason of the environment being a peculiar terrain exhibiting both land and water features with recurrent or semi-diurnal, alternating, oxidation-reduction processes. A minimum data-set (MDS) of soil properties was chosen and each property was rated on a 5-point scale according to criteria for fertility classes in agricultural production and these were transformed into soil quality classes. Soils in quality classes 1 and 2 that require minor to moderate management inputs are deemed to be ideal agricultural soils in sustainable agriculture while those in class 3 represent low productivity with high production costs. Soils in classes 4 and 5 are non-agricultural even on a short-term basis. The soils in the study area belong to class 3 in subclasses 3(i) and 3(ii) described as fairly (50-60%) and marginally (40-50%) fertile, respectively, in productive agriculture, which also reflects the health of the soils in ecological functions such as ecosystem buffering. Soils with scores below 50% are best preserved as environmental filters and, perhaps, for rejuvenation rather than their instant use in agriculture since production or crop yield is not likely to be sustainable in the long-run.

Keywords: Ecosystem buffering, Data-set, Potential productivity, Sustainability, Quantitative evaluation.

INTRODUCTION

The place of soil in agriculture is common knowledge from time immemorial and, as reported by Jenny (1961), soil conservation practices aimed at maintaining soil productivity are as old as agriculture itself with records dating to the Roman Empire. Soil productivity ratings were developed in the United States of America and elsewhere in the 1930s to help farmers select crops and adopt management practices that maximized production and minimised adverse environmental effects (Huddleston, 1984). In the 1970s, attempts were made to identify and protect soils of the highest productive capacity by defining "prime agricultural lands" (Reganold and Singer, 1979).

The more recent attempts to define the concept of soil quality and to develop indices to measure it have focused on the sustainability of human uses of soil, which is borne out of the realization that soils are fundamental to the health and productivity of both agricultural and natural ecosystems (Fournier, 1989; Parr *et al*., 1990; Doran *et al*., 1996; Boehn and Anderson, 1997; Seybold *et al*., 1998). Soil health or productivity is synonymous with soil quality and has been described as central to the concept of sustainable agriculture (Reganold *et al*., 1990; Doran and Parkin, 1994: Warkentin, 1995; Doran *et al*., 1996: Singer and Warkentin, 1996).

Soil quality is an emerging concept and guidelines for evaluating it have continued to evolve with respect to (i) the specific soil function(s) to assess, (ii) the most appropriate soil properties to use, and (iii) the level of a characteristic that contributes positively or negatively to quality. In an agricultural context, according to Singer and Ewing (2000), the measurement of properties should lead to a relatively simple and accurate way to rank soils based on potential plant production without soil degradation while, in a natural ecosystem, soil quality may be observed as a baseline value or set of values against which future changes in the system may be compared. In either case, a high-quality soil is defined as "one posing no harm to any normal use by humans, plants or animals; not adversely affecting natural cycles or functions; and not contaminating other components of the environment" (Moen, 1988; Denneman and Robberse, 1990; Cairns, 1991; Sheppard *et al*, 1992).

As noted by Karlen *et al*. (1997), the Soil Science Society of America Ad Hoc Committee on Soil Health described soil quality as "the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation". In view of the multiplicity of soil quality definitions, Singer and Ewing (2000) identified three soil functions as encompassing those aspects of soil quality that are most debated in the literature to include: (i) provide a medium for plant growth, (ii) regulate and partition water-flow through the environment, and (iii) serve as an effective environmental filter or buffer. With the escalation in the world population and increased awareness to conserve soil for greater productivity, efforts have continued to be made to assess the potential of soil in agricultural and or ecological systems.

A handful of methods to categorise soil quality have been in use such as the Storie Index Rating (Storie, 1964), Productivity Index (Kiniry *et al.*, 1983; Pierce *et al.*, 1984), Soil Quality Index (Parr *et al.*, 1992; Karlen *et al.*, 1997), Soil Quality (Larson and Pierce, 1994), (Soil) Quality Index (Karlen *et al.*, 1994). Other soil quality indices were developed by Smith *et al.* (1993), Halvorson *et al.* (1996), Doran and Jones, 1996: Snakin *et al.* (1996) among others. Most of the methods are qualitative, discrete, and replete with limitations and, according to Singer and Ewing (2000), there is yet no consensus as to specific values of soil characteristics and the most appropriate combination of properties that adequately describe different levels or classes of soil quality.

The foremost difficulty in soil quality evaluation is the limit or range of values of each soil property that can be considered beneficial, or which constitutes an agricultural, ecological or human health risk because it exceeds safe thresholds (Cook and Hendershot, 1996). Furthermore, although a single soil characteristic is of limited use in evaluating differences in soil quality, using more than one variable requires some system for combining the measurements into a useful index (Halvorson *et al.*, 1996). In the Storie Index Rating (SIR) system, for instance, the productivity of land is considered to be dependent upon thirty-two factors of soil, climate, and vegetative properties, but only nine properties were used in the rating because incorporating a greater number of factors made the system unwieldy (Singer and Ewing, 2000). In addition, the SIR is more of a "land quality" evaluation system like the Land Capability Classification system of Klingebiel and Montgomery (1973). Carter *et al.* (1997) noted that "soil quality" is more restrictive than "land quality". Another major issue in soil quality evaluation is the problem with ratings that produce soil quality classes along what is essentially a continuum (Bouma, 1989), or an evaluation system that is not discrete but continuous.

In any soil quality evaluation system, it is important and necessary that critical threshold values must be known, assumed or determined in order to separate soils into different quality classes (Singer and Ewing, 2000). The present work was, therefore, initiated to produce a simple, continuous, additive and quantitative or parametric soil quality evaluation system for productive and or ecological functions at the landscape scale, otherwise, to ascertain the role of soil in the immediate and wider environments of the present study.

MATERIALS AND METHODS

Guideline and Framework

Guidelines for soil quality evaluation were widely reviewed by Singer and Ewing (2000). In the present study, the guidelines given by Larson and Pierce, (1991), Gregorich *et al.*, (1994) and Papendick *et al.* (1995) that for a practical measure of soil quality, a minimum data-set (MDS) of soil characteristics that contribute to soil quality must be selected and quantified, which may include physical, chemical and biological soil properties were followed. Papendick *et al.* (1995) suggested that the MDS should include a mix of "dynamic" and relatively "static" soil properties wherein Carter *et al.* (1997) distinguished dynamic soil properties as those that are most subject to change through human use and are strongly influenced by agronomic practices, and intrinsic or static properties that are not subject to rapid change or management.

The framework for soil quality evaluation in the present work followed the procedure outlined by Gregorich *et al.* (1994) and Carter *et al.* (1997) and involved:

- i) Description of each soil function upon which soil quality was based;
- ii) Selection of a minimum data-set (MDS) of soil characteristics as indicators that influence the potential or capacity of the soils to provide each function;
- iii) Choosing indicators of soil characteristics that can be measured;
- iv) Quantification of indicators using methods of laboratory analyses to provide accurate estimates of soil characteristics;
- v) Development of criteria for rating soil properties/characteristics; and
- vi) Integration of soil property values (ratings) into soil quality classes.

Agricultural production or potential and environmental buffering were considered as two essential soil functions. Production incorporated the presence of chemical substances which promote or inhibit plant growth or that affect nutrient supply due to the quantity present or their availability (Singer and Ewing, 2000) while environmental buffering, according to Larson and Pierce (1991) considered the role of soil to attenuate the effects of harmful chemical elements within its boundaries as well as positive interaction with the environment external to the soil system.

Soil sampling, selection, and quantification of soil characteristics

A mangrove (*Rhizophora* spp.) forest ecosystem typifying a marshland/wetland and described as more productive than most terrestrial tropical and sub-tropical ecosystems, according to Schlesinger (1997), was chosen for evaluation and classification of soil quality for reasons of (i) its complexity consisting a land-water interface with properties of both land and water, (ii) the influence of saline tidewater on the soils, (iii) flooding incidence and frequency, and (iv) acid-generation in drained portions of the landscape among other things. Three soil units or sites were identified and differentiated based on their moisture regimes as (i) non-flooded upland, (ii) partially flooded and drained daily, and (iii) completely flooded and drained daily by saline tidewater from the sea.

Empirical soil quality evaluation or soil quality rating and classification

The overall capacity to perform agricultural function was calculated from the rating of soil characteristics, expressed in percentage score, by the following relation:

$$\Phi = \sum (X_1 + X_2 + \text{- - - - - - - - - - -} + X_n) K$$

Where:

Φ = soil quality (%);

X = rating of each soil characteristic/property ranging from 1 – 5, at a flat rate weighting of 100/5 = 20,

n = number of soil properties (MDS) employed, in this case 19; and

K = a constant obtained from the ratio 20/n, that is 20/19 = 1.0526 in the present work.

The number of soil properties/parameters (n) that constitute the minimum data-set (MDS) is not fixed, but open to individual choice depending on areas of interest, and each soil property should be relevant and contributory, positively or negatively, to agricultural productivity and must be rated in the criteria for fertility classes

Soil sampling and analysis

Soil sampling was done to 20cm depth from the surface. A minimum data-set (MDS) of soil characteristics that influence the health and productivity of soil was selected and their values were determined or obtained from laboratory analyses using the Glossary of Soil Science Terms (SSSA, 1996).

These included particle-size distribution or texture, soil pH, organic carbon, total nitrogen, carbon: nitrogen ratio, available phosphorus, exchangeable cations for calcium, magnesium, potassium, sodium and exchangeable acidity, cation exchange capacity, effective cation exchange capacity, exchangeable sodium percentage, percentage aluminum saturation, base saturation, and electrical conductivity or salinity. Additional observations were made on available soil depth or depth to groundwater and flooding incidence or frequency and duration. Results of laboratory soil analyses were evaluated for their nutrient content in terms of their sufficiency or otherwise, as well as the presence of substances and sundry conditions which enhance or inhibit plant growth or that affect nutrient supply due to the quantity present or their availability.

The indexing system developed and employed in the present work as described by Huddleston (1984), is one that is quantitative or parametric, additive and continuous on a scale of 100 percent with a weighting of 20 to produce a 5-point scoring scheme, viz: 1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high

RESULTS AND DISCUSSION

Soil property rating in relation to agricultural production

Soil physical and chemical properties are presented in Tables 1 and 2, respectively. All the soils had sandy loam textures (Table 1) indicating very high content of sand particle-size fractions and exceedingly low clay with moderate silt such that they are not only liable to excessive drainage and poor water storage but, more importantly, the predisposition to lack essential plant nutrients needed for growth and development of cultivated plants. They have been generally described as barely suitable for agricultural production on account of their sandy textures. As such soil unit III with the least average content of sand (63%) and highest silt (30%) is considered to have better prospect in agriculture followed by unit II and lastly unit I. On the basis of soil texture alone, soil units II and III are rated very low or 1 point, while unit I is awarded a score of zero (0) (Table 2).

Soil properties are only rated here since the present work is principally a system-development protocol aimed at providing a theoretical background and practical steps and procedure involved in soil quality evaluation and classification. Soil properties are, therefore, evaluated with regard to criteria for soil fertility classes prescribed for agricultural production in Nigeria by the Federal Department of Agricultural Land Resources (FDALR, 1990) with specifications ranging from extremely low to extremely high values but, in the present work, these were modified to range from very low to very high (Table 3).

Soil pH was generally in the acid region and ranged from 4.4 to 4.9 with average values of 4.8, 4.7 and 4.5 in soil units I, II and III, respectively (Table 2). These are described, according to FDALR (1990) standards, as strongly to extremely acidic. In this instance, soil units I, II and III scored very low or 1 point on account of soil pH for that matter.
Available phosphorus ranged from 14.79 to 18.08 $mg.kg^{-1}$ with average values of 17.46, 17.48 and 15.71 $mg.kg^{-1}$ in soil units I, II and III, respectively. The three soil units are, thus, generally rated moderate with 7.1 – 20.0 $mg.kg^{-1}$ on a score of 3 points. Organic carbon content varied from 1.31 to 3.72 with average values of 1.46, 2.57 and 3.53 percent in soil units I, II and III, respectively, and rated moderate with 1.10 - 1.5% in unit I, and very high with >2.0% in units II and III (Table 3).

Total nitrogen ranged from 0.14 to 0.22 with mean values of 0.12, 0.18 and 0.22 percent in soil units, II and III, respectively, and rated moderate with 0.101 – 0.200% in units I and II and high with 0.201 – 0.300% in unit III. Carbon: nitrogen ratio ranged from 11.43 to 16.91 with mean values of 12.27, 14.28 and 16.41 in soil units I, II and III, respectively, and were rated low with 10.0 - 14.0 in units I and II and moderate with 15.0 – 19.0 in unit III (Table 3).

Exchangeable calcium ranged from 3.10 to 8.95 $Cmol_c.kg^{-1}$ with mean values of 3.75, 7.10 and 7.33 $Cmol_c.kg^{-1}$ in soil units I, II and III, respectively, and rated low with 2 – 5 $Cmol_c.kg^{-1}$ in the unit I and moderate with 5.1 – 10.0 $Cmol_c.kg^{-1}$ in units II and III.

Exchangeable magnesium ranged from 1.70 to 5.16 with average values of 1.98, 3.90 and 4.11 $Cmol_c.kg^{-1}$ in soil units I, II and III, respectively, with moderate ratings of 1.1 – 3.0 $Cmol_c.kg^{-1}$ in unit I and high of 3.1 – 8.0 $Cmol_c.kg^{-1}$ in units II and III. Exchangeable potassium ranged from 0.09 to 0.20 with mean values of 0.13, 0.18 and 0.15 $Cmol_c.kg^{-1}$ in soil units I, II and III, respectively, and generally rated very low with <0.2 $Cmol_c.kg^{-1}$ in units I, II and III. Exchangeable sodium ranged from 0.12 to 1.62 with average values of 0.13, 1.46 and 1.61 $Cmol_c.kg^{-1}$ in soil units I, II and III, respectively, and rated low with 0.1 – 0.3 $Cmol_c.kg^{-1}$ in unit I and high with 0.8 – 2.0 $Cmol_c.kg^{-1}$ in units II and III (Table 3).

Table 1: Particle-Size Distribution (Texture) of the Soils.

Soil Unit (Site)	Sand	Silt	Clay	Textural Class Name
	<-------------	%	------------->	
I	75	17	8	Sandy Loam
II	67	26	7	Sandy Loam
III	63	30	7	Sandy Loam

Table 2: Average values of soil chemical characteristics of the study area, 2008

Soil Unit (Site)	pH	P	Total N	Org C	C/N	Ca	Mg	K	Na	CEC	EA	ECEC	Al Sat	ESP	BS	EC
	H_2O	$Mg.kg^{-1}$	<-----%----->		Ratio	<------------------------ $Cmol_c.kg^{-1}$ ------------------------->							<------------ % ------------>			dSm^{-1}
I	4.8	17.46	0.12	1.46	12.27	3.75	1.98	0.13	0.13	5.98	1.10	7.08	12.95	2.16	83.49	20.0
II	4.7	17.48	0.18	2.57	14.28	7.10	3.90	0.18	1.46	12.64	4.33	16.96	20.73	11.59	76.57	21.0
III	4.5	15.71	0.22	3.53	16.41	7.33	4.11	0.15	1.61	13.18	12.70	25.88	38.10	12.75	58.78	36.5

Table 3. Criteria for soil fertility classes on a 5-point scale [D.A.L.R (1990)]

S/No	Soil Property/Characteristic	Fertility Class Range/Score				
		1	2	3	4	5
1	Soil Texture in the Loam sub-classes with LOAM as standard, having increasing % Clay (Maximum % Clay content)	Very low Sandy Loam (20)	Low Silt Loam (27)	Moderate Sandy Clay Loam (35)	High Clay Loam (40)	Very high Silty Clay Loam (40)
2	Soil Reaction (pH)	Extremely to strongly acid 4.5 - 5.5	Moderately to slightly acid 5.6 - 6.5	Neutral 6.6 - 7.2	Slightly alkaline 7.3 – 7.8	Moderately alkaline 7.9 – 8.4
3	Available Phosphorus (Bray-1P) ($Mg.kg^{-1}$)	Very low $<$ 3.0	Low 3.0 – 7.0	Moderate 7.1 – 20.0	High 20.1 – 35.0	Very high $>$35.0
4	Organic Carbon (%)	Very low $<$ 0.4	Low 0.40 – 1.0	Moderate 1.10 – 1.5	High 1.51 – 2.0	Very high $>$2.0
5	Total Nitrogen (%)	Very low $<$0.050	Low 0.050 – 0.10	Moderate 0.101 - 0.200	High 0.201 – 0.300	Very high $>$0.300
6	Carbon-Nitrogen (C/N) Ratio	Very high $\geq$25.0	High 20.0 – 24.0	Moderate 15.0 – 19.0	Low 10.0 – 14.0	Very low $<$10.0
7	Exchangeable Calcium ($Cmol_c.kg^{-1}$)	Very low $<$2.0	Low 2.0 – 5.0	Moderate 5.1 – 10.0	High 10.1 – 20.0	Very high $>$20.0
8	Exchangeable Magnesium ($Cmol_c.kg^{-1}$)	Very low $<$0.3	Low 0.3 – 1.0	Moderate 1.1 – 3.0	High 3.1 – 8.0	Very high $>$8.0
9	Exchangeable Potassium ($Cmol_c.kg^{-1}$)	Very low $<$0.2	Low 0.2 – 0.3	Moderate 0.4 – 0.6	High 0.7 – 1.2	Very high $>$1.2
10	Exchangeable Sodium ($Cmol_c.kg^{-1}$)	Very high $>$2.0	High 0.8 – 2.0	Moderate 0.4 – 0.7	Low 0.1 – 0.3	Very low $<$0.1
11	Cation Exchange Capacity ($Cmol_c.kg^{-1}$)	Very low $<$6.0	Low 6.0 – 12.0	Moderate 12.1 – 25.0	High 25.1 – 40.0	Very high $>$40.0
12	Exchangeable Acidity ($Cmol_c.kg^{-1}$)	Very high $>$8.0	High 6.1 – 8.0	Moderate 4.1 – 6.0	Low 2.0 – 4.0	Very low $<$2.0
13	Effective Cation Exchange Capacity ($Cmol_c.kg^{-1}$)	Very low $<$10.0	Low 10.0 – 20.0	Moderate 20.1 – 40.0	High 40.1 – 60.0	Very high $>$60.0
14	Exchangeable Sodium Percentage (%)	Very high $>$20.0	High 15.1 – 20.0	Moderate 12.1 – 15.0	Low 10.0 – 12.0	Very low $<$10.0
15	Percent Aluminium Saturation (%)	Very high $\geq$16.1	High 14.1 – 16.0	Moderate 12.1 – 14.0	Low 10.1 – 12.0	Very low $\leq$10.0
16	Percent Base Saturation (%)	Very low $<$20.0	Low 20.0 – 40.0	Moderate 40.1 – 60.0	High 60.1 – 80.0	Very high $>$80.0
17	Electrical Conductivity, i.e. salinity ($dS.m^{-1}$)	Very high	High	Moderate	Low	Very low

		3.5 – 4.0	3.0 - 3.4	2.5 – 2.9	2.0 – 2.4	<2.0
18	Available Soil Depth (i.e., Depth to ground water)(cm)	Very low	Low	Moderate	High	Very high
		10.0 - 15.0	15.0 – 20.0	20.0 – 25.0	25.0 – 30.0	>30.0
19	Flooding Incidence and Frequency	Full flooded and drained daily	Partially flooded and drained daily	Seasonally flooded and drained daily	Seldom flooded and drained	Non-flooded

Source: Adopted from F.D.A.L.R (1990) and highly modified in the present work to ranged from very low to very high scores.

Cation exchange capacity ranged from 5.05 to 15.90 with average values of 5.98, 12.64 and 13.18 $Cmol_c.kg^{-1}$ in soil units I, II and III, respectively, and rated very low with <6.0 $Cmol_c.kg^{-1}$ in unit I and moderate with 12.1 – 25.0 $Cmol_c.kg^{-1}$ in units II and III. Exchangeable acidity ranged from 1.05 to 22.83 with mean values of 1.10, 4.33 and 12.70 $Cmol_c.kg^{-1}$ in soil units I, II and III, respectively, and rated very low with <2.0 $Cmol_c.kg^{-1}$ in the unit I, moderate with 4.1 – 6.0 $Cmol_c.kg^{-1}$ in unit II and very high with >8.0 $Cmol_c.kg^{-1}$ in unit III. Effective cation exchange capacity ranged from 6.20 to 33.29 with average values of 7.08, 16.96 and 25.88 $Cmol_c.kg^{-1}$ in soil units I, II and III, respectively, and rated very low with <10.0 $Cmol_c.kg^{-1}$ in unit I, low with 10.0 – 20.0 $Cmol_c.kg^{-1}$ in unit II and moderate and very high with 20.1 – 40.0 $Cmol_c.kg^{-1}$ in unit III (Table 3).

Exchangeable sodium percentage ranged from 1.74 to 15.49 with mean values of 2.16, 11.59 and 12.75 percent in soil units I, II and III, respectively, and rated very low with $<10.0\%$ in unit I, low with 10.0 – 12.0% in unit II and moderate with 12.1 – 15.0% in unit III. Aluminum saturation ranged from 10.72 to 62.93 with mean values of 12.95, 20.73 and 38.10 percent in soil units I, II and III, respectively, and rated moderate with 12.1 – 14.0% in unit I, very high with $\geq 16.1\%$ in unit II and extremely high with 38.10% in unit III (Table 3).

Percentage base saturation ranged from 31.42 to 86.13 with average values of 83.49, 76.57 and 58.78 percent in soil units I, II and III, respectively, and rated very high with $>80.0\%$ in unit I, high with 60.1 – 80.0% in unit II and moderate with 40.1 – 60.0% in unit III. Electrical conductivity ranged from 21.0 to 38.0 $dS.m^{-1}$ with average values of 20.0, 21.5 and 36.5 $dS.m^{-1}$ in soil units I, II and III, respectively, and rated extremely high with >4 $dS.m^{-1}$ in units I, II, and III (Table 3).

Available soil depths were rated very high with >30.0cm in soil unit I, very low with 10.0 – 15.0cm in unit II and extremely low with <10.0cm in unit III. Flooding incidence and frequency are described as non-flooded in unit I on a score of 5 points, partially flooded and drained daily in unit II on a score of 2 points, and totally flooded and drained daily in unit III on a score of 1 point. Soil unit/site II was intermediate between units I and III and represents the current land-water interface with alternating 6-hourly oxidation-reduction reactions in the soil in the study area.

The potential of a soil is a composite expression of its ability to function relative to a specific use (Gregorich *et al.*, 1994) which, in the current context, is the production of arable crops in agriculture irrespective of any particular crop. It is a qualitative attribute of every single soil mapping unit but the capacity of a soil to function in agriculture is a reflection or measure of its quality, which is expressed quantitatively in maximum growth and yield of crops (Tisdale and Nelson, 1975). It follows, therefore, that a high-quality soil will promote healthy growth and proper development in cultivated plants to produce high yield, and *vice versa*. In the same vein, since the concept of soil quality also relates to natural ecosystems, it stands to reason that a high-quality soil reflects its superlative role to produce a healthy environment and *vice versa*.

The soils in the present study were evaluated based on their physical and chemical properties whether these were, according to Singer and Ewing (2000), desirable or undesirable in terms of their sufficiency or otherwise, and the presence of substances which promote or inhibit growth, or that affect nutrient supply due to the quantity present. In the event that a soil unit is rated very low in quality or has inconsequential agricultural potential and is, therefore, termed unlikely to enhance healthy plant growth except at extremely great costs in management inputs., Or its use will lead to environmental risks/degradation, it shall be consigned to play its natural function to develop or rejuvenate and preserve the environment, referred to as ecosystem buffering and stabilization.

A simple matching system of each soil characteristic of agriculture was adopted (Table 3). Negative values are not employed even where an undesirable soil property or the presence of harmful substances will drastically reduce the potential, hence the productivity of the soil in agriculture. However, in any extreme case below the score 1 or very low, a zero or 0 value was awarded, notwithstanding the severity of that soil property since the system is neither a subtractive nor a multiplicative evaluation process. For a similar reason, no score shall exceed the maximum of 5 points (Table 3). Moreover, unlike other soil quality evaluation systems currently in use where the number of soil parameters (n) is kept to a manageable size to avoid being cumbersome in the computation, in the present report, it is virtually limitless since the constant (K) equilibrates the scores to fall between 1 and 100 percent no matter the number of parameters employed or the size of n. Indeed, the more the number of soil properties employed and rated, the better the evaluation as interactions tend to compensate for each other.

The scores assigned to the soil units to indicate their potential in agricultural production are shown in Table 4. Applying the equation for rating soil characteristics, expressed in a percentage score, the results show potential scores of 54, 47 and 41 in soil units I, II and III, respectively. Multiplying these figures by the constant (K), the quality or capacity of each soil to perform an agricultural function is 56.8404, 49.4722, and 43.1566 percent in units I, II, and III, respectively, which makes the system a continuous evaluation process.
The quality ratings are then integrated into a new classification system to indicate soil quality classes and their interpretation is shown in Table 5. All the soils in the study fall into soil quality class 3. Soil units II and III are classified as being marginally fertile and require enormous amounts of management inputs to ameliorate them for use in agricultural production. In these soil units, only a realistically acceptable cost of production and the economic value of cultivated crops can and should justify their use in sustainable agricultural productivity. This is more so because the soils are just a step away from being non-agricultural or non-productive unless they are cultivated to strictly water-loving crops that will also withstand extreme salinity and free-oxygen deprivation

as well as toxic gasses such as dinitrogen (N_2), nitrous oxide (N_2O), hydrogen (H_2), hydrogen sulphide (H_2S), carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4) arising from reduction or anaerobic and organic fermentation reactions in waterlogged soil (Reddy *et al*., 2000, de Oliveira *et al*., 2013, Reed, 2018). Conversely, soil unit I qualifies as being fairly fertile even as it requires great amounts of management inputs in productive agriculture. The relative advantages of the unit over units II and III include the lower levels of sodium and aluminum saturation or toxicity as well as freedom from flooding and better soil depth for plant root development among other qualities (Table 4).

In this system, measurable soil characteristics are converted to the corresponding degrees of soil quality in terms of inherent fertility ranking in their natural state without any human intervention through supportive or ameliorative agricultural management practices such as fertilizer and manure application, liming and others. The crucial deductions from the data in the present study are that except for soil unit I that is just fairly fertile and can be cultivated to crops but at great costs in managing soil acidity, salinity and nutrient deficiency challenges, especially potassium Soil units II and III are only marginally fertile and should better be preserved to perform other critical environment buffering roles rather than for sustainable productive agriculture. The results of the present study show that soil unit or site I situated in uplifted platform produced much greater growth statistics far above units II and III in sugar cane crop cultivated at the experimental site.

Table 4: Potential and Quality Rating of the Soils in Agricultural Production in relation to the study area, 2008

S/ No	Soil Property/Characteristic	Soil Unit (Site) I	Soil Unit (Site) II	Soil Unit (Site) III
		Potential Score		
1	Particle-size distribution (Texture)	0	1	1
2	Soil reaction or acidity (pH)	1	1	1
3	Available Phosphorus (Bray-1-P) ($mg.kg^{-1}$)	3	3	3
4	Organic carbon (%)	3	5	5
5	Total Nitrogen (%)	3	3	4
6	Carbon-Nitrogen (C/N) Ratio	4	4	3
7	Exchangeable Calcium ($Cmol_c.kg^{-1}$)	2	3	3
8	Exchangeable Magnesium ($Cmol_c.kg^{-1}$)	3	4	4
9	Exchangeable Potassium ($Cmol_c.kg^{-1}$)	1	1	1
10	Exchangeable Sodium ($Cmol_c.kg^{-1}$)	4	2	2
11	Cation Exchange Capacity ($Cmol_c.kg^{-1}$)	1	3	3
12	Exchangeable Acidity ($Cmol_c.kg^{-1}$)	5	3	1
13	Effective Cation Exch. Capacity ($Cmol_c.kg^{-1}$)	1	2	3
14	Percentage Aluminium Saturation (%)	3	1	0
15	Exchangeable Sodium Percentage (%)	5	4	3
16	Percentage Base Saturation (%)	5	4	3
17	Electrical Conductivity (Salinity) ($dS.m^{-1}$)	0	0	0
18	Available Soil Depth i.e. Depth to ground water (cm)	5	1	0
19	Flooding Incidence (Frequency and Duration)	5	2	1
	Soil Potential (Sum of Scores) = $\sum(X_1+X_2+...+X_n)$	**54**	**47**	**41**
	Soil Quality Rating = $\sum(X_1+X_2+...+X_n)K$ (%)	**56.84**	**49.47**	**43.16**

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Table 5: Soil Quality Classification System (SQCS) for Productive and or Ecosystem Functions of the study area, 2008

Soil Quality Class	Soil Quality Sub-Class	Soil Quality Range (%)	Agricultural /Ecological Potential	Management Need/Constraint or Risk
1	(i)	90 - 100	Extremely fertile/healthy	Requires very minor management inputs
	(ii)	80 – 90	Highly fertile/healthy	Requires little management inputs
2	(i)	70 – 80	Very fertile/healthy	Requires modest management inputs
	(ii)	60 – 70	Moderately fertile/healthy	Requires normal management inputs
3	(i)	50 – 60	Fairly fertile/healthy	Requires large management inputs
	(ii)	40 – 50	Marginally fertile/healthy	Requires enormous management inputs
4	(i)	30 – 40	Barely fertile/healthy	Requires unsustainable inputs (unproductive)
	(ii)	20 – 30	Not fertile/unhealthy	Requires regeneration or preservation
5	(i)	10 – 20	Grossly infertile/unhealthy	Degraded or juvenile soil (Barren/Regolith)
	(ii)	0 - 10	Despoiled/Ruined	Hazardous soil (Harmful/Unsafe)

Comparable to the Land Capability Classification system of Klingebiel and Montgomery (1973) as adopted by the United Nations Food and Agriculture Organization (FAO, 1976) where lands in Capability Classes V – VII are assigned to non-arable agriculture such as pasture, plantation crop farming or forestry, soil units II and III in the present study can, therefore, be dedicated to forestry use. Here the mangrove trees and their accompanying vegetation will be allowed to rehabilitate the waterlogged and highly saline mangrove ecosystem in the study area. This is more so as the mangrove species in the region, according to Nyananyo (2002), are known for their peculiar colonising and stabilising habits in continually pushing seaward and facilitating land accretion. This way, the Nigerian coastline can continue to be reclaimed and more land made available for broad-spectrum human development in the Niger Delta, in particular, and in Nigeria as a whole.

CONCLUSION

The current trend in soil quality evaluation focuses on the functions of soil in agricultural and natural systems. Thus, measurable soil properties are rated according to their expected impact on predetermined functions and integrated into soil quality classes to indicate different degrees of soil productivity and environmental health. Highly productive soil is the product of a healthy environment and *vice versa*. As such, soils in quality classes 1 and 2 in the current classification system require minor to moderate management inputs and may be deemed to be ideal agricultural soils while those in class 3 represent low productivity with high production costs.

Soils in classes 4 and 5 are non-agricultural or unproductive soils for reasons that may include raw unconsolidated mineral matter such as regolith, for example, Regosols or Inceptisols which are prone to degradation through erosive forces or affected by pollution that poses threats to plants, animals and human wellbeing or to the wider environment. This last group of soils requires remediation or pedologic time through conscious preservation efforts/strategies to develop or rejuvenate and become a stable ecological entity or a healthy environment conducive to plant and animal life. They as well will serve human welfare by being productive and sustainable in agriculture over time, including sites for other human activities and serve as soil reclaimanants.

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