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Research Article
Determination of Minimum Data Set for Vegetable Fields under Biofertilizer-fortified Compost Farming in Southwestern Nigeria

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Abstract
Background and Objective: The concept of minimum data set determination for agricultural soils is vital and indispensable for appraising the functional status of soils and for validating the appropriateness of different management practices. The present study aimed at selecting factors as Minimum Data Set (MDS) and to integrate the selected factors into a unified Soil Quality Index (SQI) for vegetable fields under selected biofertilzer-fortified compost farming systems in southwestern Nigeria (6°.35'N and 4°.50' E). **Materials and Methods:** The farms are organic vegetable fields located in 5 out of the 6 states in the study area. The MDS indicators were selected by using the Principal Component Analysis (PCA)/correlation coefficient analysis approach on 12 soil physicochemical and biological properties. The linear function approach was used for indicator scoring, while indicator scores were integrated to obtain a unified SQI value. **Results:** Significant values were obtained for all physicochemical and biological properties examined. Four uncorrelated and independent soil properties (IR, BD, pH and Av.P) were selected as MDS indicators. Also, MDS indicator scores and SQI value recorded were significantly high. **Conclusion:** Functional MDS indicators and significant SQI value were determined for the present study area as influenced by biofertilzer-fortified compost application.

Key words: Biofertilzer, compost, correlation, physicochemical, indicators, management

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Soil quality evaluation remains a challenging issue globally because of high degree of variability in the properties and functions of soils[1]. Thus, growing concerns about effects of agricultural practices on croplands and their consequent effects on crop productivity and soil quality have kindled renewed interests in the search for scientific means of quantifying their impacts on soil quality[2]. However, in recent times, the concept of minimum data set has been progressively integrated into various aspects of sustainable soil quality monitoring and control of environmental risks[3]. A minimum data set is a small subset of attributes consisting of physical, chemical and biological soil properties that provides practical assessment tool for assessing soil quality[1]. Although, soil quality has been variously defined in broad terms by many authors[4,5], however, from agricultural point of view, soil quality may be defined as 'the capacity of soil to function within ecosystem and land use boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health[1].

A Minimum Data Set (MDS) is deemed to be reliable if it considered inclusion of inherent and dynamic soil properties at the initial selection stage[6]. Inherent properties of the soil (texture, mineralogy etc.) are recalcitrant to changes and are relatively permanent, while dynamic soil properties (pH and OC etc.) are sensitive to changes and are mostly affected by land use and other management practices. Hence, soil dynamic properties are often called manageable soil properties because of their relative flexibility to changes[2]. Minimum data sets for agricultural lands have been determined by using methods such as; Expert Opinion (EO)[7], mathematical/statistical approach[1] or combination of both approaches[3,4]. Importantly, MDS indicators are useful instruments for giving vital information against soil quality deterioration[8].

Land use for various agricultural purposes in the southwestern region of Nigeria is characterized by low nutrients due to intensive cropping and excessive use of chemical inputs which has diminished soil/crop productivity and rendered the soil vulnerable to leaching, compaction and erosion etc.[8,9]. Moreover, acceptance of the idea of organic farming is generally low in Nigeria, but comparatively higher in the southwestern region of the country than other regions. In spite of this, organic farming in the southwestern zone is mainly confined to research institutions and non-governmental farming establishments[10]. Besides, organic farming of horticultural crops is the most affected with the establishment of only one horticultural institute (NIHORT, Ibadan, Oyo state) by the government since 1975. Although these institutions are not relenting in their efforts to propagate organic farming as a viable and sustainable means of ameliorating the menace of inorganic farming on croplands, most farmers are still threatened by government policies, labor intensity, low and unpredictable output issues attached to organic farming in the region[11].

Thus, in view of the apparent reluctance of farmers to embrace organic farming and the continuous challenges posed by unchecked use of chemical inputs on soil quality and crop productivity, it is very exigent to put in place a sustainable agricultural practice and an efficient evaluation method for monitoring land use impacts on soil quality so as to avoid further land degradation in this agro-zone. Therefore, this study aimed at determining Minimum Data Set (MDS) of sensitive indicators for selected biofertilzer-fortified compost vegetable farms in southwestern agro-zone of Nigeria, with the view to recommending its use for periodic monitoring and assessment of soil quality level of organic vegetable production systems in the present study area.

MATERIALS AND METHODS

Description of study area: The study was conducted at selected organic vegetable farms located in southwestern region of Nigeria (6°.35'N and 4°.50' E) during a 3 years (2017-2019) period. The region (Fig. 1) comprises of 6 states (Oyo, Ogun, Osun, Ondo, Ekiti and Lagos) covering an area of about 16,409 km^2. The climate of the region is basically tropical and all states in the study area are similarly characterized by bimodal rainfall with 2 peaks (between 1150 and 1250 mm) in late July/early August and October/November with temperature range of between 21 and 28°C. Vegetation varied from rainforest to derived Savanna and the soil is typically sandy loam with clay and fine sand fractions of Alfisol order that originated from underlying metamorphic basement rock[12].

Sampling sites and soil sample collection: The sampling sites (Fig. 1) are located in five (Oyo, Ogun, Osun, Ondo and Ekiti) out of the six states in the study area: (A) National Institute of Horticultural Research (NIHORT), Idi-ishin, Ibadan (7°.37'N,3°.94' E), Oyo state, (B) Olusegun Obasanjo Centre for Organic Agriculture Research and Development (OOCORD), Ota (7°.95' N, 4°.78' E), Ogun state, (C) Orin-Ekiti farm settlement, Orin (7°.83' N,5°.23' E), Ekiti state, (D) Ile-Oluji farm settlement, Ile-Oluji (7°.27' N, 4°.88' E), Ondo state and (E) Isale-Osun farm settlement, Osogbo (7°.76' N, 4°.56'E), Osun state. The study sites are organic farms that uses compost

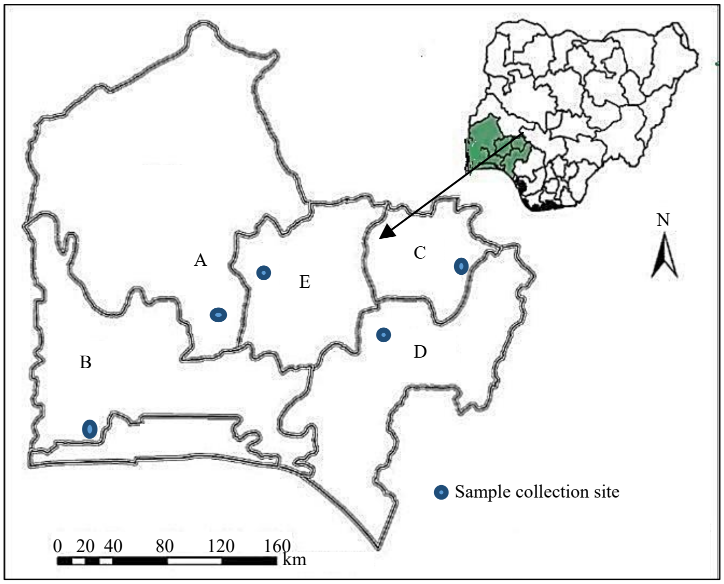

Fig. 1: Map of Nigeria showing south western region and sampling sites
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(from animal and plant wastes) proportionally mixed with biofertilzer formulations containing consortium of Plant Growth Promoting (PGP) micro-organisms (*Azospirillum* sp., *Azotobacter* sp., Phosphate solubilizers and Arbuscular mycorrhizal fungi (AMF) sp.) procured from International Institute of Tropical Agriculture (IITA), Moniya, Ibadan, Nigeria. Soil samples were collected by using soil auger and after each collection period, samples were kept in sterile bags and immediately taken to the laboratory for further analysis.

Soil sample analysis: The samples were allowed to dry in the open air until attainment of friability. Soil Water Holding Capacity (WHC) was determined by following the method described by Ibitoye[13]. The Bulk Density (BD) was obtained by the gravimetric soil core method described by Blake and Hartage[14]. The total porosity was obtained from BD determined by using the method developed by Daniel and Sutherland[15]. Infiltration Rate (IR) was determined by using the method of Adeyemo *et al.*[12]. The organic carbon content was determined by using the Walkley-Black wet oxidation procedure described by Nelson and somer[16]. Soil pH was determined in distilled water by using the pH meter with water ratio of 1:2. EC was determined following the procedure described by Reeuwijk[17]. Available nitrogen (N) was estimated by using the alkaline potassium permanganate distillation method employed by Subbiah and Asija[18], available phosphorus (P) was determined by using the method of Olsen *et al.*[19], while available potassium (K) was measured by using 1N NH OAC (pH 7) as an extractant[20]. Soil DHA was determined by using the method of Klein *et al.*[21] and MBC was measured by using the fumigation extraction method described by Jenkinson and Ladd[22].

Determination of Minimum Data Sets (MDS): The Principal Component Analysis (PCA) and correlation coefficient analysis were used to determine MDS and only PCs with eigen values $\geq$1 were examined. Under each PC, only the highly weighted factor loadings (with absolute values $\geq$0.50) were considered from each PC. The highly weighted and uncorrelated factors (assumed to be a correlation coefficient >0.60) in each PC were retained in the MDS. Also, among well correlated variables, the variable with highest factor loading (absolute value) was chosen for MDS[1].

Scoring of selected Minimum Data Set (MDS) indicators: The selected MDS were transformed into combinable unit scores (between 0 and 1) and three types of linear scoring functions viz., 'more is better', 'less is better' and 'optimum' were generated by using linear scoring function equations given by Prasad *et al.*[23]:

$$L = \frac{x-s}{t-s} \quad (1)$$

$$L = 1 - \frac{x-s}{t-s} \quad (2)$$

$$L= \frac{x-s}{t-s} + L = 1- \frac{x-s}{t-s} \quad (3)$$

where, L is the linear score, x is the mean of soil parameter value and s and t are the lower and upper threshold values. Equation 1 is used for "more is better" scoring function, Eq. 2 for "less is better" and combination of both for "optimum" scoring function (Eq. 3). The 'more is better' scoring functions was assigned to WHC, POR, OC, Av. N, Av. P, Av. K, DHA and BMC, 'optimum' function was assigned to pH, EC and IR, while 'less is better' function was assigned to BD. If the calculated score is >1.0, it was considered as 1.0[1].

Computation of Soil Quality Index (SQI): Soil quality computation was done following the function based approach. The individual scores of each indicator were aggregated to obtain unified SQI by using the equation given by Prasad *et al.*[23]:

$$SQI: i=1\sum^{n} \frac{L}{n} \quad (4)$$

Data analysis: Statistical analyses including Principal Component Analysis (PCA) and correlation co-efficient were used to determine Minimum Data Sets (MDS) and Soil Quality Indexes (SQIs) with Excel Microsoft word[24] and IBM® SPSS® Statistics V21×86 model Software Application (IBM, NY, USA).

RESULTS

Soil physico-chemical and biological properties of the study sites: In the present study, the mean values for all soil physico-chemical and biological properties at the various study sites were significant (Table 1). Highest values for WHC (24.9%), POR (44.5%), IR (3.7 cm h^{-1}) and OC (0.89%) were obtained at site D, while sites B and E recorded highest values for BD (1.29 g cm^{-3}) and EC (3.33 dS m^{-1}), respectively. Soil macro-nutrients (Av. N, Av. P and Av. K) showed differing values among the sites. However, highest value of Av. N (32.40 mg kg^{-1}) was found at site D, while highest Av. P (21.41 mg kg^{-1}) and Av. K (159 mg kg^{-1}) were obtained at site E and D, respectively. The biological variables examined (DHA and BMC) gave values between 137.77 and 190.44 µgTPFg^{-1} for DHA and 198.0 and 255.3 µg g^{-1} for BMC among the sites. Overall, significantly higher mean values of physico-chemical and biological parameters were obtained at sites C, D and E over sites A and B.

Selection of Minimum Data Set (MDS) indicators: Results of Principal Component Analysis (PCA) and Correlation Co-efficient Analysis (CCA) showed only 2 Principal Components (PCs) with eigenvalues $\geq$1 (Table 2). Principal component 1 and 2 accounted for 83.77 and 12.81% variance, respectively with cumulative variance of 96.69%. However, PC1 had maximum number 9 of highly weighted factors viz: WHC (1.020), POR (.961), IR (1.082), BD (-1.028), EC (.692), OC (.564), Av. K (.802), DHA (1.010) and BMC (.933). Among the highly weighted variable, IR recorded highest factor loading (1.082) and was positively correlated (Table 3) with other highly weighted factors except with BD, where it recorded strongly negatively correlation (r-.970**). Thus, IR and BD were selected as MDS indicators from PC 1. In PC 2, only 2 factors viz: pH (.827) and Av. P (-1.037) were highly weighted and both were negatively correlated (r-.927**) with each other (Table 3). Hence, the two variables were retained for inclusion in the MDS. Therefore, the final variables selected

Table 1: Soil physicochemical and biological values and their threshold values

	Study sites						Threshold values	
Soil properties	A	B	C	D	E	Mean (x)	Lower (s)	Upper (t)
WHC (%)	18.5	18.8	24.4	24.9	22.4	21.8	10	25
POR (%)	35.2	33.4	44.3	44.5	42.4	39.9	20	60
IR (cm h^{-1})	2.5	2.6	3.9	3.7	3.1	3.1	1	4
BD (g cm^{-3})	1.28	1.29	1.02	1.01	1.11	1.14	0.9	1.8
pH (1:25)	6.99	6.78	6.69	6.71	6.48	6.73	5	9
EC (dSm^{-1})	1.95	2.25	2.99	3.22	3.33	2.75	0.2	4
OC (%)	0.55	0.54	0.66	0.89	0.86	0.70	0.3	1.5
Av. N (mg kg^{-1})	25.28	28.16	32.31	32.40	31.19	29.87	15	45
Av. P (mg kg^{-1})	14.29	16.22	16.24	16.53	21.41	16.94	12	55
Av. K (mg kg^{-1})	140.40	143.23	154.57	159.62	157.43	151.05	100	300
DHA (µgTPFg^{-1})	137.77	142.71	187.24	190.44	172.41	166.11	25	275
BMC (µg g^{-1})	198.0	211.7	250.2	255.3	241.6	231.36	50	380

WHC: Water holding capacity, POR: Porosity, IR: Infiltration rate, BD: Bulk density, EC: Electrical conductivity, OC: Organic carbon, Av. N: Available Nitrogen, Av. P: Available Phosphorous, Av.K: Available Potassium, Deh: Dehydrogenase, BMC: Biomass carbon, A: National institute of horticultural research (NIHORT), Idi-ishin: Ibadan, Oyo state, B: Olusegun Obasanjo centre for organic agriculture research and development (OOCORD), Ota, Ogun state, C: Orin-Ekiti farm settlement, Orin: Ekiti state, D, Ile-Oluji farm settlement, Ile-Oluji, Ondo state, E: Isale-Osun farm settlement, Osogbo, Osun state

Table 2: Result of Principal Component Analysis (PCA)

Parameters	PC 1	PC 2
Eigenvalue	10.05	10.530
Variance (%)	83.77	12.810
Cumulative (%)	83.77	96.690
Eigen vectors (factor loading)		
WHC	10.020	00.067
POR	00.961	-00.035
IR	10.082	00.258
BD	-10.028	-00.071
pH	-00.257	00.827
EC	00.692	-00.467
OC	00.564	-00.487
Av. N	00.875	-00.176
Av. P	-00.104	-10.037
Av. K	00.802	-00.320
DHA	10.010	00.022
BMC	00.933	-00.119

WHC: Water holding capacity, POR: Porosity; IR: Infiltration rate, BD: Bulk density, EC: Electrical conductivity, OC: Organic carbon, Av. N: Available Nitrogen, Av. P: Available Phosphorous, Av. K: Available Potassium, BMC: Biomass carbon, Deh: Dehydrogenase and Boldface values: Highly weighted factor loading, Boldface and underscored values = MDS indicator

Table 3: Correlation matrix of relationship among physicochemical and biological soil properties

TDS	WHC	POR	IR	BD	pH	EC	OC	Av. N	Av. P	Av. K	DHA	BMC
WHC	1											
POR	0.975**	1										
IR	0.972**	0.927*	1									
BD	-0.997**	-0.987**	-0.970**	1								
pH	-0.596	-0.631	-0.486	0.588	1							
EC	0.885*	0.903*	0.778	-0.880*	-0.882*	1						
OC	0.770	0.808	0.598	-0.766	-0.728	0.910*	1					
Av. N	0.944*	0.897*	0.909*	-0.928*	-0.776	0.933*	0.756	1				
Av. P	0.327	0.417	0.171	-0.329	-0.927*	0.724	0.665	0.505	1			
Av. K	0.935*	0.939*	0.834	-0.929*	-0.796	0.987**	0.925*	0.943*	0.612	1		
DHA	0.999**	0.974**	0.968**	-0.995**	-0.633	0.902*	0.777	0.958*	0.364	0.945*	1	
BMC	0.980**	0.949*	0.934*	-0.970**	-0.728	0.943*	0.809	0.988**	0.469	0.969**	0.988**	1

**Correlation is significant at the 0.01 level (2-tailed), *Correlation is significant at the 0.05 level (2-tailed), TDS: Total data set, WHC: Water holding capacity, POR: Porosity, IR: Infiltration rate, BD: Bulk density, EC: Electrical conductivity, OC: Organic carbon, Av. N: Available Nitrogen, Av. P: Available Phosphorous, Av.K: Available Potassium, Deh: Dehydrogenase, BMC: Biomass carbon

Table 4: Indicator scoring and SQI computation

		Threshold values					
MDS Indicator	Mean indicator value (x)	Lower (s)	Upper (t)	Scoring function	Scoring process	MDS score	SQI ($i=1\sum^{n}L/n$)
IR	30.10	1	4	Optimum	0.7+0.3 (Eq. 3)	1.00	
BD	10.14	0.9	1.8	Less is better	1-0.24/0.9 (Eq. 2)	0.73	0.81
pH	60.73	5	9	Optimum	0.43+0.57 (Eq. 3)	1.00	
Av. P	16.94	8	25	More is better	8.94/17 (Eq. 1)	0.52	

IR: Infiltration rate, BD: Bulk density, Av. P: Available Phosphorous, MDS: Minimum data set, SQI: Soil quality index

as MDS indicators for the biofertilizers-fortified vegetable fields in the present study area are IR, BD, pH and Av. P.

Indicator scoring and Soil Quality Index (SQI) computation: Results of indicator transformation into scores and SQI computation in the present study are as presented in Table 4. Obtained data revealed that IR and pH falls within the 'optimum' scoring function and each variable was scored 1.0. Also, BD with 'less is better' scoring function gave indicator score of 0.73. The 'more is better' scoring functions was used to analyze Av. P and an indicator score of 0.52 was obtained. Soil Quality Index (SQI) was computed by adding all MDS indicator scores and the product was divided by the number of MDS indicators (Eq. 4) to obtain an SQI value of 0.81 for the biofertilizers-fortified vegetable fields in the study area.

DISCUSSION

The present study recorded significant values for all the physico-chemical parameters evaluated with all values falling within the stipulated threshold values given by several authors for most organic production systems[7,23]. Enhancement of soil parameters could be ascribed to the reported unique influences of biofertilzer-compost integration in improving soil structure, reducing bulk density, increasing porosity, water infiltration rate and soil water holding capacity on agricultural soils in southwestern Nigeria[12]. Furthermore, the observed variation in the soil property values between sites A and B and sites C, D and E could be due to effects of slight differences in climate as a result of geographical location, certain parts of the states (Oyo and Ogun), where sites A and B are located falls within the transition zone between the rainforest and derived Savanna vegetation zones, while sites C, D and E (Ekiti, Ondo and Osun states) are located within the rainforest vegetation zone[25,26].

The final appearance of IR, BD, pH and Av.P in the present MDS of the study area by using the PCA/correlation coefficient approach is consistent with the works of many authors[3,5], who have reported the reliability of the statistical approach for reducing dimensionality of complex data sets. All the variables selected as MDS indicators (IR, BD, pH and Av. P) in the present study are uncorrelated and independent of each other and thus, their appearance in the MDS is considered significant. The manifestation of IR and BD in the MDS could be influenced by soil particle aggregation, microbial activities for macrospores formation as well as amount of clay particles in soils[12].

Moreover, expected changes in the pH status of the soil as a result of increased production of various organic acids such as; humic, succinic, lactic and oxalic acids, etc. from microbial decomposition of organic matter in the compost[25,26] might have contributed to the appearance of pH in the present MDS. The presence of Av. P in the current MDS confirmed earlier report by Soremi *et al.*[9] that soils of southwestern Nigeria are low in phosphorous and that the little available P is rapidly used up by the plants since phosphorous mostly exists in stable and insoluble forms with Aluminum (Al-P), Iron (Fe-P) and Calcium (Ca-P).

The transformation of selected MDS indicators into scores by using linear scoring function approach is in line with the works of many authors who have reported lower capacity of the non-linear function approach for predicting the end point variables[6,23]. The threshold values used in calculating indicator scores was based on measured values suggested by various authors[7,23] for most agricultural systems. Assignation of 'more is better' scoring functions to WHC, POR, OC, Av. N, Av. P, Av. K, DHA and BMC were based on their important roles in nutrient availability and retention[6]. Also, 'optimum' functions were assigned to pH, EC and IR because of their defined limits for biological and chemical activities in the soil[23], while BD was assigned 'less is better' function because of its inhibitory influences on plant root and microbial growth[1].

Furthermore, the SQI value (0.81) recorded for the biofertilzer-compost vegetable fields in the current study is higher than the SQI values (0.39-0.50) obtained by Klimkowics-Pawlas *et al.*[1], but falls within the 'very high' soil quality grade (>0.60) proposed by Li *et al.*[27]. Therefore, improved management practices including liming, buffering and application of more balanced biofertilzer-compost components would be required for optimizing the effectiveness of the determined MDS and SQI for periodic monitoring of changes in soil quality at the present study area.

CONCLUSION

The present study concluded that both the functional MDS indicators and significant SQI value obtained were influenced by biofertilzer-fortified compost application and would serve as powerful tools for diagnosing nutrient needs and soil quality status of the vegetable fields in the present study area.

SIGNIFICANCE STATEMENTS

This study discovered that infiltration rate, bulk density, pH and available phosphorous were the most sensitive soil properties for use as MDS indicators in the present study fields. The study also revealed that both the MDS indicators and SQI value obtained were influenced by biofertilzer-fortified compost application and would serve as vital instrument for evaluating soil fertility and quality statuses of the vegetable fields in the present study area.

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