ASSESMENT OF SOIL QUALITY AND ITS RELATION TO FRUIT CROP PRODUCTIVITY

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ABSTRACT

Assessment of soil quality is important to sustaining high crop yield. Therefore, a proper soil quality assessment by integrating soil characteristics to get overall assessment with making soil quality index (SQI) to reflect soil productivity and supporting plant growth is necessary. This study aims to determine the SQI and its relation to fruit crop productivity which was carried out at seven locations with variable soil charavteristics. The location of the research was Saree and Nisam-Aceh province, Gelumbang and Banyuasin 3-South Sumatera Province, Metro and Gedong Tataan-Lampung Province, and Kelapa- Bangka Belitung Province. The analisis of soil quality index used eight (8) key soil characteristics that have most important role in determining and managing crop growth and production, i.e: effective depth, texture. bulk density, pH, organic matter content, cation exchange capacity, and base saturation as indicator parameters. Each parameter was given a score between 0-5. The result showed that Soil Quality Index can accurately assessed soil quality by using the 8 key parameters as a dataset. The soils studied were categorized as medium to very good soil quality, with low organic carbon and low cation exchange capacity being the most common limiting factors. SQI has a relatively good positive correlation to fruit crop performance with R^2 *of 0.692.*

INTRODUCTION

Food self sufficiency is one of the targets in Indonesia agricultural development. To accelerate the achievement of the target, soil as a main resource should be able to be managed for optimum production. Soil is a fundamental component of agriculture as such soil quality is one of the key factors to reach food self sufficiency. In general term, soil quality is the capacity of the soil to function within the boundaries of an ecosystem to maintain biological productivity and environmental quality as well as to improve the health of plants and animals (Doran and Parkin, 1994). In term of crop production, soil quality also refers to the capacity of the soil to support crop growth and production (Thoumazeau *et al.* 2019) by providing a physical, chemical and biological environment especially for the exchange of water, nutrients, energy and air (Martunis et. al., 2016). Therefore, high soil quality is more or less equivalent to high productivity and long-term resilience without significant soil or environmental degradation (Kiani et al., 2017). Nevertheless, no soil is likely to provide all those above functions, some of which occur in natural ecosystems and some of which are the results of human modifications.

Soil quality decline is an important factor in crop production system that cannot be ignored. Soil quality is dynamic in nature and subject to degradation with time. It may degrade due to excessive land utilization for agricultural activities (Reijntjes *et al.* 1992). Soil quality degradation may also occur due to the increased pressure on land resources associated with the intensification and expansion of human activities. Soil quality may decrease periodically due to agricultural mismanagement. Agricultural activity is considered as a main trigger of land degradation, especially in developing countries (Barbier EB 2004; Giliba *et al.* 2011; Marshall 2012).

Maintaining the functions of soil is therefore, central to the achievement of sustainable agricultural development. Soil quality may be used as key elemen on soil management to achieve sustainable production (Nakajima *et. al.* 2016). Therefore, a proper evaluation of soil condition is necesassy to guarantte that sustainable production to be achieved. The evaluation of soil quality should not use a single indicator but should use composite or multiple indicator that are integrated to an index.

The soil quality index (SQI) is a quantitative assessment concept and is widely used in the evaluation of agricultural production areas. Identification of soil quality index need a selection of soil characteristics as indicator parameters based on their functionalities and reation to crop growth and production as well as their sensitivity to land management (Doran and Parkin, 1994). In calculating SQI, principal component analysis (PCA) and expert opinion (EO) methods can be used for selecting key parameter (Vasu, et.al., 2016, Mukhopadhyay et.al., 2016). Some researcher stated that no single parameter can be appropriate as a measure of soil quality (Dexter and Czyz 2000). In land suitability evaluation, some indicator parameters are used as criterion to identify suitability classes but they are not well enough to represent soil quality as a whole. Therefore, a soil quality evaluation system that integrate various important parameter into a single index value is necessary.

This study aims at evaluating soil characteristics at 7 location and evaluating how soil quality can be assesed by integrating various soil characteristics that have a great influence in fruit crop production into soil quality index.

METHODS

Description of the Areas

The study was conducted on seven locations with more or less similar climatic condition, i.e Saree Aceh, Nisam Aceh, Gelumbang-Muara Enim South Sumatera, Banyuasin 3 South Sumatera, Kelapa Bangka Island, Metro Lampung, and Gedong Tataan Lampung. The seven areas were characterized by humid climate with annual rainfall about 2000 – 2500 mm. The mean annual air temperature was 26 – 27.5 °C. The land use of study areas before fruit crop was generally bush.

Soil Characterization

The seven study areas were observed in term of soil characteristics. Composite disturbed soil samples for laboratory analysis were collected from each location and air dried to pass a 2 mm sieve. The methods used in laboratory analysis for physical and chemical properties were standard method (BBSDLP 2005, 2006). The particle size distribution of each sample was determined by the pipette method after removal of organic matter and carbonates. The pH was measured on saturation extracts using standard pH meter. Organic C was measured by using Walkley-Black procedure. Exchangeable cations and cation-exchange capacity were determined by using NH_4-Acetat 1N- pH7. Bulk density (B) measured using core sample/gravimetric method. Upon soil sampling, some parameters such as effective soil depth and soil drainage were observed directly on the field.

Fruit crop (especially *Citrus* sp) was transplanted on more or less the same time i.e. on the 2nd week of October 2018. Upon transplanting, plant height was measured. Plant height was then measured every 6 mounth until September/October 2020. When crops had fruited, the fruit production was also measured. The differences in plant height after one year of transplantion and average fruit production per plant per year reflect plant performance as a response to soil and environment condition.

Analysis of Soil Quality Indeks

The analisis of soil quality index was started with the selection of parameters most vital for determining and managing plant growth and production. As some of soil parameters were synthesized and redundant, only 8 parameters were selected, i.e: effective depth, soil drainage, texture. bulk density, pH, organic matter content, cation exchange capacity, and base saturation. Those parameters are soil paramters that very often used for soil quality monitoring (Asgarzadeh *et al.* 2010; Moncada *et al.* 2014) and are used as criteria in land suitability evaluation for fruit crops (Harjowigeno and Widiatmaka, 2007). The 8 parameters were weighted differently for their different roles in plant growth and production; thus, each parameter was attributed to a weight coefficient (Table 1).

The next step was scoring for each parameter from 0 to 5 (Table 2). This score was derived from the categorizations for each parameter which have been used to assess soil quality by the Indonesian Center for Agricultural Land Resource Research and Development (Pusat Penelitian dan Pengembangan Sumberdaya Lahan Pertanian Indonesia), Bogor.

Soil quality index was then calculated as follow:

$$\text{SQI} = \sum_{i=1}^{n} Wi\ x\ So \quad \text{................................(1)}$$

Keterangan:
SQI = Soil quality index
Wi = weighted coefficient for each selected indicator parameter
So = the score for ech selected key indicator parameter
n = 8 (the number of selected key indicator parameter)

The SQI was then used for categorization of soil quality from which the soil quality level was classified into seven categories (Table 2) for interpretation and comparison. A higher SQI value indicated better soil quality.

Table 1 Soil parameter and their corresponding score to calculate soil quality index

Key Parameters	Score				
	1	2	3	4	5
	Very bad	Bad	Moderate	Good	Very good
Efective depth (cm)	< 20	20 - 40	40 - 60	60 - 80	> 80
Drainage	VP	P, E	SE	SP	MW, W
Texture class	S	LS, HC	C, SiC, SC,	Si, SL	L, SiL, CL, SCL, SiCL
Bulk density (g/cm^2)	> 1,6	1,3-1,6	1,1-1,3	1.0 - 1,1	≤ 1.0
pH	< 3.5	3.5 – 4.5	4.5 – 5.0	5.0 – 5.5	5.5 – 6.6
C-organic content	> 8.5	8.0 – 8.5	7.5 – 8.0	6.5 - 7.5	> 4.0
CEC (cmol/kg)	0	< 0.8	0.8 – 2.0	2.0 – 3.0	> 3.0
Base saturation (%)	0	< 5	5 - 16	16.0 - 24.0	> 24.0
	< 10	10 - 20	20 - 35	35 - 50	> 50

Sources: BBSLDP 2005, 2006, Mukherjee and Lal 2014, Nakajima *et al* 2015

MW = moderately well, W = well, SE = somewhat excessive, SP = somewhat poor, P = poor, E = excessive, VP = very poor, S = Sand; LS =loamy sand; SL = sandy loam; L = Loam; SiL = silty loam, SiCL = silty clay loam; SCL = sandy clay loam; CL = clayey loam; SC = sandy clay, Si = silt, SiC = silty clay, C = clay; HC = heavy clay

Table 2 Criteria for classification of soil quality level based on SQI

No	SQI	Category
1	≤1.00	Very bad
2	1.00< x <2.00	Bad
3	2.01< x ≤ 2.50	Slightly bad
4	2.50< x ≤ 3.50	Moderate
5	3.51 < x ≤ 4.00	Fairly good
6	4.01 < x ≤ 4.50	Good
7	4.51 < x ≤5.00	Very good

RESULTS AND DISCUSSION

The Soil Characteristics

The major physical and chemical properties of the soils were presented in Table 3 and Table 4. The soil characteristics of the seven locations are variable. Soil effective depth vary from 40 cm to aver 100 cm. The clay content of two locations (Gedong Tataan and Nisam) showed values of > 50 %, whereas in three other locations (SMK UN Banyuasin, SMK N Gelumbang, and SMK PP Saree) is slightly greater than 30 %. The lowest clay content is at SMK N Kelapa (6.5 %). The differences of parent material seem to contribute to clay content variability. Most soil showed more or less normal bulk density ranging from 0.95 – 1.15 gram/cm^3, and only soil from SMK Metro showed high bulk density (1.38 gram/cm^3)

The pH of the soils was generally very acidic to acidic, except for soil from SMK Metro, SMK Gedong Tataan, and SMK Saree that are slightly acidic. In term of organic carbon, mostly soil showed very low to low levels, except for soil of SMK Saree that showed moderate level and soil of SMK Gelumbang that showed high level. For organic nitrogen, no location featured high levels of organic nitrogen (> 0.51%), mostly showed very low and low levels of organic nitrogen (<0.21%). While for available phosphate, 2 locations demonstrated very high level (>35 ppm) i.e. SMK Gelumbang and SMK Gedong Tataan.

The cation exchange capacity (CEC) of the soils different among the soil but no locations demonstrated high cation exchange capacity (CEC) (>24 cmol/kg). Exchangeable Ca^{++} and Mg^{++} contents of the soils range from very low to low except those of soil at SMK Gelumbang and SMK Metro which is categorized as moderate. This result suggests that continuous application of organic material (compost) and lime to increase soil pH in SMK N Gelumbang provide more influence rather than parent material. Mostly locations showed moderate to high exchangeable potassium (> 0.3 cmol/kg) and only 1 location showed low exchangeable potassium (< 0.3 cmol/kg). Mostly locations showed very low aluminum saturation (< 10%), except for SMK Banyuasin (moderate) and SMK Nisam (very high).

Table 3. Effective Depth, Drainage, Bulk Density and texture of soil at seven locations

Location	De (cm)	Dr	BD (g/cm^3)	Particle composition (%)			Texture class
				Sand	Silt	Clay	
SMKN Gelumbang	100	W	0.95	45.1	21.7	33.2	SCL
SMKN Saree	60	W	1.00	16.6	51.6	31.8	SiCL
SMKN Kelapa	40	P	1.08	69.7	23.8	6.5	LS
SMKN Banyuasin	90	MW	1.10	19.1	43.6	37.3	SiCL
SMKN Metro	100	SP	1.38	22.9	35.8	41.3	C
SMKN Gdg Tataan	100	MW	1.15	14.3	30.9	54.8	C
SMKN Nisam	70	MW	1.22	13.8	30.3	55.9	C

Note: De = Effective depth, Dr = drainage, MW = moderately well, W = well, SE = somewhat excessive, SP = somewhat poor, P = poor, E = excessive, VP = very poor, BD = bulk density, KP = soil penetration resistance, SiCL = Silty clay loam, SL = sandy loam, SCL= sandy clay loam, C = Clay

Table 4. Major soil chemical characteristics of soil at seven locations

Location	pH H_2O	C-Organik (%)	N-total (%)	Available P_2O_5	Cation Exchangeable (NH_4-Acetat 1N, pH7)						Al (cmol/kg)	K- Al (%)
					Ca	Mg	K	Na	CEC	KB *		
					------------------------- cmol/kg ---------------------					%		
SMKN Gelumbang	6.1	3.9	0.4	385.0	10.30	1.4	0.5	0.03	20.2	60.6	ND	0
	SA	T	Sd	ST	Sd	Sd	Sd	SR	Sd	T	SR	SR
SMKN Saree	5.4	2.1	0.4	8.2	4.00	1.7	0.8	0.02	13.8	47.2	ND	0
	A	Sd	Sd	SR	R	Sd	T	SR	R	Sd	SR	SR
SMKN Kelapa	4.5	1.0	0.1	8.9	-	5.7	0.5	0.30	11.6	100.0	0.6	4.8
	VA	SR	R	SR	-	Sd	Sd	R	R	ST	SR	SR
SMKN Banyuasin	4.4	1.5	0.1	21.7	1.80	0.3	0.3	0.35	10.2	27.3	2.6	25.3
	VA	R	R	Sd	SR	SR	Sd	R	R	R	SR	Sd
SMKN Metro	6.3	1.28	0.26	21	12.07	1.9	0.39	0.13	15.86	91.33	0	0
	SA	R	Sd	R	Sd	Sd	Sd	SR	Sd	ST	SR	SR
SMKN Gedong Tataan	5.9	1	0.14	167.2	1.31	0.5	3.65	0.3	10	57.7	ND	0
	SA	R	R	ST	SR	R	ST	R	R	T	SR	SR
SMK N 1 Nisam	4.8	0.21	0.04	11.5	0.18	0.65	0.1	0.19	15.63	7.18	10.92	70
	VA	SR	SR	R	SR	R	R	SR	R	SR	SR	ST

Remark: CEC = Cation exchange capacity, KB = Base saturation, K-Al = Aluminum saturation, A = acidic, SA = slightly acidic, VA = very acidic, ST = very high, T = high, Sd = moderate, R = low, SR = very low, ND = not detected

Soil Quality Index (SQI)

Soil quality indexes for the 7 locations as calculated using the 8 key parameters are shown in Table 5. Soil quality is different in different locations because its performances are different or attributable to different types of parent material and to soil management.

Tabel 5 Result of soil quality assessment using Soil Quality Index on each location

Location	De	Dr	Txt	BD	pH	C-Org	CEC	KB	SQI	Class
	(.15)	(.15)	(.15)	(.10)	(.15)	(.10)	(.10)	(.10)		
Gelumbang	5	5	5	5	5	5	4	5	4,90	VG
Saree	3	5	5	5	4	4	3	4	4,15	G
Kelapa	2	2	2	4	3	3	3	5	2,85	M
Banyuasin	5	5	5	4	3	3	3	3	4,00	FG
Metro	5	4	3	2	5	3	4	5	3,95	FG
Gedong Tataan	5	5	3	3	5	3	3	5	4,10	FG
Nisam	4	5	3	3	3	2	3	1	3,15	M

Remark: Numbers in the bracket are the weight of each parameter

De = effective depth, Dr = drainage, Txt = texture, BD = bulk density, C-org = C-organic content, CEC= cation exchange capacity, KB = base saaturation, VG = very good, G = good, FG = fairly good, M = moderate

The 7 locations with different soil characteristics showed variable score for each indicator parameter. This attributable to variability of soil quality as indicated by the different of the total scores that represent soil quality index that range from 2.85 to 4.90. A higher score indicated better quality for the corresponding parameter. The highest SQI (4.90) was found for location of SMK Gelumbang and is categorized as very good. The lowest SQI (2.85) was found at location of SMK Kelapa with the category of moderate (Table 5). Of the 7 locations studied, 1 location showed a very good soil quality, 1 location showed a good soil quality, 3 locations showed fairly good soil quality, and 2 locations showed moderate soil quality. For the studied locations, there was no soil quality that was categorized as slightly bad, bad and very bad.

The Relationship of SQI to Fruit Crop Performance

Plant performance as indicated by the change in plant height and production of citrus sp on the 7 different soils is shown in Table 6. Soil at SMK N Gelumbang resulted in highest plants performance, followed by soil at SMK Saree, soil at SMK Banyuasin, and soil at SMK Gedong Tataan, respectively. The soil at SMK Kelapa with the lowest SQI showed the lowest plant performance.

Tabel 6 Fruit crop performance at each location

Location	Number of crops	Crop performance			Relative Performa (%)***
		MAI* (cm)	Production**	% fruited crop	
SMKN Gelumbang	425	110 - 120	-	90 - 100	90
SMKN Saree	425	50 - 70	3.5 – 4.0	90 - 100	90
SMKN Kelapa	179	30 - 40	1.0 – 1.5	70 - 90	50
SMKN Banyuasin	250	60 - 75	2.5 – 3.0	90 - 100	90
SMKN Metro	350	45 - 60	-	90 - 100	85
SMKN Gdg Tataan	231	-	2.0 – 3.0	60 - 80	80
SMK N Nisam	370	40 - 60	1.8 - 2.0	35 - 50	75

Remark: MAI = Mean annual increment = change in plant height in the first year
** Production per crop per year (kg/crop/year)
*** Compared to an expected production of the corresponding crops

The soil at SMK Gelumbang is derived from old sediment rock (sand stone, clay stone) which was originally low in nutrient. Nevertheless, in this location soil amendment with organic material and lime to improve soil quality had been consistently practiced. This practiced has apparently resulted in better soil physical and chemical charakteristics. Compost amendment may result in increasing waterholding capacity, porosity, and surface area (Cogger, 2005), lower bulk density and higher macroporosity (Rivenshield and Bassuk, 2007**)**, increasing soil pH (Weindorf et al., 2006), and increasing phosphorus (P) and potassium (K) availability (Johnson et al., 2006).

The scatter plot of SQI against fruit crop relative performance demonstrated that correlation of SQI to relative crop performances was good with correlation coefficient (r) = 0.832 (Figures 1). This suggest that assessment of soil quality using soil quality index with the 8 key parameters may provide good result. Crop yield is obviously related to soil quality though other factors such as climate, pest and disease and soil management may also influence crop yield.

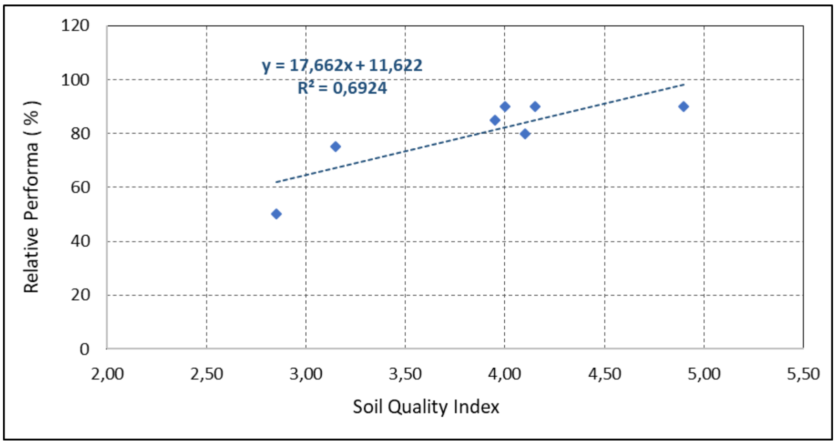

Figure 1 The relationship of soil quality index to fruit crop performance

The results demonstrated that the 8 key parameters selected could reflect well soil quality to support fruit crop growth and production. The 8 selected parameters may represent soil quality in term of water retention capacity, water and nutrient supply, providing good aeration and easiness of root penetration (Cherubin MR *et al*. 2016, Rachman, 2019). An SQI can identify productivity problems, make realistic estimates of food production, evaluates land and soil management, and agricultural systems.

In calculation soil quality index, the soil characteristics were assumed to have different importance but with no tradeoff between them. For example, shallow soil effective depth could not be compensated for by excellent quality of CEC, or vice versa. Therefore, it is possible that even though an SQI score is high due to high scores on various parameters, productivity potential might be low due to one or several very low to low scoring parameters (≤ 2.00). Assessment of soil quality using soil quality index (SQI) may provide an incomplete information as the crop productivity may be influenced mainly by the most limiting factor.

CONCLUSION

Soil characteristics of the 7 locations are variable reflecting the difference in the composition of parent rocks and soil management. The different characteristics result in different soil quality. The majority of the soils studied were classified as "medium" quality, with the most common limiting factors being low levels of organic carbon and cation exchange capacity.

The SQI calculated using the 8 key parameters can accurately asses soil quality for fruit crop production in the studied location as it has good correlation to fruit crop performance ($r = 0.832$, $R^2 = 0.693$). The 8 key parameters used were: effective depth, drainage, texture class, bulk density, pH, C-organic content, cation exchange capacity, and base saturation.

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