Development of technique to determine soil quality index for assessing soil condition

L M Rachman*
Department of Soil Science and Land Resources, Faculty of Agriculture, Bogor Agricultural University, Bogor, Indonesia

*latiefra@apps.ipb.ac.id

Abstract. An assessment of soil condition related to soil and soil use is still rely to soil type based on soil classification and land suitability class. Soil type and land suitability class cannot be used to evaluate soil condition/quality changes effectively. In many cases, soil type and land suitability class are remaining the same even there has been soil condition/quality change. Soil Quality Index (SQI) is the best solution to answer this circumstance. Two schemes proposed to determine SQI, i.e., Simple Scheme of SQI (SS-SQI) and Comprehensive Scheme of SQI (CS-SQI), both compose of few soil physical, soil chemical, and soil biology parameters with their own proportion then each soil properties are scored and finally summarized to get the total score. SS-SQI and CS-SQI consists of 13 and 20 soil properties, respectively. Field investigations supported by laboratorial analysis conducted at 48 locations in Banten Province, Indonesia. Results showed that average score of SS-SQI is similar or very close with average score of CS-SQI. The average SQI score is 4.486 and classified as slightly high. In the “numeral” form, SQI is easier, practical and much more sensitive used as a tool to monitor and evaluate change and dynamic of soil condition/quality.

1. Introduction
Soil evaluation now considers the environment implications as well as economic productivity, seeking to be more holistic in its approach. Sometimes, exploitation with relatively low regard and attention for maintenance of soil quality has dominated and producing degradation [1,2]. Therefore, soil quality assessment is very important since it provides a basic means to evaluate the sustainability of agricultural and land management systems [3]. Soil quality can be defined as “the soil’s capacity or fitness to support crop growth without resulting in soil degradation or otherwise harming the environment. In addition to assessments of degradation, a more quantitative assessment is needed of how farming practices are affecting the capacity of the soil to produce food and perform certain environmental function (i.e. soil quality) and whether the capacity is being degraded, aggraded, or is remaining unchanged [4,5]. Soil quality depends in part on soil’s natural or inherent composition, which is a function of geological materials and soil state factors or variables (e.g., parent material and topography) [6]. Attribute of inherent soil quality, such as mineralogy and particle size distribution, are mainly viewed as almost static and usually show little change over time. The type of area, i.e. whether in semiarid, temperate, pole, subtropical or tropical area should be taken into consideration in soil quality assessment and the development of Soil Quality Index. Indonesia and other tropical areas which have very high rainfall and intensive weathering can lead to produce acid soils with high content of Aluminium (Al) and Ferry (Fe) contents that can inhibit plant growth and reduce plant production. Soil quality index is needed to
identify problem production areas, make realistic estimates of food productions, monitor changes in sustainability and environmental quality as related to agricultural management, and assist federal and state agencies in formulating and evaluating sustainable agricultural and land-use policies [7,8].

Unlike air or water for which we have quality standards, soil quality has been difficult to define and quantify [5]. Present approaches to quantify soil quality are concerned with either directly characterizing different attributes of quality (e.g., soil properties) or identifying specific indicators that can represent the attribute in question [9]. Soil quality, like yield potential, is an elusive concept that is difficult to define and measure [10]. The ability to assess soil quality and identify key soil properties that serve as indicators of soil function and soil productivity is complicated by the many issues defining quality and the multiplicity of physical, chemical, and biological factors that control biogeochemical processes and their variation in time, space, and intensity [11]. Practical assessment of soil quality requires consideration of these functions and their variations in time and space [12]. Soils have various levels of quality that are basically defined by stable natural or inherent features relates to soil-forming factors and dynamic changes induced by soil management [13]. Detecting changes in the dynamic component of soil quality is essential to evaluating the performance and sustainability of soil management systems. Recently proposed an approach based on establishing a minimum data set of temporarily variable soil properties and pedotransfer function [13]. This approach relies on available soil surveys for input data and simulation models to design sustainable management systems and establish soil standards for managing soil quality. Emphasis should be placed on defining soil quality, identifying soil quality indices, and assessing their importance of soil quality [14-16].

There has not been a technique to determine soil quality in Indonesia. Assessment of soil quality is still relies to soil type based on soil classification and land suitability class. Both, however, cannot be used to evaluate soil condition/quality changes effectively since these two tools are not sensitive to soil condition/quality changes affected by soil management practices. In many cases, soil type and land suitability class are remains the same even there has been soil condition/quality change. An analysis of soil properties alone, no matter how comprehensive or sophisticated, cannot provide a measure of soil quality unless the property evaluated is calibrated against the designated role or function of the soil [5], i.e., crop production. It should be better if the Soil Quality Index is calibrated or related against the crop production in the area which the Soil Quality Index is assessed.

The purpose of this study is to develop a technique to assess soil quality by determining soil quality index. Soil Quality Index is more adapted and suitable for agriculture sector in digital transformation era to support “smart farming” and “precision farming.

2. Methods

2.1. Schemes of determining SQI

Considering that determining soil quality index can require abundant data of land and soil properties, author differentiates development of SQI for agriculture sector into two SQI schemes, depending on the goal of the determination of AQI, data availability, and cost considerations. Both are Simple Soil Quality Index (S-SQI) and Comprehensive Soil Quality Index (C-SQI) schemes.

S-SQI scheme involves 13 soil parameters consisting of 4 soil physical properties (effective soil depth, bulk density, soil drainage, and soil texture), 8 soil chemical properties (pH, Cation Exchange Capacity —CEC, N-organic, available -P, exchangeable K, Ca, Mg, and Al saturation) and 1 soil biological properties (C-organic).

C-SQI scheme involves 20 soil parameters consisting of 6 soil physical properties (effective soil depth, bulk density, soil drainage, soil texture, available water and soil permeability), 13 soil chemical properties and 1 soil biological properties and for total of 20 soil properties or parameters (pH, Cation Exchange Capacity —CEC, N-organic, Available-P, exchangeable K, Ca, Mg, Al saturation, and Fe, Mn, Cu, Zn) and 1 soil biological properties (C-organic).
2.2. Scoring of soil quality index and classification of soil quality index

2.2.1. Scoring of Soil Quality Index. Scoring of Soil Quality Index is calculated from the total of total score of each soil parameter. The total score of each parameter founded from multiplication of proportion (weighting coefficient) and score of each parameter (scale of 1 to 7). Thus, the total score of Soil Quality Index, theoretically, varies from 0 to 7, let say 6.06, 4.89, 5.45, etc.

2.2.2. Classification of Soil Quality Index. The total score or Soil Quality Index can be classified as follow table 1:

| Category         | Number of SQI         |
|------------------|-----------------------|
| Very low         | SQI ≤ 1.00            |
| Low              | 1.00 < SQI ≤ 2.00     |
| Slightly low     | 2.00 < SQI ≤ 3.00     |
| Moderate         | 3.00 < SQI ≤ 4.00     |
| Slightly high    | 4.00 < SQI ≤ 5.00     |
| High             | 5.00 < SQI ≤ 6.00     |
| Very high        | 6.00 < SQI ≤ 7.00     |

2.3. Soil Investigation

Field investigations supported by laboratorial analysis at 48 locations in Banten Province were carried out in soils planted with food crops (paddy, corn, soybean, peanut), in three districts (Lebak, Pandeglang, and Serang) and two cities (Serang and Cilegon). The properties of the soils analyzed were 13 soil parameters for S-SQI scheme and 20 soil parameters for C-SQI scheme.

3. Results and discussion

3.1. Proposed Soil Quality Index and Soil Quality Index Classification for Agriculture

3.1.1. Parameter set of Simple Soil Quality Index scheme. A minimum data set of soil properties consists of 13 soil parameters that can be considered as the most important soil parameter related to soil productivity and sustainability of soil to life of all living creatures and its proportion in the scoring of the S-SQI scheme is presented in Table 2. The weighting coefficient (proportion) for scoring of SQI of each soil parameter is different depending on the importance of the soil parameter. The total organic-C proportion is the highest (0.15), indicating that it is the most important soil parameter. The total weighting coefficients of physical and chemical properties are 0.36 and 0.49, respectively,

3.1.2. Comprehensive Soil Quality Index for agriculture. A more complete set of soil properties which consists of 20 soil parameters are constructed for C-SQI scheme. Aside from 13 soil parameters used in S-SQI scheme, there are addition of 7 soil parameters which completed to construct C-SQI scheme, i.e., availability of water, soil permeability, base saturation, and availability of soil micronutrients of Fe, Mn, Cu and Zn (see Table 2). In this scheme, the weighting coefficient (proportion) of total organic-C is still the highest (0.15), indicating that it is the most important soil parameter in producing soil productivity and guarding sustainability of soil to life of all living creatures. The total weighting coefficients of physical and chemical properties remains the same, 0.36 and 0.49, respectively.
Table 2. Soil properties are proposed as parameters for the S-SQI scheme and their proportion for scoring.

| No | Soil Properties                  | Function                                                                 | Proportion$^a$ | Remarks |
|----|----------------------------------|--------------------------------------------------------------------------|----------------|---------|
| 1  | Effective soil depth             | Representing maximum rooting depth and volume of soil that can provide total nutrients, water and gases needed by plants | 0.09 0.07      | FO      |
| 2  | Soil Bulk Density$^b$            | Easiness of plant root to enter and penetrate soil, representing soil aeration and soil permeability | 0.09 0.07      | FO and/or LA |
| 3  | Soil Drainage                    | Condition related with inundating and soil aeration in the soil           | 0.09 0.05      | FO      |
| 4  | Soil Texture                     | Particle size distribution representing capacity to retain and release nutrients and water and soil aeration | 0.09 0.07      | FO and/or LA |
| 5  | Soil pH                          | Availability of soil nutrients in the soil and soil reaction (acid or bases) | 0.08 0.07      | FO and/or LA |
| 6  | Cation Exchange Capacity (CEC)   | Capacity of soil to provide and exchange of cations needed by plants     | 0.07 0.06      | LA      |
| 7  | Total Soil N$^c$                 | The total amount of organic Nitrogen in the soil                         | 0.06 0.05      | LA      |
| 8  | Available Phosphate$^c$          | Capacity of soil to supply available phosphate to support plant growth and plant production | 0.06 0.05      | LA      |
| 9  | Exchangeable K$^e$               | Availability of exchangeable K in soil to support plant growth and plant production | 0.06 0.05      | LA      |
| 10 | Exchangeable Ca$^d$              | Availability of exchangeable Ca in soil to support plant growth and plant production | 0.05 0.04      | LA      |
| 11 | Exchangeable Mg$^d$              | Availability of exchangeable Mg in soil to support plant growth and plant production | 0.05 0.04      | LA      |
| 12 | Exchangeable Al                  | Stipulate Aluminium toxicity for plant                                   | 0.06 0.05      | LA      |
| 13 | Total organic-C                  | A major terrestrial pool for C,N,P,S and the cycling and availability of these elements and in improving soil physical, chemical and biological soil properties | 0.15 0.15      | LA      |
| 14 | Water availability               | Capacity of soil to provide plant-available water or available water for plant | 0.05           | LA      |
| 15 | Soil permeability                | The rapidity of water movement in the soil profile                       | 0.05           | FO and/or LA |
| 16 | Base Saturation                  | Percentage of bases (cations) indicating the abundant (amount) of bases in the soil | 0.03           | LA      |
| 17 | Availability of Soil Micronutrients | Availability of soil micronutrients (Fe, Cu, Mn, Zn) to support plant growth and plant production | 0.05$^e$       | LA      |
|    | Total                            |                                                                          | 1.00 1.00      |         |

$^a$ representing as weighting coefficient for scoring of Soil Index Quality

$^b$ [17]
can be replaced by Analytical Soil Test to measure nutrient availability in the soil

Average of soil-micronutrient of Fe, Cu, Mn, and Zn

S-SQI = Simple-Soil Quality Index scheme
C-SQI = Comprehensive-Soil Quality Index scheme

FO = field observation
LA = laboratory analysis

3.2. Score of SQI

3.2.1. SQI score of investigated soil. The average SQI scores of 48 soil locations studied in Banten Province are 4.48 (S-SQI) and 4.50 (C-SQI) which are categorized as slightly high (see table 3). Score varies from 3.27 (moderate) up to 5.23 (high). The score produced by S-SQI is very close to C-SQI. For the individual soil, the two schemes produced the highest difference of 0.18 (sample no 4 for soybeans) and the same score at three samples (sample no 4 and 10 of paddy rice; no 9 for corn). For all soil locations studied, the total difference of the two schemes is 0.10. This suggests that for simple soil evaluation and soil investigation which do not require detail information, S-SQI is more recommended because it requires less or fewer investigations or observation of soil parameters.

Table 3. SQI Score of soil investigated planted with food crops in Banten Province.

| No | Sawah-Rice | Corn | Soybeans | Peanut |
|----|------------|------|----------|--------|
|    | S-SQI | C-SQI | S-SQI | C-SQI | S-SQI | C-SQI | S-SQI | C-SQI | S-SQI | C-SQI |
| 1  | 4.54  | 4.46  | 4.55  | 4.62  | 4.23  | 4.21  | 3.99  | 3.98  |
| 2  | 4.31  | 4.28  | 4.70  | 4.65  | 4.66  | 4.80  | 3.73  | 3.74  |
| 3  | 5.22  | 5.10  | 4.12  | 4.08  | 4.77  | 4.89  | 4.44  | 4.46  |
| 4  | 4.96  | 4.96  | 4.54  | 4.59  | 4.76  | 4.94  | 4.29  | 4.35  |
| 5  | 4.53  | 4.64  | 3.92  | 3.98  | 3.81  | 3.80  | 3.87  | 3.88  |
| 6  | 4.51  | 4.53  | 4.10  | 4.07  | 4.71  | 4.72  | 3.27  | 3.36  |
| 7  | 4.60  | 4.64  | 4.53  | 4.60  | 4.09  | 4.11  | 3.62  | 3.58  |
| 8  | 4.36  | 4.41  | 3.58  | 3.63  | 4.62  | 4.42  | 4.33  | 4.24  |
| 9  | 4.99  | 4.95  | 4.83  | 4.83  | 4.74  | 4.61  | 4.73  | 4.78  |
| 10 | 5.01  | 5.01  | 4.89  | 4.85  | 4.89  | 4.87  | 5.18  | 5.23  |
| 11 | 4.60  | 4.64  | 4.74  | 4.85  | 4.85  | 4.89  | 4.92  | 4.96  |
| 12 | 4.36  | 4.41  | 5.11  | 5.26  | 4.30  | 4.37  | 4.45  | 4.54  |

Average of SC-SQI = 4.48
Average of CS-SQI = 4.50

3.2.2. Advantage of SQI Scoring. In the “numeral” form, SQI is easier and more practical and sensitive to be used as a tool to monitor and evaluate change and dynamic of soil condition/quality. SQI also will be more adapted and suitable for agriculture sector in digital transformation era to support “smart farming” and “precision farming.

4. Conclusions

There are 2 (two) schemes of SQI, i.e. Simple Scheme (S-SQI) and Comprehensive Scheme C-SQI) were introduced as a technique to determine Soil Quality Index (SQI) to assess soil quality/condition. S-SQI scheme and C-SQI scheme involves 13 and 20 soil properties/parameters, respectively.

Score of soil quality of soil under investigation at 48 locations in Banten Province varies from 3.27 (moderate) up to 5.23 (high) with average between 4.48 (S-SQI) and 4.50 (C-SQI) and classified as slightly high. Score of S-SQI is almost similar with C-SQI, which means S-SQI produces SQI is as well as C-SQI.

SQI will be easier and much more sensitive to be used as a tool to monitor and evaluate soil change and dynamic of soil condition.
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