Formulation of soil quality index plus to support soil management in preventing soil degradation in dryland farming

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Abstract. Soil degradation threat to achieving sustainable agriculture is very prominent, especially in tropical areas like Indonesia. Soil degradation is a process of decreasing the function, quality, and productivity of the soil. Therefore, a soil management technique is needed to prevent soil degradation. The crucial problem faced is the unavailability of instruments and methods to assess and monitor soil quality and provide direction in maintaining the soil from soil degradation. Soil types and land suitability classes systems cannot assess soil quality and soil degradation due to land and soil management. Besides, both of the systems are not sensitive and satisfactory to evaluate changes in soil quality and soil degradation. The purpose of this study was to develop Soil Quality Index Plus (SQI-Plus) to evaluate soil quality in supporting development of soil management techniques, monitoring and evaluation of soil quality, and providing recommendations for maintaining soil quality to prevent soil degradation. SQI-Plus is presented in numerical forms and followed by letters which indicating one or more limiting factors for plant growth and production which needs to be repaired or rehabilitated to achieve optimal production and preventing soil degradation.

1. Introduction

Food and agriculture production in Indonesia is broadly derived from the wetland and dry land. Dryland farming is more challenging and faces many problems and handicaps. In addition to having land with soil fertility or quality that is generally low or marginal, dryland farming also often faces issues, obstacles, handicaps, constraints, and vulnerabilities related to erosion and drought in the upstream area and flooding in the downstream area. Therefore, dryland farming deserves greater attention and serious efforts to protect it from various degradation threats that can reduce soil function, quality, and productivity. Currently, there are two systems, i.e., soil types and land suitability classes that are known and usually used for assessing and studying about soil and land. Both can not be used satisfactory to assess the soil quality and its changes and soil degradation caused by soil management. Therefore, a soil appraisal system is still needed, which can evaluate soil quality and its changes. The soil condition assessment approach with soil quality determination techniques is considered more suitable for determining soil quality, soil fertility, and soil productivity potential. One way to determine soil conditions through soil quality is to use the Soil Quality Index method.
Some issues and problems on dryland farming in tropical areas including Indonesia are processes associated with intensive weathering and erosion which finally produce acidic soils reaction or low soil pH, low content of organic matter, bases (particularly potassium, calcium, and magnesium), available phosphate, organic nitrogen and excessive content of Aluminium, Ferric, and Manganese which can be toxic to plants. Several other factors that arise as obstacles and problems in agriculture are climate, clearly lack of rainfall, which causes drought in the dry season, and excess or high rainfall that triggers flooding in the rainy season. Topographic factors can affect the intensity of erosion as well as drought and floods.

Soil degradation is a big issue in agricultural lands. Soil degradation is produced by wrong or poor land or soil management. Soil degradation is an event of decreasing soil quality, function, or ability to support human activities due to changes in one or more characteristics, characteristics, or soil characteristics. Lal [1] and Tesfahunegn [2] states that land degradation is the loss of productivity or potential or actual utility due to natural factors or caused by humans. Generally, soil degradation is produced by erosion, incorrect soil cultivation, incorrect fertilization, land burning, poor irrigation, waste pollution, etc. The rate of soil degradation is determined mainly by the causes of degradation [1]. The consequences can be in the form of erosion of the top layer of fertile and loose soil by water flowing over the land surface, physical damage such as damage to soil aggregates into fine-sized soil aggregates and release of primary particles, lowering and depletion of nutrients and imbalance, soil poisoning, and decreased ability of the soil to absorb and bind water and nutrients.

The crucial problem faced is the unavailability of instruments and techniques to assess and monitor soil quality and provide direction in maintaining the soil from soil degradation. The system of soil recognition, knowledge, and understanding of soil types only or more produces information about soil names such as Alluvial, Podsollic, Latosol, Kambisol, Grumusol, etc., as well as the process of formation and the main characteristics behind the naming of these soils. This system cannot correctly and accurately assess soil quality and productivity. Besides, this system is also can not evaluate soil quality changes because the soil type or soil name would not be changed due to land or soil management. Both degradation and improvement resulted from land or soil management would not change soil type or soil name. Meanwhile, the land capability class designation system provides information on the suitability of land use for commodities and limiting factors for plant growth and production. This system provides the level of land productivity in very global, only grouping the evaluated land into very high potential productivity, high potential productivity, low to moderate potential productivity and not appropriate (no suitable for agriculture land). Besides, this system is also not sensitive and accurate to assess changes in soil conditions due to the management that has been applied. Thus, a system that can determine soil quality in a more precise, measurable, and quantitative manner is needed so that at the same time, it can be used to show changes in soil quality due to degradation or improvement resulting from soil management.

The purpose of this study was to develop Soil Quality Index Plus (SQI-Plus) to evaluate soil quality in supporting development of soil management techniques, monitoring and evaluation of soil quality, and providing recommendations for maintaining soil quality to prevent soil degradation.

2. Methodology

2.1. Step in formulating SQI Plus
The first step to compile SQI Plus is to select and define the key parameters and then providing score for the selected key parameter. Afterward determine the weighting coefficient of each key parameter according to how important and the magnitude of the parameter function. Next is to calculate the final SQI Plus score and determine the category or level of soil quality. The final stage is to determine soil key parameters that are inhibiting plant growth and production.

2.2. Selection and determination of key parameters
Eventually, there is a number of soil physical, chemical, and biological properties involved in plant growth and production. Soil quality assessment usually uses the selected soil physical, chemical, and biological properties as key parameters to be set and analyzed or modeled [3]. The basis and criteria
used to select key parameters are: 1) parameters that play a significant role or function and determine the growth and production of plants, especially those according to the type of commodity or group of plant commodities, 2) represent aggregates or a similar set of soil properties or characteristics, 3) not very volatile or highly mobile, and 4) can be easily analyzed in any soil laboratory at an affordable cost. Several other supporting criteria should be considered in selecting key parameters are the importance and purpose of soil quality evaluation, whether soil quality evaluation is directing to management planning, production estimates, and research or modeling purposes, etc. Based on all these criteria and consideration, limited ultimate soil key parameters would be selected.

2.3. Determination of the weighting coefficient of key parameters
Each of the selected soil key parameters then are given a weighted coefficient based on their different roles and functions in supporting plant growth and production.

2.4. How to score each key parameters and total SQI Plus score
Each key parameter is to give a score on a scale of 0 to 5. The score of each key parameter is acquired by categorizing each analysis result of the key parameters based on the criteria widely used by the Indonesian Center for Agricultural Land Resource Research and Development, Bogor, Indonesia.

2.5. SQI Plus score categorization
After obtaining the SQI Plus scores, the next step was to classify the into seven categories: very good, good, moderately good, moderate, somewhat bad, bad, and very bad.

2.6. Limiting factors in SQI Plus.
In the SQI Plus system, soil limiting factors that inhibiting plant growth and production are written as letters behind the SQI Plus score. A letter is the limiting factor, if the parameter score is equal to or less than 2.

3. Results and discussion

3.1. Development and formulation of SQI Plus
3.1.1. Selected key parameters for SQI Plus. Ten key parameters were selected and chosen for determining SQI Plus (see Table 1), representing soil physical, chemical and biological properties.

| Soil Properties                  | Key Parameter                                      |
|----------------------------------|----------------------------------------------------|
| Soil Physical Properties         | • Effective soil depth                             |
|                                  | • Texture class                                    |
|                                  | • Bulk density                                     |
|                                  | • Drainage                                         |
| Soil Chemical Properties         | • pH (Soil reaction)                               |
|                                  | • Cation exchangeable capacity (CEC)               |
|                                  | • Macronutrients /elements: available               |
|                                  | Phosphorus (P), exchangeable Potassium (K)         |
| Soil Biological Properties       | • Aluminium saturation                             |
|                                  | • Total carbon organic                             |

The selected key parameters were principle and fundamental soil properties that regulate, govern, and take effect on plant growth and production. The number of ultimate key parameters should be strictly limited to attain an effective and efficient soil quality assessment financing by using the SQI Plus technique.
3.1.2. *The weighting coefficient of the key parameter.* The determination of the weighting coefficient of each key parameter is based on the degree of role, function, and influence of those parameters on growth and development of plants (see Table 2). The total weighting coefficient of the key parameters is 100%.

| Key Parameter                              | Weighting Coefficient (%) | Key Parameter                              | Weighting Coefficient (%) |
|--------------------------------------------|----------------------------|--------------------------------------------|----------------------------|
| Soil depth                                 | 10                        | Cation exchangeable capacity               | 8                         |
| Soil texture                               | 9                         | Available phosphor                         | 8                         |
| Bulk density                               | 9                         | Exchangeable Potassium                     | 8                         |
| Soil drainage                              | 9                         | Aluminium saturation                       | 5                         |
| Soil reaction (pH)                         | 9                         | Organic carbon                             | 25                        |

Source: Rachman et al. [4]

Soil organic carbon (SOC) receives the highest weighting coefficient, i.e., 25%, since SOC has a considerable role and function on many soil physical, chemical, and biological soil properties that producing better soil for the growth and development of plants [5]. Aluminium saturation obtained the lowest weighting coefficient, i.e., 5%, since the aluminium saturation effect for plant growth and production was considered the smallest as compared to the other key parameters. Too high level of aluminium that particularly occurs in acid soils can be toxic to plants and can reduce the level of available phosphor in soil.

3.1.3. *The key parameter and SQI Plus scoring.* Determination of key parameter in SQI Plus score is by providing a score from 0 to 5. The score of each parameter comes from the categorizations for each key parameter (see Table 3). The criteria to evaluate the key parameters is in use to assess and categorize soil properties by the Indonesian Center for Agricultural Land Resource Research and Development, Bogor, Indonesia.

| Key parameters          | Unit          | Score   |
|-------------------------|---------------|---------|
| **Physical Properties** |               |         |
| Effective soil depth    | Cm            | <10     |
|                         | S             | 10-20   |
|                         | LS            | 20-40   |
|                         | SL            | 40-60   |
|                         | HC            | 60-80   |
|                         | C, Si, SiC, Si| >80     |
|                         | Si, Cl, SiL, L| <0.8    |
| Texture                | g/cm³         | >1.6    |
| Bulk density            | Very bad      | 1.4 – 16 |
| Drainage               |                | 1.2 - 1.4 |
|                        |                | 1.0 - 1.2 |
|                        |                | 0.8 - 1.0 |
|                        |                | Good    |
| **Chemical Properties** |               |         |
| pH                      | < 4.0         | 4.0-4.5 |
|                        | > 8.5         | 8.0-8.5 |
|                        | 7.5-8.0       | 7.0-7.5 |
|                        | 6.5-7.0       | 6.0-6.5 |
| Cation exchange capacity| <2            | 2-5     |
|                        | 5-16          | 16-24   |
|                        | 24-40         | >40     |
| Available phosphor     | <5            | 5-10    |
| Exchangeable potassium | <0.05         | 0.05-0.1|
|                        | 0.5-0.1       | 0.3-0.6 |
|                        | 0.6-1         | 1       |
| Aluminium saturation   | ≥60           | 40-60   |
|                        | 20-40         | 10-20   |
|                        | 5-10          | < 5     |
| **Biological Properties** |            |         |
| Organic carbon         | <0.5          | 0.5-1   |

Source: Rachman et al. [4]

Remark: C = clay; HC = heavy clay; Si = silt; S = sand; L = loam; SiC = silt clay; SC = sandy clay; CL = clay loam; SiL = silty loam; SL = sandy loam; SiCL = silty clay loam; SCL = sandy clay loam; LS = loamy sand

*Mostly derived from quantification of criteria that is used to assess the soil properties by Indonesian Center for Agricultural Land Resource Research and Development [Pusat Penelitian dan Pengembangan Sumberdaya Lahan Pertanian Indonesia], Bogor.*
The total score of SQI Plus is the sum of the scores for every key parameter, which were obtained by multiplying the weighting coefficient by the score of each key parameter. Mathematically, the calculation formula is as shown in equations (1) and (2). Based on this equation, the SQI Plus concept result from the weighted coefficient average of all the parameters used.

\[ TSP_i = P_i \cdot SP_i \]  
\[ TSSQI = \sum TSP_i \]  

Remarks: TSPi = total score of soil key parameter i; Pi = proportion (weighting coefficient) of the key parameters of the soil; SPi = score of a key parameter; TSSQi = total soil quality index score.

3.1.4. **Format of the writing of the SQI plus.** If the SQI Plus score is known, the design for writing information related to soil quality in a location follows the rules presented in Figure 1. In the figure, it shows some letters after the SQI number that indicates inhibiting factors for plant growth and production.

![Figure 1. Illustration of results as presented by Soil Quality Index Plus](image)

**3.1.5. Categorization of SQI Plus score.** After obtaining the SQI score, the next step was to group the SQI score into seven categories for interpretation and comparison.

| Score       | Category  | Very bad | Bad      | Rather bad | Medium | Moderately good | Good     | Very good |
|-------------|-----------|----------|----------|------------|--------|-----------------|----------|-----------|
| \(\leq 1.00\) |           |          |          |            |        |                 |          |           |
| \(1.00 - 2.00\) |           |          |          |            |        |                 |          |           |
| \(2.00 - 2.75\) |           |          |          |            |        |                 |          |           |
| \(2.75 - 3.50\) |           |          |          |            |        |                 |          |           |
| \(3.50 - 4.00\) |           |          |          |            |        |                 |          |           |
| \(4.00 - 4.50\) |           |          |          |            |        |                 |          |           |
| \(4.50 - 5.00\) |           |          |          |            |        |                 |          |           |

Source: Rachman et al. [4]

3.1.6. **A technique for determining limiting factors on SQI plus.** In the Table 3 (criteria for scoring of soil parameters), there is a value interval, which is the limit where these parameters can inhibit plant growth or production. The break is a score of 2. In other words, if a parameter has a score \(\leq 2\) is considered, it can inhibit plant growth, and then the parameter is placed behind the index value as a limiting factor. As an example of the SQI Plus value in Figure 1, based on this figure, the soil has limiting factors in soil reaction (pH), phosphorus (P), nitrogen (N), and soil organic matter (OC).

3.2. **Application and usage of SQI plus for soil management recommendation and preventing soil degradation**

3.2.1. **Benefits of using SQI plus for agricultural land management.** The benefits of using SQI Plus are:

- In the form of numbers, the SQI Plus provides soil information or soil quality data that will be easier to be understood by agricultural practitioners, particularly farmers, agricultural extension workers, the agriculture government officers, and other users.
- It provides information on soil key parameters that support and inhibit growth. This information can assist in planning before planting, to prevent soil degradation.
It is more comfortable and more practical to explain and understand soil or soil conditions. The strengths in points 1 and 2 are the primary basis for delivering information, either directly or indirectly. Direct communication can be in the form of; (1) the current condition of the soil, whether it is in the good or bad category, (2) what factors are hindering plant growth and development. While indirect information is information that has gone through the processing stage which produces data in the form of; (1) planning strategies before planting, (2) anticipatory steps so that the soil remains at good quality, (3) prediction of soil productivity and fertility, (4) formulation fertilizer and other soil management recommendation, (4) evaluation of soil conditions per planting period.

3.2.2. Weaknesses and limitations of using SQI plus for agricultural land management. The weaknesses and limitations of the SQI Plus system that has to consider are as follows:

- The SQI Plus value is an illustration of the potential for soil fertility or crop productivity. So to explain the relationship between the SQI Plus value and degraded soil, further analysis is needed.
- The SQI Plus value is a weighted average number, so there is a possibility that, although the SQI Plus value of the soil is high, it has a low fertility potential. It happens when the soil has one or more limiting factors. The level of growth and production of the crop would be determined by the worst or lowest of components or parameters that inhibit plant growth and production. The limiting factor is a parameter with a low score (≤ 2), to inhibit plant growth and production.

3.2.3. Application of the SQI Plus for developing agricultural land management and preventing soil degradation. The SQI Plus provide data about the level soil quality and potential productivity of each plot unit or soil plot, together with limiting factors of key parameters for plant growth and production. The application of the SQI plus is very useful for agricultural land management, primarily to determine fertilizer recommendations and other management to achieve optimal productivity and achieve sustainable agriculture. If the SQI Plus technique is used at the same location at two different times, it will provide information about the applied management performance. If the SQI score decreased or the number of the limiting factor of key parameters increased, soil degradation occurred. Thus, we can use this information to improve management to avoid soil degradation and rehabilitate degraded soils.

4. Conclusion

SQI Plus technique successfully developed for assessing soil quality, both in the form of score and category of soil quality levels, and indicators of soil limiting factors that can inhibit plant growth and production. In addition to assessing soil quality, if set at two times or periods, the SQI Plus score and its limiting factors can also be used to evaluate soil management performance. If the score decreases, it indicates that soil management has resulted in soil degradation. Conversely, if the score rises, it means that the applied land management can improve the soil’s quality. The letter behind the SQI score on the SQI Plus system indicates what matters or factors or soil parameters need to improve in soil management. In that way, the SQI Plus technique is useful to monitor and prevent soil degradation.

Acknowledgment

Much of work written in this manuscript can be accomplished from multiyear research of Best Applied Research of High Education (2018 – 2020) funded by Ministry of Research and Technology/National Research and Innovation Agency of Republic Indonesia.

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