Concept and Assessment Methodologyof Soil Quality: A Review

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ABSTRACT

Soil quality refers to the ability of the soil to function effectively within its ecosystem within its ecosystem boundaries, sustaining biological productivity, maintaining environmental integrity and promoting plant and animal health. It comprises two interconnected components (i) Inherent Qualities (Soil Formation & Characteristics) (ii) Dynamic Qualities (Soil Erosion & Management). It is evaluated to learn about the effects of management practices on soil function. Sustainability of agriculture system is inwardly linked to maintenance of soil quality. Therefore, soil quality assessment is of paramount importance to know the appropriate management practices to be adopted for sustainable crop production. By just measuring yield of crop, quality of water or any other, soil quality cannot be judged. As we know, soil have different properties (chemical, physical and biological), that interact in a precipitously manner to give, soil its capacity to perform or function. Thus, soil capacity can be surmised from measuring changes in its properties or of ecosystem'sattributesand cannot be measured directly. Assessment of Soil quality composed of three key steps (1) Selection, measurement and minimization of the set of relevant soil attributes. (2) Quantification of the selected soil attributes through direct measurement and assigning an appropriate Score. (3) Integration among the scored attributes to construct the final index, by providing criteria for defining the weight of each attribute or group of attributes. Soil quality assessment will allow interpreter to identify the attributes which are most significant, quantify the relative contribution ofsoil properties and subsequently assess the overall quality of soils.

Keywords: Soil quality, Assessment, Minimum data set, SQI

1. INTRODUCTION

"Soil" is defined by the Soil Science Society of America (SSSA) as "the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of plants". Because of the five basic functions (sustaining life of plants and animals, regulating water, filtering potential pollutants, cycling nutrients and supporting structures)soil is also known as soul of infinite life. It plays a vital role in maintaining environmental quality at the local, regional and global levels within the Earth's biosphere.

Soil health or quality status is the basis of productivity and sustainability of the production system in agriculture and is recently represented and adopted holistic approach. Soil health is defined as “the capacity of soil to function as vital living system, within ecosystem and land use boundaries to sustain plant and animal productivity, maintain or enhance water and air quality and promote plant and animal health” (Doran and Zeiss, 2000). It deals with the integration and optimization of the physical, chemical and biological properties of the soil for improved productivity and environmental quality. It is not only affected by soil genesis but also by other factors which are related to soil use and management (Moebius-Clune, 2016).

Agood quality agricultural soil promotes and sustains good agricultural productivity with less environmental impact and possesses utmost physical, chemical and biological attributes to fulfil these requirements (Reynolds et al., 2009). Since all agricultural activities are directly or indirectly affected by how the “soil is handled” soil health becomes a top priority. The productivity and sustainability of any agricultural system depends not only on management practices but also on environmental conditions and soil quality.

To assess soil quality, we need to consider a variety of physical, chemical and biological attributes known as indicators. Many indicators have been developed for ecological and environmental analyses, such as nutrient loss potential on fields (Lemunyon and Gilbert, 1993) and the environmental impacts of different land use mosaics. Integrated soil quality indices, which combine various soil properties, offer a more comprehensive indication of soil quality compared to individual parameters. These indicators could be used to track the soil a single index may aid in more precise soil health assessment (Jaenicke and Lengnick 1999; Bucher 2002). Therefore, the aim of this paper is to explore the concept of soil quality and examine current methodologies employed in assessing it.

2.CONCEPT OF SOIL QUALITY

As suggested in the early 1990s, soil quality is “the capacity of a soil to function”. More specifically, soil quality has been defined as by USDA (1994) Soil quality can be defined as “the capacity of a specific kind of soil to function, within its natural or managed ecosystem boundaries, to sustain animal and plant productivity, maintain or enhance air and water quality and support human health and habitats” (Doran & Parkin, 1994). Also, soil quality can be considered as the ability of a soil to fulfil its functions in the ecosystem, which are determined by the integrated actions of different soil properties.

Soil Quality mainly encompasses two distinct but related parts (Carter, 2002)

2.1 Inherent Qualities (Soil Formation & Characteristics)

Inherent soil quality refers to a soil's innate capacity to function, such as the natural drainage rate of sandy soil compared to clayey soil, or the root space available in deep soil versus soil with shallow bedrock. These traits are enduring and not easily altered. In assessing soil suitability for particular purposes, inherent soil quality serves as a basis for comparison between different soils. Traditional studies in land evaluation have primarily focused on practically interpreting these inherent soil properties.

2.2 Dynamic Qualities (Soil Erosion& Management)

Dynamic soil quality refers to the way soil evolves in response to management practices. The decisions made regarding management influence factors such as soil organic matter content, soil structure, and its capacity to retain water and nutrients. A key objective of soil-quality research is to understand how soil management practices can be optimized to enhance its functionality. This dynamic nature of soil quality is central to the evaluation and preservation of healthy soil resources.

The soil quality can be classified as physical, chemical, or biological depending on the soil components taken into account. While biological and certain physical components are associated with dynamic soil quality, the majority of physicochemical parameters are related to inherent soil quality. However, biological properties are of focus of soil quality,this does not lessen the significance of chemical and physical component(Ball & De la Rosa, 2006).

3. NEED FOR ASSESSMENT OF SOIL QUALITY

Soil quality assessment aims to understand the impacts of management practices on soil function. The reasons for conducting soil quality evaluations can be categorized as follows:

3.1 Assessment as a monitoring tool

In soil quality assessment we test various indicators in the soil and these indicators tell us about any increase or decrease in their value over time i.e., increase or decrease in the soil quality

3.2 Evaluation and trouble-shooting

Monitoring of these indicators may reveal potential problems even before they arise like decrease in productivity, low nutrient status of soils etc. The earlier issues are identified, the simpler they are to address.

3.3 Evaluation of alternative practices

In soil quality assessment we evaluate different practices followed by farmers and compare them. So, by this we can decide which practices are good for soil and which practices farmers should avoid maintaining or enhancing soil quality.

3.4 Adaptive management tool assessment

Soil quality assessment tools enable the examination of the potential impacts of altering management practices before fully committing resources to those changes. They can also facilitate comparisons of the effects of various management practices on similar soils. Problems such as low productivity, low nutrient status of an area can be solved through soil quality assessment.

3.5 Awareness and education

The soil quality concept underscores an ecological approach to land management, recognizing that management actions have complex and multifaceted effects within systems like soil. These effects can be both direct and indirect. For instance, tillage serves various purposes such as loosening surface soil, preparing seedbeds, and controlling weeds and pests. However, it can also disrupt soil structure, accelerate the decomposition and loss of organic matter, heighten erosion risks, diminish habitats of beneficial organisms, and lead to soil compaction. Understanding the trade-offs inherent in different management options is a crucial initial step toward enhancing land management practices and informing public policy. Educational assessment tools, including individual consultations and on-site testing during field days, are valuable for this purpose.

4. ASSESSMENT METHODOLOGY

Assessing soil quality is essential for determining the most suitable management practices necessary for achieving sustainable crop production. Soil quality assessment evaluates how effectively soil fulfills all of its functions. Soil quality cannot be accurately assessed solely by measuring crop yield, water quality or any other outcome.As we know, soil possesses chemical, biological and physical properties that interact swiftly to determine its capacity to function or perform (Bunemanna et al., 2018) Thus, soil capacity cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as indicators (Karlen et al., 2001). Indicators comprise a comprehensive collection of measurable attributes obtained from functional relationships, and they can be assessed through field observations, sampling, remote sensing, surveys, or compiling existing data.

5. CHARACTERISTICS OF SOIL INDICATORS

Soil indicators must be readily measurable, comprising a blend of physical, chemical and biological properties of the soil. They should possess sensitivity to detect changes in management practices, exhibit low measurement errors and ideally have established expected or threshold values. Community acceptance and involvement are crucial, alongside cost-effectiveness. It's important to note that the indicators utilized by various researchers or in different regions may vary, as soil health assessment is tailored to specific purposes and sites.

6. CLASSIFICATION OF SOIL INDICATORS

Soil health indicators can be categorized into those that directly assess soil properties and those that measure outcomes influenced by the soil, such as productivity, vegetation, water and air quality. Indicators directly assessing soil properties are classified as:

6.1 Physical indicators

Physical indicators pertain to the organization of solid particles and pore spaces within the soil. Examples encompass soil depth, bulk density, porosity, aggregate stability, texture, among others. These indicators predominantly signify constraints on root growth, seedling emergence, as well as the infiltration and movement of water throughout the soil profile.

6.2 Chemical indicators

Chemical indicators include determination of soil reaction, salinity, organic matter content, cation exchange capacity, available plant nutrients or those that are needed for plant growth and development. The soil's chemical condition affects soil-plant relations, water quality, buffering capacities, availability of nutrients and water to plants and other organism.

6.3 Biological indicators

Biological indicators comprise measures such as potentially mineralizable nitrogen, soil microbial biomass, soil respiration, enzyme activity, microbial biodiversity, nematode communities, and earthworm populations.

7. ASSESSMENT OF SOIL QUALITY

The generality and reliability of a developed soil health index mainly depends upon its ability to account for soil heterogeneity in space and time (De Paul and Lala, 2016), use of standard soil sampling scheme and analytical procedures (Nortcliff, 2002) and model limitations, related to indicator selection, algorithms and assumptions used for assessment. Thus, assessment of soil health/qualityencompasses three main steps (Andrews et al., 2002) (Figure 1)

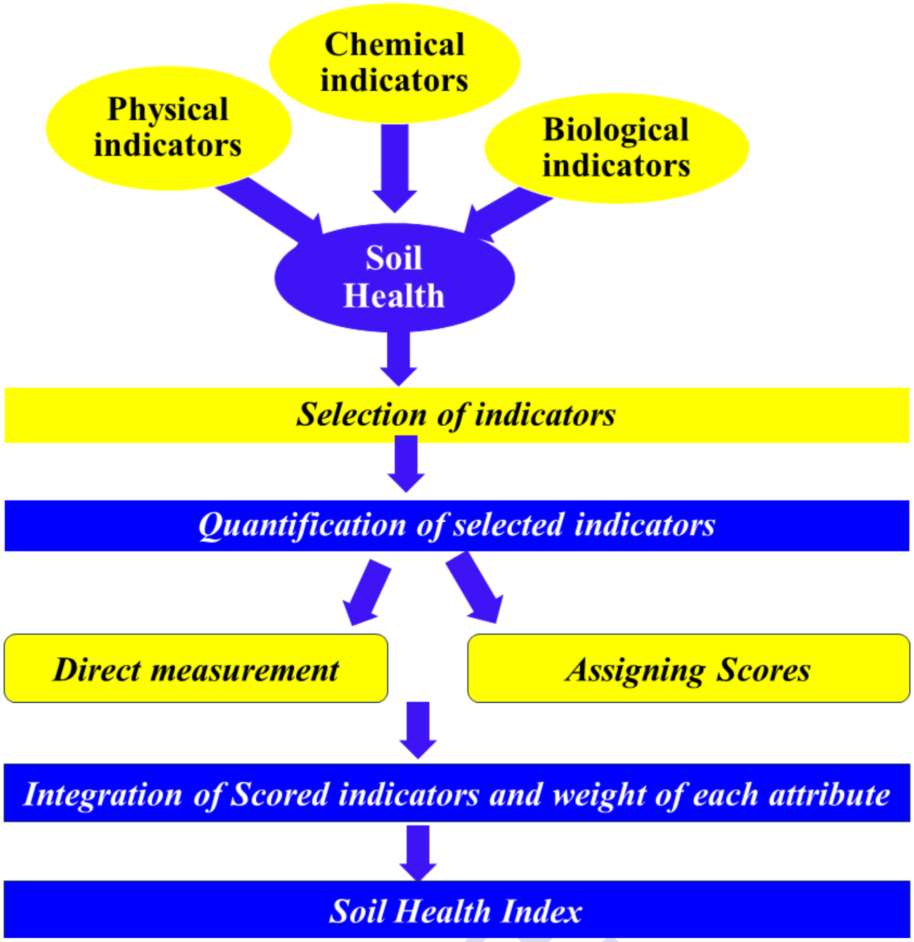

Figure 1 Steps for soil health assessment

7.1 For Minimum Data Set (MDS) selection of appropriate indicators

Selection serves as a building block for soil health index. Many researchers have focused on selecting soil health attributes (Bastida et al., 2008, Ewing and Singer, 2012 and Bunemanna et al. 2018) based on the principles like measurement of relevant scientifically based data, sensitivity analysis to clarify variations in soil functions, manageable accurate and costeffective measurements and reflections and connection between soil functions and management targets (Doran and Parkin 1996,Schloter et al., 2003, Idown et al., 2008, Cardoso et al., 2013 Lima et al., 2013 and Morrow et al., 2016).Each indicator has a unique combination of goal or criteria that must be satisfied for it to be included in Minimum Data Set (Andrews et al., 2004, Govaerts et al., 2006, Erkossa et al., 2007, Raiesi, 2017 and Andrea et al., 2017). Expanding the array of indicators may lead to increased collinearity and complexity in the relationships between indicators and management strategies. Additionally, the costs associated with measurements can become prohibitive, particularly when detailed assessments of soil biological parameters are involved. For these reasons, the number of soil quality indicators that are actually analyzed on a given set of samples needs to be reduced to a minimum dataset. In the first proposed minimum datasets, this selection was based on expert judgment (Doran and Parkin, 1994). Subsequently, statistical data reduction by multivariate techniques such as principal component analysis (PCA), redundancy analysis (RDA) and discriminant analysis (Andrews and Carroll, 2001; Lima et al., 2013; Schipper and Sparling, 2000; Shukla et al., 2006) and multiple regression became more common. After this initial data reduction, simple or multiple correlation analysis can further decrease the number of indicators (Andrews and Carroll, 2001), sometimes followed by the use of expert judgment for choosing only one out of two or more highly correlated soil properties (Sparling and Schipper, 2002). Using these methods, the final selection of indicators usually falls within the range of 6 to 8. Soil properties essential for soil function but demonstrating limited variability within a specific study are typically excluded from the minimum dataset.

7.2 Transformations of indicator values to scores

Following the identification of variables for the minimum data set, each observation of every MDS indicator is typically transformed using two techniques

a) Linear scores b) Non-linear scores (Andrews et al., 2002)

a. Linear scores

Indicators are ranked in ascending or descending order depending on whether a higher value was considered “good” or “bad” in terms of soil function(Sharma et al., 2014).

i. For ‘more is better’ indicators, each observation was divided by the highest observed value such that the highest observed value received a score of 1.

ii. For ‘less is better’ indicators, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value receives a score of 1.

iii. For many indicators, such as pH observations were scored as ‘higher is better’ upto a threshold value then scored as ‘lower is better’ above the threshold.

b. Non linear scores

The indicators undergo transformation via nonlinear scoring functions constructed using curve-fitting equations.(Andrews et al., 2002, Fernandes et al., 2011, Svoray et al., 2015).

- The shape of each decision function, typically some variation of a bell-shaped curve (‘mid-point optimum’)
- a sigmoid curve with an upper asymptote (‘more is better’)
- a sigmoid curve having a lower asymptote (‘less is better’)

These scoring functions are determined based on agronomic and environmental functions, derived from a thorough literature review and consensus among collaborating researchers.

7.3 Integration of indicators into indices can be:

a) Additive Index

The most common approach is “additive”, assigning equal weight to each selected attribute. The additive index is a summation of the scores from MDS indicators (Fine et al., 2017, Svoray et al., 2015).

b) Weighted Additive Index

In a weighted additive index, the relative weight assigned to each soil function can be either equal or differential. Differential relative weights might be determined based on the number of attributes in each soil function or the relative importance of each soil function. The MDS variables for each observation can be weighted using the results of Principal Component Analysis (PCA), insights from literature review, or advice from experts.

As shown in the figure 2, there are various approaches currently being used for soil health index assessment. These include 3 steps and each step can be done in a no. of ways for example for selection of indicators for minimum data set (MDS) one can use PCA or expert advice or ANOVA, similarly for step 2 and 3 i.e., Scoring and Integration, linear or non-linear scoring and additive or weight additive methods can be used respectively (Yu et al., 2018).

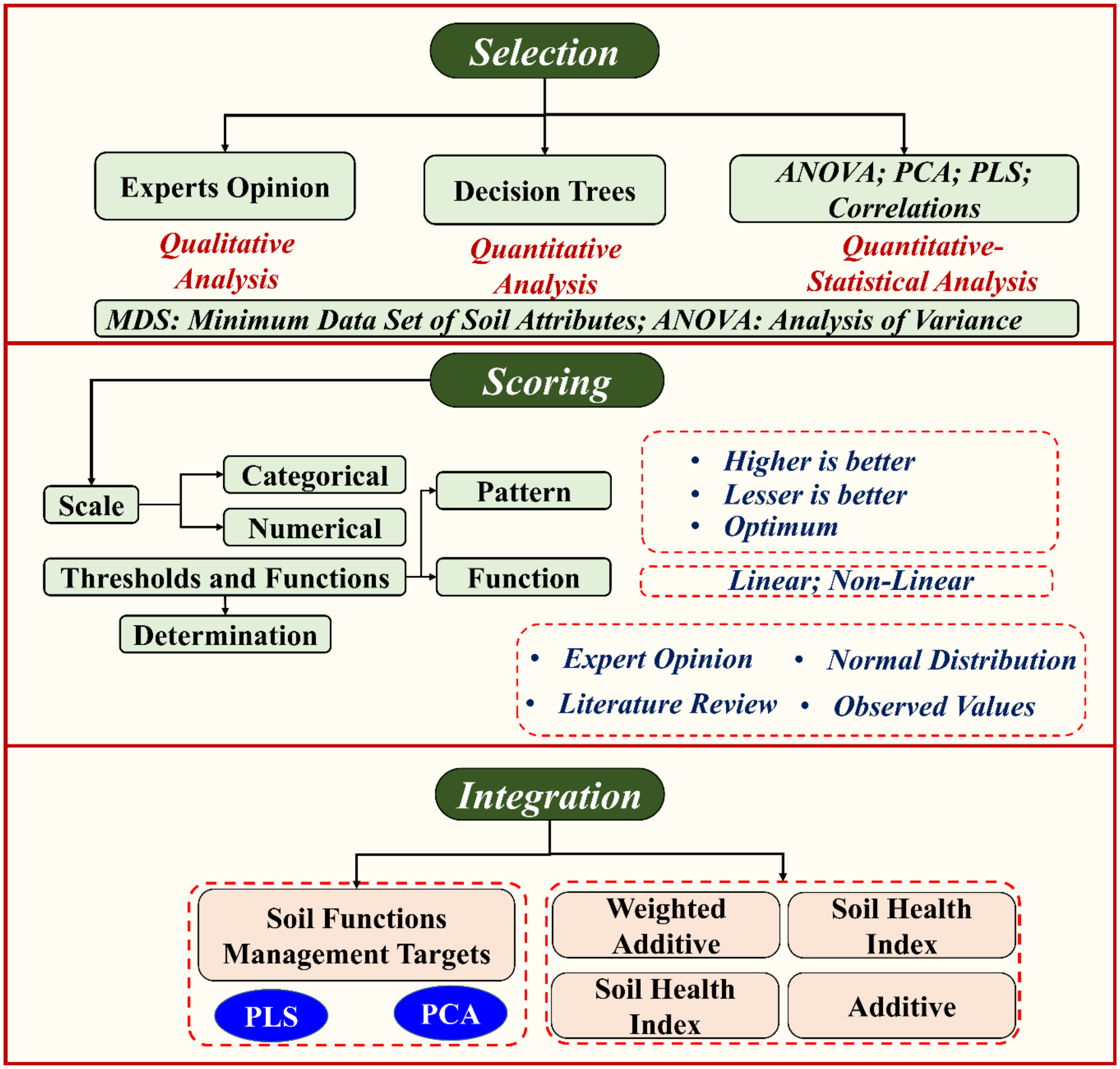

Figure 2 Procedure and methodologies used for assessing soil health index

8. CONCLUSION

In conclusion, it is crucial to preserve and enhance soil quality if environmental sustainability is to be achieved. However, because soil has many different characteristics and is evaluated using a variety of indicators, determining the quality of the soil is a difficult task. Even though soil-quality indicators are useful instruments, it is still difficult to develop a soil-quality index that is applicable to all situations. Different approaches, like the EO and PCA methodologies, have different benefits and limitations, thus it's important to carefully assess which ones apply in which situations. The interpretation of soil-quality data is also impacted by the choice between linear and non-linear scoring techniques; although the latter need more time and experience, they frequently offer a more thorough understanding of soil functionality. Ultimately, the selection of an appropriate assessment method depends on factorssuch as site conditions, intended use, and available data, highlighting the need for informed decision-making in soil-quality management.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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