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A Case Study

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Soil quality concepts and assessment

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Summary

Soil quality has become an internationally accepted science based tool for advancing the assessment, education and understanding of soil resources. Soil quality assessment is important for measuring changes in soil properties over time that helps to define effective management strategies, soil quality cannot be measured directly and there are different indicators (approaches) that can be used to quantify soil quality. These indicators signal desirable or undesirable changes in land and vegetation management that have occurred or may occurs in the future. Finally, various soil quality indexing approaches are available, that can be applied to deserve a range of critical test values within which soil quality and soil health accounts can be defined.

Key words : Soil quality, Concepts, Data set, Parameters, Soil quality assessment

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Introduction

The soil quality concept evolved in response to increased global emphasis on sustainable land use and with a holistic focus emphasizing that sustainable soil management requires more than soil erosion control. Some important soil functions (or ecosystem services) include: water flow and retention, physical stability and support; cycling of nutrients; buffering and filtering of potentially toxic materials and maintenance of biodiversity and habitat. High rates of soil erosion, losses of organic matter, reduction in fertility and productivity, chemical and heavy metal contamination and degradation of air and water quality have sparked interest in the concept of soil quality and its assessment (Karlen *et al.,* 2001). Improper management can lead to deleterious changes in soil function, a need for tools and methods to assess and monitor SQ was recognized (Doran and Jones, 1996). The optimum time and location for making assessments depend on the objectives which include:

– Selection of sites for monitoring,

– Gathering of inventory data used in making decisions,

– Identification of areas at risk of degradation, and

– Targeting of management inputs.

Soil quality assessments are thus, used to evaluate the effects of management on the health of the soil. The concept of soil health was recognized by considering biological and physical properties of surface horizons. In addition to soil properties, farmers used plant, animal and human health and water properties to judge the health of soils.

Dynamic and inherent soil qualities:

The quality of a soil is a combination of inherent and dynamic soil properties. The focus of most soil quality work is dynamic soil properties and how they change in relation to the inherent features of the soil. Inherent or use-invariant properties change little, if at all, with land use or management practices. They may include soil texture, depth to bedrock, type of clay, CEC and drainage class. These properties were established as soil formed over millennia (Seybold *et al.*, 1997).

Dynamic properties or use-dependent properties can change over the course of months and years in response to land use or management practice changes and include organic matter, soil structure, infiltration rate, bulk density, and water and nutrient holding capacity. Changes in dynamic properties depend both on land management practices and the inherent properties of the soil.

Changes in dynamic properties depend both on land management practices and the inherent properties of the soil. The organic matter levels in soil depend on Tillage practices and the types of plants growing (management), but the total amount of organic matter is constrained by Soil texture and climate (inherent features).

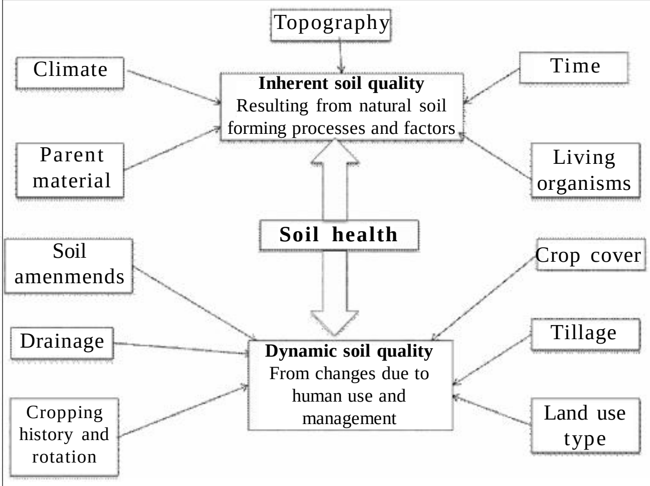

Fig 1: Relation between inherent and dynamic soil quality

Inherent quality relates to the genetic characteristics while dynamic soil quality is affected by management practices. The inherent and dynamic soil quality components do interact.

Soil quality parameters:

Indicators are a composite set of measurable attributes which are derived from functional relationships and can be monitored via field observation, field sampling, remote sensing, survey or compilation of existing information. These indicators may directly monitor the soil, or monitor the outcomes that are affected by the soil, such as increase in biomass, improved water use efficiency and aeration. Several researchers have observed different set of key indicators for assessing soil quality depending upon the soil types and other variations. Mairura *et al.* (2007) reported the integration of scientific and farmer's evaluation of soil quality indicators and emphasized that the indicators for distinguishing productive and non-productive soils include crop yields and performance, soil colour and its texture.

The indicators used or selected by different researchers in different regions may not be the same because soil quality assessment is purpose and site specific (Wang and Gong, 1998 and Shukla *et al.*, 2006). However, while selecting the indicators, it is important to ensure that indicators should fulfil all relevant characteristics of an ideal indicator. Hence, to understand the changes in processes and functions, quantitative measurement of attributes or indicators is inevitable.

Key concept in soil quality assessment:

Soil quality indicators:

Soil quality assessments are conducted by evaluating indicators. Indicators can be physical, chemical and biological properties, processes, or characteristics of soils. They can also be morphological or visual features of plants. Soil quality indicators are selected because of their relationship to specific soil properties and soil quality. A qualitative assessment is the determination of the nature of an indicator. A quantitative assessment is the accurate measurement of an indicator. For example, a qualitative assessment of infiltration would be the observation of excessive runoff water from a field. A quantitative assessment would measure the infiltration rate. Qualitative assessments have an element of subjectivity and thus, are best done by the same person over time to minimize variability in the results. Indicators measured with a quantitative method have a precise, numeric value. Therefore, different people conducting the same measurement should be able to produce very similar results. Useful indicators are easy to measure, able to measure changes in soil functions, assessed in a reasonable amount of time, accessible to many users and applicable to field conditions, sensitive to variations in climate and management, representative of physical, biological or chemical properties of soil, assessed by qualitative and/or quantitative methods.

There are three main categories of soil indicators: chemical, physical and biological. The categories do not neatly align with the various soil functions, so integration is necessary.

Chemical indicators can give you information about the equilibrium between soil solution (soil water and nutrients) and exchange sites (clay particles, organic matter); plant health; the nutritional requirements of plant and soil animal communities; and levels of soil contaminants and their availability for uptake by animals and plants. Indicators include measures of electrical conductivity, soil nitrate, soil reaction (pH).

Results of chemical tests are soil quality indicators which provide information on the capacity of soil to supply mineral nutrients, which is dependent on the soil pH. Soil pH is an estimate of the activity of hydrogen ions in the soil solution. It is also an indicator of plant available nutrients. High activity is not desirable and the soil may require liming with base cations Ca or Mg in order to bring the solution back to neutral.

Physical indicators provide information about soil hydrologic characteristics, such as water entry and retention, that influences availability to plants. Some indicators are related to nutrient availability by their influence on rooting volume and aeration status. Other measure tells us about erosional status. Indicators include measures of aggregate stability, available water capacity, bulk density, infiltration, slaking, soil crusts, soil structure and macropores.

Soil physical properties are estimated from the soil's texture, bulk density (a measure of compaction), porosity, water-holding capacity (Hillel, 1982). The presence or absence of hard pans usually presents barriers to rooting depth. These properties are all improved through additions of organic matter to soils. Therefore, the suitability of soil for sustaining plant growth and biological activity is a function of its physical properties (porosity, water holding capacity, structure and tilth).

Biological indicators of soil quality that are commonly measured include soil organic matter, respiration, microbial biomass (total bacteria and fungi) and mineralizable nitrogen. Soil organic matter plays a key role in soil function, determining soil quality, water holding capacity and susceptibility of soil to degradation (Giller and Cadisch,1997 and Feller *et al.*, 2001). In addition, soil organic matter may serve as a source or sink to atmospheric CO_2 (Lal, 1993) and an increase in the soil C content is indicated by a higher microbial biomass and elevated respiration (Sparling *et al*., 2003). It is also the principal reserve of nutrients such as N in the soil and some tropical soils may contain large quantities of mineral N in the top 2m depth (Havlin *et al.*, 2005).

Minimum data set :

A minimum data set (MDS) was proposed to measure soil quality and its changes due to management practices through selection of key indicators such as soil texture, organic matter, pH, nutrient status, bulk density, electrical conductivity and rooting depth (Larson and Pierce, 1994).

Collecting a minimum data set helps to identify locally relevant soil indicators and to evaluate the link between selected indicators and significant soil and plant properties (Arshad and Martin, 2002). For smallholder farmers these tools need to be simple measures of soil health and soil quality such as consistency, colour and workability (Murage *et al.*,2000). For extension and policy personnel, they provide basic information needed to arrive at management decisions (Barrios *et al.*, 2006). For researchers, there is need to conduct sufficiently detailed tests while controlling for variation in order to develop meaningful assessments of soil status, often expressed as an index of soil quality (Kang *et al.*, 2005).

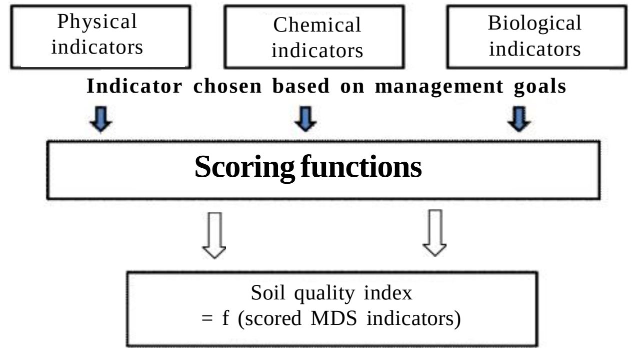

Fig 2: Framework for selecting indicators for a minimum data set

Methods of soil quality assessment:

A variety of methods or approaches are currently used to measure and assess soil quality. The methods discussed in this guide range from primarily qualitative to purely quantitative. They are as follows:

– Soil health card
– NRCS soil health card template (NRCS template)
– Soil quality test kit
– Laboratory analysis.

Indexing dynamic soil quality involves three steps.

The first is selecting appropriate soil quality indicators to efficiently and effectively monitor critical soil functions (e.g. nutrient cycling; water entry, retention, and release; supporting plant growth and development) as determined by the specific management goals for which an evaluation is being made. Collectively these indicators form a minimum data set (MDS) that can be used to determine how well critical soil functions associated with each management goal are being performed. Each indicator is then scored, often using ranges established by the soil's inherent capability to set the boundaries and shape of the scoring function. This step is required so that biological, chemical and physical indicator measurements with totally different measurement units can be combined [e.g. earthworms per unit area, pH, and bulk density. Indicator scoring can be accomplished in a variety of ways (e.g. linear or nonlinear, optimum, more is better, more is worse) depending upon the function. For some management goals the same indicator may be included under different functions and even scored in different ways (e.g. ''more is better'' for NO_3–N supporting plant growth but ''less is better'' with regard to leaching). The unit less values are combined into an overall index of soil quality and can be used to compare effects of different practices on similar soils or temporal trends on the same soil. Finally, to understand the complete value of dynamic soil quality assessment.

Indices of soil quality:

Finally, various soil quality indexing approaches (Andrews and Carroll, 2001 and Granatstein and Bezdicek, 1992) are available and can be applied to derive a range of critical test values within which soil quality and soil health assessments can be defined (Arshad and Martin, 2002).

A single soil characteristic is of limited use in evaluating differences is soil quality. Using more than one quantitative variable require some system for combining the measurements into useful index. Even an index designed only to rate productivity is not likely to be useful for all crops and soils leading to advocate regionally targeted system.

High quality soils for paddy–rice may be of poor quality with slow infiltration and permeability. The physical and chemical properties often constrain the production of other crop.

Non-quantitative index:

It does not combine evaluated parameters in to a numerical index that rates soil along the continuous scale

USDA land capability classification and USBR irrigation suitability

Result in numerical index, typically with highest number being assigned to the best quality soils. These system may be additive, multiplicative or more complex function and are easier to use with GIS and other automated data retrieval and display system. They typically provide a continuous scale of assessment.

Quantitative index:

Storie index rating (*SIR*):

Storie (1954 and 1976) considered the productivity of land to be dependent on 32 properties of soil, climate and vegetative properties amongst 9 are used in SIR.

$$\mathbf{SIR = (A \times B \times C \times Xi) \times 100}$$

where,

A- Soil morphology, B-Surface texture, C- Slope and X- Six variable (drainage class, sodicity, acidity, erosion, micro relief, fertility). These are converted to their decimal value and multiplied together.

Rating :

80-100 excellent (Grade I), 60-79 Good (Grade II), 40-59 Fair (Grade III) 20-39 Poor (Grade IV), 10-19 Very poor (Grade V), <10 Not suitable for agriculture (Grade VI) (FAO,1976).

Limitation:

As it is based on the product of factors even one moderate factor reduce the value of index considerably.

Actual and potential productivity:

Ricquier *et al.* (1970)

It is modified version of storie index.

Nine factors are considered:

(H) Moisture (D) Drainage (P) Depth (T) Structure, (N) Base saturation (S) Soluble salts (O) Organic matter (A) CEC and (M) mineral reserves.

Each factor rated on a scale 0 to100. The percentages cumulatively multiplied to obtain productivity index.

$$\mathbf{Productivity\ index = H \times D \times P \times T \times N\ or\ X \times O \times A \times M}$$

Index rating:

65-100 excellent, 35-64 good, 20-34 average, 8-19 poor,<8 very poor

Limitations:

One limiting factor reduces the index of productivity and assigning the values for factors like drainage is difficult.

Index of soil quality as a function of six specific soil quality elements

SQ = f (SQE1, SQE2, SQE3, SQE4, SQE5, SQE6)

where,

SQE1 = Erosivity (limits for erosion losses).

SQE2 = Food and fibre production (yield goals of crop production).

SQE3= Groundwater quality (concentration limits for chemical leaching from rooting zone).

SQE4 = Surface water quality (nutrient, chemical and sediment loading limits to adjacent surface water systems).

SQE5 = Air quality (production and uptake rates for trace gases that contribute to O_3 destruction or greenhouse effect).

SQE6 = food quality (nutritional composition and chemical composition of food).

Weighing factors are assigned to each soil quality elements. Relative weights of these co-efficients being determined by geographical considerations, social concerns, economic constraints. For example, In a given region, food production may be the primary concern and air quality of secondary importance SQE2 would be weighted more heavily than SQE5.

Parr *et al.* (1992) suggested that a SQI could take the form of equation.

SQI = f (SP, P, E, H, ER, BD, FQ, MI)

where, SQI is the function of soil properties (SP), Potential productivity (P) Environmental factors (E), Human and animal health (H), Erodibility (ER), Biological diversity (BD), Food quality and safety (FQ), Management inputs (MI).

Karlen *et al.* (2001), developed QI based on a 10 year crop residue study where SQ is based on four soil functions. Accommodating water entry, Retaining and supplying water to plants, Resisting degradation and Supporting plant growth Numerous properties were measured and values normalized based on standard scoring functions. One function is based on the concept that more of a property is better, one that less is better and third that an optimum is better. Lower threshold values receive a score of zero, upper threshold values receive a score of one and baseline values receive a score of one-half. Priorities are then assigned to each value. Aggregate stability was given the highest weight among factors important in water entry. After normalizing, each value is then multiplied by its weighing factor (wt) and products are summed.

SQI = q we (wt) +q wt (wt) + q rd (wt) + q spg (wt)

Formulas in the soil quality/ sustainability domain.

The indicator of degradation risk of soils is defined with the soil threats tndex (STI): STI= (SRP * DI_{in}) where : SRP–Soil response properties, DI_{in} is the degrading impacts, the external factors of degradation (e.g. soil management, climate change) from i to n.

Cumulative degradation effect (CDE) can be defined as: **CDE = STI * at.**

where, STI - Soil threats tndex, Δt is the time period of observation.

SQI = SFA * SRP

SSI = SQI * (100 - CDE)

where, SSI is Soil sustainability index, SQI Soil quality index, CDE Cumulative degradation effect (Institute for environment and sustainability).

Recent advances in soil quality assessment:

A number of assessment tools have been developed

– Soil conditioning index (SCI)

– Soil management assessment framework (SMAF)

– Agroecosystem performance assessment tool (AEPAT)

– Cornell 'New soil health assessment'.

Soil conditioning index (SCI) predict the consequences of cropping systems and tillage practices on soil organic matter.

SCI = (OM x 0.4) + (FO x 0.4) + (ER x 0.2)

OM (Organic material), FO (Field operations), ER (Erosion) can be negative (degrading); positive (aggrading) or near zero (maintained).

Weakness:

It is biased towards tillage and does not account very well for organic matter additions.

At the 2005 international conference on soil, water and environmental quality-Issues and Strategies in New Delhi, India, the SMAF was described and several case studies were presented (Weinhold *et al.*,2006).

The SMAF and AEPAT were developed as malleable tools for assessing soil response to management. The cornell assessment builds on the SMAF approach to score laboratory tests in terms of soil functions. The SMAF has been implemented as part of conservation effects. Assessment project (CEAP) combining SMAF and CEAP survey approach appears to be a successful approach for using the SMAF for model output and in spatially variable fields as well as adapting the SMAF for wide use by STLs (Weinhold *et al.,*2008).

Soil management assessment framework (SMAF) could be used to assess soil response to management within the environmental context in which it occurs (Andrews *et al*., 2004). He reported SMAF integration into a additive index by selecting 81 indicators and 169 selection rules for the integration step accommodated by summing the scores for each indicator, dividing by the total number of indicators, and then multiplying by 10.

SQI= p: **Si x10**

where, S represents the scored indicator value and n is the number of indicators in the MDS. Using the number of indicators in the MDS as a divisor corrects for any missing data in the data set. The index value was multiplied by 10 to provide index value in the range (1 to 10 rather than 0 to 1) found to be more amenable for producers and other potential users.

Future direction :

The use of electronic technology will significantly increase the demand for and ability to process more data. Further innovations will result in model approaches in soil genetic studies that will demonstrate the integral role of soils in ecosystems. Particularly the use of ICT including on-line delivery content through wikis, blogs and social book marking is set to push sharing of soil health information to a new level. At the more fundamental level, basic research will be needed in order to select and develop proper indicators, applicable at different farmer scales. Innovations will be required in setting up effective study programmes, which would guarantee the accumulation of the necessary baseline soil data in order to develop appropriate minimum datasets.

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