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# CHARACTERIZATION OF SOIL QUALITY INDICATORS: A STUDY

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## Abstract

The definition of soil quality encompasses physical, chemical and biological characteristics, and it is related to fertility and soil health. Many indicators can be used to describe soil quality, but it is important to take into account sensitivity, required time, and related properties, than can be explained. Properties related to organic matter content, such as C/N ratio, organic carbon fractions (humic acids, fulvic fraction); enzymatic activity (β glucosidase, urease, aryl sulfatase, phosphatases) or aggregate stability, can be used as soil quality indicators. They provide early information about mineralization processes, nutrient availability and fertility, as well as effects resulting from changes in land use, or agricultural practices (e.g. tillage or application of different types of organic matter). In this context, biological properties have been used as soil quality indicators, because of their relationship with organic matter content, terrestrial arthropofauna, lichen, microbial community (biomass or functional groups), metabolic products as ergosterol or glomalin and soil activities as microbial respiration and enzyme production.

Key words: Biological indicators, soil quality.

## INTRODUCTION

The interest in soil quality can be traced back to the ancient Inidan civilization. Trough the time, the use of agricultural residues, application of organic matter, rotation, and tillage practices has been fundamental in maintaining soil fertility. One important discovery, at the end of the nineteenth century, was the nitrogen fixing microorganisms, associated with roots that opened the door to a better understanding of rhizosphere and the development of soil ecology as related to soil fertility.

Traditional soil management in agriculture is based on temperate crop rotations with grass crops for livestock production, improving soil structure and increasing fertility, with an important role of animals and natural fertilizers. After the Second World War, this traditional system was reduced, increasingly separating livestock from arable land, which lead to the elimination of grass and animal manure application in many arable crop systems. Soil management was neglected, leading to growing concerns about the physical condition of the soil, which was evident in the report "Modern agriculture and the earth" (Ingram, 2008); soil erosion (Morgan, 1985 and Dazell *et. al.*, 1987) and leaching of nutrients. These concerns triggered definitions of national policies in Canada, United States (Saini and Grant, 1980) and England (Defra, 2006) aiming at land conservation and recovery of soil's ability to meet its multiple functions, concepts that finally met in "soil quality".

This concept of soil science dates back to the 1970s. When Warkentin (1977) suggested the development of a concept of soil quality that encompasses the following facts :

1. Land resources are being evaluated for different uses
2. Multiple stakeholder groups are concerned about resources
3. Priorities of society and the demands on land resources are changing
4. Soil resources and land use decisions are made in a human or institutional context.

The Soil Science Society of America (SSSA), after much discussion about the subject, came with a broad definition: "The ability of a specific type of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or improve air quality and water to support human health and livable" (Karlen *et al.,* 1997).

## SELECTION OF SOIL QUALITY INDICATORS

Soil quality is estimated by observing or measuring different properties or processes, and, several of these indicators can be used to determine soil quality indices. According to different authors (Doran and Zeiss 2000), indicators should be limited and manageable in number by different types of users, simple and easy to measure, cover the largest possible situations (soil types), including temporal variation, and be highly sensitive to environmental changes and soil management (Dick, 2000). The selection of indicators thus depends on the soil and functions being assessed. These features include, among others: support for the development of living organisms, water and nutrient flows, diversity and productivity of plants and animals, elimination or detoxification of organic and inorganic contaminants. Likewise, the selection depends on the sensitivity of these properties to soil management or changes in climate, as well as the accessibility and usefulness to producers, scientists, conservationists and policy makers (Dora and Parkin, 1996; Rezaei *et al.*,2006). The selection of indicators implies knowing research needs, and the power to interpret the indicator: the land use, the relationship between the indicator and the soil function that is being evaluated, the easiness and reliability of the measurement, the variation in time of the crop, application of organic matter or crop rotation in relation to sampling, the sensitivity of the soil property to be measured against changes in the ecosystem (Rezaei *et al*.,2006).

In fact, some authors suggest that a soil quality indicator is not adequate if it is not directly related to the target user. If the goal is a quality index for soil crop production, then soil organic matter, infiltration, soil aggregation, pH, microbial biomass, N forms, bulk density, electrical conductivity or salinity, and available nutrients, represent a group of indicators that can be used to describe most of the soil basic functions like the ability to accept, hold and release water to plants, maintain productivity, and respond to management and erosion processes (Rezaei *et al.*,2006).

Brejda and Moorman (2001) stated that soil quality can not be measured directly but can bemeasured through some sensitive indicators. Further, they emphasized that the changes inthese indicators are used to determine whether soil quality is improving, stable, or declining with changes in management, land-use, or conservation practices. Indicators of soil qualitycan be defined loosely as those soil properties and processes that have greatest sensitivity tochanges in soil functions (Andrews *et al*., 2004). 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 (Walker and Reuter, 1996). Indicators signal desirable or undesirable changes in land and vegetation management that have occurred or may occur in the future. These indicators may directly monitor the soil, or monitor the outcomes that are affected by the soil, such as increases in biomass, improved water use efficiency, and aeration. Soil quality indicators can also be used to evaluate sustainability of land-use and soil management practices in agroecosystems (Shukla *et al*. 2006). The predominant soil quality indicators at micro and macro farm scale as suggested by Singer and Ewing (2000) have been listed in Table 1.

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. Parr *et al.* (1992) suggested that increased infiltration, aeration, macropores, aggregate distribution and their stability and soil organic matter and decreased rate of bulk density, soil resistance, erosion and nutrient runoff are some of the important indicators for improved soil quality. However, while selecting the indicators, it is important to ensure that the indicators should i) correlate well with natural processes in the ecosystem (this also increases their utility in process-oriented modelling, ii) integrate soil physical, chemical, and biological properties and processes, and serve as basic inputs needed for estimation of soil properties or functions which are more difficult to measure directly, iii) be relatively easy to use under field conditions, so that both specialists and producers can use them to assess soil quality, iv) be sensitive to variations in management and climate and v) be the components of existing soil databases wherever possible (Doran *et al***.** 1996; Doran and Parkin 1996; Chen 1998). Interpreting soil quality by merely monitoring changes in individual soil quality indicators may not give complete information about soil.

**PHYSICAL INDICATORS CHEMICAL INDICATORS BIOLOGICAL INDICATORS**

**Table 1.** Predominant soil quality indicators at micro and macro farm scale

| **Physical Inidcator** | **Chemical Indicator** | **Biological Indicator** |
|---|---|---|
| Passage of air | BSP | Organic carbon |
| Structural stability | Cation exchange capacity | Microbial biomass carbon |
| Bulk density | Contaminant availability | C and N/Oxidizable carbon |
| Clay mineralogy | Contaminant concentration | Total biomass |
| Colour | Contaminant mobility | Bacterial |
| Consistence (dry, moist, wet) | Contaminant presence | Fungal |
| Depth of root limiting layer | Electrical conductivity | Potentially mineralizable N |
| Hydraulic conductivity | Exchangeable sodium | Soil respiration |
| Oxygen diffusion rate | percentage | Enzymes |
| Particle size distribution | Nutrient cycling rates | Dehydrogenase |
| Penetration resistance | pH | Phosphatase |
| Pore conductivity | Plant nutrient availability | Arlysulfatase |
| Pore size distribution | Plant nutrient content | Biomass C/total organic |
| Soil strength | Sodium adsorption ratio | carbon/ |
| Soil tilth | | Respiration /biomass |
| Structure type | | Microbial community |
| Temperature | | fingerprinting |
| Total porosity | | Substrate utilization |
| Water holding capacity | | Fatty acid analysis |
| | | Nucleic acid analysis |

Source: Singer and Ewing (2000)

Soil Quality and Productivity Improvement– Indian Perspectives 215 quality. Therefore, combining them in a meaningful way to a single index may assess soil quality more precisely (Jaenicke and Lengnick, 1999; Bucher, 2002) which is used to gauge the level of an improving or declining soil condition (Wienhold, 2004).

## SOIL QUALITY INDICATORS INFLUENCES SOIL FUNCTIONS AND SUSTAINABILITY

### Chemical indicators and their soil functions

Of the various indicators, pH is one of the important indicator, which influence some of the soil functions. It can provide trends in change in soil health in terms of soil acidification (surface and sub surface) (Moody and Aitken, 1997), soil salinization, electrical conductivity, exchangeable sodium (soil structural stability) (Rengasamy and Olsson, 1991), limitations to root growth, increased incidence of root disease, biological activity, and nutrient availability (e.g. P availability at either high pH > 8.5 or low pH < 5; Zn availability at high pH > 8.5) (Doran and Parkin, 1996). Soil pH trends also provide changed capacity of the soil for pesticide retention and breakdown as well as the mobility of certain pesticides through soil.

Organic matter is essential for good soil structure especially in low clay content soils, as it contributes towards both formation and stabilization of soil aggregates (Dalal and Mayer, 1986). Other functions include: contribution to low cation exchange capacity, especially in low clay content soil, pesticide retention (Kookana *et al.*, 1998), microbial biodiversity, water retention in sandy and sandy-loam soils, and provision of carbon sink and source for greenhouse gases. Trends in soil organic matter content provide an integrated measure of sustainable ecosystem (Karlen *et al.*, 1997). Status of plant available nutrients, for example, N, P, S and K indicate the systems sustainable land use, especially, if the nutrient concentration and availability are approaching but remain above the critical or threshold values. In the long-term, nutrient balance of the system (e.g. Input efficiency =output) is essential to sustainability. Thus, available nutrients are indicators of the capacity to support crop growth, potential crop yield, grain protein content (Dalal and Mayer, 1986), and conversely, excessive amounts may be a potential environmental hazard (e.g. algal biomass).

### Physical indicators and their soil functions

The physical indicators of soil health reflect the capacity to accept, store, transmit and supply water, oxygen and nutrients within ecosystem. This includes monitoring of soil structure through pore size distribution, aggregate stability, saturated hydraulic conductivity, infiltration, bulk density, and surface crust. Rooting depth provides a good indicator of buffering against water, air and nutrient stress. Soil surface cover can be used as Soil Quality and Productivity Improvement Under Rainfed Conditions – Indian Perspectives 217 an indicator of soil surface protection against raindrop impact, and hence enhanced infiltration, reduced surface crust, and reduced soil erosion and runoff. Soil water infiltration measures the rate at which water enters soil surface, and transmitted through the immediate soil depth (Arshad *et al.* 1996). Rainfall is rapidly absorbed by soil with high infiltration rate, but as the soil structure deteriorates, usually with the loss of organic matter, increase in exchangeable sodium and low electrolyte concentration, infiltration rate of a soilbecomes low (Rengasamy and Olsson, 1991).

Effective soil depth is a good indicator of plant available water capacity, subsoil salinity and other root growth constraints in the soil profile. It is not known whether trends can be discerned over relatively long periods (Walker and Reuter, 1996; Doran and Parkin, 1996). Surface crust retards seed germination and reduces aeration and water entry. It provides an indication of soil structure decline (Aggarwal *et al.* 1994, Bridge, 1997).

### Biological indicators and their soil functions

In the set of biological soil quality indicators, soil microbial biomass and/or respiration, potentially mineralizable N, enzyme activity, fatty acid profile or microbial biodiversity, nematode communities and earthworm populations are quite predominant. Soil microbial 218 Resource Management for Sustainable Agriculture biomass is a labile source and sink of nutrients. It affects nutrient availability as well as nutrient cycling and is a good indicator of potential microbial activity (Dalal and Mayer, 1987) and capacity to degrade pesticides (Perucci and Scarponi, 1994). Although useful as a research tool, its cumbersome measurement and variability with short-term environmental conditions makes it difficult as a routine soil quality indicator (Sparling, 1997; Dalal, 1998).

Respiration measurements are also similarly affected. However, respiration rates can be measured in the field using portable CO2 analysers. Easily oxidizable N and potentially mineralizable N are measured by alkaline-KMnO4 method and aerobic or anaerobic incubation respectively. Anaerobic method is considered to be more effective and is recommended as routine procedure. Potentially mineralizable N measures soil N supplying capacity and is also a surrogate measure of microbial biomass and a labile fraction of soil organic matter (Rice *et al.* 1996). Soil enzyme activity is often closely related to soil organic matter, microbial activity and microbial biomass. It is sensitive to change in management practice and can readily be measured. Of numerous soil enzymes, dehydrogenase is a potential indicator of active soil microbial biomass. However, it is very sensitive to seasonal variability. Potentially useful indicators of soil quality could be beta-glucosidase, urease, amidase, phosphatase, and aryl-sulphatase and fluorescein diacetate hydrolyzing enzymes.

### Assessment of soil quality- Recent approaches

Assessment of soil quality is a sensitive and dynamic way to document soils condition, its response to management, or its resistance to stress imposed by natural forces or human uses (Larson and Pierce, 1991). It is needed to identify problem production areas, make realistic estimates of food production, monitor changes in sustainability and environmental quality as related to agricultural management, and to assist government agencies in formulating and evaluating sustainable agricultural and land-use policies (Granatstein and Bezdicek, 1992). As stated earlier, soil quality can be assessed by measuring soil attributes or properties that serve as soil quality indicators. The changes in these indicators signal the changes in soil quality (Brejda and Moorman, 2001). The first step is selecting the appropriate soil quality indicators to efficiently and effectively monitor critical soil functions as determined by the specific management goals for which an evaluation is being made.

These indicators together form a minimum data set (MDS) that can be used to determine the performance of the critical soil functions associated with each management goal. In order to combine the various chemical, physical and biological measurements with totally different units, each indicator is then scored using ranges established by the soil's inherent capability to set the boundaries and shape of the scoring function. 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. These unitless 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. Andrews and Carroll (2001) suggested that dynamic soil quality assessment could be viewed as one of the components needed to quantify agroecosystem sustainability.

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