Review Article

Soil Quality Attributes for a Sustainable Agriculture: A Review

ABSTRACT

Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. 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. Soil quality often is related to soil degradation, which can be defined as the time rate of change in soil quality. Soil quality should not be limited to soil productivity, but should encompass environmental quality, human and animal health, and food safety and quality. In characterizing soil quality, biological properties have received less emphasis than chemical and physical properties, because their effects are difficult to measure, predict, or quantify. Improved soil quality often is indicated by increased infiltration, aeration, macropores, aggregate size, aggregate stability, and soil organic matter, and by decreased bulk density, soil resistance, erosion, and nutrient runoff.

Keywords: dynamic soil quality, inherent soil quality, soil function, soil health, soil indicator, sustainable agricultural

1. INTRODUCTION

Soil, like air and water, is a fundamental natural resource supporting a variety of ecosystem goods and services to the benefit of the mankind (Maikhuri and Rao 2012). Soil is the greatest reservoir and the last frontier of biodiversity which is composed of the four basic components viz. mineral solids, water, air and organic matter including living biota (Brady and Weil 2002; Elias 2016; Gugino et al. 2009b). It is a complex body which subsist as many forms, each with diverse properties that may vary widely across time and space as a function of many factors. This complexity makes the evaluation of soil quality much more challenging than that of water or air quality. Evaluation of soil quality now considers environmental implications as well as economic productivity, seeking to be more holistic in its approach. Thus, soil quality research draws from a wide range of disciplines, blending the approaches of biologists, physicists, chemists, ecologists, economists and agronomists, among others (Carter et al. 1997; Gregorich et al. 1997).

Water movement, water quality, land use and vegetation productivity all have relationships with soil and plays a vital role in sustaining life on the planet. But many of us fail to consider the importance of preserving the health of the earth's soils for now and generations to come by considering soil are a highly valuable and non-renewable dynamic natural resource which is essential to life. Nearly all of the food that humans consume, except for what is harvested from marine environments, is grown in the Earth's soils. In more recent years, due to concerns with soil degradation and the need for sustainable soil management in agroecosystems, there has been a renewed scientific attention to soil variables. Coupled with this is the idea of soil use which has emphasized the value of soil and soil properties for a specific function. Generally, modern concerns with soil quality evolve around the various functions that soils perform in ecosystems. Thus, soil quality becomes inseparable from the idea of system sustainability, and is considered a key indicator of ecosystem sustainability. The emphasis for soil quality shifts away from suitability for use to whether soil functions are operating at some optimum capacity or level within an ecosystem (Schoonover and Crim 2015).

Placing a value upon soil in regard to a specific function, purpose or use leads to the concept of soil quality. However, in contrast to water and air, for which the function can be directly related to human and animal consumption, the function placed upon soil is often diverse and usually not directly linked or involved with human health and the concept of quality here is relative to a specific soil function or use (Doran and Parkin 1994).

Understanding soil quality attributes and their relationships with sustainable agriculture is very important to recognize associated problems and to set appropriate resolving measures. The concept of soil quality has grown out of concern about the sustainability of agriculture (Parr et al. 1992; Warkentin 1995). Authors (De la Rosa and Sobral 2008) also indicated that environmental sustainability will only be achieved by maintenance and improvement of soil quality because soil also affects water quality, air quality, and biotic quality. Thus, Protecting and/or improving soil quality can provide a stepping stone to improving environmental quality as a whole. For example, planting cover crops when a field would otherwise be bare, helps reduce soil erosion and aids in soil and nutrient retention on site, limiting its transportation to waterways where water quality would be affected.

Hence, soil quality is not a perceived technology; instead, it is a concept that can be used in making land management decisions. Researchers have generally agreed upon the soil properties that determine soils' capacity to function and have emphasized that soil quality must be understood in context and research has included the following viz. (1) soil management research, where the effects of management on soil properties and dependent processes are assessed; (2) measurement development for soil quality assessment to be carried out by the farmers themselves, by advisors, or consultants and (3) systems assessments, that consider the physical and cultural contexts that impact soil quality decision-making. Therefore, the main objective of this seminar review is to congregate and synthesize the available information related to soil quality, soil assessments, the role of soil quality for sustainable agriculture. Moreover, the paper includes issues and/or constraints and research implications related to soil quality in Ethiopia.

1.1.Conception and Definitions of Soil Quality

Soil quality is not a new topic because early scientific endeavors recognized the importance of categorizing soil type and soil variables in regard to land or soil use, especially for agricultural purpose (Carter et al. 1997). Historically, soil quality meant suitability or limitations of a soil for a particular use (Warkentin and Fletcher 1977). Warkentin and Fletcher (1977) also discussed soil quality from the perspective of soils having value in the biosphere. These authors clinched that the soil quality concept has both intrinsic and current use components and added that soil quality is a key element for evaluating the sustainability of agricultural systems. According to (Bremer and Ellert 2004) concerns about soil quality stem from three major issues in agriculture: (i) Are the land resources required for continued agricultural productivity being maintained? (ii) Are agricultural lands harming the environment (water quality, air quality, biodiversity)? and (iii) Are agricultural products safe and nutritious? In fact, for many soil scientists, ecologists, agronomists, and other professionals around the world, the continuing degradation of natural resources is closely associated with a loss of soil quality and their rationale is that if soils are managed/maintained in a manner that ensures the biological, chemical, and physical properties and processes are sustained and functioning properly, much of the current degradation can be mitigated.

The concept of soil quality literally to some group seems unnecessary and redundant among the soil science profession because they assume that "everyone" knows what a good soil constitutes and where it found. To others, quantifying soil quality is impossible because of "natural differences" among soil orders and even between the same soil series found in different places. What constitutes good soil quality may be different according to land use and/or geographic region. For this reason, (Karlen et al. 1997) and (Doran and Parkin 1996) suggest that soil quality should be evaluated based on how well a soil functions within its specific ecosystem (agriculture, urban, etc.). For example, in an agricultural field, the capacity of a soil to function and sustaining crop growth would depend on several soil characteristics including bulk density, soil moisture, infiltration, and biological activity, to name a few. Many of these properties can be changed by management and soil quality can be improved according to its function.

Presently, soil quality has been defined by some scientists as the "*fitness for use*" (Acton and Gregorich 1995a; Pierce and Larson 1993), and by others as the "*capacity of the soil to function*" (Arshad and Martin 2002; Doran and Parkin 1994; Karlen et al. 2001) but the soil science expert community and others are used the second definition of soil quality which balances the physical, biological, and chemical components of soil as proposed by Karlen *et al*. (2001) and the expanded version of this functional definition is:

> "*The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation*."

The imbedded concept in this definition is the capacity of the soil to carry out ecological functions that support terrestrial communities (including agroecosystems and humans), resist erosion, and reduce negative impacts on associated air and water resources with the fitness of soils to perform particular ecosystem functions.

The concept of soil quality has undergone an evolutionary process that began with a definition and the identification of parameters that could be used to assess soils in a holistic fashion and relate soil properties to processes and management practices. Basically, the conception of soil science dates back to the 1970s when Warkentin and Fletcher (1977) suggested the development of a concept of soil quality. These authors portray that the concept of soil quality was introduced for proper stratification and allotment of agricultural inputs by making our understanding of soils more complete. According to (Loganathan and Narendiran 2016) the interest in soil quality can be traced back to the ancient agricultural civilization. In the course of time, understanding the use of agricultural residues, application of organic matter, crop rotation, and tillage practices has been fundamental in maintaining soil fertility. Thus, the soil quality discussion which has developed since the late 1980's has raised important issues about soil assessment and management. At the same time, it is often frustrating due to the lack of direct testing of the proposed concepts. The current discussion of soil quality is distinguished from previous soil assessment efforts by its attention to the dynamic soil characteristics that are affected by management choices.

The characteristics that define a high-quality soil depend on the inherent features of the soil, landscape, climate, and land use. But there are some general features that most authors imply are necessary for a soil to be described as healthy or of high quality. Quality soil is thought to be: high in organic matter and biological activity, friable with stable aggregates, easily penetrated by plant roots, easily infiltrated by water rather than running over the surface and low in weed and disease pressure. Quality soil will produce healthy crops over the long-term without increasing levels of inputs. It will control water flow and will filter and degrade potential environmental contaminants. Healthy soil is buffered against wide swings in temperature, moisture and other environmental conditions. This buffering capacity will be reflected in low levels of pest outbreaks and relatively stable production levels.

These definitions (Table 1) imply that quality with respect to soil can be viewed in two ways: (1) as inherent properties of a soil; and (2) as the dynamic nature of soils as influenced by climate, and human use and management (Seybold et al. 1999). With respect to inherent properties, a soil is a result of the factors of soil formation viz. climate, topography, vegetation, parent material, and time (Brady and Weil 2002; Elias 2016). Each soil, therefore, has an innate capacity to function, e.g., some soils will be inherently more productive or will be able to partition water much more effectively than others. This view of the definition is useful for comparing the abilities of one soil against another, and is often used to evaluate the with or suitability of soils for specific uses. Thus, an intrinsic part of the soil quality is covering a soil's inherent capacity for crop growth. For example, sandy soil drains faster than clayey soil. Deep soil has more room for roots than soils with bedrock near the surface. These characteristics do not change easily.

However, it can be influenced by pedogenic processes and the changes are more pronounced in tropical climate due to physical and chemical weathering enhanced by high temperature and precipitation.

The dynamic soil quality part is influenced by the soil user or manager which underlines the lessons of history that good quality soils can be degraded by poor management practices. This argument is further strengthened by (Larson and Pierce 1994) who reported as dynamic soil quality changes in response to soil use and management. As (Richter 1987) proposed also as the distinction between inherent and dynamic soil quality can also be characterized by the genetic (or static) pedological processes versus the kinetic (or dynamic) processes in soil. (Koolen 1987) and (Carter 1990) also make a distinction between state properties and behavioral properties in soil, which correspond to the concepts of inherent and dynamic soil quality.

Therefore, dynamic soil quality is how soil changes depending on how it is managed. Management choices affect the amount of soil organic matter, soil structure, soil depth, and water and nutrient holding capacity and one goal of soil quality/health research is to learn how to manage soil in a way that improves soil functions because soils respond differently to management depending on the inherent properties of the soil and the surrounding landscape. As a result, understanding soil quality/health means assessing and managing soil so that it functions optimally now and is not degraded for future use and by monitoring changes in soil health, a land manager can determine if a set of practices is sustainable or not.

The concept of soil quality has been suggested by several authors (Acton and Padbury 1993; Granatstein and Bezdicek 1992; Karlen et al. 1992; Lal 1991; Papendick and Parr 1992; Sanders 1992) as a tool for assessing long-term sustainability of agricultural practices at local, regional, national, and international levels. Sustainable management of soils and land supports agricultural productivity, food security, climate change mitigation and resilience, and a range of ecosystem services. Indeed, many of the Sustainable Development Goals (SDGs) are closely related to soil health, SDG 15 specifically calls for halting and reversing land degradation by 2030. As (Doran and Parkin 1994) suggested that soil quality assessments could be used as a management tool or aid to help farmers select specific management practices and as a measure of sustainability. They also suggested that approaches used to define and assess soil quality should be tailored for specific applications such as sustainable production, environmental quality, and animal or human health. Soil quality may also provide a focal point or vocabulary for communication between scientists and non-scientists, if the concept can be clearly defined.

Table 1. Some concepts, definitions and descriptions of soil quality since 1970s by different authors and institutes (authors compiled)

Concepts and Definition of soil quality	References
"The concept of soil quality encompasses the following facts: Land resources are being evaluated for different uses; Multiple stakeholder groups are concerned about resources; Priorities of society and the demands on land resources are changing and Soil resources and land use decisions are made in a human or institutional context".	(Warkentin and Fletcher 1977)
"The sustained capability of a soil to accept, store and recycle water, nutrients and energy."	(Anderson and Gregorich 1984)
Soil qualities are defined as inherent characteristics or properties of a soil, such as texture, slope, structure, and soil color.	(USDA 2006)
"The capacity of a soil to function within its ecosystem boundaries and interact positively with the environment external to that ecosystem."	(Larson and Pierce 1994)
"A composite measure of both a soil's ability to function and how well it functions, relative to a specific use".	(Gregorich et al. 1994)
"Reflect the fitness of a soil body, within land use, landscape and climate boundaries, to protect water and air quality, sustain plant and animal productivity and quality, and promote human health".	(Harris and Bezdicek 1994)
"How effectively soils accept, hold, and release nutrients and other chemical constituents; accept, hold, and release water to plants, streams and groundwater; promote and sustain root growth; maintain suitable biotic habitat; and respond to management and resist degradation".	(Larson and Pierce 1994)
"The capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health"	(Doran and Parkin 1994)
"The soils capacity or fitness to support crop growth without resulting in soil degradation or otherwise harming the environment"	(Acton and Gregorich 1995b)
"capacity of a soil to function, within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health".	(Doran 1996)
Assert that soil quality is intended to protect the ability of ecosystems to function properly.	(Cook and Hendershot 1996)
"The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation."	(Karlen et al. 1997)
soil quality can only be evaluated on assessing the outcomes of soil functions, i.e., by comparing 'what the soil does' to 'what the soil is asked to do'	(Carter et al. 1997)
The whole thrust of soil quality research arose from the recognition that soils are a vital component of and provide necessary services to the ecosystem and that the ability of soils to continue to provide those services is threatened by degradation.	(Daily et al. 1997)
Soil quality is a measure of the conditions of soil relative to the requirement of one or more species and	(Johnson et al. 1997; Lal

/or to any human need or purpose.	1997)
Stated that the concept of soil quality includes soil fertility, potential productivity, resource sustainability, and environmental quality.	(Singer et al. 2000)
The soil-quality concept is related to the concepts of sustainability of soil use and management	(USDA 2006)
"Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation".	(SSSA 2008)

1.2.Soil Health versus Soil Quality and Basic Functions

Only "living" things can have health, so viewing soil as a living ecosystem reflects a fundamental shift in the way we care for our nation's soils. Soil isn’t an inert growing medium, but rather is teaming with billions of bacteria, fungi, and other microbes that are the foundation of an elegant symbiotic ecosystem. In the scientific community, soil quality and soil health are used and defined synonymously (Acton and Gregorich 1995b; Doran and Parkin 1994; Harris and Bezdicek 1994; Karlen and Stott 1994; Larson and Pierce 1994) and currently the terms are becoming increasingly familiar worldwide. A modern consensus definition of soil health is “the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans”. Whereas, concise definitions for soil quality include “fitness for use” and “the capacity of a soil to function.” Combining these, soil quality is the ability of a soil to perform the functions necessary for its intended use (USDA-NRCS 2012). According to Moebius *et al*. (2016) soil health is a concept that deals with the integration and optimization of the chemical, physical, and biological processes of soil that are important for sustained productivity and environmental quality (Figure 1).

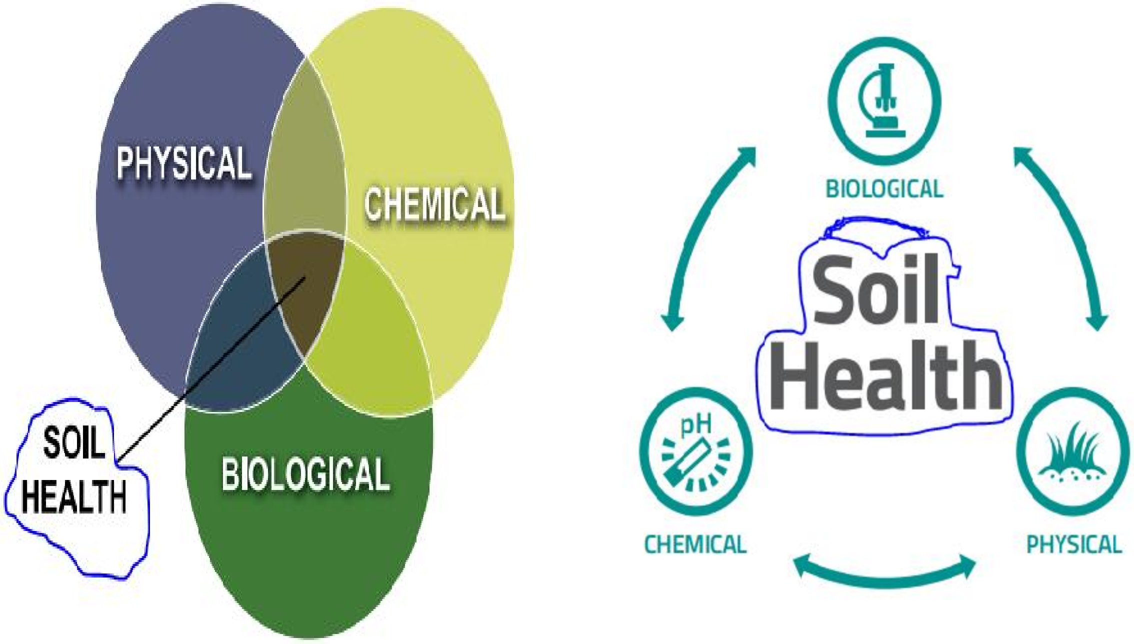


Figure 1. The concept of soil health deals with integrating the physical, biological and chemical components of the soil (Source: the *Rodale Institute* and *AgSource Laboratories,* respectively).

Doran and Parkin (1994), defined soil quality as “the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health.”Moreover, soil health is a concept which deals with the integration and optimization of the physical, chemical and biological properties of soil for improved productivity and environmental quality. Essentially the Rodale Institute stated that there is no standard definition of soil health, since there are a few clear indicators of a healthy soil community many of which have informed organic farming practices. Organic growers rely on the surrounding soil and ecosystem biology to support their crops rather than the chemistry of pesticide, herbicide and fertilizer companies (https://rodaleinstitute.org/our-work/soil-health/).

Consideration of soil as a finite and living resource, led to the concept of soil health defined as the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain or enhance the quality of air and water, and promote plant, animal and human health (Doran and Parkin 1996; Doran and Zeiss 2000).

In general, soil health and soil quality are considered synonymous and can be used interchangeably, with one key distinction conceptualized by scientists and practitioners over the last decades: soil quality includes both inherent and dynamic quality. Inherent soil quality refers to the aspects of soil quality relating to a soil’s natural composition and properties (soil type) influenced by the natural long-term factors and processes of soil formation which cannot be influenced by human management. Whereas, dynamic soil quality, which is equivalent to soil health, refers to soil properties that change as a result of soil use and management over the human time scale. Thus, soil health invokes the idea that soil is an ecosystem full of life that needs to be carefully managed to regain and maintain our soil’s ability to function optimally and the term ‘soil health’ has been generally preferred by farmers, while scientists have generally preferred ‘soil quality’ (Gugino et al. 2009a; Moebius-Clune et al. 2016).

Healthy soil gives us clean air and water, bountiful crops and forests, productive grazing lands, diverse wildlife, and beautiful landscapes. Soil does all this and others (Figure 2) by performing five essential functions: (1) Regulating water, (2) Sustaining plant and animal life, (3) Filtering and buffering potential pollutants, (4) Cycling nutrients and Physical stability and support. At the heart of soil health is the integration of soil physical, chemical and biological processes and functions. A healthy soil will be a balance of all three components. For years we have relied on inexpensive soil testing procedures to assess chemical properties, but methods for rapid assessment of the physical and biological status of the soil are not generally offered. The Cornell Soil Health Assessment can be used to evaluate and integrate these different processes and functions for the purpose of improving soil health.

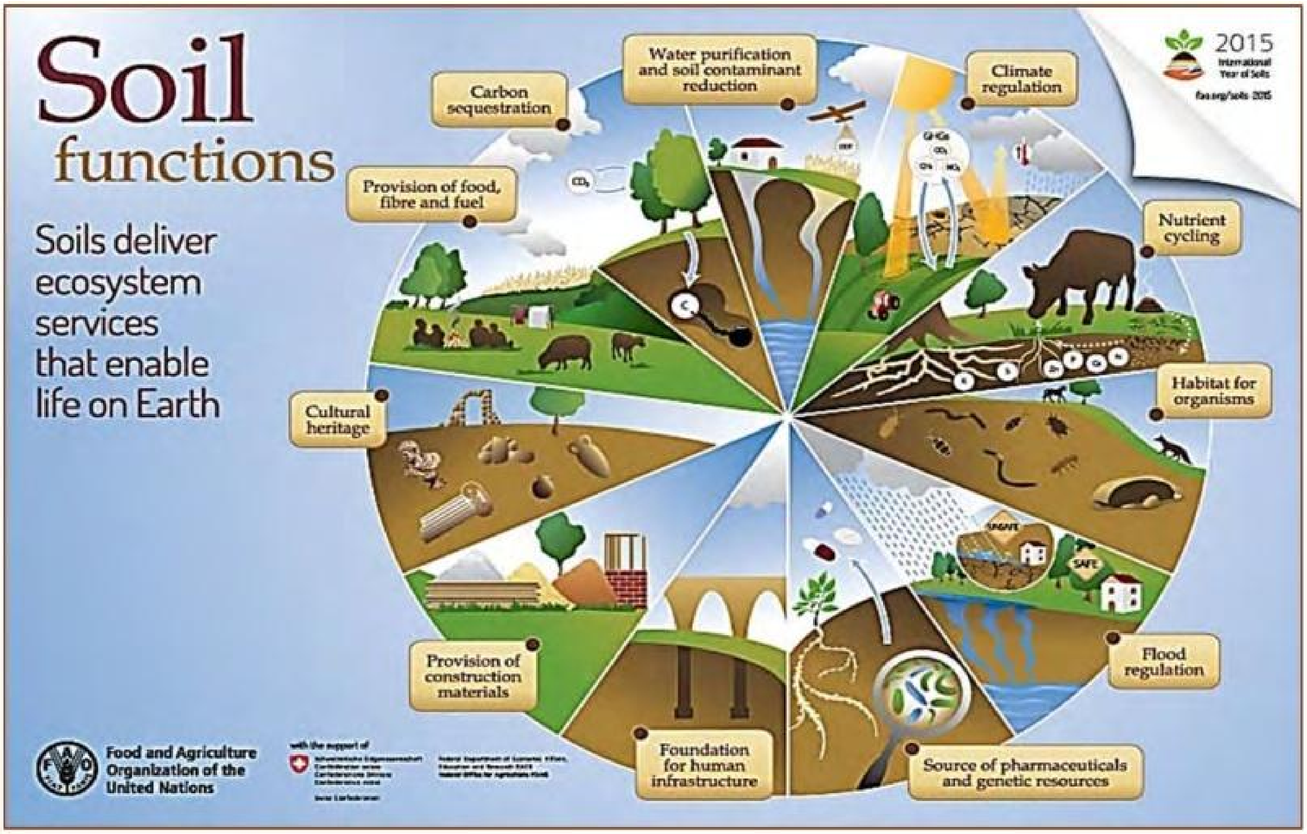


Figure 2. Soil functions adopted from FAO fact sheet prepared for 2015 international year of soil.

Table 2. Characteristics of a healthy/quality Soil

Features of healthy soil	Descriptions
Good soil tilth	Soil tilth refers to the overall physical character of the soil in the context of its suitability for crop production
Sufficient depth	Sufficient depth refers to the extent of the soil profile to which roots are able to grow and function. A soil with a shallow depth as a result of a compaction layer or past erosion is more susceptible to extreme fluctuations in the weather, thus predisposing the crop to drought or flooding stress.
Sufficient but not excess supply of nutrients	An adequate and accessible supply of nutrients is necessary for optimal plant growth and for maintaining balanced cycling of nutrients within the system. Excess nutrients can lead to leaching and potential ground water pollution, high nutrient runoff and greenhouse gas losses, as well as toxicity to plants and microbial communities.
Small population of plant pathogens and insect pests	In agricultural production systems, plant pathogens and pests can cause diseases and damage to the crop. In a healthy soil, the population of these organisms is low and/or inactive. This could result from direct competition from other soil organisms for nutrients or niche habitats, hyperparasitism, etc. Also, healthy plants are better able to defend themselves against a variety of pests (similar to the human immune system).
Good soil drainage	Even after a heavy rain, a healthy soil will drain more rapidly as a result of good soil structure and an adequate distribution of different size pore spaces, but also retain adequate water for plant uptake.
Large population of beneficial organisms	Soil microbes are important to the functioning of the soil. They help nutrient cycling, decomposition of organic matter, maintenance of soil structure, biological suppression of plant pests, etc. A healthy soil will have a high and diverse population of beneficial organisms to carry out these functions and thus help maintain a healthy soil status.
low weed pressure	Weed pressure is a major constraint in crop production. Weeds compete with crops for water and nutrients that are essential for plant growth. Weeds can interfere with stand establishment, block sunlight, interfere with harvest and cultivation operations, and harbor disease causing pathogens and pests.
Free of chemicals and toxins that may harm the crop	Healthy soils are either devoid of harmful chemicals and toxins or can detoxify and/or bind such chemicals making them unavailable for plant uptake due to their richness in stable organic matter and diverse microbial communities.
resistant to degradation	A healthy, well aggregated soil is more resistant to adverse events including erosion by wind and rain, excess rainfall, extreme drought, vehicle compaction, etc.
Resilience when unfavorable conditions occur	A healthy soil will rebound more quickly after a negative event such as harvesting under wet soil conditions or if land constraints restrict or modify planned rotations.

Source: Gugino *et al*., 2009

1.3.Soil Quality Attributes/Indicators and their roles in soil system

Soils have chemical, biological, and physical properties that interact in a complex way to give a soil its quality or capacity to function (genesis and classification). Thus, soil quality and many soil ecosystem functions cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as indicators (Box 3), which are easily measurable soil properties to determine the status of soil quality (Acton and Padbury 1993).

Because of the multiple and complex functions associated with soil quality, its assessment necessitates the integration of chemical, physical, and biological soil properties. Of particular interest are properties that can serve as early and sensitive indicators of ecosystem stress or changes in soil productivity. Given the pervasive role of organic matter in promoting soil ecosystem functions, it is not surprising that researchers have found soil organic matter-related properties to be important indicators of soil quality (Arshad and Coen 1992; Gregorich et al. 1994; Islam and Weil 2000; Kennedy and Papendick 1995; Larson and Pierce 1991; Wander and Bollero 1999). Popp *et al.*, (2002) cited in (Weil and Magdoff 2004) highlighted that soil pH and SOM are the two most commonly included soil quality indicators in many studies. Dumansky (1994) also concluded that "soil organic matter is emerging as a key indicator for assessing sustainability" of land management systems.

Box 3. What are indicators?

Indicators are representations that communicate correct and relevant information quickly and easily to people who are not necessarily experts in the field. In contrast, data are values that need further processing before they provide meaningful information, such as a statistic. Statistics describe real phenomena according to exact definitions, but they often require interpretation. Indicators communicate a correct message without further interpretation (note: the term 'indicator' is also used generically for any variable related to the information of interest). Indicators may be based on a simple relationship between observation and information needs, e.g., a fuel gauge. Indicators might also be based on a proxy relationship between observation and information needs, e.g., the "canary in a coalmine". Finally, indicators might be based on many measurements related to the needed information, e.g., gross domestic product. When expressed relative to an agreed standard, indicators are often referred to as indices, e.g., greenhouse gas index, consumer price index and soil quality index.

Table 3. Key soil indicators for soil quality assessment (after Arshad and Coen, 1992, Doran and Parkin, 1994, Gregorich *et al*., 1994, Larson and Pierce, 1991, Carter *et al*., 1997, Karlen *et al.*, 1997)

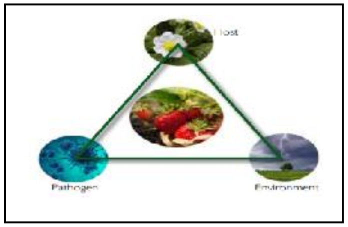
Selected indicator	Rationale for selection
Organic matter	Defines soil fertility and soil structure, pesticide and water retention
Topsoil-depth	Estimate rooting volume for crop production and erosion
Aggregation	Soil structure, erosion resistance, crop emergence an early indicator of soil management effect
Texture	Retention and transport of water and chemicals
Bulk density	Plant root penetration, porosity, adjust analysis to volumetric basis
Infiltration	Runoff, leaching and erosion potential
pH	Nutrient availability, pesticide absorption and mobility
EC	Defines crop growth, soil structure, water infiltration
Pollutants	Plant quality, and human and animal health
Soil respiration	Biological activity, process modeling; estimate of biomass activity, early warning of management effect on organic matter
Forms ofN	Availability of crops, leaching potential, mineralization/ immobilization rates,
Extractable N, P and K	Capacity to support plant growth, environmental quality indicator

Table 4. Proposed MDS of physical, chemical, and biological indicators for screening the quality or health of soils (After Doran *et al*., 1996 and Larson and Pierce, 1994)

Indicators	Relationship to soil condition and function: rationale as a priority measurement
Physical	
Texture	Retention and transport of water and chemicals; modeling use, soil erosion and variability estimate
Depth of soil and rooting	Estimate of productivity potential and erosion; normalizes landscape and geographic variability
Infiltration and bulk density	Potential for leaching, productivity, and erosivity; bulk density: SBD needed to adjust analyses to volumetric basis
Water holding capacity	Related to water retention, transport, and erosivity; available H_2O; calculate from SBD, texture, and OM
Chemical	
Soil organic matter (OM)	Defines soil fertility, stability, and erosion extent; matter (OM); use in process models and for site normalization
pH	Defines biological and chemical activity thresholds; essential to process modeling
Electrical conductivity	Defines plant and microbial activity thresholds; presently lacking in most process models
Extractable N, P, and K	Plant available nutrients and potential for N loss; productivity and environmental quality indicators
Biological	
Microbial biomass C and N	Microbial catalytic potential and repository for C and N; modeling: early warning of management effects on OM
Potentially mineralizable N	Soil productivity and N supplying potential; mineralizable N; process modeling (surrogate indicator of biomass)
Soil respiration	Microbial activity measure (in some cases plants); process modeling; estimate of biomass activity

Table 5. Soil health indicators and their relation to soil function compiled from Moebius *et al*., 2016

Category	**Indicator**	**How soil texture relates to soil function**
Physical	Soil texture	Texture affects many important soil processes due to the total amount of pore space and how varied pore space is within aggregates. Soils with higher clay contents generally have higher ability to retain nutrients (more CEC) and can accumulate, or sequester, more organic matter. In addition, soil organisms and plant roots live and function in pore spaces. When the soil loses porosity (generally due to management), roots cannot grow as well, and many organisms have more difficulty surviving.
	Available Water Capacity	Water is stored in medium and small sized soil pores and in organic matter. Available Water Capacity is an indicator relating the laboratory measured weight of soil to water storage capacity in the field, and therefore how crops may fare in extremely dry conditions. Soils with lower storage capacity have greater risk of drought stress. Sandy soils, which tend to store less organic matter and have larger pores, tend to lose more water to gravity than clayey and loamy soils.
	Surface and subsurface hardness	Field penetration resistance is an indicator of the soil compaction status. Compaction occurs when large pores are packed closer together through tillage or traffic with heavy equipment, particularly on wet soils. Large pores are necessary for water and air movement and to allow roots and organisms to explore the soil. When surface soils are compacted, runoff, erosion, slow infiltration, and poor water storage result.
	Wet Aggregate Stability	Wet Aggregate Stability tests the soil's physical ability to hold together and sustain its aggregation, or structure, during conditions with the most impact: a heavy rain storm or other rapid wetting event, such as irrigation, after surface drying weather. This is a good indicator of both physical and biological health. Soils with low aggregate stability tend to form surface crusts and compacted surface soils, which can reduce air exchange and seed germination, increase plant stress and susceptibility to pathogen attack, and reduce water infiltration and thus storage of water received as rainfall. This leads to runoff, erosion and flooding risk downstream during heavy rainfall, and higher risk of drought stress later. Poor soil aggregation also makes the soil more difficult to manage, as it reduces its ability to drain excess water, so that it takes longer before field operations are possible after rain events.
Biological	Total soil organic matter	Soil organic matter is where soil carbon is stored. OM in its various forms greatly impacts the physical, biological and chemical properties of the soil. OM acts as a long-term carbon sink, and as a slow-release pool for nutrients. It contributes to ion exchange capacity (nutrient storage), nutrient cycling, soil aggregation, and water holding capacity, and it provides nutrients and energy to the plant and soil microbial communities.
	Soil Protein Index	Plant residues are ultimately the source of much of the SOM. Microbial biomass builds up as plant residues and other organic matter amendments decompose in the soil. Residues are made up of several types of compounds that are largely similar in composition, of these compounds, protein contains the largest fraction of N. Protein content, as organically bound N, influences the ability of the soil to store N, and make it available by mineralization during the growing season. Soil protein content has also been associated with soil aggregation and thus water storage and movement.
	Soil Respiration	Respiration is a direct biological activity measurement, integrating abundance and activity of microbial life. Thus, it is an indicator of the biological status of the soil community, which can give

		insight into the ability of the soil's microbial community to accept and use residues or amendments, to mineralize and make nutrients available from them to plants and other organisms, to store nutrients and buffer their availability over time, and to develop good soil structure, among other important functions.
	Active Carbon	Due to its role in providing available food and energy sources for the soil microbial community, active carbon is positively correlated with percent organic matter aggregate stability, and with measures of biological activity (such as respiration) and Microbial biomass. Research has shown that active carbon is a good "leading indicator" of soil health response to changes in crop and soil management, usually responding to management much sooner (often years sooner) than total organic matter percent.
Chemical	Standard Nutrient Analysis (pH and extracts plant macro- and micronutrients)	Nutrient availability is critical to crop production. Of the eighteen elements needed by plants, only three N, P, and K are commonly deficient in soils. Deficiencies of micronutrients such as Mg, S, B, Mn and Zn can occur, but it is unusual. Crops do not grow properly if nutrients are not present at the right time of the season in sufficient quantities and in balance with one another. When plants don't grow well they are more susceptible to disease, loss of yield, and poor crop quality which leads to reduced economic returns.
Adds-on	Potentially Mineralizable Nitrogen	The PMN test provides us with one indication of the capacity of the soil biota to recycle organic nitrogen that is present into plant available forms.
	Root Health Bio-assay	Pathogen pressure refers to the degree to which plants encounter potentially growth-limiting attack by disease causing organisms. This is a function of: • The presence of pathogen • The host • The environmental condition 
	Heavy Metal Contamination	Most heavy metals are adsorbed strongly to clays and organic matter, which limits the potential for plants to take these up when soil pH is not in the acid range
	Salinity	High salinity decreases the osmotic potential of the soil water relative to plant water.

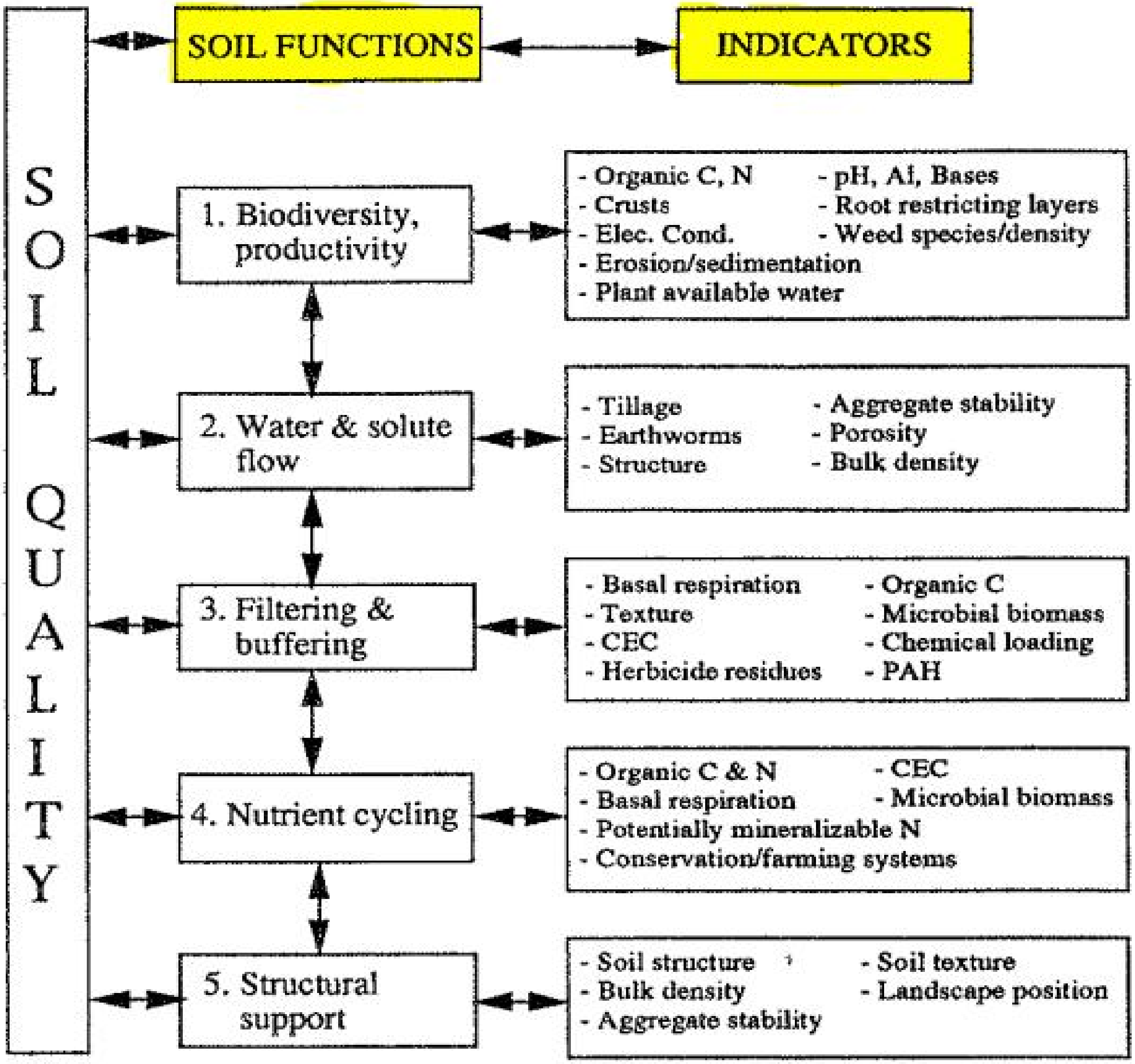


Figure 3. Graphical representation of the concept of soil quality using soil functions and indicators of soil quality, adapted from Seybold *et al*., 1997.

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 et al. 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 (Doran 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).

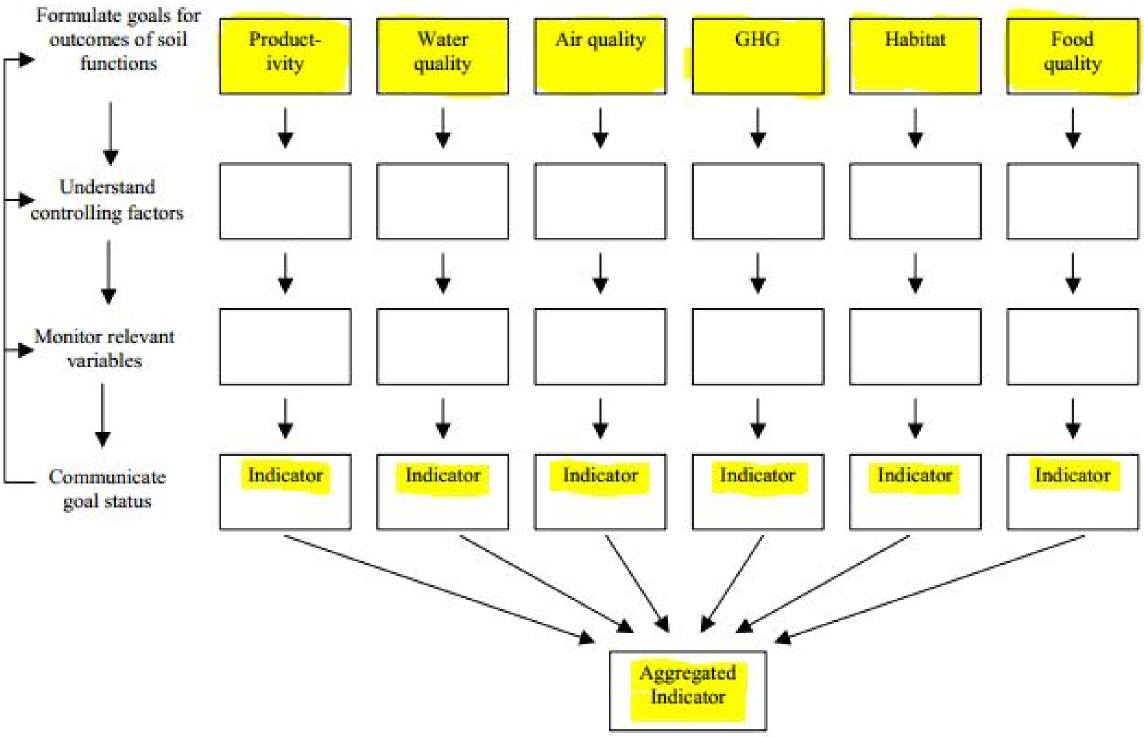


Figure 4. Proposed flowchart for the evaluation of soil quality (Bremer and Ellert 2004).

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). As (Brejda and Moorman 2001) stated that soil quality cannot be measured directly but can be measured through some sensitive indicators. Further, they emphasized that the changes in these 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 quality can be defined loosely as those soil properties and processes that have greatest sensitivity to changes 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).

Several researchers have observed different set of key indicators for assessing soil quality depending upon the soil types and other variations. The integration of scientific and farmer's evaluation of soil quality indicators is reported by (Mairura et al. 2007) 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 modeling, 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). Interpreting soil quality by merely monitoring changes in individual soil quality indicators may not give complete information about soil.

Table 6. Potential indicators initially evaluated for use in the soil health assessment protocol.

Physical	**Biological**	**Chemical**
Texture	Root pathogen pressure assessment	Phosphorus
Bulk density	Beneficial nematode population	Nitrate nitrogen
Macro-porosity	Parasitic nematode population	Potassium
Meso-porosity	Potentially mineralizable nitrogen	pH
Micro-porosity	Cellulose decomposition rate	Magnesium
Available water capacity	Particulate organic matter	Calcium
Residual porosity	Active carbon	Iron
Penetration resistance at 10 kPa	Weed seed bank	Aluminum
Saturated hydraulic conductivity	Microbial respiration rate	Manganese
Dry aggregate size (<0.25 mm)	Soil proteins	Zinc
Dry aggregate size (0.25 - 2 mm)	Organic matter content	Copper
Dry aggregate size (2 - 8 mm)		Exchangeable acidity
Wet aggregate stability (0.25 - 2 mm)		Salinity
Wet aggregate stability (2 - 8 mm)		Sodicity
Surface hardness with penetrometer		Heavy metals
Subsurface hardness with penetrometer		
Field infiltrability		

Source: (Moebius-Clune et al. 2016)

The Cornell Comprehensive Assessment of Soil Health (CCASH) protocol emphasizes the integration of soil biological, physical, and chemical measurements. These measurements include soil texture, available water capacity, field penetrometer resistance, wet aggregate stability, organic matter content, soil proteins, respiration, active carbon, and macro- and micro-nutrient content assessment. Additional indicators are available as add-ons, including root pathogen pressure, salinity and sodicity, heavy metals, boron and potentially mineralizable nitrogen. These measurements were selected from 42 potential soil health indicators (Table 6) that were evaluated for: Sensitivity to changes in soil management practices; Ability to represent agronomically and environmentally important soil processes; Consistency and reproducibility; Ease and cost of sampling; cost of analysis and ease of interpretation for users.

Table 7. Potential biological, chemical, and physical indicators of soil quality, measurable at various scales of assessment (compiled from Karlen *et al*. 2001; Singer and Ewing, 2000)

Scale	biological Indicators	Chemical Indicators	physical Indicators
Point scale indicators	Microbial biomass	pH	Aggregate stability
	Potential N mineralization	Organic C and N	Aggregate size distribution
	Particulate organic matter	Extractable macronutrients	Bulk density
	Respiration	Electrical conductivity	Porosity
	Earthworms	Micronutrient concentrations	Penetration resistance
	Microbial communities	Heavy metals	Water-filled pore space
	Soil enzymes	CEC and cation ratios	Profile depth
	Fatty acid profiles	-	Crust formation and strength
	Mycorrhizal populations	-	Infiltration
Field - farm or watershed scale indicators	Crop yield	Soil organic matter changes	Topsoil thickness and color
	Weed infestations	Nutrient loading or mining	Compaction or ease of tillage
	Disease pressure	Heavy metal accumulation	Ponding (infiltration)
	Nutrient deficiencies	Changes in salinity	Rill and gully erosion
	Growth characteristics	Leaching or runoff losses	Surface residue cover
Regional – national or international scale indicators	Productivity (yield stability)	Acidification	Desertification
	Species richness, diversity	Salinization	Loss of vegetative cover
	Keystone species and ecosystem engineers	Water quality changes	Wind and water erosion
	Biomass, density and abundance	Air quality changes	Siltation of rivers and lakes

Box 4. Some key functions of soil microbes include:

- Decomposition of organic matter (crop residue)
- Mineralization and recycling of nutrients
- Fixation of nitrogen
- Detoxification of pollutants
- Maintenance of soil structure
- Biological suppression of plant pests
- Parasitism and damage to plants

1.4. Soil Quality Indices

In considering soil quality, attempts have been made to examine the factors that indicate 'good' soil health or soil quality, to reach consensus on the definition, upon the key soil attributes that translate into variables (Pedotransfer functions) to be examined, on their data value ranges, their value limits, threshold values, comparability; and to aggregate or integrate the variables/values in such a way as to then develop meaningful indices that characterize the quality/health of varying soils in various world regions, across nations, or in local areas, and at the farm level (Synonymous, 2003). Thus, an appropriate Soil Quality Index (SQI) may have three component goals: environmental quality, agronomic sustainability, and socio-economic viability (Andrews *et al*., 2002).

Soil quality indices are decision tools that effectively combine a variety of information for multi-objective decision making (Karlen and Stott, 1994). A number of soil quality and fertility indices have been proposed (Andrews et al. 2004; Beck 1984; Karlen et al. 1998; Stefanic et al. 1984; Trasar-Cepeda et al. 1997), none identifies state of soil degradation that affects its functionality.(Bastida et al. 2008), build on the approach of (Andrews et al. 2002), suggested microbiological degradation index. While many workers appreciated and recommended the use of soil quality indices, reservations about their utility also expressed. Many times, the concepts associated with soil quality are used in close association with the concepts of sustainability, leading to a degree of confusion and inappropriate use of the term soil quality (Sojka and Upchurch 1999). Even though the importance of evaluation of soil quality is being increasingly realized, there is yet no global consensus on how this should be defined.

One way to integrate information obtained from MDS measurements is to develop a soil quality index. Such an index could be used to monitor and predict the effects of farming systems and management practices on soil quality, or could provide early signs of soil degradation (Parr *et al.*, 1992). Granatstein and Bezdicek (1992) suggest also the need for a soil quality index that reflects both the general potential for human use and unique biophysical conditions of a specific location. The first concept of a soil quality index was introduced by (Rust et al. 1972) who related soil quality to the environmental impacts of agrochemicals (e.g., soluble N fertilizers).

Selections of soil quality indicators or synthetic indices are guided by the goal of ecosystem management. If achieving sustainability is the goal of agroecosystems management, a soil quality index will constitute one component within a nested agroecosystems sustainability hierarchy (Figure 5). Management goals may also differ by the interests and visions of different sections of people concerned with agriculture (Table 7).

Once the management goals are identified, soil quality indexing involves three steps: (i) selection of soil properties/indicators constituting the minimum data set(ii) transformation of indicator scores enabling quantification of all indicators to a common measurement scale and (iii) combining the indicator scores into the index (Figures 5 a and b).

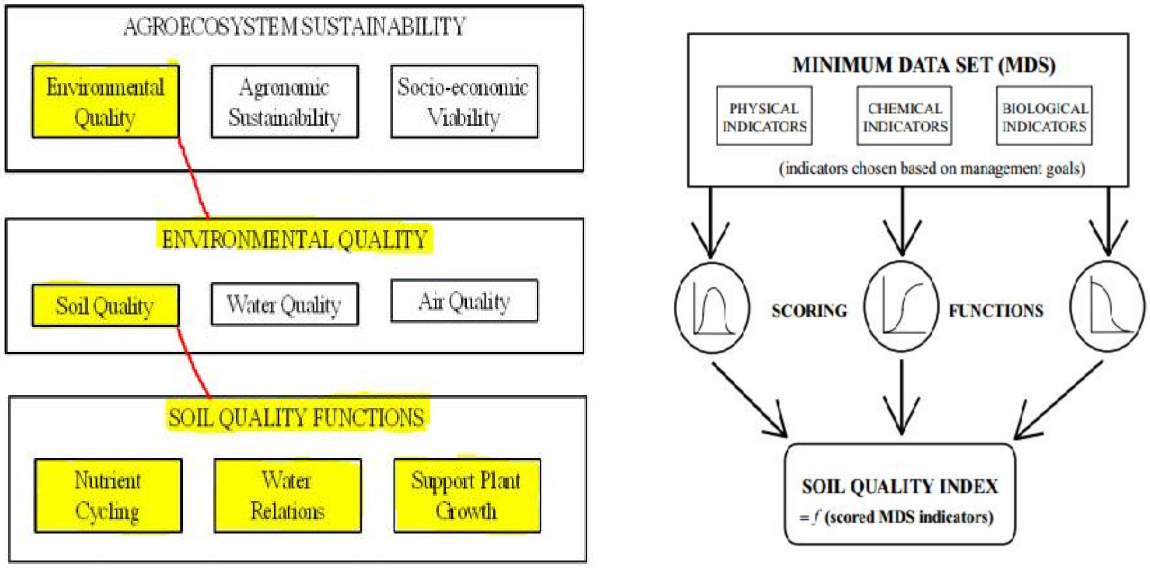


Figure 5. (a) Nested hierarchy of agroecosystems sustainability showing the relationship of soil quality to the larger agroecosystems, (b) Conceptual relationship between soil quality MDS, scoring functions, and index values. Adopted from (Maikhuri and Rao 2012).

2. FACTORS INFLUENCING SOIL QUALITY

Due to improper land use and management, soil degradation is threatening food security (Oldeman *et al*., 1990). Soil quality and its importance for sustainable agricultural development has received much attention in recent years (Dumanski and Pieri 2000; Liu et al. 2010). Karlen *et al*. (1992) stated that inherent interactions among the five-basic soil forming factors [parent material, climate (including water and temperature effects), macro- and micro-organisms, topography and time] create a relatively stable soil quality that has distinct physical, chemical, and biological characteristics in response to prevailing natural or non-anthropogenic factors. However, humankind, the anthropogenic force described as a sixth soil forming factor in the basic model for describing a soil (SSSA 2008) interacts with the non-anthropogenic factors and influences soil quality both negatively and positively.

Soil and crop management practices imposed on land resources by humankind thus determine whether inherent soil quality will be lowered, sustained, or improved over relatively short time intervals. The relative importance of anthropogenic or management factors compared to non-anthropogenic physical, chemical, or biological factors will generally be determined by the function or application for which a soil quality assessment is made (Karlen, n.d).There are several fundamental properties of soils that influence soil quality. A well balanced healthy soil is one that is likely to be the most robust and capable of meeting the requirements for a wide range of uses. Some properties, such as texture, are static and cannot be changed readily. Others are more sensitive to change and it is these which in need to be monitored carefully to maintain optimum levels.

2.1.Processes Influencing Soil Quality

Ecosystem processes which were relevant to environmental quality and agricultural sustainability are (1) soil structure, including form, stability, and resiliency to respond to stress; (2) nutrient cycling, involving transformations such as mineralization and immobilization; and (3) biological interactions, including trophic relations within food webs. These processes may influence soil quality because they are easily influenced by soil and crop management inputs into agroecosystems. Tillage, fertilization, practices, and pest control are identified as practices capable of influencing soil structure, nutrient cycling, and biological interactions, respectively

(Bronick and Lal 2005). They also stated that by understanding agroecosystems processes, it would be possible to identify practices or mechanisms to mitigate environmental degradation through surface water eutrophication, groundwater contamination, soil erosion, sedimentation, and contamination by pesticide residues.

2.2.Management Practices Influencing Soil Quality

Management practices that influence soil organic matter content are the most important with respect to soil quality; because soil organic matter was the component that showed the greatest decline when virgin prairie was first broken for cultivation (Karlen, n.d; Bauer and Black, 1981).The use of management strategies that add or maintain soil carbon, therefore, appear to be needed to improve the quality of our soil resources (Karlen *et al*., 1992).

Table 8. Processes associated with land use and management practices that reduce soil quality

Process	Effect on soil attributes/quality	Possible effect on environment
Erosion	Topsoil removed, nutrients lost; capacity to regulate water and energy flow in soil reduced	Deposition of soil material and pesticides in streams and rivers
Loss of OM	Soil fertility and structure reduced; capacity to regulate energy flow in soil reduced	Increased soil erosion and degradation, and enhanced greenhouse effect from released CO_2
Loss of structure	Soil porosity and stability reduced; capacity to store and transmit water reduced	Increased runoff and soil water erosion
Salinization	Excess soluble salts and nutrient imbalance; adverse medium for crop growth	Increased bare soil and soil wind erosion
Chemical contamination	Presence of toxins; capacity to act as an environmental buffer exceeded	Movement of chemical via runoff and/or leaching

Source: Carter *et al*., 1997

3. SOIL QUALITY/HEALTH ASSESSMENT

Soil quality is an effective tool for monitoring soil function. Assessing soil quality (Box 1) involves measuring physical, chemical, and biological soil properties and using these measured values to identify properties of the soil that may be inhibiting soil function or to monitor how changes in management are affecting soil functions (Arnold et al. 2005). Soil quality can only be assessed by measuring properties and therefore involves both an observer and an interpreter. The concepts of soil quality/health, and soil quality/health assessment are highly contentious within the soil science community (Karlen et al. 2008), because many believe those terms have generalized and oversimplified the collective knowledge and wisdom developed through several centuries of intensive, in depth, global studies of soil resources (Letey et al. 2003).

Box 1: Why assess soil quality/health?

- Increase awareness of soil health
- Understand constraints beyond nutrient deficiencies and excesses
- Target management practices to alleviate soil constraints
- Monitor soil improvement or degradation resulting from management practices
- Facilitate applied research, compare management practices to develop recommendations for farm and field specific soil health management planning
- Land valuation – facilitate the realization of equity embodied in healthier soils
- Enable assessment of farming system risk.

Source:(Moebius-Clune et al. 2016)

Soil quality assessment is a tool to assess management-induced changes in the soil and to link existing resource concerns to environmentally sound land management practices. 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. Useful Indicators (Box 2) are measured to monitor management induced changes in the soil.

Box 2: Useful indicators are: (**Source:(Moebius-Clune et al. 2016)**

- 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.

Soil quality indicators are selected because of their relationship to specific soil properties and soil quality. For example, soil organic matter is a widely used indicator, because it can provide information about a wide range of properties such as soil fertility, soil structure, soil stability, and nutrient retention. Similarly, plant indicators, such as rooting depth, can provide information about the bulk density or compaction of the soil.

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). 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. As (Andrews and Carroll 2001) suggested that dynamic soil quality assessment could be viewed as one of the components needed to quantify agroecosystems sustainability.

In general, soil quality assessment is carried out by selecting a set of soil properties which are considered as indicators of soil quality. Soil functions are sensitive to soil quality indicators (Aparicio and Costa 2007), hence the indicators should be easy to measure (Dumanski and Pieri 2000). The selection of minimum soil data set (MDS) is based on methods such as principal component analysis (PCA) (Andrews and Carroll, 2001), expert opinion (EO) (Andrews *et al*., 2002) and factor analysis (Shukla et al. 2006). PCA reduces the dimension of large volume of data and facilitate the indicator selection by categorically grouping the soil properties into principal components (PC). Expert opinion, primarily based on available literature, field experience and knowledge of soil scientists, emphasizes on the cause-effect relationship of soil properties influenced by pedogenic processes (Pal et al. 2014).

4. SOIL QUALITY ISSUES AND CONSTRAINTS IN ETHIOPIA

Ethiopia is trapped in a vicious cycle of poverty (Esser et al. 2002) and in many parts of Ethiopia, land degradation in the form of soil erosion, nutrient depletion, soil compaction, and increased salinization and acidity pose a serious threat to sustainable intensification and diversification of agricultural production systems. Moreover, prevailing soil management practices including over tillage and blanket fertilization are key factors in Ethiopian agriculture's contribution to climate change (Zelleke et al. 2010). The key soil level bottlenecks identified in various parts of Ethiopia are:

- Nutrient depletion (-122 (N), -13 (P) and -82 (K) kgha^{-1}yr^{-1} , the highest in Sub-Saharan Africa)
- OM depletion(crop residue removal, intensive tillage, dung burning and deforestation)
- Biological deterioration (Loss of SOM and decline in the biotic activity of soil fauna but the ignored part due to measurement facility)
- Chemical degradation (Salinity, sodicity, and Acidity)
- Physical land degradation (deterioration of soil structure, crusting, compaction, erosion, and desertification).

Poor land-use practices and population pressure are the major drivers. There is a lack of reliable and consistent data on the extent and rate of soil loss (t/ha/yr) (Eyasu 2003; Gebreselassie et al. 2016). Different data sources report different estimates on the amount of soil loss from arable land (Table 10).

Table 9. Estimates of rates of soil loss on croplands in Ethiopia

Soil Loss (t/ha/yr)	Method used	Sources
130	USLE and guess estimation	(Constable and Belshaw 1986)
42	Measurement from 8 runoff plot across the country	(Hurni 1988)
75	Measurement from runoff plots	(Tegene 1992)
300	Secondary data and estimates	(Hawando 1997)
100	Guess estimate	(Bekele-Tesemma 1997)

Source: **(Eyasu 2003; Gebreselassie et al. 2016)**

Ethiopia faces a wider set of soil fertility issues beyond chemical fertilizer use, which has historically been the major focus for extension workers, researchers, policymakers, and donors. If left unchecked, this wider set of issues will limit future output and growth in agriculture across the country; in some areas, they already limit the effectiveness of chemical fertilizer. These chemical, physical, and biological issues interact and include loss of organic matter, macronutrient, and micronutrient depletion, topsoil erosion, acidity, salinity, and deterioration of other physical soil properties. In addition, Ethiopia has soil types with inherent characteristics which can be problematic for crop production and which need special management.

Table 10. From (Zelleke et al. 2010) working paper identified four major areas in which on-farm practices need major change across Ethiopia

Fertility problem	Cause	References
Severe organic matter depletion	Organic matter depletion is driven by competing uses for crop residues and manure as livestock feed and fuel, respectively.	Bojo and Cassels (2005)
Limited intercropping and crop rotation	Even though the benefit is clear and have been identified by research but have not been translated into widespread use.	Reddy and Kidane (1993); Getachew *et al.* (2006)
Limited use of integrated, locally tailored solutions to tackle complexity of constraints	Absence of up-to date, comprehensive, and actionable soil data. Much of this data is based only on N and P nutrient levels and yield response, with very little information available on other aspects of soil health (micronutrients, organic matter, physical properties).	(Zelleke et al. 2010)

5. SUMMARY AND IMPLICATIONS

5.1.Summary

Although soil quality can be simply defined as a soil's "fitness for use", it is in reality a complex concept and significantly more challenging in its assessment than air or water quality. Soil quality can basically be divided into inherent and dynamic quality. The former is a component of land quality, whereas the latter is strongly influenced by the soil manager. Measurement of soil quality involves placing a value upon soil in relation to its fitness to perform a specific function or purpose. Functions can vary in relation to both use of soil and scale. Once a function has been established, it is possible to identify and characterize soil processes and attributes that describe the function, the indicators that are related to the attribute(s), and methodologies for measuring these. This allows the development of soil quality standards and control techniques, and subsequently the design of sustainable land management systems.

Accurate information about soil fertility is critical to develop smart policies regarding the preservation and rehabilitation of natural resources especially soil. Information on the fertility properties of the diverse soils will enable to continue its tremendous gains in crop production and productivity, while simultaneously ensuring that growth is achieved through sustainable means. Soil quality has emerged as a unifying concept for educating professionals, producers, and the public about the important processes that soils perform and as an assessment tool for evaluating current management practices and comparing alternative management practices. Soil attributes comprising a MDS have been identified and both laboratory and field methods have been developed for measuring these attributes.

Overall, the following conclusions can be given in regard to the concept of soil quality:

- The concept of soil quality is not altogether new, but is undergoing development in response to the idea that soils are part of land or terrestrial ecosystems. Thus, soil quality brings together old and new ideas about soil and land.
- It is important to recognize the difference between inherent and dynamic soil quality, as well as the difference between soil and land quality. Further, although soil quality describes an objective state or condition of the soil, it is also subjective or evaluated partly on the basis of personal and social determinations.
- Ecosystem concepts such as function, processes, attributes, and indicators, provide a useful and robust framework to describe soil quality. This framework is also useful when it is directed towards the intensive manipulation, engineering, and/or management of the soil resource.

- In the context of using soil intensively as a resource, soil quality becomes a technology or an applied science, directed towards problem solving (e.g., better soil management) and can be seen as a key to sustainable land management.
- The basic idea of "fitness for use" in regard to agricultural and/or industrial use of soil, reflected in early attempts to classify "soil suitability" or "land capability", is the basic premise of soil quality. If a soil is not suitable for specific use then it is not appropriate to assign or describe quality for that specific use or function. In many cases, however, it is not possible to make a perfect match between the soil and its intended use, and quality must be built into the system.
- A large range of attributes, such as chemical, physical, and biological properties, can be used to describe soil quality. Attributes need to be selected for specific soil uses. However, some attributes have a wide utility and can serve a wide range of purposes. Thus, a "minimum data set", composed of a limited number of key attributes, is the usual approach in soil quality investigations,
- A major impediment to the evaluation of soil quality is the lack of standardization, related to both methodology and "critical limits". Soil quality standards are required to ensure that soil sampling, description, and analysis can set the limits for a quality soil and detect adverse changes in soil quality.

5.2.Policy and Research Implications

In the way forward, we need ways of monitoring, on a reasonably regular basis, the quality of soils at all levels from global, through to continental, national, regional and landscape/ catchment areas. It is only in this way that we shall be able to evaluate the sustainability of the use to which we are putting the land. It should be in the mind of everyone that is not many years hence we shall reach the critical stage when there are more people than the land can feed. It is therefore in the interest of everyone to ensure that soils will be well-managed into the future. Equally important in the quest for sustainable development is that there be measures put in place that protect the land, prevent the continuously increasing damage to land, and for those in authority to bring in protection measures.

MoARD, local experts, and stakeholders have identified six priority areas for action to improve soil fertility in Ethiopia:

- Implement soil fertility solutions appropriate to Ethiopia's extremely diverse agro-ecology and varied local soil fertility needs through ISFM.
- Make effective use of organic carbon resources by increasing the amount of manure and crop residues used as organic nutrient sources.
- Mitigate severe topsoil erosion in cultivated highlands through interventions at the individual farm level as well as through large-scale community and regional projects in targeted areas.
- Reduce constraints on value chains for chemical and bio-fertilizers to ensure that uptake and use of these interventions are not constrained.
- Create a central repository of national and local soil data and effective knowledge dissemination channels to ensure that this information provides the fact base for actions to improve soil health.
- Link major soil fertility efforts to relevant international projects and experts to maximize relevance of projects already underway and ensure transfer of applicable knowledge and experiences.

This generation has a responsibility for safeguarding and sustaining the environment and handing it on to the next generation in a reasonable condition. There is much evidence to date that we have not been looking after the environment, including soils, adequately, and there is much evidence of temporary and permanent damage. Yet the population of the world is increasing rapidly – expected to be 10 billion by 2050. Thus, there will be increasing pressure to produce more and more food to feed this growing population but there is more and more evidence of widespread land degradation and in some developing countries including Ethiopia declining soil fertility. Therefore, essential improvements to safeguard the soils will require:

- A good understanding of the nature of soils and their properties
- Strong national soil/land databases which can be regularly added to and which provide basic information on which to develop a sustainable land use policy
- A better knowledge of soil quality, and the soil quality requirements for particular land uses, involving the identification and change of the important parameters with time.

- A much better understanding of the effects of particular types of land use and management practice on soils.
- A much better knowledge of ecosystems in which soils occur and, in particular, the soil ecosystem.
- Development of land use practices and management systems that do not degrade the soil
- Lastly and very importantly better knowledge of the fate and behavior of pollutants entering the soil from a wide range of sources

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