Review Article

Soil Quality Indicators: A Comprehensive Review.

Abstract

The ability of soil to function as a vital living system within land use limitations is characterized as soil quality and soil health. This function which sustains soil microbial production, also preserves the quality of the surrounding environment and human health. Traditionally, soil evaluations were primarily concerned with agricultural productivity. Soil health also include soil's impact in water quality, climate change, and human health. The overall health of animals, humans, and ecosystems within its area is also linked to soil health. Soil quality and soil health are not interchangeable terms. Soil quality is determined by what it does (functions), whereas soil health considers soil to be a live biological entity that influences plant health. Many soil activities and ecosystem services rely on SOC (Soil Organic Compounds) and its dynamics.

Keywords: Ecosystem productivity, Climate, Soil Health, Organic Carbon, Soil Quality Indicators.

Introduction

Soil is a very complex ecosystem which is full of useful resources **[74].** Soil is also the foundation of both agricultural and wild plant ecosystems. Thus, for the majority of land-based life, the thin layer of soil covering the earth's surface signifies the difference between survival and extinction **[25].** On the basis of degree of pollution in the air and water their quality are determined in the ecosystem **[14].** Soil health, which is an essential part of ecological sustainability, deteriorates due to soil degradation. The ability of a soil to operate and offer ecological services is characterized as soil health **[70].** The word soil quality is usually related with suitability of soil for certain usage and the word soil health used widely to denote the ability of soil to perform as vibrant living system in order to protect biological productivity and improve ecological health. The Land degradation is the main cause of poor Land management practices that remove organic matter without replacing it with crop cover. This includes intensive tillage and soil erosion, as well as atmospheric pollution and desertification **[24].** It is Must to develop efforts and have measures in place to preserve and rebuild soil health in the agricultural sector. Soil organic matter, soil respiration, soil biota biomass, microbial biomass C and N, enzyme activity, pH, electrical conductivity (EC), cation exchange capacity, plant available nutrients. porosity, aggregate stability, infiltration, bulk density, soil available water, and soil and rooting depths are some of the indicators used **[12].** As a result, in order to sustain agriculture for subsequent generations, we must design methods of cultivation that retain and improve the quality of the soil. Throughout this paper, the terms "soil quality" and "soil health" will be used interchangeably. Generally, soil quality is related to a soil's suitability for a particular purpose, while soil health is used in a broad sense to emphasize the soil's ability to support biological productivity, enhance environmental quality, and sustain the health of plants and animals **[24]**.The utilization of chemicals for pest and disease control in agriculture has a Negative effect on the ecosystem and has resulted in negative environmental alterations, one of which is soil degradation. These alterations can only be remedied by the elimination of these chemicals **[66].** Biochar has been created during the past 20 years as a potential addition to composting and soils with a variety of favourable effects **[34].** Land use, agricultural practice, soil pollution, soil sealing and climate change have all contributed to the greater impact on soil function caused by technology development and population growth **[31].**

Soil Quality Indicators

Soil indicators play a critical role in determining soil quality. They are selected based on their significance for soil functions, potential determinants of soil quality, and their impact on ecosystem services **[60].** Soil quality and health indicators are mainly about how they help us understand how ecosystems work and how they combine physical, chemical and biological elements, how sensitive they are to management and climate changes, and how useful they are to farmers, producers, environmentalists and policy makers **[23]**. Indicators are a collection of things you can measure based on how things work together. You can track them through field surveys, field samplers, remote sensing, surveys, or just by looking at what's already out there **[39].** Soil quality indicators have been extensively studied; however, there is no definitive definition of the most suitable soil indicator category. Soil quality indicators can be divided into three main categories: biological indicators, chemical indicators, and physical indicators. These indicators provide a visual representation of the alteration that occurs in the soil as a result of anthropogenic processes **[60].** Although the chemical and physical soil quality indicators are typically employed, soil biological indicators have proven to be more responsive (due to their rapid response to environmental changes) and are therefore superior soil quality indicators **[52].** It is therefore essential to examine the impact of a variety of management techniques on soil biological indicators in order to assess the sustainability of management techniques as well as their potential ecological and economic impacts **[59].**

Table1ClassificationofSoilQualityIndicators.

PhysicalIndicators	**BiologicalIndicators**	**ChemicalIndicators**
WaterHoldingCapacity	OrganicCarbon	pH
Bulk Density	Enzymes	ElectricalConductivity
Temperature	MicrobialCommunity	NutrientCyclingRates
Passageofair	Bacterial	Salinity
ParticleSizeDistribution	TotalBiomass	Alkalinity
SoilTilth	Fungal	CationExchangeCapacity

Source **[61]**.

1 Biological indicators

The majority of soil biological activity is concentrated in the upper layer, which can range in depth from a few centimetres to 30 centimetres. In the upper layer, biological components make up only a small portion of the total volume of soil, accounting for less than 0.5% of total organic matter, and are mainly composed of soil organisms **[50].** Biological indicators are utilized to gain an understanding of the living components of soil. In common with physical and chemical indicators, biological indicators are linked to soil functions, and can be used to evaluate soil functions in order to evaluate soil quality **[18].** Singh said that in the dry, arid areas of western India, there was a decrease in the number of earthworms and other animals living in the soil, as well as a decrease in the amount of moisture in the soil, acidity in the soil, and the palatability of food sources **[62].** Earthworms are essential for the preservation of soil-based organic matter in aggregates **[2,6,8,41]**.The activity of earthworms is largely dependent on environmental factors, such as temperature and moisture content **[47]**. A quantifiable assessment of the diversity and fluctuation of the microbial community may be used to assess soil quality **[77].** Microbial diversity is influenced by the cropping system as well. Greater microbial diversity has been seen in soils with a farming system centred on cereals without legumes **[26].** In Table 1 List of few biological indicators which also helps in regulating nutrient cycling processes like nitrogen cycle phosphorus cycle and carbon cycle and are involve in many other Biological Processes.

(a) Microbial Community

The soil system is home to an immense number of microbes, yet little is known about these microscopic organisms, which are responsible for a variety of processes taking place in the soil and sustaining the productivity of both natural and managed agroecosystems **[73,57]**. Soil microbes play a major role in the interactions between soil and plants, and are essential for preserving soil quality. Nutrient cycling is one of the most significant interactions between the two organisms. In a healthy soil-plant ecosystem, soil biota are responsible for regulating the flow of nutrients, the growth of roots, and the storage of nutrients. Additionally, fertilization may be mediated by efficient rhizosphere microbes prior to the use of the crop/plant **[27]**. These biological components are essential for nutrient cycling and the decomposition of organic matter The majority of soil biological activity is concentrated in the upper layer, which can range in depth from a few centimetres to approximately 120 centimetres. The topsoil accounts for only a small portion of the soil volume (0.5%), and accounts for less than 10% of soil organic matter (SOM) **[50]**. One of the primary roles of soil microorganisms is the degradation of various types of organic matter found in soil. This includes residues of dead plants and animals, as well as the waste products of living organisms. These organic components must be transformed into simple, inorganic forms to be accessible to autotrophs. This process of converting organic matter into inorganic form is referred to as mineralization, and is primarily achieved by the decomposing of organic matter, primarily by soil microorganisms such as fungi and bacteria **[35]**.A potential management technique is to employ Plant Growth Promoting Rhizobacteria (PGPR) as an agronomic treatment to reduce niche shortages and efficiently fill them. It has been demonstrated that PGPRs are particularly and efficiently colonized in soils with low microbial biomass **[30]**. Organic agriculture may seek to control plant pathogens through competition and/ or antagonism by utilizing treatments that promote a more diverse and even microbial community **[65]**.

(b) Enzymes

Enzymes serve as essential catalysts in life processes, and similarly, they wield significant influence in soil, contributing significantly to its health and environmental stability. Soil enzymatic activity primarily originates from microorganisms, manifesting as intracellular, cell-associated, or free enzymes. The equilibrium among chemical, physical, and biological factors, particularly microbial enzyme activities, plays a distinctive role in upholding soil health. Therefore, assessing soil health necessitates indicators encompassing all these facets. The well-being of soils is imperative for preserving the integrity of terrestrial ecosystems, allowing them to either withstand or recover from various disruptions, such as drought, climate fluctuations, pest incursions, pollution, and human activities, including agricultural practices **[29]**.These enzymes (Table 2) play key biochemical functions in the overall process of organic matter decomposition in the soil system **[64]**. Soil enzyme activity includes carbon cycle transformations (such as C- glucosidase, invertase, etc.), general enzyme activity (such as dehydrogenase, catalase, etc.), and nitrogen cycle transformation (such as urease, etc.). Nitrogen supply rate in soil is directly related to soil enzyme activity, and is often used as an indicator of nitrogen deficiency. Other soil enzyme activities include N-acetyl glucosaminidase and protease **[20,40]**.

Table 2Soil enzymes as indicators of soil health.

Soil Enzymes	**Enzyme Reactions**	**Indicator of Microbial activity**
Cellulase	Cellulose hydrolysis	C-cycling
Phenol oxidase	Lignin hydrolysis	C-cycling
Dehydrogenase	Electron transport system	C-cycling
Urase	Urea hydrolysis	N-cycling
Amidase	N-mineralization	N-cycling
Phosphatase	Release of PO_4^-	P-cycling
β-glucosidase	Cellobiose hydrolysis	C-cycling
Arylsulphatase	Release of SO_4^-	S-cycling

Source **[21].**

OrganicCarbon

Soil Organic Carbon(SOC) dynamics are becoming increasingly important in terms of its effects on climate change and agricultural production. Organic C in soil has one of the slowest rates of turnover in terrestrial ecosystems **[69]**. Temperature and precipitation play the most crucial roles in regulating soil organic carbon (SOC) levels **[4].**The microbial biomass carbon content may be associated with the total carbon content by a microbial quotient, which can be used to measure the organic matter dynamics of soil and provide an indication of net C losses or build-ups **[5]**.

Table 3 Soil Organic Carbon (OC) concentration recommendations for soil condition.

Level of OC (% or g/100 g)	Level
>8.70	Organic Soil material
3.0-8.70	Extremely High
2.00-2.99	Very High
1.60-1.99	High
1.00-1.59	Moderate
0.60-0.99	Low
0.40-0.59	Moderately Low
<0.40	Extremely Low

Source**[36].**

(c) Bacteria

Bacteria are among the most abundant organisms on Earth, with an average of over 100 billion per teaspoon of agricultural soil. This is a relatively well-known fact; however, it can also be argued that bacteria are the dominant form of life on the planet **[44]**. About one to fifty percent of bacterial communities possess the ability to solubilize P **[43]**. Phosphate solubilizing bacteria (PSB) has the capability to immobilize immobilized forms of both inorganic and organic P into the majority of available form for plants in an environmentally friendly manner. It has been observed that PSB inoculation results in increased mineralization or in-solubilization of immobilised P in soil **[58]**.Nematodes are essential for the completion of important soil processes. Controlled experiments have demonstrated that nematodes play a direct role in the mineralization of nitrogen and the distribution of biomass within plants. Furthermore, in Petri-Dish experiments, it has been demonstrated that the ammonium form of nitrogen is more accessible when bacteorivorous and fungivorousnametodes are present, compared to when they are absent **[7]**. In previous biogeographic studies, various parameters have been observed to be associated with alterations in the bacterial community composition of soil. The most prominent of these is the observation that pH affects bacterial communities at both regional and continental levels **[45,32]** Other parameters, such as the ratio of carbon to nitrogen, moisture, and soil temperature, have also been associated with alterations in soil bacterial communities **[32]**.

2 Physical Indicators

Soil degradation, compaction, bulk density, soil penetration resistance, and other physical soil properties are significantly altered by traditional agriculture through the use of CT **[13].** The structure of the soil can be significantly altered through the application of management techniques **[10].** Bulk density is a typical method for determining how much tillage or crop residue has been applied to agricultural land. It measures how much the soil compacts and how effectively the soil can sustain itself, transfer water and nutrients, and aerate itself. The crop residue incorporation into the soil in conservation tillage plays a pivotal role in decreasing bulk density **[13].** The surface seal and the soil crust are essential indicators of the soil. Precipitation leads soil aggregates to break down and lead to the release of smaller particles, which are redistributed by the near-surface and occupy the shallowest pores. This procedure results in closing and surface sealing, which reduces water penetration and, as a result, increases run-off and soil loss **[33].** Conservation agriculture is characterized by appropriate crop rotation, which not only enhances the physical characteristics of the soil, but also contributes to a decrease in soil erosion. **[38].** The physical integrity of the soil should be sufficient to sustain its structural integrity and maintain the upright position of plants, while also being sufficiently weak to facilitate the extensive infiltration of plant roots, flora and fauna into the soil **[67].** The intensive cultivation of field-crops can lead to a decrease in the physical health of agricultural soils. This decrease in soil physical quality can be associated with a decrease in crop yield, as well as adverse environmental effects associated with the movement of soil out of the field **[71].**

(a) WaterHoldingCapacity

Water retention is a fundamental hydraulic property of soil, which is responsible for the functioning of soil in ecosystems and has a significant influence on soil management. While some soil survey programs may measure soil water retention, this is not feasible during the design phase of some projects or in larger-scale applications. Therefore, water retention must be estimated from other available soil properties **[53]**. The watermark sensor was employed to determine the water retention of the soils at various pressures. These matrix sensors are suitable for use when multiple replicates are required, and are more durable in soil than the gypsum block sensor. To measure the soil metric potential, the electrical resistance was inserted at a depth of 20 cm, followed by a uniform irrigation of the block of soil to saturation. The water mark readings were then monitored. As the water content decreases due to evaporation and percolation, the water mark reading will vary accordingly. The pressure and moisture content were recorded at each value of the electrical resistance, and a water retention curve was then constructed for each plot **[1].** It has been demonstrated that biochar can improve the water retention capacity of soil, however, there is currently no definitive knowledge regarding the effects of factors such as soil type, quality of biochar, or climate. The addition of biochar to a given soil alters its texture and structure, which in turn affect its moisture characteristics in a particular way depending on the type of biochar and soil characteristics. Additionally, biochar, due to its highly porous nature, has a direct impact on soil's water-holding capacity due to its inner porosity. Soil organic matter plays a role in both the structure of the soil and its ability to absorb water, so it's important to understand how organic matter affects water retention. This could be caused by changes in the amount of organic matter in the soil due to climate change or changes in management practices **[54]**.

(b) Temperature

The temperature of the soil is a combination of the rate of heat flux within the soil and the rate of heat exchange between soil and the atmosphere **[28].** The temperature of the soil is a significant factor that influences the physical, chemical, and biological processes that are involved in the growth of plants **[11]**. Soil temperature affects the rate at which organic matter decomposes and the mineralisation of various organic materials in the soil. The primary determinants of soil temperature are the movement of heat within the soil and the exchange of latent heat at the surface **[76,49]**. Solar radiation is the primary source of soil temperature, which can be measured using a thermometer. The temperature of the soil can vary seasonally and daily, which may be caused by variations in radiant energy levels and energy changes that occur through the soil surface **[15]**. The presence of a range of soil temperatures between 10°C and 28°C has been observed to have an effect on soil respiration. This is due to an increase in extracellular enzymes that are responsible for the degradation of polymeric organics in soils, these resulted in an increase in the metabolism rate of soil microorganisms at a soil temperature between 10°C and 24°C, necessitating either additional feeding or the burning of their own fat reserves **[17],** as well as an increase in microbial uptake of soluble substrates **[3]** and an increase in microbial respiration rates **[72]**. At a temperature below 0°c the accumulation of soil matter increases due to the slow rate of decomposition **[3]**.

3 Chemical indicators

Agronomic practices can alter the chemical composition of soil, thus affecting its fertility. The effects of soil chemical fertility on tillage practices, as well as the extent of these changes, are dependent on a variety of elements, including the soil type, the cropping system, the climate, the application of fertilizer, and the management practices employed **[13].** Covering land with crop residues (Mulching) can improve the physical health of the soil and reduce the negative consequences of traditional tillage practices.**[75].** Chemical processes carried out in the soil have an effect on the microbiological processes that take place in the soil; such as the cycling of nutrients, water availability, supply and retention, carbon storage and supply all of which strongly affect biological activities **[60].**

(a) Electrical Conductivity (EC)

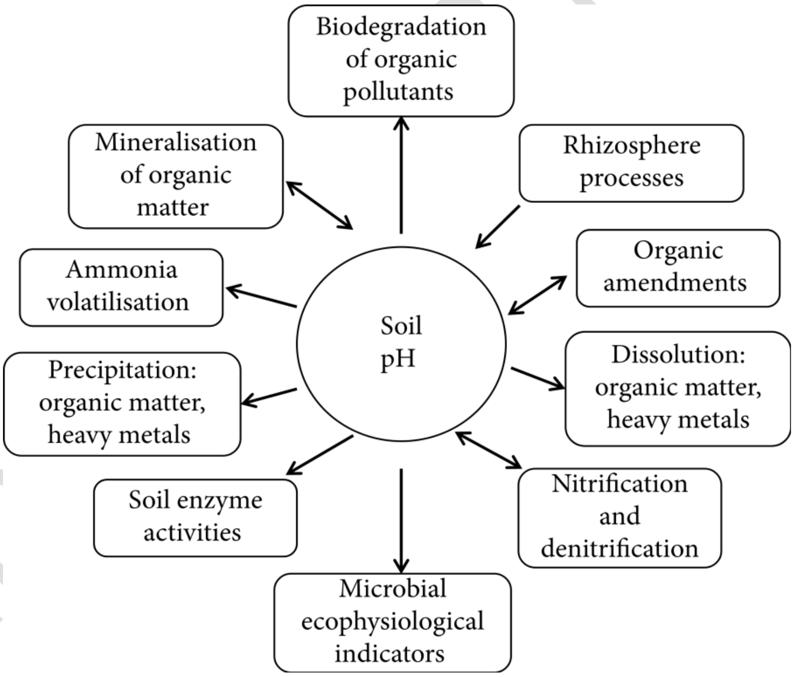
The electrical conductivity of a soil solution is a dependable measure of its Solute Concentration, with an average solubility concentration of 1 ds/m approximately equal to 10 Meq/L. This concentration is determined by the presence or absence of a cation or anion **[56]**.The electrical conductivity of the soil is an important measure of its health and quality. It is determined by the amount of electrical current that can be transmitted through the soil, which is affected by factors such as moisture, salinity and mineral composition. A high electrical conductivity indicates an abundance of salt, which can be damaging to the growth of plants. Conversely, a low conductivity indicates poor moisture retention. By monitoring soil electrical conductivity, farmers can gain insight into the precision of their irrigation and nutrient management, as well as assess soil contamination **[55]**.

(b) pH

Soil pH is often referred to as the ‘master soil variable’ as it plays a significant role in the Biogeochemical processes of the soil. The pH of the soil affects a wide range of biological, chemical and physical characteristics and processes that influence the growth and biomass yield of plants **[9,46]**. Soil pH plays a critical role in the regulation of enzyme activity **[51,64]**, in soil and may indirectly control enzymes through its influence on the microbes that generate them **[16]**. The soil pH level has a significant influence on biodegradation, as it affects microbial activity, microbial population and diversity, enzymes involved in the degradation process, and the characteristics of the materials to be degraded. The soil pH level was the primary factor in the decomposition of atrazine **[37]**.

Specific enzymes operate within a specific range of pH values. Microbial action is responsible for the mineralization of organic matter, typically in the form of carbon, nitrogen, phosphorus, and sulphur. The pH of the soil has a direct influence on the activity and activity of the microbial population, which in turn affects the functioning of the extracellular metabolic enzymes that facilitate the microbial conversion of organic substances. Furthermore, at higher soil pH values, the C and N mineralization fractions increase due to the disruption of the bonding between organic components and clays **[19]**. It was determined that 61% of the rate of decomposition was attributed to soil pH and the C/N ratio, with a corresponding increase in carbon dioxide efflux and net N mineralization and net nitrification occurring in alkaline soils compared to acidic soils **[42]**.

Fig 1 Some bio-geochemical processes and their relations with soil pH.



Source **[48].**

Conclusion

As a result, we must develop farming practices that preserve and enhance the quality of the soil in order to sustain agriculture for future generations. To assess soil quality, soil indicators are essential. They are chosen for their importance to ecosystem services, capacity to influence soil quality, and relevance for soil processes. The temperature and moisture content of the environment have a big impact on the activity of earthworms. The interactions among soil and plants are greatly influenced by soil bacteria, which are also crucial for maintaining soil quality.

A key hydraulic attribute of soil, water retention, is what allows soil to operate in ecosystems and has a big impact on how soil is managed even though certain soil survey programs.

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