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Soil Health Indicators and Analysis

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Abstract:

A group of quantifiable physical, chemical, and biological characteristics that represent soil functionality and are used for assessing soil health are known as soil health indicators. By assessing changes in soil characteristics and functions, these indicators aim to shed light on soil health as a tool for sustainability. A mix of physical, chemical, and biological indicators is necessary to precisely determine the state of the soil and carry out corrective actions promptly. Effective indicators of soil health are soil characteristics that react rapidly to changes brought about by nature or human activity. Bulk density, soil aggregate stability, and water-holding capacity are regarded as the best physical markers. Although they sometimes react more slowly than biological and biochemical signs, chemical indicators including pH, electrical conductivity (EC), soil organic carbon, and nutritional status are well known. When agricultural techniques produce perturbations, biological markers such as respiration, mycorrhiza, lipid profile, soil enzymes, and earthworm presence respond rapidly. To provide a thorough understanding of soil health, this chapter examines a methodical approach to soil health evaluation that integrates physical, chemical, and biological indicators.

Introduction:

Due to the overuse of chemical fertilizers devoid of organic matter, high pH, $CaCO_3$, and low levels of organic carbon, extensive tillage with heavy machinery, and tightly spaced cereal–cereal rotations, modern agricultural methods have exploited soils more and more. The ability of biological soil health indicators to recover and maintain ideal circumstances for crop development without compromising financial yields has been weakened by these methods, which have had several detrimental effects on soil health. Additionally, according to Katyal et al. (2016), these variables have accelerated soil deterioration, progressively decreasing soil health indicators and making soils

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unproductive. The significance of protecting forests for biodiversity, offering ecosystem services, and recovering degraded areas is highlighted by public awareness and the focus on environmental conservation, (Cardoso et al., 2013). Maintaining perfect soil fertility and excellent soil health indicators to satisfy current demands without endangering the productive capacity of future generations requires sustainable agriculture methods. High-quality produce must be ensured while supporting environmentally and economically sustainable yields through rational soil management. Soil health indicators must be maintained or restored to do this. Healthy soil is "the continued capacity to function as a vital living system within ecosystem and land-use boundaries, sustaining biological productivity, promoting air and water quality, and maintaining plant, animal, and human health". To evaluate the sustainability of a production system, it is crucial to monitor changes in soil health indicators—chemical, physical, and biological—and their impact on the soil's ability to support plants, which affects the soil's capacity to sustain plant development and carry out environmental tasks. This article focuses on the methods for analyzing soil health indicators in the lab and their real-world usage in field management and crop production.

SOIL HEALTH INDICATOR:

Soil health indicators	**Rationale for selection**
Bulk density	Plant root penetration, porosity, adjust analysis to volumetric basis
Soil aggregate stability	Soil structure, erosion resistance, crop emergence is an early indicator of soil management effect
Water holding capacity /infiltration	Runoff, leaching, and erosion potential
pH	Nutrient availability, pesticide absorption, and mobility, process models
EC (electric conductivity)	Define crop growth, soil structure, and water infiltration; presently lacking in most process models
CEC (cation exchange capacity)	CEC Represents the total amount of exchangeable cations that soil can absorb
Soil organic carbon/organic matter	Define soil fertility and soil structure, pesticide and water retention, and use in process models
Soil nutrients status	Availability of crops, leaching potential, mineralization/immobilization rates, process modeling, capacity to support plant growth, environmental quality indicator
Mycorrhiza	Nutrient mobilization, soil aggregation
Trichoderma	Residue decomposition
Earthworm	Indicates relative change in soil structure, nutrient recycling, regulates soil water, and aeration, and provides drainage

The four main components of soil—air, water, minerals, and organic matter—all contribute to soil health indicators, which measure how well the soil works. Although the characteristics of healthy soil can change based on certain circumstances and places, a few essential characteristics always point to the presence of healthy soil. The properties of the soil, its use, the surrounding environment, and its strong relationship to crop growth and production under different management techniques all play a role in the selection of soil health indicators.

PHYSICAL SOIL HEALTH INDICATOR:

Indicators of the physical health of the soil provide information on the flow of air and water through the soil, as well as the variables affecting erosion, root growth, and germination. Supporting chemical and biological processes in the soil is based on these markers. As will be covered in more detail below, bulk density, water-holding capacity, and soil aggregate stability are important physical markers that are pertinent to crop productivity.

Water Holding Capacity and Bulk Density- The capacity of soil to retain water for crop utilization is referred to as its soil water retention capacity. This characteristic is vital for crop productivity, as the ability of soil to hold water significantly influences plant growth and development. Soils with higher water retention can enhance crop growth while minimizing nutrient and pesticide leaching. Consequently, factors like infiltration, soil water availability, and distribution are essential to understanding a soil's water-holding capacity.

There has been increasing focus on soil water infiltration, which is the rate at which water penetrates the soil surface and moves into the soil profile (Dalal and Moloney, 2000). The infiltration rate, widely used as an indicator of soil health, is a critical parameter in assessing the impact of land-use changes. This rate varies significantly based on soil management practices, land use, and temporal factors (Arias et al., 2005).

Aggregate Stability:

The ability of soil aggregates—clusters of particles held together by organic matter, clay, and microbial activity—to resist breaking down in the face of outside factors like water intrusion, erosion, or mechanical disturbance is known as soil aggregate stability. This characteristic is crucial for maintaining soil fertility, permeability, and structure and is a major indicator of soil health. (Shah et.al.,2017)

Soil Chemical Health Indicators:

The ability of the soil to retain toxic chemical components or chemicals that could affect the environment and plant growth, as well as to provide vital nutrients to plants, are closely related to indicators of soil chemical health. Soil pH, electrical conductivity, cation exchange capacity (CEC), soil organic carbon, and total nutritional status are important chemical markers. (Kelly et al. 1999).

Soil pH, Electrical Conductivity, and Cation Exchange Capacity:

The solubility of different compounds, the bonding of ions to exchange sites, and the activity of soil microbes are all influenced by the pH of the soil, which is a crucial indicator of its chemical properties. It establishes if the soil is basic, neutral, or acidic. Usually, a glass electrode pH meter in a 1:2 soil-to-water suspension calibrated with buffer solutions at pH 4.0 and 7.0 is used in an electrometric approach to measure the pH of soil. Another important and readily quantifiable indicator of soil health and quality is soil electrical conductivity (EC), which gauges salt concentration (Arnold et al., 2005).

According to Vargas Gil et al. (2009), electrical conductivity (EC) is a chemical indicator that shows how different crop management techniques affect the biological quality of the soil. It emphasizes how crucial it is to thoroughly evaluate EC as a crucial indication of soil health in a variety of ecosystems The Piper method, which uses a conductivity meter in a 1:2 soil-to-water suspension, can be used to estimate the EC of soil samples.

Cation exchange capacity (CEC) is recognized as a critical indicator of soil chemical quality, particularly for its role in retaining essential nutrient cations such as calcium (Ca), magnesium (Mg), and potassium (K), while immobilizing potentially toxic cations like aluminium (Al) and manganese (Mn); (Ross et al., 2008). These properties make CEC a valuable marker of soil health, providing insights into the soil's capacity to retain nutrients, pesticides, and other chemicals. CEC primarily depends on the ion exchange capacity of negatively charged organic matter, clay, and soil colloids. It can be measured using methods such as the ammonium acetate method at pH 7 or the barium chloride-triethanolamine method at pH 8.2).

Soil Organic Carbon-Crop yields and soil organic carbon (SOC), a crucial measure of soil health, are typically positively connected (Bennett et al., 2010). SOC affects vital soil processes such as aggregate stability, water-holding capacity, and nutrient storage, especially nitrogen (N) Furthermore, SOC has a major effect on microbial activity, which makes it an essential part of soil fertility, particularly in tropical areas. Its significance in evaluating the health of the soil is highlighted by its interactions with the chemical, physical, and biological characteristics of the soil. The

Walkley and Black method is often used to measure SOC content.

Available Nutrients (N, P, S, Zn, and Fe):

When evaluating the health of the soil, available soil nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S), zinc (Zn), and iron (Fe) are essential markers. Extractable nutrients serve as markers of environmental quality and productivity by offering crucial information about nutrients that plants may access and possible losses from the soil. Assessing extractable nutrients aids in determining threshold values for environmental hazard evaluations as well as the soil's ability to support plant development (Dalal and Moloney, 2000). The cycle of other nutrients, especially nitrogen, is intimately related to the cycling of soil organic carbon (WeilandMagdoff,2004).

Nutrient Measurement Methods:

1. **Nitrogen (N)**- The alkaline permanganate method with a Kjeldahl distillation machine is used to quantify mineralizable nitrogen.
2. **Phosphorus**-Olsen's reagent (0.5M $NaHCO_3$, pH 8.5) is used to extract phosphorus from neutral to alkaline soils.
   - Bray's P-1 extractant (0.03N NH_4F and 0.025N HCl) is frequently used for acidic soils.
   - The ascorbic acid method is chosen because of its stable blue color, as the blue color intensity in the Dickman and Bray (1940) method for phosphorus detection fades quickly.
3. **Sulphur (S)-** extracted with Morgan's universal extractant (pH 4.8) and measured with UV/visible spectrophotometer using the turbidimetric method
4. **Micronutrients (Zn, Fe, Cu, Mn)-** The extraction process uses chelating agents such as EDTA and DTPA along with neutral ammonium acetate. Atomic absorption spectrometry (AAS) or calorimetric methods are used to quantify the extracted micronutrients.

Microbiological and Biochemical Health Indicators:

Maintaining soil health and promoting sustainable practices depend on the diversity and activity of soil microbes, which enable vital processes including the cycling of nutrients and carbon. When it comes to environmental changes, such as changes in soil management and use, microbial indicators are more sensitive than physical and chemical characteristics (Masto et al., 2009).

Earthworm-Although some species can reach sizes that place them in the megafauna category (>200 mm), earthworms are classified as macrofauna (varying in size from 4 to 200 mm)). Because of their capacity to alter soil properties and structure through their etho-physiological activities, they are considered soil engineers (Gavinelli et al., 2018). It is ideal to sample earthworms during cool, rainy seasons; dry or frozen soils should be avoided. Autumn, spring, and some winter months are the best times to sample in temperate climates.

Trichoderma-Trichoderma is a helpful soil fungus that promotes biological control and increases plant growth, making it a crucial indication of soil health. It promotes soil biodiversity, increases nutrient availability through the breakdown of organic matter, and aids in the suppression of dangerous diseases. When Trichoderma is present, the soil is healthy, balanced, and able to sustain strong plant growth. (Van Bruggen et al.,2000)

Arbuscular Mycorrhizal Fungi- More than 80% of terrestrial plants have a symbiotic connection with arbuscular mycorrhizal fungus (AMF). AMF creates infectious propagules, such as spores, an intraradical phase with vesicles and arbuscules, and an extraradical phase with hyphae that grow into the soil, to form a new mycorrhizal association Different species, have different capacities for AMF colonization. For species such as Gigaspora and Scutellospora, spores are especially successful at infecting roots; however, all forms of inoculum were equally effective for Glomus and Acaulospora. AMF communities are influenced by several factors, such as host species (Gosling et al., 2013), soil type, nutrient concentrations (Gosling et al., 2013), and agricultural management practices. Through their extraradical hyphae, AMF extracts nutrients from the soil for the plant's needs, which they then trade for photosynthates that the plant produces in the rhizosphere and root cortex (Smith and Read, 2008).

CONCLUSION:

Indicators of soil health are crucial for preserving soil quality. Because of management techniques, physical indicators may take longer to change than biological and chemical indicators, which are more prone to changes in a shorter period. Optimizing sustainable crop production requires the development of sustainable management strategies for soil health indicators using a methodical approach that incorporates physical, chemical, and biological concepts. For certain soil health indicators, for which there is currently little data, essential levels must be established. The restoration, enhancement, and maintenance of soil health indicators should be the three main focuses of research experiments. To evaluate soil health indicators under various edaphic, climatic, and management circumstances, a systematic study is required. Indicators of soil health have been shown to improve with conservation agriculture techniques such as integrated nutrient management, soil cover management, zero tillage, residue recycling, crop rotation, and the use of organic amendments.

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