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# 2. Soil Health as Key to Achieving Sustainability in Agriculture

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***Abstract:***

*Soil health ties agricultural and soil science to policy, stakeholder demands, and long-term supply-chain management. Soil health is the ability of soil to continue to operate as a vital living ecosystem that sustains plants, animals, and humans. While crop production has traditionally been the main emphasis of soil evaluations, soil health now also takes into account how the soil affects water quality, climate change, and human health. Despite rising acknowledgement of the significance of soil biodiversity, chemical markers continue to dominate efforts to measure soil health due to a lack of practical understanding and efficient techniques. This viewpoint discusses the definition and history of soil health as well as similarities to other soil ideas. We go over the ecosystem services that soils give, the tools used to evaluate the functionality of soils, and how they are incorporated into practical soil-health indices. Instead of only being a quantitative attribute, soil health should be viewed by scientists as an overarching principle that supports long-term sustainability goals. As a living system, the soil's health and quality preserve not just its biological products but also the environment and human health. A healthy environment based on plant inputs and soil interactions is known as "soil health." Negative impacts on soil health, soil pollutants, and soil loss strategies are becoming less common in developing nations.*

## 2.1 Introduction:

A healthy soil performs as a living, dynamic system that offers a range of ecosystem services, including preserving water quality and plant production, managing the decomposition of recycled nutrients, and eliminating greenhouse gases from the environment. The diversity and activity of soil microorganisms are essential to the health of the soil and are therefore strongly related to sustainable agriculture. For soil and water, the scenario for improving soil quality evolves over time. Because of soil processes, the earth was regarded the domain's environment rather than a part of it. At the same time, globally accepted canons, indications, and requirements for pleasant air and water quality.

Soil quality, a notion related to soil health, is expanding, with soil quality rules in some countries having been successful to date (Filip, 2002; Nortcliff, 2002). Industrial agriculture, or so-called green revolution technology, increased agriculture's dependence on outside inputs, damaged the environment, depleted natural resources, harmed people's health, and presented sustainability problems for the industry as a whole. Numerous facts show that agrochemical-based, external input-heavy agriculture is not long-term viable due to a progressive decline in productivity factor and adverse effects on the health and quality of the soil, including soil organic carbon.

The foundation of organic farming is the management of soil organic matter, which protects the physical, chemical, and biological properties of the soil. In comparison to conventionally managed soil, organically managed soil has higher soil organic carbon and total nitrogen, decreased nitrate leaching, and higher biological soil quality. Research over a long period of time has shown that organic management generates more carbon from soil microbial biomass than conventional management. Organic agricultural practises have also been associated with increased soil ecosystem quality and long-term sustainability at the farm level. The nutrients in the soil, water, sunlight, and carbon dioxide (CO2) are all used by plants for photosynthesis and to generate food for people and other animals. In addition, soils hold onto rainwater and irrigation water before releasing it to support plant growth and reproduction. Through processes like precipitation and clay surface adsorption, which maintain the soil environment's chemical balance, soils also act as a filter for hazardous and nonhazardous metals. Most of the aforementioned soil functions are advantageous to both people and animals (Palm et al. 2007).

Excessive tillage activities result in the physical breakup of aggregates, which leads to surface crusting and compaction, which decreases infiltration and increases surface water runoff and soil erosion. The bulk of soil processes that are mediated by soil microbes are impacted by the loss of soil organic matter (SOM). Soil quality (SQ) deterioration harms ecosystem processes by bringing about unfavourable changes in soil properties.

Soil health refers to the soil's continuous capacity to perform as a crucial biological system. Within land-use limits, biological components are crucial for ecosystem function because they can preserve both the biological productivity of the soil and the quality of the surrounding environment. The soil is the main source of mineral nutrients for the bulk of living creatures. The right mineral elements reach the food chain thanks to soil management, which prevents mineral elements from being depleted or toxic to plants. Crop productivity, environmental sustainability, and human health are all directly and indirectly impacted by soil management. Soil management will be more and more important in the years to come due to the anticipated increase in world population and the associated demand for higher food production. The goal will be to manage soils sustainably through proper nutrient management and useful soil conservation practises in order to achieve future food security.

## 2.2 Soil Health:

Long-term agricultural production depends on the health of the soil, a valuable natural resource. According to Doran and Zeiss (2000, p. 20), "soil health" is "the capacity of soil to function within ecosystem boundaries to sustain biological activity, maintain environmental quality, and promote plant and animal health." The increased soil water retention and availability, soil aggregation, nutrient cycling and storage, and microbial diversity and function are only a few of the ecological services that soils provide. Assessing the soil's fitness to carry out planned functions and its capacity to withstand degradation are both parts of the process of assessing the soil's health. Land managers, producers, and researchers use a number of qualitative and quantitative markers to evaluate the relative worth of soil health. The following features should be found in a healthy soil:

- High organic content
- Good soil structure and tilth
- Enhanced water retention and penetration
- Compaction resistance
- High biological activity in the soil
- Availability and recycle of plant nutrient
- Resistance to erosion
- Absence of dangerous substances

### 2.2.1 Significance of Soil Health and Soil Quality:

Soil quality must be maintained in order to preserve animal and plant productivity, keep water or beautify the air, and ensure human habitation and fitness (Karlen et al., 1997; Arshad and Martin, 2002). Soil disease resistance has been understood for decades thanks to the application of soil health crops in recent years (Janvier et al., 2007). Soil health was defined by Van Bruggen and Semenov as the soil's tolerance to shocks and pressures (Van Bruggen and Semenov, 2000). It is sometimes difficult to distinguish between soil quality and soil health because the latter emphasises biotic soil inputs (Anderson et al., 2003). The health of the soil influences the health of the ecosystem, which affects the wellbeing of people, animals, and plants (Habberen, 1992; Doran, 2002).

## 2.3 Components of Soil Health for Sustainable Agriculture:

In the scientific literature, the phrases "soil health" and "soil quality" are frequently used interchangeably, and some people believe they are functionally equivalent. Farmers prefer the term "soil health," whereas scientists prefer the term "soil quality." 183 biotic indicators were created and tested by Ritz et al. (2009) for soil monitoring. Candidates for biological indicators that were most prevalent included: (1) Soil respiration and carbon cycling from multiple substrate-induced respiration; (2) Soil microbial taxa and community structure using terminal restriction fragment length polymorphism techniques; (3) Soil microbial community structure and biomass using extracted lipids, particularly phospholipid fatty acids; (4) Soil biochemical processes from multi-enzyme profiling; and (5) Nematodes, including (6) microarthropod; and (7) Visual recording of soil flora. (8) pitfall traps for invertebrates that live in the soil and on the ground, as well as (9) microbial biomass, the overall amount of life underground. However, they came to the conclusion that more research was required to understand how these biological indicators are affected by management changes, how they connect to soil functions, and how they may be used to highlight particular ecological processes. For the long-term growth of our agricultural systems and the appropriate use of national and international agricultural monitoring systems (ground truth data), it is essential to determine the components of soil health.

Healthy soil has been shown to prevent infections, maintain biological activity, break down organic matter, neutralise dangerous chemicals, and recycle nutrients, energy, and water. Karlen et al. (2003) defined soil quality as "the capacity of a specific type of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or improve water and air quality, and support human health and habitation." Additionally, soil quality was described by Bouma et al. (2017) as "the intrinsic capacity of a soil to contribute to ecosystem services, including biomass production." A deeper comprehension of soil quality can help targeted ecosystem services. The idea of soil quality is evolving to incorporate biological characteristics and processes that interact with chemical and physical components. The terms "soil quality" and "soil health" are frequently used interchangeably in the literature, as was already mentioned. In terms of timeline, they can be distinguished; "soil health" refers to the state of the soil over a brief period, whereas "soil quality" relates to the state of an individual over a long period (quality of life). Terms for soil state include "soil health" and "soil quality," and measuring these will help determine how past, present, and future land uses may affect the viability of agriculture.

### *2.3.1 The Distribution of Soil Microbes:*

For microorganisms, soil aggregates offer a physical environment and play a significant role in regulating their overall population. In humic rendzina (heavy loam calcareous soil), aggregates 1-3 mm contained more bacteria, actinomycetes, and fungus than aggregates 5-7 mm. The population density of soil bacteria can also be influenced by the climate, vegetation, total organic carbon, and pH. When environmental and management parameters were considered in relation to the diversity and abundance of rhizosphere microorganisms, it became clear that soil type had a substantial impact on the microbial population. While modifications to soil pH, P, and K levels and root length indirectly increased bacterial population, fungal biomass was associated with an increase in above-ground plant output.

### *2.3.2 Element of Farming Methods to Enhance Soil Health:*

Crop management practises that significantly affect soil quality include tillage, water and fertiliser management, cropping techniques, and land-use conversion.

***A. Effect of Tillage:*** One of the most crucial land management techniques is tillage, which improves soil aeration and infiltration rates, prepares seedbeds, conserves soil and moisture, exposes soil-borne illnesses and insects to light, and controls weeds. To lessen the negative effects of tillage on soil quality, modern tillage concepts including no tillage, minimum tillage, stubble-mulch tillage, and conservation tillage practises have been created. In semiarid regions with rainfed conditions, zero tillage or conservation tillage techniques combined with crop residue integration increase the chance of crop production sustainability

(Sharma et al. 2005). Conservation tillage increased soil accessible P in the topsoil (0–20 cm) by 3.8%, K by 13.6%, and soil organic matter by 0.17% when compared to conventional tillage practises (Shao et al., 2016). Reduced soil erosion and improved soil moisture content are benefits of keeping crop residues on the top soil surface layer (full cover, no till; partial cover, strip tillage) (Celik et al., 2013; Mullins et al., 1998). Cereal rotations and legume cover crops increase soil SOC reserves (Fortuna et al. 2008).

***B. Effect of Cropping Systems:*** In general, methods based on annual crop production such as agroforestry and tree plantations keep soil quality better. In comparison to cereal cropping systems without pulses, cereal farming systems with pulses improve soil quality better (Wienhold et al. 2006). In systems where rice is the primary crop, ploughing (puddling) causes the breakdown of capillary pores, a decreased void ratio, poor soil aggregates, dispersed fine clay particles, and low soil strength, as well as the formation of surface crusts and cracks after drying (Masto et al. 2008). According to Weerasekara et al. (2017), farming practises focused on pulse crops and cover crops prevent soil erosion and nitrogen loss. Utilising cover crops in crop rotation has numerous benefits, including a reduction in weeds, carbon sequestration, soil moisture conservation, and nonpoint source pollution. By fixing atmospheric nitrogen, legume cover crops increase soil nitrogen and decrease the demand for external N fertiliser.

***C. Nutrient Management:*** According to Mandal et al. (2007), the INM ensures that crops receive appropriate nutrition while reducing the negative effects of hidden shortfalls and nutritional imbalance. Long-term INM practises considerably improved soil aggregation stability and physical quality as well as the yield of the maize-wheat system (Dutta et al. 2015). on contrast to irrigated production, the impact of INM is more notable on output from rainfed systems. Inceptisols in a tropical Indian soil under pearl millet farming have increased aggregation stability, labile carbon, and dehydrogenase activity due to long-term INM practises (Sharma et al. 2014). The SOC content, available nutrients, MBC, and the enzymes dehydrogenase and alkaline phosphatase in the topsoil of vertisols under soybean-wheat cropping systems were improved by using organic manures like cattle dung manure, vermicompost, and poultry manure in combination with mineral fertilisers based on N equivalents and crop nutrient requirements (Ramesh et al. 2009). In light-textured soil, farm compost application increases SOC content, earthworm population, and MBC while lowering BD, providing a favourable environment for crop growth and increasing yield in maize-based cropping systems (D' Hose et al. 2012).

***D. Organic Farming:*** In order to increase physical, biological, and environmental resources such soil nutrient mineralization, microbial activity, abundance, and variety as well as yield and product quality, organic farming is gaining favour as the most sustainable agricultural method. When compared to mineral fertilisation, organic farming has been demonstrated to increase soil organic matter, N supply capability, and soil N sequestration by about 50% (Sesbania rostrata yielded 16.8 tonnes ha-1 dry matter in 13 weeks) (Gong et al., 2011 and Matoh et al., 2008). The organic systems with compost and peat sources had higher microbial populations and enzyme activity than conventional systems, according to a 12-year research of the rice (Oryza sativa) and maize (Zea mays) crops (Chang et al., 2014). The physical and chemical properties of the soil can be enhanced by organic farming. In comparison to conventional systems, organic systems in clay soil, for instance, increased soil water content by 15%, retention capacity by 10%, and bulk density by 8% in the top 20 cm of soil (Bassouny et al., 2016). Organic farming is less productive than conventional farming, however after 10–13 years of cropping, organic productivity can match conventional yield (Schrama et al., 2018). In general, the best way to enhance the quality of the land and the crops is through organic farming.

### *2.3.3 Impact of Organic Farming on Soil Health:*

*Impact on soil physical qualities*: Soil physical attributes include structure, texture, bulk density, porosity, and water-holding capacity, among other things. It has been demonstrated that organic farming enhances the physical properties of the soil, including its structure, water-holding capacity, aeration, and temperature. Papadopoulos et al. (2014) claim that organic management can improve soil structure, organic matter content, and porosity. Crop rotation is a crucial part of organic farming since it alters the soil's physical composition both directly and indirectly. Changes in soil structure are directly influenced by the buildup of organic matter in the soil during the lean phase. In addition, crop rotation alters the architectural design of the diverse root systems of many different crops. Since organic farming absorbs more water and has less run-off, it is preferable in regions with significant rainfall, claim Lotter et al. (2003).

*Impact on chemical properties of soil*: Contrary to conventional agriculture, organic agriculture adds essential nutrients for quality improvement by following the natural cycle. While simultaneously boosting the amount of organic carbon in the soil, organic farming has the ability to maintain soil fertility. The sustainability of soil organic carbon and the availability of nutrients to plants are both guaranteed by the use of diverse organic inputs, such as FYM, vermicompost, green manuring, and so forth. High-quality FYM application enhances soil total nitrogen and organic matter, which is "a crucial substrate of cationic exchange and the warehouse of most available nitrogen, phosphorus, and sulphur; the primary energy source for microorganisms; and a key determinant of soil structure." Phosphorus is released more readily from decaying matter and its fixation in soil is reduced by organic acids and the humus they contain. Micronutrient availability for the plant is also guaranteed by organic nutrient input.

*Organic inputs' effects on the biological characteristics of soil:* While many academics restrict the idea of soil quality to physical and chemical characteristics, others believe that biological criteria are important and should be considered when evaluating soil quality. Since the flora and fauna in the soil have a significant impact on soil quality, these biological characteristics are essential for determining soil quality. The living components of soil organic matter are soil microbes. For soil to be produced, microbial biomass and activity in the soil are essential. It has been demonstrated that switching to organic farming increases microbial activity and biomass by 20–30% and 30–100%, respectively. In comparison to soil with a low organic matter concentration (which is treated inorganically), soil with a high organic matter content exhibits greater microbial activity and provides more soil N. Arbuscular mycorrizal fungi are a special type of fungus that collaborates with the plant's root system to increase water and nutrient intake. This mutualistic relationship helps plants absorb more phosphorus from the soil and shields them from many diseases. Increased microbial activity, which increases competition, parasitism, and predation in the rhizosphere, reduces the likelihood of plant disease infestation in organic farming.

*Natural resources and biodiversity:* The term "soil biodiversity" describes the diversity of taxonomic groupings found in soil, including nematodes, earthworms, fungi, bacteria, and worms. Numerous studies show that during the past 40 years, the quantity and diversity of a variety of plant and invertebrate species have decreased as a result of modern agriculture's intensification and expansion, posing a threat to biodiversity globally. Contrarily, organic farming supports the preservation of biodiversity.

The agro-economic and agro-ecological performance of biodynamic, bioorganic, and conventional farming systems in Central Europe were compared over a 21-year period, and the results showed that organic farming produced greater biodiversity and increased soil fertility. Recent studies, however, found no difference in any of the evaluated soil and microbial properties between conventional and organic farms, despite the fact that N mineralization was higher in organic farms. They also found no effect of landscape heterogeneity.

## 2.4 Soil Quality:

For optimum input allocation to increase the output of food and fibre, Warkentin and Fletcher (1977) established the idea of soil quality. Soil quality, according to Karlen et al. (1997), is "the capacity of a specific type of soil to function within a natural or managed ecosystem to sustain plant and animal productivity, maintain or improve water and air quality, and support human health."

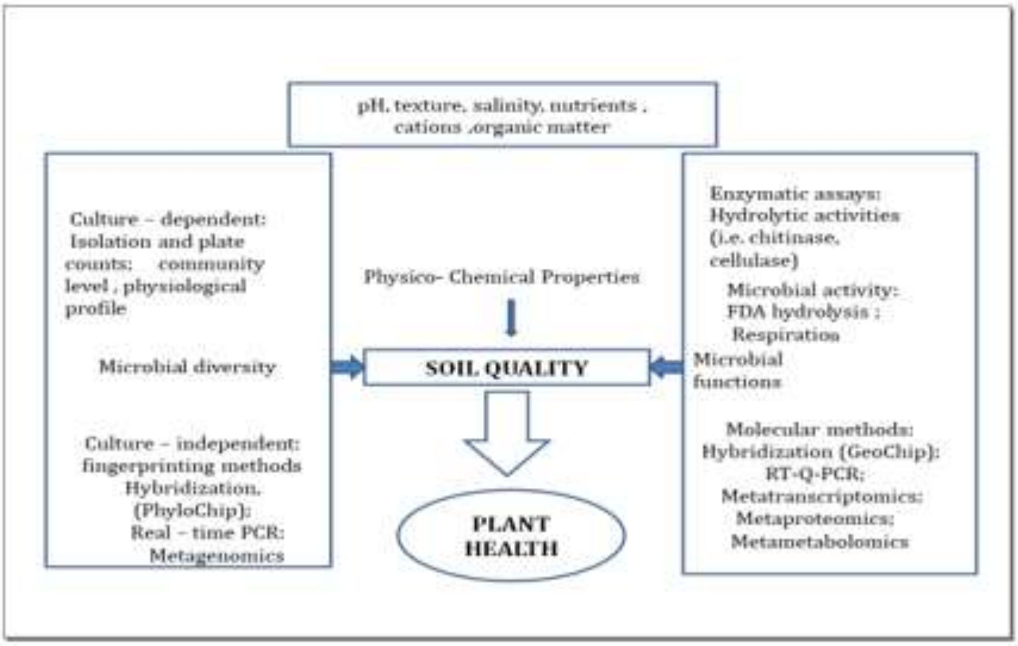

**Figure 2.1:** Elements that influence soil quality and some of the methods used. [Source: Antonio de Vicente, Diversity (2012), Institute for Horticultural Mediterranean and Subtropical Horticulture "La Mayora" (UMACSIC), Malaga, Spain].

### 2.4.1 Soil Quality Assessment:

The adverse impacts on soil functions caused by improper management and other natural variables are the main reason why soil quality assessment is necessary. By measuring changes in soil qualities brought on by management, shifting land uses, deforestation, and other causes, soil quality evaluation is a process.

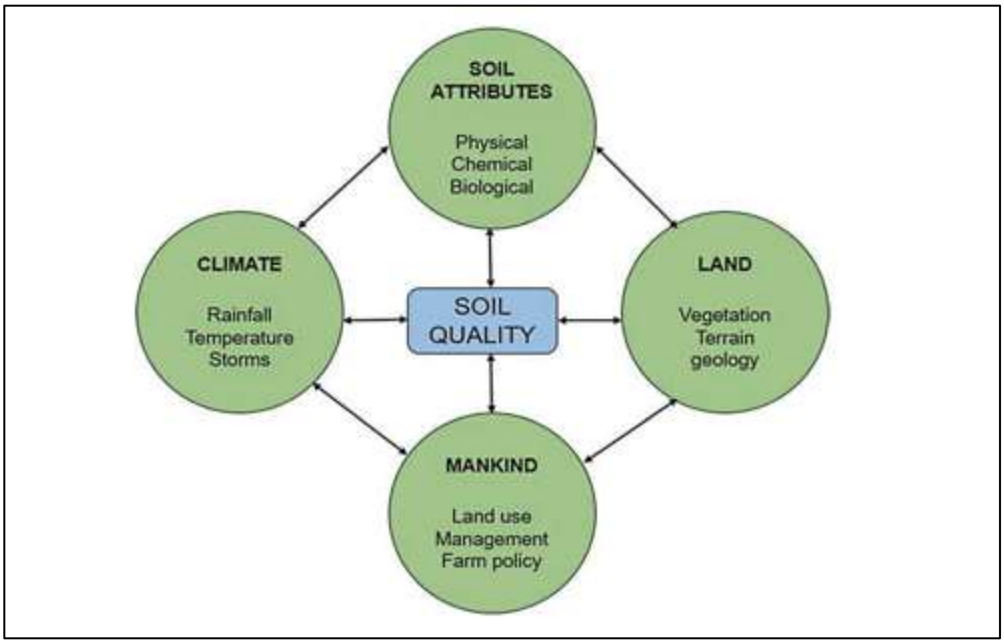

**Figure 2.2: Factors influencing soil quality. (Modified from Arshad and Coen 1992)**

### 2.4.2 Soil Quality Indicators:

More (2010) classifies soil quality indicators into four categories:

- Visual indicators
- Physical indicators
- Chemical indicators
- Biological indicatssors

**A. Visual Indicators:**

Visual indicators are obtained from field observations of qualitative soil characteristics such as soil depth, colour, erosion, gully formation, salt deposition, drainage, surface ponding, soil structure, consistency, mottles, rooting depth, root development, earthworm population, rat activity, and so on. Visual SQ indicators have the main benefit of being immediately examined without the requirement for time-consuming laboratory analysis (Bunemann et al. 2018). One of the numerous visible markers of soil quality that has lately attracted attention in the literature is soil structure (Emmet-Booth et al. 2016).

### B. Physical Indicators:

Texture, structure, hydraulic conductivity, infiltration, porosity, bulk density, and aggregate stability are examples of physical SQ indicators. They are associated to seedling emergence, root growth, water movement, water holding capacity, penetration resistance, and other parameters, and they are used to evaluate physical SQ. Physical factors have a key role in controlling soil erodibility and the interactions between soil, plants, water, and the atmosphere (More 2010).

### C. Chemical Indicators:

Important soil chemical processes include ionic diffusion, leaching, acidification, alkalinization, salinization, mineralization, and others. A desirable nutrient concentration must be maintained for the chemical quality of the soil. Chemical markers of SQ include pH, EC, salinity, sodicity, organic carbon, nitrogen fractions, phosphorus concentration, cation exchange capacity (CEC), and concentrations of heavy metals. Due to their ability to detect the bulk of nutrient-related changes in soil, soil pH and available P are the chemical indicators used in SQ evaluation most frequently. The pH of the soil is used to determine the activity of hydrogen ions in the soil solution. Indicators of plant nutrition are also present.

### D. Biological Indicators:

Mineralizable nitrogen, soil organic matter, respiration, and microbial biomass (total bacteria and fungus) are biological markers of soil quality. Microorganisms play a significant role in organic matter decomposition and nutrient recycling. Key indicators of soil quality include earthworms, nematodes, termites, microorganisms, and their behaviour. Microbial biomass is a vital part of the soil's "active ingredient," which breaks down organic pollutants and circulates nutrients (Stenberg et al. 1998).

Enzymes including dehydrogenase, urease, phosphatases, and glucosidase are used to measure nutrient mineralization in soil and can give an early warning of potential risks to soil quality (Comino et al. 2018). The most reliable indicator of the soil's structural, microclimatic, nutritional, and hazardous status is the amount of earthworms present. By recycling soil nutrients, aiding in the gradual mixing of soil layers, and creating a better aeration and drainage system, earthworms play a crucial part in the conservation and improvement of soil. Earthworms are indicators of the water and nutrient cycles.

## 2.5 Critical Issues and Needs for Sustainable Management:

On the second day of the session, critical concerns for sustainable management were highlighted in a large group format. Small groups determined high priority research needs for identifying sustainable agricultural land management and management "strategies" to ensure long-term sustainability after identifying the primary concerns.

- An ecological strategy to managing diverse land uses in a sustainable manner.
- Consideration of farm size when developing sustainable agricultural method.

- Explain the crucial relevance of soil in terms of the environment, society, and economics.
- Prescriptive and descriptive assessment of agricultural system sustainability for land managers and scientists.

## 2.6 Conclusion:

W3The essential prerequisite for achieving sustainable agricultural and livestock production is the preservation of soil fertility and soil health. Organic farming methods, which are extremely complex and integrated biological processes, may be a viable technology alternative for maintaining good soil health. Because organic practises affect more than one component of the system at the same time, they have both direct and indirect effects on soil properties. Previous research on the impact of organic practises on several aspects of crop productivity, soil health, and the environment suggests that organic farming has the capacity to sustain soil health and fertility. Utilising an organic system enhances soil physical characteristics, microbial population and diversity, and nutrient mineralization. Surprisingly, the source of organic fertiliser (plant or animal-based) can influence microbe abundance and crop productivity. While plant fertiliser increases soil microbial abundance, animal fertiliser increases crop yield while decreasing the number of microorganisms. Organic cultural practises, on the other hand, are more expensive due to high labour costs and the lack of uniformity and stability of organic fertilisers. Accepting the appropriate crops and cropping practises that insulate more carbon will improve soil health. As a result, assessing soil health biological markers is critical. Despite the fact that numerous soil health and soil quality indices and measures have been introduced around the world, they are acceptable and appropriate specifications, descriptions, and methods for soil health and soil quality evaluation are no longer in situ.

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