International Journal of Advanced Biochemistry Research 2024; SP-8(4): 204-211

International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; SP-8(4): 204-211
www.biochemjournal.com
Received: 06-02-2024
Accepted: 13-03-2024

Ankana Moulik
Department of Agricultural Engineering, Swami Vivekananda University, Barrackpore, West Bengal, India

Anusmita Bhowmik
Department of Agricultural Engineering, Swami Vivekananda University, Barrackpore, West Bengal, India

Parijat Bhattacharya
Department of Agriculture, Swami Vivekananda University, Barrackpore, West Bengal, India

Corresponding Author:
Parijat Bhattacharya
Department of Agriculture, Swami Vivekananda University, Barrackpore, West Bengal, India

Soil-health: Concepts, implications and management

Ankana Moulik, Anusmita Bhowmik and Parijat Bhattacharya

DOI: https://doi.org/10.33545/26174693.2024.v8.i4Sc.965

Abstract
Soil is a crucial component of the natural world. Soil health is the capacity of the soil to function as a dynamic living system to support biological production, maintain environmental quality, and promote plant, animal, and human health. By all circumstances, soil health should be given priority because it is a crucial and dynamic living resource that may provide ecosystem services without endangering the environment. Assessments and indicators can be used to pinpoint specific problems and factors in addition to identifying general features of soil health. When considering management choices to increase soil health, there are a few broad methods to bear in mind. These include controlling organic matter, reducing disturbances, enhancing the soil biota, keeping living plants, and preserving as much soil cover as feasible. Because it maintains the soil's structure, improves water absorption, raises yields of wholesome crops, helps prevent plant diseases and pests, and increases carbon sequestration, soil health has a significant impact on agricultural productivity and quality. Soil health also shares vital connections with biogeochemical cycles like carbon cycle, nitrogen cycle and phosphorus cycles etc. In order to have broader effects, this review places a heavy emphasis on measuring and quantifying agricultural practices' contributions to enhance soil health. Thus, for ensuring sustainable agricultural output and the maintenance of biodiversity, soil health management is essential.

Keywords: Soil health, assessment of soil health, impact, management, biogeochemical cycles

1. Introduction

The natural environment depends on soil in many ways. We are all concerned about the health of the soil since it is a dynamic living resource that is crucial for the production of food and fiber as well as for maintaining the balance of the planet and ecosystems. Plant, animal, and human health are all significantly influenced by soil quality, which also dictates agricultural sustainability and environmental quality (Andrews, Karlen, and Mitchell *et al.*, 2002) [2]. Numerous conferences, reports, and publications from the early to mid-1990s focused on defining, evaluating, and monitoring soil quality and soil health, highlighting how crucial soil was not only for producing food and fibre but also for maintaining ecosystem function and local, regional, and global environmental quality. The phrase "soil health" has its historical roots in the term "soil quality," which refers to a soil's ability to support agriculture and its near environment. Soil quality also affects the health of plants, animals, and entire ecosystems' water quality and ecosystems (Arshad and Coen *et al.*, 1992) [3]. Despite the fact that the terms are frequently used interchangeably, soil health is distinct from soil quality because the scope of soil health goes beyond human health to encompass more general sustainability goals, such as planetary health, whereas the scope of soil quality typically focuses on ecosystem services with reference to humans (Doran *et al.*, 1996; Karlen *et al.*, 2019) [16, 43]. The newest and most inclusive of the four terms is soil security, which was first used in 2012 (Arshad and Coen *et al.*, 1992; Van Es *et al.*, 2009) [3, 35]. It includes soil health and refers to the soil's manageable features by the word soil condition. It serves as a medium for plant growth, produces net primary productivity, and sustains all terrestrial life by providing the elements necessary for its survival. For soil microbes, the main source of energy is soil organic matter, which makes up roughly 45–60% of the mass of the soil as SOC.

1.1 The following are the three main parts of SOM: (1) plant and animal leftovers, (2) live microbial biomass, (3) active or labile SOM. The topic of soil deterioration is crucial in the modern era and has sparked some significant debate. It alludes to the deterioration of soil's innate ability to generate economic output and fulfil ecological requirements. It is the end product of dynamic soil regenerating and degrading processes that are controlled by anthropogenic and natural causes (Papendick *et al.*, 1992; Larkin *et al.*, 2015) [68, 50].

2. Methods for Assessing in Soil Health

The quality of the farmland affects agricultural production, and a soil test can quickly identify an issue with crop growth conditions. Regular soil testing is crucial not just for farmers but for all other agribusiness operators as well, such as crop insurers, banks, input suppliers, or commodities merchants. However, authorised laboratories only describe the features of the present field. It is therefore preferable to integrate laboratory results with historical information from satellite imagery analytics when reviewing soil test results for recommendations about field amelioration (Idowu *et al.*, 2009) [35]. Assessing of soil health determines the investigated elements or the characteristics of the field / ground that might have a positive or negative influence on crop development. Acceptable indicators of soil health include characteristics like carbon changes, nutrient cycling, soil structure preservation & pest - disease control. The most common forms of analysis and measurement are: (i) soil hydration, (ii) salinity, (iii) mineral composition, (iv) pH value, (v) chemicals & pesticides contamination, (vi) texture, and as well as structure (Cherlinka *et al.*, 2022) [84]. The methods for assessing soil health are illustrated in Fig 1.

2.1. Soil Hydration Testing: For the development of plants, soil water acts as a solvent and a transporter of dietary components. More frequently than not, crop yield is influenced by the amount of water available rather than a lack of other dietary ingredients. Even the water in the soil serves as a fertiliser. Water in the soil controls soil temperature and is necessary for weathering and soil formation processes. It is also necessary for the metabolic processes of microbes. The chemical and biological processes of the soil are assisted by soil water. It is a key component of the developing plant. (Cherlinka *et al.*, 2022) [84].

2.2. Soil Zone Sampling

This approach recommends obtaining typical samples from each field zone. Depending on the soil type or crop maps, the field is separated into zones. Since the circumstances in each zone are identical, the number and size of the zones are determined by their variability. The sizes typically vary from 2 to 10 acres. More soil test probes are needed for bigger zones i.e. at least five subsamples per zone, two subsamples per acre (Cherlinka *et al.*, 2022) [84].

2.3. Soil Salinity Test

Esting for soil salinity aids in determining a land's appropriateness for agricultural use. Analysis of field salinity can be done by, total soluble salts from groundwater extract evaporation, as well as a saturated paste extract or distilled water-earth dilution's electric conductivity, are also measured (Hardie *et al.*, 2012; Cherlinka *et al.*, 2022) [26, 84].

2.4. Soil Test for Chemical & Pesticides Contamination -

Pesticides help in controlling the non-beneficial organisms that destroy crops. Chemicals effectively suppress weeds, manage crop diseases, or combat pests. Highly aggressive substances leaches into groundwater, remains in the land for many years, and harms the soil health (Hochmuth *et al.*, 2014; Cherlinka *et al.*, 2022) [27, 84].

2.5. Soil Test for Texture & Structure

Agricultural soil testing examines the kind of soil as well as its physical characteristics, such as texture, structure, and wetness, in addition to its chemical composition. The primary components are clay, sand, and silt, and their ratios determine the ground's texture and capacity to hold onto moisture and nutrients. For instance, a soil texture test aids in precise irrigation and fertigation planning since sandy fields dry up more quickly than clay ones. The size of the components and pore spaces in soil determine how water and air move through the ground. Small pore gaps and finer clay fields characterise them. As a result, they are vulnerable to compaction and need frequent aeration (Hochmuth *et al.*, 2014; Cherlinka *et al.*, 2022) [27, 84].

Fig 1: Methods for Assessing Soil Health

3. Relationship between Soil & Bio-Geochemical Cycles

Any of the natural processes by which the fundamental components of biological stuff are transferred. The abbreviation "biogeochemical" refers to the analysis of each cycle's biological, geological, and chemical components. From the nonliving (abiotic) to the living (biotic) components of the biosphere, and back again, elements are transported through biogeochemical cycles in a variety of ways. All the chemical components that make up live cells must be recycled continually in order for the living components of a big ecosystem (such as a lake or forest) to thrive. A reservoir (nutrient) pool, which is a bigger, slower-moving, typically abiotic section of each biogeochemical cycle, and an exchange (cycling) pool, which is a smaller, more active portion focused on the quick exchange between the biotic and abiotic components. Gaseous biogeochemical cycles, in which the reservoir is the air or the oceans (by evaporation), and sedimentary biogeochemical cycles, in which the reservoir is the Earth's crust, can be categorised. Iron, calcium, phosphorus, sulphur, and other more earth-bound elements are part of the sedimentary cycle, while nitrogen, oxygen, carbon, and water are part of the gaseous cycle. The environment provides the nutrients that plants and some animals need. The majority of other animals' needs are met by the plants and animals that they devour. When an organism dies, the elements fixed in its body are released back into the environment by decomposers (organisms that degrade, such as bacteria, insects, and fungi), making them available to other living things once more. The highest diversity of species on earth are found in soils, which also play a crucial part in the major global biogeochemical cycles of carbon, nutrients, and water. Soils provide essential ecosystem services as a result, and management to alter a soil process in support of one ecosystem service can either have positive co-benefits for other services or result in negative trade-offs. Though there are still knowledge gaps and a need for fundamental research to better understand the connections between various aspects of soils and the variety of ecosystem services they support, there is enough information already available to implement best practices (Perez-Quezada *et al.*, 2021) [70].

3.1. Carbon Cycle

A sizable fraction of the carbon (C) present in Earth's terrestrial ecosystems is found in the soil. Terrestrial ecosystems contain about 3170 gigatons of carbon overall. Due to landscape heterogeneity, processes including rainfall infiltration, soil erosion and sediment deposition, and soil temperature can all change locally. These processes all have an impact on carbon input and carbon loss rates, which causes variations in SOC levels along topographic gradients. For instance, the slope location affects soil moisture and nutrient levels, which then affects plant root development and may have an effect on soil carbon. The fluctuation in the carbon sequestration capacity is caused by changes in carbon inputs and losses from land use, land management, and landscape-level influences on carbon input and loss rates (Ontl and Schulte *et al.*, 2012) [63].

3.2. Nitrogen Cycle

A fundamental component of the productivity of terrestrial ecosystems is the transformation and availability of nitrogen (N), a critical nutrient for plant development. In agroecosystems, nitrogen fertiliser is frequently used to increase crop yields, but excess nitrogen losses cause eutrophication of waterbodies and worsen atmospheric concentrations of the greenhouse gas nitrous oxide. The C-to-N ratios of plant residues can influence microbial mineralization and immobilisation of N, which can change the net balance of soil mineral N. In addition to the primary crop, cover crops can absorb soil nitrate to lower nitrogen (N) losses through leaching and denitrification. Leguminous cover crops can also reduce the need for exogenous N fertilisers and related N losses by supplying additional crop N through biological N fixing. (LeBauer and Treseder *et al.*, 2008.) [55] It has been frequently utilised to assess the abundances and activity of microbial populations involved in particular N cycling activities based on the abundance and expression of genes encoding important enzymes involved in soil N transformations. Various microbial assemblages, for instance, are in charge of N fixation, nitrification, and denitrification (Gaby and Buckley *et al.*, 2014) [21]. The conversion of atmospheric nitrogen to physiologically usable ammonium is known as biological N fixation. N-fixing bacteria's nifH genes, which encode a subunit of the nitrogenase reductase enzyme that catalyses the conversion of dinitrogen to ammonia, are frequently the focus of molecular investigation. (Parkin *et al.*, 2006; Sainju *et al.*, 2021) [69, 74].

3.3. Sulphur Cycle

A crop's need for S or any other nutrient can be expressed as either the total amount of that nutrient in the crop (kg / ha) or as the concentration of that nutrient in the entire plant or in a particular area of the plant that is necessary for optimum growth (g/ kg).The total amount of Sin soils varies greatly and is influenced by the amount of organic matter, the parent material of the soil, the amount of S provided through fertiliser amendments, and atmospheric deposition. While organic S is subject to mineralization and immobilisation, inorganic S is subject to adsorption, desorption, precipitation, and oxidation-reduction processes.By mineralization (converting from organic form to inorganic sulphate), the sulphur present in residue and humus in organic forms is made plant-available(Parkin *et al.*, 2006) [69]. Since soil S is continuously cycled between inorganic and organic forms, these activities establish a soil's capacity to deliver S over the short- and long-term. The literature contains a thorough review of the soil S cycle. In the majority of non-calcareous surface soils, the organic S pool accounts for 95% or more of the total S. Remains of plants and animals, microbial biomass and metabolites, and humus all contain organic S. Mineralization makes organic S available to plants, whereas immobilisation is the process by which soil biota transforms sulphate into organic forms that are inaccessible to roots. Soil organic S content is closely connected to soil organic C and soil total N (Scherer *et al.*, 2009) [90].

3.4. Phosphorus Cycle

Soil bacteria have a role in the biogeochemical cycle of phosphorus in the agro-ecosystem. These bacteria control how much phosphorus is available in the soil. Little is known about how phosphorus cycling bacteria react to high- and low-doses of inorganic nitrogen fertilisers or compost manure, which is made from home waste and plant materials.

Nevertheless, only a very little amount of phosphate is available to plants for absorption due to the phosphate ions' reactivity during redox reactions in the soil. The remaining portion either becomes immobile in the soil or is leached away, starving soil-dwelling microorganisms and plants of phosphorus. Abiotic and biotic variables affect the bioavailability of phosphorus in the soil. At the biotic level, phosphorus can be mineralized and solubilized by bacteria that can produce organic acid through the metabolism of carbon and create hydrolytic enzymes like phosphatase. On the other hand, plants control the availability of phosphorus through modifying the rhizosphere's chemistry through the production of phosphatase, organic acids, mycorrhizae, and root exudate. In addition, abiotic factors including soil temperature, pH, depth, and drying and rewetting affect how much phosphorus is available in the soil and how reactive it is (Chen *et al.*, 2020) [93].

4. Management of Soil Health

Due to the serious concern over poor soil health and grave land degradation, there is a need for a workable solution for eco-restoration and maintenance of soil resources that could sustain long-term soil productivity and enhance food security for the underprivileged farmers as well. Soil health is both correlated with nutritional security and human wellbeing. The aspects of soil that are crucial to life are the (I) physical attribute for transporting air, water, and for the gaseous exchange with the habitat; (II) chemical attribute for regulating soil reactions and nutrient availability; (III) biological attribute for providing energy, food and taking part in nutrient cycling; and lastly; (IV) Ecological attribute for maintaining hydrological and energy budgets as well as landscape processes. (Larkin *et al.*, 2015) [50]. The ability of soil is of a biological active entity that sustains as multiple ecosystem services, such as net primary productivity (NPP), food and nutritional security, biodiversity, water purification and renewability, carbon sequestration, air quality, and atmospheric chemistry with elemental cycling for human well-being and nature conservation. Essential techniques for assessing the agricultural ecosystem sustainability and environmental effect are the evaluation of the soil health connecting to its soil quality. The different techniques of soil management are illustrated in Fig 2.

4.1 Cover Crops, Crop rotation, Manures & Composts

When a crop is produced largely to cover the soil to prevent soil erosion and nutrient losses in between seasons of crop production, the crop are referred to as a cover crop. Cover crops have several advantages and applications, such as reducing soil erosion and runoff, improving soil structure and tilth, adding and recycling nitrogen, increasing soil productivity, and controlling weeds, pests, and diseases. Increasing soil fertility, improving soil tilth and aggregate stability, managing soil water better, and reducing erosion have all been linked to crop rotations. Due to the presence and activity of several plant species in the soil, crop rotations are also linked to enhanced soil microbial biomass and activity (Pahalvi *et al.*, 2021) [67]. They can also result in increased microbial diversity. Compared to regular crop rotations or cover crops, green manuring typically results in higher organic matter inputs, improving soil fertility and structure as well as causing noticeable changes in the features of the soil microbial population. The nutritional and fertility advantages of green manures, notably the addition of C (organic matter) and N to soil, have long been recognized. When compared to other forms of organic matter additions, such as manure or sawdust, green manures affect microbial communities in ways that are noticeably different while also increasing microbial biomass and activity.

4.2. Controlling of Organic Matter

The foundation for thriving plants, animals, and people is rich, nutritious soil. And the basic cornerstone of healthy and productive soils is soil organic matter (SOM). For the development of ecologically appropriate agricultural practices, it is crucial to comprehend the function of organic matter in sustaining a healthy soil. One of the main indices of soil health, soil organic matter, is essential for the long-term sustainability of agroecosystems and the earth's biogeochemical cycles. Organic matter strengthens soil structure, increasing water penetration after rainfall and the soil's capacity to store water. It also promotes root development into more porous soil (Jensen *et al.*, 2019) [39]. Better plant health is the consequence, and nutrients that are mobile, like nitrates, may get to the root more easily (Magdoff *et al.*, 2009) [82]. Benefits of soil organic matter include higher nutrient and water retention, which improves soil quality and increases plant productivity in both agricultural and natural contexts. SOM increases soil structure and decreases erosion, which improves the quality of both surface and groundwater, increases food security, and lessens adverse effects on ecosystems. Crop residues, rotations, and cover crops can all be used to supply organic matter, as can off-field sources of organic amendments such compost, manures, and mulches. Increased organic matter conservation can be achieved by reducing tillage, sustaining active crop development, controlling erosion, limiting field traffic, and preserving plant residues (Larkin *et al.*, 2015) [50].

4.3. Soil Biota Enhancement

According to the Soil Quality Institute (2001), soil biota consists of microorganisms (bacteria, fungus, archaea, and algae), soil animals (protozoa, nematodes, mites, springtails, spiders, insects, and earthworms), and plants that live entirely or in part in or on the soil or pedosphere. The soil is a heterogeneous environment with scarce resources that are scattered widely in time and space throughout a continuum of ecosystems with sizes ranging from microscopic to landscape scale (Lehmann *et al.*, 2020) [56]. Several biogeochemical processes that occur as a result of the interaction of soil organisms within food webs cause elements to be released, changed, and relocated within the pedosphere. By physically fusing soil particles together and increasing the quantity and size of aggregates that serve as habitat for microfauna, soil organisms have an impact on soil structure (www.sare.org).

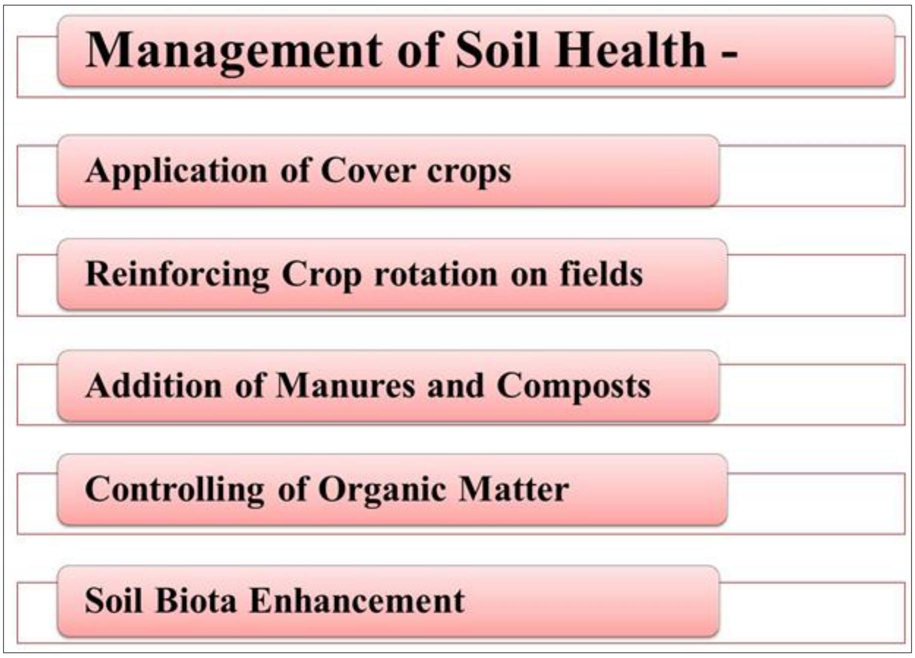

Fig 2: Management of Soil Health

5. Impact of Soil Health on crop yield & quality

When growth circumstances are less than ideal, the advantages of healthy soil in sustaining crop yield are most noticeable. Crops can survive more variations in the weather, including intraseasonal dryness and short-lived extreme precipitation events, when the soil is healthy. In order to reduce the effects on soil health and crop output caused by increasingly unstable weather, conservation planning must be given more serious consideration. The main component of soil that affects how the soil works is organic matter. Depending on the soil type and other formation factors, the organic matter component of the soil system only makes up a small portion of the topsoil horizon (1–5% or more by dry weight), but it is crucial for the soil's physical, biological, and chemical functions as well as its overall ecosystem services (Chapin *et al.*, 2002) [10]. The primary services for production agriculture include the provision and cycling of nutrients, the control of pests and pathogens, the generation of growth-promoting compounds, the availability of water, and the building of stable aggregates to lower the danger of soil erosion. However, these processes are successively influenced by one another, with organic matter serving as the foundation for all of the closely related processes. Bulk density, aggregate stability, and soil microbial biomass are only a few of the physical and biological characteristics of soil that are correlated with the quantity and turnover of soil organic matter (Bünemann *et al.*, 2018) [8]. Through a variety of physical, chemical, and biological processes, organic matter and clay are closely connected. They play a key role in the production of soil aggregates and have an impact on stability on various scales. Thus, when establishing important limits for soil functioning, it is crucial to take both clay and organic matter into account. A key factor in determining the physical behaviour of soil is the amount of soil organic C interacting with clay. Found that soils with clay/SOC ratios under 10 had superior structural stability and were less affected by management approaches. Earthworm abundance is one of the biological characteristics of soil that can be used as a measure of soil quality; earthworms are vital for the decomposition of organic matter and the development of soil aggregates, and they are affected by a number of agricultural techniques.The primary soil characteristics that are taken into account as indicators of soil health include rooting conditions, toxicity, salinity, oxygen availability to roots, and workability (Koch *et al.*, 2013). These indicators are very much important for the development of a crop and thus impacts crop yield and its quality. Thus maintaining and taking proper care of soil health will result in best quality and higher yield of crops.

6. Conclusion

6.1 Wendell Berry, in The Unsettling of America: Culture and Agriculture, once said that "The soil is the great connector of lives, the source and destination of all. It is the healer and restorer and resurrector, by which disease passes into health, age into youth, death into life. Without proper care for it we can have no community, because without proper care for it we can have no life." Soil health is the foundation of productive agriculture. Assessing soil health identifies the components or ground-level properties that may have a favourable or unfavourable impact on crop development. The multidimensionality of the soil-health concept allows for the alignment of soil management goals with sustainability goals and should be used as the foundation for consideration of a large-scale soil health preservation. Soil health plays a significant role in the global cycling of important elements like Carbon (C), Nitrogen (N), Phosphorus (P), and Sulphur (S). Soil aids in mediating groundwater infiltration (percolation) from the surface throughout the hydrologic (water) cycle. By participating in processes like nitrogen fixation and other forms of decomposition, soil-dwelling microorganisms can also play a significant role in the biogeochemical cycles. Management in soil health has its different attributes which keeps together all the biological, physical, chemical and ecological aspects of Soil health. Crop quality and quantity are closely related to soil health. The vital nutrients, water, oxygen, and root support that crop plants require to grow and flourish are provided by soils. They also act as a buffer to shield sensitive plant roots from sharp temperature changes. Hence, preserving soil health is of the utmost significance for ecosystem functioning and food and nutritional sustainability.

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