AGRIALLIS
Science for Agriculture and Allied Sector: A Monthly Magazine
Volume 6, Issue 8
www.agriallis.com

Article Id
AL04373

# SOIL HEALTH AND MANAGEMENT PRACTICES: BUILDING RESILIENCE FROM THE GROUND UP

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Soil health is fundamental to sustainable agriculture, environmental quality, and climate resilience. This abstract explores the significance of soil health and the practices essential for its management. Key components of soil health include physical structure, chemical composition, and biological activity. Effective management practices such as crop rotation, green manures, cover cropping, reduced tillage, organic amendments, and integrated pest management are vital for enhancing soil structure, nutrient cycling, and microbial diversity. These practices not only improve crop yields and farm profitability but also enhance soil carbon sequestration, water retention, and resistance to erosion. Moreover, they mitigate the impacts of climate change by reducing greenhouse gas emissions and increasing the resilience of agricultural systems to extreme weather events. Additionally, they help mitigate climate change impacts by reducing greenhouse gas emissions and increasing the resilience of agricultural systems to extreme weather events. the critical need for adopting comprehensive soil management strategies to build resilient agricultural systems from the ground up, ensuring long-term sustainability and food security. By prioritizing soil health, we can create a more resilient and productive agricultural landscape capable of withstanding the challenges posed by climate change and other environmental stressors.

Climate resilience, environmental quality, and sustainable agriculture all depend on healthy soil. The ability of soil to continue serving as a viable living ecosystem that supports people, animals, and plants is referred to. Fertile soils serve as the basis for successful agricultural systems by facilitating plant development, nutrient cycling, water filtration, and carbon sequestration. However, soil deterioration brought on by contemporary farming methods poses a challenge to both environmental sustainability and food security. Physical, chemical, and biological aspects of soil health are all included. The structure and texture of the soil are examples of physical qualities that affect root development, water infiltration, and erosion resistance. The availability of nutrients, pH, and the existence of pollutants are examples of chemical attributes. The variety and activity of soil organisms, which are crucial for the breakdown of organic matter, nutrient cycling, and the maintenance of plant health, are correlated with biological features (Doran & Zeiss, 2000).

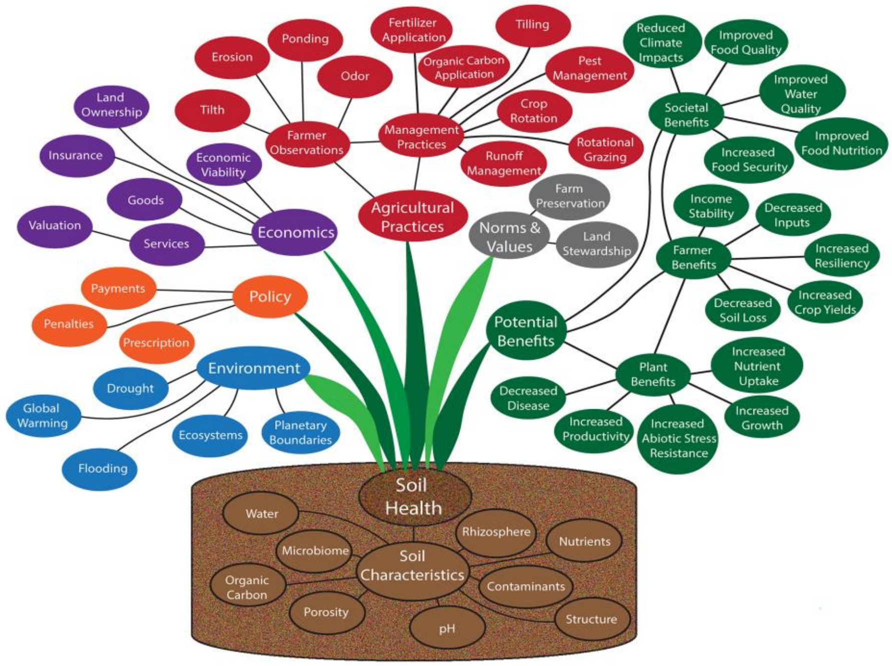
Maintaining and improving the health of the soil requires effective soil management techniques. Crop rotation, cover crops, less tillage, organic amendments, and integrated pest management are some of these techniques. Crop rotation increases soil fertility and disrupts the cycles of pests and diseases. Cover crops improve soil structure, supply organic matter, and prevent soil erosion. Less tillage preserves soil moisture and structure by reducing soil disturbance (Lal, 2004).

Compost and manure are examples of organic amendments that supply nutrients and increase the amount of organic matter in the soil, which promotes a thriving microbial population. By lowering dependency on chemical inputs, integrated pest management improves soil health and ecological balance (Altieri, 1999).

Soil is a dynamic living resource whose wellbeing is vital to both the production of food and fibre for global balance and ecosystem function and in that, it represents a unique balance between physical, chemical and biological factors (Doran *et al.*, 1996).

Soil management in the 20th century emphasized the physical and chemical characteristics of soils that were important for production. All that was used to evaluate soil was its chemical and physical makeup, such as the amount of nutrients it contains, the size of its aggregates, and its ability to hold water. The management strategies for drainage and erosion are readily obvious, but it takes specific observational methods to evaluate how these strategies impact the intricate network of living things. measurements of the live part of the soil offer proof that soil and plant microbiomes can be altered by agricultural management techniques. We know relatively little about how agricultural management techniques affect the living component of soil; hence the microbiome component of soil is rarely evaluated in evaluations of soil health. Large-scale agriculture systems with monocultures, traditional tillage, and heavy inputs of synthetic fertilizers and agrochemicals suppress or eradicate microbes that flourish in healthy soils. Microbes are unable to perform what they have been able to do for hundreds of millions of years when microbial communities are disrupted:

obtaining, recycling and preserving water and nutrients, which are necessary for feeding plants and animals and boosting plant resilience to disease and environmental stress (D. A. Neher, *et al.*, 2022).

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Schematic diagram showing the relationships and nodes pertaining to soil health. **Brown** nodes represent soil qualities, **blue** represents the environment, orange represents policy, **purple** represents economics, **red** represents agricultural practices, and **grey** represents norms and values. The possible **green** advantages of healthy soil are also demonstrated. Not every connection is shown for the sake of simplicity. Growing knowledge of the type and strength of linkages among nodes can help guide initiatives to strengthen soil health and boost benefits to farmers, plants, and society as a whole (D. A. Neher, *et al.*, 2022).

Environmental and societal well-being are largely dependent on healthy soils, which are also essential for human health, biodiversity, water quality, food and nutrition security, and mitigation and adaptation to climate change (Manter *et al.*, 2017).

Farmers are starting to use the expression "soil health" to mean the state of their soil in relation to crop growth. The idea of soil health and human health are comparable. Just as certain ranges of human qualities, like blood sugar levels and body temperature, are necessary for good health, so too do certain ranges of soil features, like water and nutrient contents, for healthy plant growth. Every element of a healthy person, including their internal organs, needs to be functioning properly for them to grow and develop, just as the biological, chemical, and physical components of soil must be present and in good condition for crops to grow that are both healthy and productive. subsequently, considering the importance human health is Healthy soils are characterized in part by the lack of infectious illnesses and parasites, as well as by the low concentrations of organisms like weeds and parasites that could impede plant growth (Magdoff, F., 2001).

The long-term viability of agroecosystems and the global biogeochemical cycles depend critically on soil organic matter, one of the main markers of soil health. Keeping the many different species that comprise soil biology in an appropriate habitat is a major component of managing for soil health (and enhanced soil performance). Because organic matter serves as the principal food supply for soil microorganisms, managing soil organic matter is essential to preserving the physical, chemical, and biological characteristics of the soil. Organic matter fixes soil structure and water relations (here referring to all aspects of water infiltration, storage, availability, etc.) and improves soil fertility in addition to giving nutrients and energy to the Organic matter improves soil fertility and stabilizes soil structure and water relations, which are defined as every element of water infiltration, storage, availability (Magdoff, F., & Van Es, H. 2000).

## Requirement for Soil Health and Management

1. Enhancing Crop Productivity
2. Mitigating Climate Change
3. Improving Water Management
4. Promoting Biodiversity
5. Ensuring Food Security and Sustainability

## Factors Affecting Soil Health

### Physical Factors

**Soil Texture:** The ratios of clay, silt, and sand particles form the texture of the soil, which affects aeration, drainage, and water retention. Clayey soils hold moisture but may have poor drainage and aeration, whereas sandy soils drain rapidly but keep little moisture (*Brady, N. C. 1984).*

**Soil Structure:** Porosity, permeability, and root penetration are all impacted by how soil particles are arranged into aggregates. A healthy soil structure promotes microbial activity, lowers erosion, and improves water infiltration (Bronick & Lal, 2005).

**Bulk Density:** Compacted soil can limit root growth and reduce aeration and water infiltration. A high bulk density is indicative of this. Although the ideal bulk density varies depending on the kind of soil, healthier root development often requires lower bulk densities (Hillel, 2003).

## Chemical Factors

**Soil pH:** Microbial activity and nutrient availability are impacted by soil pH. 6 to 7.5 is the ideal pH range for most crops. Lime or sulphur amendments may be necessary to correct pH values in soils that are excessively acidic or alkaline (Marschner, H. Ed. 2011).

**Content of Nutrients:** For plants to thrive, sufficient levels of nitrogen, phosphorous, potassium, and trace elements must be accessible. Plant health and soil microbes can be harmed by nutrient toxicities as well as deficits (Havlin et al., 2016).

**Salinity:** By influencing water intake and producing ion toxicity, high salt concentrations can hinder plant growth. Techniques include sufficient irrigation, appropriate drainage, and the use of salt-tolerant crops are all part of managing salinity (Rengasamy, 2010).

## Biological Factors

**Organic Matter in Soil**: Organic matter enhances soil nutrient availability, water retention, and structure. It provides nourishment for soil organisms as well. Soil organic matter can be increased by methods such as applying compost or cover crops (Lal, 2004).

**Microorganisms found in soil:** Fungi, bacteria, and other microorganisms are essential for the breakdown of organic matter, the cycling of nutrients, and the prevention of illness. One important sign of good soil is a varied and active microbial population (Van der Heijden et al., 2008).

**Root Health and Activity:** Microbial activity and soil structure are enhanced by robust root systems. Crop rotation, less tillage, and adequate irrigation are examples of practices that promote root health and activity (Bernard, *et al.*, 2014).

## Components of Soil Health

### Soil Structure

A soil's ability to hold and transfer fluids and both organic and inorganic substances, as well as to enable vigorous root growth and development, is referred to as its structure. Other characteristics of soil include its size, shape, and arrangement of solids and voids, as well as the continuity of its pores and voids. To increase agronomic production, improve porosity, and improve soil fertility, favourable soil structure and high aggregate stability are crucial (Lal, R., 1991).

### Soil Organic Matter

Decomposed plant and animal remain make up soil organic matter, or SOM. It is essential for enhancing soil structure, water retention, and nutrient availability. SOM in soil health, emphasizing its function in improving soil structure, sequestering carbon, and cycling nutrients (Lehmann, J., & Kleber, M. 2015).

### Soil pH

soil pH's function in soil repair and plant feeding. It examines how soil pH impacts nutrient availability and remediation approaches' efficacy, highlighting the significance of soil pH in preserving soil health. Hence, the pH of the soil is referred to as the "master soil variable" since it affects a wide range of biological, chemical, and physical characteristics and processes in the soil that have an impact on biomass yield and plant growth (Neina, D., 2019).

### Soil Microbiology

The influence of soil bacteria on ecosystem processes remains poorly understood, despite their ubiquity. In this article, we examine the several functions that soil microorganisms perform in terrestrial ecosystems, focusing in particular on how they affect plant diversity and production. Microorganisms in the soil play a significant role in controlling plant productivity, particularly in environments with low nutrient levels where plant symbionts obtain scarce resources. About 5–20% (in grasslands and savannah) to 80% (in temperate and boreal forests) of the total nitrogen and up to 75% of the phosphorus that plants absorb each year comes from mycorrhizal fungi and nitrogen-fixing bacteria. Through the mineralization of nutrients and competition for those resources, free-living microorganisms also play a significant role in controlling plant productivity (Van Der Heijden, *et al.*, 2008).

## Management Practices

### Crop rotation

Crop rotations provide several advantages for both crop yield and soil condition, and they fulfil several purposes. They can aid in the preservation, upkeep, or replenishment of soil resources, such as organic matter, inputs of nitrogen and other nutrients, and the chemical and physical characteristics of the soil. Crop rotations have been linked to better soil water management, less erosion, and increased soil tilth and aggregate stability (Ball, B. C. *et al*., 2005). Crop rotations are also linked to higher soil microbial activity and biomass, and because they introduce and maintain a range of plant species in the soil, they may also result in higher microbial diversity. Crop rotations that blend legumes, cereals, solanaceous plants, cucurbits, brassica, etc. in a way that maximizes variety and varied plant and root system types may have the most impact on soil microbial populations (Garbeva *et al.*, 2004).

### Conservation Tillage

Depending on the type of pathogen and the circumstances, conservation tillage may have opposite effects on soilborne pathogens and diseases, such as increases or decreases. the effect of conservation tillage on soilborne illnesses. Some soilborne diseases are predicted to decline with conservation tillage over time as a result of healthier crops and disease suppression by a larger, more diverse microbial community. This is because reduced tillage has positive effects on soil health, particularly reduction of erosion and increases in soil organic matter, microbial biomass, and diversity. This has been noted in relation to some Rhizoctonia illnesses and root rots (Larkin, R. P. 2015).

### Cover crops

A cover crop is characterized as a crop that is mainly planted to cover the soil to prevent nutrient losses and soil erosion in between crop-production cycles. Benefits and applications of cover crops include decreased soil erosion and water runoff, increased soil structure and tilth, increased soil productivity, and the control of weeds, pests, and diseases. In addition to contributing to agricultural diversity, cover crops can also benefit from employing multispecies cover crop combinations rather than single species, which could have additional benefits. It has been demonstrated that the use of cover crops in vegetable production systems increases the amount of organic matter present, porosity, aggregate stability (the capacity to withstand disintegration), and available water. It also decreases soil bulk density and penetration resistance while suppressing weeds. It has been demonstrated that high residue autumn and winter cover crops are crucial for maintaining plant-available N, supplying C, boosting fertilizer efficiency, and enhancing the physical characteristics of the soil (Larkin, R. P. 2015).

**Green manures**

The term "green manuring" particularly describes the addition of new plant material to improve the soil. Therefore, the only purpose of growing crops for green manure is to use them as organic matter in the soil when they are still fresh and green. Compared to conventional crop rotations or cover crops, green manuring typically yields higher organic matter inputs, which improves soil fertility and structure and significantly alters the properties of the soil microbial population. Green manures have long been utilized for their nutritional and fertility properties, especially for improving soil's C and N contents (Larkin, R. P. 2015).

**Reduced Tillage**

Greenhouse gases like CO2 and N2O are released during agricultural operations like soil tillage. Therefore, lowering tillage could enhance soil quality and lower greenhouse gas emissions. Under reduced tillage, the average abundance of perennials nearly doubled over time, resulting in a change in the composition of the communities under different tillage systems. In spite of the rise in weeds, yields from conventional and reduced tillage methods were comparable (Armengot, *et al.*, 2015)

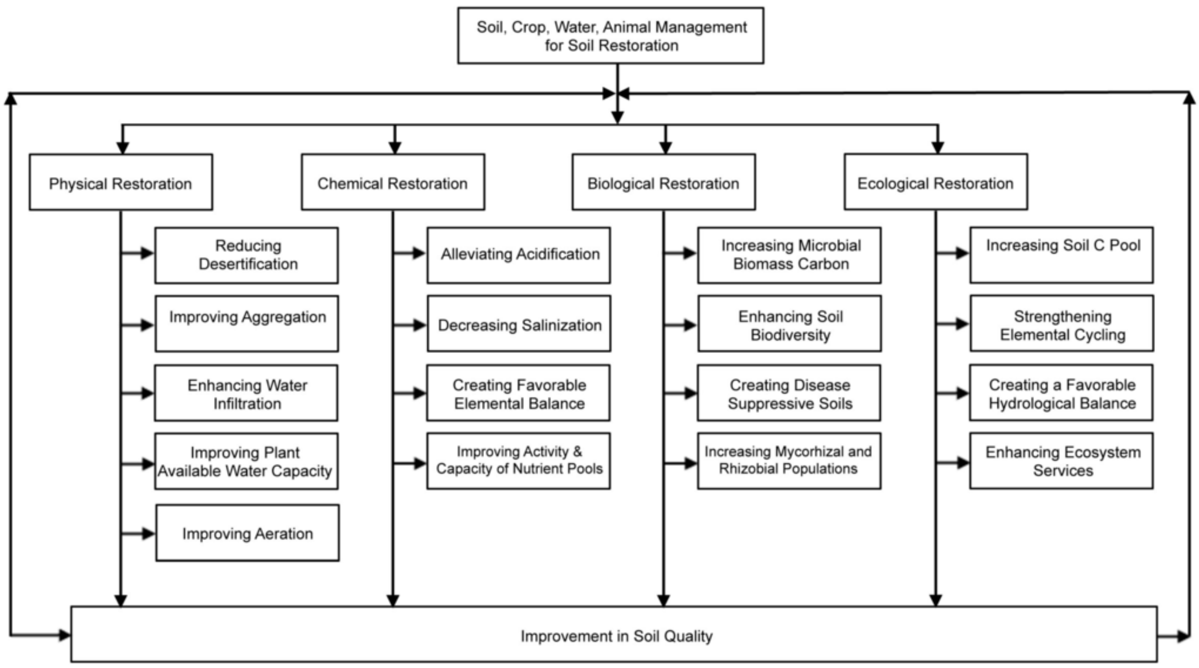
**Building Resilience from the Ground Up**

The ability of the soil to regain its quality in the face of any anthropogenic or natural disturbances is referred to as soil resilience. In contrast to soil resistance, soil resilience refers to "elastic" qualities that allow a soil to return to its original state once any disturbance or destabilizing factor has subsided (Lal, R. 1997).

## Benefits of Soil Restoration

- **Enhanced Productivity:** Healthy soils support higher and more stable crop yields.
- **Increased Resilience:** Improved soil quality helps buffer against drought, heavy rainfall, and other environmental stresses.
- **Climate Change Mitigation:** Healthy soils sequester carbon, reducing greenhouse gas emissions.
- **Improved Water Quality:** Reduced runoff and erosion lead to better water infiltration and reduced pollution.
- **Biodiversity Support:** Healthy soils sustain diverse plant and microbial communities, supporting overall ecosystem health.

Maintaining agricultural output and environmental quality requires strengthening soil resilience. By implementing techniques that enhance soil health, soils become more resilient to environmental stressors and are able to recover from them (Lal, R. 2015).

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## Conclusion

Climate resilience, environmental quality, and sustainable agriculture are all dependent on healthy soil. Biological activity, chemical composition, and soil structure are all interrelated, and this interconnectivity is the basis of resilient and productive agricultural systems. This interdependence emphasizes how important it is to acquire and put into practice efficient soil management techniques that strengthen these essential elements. Techniques including integrated pest management, crop rotation, cover crops, decreased tillage, and organic amendments have shown to offer significant advantages. Crop rotation enhances soil fertility and structure by upsetting insect and disease cycles. Cover crops increase the amount of organic matter in the soil, prevent erosion, and provide food for healthy soil organisms. By reducing soil disturbance, less tillage helps to maintain the moisture and structure of the soil. Compost and manure are examples of organic amendments that replenish the soil with nutrients and organic materials. encouraging a healthy microbial population. By lowering dependency on chemical inputs, integrated pest management improves soil health and ecological balance.

When these methods are combined, the health of the soil is improved, which raises crop yields, increases farm profitability, and strengthens the soil's resistance to environmental stresses. Because healthy soils can hold onto water better, they lower the chance of drought and flooding. Additionally, they sequester more carbon, which helps to mitigate climate change by lowering the atmospheric concentrations of greenhouse gases. Furthermore, because of climate change, extreme weather events such as lengthy dry spells and strong rains are becoming more frequent and severe, and healthy soils are better able to endure them. We can develop agricultural systems that are more resilient to these difficulties by increasing soil resilience, assuring long-term food security and sustainability. Soil health is not limited to agriculture; it affects biodiversity, ecological services, and human health as well. Rich soils support a variety of plant and animal species, filter water, and break down contaminants. They emphasize the wider environmental implications of preserving soil health and are essential to the global carbon cycle and climate regulation.

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