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Soil Health and Nutrient Management

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Short Communication

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ABSTRACT

Soil health and appropriate nutrient management are critical components of sustainable agriculture, influencing crop yield, environmental sustainability, and overall food security. The ability of soil to function as a living ecosystem is referred to as soil health. supports plant and animal life while protecting the environment. It refers to how physical, chemical, and biological activity interact in the soil. Mineral matter, organic matter, water, and air are all critical components of soil health, and each contributes to plant growth. Soil health indicators include physical, chemical, and biological factors that help assess the soil's state. For optimal soil health, these indicators must be balanced.
However, there are significant issues to address, such as decreased soil organic matter, declining soil fertility due to nutrient deficits, physical soil degradation, and chemical soil degradation caused by excessive chemical use. Practices for sustainable soil management are critical for addressing these concerns. Balanced fertilization, organic matter incorporation, crop rotation, cover cropping,

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reduced tillage, and precision nutrient delivery are examples of these. Mitigating issues such as nutrient pollution, soil erosion, and soil deterioration is critical to maintaining agriculture's long-term viability.

Keywords: Soil health; soil structure; aggregates; physical properties.

1. INTRODUCTION

Soil health and nutrient management are critical components of long-term agriculture. The soil is a living environment that serves as the foundation for crop production [1], and the quality of this ecosystem has a direct impact on plant growth [2,3], crop yield [4,5], and environmental sustainability [6,7]. Proper nutrient management is critical for maintaining soil fertility and avoiding the abuse of fertilizers, which can be harmful to the environment [8,9]. This chapter investigates the significance of soil health and the optimal nutrient management practices to promote productive and environmentally responsible agriculture [10,11].

2. WHAT IS SOIL HEALTH?

Soil health refers to a soil's ability to function as a vibrant ecosystem that supports plant life, wildlife, and human activities. A healthy, well-balanced soil has physical, chemical, and biological properties that promote optimal plant development and environmental preservation.

Or, According to Doran and Zeiss [12], soil health is "the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or improve water and air quality, and promote plant and animal health."

2.1 Understanding Soil Health

1. Soil as a Dynamic Ecosystem: Soil is a complex and ever-changing ecosystem made up of physical, chemical, and biological factors. Various creatures, such as bacteria and fungi, earthworms, and nematodes, play pivotal roles in nutrient cycling and the preservation of soil structure [13,14].
2. Soil Composition: Soil consists of a blend of minerals, organic matter, water, and air. Striking the right balance in soil composition is essential for promoting plant health and facilitating robust growth.
3. Soil Nutrient Capacity: Soil fertility alludes to the soil's capacity to supply vital nutrients to plants. Nutrients like nitrogen (N), phosphorus (P), and potassium (K) are indispensable for the optimal growth of plants.

2.2 SOIL COMPONENT

1. **Mineral Matter:** Mineral matter makes up the largest portion of soil. It consists of tiny mineral particles that come from the weathering of rocks and minerals. These particles can vary in size and include sand, silt, and clay. The proportions of these different-sized particles determine the soil's texture [15-17]. For example, sandy soils have larger, coarser particles, while clay soils have smaller, finer particles. The mineral matter provides essential nutrients for plants and serves as a framework for soil structure.
2. **Organic matter:** Plant and animal wastes in various phases of decomposition are included. This component is high in organic carbon and has an important role in soil health. It adds to the structure, moisture-holding capacity, and nutrient content of the soil. Bacteria and fungi decompose organic materials to form humus, which is a stable form of organic carbon that improves soil fertility. Organic matter is also important for increasing soil structure and aeration [18-20].
3. **Soil Water:** Soil serves as a reservoir for water. The soil pore space is the gap between soil particles that holds water. The ability of soil to retain and release water is influenced by its texture and structure. Sandy soils drain quickly, Clay soils, on the other hand, retain water for extended periods. Proper soil moisture is required for plant growth and provides the medium for nutrient transport to plant roots.
4. **Soil Air:** There is air in the crevices between soil particles. This soil air is essential for root respiration and provides oxygen to soil organisms. Good soil structure ensures that there is a balance of air and water in the soil. When the soil becomes compacted or waterlogged, it can limit the exchange of gases and harm plant and microbial activity [21-25].

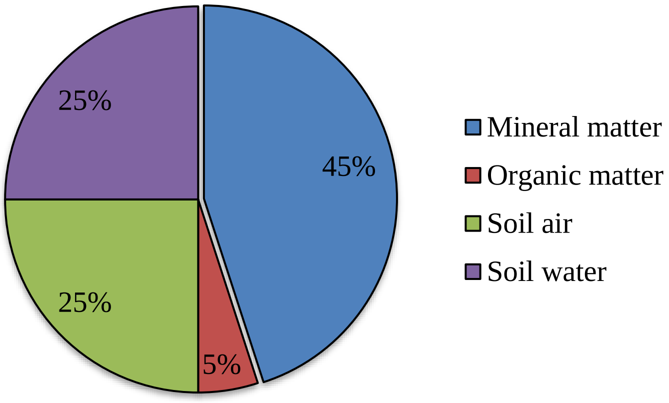


Fig. 1. Mineral particles, water, air, and soil are all soil components

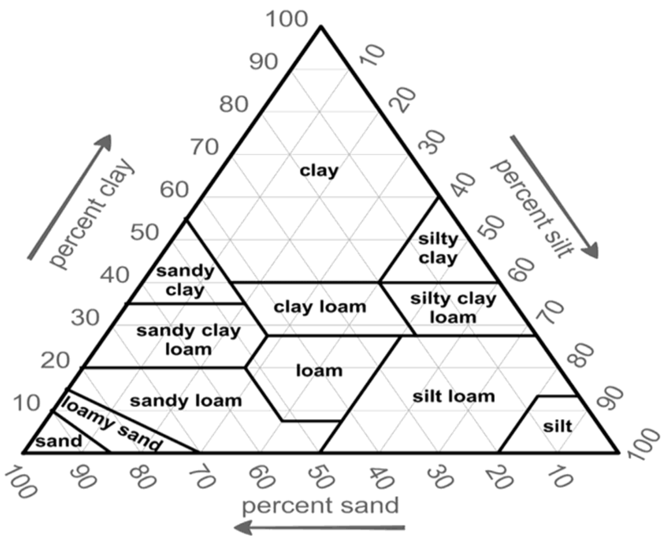


Fig. 2. If the percentages of sand, silt, and clay are known, a soil textural triangle can be used to determine soil texture (source: USDA)

The Soil Textural Triangle is a graphical representation used by soil scientists and agricultural experts to determine and classify the texture of soil based on its proportions of sand, silt, and clay particles. It is a handy tool for understanding soil characteristics and behaviors. Here's how it works.

Components: The textural triangle consists of three sides, each representing one of the primary soil particles:

- Sand: The largest soil particles.
- Silt: Particles that are smaller than sand but larger than clay
- Clay: The smallest soil particles.

- **Relative Proportions:** Each side of the triangle corresponds to one of these soil components, and the triangle's interior represents all possible combinations of these components. The triangle's vertices represent pure sand, pure silt, and pure clay soils.
- **Positioning a Soil:** To determine a soil's texture, a soil sample is analyzed to determine the percentage of sand, silt, and clay in it. These percentages are then plotted on the soil textural triangle. The point where these three percentages

intersect within the triangle indicates the soil's texture. For example:

- If the intersection point is closer to the sand side, it's sandy soil.
- If it's closer to the silt side, it's a silty soil.
- If it's closer to the clay side, it's a clayey soil.

Loam: Loam: Loam is a well-balanced blend of sand, silt, and clay. and is often considered ideal for plant growth because it combines the desirable characteristics of these three soil components. The soil textural triangle helps in understanding a soil's physical properties, such as drainage, water-holding capacity, and aeration.

Different plants have specific preferences for soil texture, so knowing the texture of the soil is crucial for successful agriculture and gardening. Soil texture affects how nutrients, water, and air move through the soil, making it a fundamental consideration for soil management and crop production.

2.3 Assessing Soil Health

- Soil Testing: Soil testing is an important step in determining soil health. It aids in the determination of nutritional levels, pH, and organic matter content. The findings inform nutrient management decisions.
- Soil Organic Carbon Measuring: Soil organic carbon is an important measure of soil health. It has an impact on soil structure, water retention capacity, and nutrient availability.
- Bioindicators: Biological indicators like earthworm populations and microbial activity can provide information on soil health. A thriving soil ecosystem has a high diversity and richness of soil organisms. Indicators of Soil Health Assessing soil health involves various indicators, including soil organic matter, pH, nutrient levels, water-holding capacity, and biological activity. These indicators provide valuable insights into soil quality and its ability to support plant growth.

2.4 Indicators of Soil Health

Soil health indicators are parameters or characteristics of soil that are assessed to gauge the overall condition and functionality of the soil. These indicators provide valuable insights into the ability of soil to support plant and animal productivity, preserve environmental quality, and enhance ecosystem health. Physical, chemical, and biological markers are used to assess soil health., each offering specific information about the soil's well-being. Here's some information about these categories of soil health indicators:

2.5 Understanding the Three Soil Health Processes

When considering soil health, it's essential to recognize the interplay among its three major dimensions: the physical, the chemical, and the biological. These realms are intricately connected, and any compromise in one dimension can ripple through the others. A soil is considered healthy when it achieves a harmonious balance across these realms, thereby creating optimal conditions for plant growth, enhancing crop resilience, and reducing the need for additional inputs. Historically, there was a tendency to overemphasize the chemical aspects of soil health, leading to advancements in testing methods and crop recommendations. However, the physical and biological facets of soil received comparatively less attention. In recent years, ongoing research has focused on better understanding the physical and biological aspects of soil. This research has yielded a more comprehensive understanding of soil health, paving the way for more holistic short-term and long-term soil management strategies aimed at improving its overall health.

2.6 Physical Processes

The physical processes affecting soil health can be influenced by inherent characteristics or dynamic factors, some of which can be rectified while others are more challenging to address.

- ✓ **Internal drainage:** Poor internal drainage hinders root growth and function, potentially fostering disease development [26].
- ✓ **Water availabilit**y: It depends on soil texture, organic matter content, and rooting depth, with these factors affecting how well the soil can retain and provide water to plants [11].
- ✓ **Soil aggregate stability:** Adequate soil organic matter is essential for generating humates and other substances that bind soil particles together, contributing to the formation of stable soil aggregates (crumbs) and improving soil structure [27].
- ✓ **Soil structure:** Soils with diverse pore sizes can offer optimal drainage, aeration,

and root support while retaining moisture when needed [28].

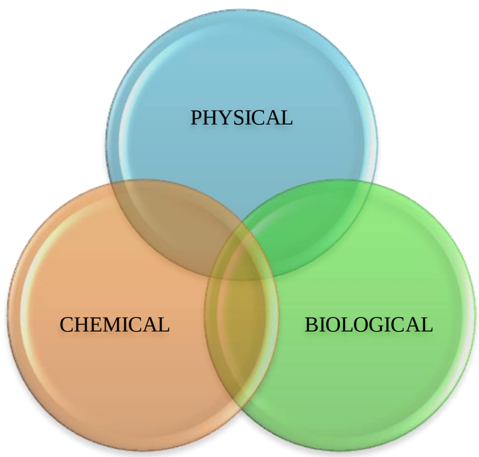
- ✓ **Compaction:** The presence of compaction layers, whether near the surface or deeper in the soil, can hinder root penetration and water drainage, leading to issues like excess runoff and erosion.

List 1. Soil health indicators

Indicator	Description
Physical	
Soil Texture	Particle proportions of sand, silt, and clay.
Soil Structure	The grouping of soil particles into aggregates or peds.
Bulk Density	Soil mass per unit volume. It has an impact on root growth and aeration.
Porosity	Amount of pore spaces in soil. Influences water retention and drainage.
Soil Depth	Depth of the soil profile, affecting root development.
Soil Erosion	Loss of topsoil due to water or wind.
Chemicals	
pH	A measure of soil acidity or alkalinity. Influences nutrient availability.
EC	Indicates salt levels in the soil.
Cation Exchange Capacity (CEC)	The capacity of soil to retain and exchange cations (nutrients) with plant roots.
Macronutrients (N, P, K)	Essential elements required for plant growth.
Micronutrients (Fe, Zn, Cu, etc.)	Essential trace elements are needed in smaller quantities.
Soil Organic Carbon (SOC)	Amount of carbon in the soil. Reflects organic matter content.
Base Saturation	Base cations (Ca2+, Mg2+, K+, Na+) occupy a large proportion of cation exchange sites.
Biological	
Soil Microorganisms (Bacteria, Fungi, etc.)	Diversity and abundance of soil microbes. Indicate nutrient cycling.
Earthworm Activity	Presence and activity of earthworms, indicating soil aeration and organic matter decomposition.
Soil Respiration	The release of CO_2 by soil microbes during organic matter decomposition.
Mycorrhizal Fungi	Symbiotic fungi form associations with plant roots to enhance nutrient uptake.
Enzyme Activity	Activity of enzymes involved in nutrient cycling and organic matter decomposition.
Biodiversity	Variety of plants, animals, and microbes in the soil ecosystem. Affects nutrient cycling.
Soil Microorganisms (Bacteria, Fungi, etc.)	Diversity and abundance of soil microbes. Indicate nutrient cycling.

Chemical processes

Chemical processes Chemical processes within the soil play a pivotal role in supplying vital nutrients to plants. Among these processes, soil pH is of utmost importance as it directly influences nutrient accessibility. It's crucial to address any deviations in soil pH before initiating planting, as neglecting this adjustment can severely impact initial plant establishment and subsequent crop yields. Furthermore, chemical processes encompass a spectrum of nutrients, including macronutrients (such as N, P, and K, needed in larger quantities), secondary nutrients like Ca, Mg, and S, as well as micronutrients (e.g., B and Zn) required in smaller amounts.



Picture 1. Chemical processes

Specific recommendations have been developed to rectify deficiencies in these essential nutrients, tailored to the specific requirements of berry crop production.

2.7 The Biological Processes

- Our understanding of soil biology has taken a prominent role in contemporary scientific research. Soil is a complicated thing and diverse environment with variable conditions, and a significant portion of biological activity occurs near its surface, where organic matter is most abundant. Within the soil, three main categories of organic matter can be identified: living, dead, and very dead, each contributing significantly to the production of robust and high-yielding crops. Organic matter added to soil produces numerous benefits.
- **Living Organic Matter:** This category includes plant roots, bacteria, fungi, nematodes, and a variety of other organisms. They interact with the soil environment in intricate ways, utilizing resources, decomposing organic matter, reusing nutrients to make them available to plants influencing other biota (such as pathogen suppression), and responding to chemical and physical changes in the soil. The role of living organic matter is multifaceted and essential for a healthy soil ecosystem.
- **Dead Organic Matter:** Comprising recently deceased soil organisms and crop residues, dead organic matter serves as a source of energy and nutrients for soil organisms to thrive and perform their functions. Often referred to as "active" or "particulate" organic matter, it is a crucial partner in the process of nutrient mineralization for plants, soil aggregation, and the formation of humus.
- **Very Dead Organic Matter:** This fraction is not biologically active and consists of welldecomposed organic materials known as humus. Humus plays a pivotal role in supporting the chemical processes of the soil. It possesses a high density of negative charges that retain nutrients and cations within the soil, has excellent water-holding capacity, and serves as a carbon reservoir.

2.8 The Imperative for Improved Soil Management: Present Challenges

Each year, we receive reports of bountiful harvests, yet the persistent issues of malnutrition and inadequate farmer income continue to plague us. The root cause of this problem often lies in a lack of awareness and understanding regarding soil nutrient imbalances.

Despite increasing agricultural yields, disparities in soil nutrients play a significant role in these ongoing challenges. Soil health is confronted with numerous pressing challenges:

- ✓ **Soil Erosion:** Soil erosion, both from wind and water, is a severe threat to soil health. It leads to the loss of topsoil, which is rich in organic matter and nutrients. Erosion is often exacerbated by poor land management practices, deforestation, and extreme weather events.
- ✓ **Soil Degradation:** Soil degradation is a broad term that encompasses various processes like erosion, compaction, salinization, and acidification. These processes reduce the soil's ability to support plant growth and can lead to decreased agricultural productivity [29].
- ✓ **Decline in Soil Organic Matter:** Many soils are experiencing a decline in organic matter due to factors like intensive farming, overuse of synthetic fertilizers, and inadequate incorporation of crop residues. Soil organic matter is crucial for soil structure, nutrient retention, and microbial activity.
- ✓ **Nutrient Depletion:** Intensive agriculture often leads to the depletion of essential nutrients from the soil, such as nitrogen, phosphorus, and potassium. This can result in nutrient imbalances and reduced crop yields.
- ✓ **Soil Contamination:** Soil can become contaminated with pollutants from industrial activities, mining, and the use of pesticides and herbicides. Contaminants like heavy metals and chemical residues can harm soil health and pose risks to human and environmental health.
- ✓ **Loss of Biodiversity:** Soil ecosystems host a diverse community of organisms, including earthworms, fungi, bacteria, and insects. Land-useLand use changes, pollution, and habitat destruction can disrupt this biodiversity, affecting nutrient cycling and overall soil health [29].

- ✓ **Climate Change:** Climate change can exacerbate soil health challenges by altering precipitation patterns, increasing temperatures, and promoting extreme weather events. These changes can impact soil moisture, microbial activity, and carbon sequestration [30,31].
- ✓ **Urbanization:** The expansion of urban areas and infrastructure development often leads to the loss of fertile agricultural land and natural soil habitats. Urbanization can disrupt soil ecosystems and reduce the availability of arable land.
- ✓ **Land Conversion and Deforestation:** The conversion of forests and natural landscapes into agricultural land can result in the destruction ofdestroy valuable soils and their unique characteristics. Deforestation, in particular, can lead to increased erosion and reduced soil health [32].
- ✓ **Inadequate Soil Management:** Poor soil management practices, such as overuse of chemical inputs, improper irrigation, and excessive tillage, can harm soil health. Sustainable soil management practices are crucial to address these issues.
- ✓ **Water Scarcity:** Water scarcity can lead to over-irrigation and salinization in arid regions, further degrading soil health. Efficient water management is essential to prevent these issues. .

2.9 How do we Manage Soil Health?

2.9.1 Some of these practices include

1. **Soil Testing:** Regularly test your soil to understand its nutrient content, pH levels, and other properties. Soil tests can guide you in making informed decisions about fertilization and soil amendments.
2. **Crop Rotation:** Rotate crops to break pest and disease cycles, improve nutrient cycling, and enhance soil structure. Different crops have different nutrient requirements, and crop rotation helps maintain soil health and fertility.
3. **Cover Crops:** Plant cover crops, like legumes, grasses, or other beneficial plants, during periods when the main crop is not growing. Cover crops help prevent erosion, add organic matter to the soil, fix nitrogen, and improve soil structure [33].
4. **Organic Matter Addition:** Increase soil organic matter by adding compost, manure, and crop residues. Organic matter enhances soil structure, water-holding capacity, and nutrient availability.
5. **Reduced Tillage:** Minimize or eliminate tillage to protect soil structure and prevent erosion. No-till or reduced-till practices help maintain soil organic matter and microbial diversity.
6. **Nutrient Management:** Apply fertilizers based on soil test results and the specific needs of the crop. Over-application of nutrients can lead to nutrient imbalances and environmental pollution.
7. **Irrigation Management:** Efficiently manage irrigation to prevent waterlogging or soil drying. Proper irrigation practices help maintain soil structure and prevent salinization [34,35].
8. **Soil Erosion Control:** Implement erosion control measures, such as planting windbreaks, contour farming, and installing silt fences. Erosion can deplete topsoil and damage soil health [36,37].
9. **Soil Conservation Practices:** Use terracing, buffer strips, and other conservation practices to reduce soil erosion and protect soil health [38,39].
10. **Pest and Disease Management:** Practice integrated pest management (IPM) to minimize the use of chemical pesticides. Reducing pesticide use can preserve beneficial soil organisms and biodiversity.
11. **Soil Microbial Diversity:** Promote soil microbial diversity by avoiding the overuse of chemicals, especially broad-spectrum pesticides and fungicides. Beneficial microorganisms play a crucial role in nutrient cycling and soil health.
12. **Crop Residue Management:** Leave crop residues on the field after harvest to protect the soil surface and add organic matter [40].
13. **Avoid Compaction:** Minimize soil compaction by using appropriate machinery and reducing heavy traffic on the field.
14. **Soil Monitoring:** Regularly monitor soil health indicators like earthworm populations, soil structure, and nutrient levels to assess the impact of your management practices [41].
15. **Education and Research:** Stay informed about the latest soil health research and practices. Attend workshops and collaborate with agricultural extension services to improve your soil management techniques [42,43].

16. **Conservation Tillage:** Consider adopting conservation tillage practices like strip-till or ridge-till, which disturb the soil less than traditional tillage methods.
17. **Agroforestry and Agroecological Approaches:** Incorporate trees, shrubs, and diverse cropping systems to improve soil health, biodiversity, and resilience [44,45].

2.10 Nutrient Management Practices

- ✓ **Balanced Fertilization:** Applying the right nutrients in the right amounts is essential. The 4Rs approach (Right source, Right rate, Right time, Right place) ensures efficient nutrient use.
- ✓ **Organic Matter Management:** Incorporating organic matter through crop residues or organic amendments enhances soil health. It improves soil structure, water retention, and nutrient availability.
- ✓ **Crop Rotation:** Crop rotation helps break pest and disease cycles and can improve nutrient management by diversifying nutrient demands.
- ✓ **Cover Crops:** Planting cover crops during fallow periods or between cash crops can improve soil health. They protect against erosion, enhance organic matter, and fix nitrogen.
- ✓ **Reduced Tillage:** Reducing tillage minimizes soil disturbance and maintains soil structure, which is particularly important for soil health.
- ✓ **Nutrient Application Technologies:** Using precision technologies for nutrient application ensures even distribution, reducing overuse and environmental impact [46,47].

2.11 Challenges and Solutions

1. **Nutrient Pollution:** Excessive nutrient application can lead to nutrient runoff, causing water pollution. Precision nutrient management and controlled-release fertilizers can mitigate this issue.
2. **Soil Erosion:** Erosion depletes topsoil and reduces soil health. Conservation practices like terracing and contour farming can mitigate erosion.
3. **Soil Degradation:** Continuous monoculture and intensive farming practices can lead to soil degradation. Implementing crop rotation and organic matter management can help restore soil health.

3. CONCLUSION

Soil health and nutrient management are at the core of sustainable agriculture. Maintaining healthy soils through balanced fertilization, organic matter management, and conservation practices is essential for long-term food security and environmental preservation. Farmers can ensure productive and sustainable agriculture for generations to come by understanding the soil ecosystem and implementing best practices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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