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One Health Approach-Role of Soil Microbes in Food Security and Climate Change

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The idea of "One Health" highlights how human, animal, plant, and environmental health are all intertwined within shared ecosystems. Food security, environmental resilience, and human well-being are all directly impacted by soil health, which is a crucial component of sustainable agriculture. Soil functions are linked to One Health objectives because healthy soils control water, cycle nutrients, maintain biodiversity, and supply clean air and water. Soil bacteria are essential to these processes because they drive biogeochemical cycles, promote plant growth, prevent disease, and slow down climate change by reducing greenhouse gas emissions and sequestering carbon. Biofertilizers enhance the physical, chemical, and biological characteristics of soil microbiomes, which are crucial for sustainability and productivity. This paper examines how important soil bacteria are to preserving soil and environmental health, protecting food systems, and preserving human health. It demonstrates how sustainable soil management may solve global issues like nutritional security, antibiotic resistance, and climate change by fusing microbial ecology with One Health viewpoints.

Introduction

The Food and Agriculture Organization of the United Nations (FAO) defines the One Health framework as "an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems." This holistic viewpoint acknowledges the interdependence of animal, plant, and environmental health with human health. In this relationship, soil health becomes essential to both agricultural output and ecological stability.
Soil is a living system whose physical, chemical, and biological properties collectively determine its capacity to sustain plant and animal life, regulate water, cycle nutrients, and support biodiversity. Management practices and land-use decisions profoundly influence these functions, making soil health a prerequisite for sustainable crop production and environmental quality. Microorganisms inhabiting the soil are particularly significant, as they mediate nutrient cycling, enhance plant growth, suppress pathogens, and contribute to climate resilience through carbon sequestration and greenhouse gas mitigation.

The relevance of soil bacteria to One Health is highlighted by their interconnectedness with food production and human health. In addition to maintaining crop yields and soil fertility, microbial processes also guarantee clean water, lower chemical inputs, and improve nutritional security. Additionally, microbial inoculants and biofertilizers provide sustainable substitutes for synthetic inputs, promoting robust agroecosystems. Soil microbial communities offer a natural answer to global health and sustainability issues in light of climate change and growing worries about antibiotic resistance.

This paper examines the role of soil microbes in maintaining soil and environmental health, securing food systems, and promoting human wellbeing. By situating microbial functions within the One Health paradigm, it aims to demonstrate how soil biology can be harnessed to achieve sustainable agriculture, ecological balance, and improved public health outcomes.

What is One Health?

According to the Food and Agriculture Organization of the United Nations (FAO):
One Health is "an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems."
It recognizes that the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent.

Soil Health

Soil health is the ability of a living soil to support plant and animal health, maintain or improve water and air quality, and sustain plant and animal productivity within natural or controlled ecosystem bounds. A balance between soil functions for productivity, environmental quality, and plant and animal health—all of which are significantly impacted by management and land-use choices—is necessary for optimal soil health.
Instead of concentrating on just one function, like crop productivity, good management strategies that take soil health into account must take into account all functions .Consequently, the close ties that soil microbes have with plants and animals strongly imply that they play a significant role in soil health.
Soil health depends on the physical, chemical and biological properties or composition of the soil, which are interrelated. soil health is the prerequisite for sustainable crop production.

Key Functions of Healthy Soil:

1. **Regulates water**: By regulating how rain and irrigation seep into the ground, soil functions as a natural water regulator. In addition to directing extra water through drainage to avoid flooding or waterlogging, it stores moisture inside its pores, making it available for crops during dry spells. In order to promote healthy growth and preserve ecological stability, this regulator makes sure that the water supply and plant requirements are balanced.
2. **Sustains life**: Provides nutrients and habitat for plants, microbes, and animals. Healthy soils provide clean air and water, abundant crops, productive grazing lands, and diverse wildlife — directly linking soil health to food security and One Health goals.
3. **Cycles nutrients:** This process breaks down complicated substances into simpler forms that crops may easily absorb, such as nitrogen, phosphorus, and potassium. Healthy plant development and soil fertility are maintained by this ongoing recycling of nutrients.
4. **Supports biodiversity**: Soil is a living ecosystem that sustains enormous biodiversity. These microscopic and macroscopic organisms work together to create intricate food webs that power vital functions including the decomposition of organic materials, the cycling of nutrients, and the prevention of illness.Soil supports agricultural productivity and preserves ecological balance.

Environmental Health

Environmental health is the area of public health that examines how human health is impacted by environmental elements such food, soil, water, air, and climate. Its main goals are disease prevention and the creation of environments that support wellbeing .

Core Areas of Environmental Health

1. **Air quality**: Managing pollutants that cause respiratory and cardiovascular diseases.
2. **Water and sanitation**: Ensuring safe drinking water and preventing waterborne diseases.
3. **Food safety**: Preventing contamination and ensuring nutritional security.
4. **Soil and land use**: Reducing exposure to toxins and supporting sustainable agriculture.
5. **Climate change**: Addressing health impacts of extreme weather, vector borne diseases, and heat stress.

How microbes maintain environmental health ?

1. Nutrient cycling & ecosystem stability

2. Support plant diversity
3. Helps in waste management

Human Health

Human health is "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity".

Human health is directly influenced by:

1. Air, water, soil quality
2. Food production systems

Link between Soil Health and Human Health

Healthy soils are essential for human health because they provide the foundation for nutritious food, clean water, and a stable environment.

1. **Nutritious food:** Crops with higher nutritional densities are produced by soils rich in organic matter and microbial diversity, which lowers the risk of hunger and micronutrient deficiencies.
2. **Clean water:** Healthy soils prevent drinking water sources from becoming contaminated by filtering pollutants and controlling water flow.
3. **Disease prevention**: Soil bacteria reduce pesticide use and human exposure to hazardous chemicals by suppressing plant diseases.
4. **Climate resilience**: Soil carbon sequestration reduces the effects of climate change, which would otherwise raise health hazards such heat stress and vector-borne illnesses.
5. **Antimicrobial resistance contro**l: In line with One Health's objectives to limit antibiotic resistance that endangers human health, sustainable soil management minimizes the abuse of agrochemicals.

Food Security

Based on the World Food Summit 1996, food security is defined when all people, at all times, have physical and economic access to sufficient safe and nutritious food.

Why Soil Microbes Matter for Food Security?

Soil Microbes Are Fundamental to Soil Health

1. Nutrient cycling (breaking down organic matter into plant-available nutrients)
1. Nitrogen fixation, making atmospheric nitrogen available to crops
2. Improving soil structure and water retention
3. Suppressing soil pathogens naturally
4. These microbial processes help maintain soil fertility and boost yield potential

Microbes Help Sustain Food Production

Healthy microbial communities directly support plant growth by:

- Enhancing nutrient uptake and root development
- Producing natural plant hormones
- Protecting plants from disease through competition and natural antibiosis
- They can also help restore degraded soils, making agriculture more resilient in the long term

Microbes in Major Biogeochemical Cycles

Nitrogen Cycle- Nitrogen-fixing bacteria such as *Rhizobium* and *Azotobacter* convert atmospheric nitrogen (N_2) into ammonia, making it available to plants. *Nitrosomonas* oxidizes ammonia to nitrite, while *Nitrobacter* converts nitrite to nitrate in the nitrification process. Denitrifying bacteria like Pseudomonas reduce nitrate back to N_2, completing the cycle.

Phosphorus Cycle-Phosphate-solubilizing microbes such as *Bacillus* and *Pseudomonas* release organic acids that convert insoluble phosphates into bioavailable forms. Fungi like *Rhizopus* mineralize organic phosphorus compounds, sustaining plant nutrition.

Sulfur Cycle-Bacteria such as *Thiobacillus* oxidize sulfide and elemental sulfur into sulfate (SO_4^{2-}), which plants can use. Sulfate-reducing bacteria like *Desulfovibrio* convert sulfate into hydrogen sulfide under anaerobic conditions.

Carbon Cycle-Decomposer microbes (fungi and bacteria) break down organic matter, releasing CO_2 into the atmosphere. Methanogenic archaea produce methane in anaerobic environments, while methanotrophic bacteria consume methane, reducing greenhouse gas emissions. Mycorrhizal fungi enhance soil carbon sequestration, storing carbon in stable forms.

Microbes in Plant Growth Promotion

Plant Growth-Promoting Rhizobacteria (PGPR) enhance root development, nutrient uptake, and stress tolerance. PGPR (Plant Growth-Promoting Rhizobacteria) produce auxins, cytokinin, and gibberellins that stimulate root elongation and shoot growth. Mycorrhizal fungi improve drought resilience and nutrient efficiency, contributing to stable yields under climate stress.

Microbes in Disease Suppression

Soil microbes compete with pathogens, produce antifungal metabolites, and induce systemic resistance in plants. This reduces crop losses and minimizes pesticide use, aligning with One Health goals of reducing chemical exposure. Beneficial microbes such as bacteria, fungi, and endophytes can suppress plant pathogens by competing for nutrients, producing antimicrobial compounds, triggering plant immune responses.

Soil Microbes in Mitigating Climate Change

From a climate change perspective, soil microbes play a dual role in regulating greenhouse gas dynamics. Microbial activities influence carbon sequestration through the stabilization of soil organic carbon, while also mediating emissions of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Microbes also play a climate change mitigation role by sequestering carbon into stable organic matter and reducing greenhouse gases like methane and nitrous oxide through methanotrophs and complete denitrification Sustainable soil management practices that support diverse and functional microbial communities—such as conservation agriculture, organic amendments, crop diversification, and reduced tillage etc. Can enhance carbon storage, reduce emissions, and increase climate resilience of agricultural systems.

Conclusion

The One Health framework emphasizes that human, animal, plant, and environmental health are inseparably linked. Soil microbes are the hidden drivers of this connection. Soil microbial communities regulate nutrient cycling, enhance soil fertility, suppress pathogens, and improve crop resilience—making them indispensable for food security. Adoption of biofertilizers, composting, and integrated microbial management ensures sustainable agriculture, healthier soils, and safer food systems. Thus, strengthening soil microbial diversity is not only an agricultural strategy but a global health imperative, aligning with the One Health vision of sustainable ecosystems, resilient food systems, and reduced environmental burden.

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