**CONTRIBUTION OF SOIL MICROORGANISMS IN UPKEEPING SOIL HEALTH**

**Abstract:**

Soil is a finite and non-renewable natural resource and is a beautiful gift of nature to humankind. However, soil health deterioration is of great concern for human, animal, and plant health today. Air, groundwater, and surface water consumed by humans can be polluted by mismanaged and contaminated soil. Adverse impacts of intensive agriculture include loss of biodiversity, nitrogen discharges into surface and groundwater, eutrophication of surface water, contamination of groundwater from pesticides and nitrate, and ammonia volatilization due to overuse or indiscriminate use of manure and fertilizers. Therefore, soil protection is a high priority, and a thorough understanding of ecosystem processes is critical in ensuring that soil remains healthy. Soil health is defined as the continued capacity of soil to function as a vital living system,within the ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health. The biological components consisting mainly of soil microorganisms can make up only a very small fraction of topsoil volume. However, soil microorganisms play a major role in nutrient (N, P, S) cycling and decomposition of organic matter. Thus, healthy soil can be identified by measuring soil microbial population dynamics. The changes in microbial populations and their activities in various soil conditionsare excellent indicators of change in soil health. The bioavailability of chemicals is also an essential issue for soil health. The impact of such substances on soil health is dependent on microbial activities. This paper will discuss the role of soil microorganisms in maintaining and sustaining soil health in this paper.

**Keywords:** Soil microbes, soil health, nutrient cycling, biological indicator

**Introduction:**

Soil is a fundamental resource base for agricultural systems and the primary medium for plant growth. Soil functions to sustain crop productivity, maintain environmental quality, and support animal and plant life. Soil, a vital non-renewable natural resource base for crop production, is under competitive demand for increased crop production to feed our ever-growing population.However, high input agricultural practices often deteriorate biological, physical, and chemical soil properties. As a result,crop productivity and soil fertility declinehas been reported in different parts of the country, particularly in the intensively cultivated areas. Soil degradation and the concomitant decline in soil fertility is often emphasized as constraints to crop productivity. This degradation has been attributed to various biotic and abiotic stresses inflicted on soil due to high input agriculture. As a result, soil health or quality has emerged as the key or cornerstone for examining and integrating relationships and functions among various biological, chemical and physical parameters of soils, which are important in sustainable land use and management. Therefore, soil protection is a high priority and a thorough understanding of ecosystem processes is a critical factor in ensuring that soil remains healthy. Soil health is defined as the continued capacity of soil to function as a vital living system within the ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and to maintain plant, animal, and human health (Doran and Safley, 1997). Soil is dominated by a solid phase consisting of particles of different sizes surrounded by water and gases, the amount and composition of which fluctuate markedly in time and space. There is a continual interchange of molecules and ions between solid, liquid, and gaseous phases which are mediated by physical, chemical, and biological processes (Doran and Parkin,1994). These processes represent a unique balance between physical, chemical, and biological components (Doran and Parkin,1994). Maintaining this balance is of great importance to soil health. The biological features consisting mainly of soil microorganisms can make up only a tiny fraction of topsoil volume. However, soil microorganisms play a major role in nutrient (N, P, S) cycling and decomposition of organic matter. Microorganisms have the capacity to indicate good soil health. The changes in microbial populations and their activities in various soil conditions act as an excellent indicator of change in soil health. The bioavailability of chemicals is also an important issue of soil health. The impact of such chemicals on soil health is dependent on microbial activities. With this background, a detailed discussion is made to study the role of soil microorganisms in maintaining and sustaining soil health.

**Soil microorganisms and their role in soil:**

The major part of soil biomass consists of bacteria, fungi, protozoa, and algae. There is an enormous number of species in each of these groups.

Bacteria are by far the most prevalent type of organism in the soil. They were the earliest form of life on earth, and as such, have evolved to be a vital component in the life cycle of the soil. Bacteria are one of the first organisms to begin decomposing residues in the soil, making previously locked-up nutrients available to plants. Bacteria also play a role in nutrient retention in the soil. Bacteria help to retain nutrients that might otherwise be lost from the soil through leaching or nutrient runoff. It has been found that per every gram of soil there are around 110 bacteria. Bacteria, having varied metabolic activities, play a major role in the global cycling of N, P and S by utilizing their capacity to use various energy sources and carbon present in the soil.

There are two main categories of bacteria - aerobic and anaerobic. Aerobic bacteria thrive in well-oxygenated environments and tend to be the more beneficial type of bacteria, helping with decomposition, bioremediation, and the suppression of disease organisms. Anaerobic bacteria live in oxygen-depleted environments and tend to be pathogenic or disease-causing themselves.

A group of bacteria known as the actinomycetes is able to break down a molecule called lignin, which is found in plant tissue, especially stems, and is difficult for most organisms to break down. Actinomycetes are very important for the decomposition of organic compounds including cellulose, chitin and recalcitrant substances such as humic acids. Its population varies from 105 to 108 per gram of soil.

Some types of bacteria also function to convert nitrogen in the atmosphere to a biologically-available form that plants can use to make amino acids and proteins. Since nitrogen is one of the most important compounds for the growth of plants, without a healthy population of nitrogen-fixing bacteria in soil, the yield and quality of a farmer’s crop are likely to suffer. Symbiotic associations of plant roots and bacteria are the keys to biological nitrogen fixation in soil.

The Rhizobium fixes atmospheric nitrogen by a symbiotic association with the roots of leguminous plants. Actinomycetes of the genus Frankia perform many functions in improving soil health by creating a symbiotic association with nonleguminous plants. Azotobacter, Azospirillum, and Bacillus, free-living bacteria, also have a good role in improving soil health by contributing minute quantities of N to soil

Much like bacteria, fungi play an active role in supporting the health of soils in a field or farm. Fungi function as decomposers, nutrient cyclers, soil structure builders, and beneficial symbionts in the soil food web. Fungi contribute around 70% of soil microbial biomass with a number of 104 to 106 per gram of soil. They can be free-living or can produce and exploit a diversity of substrates in soil either with mutually helpful or parasitic association with plant roots.

Mycorrhizal fungi play a vital role in improving soil health by acting as mediators of transporting relatively immobile nutrients like P and Zn. Mycorrhizal fungi form a symbiotic association with plant roots.

Algae are single-celled, thread-like photosynthetic organisms that inhabit moist soils. Algae is also very important in maintaining soil health. Algae create soil by forming carbonic acids that cause rocks to weather. Once resultant bits of minerals combine with dead algae, this process eventually creates soil. Algae can also excrete polysaccharides, mucilage, and slimes, which help to build soil structure by binding and aggregating soil particles. Algae can also help to repair compacted soils by forming air passageways through the soil. Nitrogen input into soil is also made by the blue-green algae as they have the capacity to fix nitrogen from the air into the soil. The range of the algal populationis 10 -106 per gram of soil. Because of their photosynthetic capacity, they increase the organic carbon content of the soil, and also conserve soil structure by producing various extracellular polymers.

Protozoa and nematodes are the major components of the soil microfauna which feed on bacteria and fungi and are also responsible for the recycling of various nutrientsin the soil. Protozoa are single-celled organisms that, in most cases, obtain their nutrients by ingesting bacteria and fungi and, on rare occasions, other protozoa. All protozoa require a moist habitat. By consuming other microorganisms, particularly bacteria and fungi, protozoa help to keep microbial populations in balance, make nutrients that were locked up inside of bacteria and fungi available to plants, and assist in the process of decay. Their populations range from 10 to 106 per gram of soil. In spite of their small contribution (~5%) to the total soil microbial biomass, they are also important ecologically because of their rapid turnover rates and mineralization of nutrients, especially N and P.

Nematodes also play a vital role in maintaining soil health. They are nonsegmented, blind roundworms that act as major consumers in the soil food web.Nematodes eat bacteria, protozoa, algae, and other small members of the soil food web such as slugs. Some species of nematodes are parasites of plants and animals but the majority of nematodes play an important role in nutrient cycling processes. They take their food from organisms that recycle organic matter.

Soil fauna is an integral part of living soil, which performs a variety of functions in soil. Not all groups of soil fauna are equally important in terms of agricultural production and soil health. Invertebrate groups like earthworms, termites, ants, nematodes, etc. are thought to be the most important biotic components of the living soil. Ants, termites, millipedes, adult, and larval insects, earthworms, and snails are the most important soil macrofauna and they have an important role in maintaining soil health. Through their feeding habits and their movement into the soil, they help redistribute organic residues in the soil profile. With an increasing number of ants, termites, and earthworms in the soil structure becomes good through the formation of soil macropores and stable soil aggregates which in turn influence water and nutrient infiltration onto the soil. Some of the organic ‘binding agents’ produced by soil biota are responsible for good friable soil structure. Individual soil particles as well as their small aggregates are bound together into larger units by fungal hyphae and fibrous plant roots. Soil microorganisms play a dominant role in nutrient cycling in soil by the decomposition of organic materials and are also responsible for mineralization and transformations of organic forms of nutrients into available inorganic forms.

Earthworms are the most important soil invertebrates in most soils worldwide, in terms of both biomass and activity (Rombke et. al. 2005). They help in organic matter or litter degradation, soil bioturbation, water infiltration, and much more.

**Soil health:**

Soil health is defined as the continued capacity of soil to function as a vital living system, within the ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health (Doran and Safley, 1997). Healthy soil is living soil. The concept of soil health/qualitythus includes at least four components. The components can be presented schematic (Fig. 1) as follows:

### Soil Productivity

Food quality/ Safety

Human/Animal Health

Environmental Quality

Fig. 1. Components of soil health

Soil health refers to “the ability of the soil to achieve its full potential and be productive under the intended land use” and “healthy soils have favourable physical, chemical and biological properties that promote plant health and maintain environmental quality”. Biological soil characteristics which indicate the population and activity potential of soil microorganisms provide life to the soil and are the most important among the three attributes of soil quality/health. The biological health of soil can easily be assessed by its microorganism population dynamics as well as by smell and feel of the same. Usually, soil with high organic matter content indicates healthy soil.

Some of the soil characteristics expected in healthy soil include:

* Good soil tilth
* Sufficient depth
* Sufficient but not an excess supply of nutrients
* Small population of plant pathogens and insect pests
* Good soil drainage
* Large population of beneficial organisms
* Low weed pressure
* Free of chemicals and toxins that may harm the crop
* Resistant to degradation
* Resilience when unfavourable conditions occur

**Indicators of soil health:**

Indicators of soil health are dynamic soil properties that are very sensitive to land management, natural disturbances, and chemical contaminants. Doran and Safley (1997) and Pankhurst et al. (1997) suggested that an indicator, regardless of its nature, must fulfilled the following criteria: 1) be interpretable; 2) correlate well with ecosystem processes; 3) integrate soil physical, chemical, and biological properties and processes; 4) be accessible to many users, and 5) be sensitive to changes. In addition, an indicator must have reproducibility, low temporal and spatial variability, and simple sampling and analytical methods.

In soil quality assessment, different attributes of soil viz., physical, chemical, and biological are assessed. Again, within each category of attributes, a number of parameters, namely under physical - bulk density, maximum water holding capacity, mean weight diameter etc.; similarly, under chemical - pH, organic carbon, available N, P and K, micronutrients, heavy metals etc., and under biological - microbial biomass C and N, soil enzymes, mineralizable C and N, soil biodiversity, soil microorganism populations and their activity etc. are analyzed/estimated/measured.

**Microorganisms as indicators of soil health:**

It is not possible to select a single species as a sole indicator of the biological status of the soil. However, the abundance and activity of a number of individual organisms may give some indication of the health of the soil. The abundance of earthworms (which is relatively easy to count in the soil in comparison to assessing the abundance of many other soil animals or bacteria and fungi) in soil may appear to be an easy measure of the biological fertility of the soil. Similarly,the abundance of many species of bacteria isa useful indicator of soil biological fertility as they are involved in most biological processes in soil. The presence of rhizobia can be used as an indicator that symbiotic nitrogen fixation will occur. A measure of the abundance of fungi and their capacity to function within the ecosystem could also be included in a suite of biological indicators.

The status of the health of soil can be indicated by its microorganism’s population dynamics. Microorganisms can respond quickly to changes and at the same time have the ability to adapt to various adverse environmental conditions. The microorganisms which are best adapted will flourish more than the others. This adaptation potentially allows microbial analyses to be discriminated in soil health assessment, and changes in microbial populations and activities may therefore function as an excellent indicator of change in soil health (Kennedy and Papendick, 1995). Higher organisms respond very slowly to any environmental degradation/stress compared to soil microorganisms. Pankhurst et al. (1997) reported that any change in either physical or chemical properties can be predicted by its alteration in microbial population dynamics and ultimately give an indication of either enhancement or deterioration of soil health.

The bioavailability of chemicals, e.g. heavy metals or pesticides, is also an important issue for soil health because of its connection with microbial activities. The impact of such chemicals on soil health is dependent on microbial activities.

A microbial indicator is defined as a microbial parameter that represents properties of the environment (state variables) or impacts on the environment, which can be interpreted beyond the information that the measured or observed parameter represents by itself.

Microbial indicators of soil health cover a diverse set of microbial measurements due to the multi-functional properties of microbial communities in the soil ecosystem. Bacteria, fungi, and protozoa indicators are grouped according to the different soil health parameters of the ecosystem like biodiversity, carbon cycling, nitrogen cycling, biomass, microbial activity, key species, and bioavailability. The indicators are related to the ecosystem (e.g. processes), community (e.g. biomass and biodiversity), or population (e.g. species or functions) levels.

**Indicators of biodiversity:**

Information about microbial diversity and their community structure is noted as an important indicator for understanding the relationship between environmental factors and ecosystem functions (Torsvik*et al.* 1996).

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| Endpoints | Soil ecosystem parameter | Microbial attributes |
| Soil ecosystem healthSoil microbial communityhealth | Biodiversity | Genetic diversityFunctional diversityStructural diversity |

**Indicators of carbon cycling:**

A major activity of soil microorganisms is organic matter decomposition. Soil microorganisms are in general heterotrophic and rely on the input of carbon energy from outside the microbial community. Organic matter in soil is largely derived from higher plants consisting of cellulose (15-60%), hemicellulose (10-30%) and lignin (5-30%). Indicators of carbon cycling represent measurements at the ecosystem level.

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| Endpoints | Soil ecosystem parameter | Microbial indicators |
| Soil ecosystem healthSoil microbial community health Atmospheric balance | Carbon cycling | Soil respirationOrganic matter decompositionSoil enzymesMethane oxidation |

**Indicators of soil biomass:**

Soil biomass means the biomass of bacteria, fungi, actinomycetes etc. Visser and Parkinson (1992) opined that “biomass is fundamental for soil processes to occur and quantification of microbial biomass is as such a measurement at the ecosystem level”.

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| Endpoints | Soil ecosystem parameter | Microbial indicators |
| Soil ecosystem health | Soil biomass  | Microbial biomassProtozoan biomass |

**Indicators of nitrogen cycling:**

The mineralization of soil organic nitrogen (N) through nitrate to gaseous N2 by soil microorganisms is a very important process in global N-cycling.

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| Endpoints | Soil ecosystem parameter | Microbial indicators |
| Soil ecosystem healthPlant healthLeaching to groundwaterSurface run-offAtmospheric balance | Nitrogen cycling | N-mineralisationNitrificationDenitrificationN-fixation |

**Indicators of microbial activity:**

Indicators of microbial activity in soil represent measurements of processes regulating decomposition of organic residues and nutrient cycling, especially nitrogen, sulphur, and phosphorus.

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| Endpoints | Soil ecosystem parameter | Microbial indicators |
| Soil ecosystem healthSoil microbial communityhealth | Microbial activity | Bacterial DNA synthesisBacterial protein synthesisRNA measurementsBacteriophages |

**Key species:**

Microbial key species in soil are the organisms that perform important functions in the soil ecosystem like nutrient cycling, plant pathogenesis etc.Key indicator species represent measurements at the population level. A number of criteria have to be fulfilled for key species to be useful in a monitoring programme, e.g., they should be ecologically relevant, preferably abundant, and easy to enumerate and identify (Oberholzer and Hoper2001).

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| Endpoints | Soil ecosystem parameter | Microbial indicators |
| Soil ecosystem healthPlant healthAnimal healthHuman health | Key species | MycorrhizaSuppressive soilHuman pathogens |

**Indicators of bioavailability of nutrients/chemicals**:

Chemical compounds may be adsorbed to soil clay particles and made unavailable to the soil biota. The bioavailable concentration of any compounds or nutrients in the soil may be equal to or lower than the total chemically extractable concentration. However, from the environmental point of view, the bioavailable fraction of a chemical compound may be a more relevant parameter than the chemically extractable fraction. Microorganisms can measure the bioavailability of a chemical compound in soil and such indicators of bioavailability represent normally the measurements at the community and population levels.

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| Endpoints | Soil ecosystem parameter | Microbial indicators |
| Soil microbial community healthLeaching to groundwaterSurface run-off | Bioavailability | Biosensor bacteriaPlasmid-containing bacteriaAntibiotic-resistant bacteriaCatabolic genes |

**Conclusions:**

Soil is a finite and non-renewable natural resource and is a wonderful gift of nature to humankind. However, deterioration of soil health is of great concern today for human, animal, and plant health. For the maintenance of soil health, its protection is very much essential. There are large numbers of microorganisms in the thin layer of the soil surface. Despite their small volume in soil, they play key roles in the decomposition of soil organic matter, nutrient cycling, soil pollutant degradation, and the formation and stability of soil structure. They adapt to changes in their environment, such as stress due to drought, flooding, substrate or food shortages, and contaminants. Soil biota also responds rapidly to soil management and land use changes and can be candidates for soil health/quality indicators. Good soil health can be indicated by its microorganism’s population dynamics. The changes in microbial populations and their activities in various soil conditions act as an excellent indicator of change in soil health. The bioavailability of chemicals is also an important issue of soil health. The impact of such chemicals on soil health is dependent on microbial activities.

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