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MICROBIAL CHARACTERISTICS OF SOIL: A TOOL FOR QUALITY ASSESSMENT AND SUSTAINABLE AGRICULTURE

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Abstract: *Soil microorganisms have significant role in plant micro and macro nutrient cycling. These microorganisms flourish in soils, which serve as an energy source for themselves. They decompose soil organic residues including manure, plant residue, pesticides and other pollutants which overall improves the soil health and increases soil nutrient levels. The organic remains are thus transformed by microbes either to biomass or mineralized to carbon dioxide, water, nitrogen, phosphorus and additional nutrients. Without soil microorganisms, insects and other animals, plant materials would accumulate in the environment which may cause several hazards. Further, the soil microbes have a significant role in nutrient cycling and in maintaining soil fertility, soil structure, aeration, physical property and water holding capacity. These microorganisms can also interact with the atmosphere. Some can serve as nucleating agents, whereas others can degrade airborne pollutants. Thus the microbial quality of soil play important role in sustainable agriculture.*

Keywords: *Soil, plant, nutrient, pesticide and agriculture.*

Introduction: Soil is the upper layer of earth in which plants grow. It is a black or dark brown material typically consisting of a mixture of organic matter, clay, rock particles, minerals, gases, liquids, and microorganisms that together support life. Soil microorganisms are an important parameter because they affect soil structure, properties and fertility [1]. It is believed that between two and four billion years ago, the first ancient bacteria and microorganisms came about in Earth's oceans. These bacteria could fix nitrogen and also released oxygen into the atmosphere. Soil microbes can be classified as bacteria, actinomycetes, fungi, algae and protozoa. Each of these groups has their characteristics functions in soil and they overall helps to keep on increasing soil fertility and make agriculture sustainable [2, 3]. These organisms thrive in soils, which serves as a resource of nutrient and energy for them. Soil microbes are mostly saprophytes and obtain carbon and energy from the organic matter and grow. After their death and decomposition, they liberate plant nutrient elements hooked with organic matter.

Most of the soil microorganisms are associated with the surfaces, and these surfaces influence the microbial use of nutrients and interaction with plants and with other living organisms. Soil pores can protect bacteria from predation. Soil microorganisms also interact with the atmosphere by serving as nucleating agents that can increase precipitation. Some soil microorganisms also can degrade different gaseous pollutants. They play major roles in the dynamics of greenhouse gases such as carbon dioxide, nitrous oxide, nitric oxide and methane. Microbes can contribute to both the production and consumption of these gases.

Micro-organisms, including fungi and bacteria, effect chemical exchanges between roots and soil and act as a reserve of nutrients in a soil biological hotspot called rhizosphere. In 2011, a team detected more than 33,000 bacterial and archaeal species on sugar beet roots [3]. The composition of the rhizobiome can change rapidly in response to changes in the ambient condition. Rhizobiome supports healthy plant growth. Plants can form new chemicals that can break down minerals, both directly and indirectly through mycorrhizal fungi and rhizosphere bacteria, and thus improves the soil structure [4].

The growth of roots stimulates microbial populations in the soil, stimulating in turn the activity of their predators (e.g. amoeba), thereby increasing the mineralization rate and it also turns the root growth, which is an indication of positive association and the soil microbial loop is formed. In the bulk soil, most bacteria are in a dormant stage, forming microaggregates, i.e. mucilaginous colonies to which clay particles are glued, offering them a protection against desiccation and predation bysoil microfau na (bacteriophages, protozoa and nematodes).

Soil health is an important parameter that indicates soil quality and soil microorganisms is an important factor to measure it, and the information obtained cannot be attained with any physical/chemical means as well as diversity analyses of higher organisms [5]. Microbes can rapidly adapt to various environmental conditions because they quickly respond to ecological changes. Microorganisms which are best adapted propagate well and their population increases. Such adaptation potentially allows microbial analyses for the assessment of soil health, and changes in microbial populations and activities may therefore function as an excellent indicator of change in soil health. In comparison to higher organisms, microbes also act rapidly in response to any environmental pressure as they have intimate relations with their surroundings due to their high surface to volume ratio. In some instances, changes in microbial populations or activity can precede detectable changes in soil physical and chemical properties, thereby providing an early sign of soil improvement [3].

Soil Health Assessment: Soil health, also referred as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. It describes the position of soil fertility and productivity as well as importance of managing soils so they are sustainable for future generations. The type and population of microorganisms is significant indicator of soil health [6,7]. For this, we need to remember that soil contains living organisms that when provided the basic necessities of life i.e. food, shelter, and water, they perform functions required to produce healthy and productive plants.

Only "living" things can have health, so viewing soil as a living ecosystem reflects that soil is not inert growing medium, but rather harbours bacteria, fungi, and other microbes that are the basis of soil microenvironment and symbiotic ecosystem [8]. Soil is an ecological unit that provides nutrients for plant growth, absorb and hold rainwater for use during dryer periods, filter and buffer potential pollutants from leaving our fields, serve as a firm foundation for agricultural activities, and provide habitat for soil microbes to flourish and diversify to keep the ecosystem running smoothly [7]. The microorganisms and minerals in soil are responsible for filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposits. The diversity and productivity of living things depends on soil quality. The carbon, nitrogen, phosphorus, and many other nutrients are stored, transformed, and cycled in the soil with the help of soil microbes.

The presence of pollutants such as heavy metals, pesticides, organic contaminants, etc. and their bioavailability is of great concern for soil health because they are associated with soil microbial activities [9]. The impact of such chemicals on soil health is dependent on the types of microbes present. Many of the soil microbes are resistant to these contaminants/ pollutants and hence promote their bioremediation from toxic to less or non toxic form and hence improve the soil quality [10]. Also, the total concentration of heavy metals in soil may not change over time periods, but their bioavailability to the plants may change [11]. For example the chromium present in the environment is the sum of hexavalent [Cr(VI)] and trivalent [Cr(III)] forms. However, the hexavalent chromium species and dichromate’s are extremely water-soluble, dominant and mobile in the environment, whereas, the Cr(III) species are less soluble and comparatively immobile and less toxic [12]. Further, due to high permeability of Cr(VI) through biological membranes it subsequently interacts with intracellular proteins and nucleic acids. Moreover, Cr(VI) is recognized to be highly toxic, carcinogenic, mutagenic and teratogenic for mammals including humans.

Due to carcinogenicity and mutagenicity of chromium, the United States Environment Protection Agency (USEPA) has designated chromium as a “Priority pollutant” or Class A” pollutant. Presence of chromate in the environment inhibits most microorganisms but also promotes the selection of resistant species. Microbial detoxification of toxic Cr(VI) to the less toxic Cr(III) by indigenous microbes offers an eco-friendly and cost–effective alternative for bioremediation of chromate contaminated wastes. Microbes bioremediate Cr(VI) either by bioreduction, biosorption or bioaccumulation. Therefore, in the soil, when analysed, the bioavailability of total chromium [i.e. Cr(VI) + Cr(III)] might be same but it may differ in the individual concentration of Cr(VI) and Cr(III). Therefore, the total content of chemicals in the soil is not a reliable indicator of its bioavailability and thereby soil health. Instead, bioavailability has to be measured in relation to bioassays and specific microbial processes.

In soil, the microbial activity is mainly present in the upper layer of soil i.e. from surface to ~25 cm approximately because there is more food source as compared to the subsoil. In this region, the microorganisms occupy small portion of the entire soil volume and makes <12% of the total soil organic matter. In spite of their less number in soil, these microbes have significant role in nitrogen, sulphur, and phosphorus cycle, and in the organic matter decomposition. Also, the microbial decomposition of dead plant and animal organic matter adds energy into the soil ecosystem. The organic remains are thus transformed either to biomass or mineralized to carbon dioxide, water, nitrogen, phosphorus and additional nutrients. Moreover, they also affect carbon, oxygen and nutrient cycle globally. Mineral nutrients encapsulated within microbes are then released and are used by plants. Microbes are also responsible for the conversion and decomposition of organic and inorganic waste substances and release nutrients and energy for plant growth as well as affect the soil physical properties [13]. Further, the extra-cellular polysaccharides produced by microbes and other cellular remains help in maintaining soil structure, because they act as binding force and make the soil aggregates stable. In this way soil microbes also indirectly contribute in maintaining/ enhancing soil water holding capacity and rate of infiltration.

Soil Microorganisms: In the soil, sometimes microorganisms live as single cells or they may also form colonies of cells. Microbes are mostly abundant in the area immediately next to plant roots (rhizosphere), where sloughed-off cells and chemicals released by roots provide ready food sources. These organisms are primary decomposers of organic matter, but they do other things, such as provide nitrogen through fixation to help growing plants, detoxify harmful chemicals (toxins), suppress disease organisms, and produce products that might stimulate plant growth [8]. Soil microorganisms have role in human life because of being important source of most of the antibiotics.

Soil microorganisms are classified as bacteria, actinomycetes, fungi, algae and proto zoa. Each of these groups has characteristic function in the soil. Among all, bacteria and fungi are relatively present in high population depending on the soil conditions [14, 15]. The degree of acidity present and the types of residues added will determine the relative abundance of these two major groups of soil microbes. Soils that are disturbed regularly by intensive tillage tend to have higher levels of bacteria than fungi. Similar situation is with flooded soils, because fungi can't live without oxygen, while many species of bacteria can. Soils that are not tilled tend to have more of their fresh organic matter at the surface and thus have higher levels of fungi than bacteria. Also, in comparison to bacteria higher levels of fungi may occur in acidic soils.

Bacteria: Bacteria are the most profused microorganisms in the soil, and have many important functions, including nitrogen fixation. One of the most eminent features of bacteria is their biochemical flexibility. The genus *Nitrobacter* can derive its energy by turning nitrite into nitrate. *Pseudomonas* can metabolize wide range of chemicals and fertilizers. *Pseudomonas aeruginosa* and other species are able to respire both aerobically and anaerobically, using nitrate as the terminal electron acceptor. The genus *Clostridium* is a very good model of bacterial versatility because it can grow anaerobically. Some nitrogen-fixing bacteria form mutually beneficial associations with plants. One such symbiotic relationship that is very important to agriculture involves the nitrogen-fixing rhizobia group of bacteria that live inside root nodules of leguminous plant. These bacteria provide nitrogen in a form that leguminous plants can use, while the legume provides the bacteria shelter and sugars for energy. There are some types of bacteria that are able to take nitrogen gas from the atmosphere and convert it into a form that plants can use it to make amino acids and proteins. Further, bacteria are the first organisms that decompose soil residues and in this way bacteria benefit plants by increasing nutrient availability. Many bacteria, for example, dissolve phosphorus, making it more available for plants to use. Bacteria also significantly participate in enzymatic transformation and energy generation, sulphur oxidation, nitrification, denitrification, organic matter transformation, etc. They overall play an important role to increase the soil fertility, plant growth promotion, and suppression of phytopathogens for development of ecofriendly sustainable agriculture.

There are many beneficial free-living soil bacteria usually referred as plant growth-promoting rhizobacteria (PGPR) that promotes the plant growth in two different ways, indirectly or directly [8]. The direct promotion of plant growth by PGPR entails either providing the plant with a compound that is synthesized by the bacterium, for example phytohormones, or facilitating the uptake of certain nutrients from the environment [14]. The indirect promotion of plant growth occurs when PGPR lessen or prevent the deleterious effects of one or more phytopathogenic organisms. This can happen by producing antagonistic substances or by inducing resistance to pathogens. PGPRs colonize the rhizosphere, the rhizoplane (root surface), or the root itself (within radicular tissues). Bacteria of diverse genera have been identified as PGPR, of which *Bacillus* and *Pseudomonas* spp. are predominant [15].

Actinomycetes: Actinomycetes are soil microorganisms, bacteria sharing some characteristics with fungi such as shape and branching properties, spore formation and secondary metabolite production. They break large lignin molecules into smaller sizes. Lignin is a large and complex molecule found in plant tissue, especially stems which is difficult for most organisms to break down. Lignin also frequently protects other molecules like cellulose from decomposition. Actinomycete helps in decomposition of soil organic matter and liberation of its nutrient and thus promotes plant growth. Resistant compounds such as cellulose, chitin and phospholipid are reduced by actinomycetes into their simpler forms and hence can be easily utilized by plants. Actinomycetes can also decompose different green manure, hedge, sludge, silage, compost and animal manure at high temperature [3]. Soil actinomycetes are the source of most of the antibiotic and thus have a direct importance for humans to cure from disease.

Fungi: Fungi are another type of soil microorganism that dominates next to bacteria. Mycorrhizal fungi help the plants to take up water and nutrients, improve nitrogen fixation in legumes, and help to form and stabilize soil aggregates. Studies indicate that using cover crops, particularly legumes, between main crops helps to maintain elevated level of spores and promotes good mycorrhizal growth in the subsequent crop. Roots that have lots of mycorrhizae are better able to resist fungal diseases, parasitic nematodes, drought, salinity, and aluminum toxicity. Mycorrhizal associations stimulate the growth of the free-living nitrogen-fixing bacteria *Azotobacter*, which in turn also produce plant growth–stimulating chemicals. Fungi also initiate the decomposition of fresh organic residues. They help get things going by softening organic debris and making it easier for other organisms to join in the decomposition process. Fungi are also the main decomposers of lignin and are less sensitive to acid soil conditions than bacteria.

Algae: Algae being photoautotrophic convert sunlight into complex molecules like sugars, which they can use for energy and to help build other molecules they need. Algae dominantly grow in the flooded soils of swamps and rice paddies, and they can be found on the surface of poorly drained soils and in wet depressions. Such soil surfaces appear as a green mat. Algae may also occur in relatively dry soils, where they form mutual beneficial relationships with other organisms e.g. lichens which are also found on rocks are an association between a fungus and an alga. Algae are also capable of performing nitrogen fixation and hence promote plant growth. The amount of nitrogen they fix depends more on physiological and environmental factors rather than the organism's abilities. These factors include intensity of sunlight, concentration of inorganic and organic nitrogen sources and ambient temperature and stability.

Protozoa: Protozoa are unicellular organisms that use a variety of means to move about in the soil. Like bacteria and many fungi, they can be seen only with the help of a microscope. They are mainly secondary consumers of organic materials, feeding on bacteria, fungi, other protozoa, and organic molecules dissolved in the soil water. Protozoa through their grazing on nitrogen-rich organisms and excreting wastes are believed to be responsible for mineralizing (releasing nutrients from organic molecules) much of the nitrogen in agricultural soils.

Conclusion: Soil microorganisms are important because they affect soil structure and fertility. The soil microbes can be classified as bacteria, fungi, actinomycetes,
algae and protozoa. Each of these groups has characteristics that define them and have significant role in enhancing soil quality that supports healthy plant growth. Also, the composition of soil microbes changes in response to the change in the surrounding environment. Microorganisms can make nutrients and minerals in the soil available to plants, produce hormones that prompt growth, stimulate the plant immune system and trigger or dampen stress responses. In general, a more diverse soil microbiome results in fewer plant diseases and higher yield. Many soil microbes enhance soil aggregation and porosity, thus increasing infiltration and reducing runoff.

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