Microorganisms for Sustainability 4
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Upendra Kumar *Editors*

Advances in Soil Microbiology: Recent Trends and Future Prospects

Volume 2: Soil-Microbe-Plant Interaction

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Microorganisms for Sustainability

Volume 4

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Advances in Soil Microbiology: Recent Trends and Future Prospects

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Chapter 1
Soil Microbial Diversity: An Ecophysiological Study and Role in Plant Productivity

Bighneswar Baliyarsingh, Suraja Kumar Nayak, and Bibhuti Bhusan Mishra

Abstract Soil is considered as one of the most competent ecosystems for subsistence of microorganisms. Soil microbial community structure and activity depend largely on structure and status of the soil habitat. Diverse heterotrophic microbial communities in soil along with their complex web of interaction facilitate the cycling of micro- and macro-nutrients in soil ecosystem. The demand of sustained plant productivity is achieved through managing soil fertility. The dynamic relationships between different components, living or nonliving, of agroecosystem control the richness of plants or crops. In turn, soil organic matter is influenced by the inputs from plants and also their chemistry makes each ecosystem somewhat unique in its microbial community. Though the role of soil microbiome is widely known, we still have a limited understanding of its complexity. Thus, understanding the microbial diversity will enhance our ability of increasing agricultural production.

Keywords Soil microbiology · Soil microbial habitat · Plant-soil microbial interaction · Microbial diversity · Soil fertility

1.1 Introduction

In the recent past, growing understandings on the potential of microorganisms have given much emphasis to explore and study the active microbial population inhabiting the soil. Since the beginning of the nineteenth century, soil

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microorganisms have gained importance as the driver of biochemical processes that are beneficial to ecosystem. These microorganisms carry out different processes of decomposition of organic substances, transformation of elements, and also recycling of nutrients that are essential for growth of animals, plants, and crops. Some soil-inhabiting microorganisms are, however, injurious to plant and animal life, acting as pathogens affecting the host directly or releasing toxic substances in the soil ecosystem. A better understanding of the soil microbes is thus important to interpret their impacts on agriculture and environment. Hence, the soil microbiologists are not only focusing on diversity of microbes in soil but also their interaction with the environment as well as with other organisms.

1.2 Historical Perspectives of Soil Microbiology

During the mid-nineteenth century, studies of microbiologists like Louis Pasteur, Selman Waksman, and Sergei Winogradsky led the foundations for the modern soil microbiology research. Among various discoveries by Winogradsky, the father of soil microbiology, some of the notable studies are the sulfur cycle, role of CO_2 and inorganic ions on microbial growth (chemoautotrophy), and nitrification. He was also honored by naming one of the nitrifying bacteria species as *Nitrobacter winogradskii*. Nitrogen fixation can be accomplished by nonsymbiotic bacteria which was first suggested by Berthelot in the late nineteenth century. Soil microbes bring about the mineralization of litters and make easy availability of the essential nutrients for the growth and development of plants and animals. It was also emphasized that the addition of stable manure to the soil is more effective than to direct addition of inorganic nutrients.

The fixation of nitrogen by leguminous plants is one of the most important and well-studied microbial process. Studies on soil fungus and bacteria involved in nitrification and denitrification and chemical transformations of nitrogen in soil along with in composts, laid foundation for the modern era of soil microbiology, and all these processes have direct effect on plant growth and productivity. The overall relationship of soil microbial population with that of soil fertility also gave rise to the concept of inoculating desired microorganisms to soil (Kuramae et al. 2012).

Apart from agronomic importance of soil microbes, in 1939 S. Waksman and Rene Dubos found a soil actinobacteria (formerly actinomycete) *Streptomyces* sp., with antibiotic properties. Waksman was awarded Nobel Prize in 1952 for the findings on antimicrobial properties of soil microbes. Studies on the actinobacteria of the soil by Krinsky, Conn, Waksman, and Curtis, by Melin and Hayner on mycorrhizal fungi, and on the soil protozoa by Cutler widened the purview of soil microbiology. Since their discovery, soil microbes are widely studied and applied to various realms of human endeavors (Balser et al. 2010).

1.3 Habitat of Soil Microorganism

Soil is not an inert material but a dynamic and most biodiverse ecosystem as it is home to several thousand different species of organisms/microorganisms. The population, composition, and activities of soil microbes are influenced by their soil habitat. Cultivated lands are rich in organic matters and contain much higher microbial population than sandy or eroded soils. Within this habitat, the soil microbes respire, compete for food, cooperate among themselves, and respond to the changes in their inhabiting environment.

Typically, differing sizes of soil aggregates and soil pores constitute the soil microbial habitat (Sylvia et al. 2005). The texture and soil types influence the composition and population of microbial community and vice versa. Some soil microbes secrete polysaccharides, gums, and glycoproteins, which glue soil minerals together, forming the basis for soil structure. Further, fungal hyphae and plant roots bind soil aggregates together that provide favorable environment for plant growth. Rudakov (1951) suggested that active humus play an important role of cementing the soil particles into aggregates. The soil cementing substances are mostly composed of (1) compounds of uronic acids, (2) bacterial proteins or products of their lytic activities, and (3) lysates of fungal cultures and/or colloidal protein compounds synthesized by soil bacteria.

Similarly the diversity of soil microbial community is influenced by physical parameters like temperature, humidity and seasonal variations (Lipson 2007), soil acidity or alkalinity (pH), oxygen levels, and availability of nutrients. The soil fertility can be indirectly correlated with the overall microbial biomass which depends on availability and quality of carbon, termed as soil organic carbon (SOC). The amount of SOC available within the initial 1m depth of soil is more than two to three times the carbon amount present aboveground (Brady and Weil 2002). Thus most biologically active region of the soil is believed to be the upper 20–30 cm of soil where abundance of soil microbial communities are present due to rich SOC (Fierer et al. 2007; Jobbágy and Jackson 2000; Veldkamp et al. 2003). Carbon availability often declines with depth, as does overall microbial biomass. Also many microorganisms exist in topsoil having rich carbon sources, than in the subsoil. They are especially abundant in the area close to plant roots (called the rhizosphere), where sloughed-off cells and root exudates provide carbon sources. It is established that there is decrease in fungal-to-bacterial ratios with increase in depth. Approximately 3×10^4 bacteria, 1.5×10^5 fungi, 6×10^4 algae, 1×10^4 protozoa, 5×10^5 nematodes, and 3×10^4 earthworms are estimated to be present in the soil (Pankhurst 1997).

Soil fertility is one of the significant parameters of natural or managed agroecosystem to achieve sustained productivity. To access the soil quality, changes in chemical, physical, and biological properties are monitored which are the indirect measure of productivity and diversity. Biological indicators considered to access soil quality are microbial biomass, soil respiration, soil enzyme activities, earthworm numbers, etc. The metabolic quotient ($q CO_2$) is the estimate of the amount of CO_2-C released per unit of microbial biomass in time that represents the thriving status of the soil microbes. Besides, biochemical indicators such as microbial enzymes are also useful in understanding soil fertility. The biological reactions most commonly studied were metabolism of nitrogenous compounds which includes ammonification, nitrification, denitrification, and the fixation of nitrogen. Microbial indicators have advantage in forecasting early to any changes in soil quality as it is being susceptible to minor changes in ecosystem.

In addition to structural diversification of soil microbes, soil organisms are naturally active during certain period of the year. Most are active when the soil is warm and moist, like during late spring and early summer. Moreover minerals, aggregation of the soil particles, and soil porosity influence diversification of bacterial community in soil microhabitats (Certini et al. 2004; Carson et al. 2007). The uniqueness of each soil ecosystem is due to typical microbial communities performing diverse activities and multifaceted interactions with their habitat (Wixon and Balser 2009) (Fig. 1.1).

1. The soil microbes provide basic macroelements of nutrition, viz., carbon, nitrogen, and phosphorous for growth and development of plants.
2. The microorganisms show indirect way of controlling the production and regulation of growth-specific phytohormones.
3. Symbiotic association with plants or plant parts (e.g., leguminous plant roots) is maintained by very special group of microbes.
4. Not all soil-dwelling microbes show beneficial interaction; some have harmful effects on higher plants. The microbes either show competition for uptake of basic nutrients from the soil or depend on the higher plants as parasites or attacking them by producing toxic chemicals.
5. Indirect injury to plant growth is observed when various bacteriophages feed on useful bacteria.
6. On the other hand, the immediate vicinity of plant parts creates a microenvironment to the microorganisms for their growth and proliferation.
7. The plant residues and root exudates are the rich source of nutrients, consumed by the microorganisms.
8. Plants metabolites may have antagonistic effects on the growth and sustainability of microorganisms.

Various groups of bacteria, fungi, and actinobacteria either penetrate the roots of plants and live there or live in close proximity of the root system. The concept of the "rhizosphere" is introduced to assign the close association between soil microorganisms and the root systems of higher plants. The "root region" encompasses both the root surface and the rhizosphere which are the zones of high microbiological activity. Typically this type of association may be considered as midway between true symbiosis, observed between root-nodule bacteria with the leguminous plants and the phenomena of parasitism. Accumulation of manure, lowering of the concentration of certain mineral nutrients, partial desiccation of the soil, and increase in soil carbonates following root excretion are the major causes of rhizosphere effect. The tuberization and protein formation in certain seeds in plants are

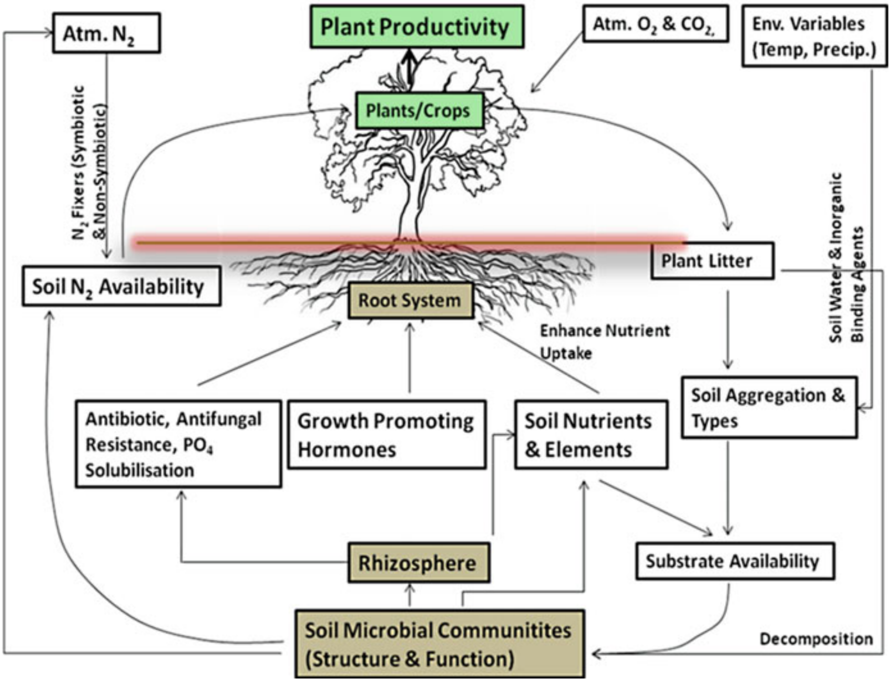

Fig. 1.1 Dynamic interactions between microbes and plants

induced by some fungi. Garrett (1951) emphasized the necessity to distinguish between rhizosphere effects and typical characteristics of living roots with that of the diseased root microenvironment.

The diversified soil microbes play pivotal roles in an array of terrestrial ecosystem functions such as nutrient recycling, sustaining plant growth, water purification, carbon storage, maintenance of soil structure, degradation of xenobiotics, nitrogen fixation, or competitor for pathogens to successfully establish desired microbial populations (Insam 2001). Similarly, the decomposition and nutrient recycling are carried out by diverse group of microbes in a cascading network of chemical process. By decomposition processes, soil microbes liberate simpler carbon compounds, nitrogen, CO_2, and minerals from dead organic material which are ultimately consumed by higher plants.

The decomposition carried out by soil microbes is either aerobic (aerobic bacteria and fungi) or anaerobic microbes. The aerobic decomposition of plant residues by the microbes produces humic acid in the soil. The abundance of humic acid and fulvic acid facilitates the gluing properties of humus. In addition, various protopectinase enzymes were produced by soil microbes like sporogenous *Bacilli*, *Bacillus polymyxa*, *B. radiobacter*, *B. mycoides*, *B. laterosporus*, and *Clostridium macerans*. Some fungi also take part in the decomposition of plant residues by producing the humic acids. *Trichoderma lignorum*, *Mucor intermedius*, and

Mortierella isabellina are few examples of fungi, mostly involved in the process of soil structure formation (Harris et al. 1966).

The solubilization of soil minerals, especially the carbonates, phosphates, and zeolites, is carried out by microorganisms with the help of CO_2; nitrous, nitric and sulfuric acids; and organic acids. Soil toxins constitute the toxins produced from soil microbes as a result of their activities. Thus the soil solution represents very dynamic part of the soil where most of the biochemical processes occur. The fouling properties of soil can be treated with heat, volatile antiseptics, or simple lime to increase productivity. Reports indicate that the germination of plant seeds and seed growth is favored by the soil microorganisms. For example, rapid evolution of CO_2 by microbial respiration creates anaerobic conditions unfavorable to oxidation and favorable for germination. Recent studies depict that microorganisms may produce hormones and/or similar substances which promotes plant growth.

1.4 Influence of Plants on Soil Microorganisms

Although, there are few experimental investigations that suggest the influence of plant diversity on soil microorganisms (Bargett and Shine 1999; Wardle et al. 1999; Stephan et al. 2000), there are reasons to expect that plant diversity can affect microbial population in the soil ecosystem. It is due to the lack of experimental procedure to accesses the direct influence of the growing plant or plant products on soil microbes. Mostly the effect of plants on soil microbes is studied indirectly by (a) measuring the numbers of microorganisms, (b) nitrifying and denitrifying capacity of the soil, and (c) oxidizing power of the soil in terms of aeration or CO_2 production. The effects of growing plants on the structure and function of soil microorganisms can be represented as:

1. The growth of soil bacteria and fungi is favored by the soluble organic and inorganic compounds like formic, oxalic, and malic acids, certain reducing and nonreducing sugars, phosphatides, and various nitrogenous compounds secreted by the plants.
2. In addition to these plants in the form of dead roots and root hairs, epidermal cells and other waste products help the growth of microorganisms.
3. Various soil minerals, including nitrates, phosphates, and potassium salts, are continuously removed by the growing plants resulting in change in soil solution and modification of microbial activities.
4. Plants excrete considerable CO_2 into the soil which increases the solubility of certain inorganic soil constituents and thereby changing the composition of the soil atmosphere.
5. Soil porosity and structure are modified and affected by the plant diversity.
6. Sometimes, plants can hinder the growth of soil microbes by removing a considerable amount of moisture from soil.

Feedback mechanisms between plant and microbial communities control the richness of plant species and productivity. For example, soil bacteria are stimulated by cowpeas, field peas, vetch, and soybean. Among the bacteria, particularly, the *Radiobacter* sp. increased in number when legumes are cultivated. In contrast, continuous production of single type of plant in a soil leaves residues that may result in a change in the chemical composition of the soil leading to microbial disequilibrium. This is evident from the fact that the pathogenic fungi population increases in soil habitat by continuous farming of wheat, flax, or clover. While the alfalfa roots have only a slight stimulating effect upon filamentous fungi, the eggplants had a significant effect (Starkey 1931). A range of stimulatory effects on soil microbes by cultivation of alfalfa, rye, and vetch plant are observed ranging least on actinobacteria, slightly on fungi, and highest toward soil bacteria.

1.5 Microbial Diversity and Soil Biological Processes

Soil is reckoned as a storehouse of microbial activity, though the space inhabited by active microorganisms is approximately less than 5% of the total occupied area. Despite their small volume, soil microorganisms are key players in the global cycling of organic matter, reworking organic residues or mineralizing them to CO_2, H_2O, N_2, P, S, and other nutrients (Table 1.1). Hence, soil microbes are playing the most vital role in plant growth regulation and contributing thereby to the interdependence of diversity – fecundity (Pradhan et al. 2014; Mitchell 2003; van der Heijden et al. 2008). Major microbiological activity is confined to the clusters of accumulated organic matter and rhizosphere. Thus, there is a growing demand to study on microbial community composition in various microhabitats in nature.

The soil as a habitat exhibits utmost variability leading to adjacent microhabitats differing widely in their physical and chemical properties. Diversified heterotrophic microbial communities residing in soil control the ecosystem carbon (C) and nitrogen (N) cycling (Fig. 1.2) through various processes that control ecosystem and represent a potential mechanistic link in between plant diversity and ecosystem function. The growth-limiting resource availability plays a key role in determining biotic community composition (Tilman 1982, 1987). The resource availability for soil microbial communities is incarcerated through organic compounds in litters which can be used for cellular energy generation (Smith and Paul 1990). Changes in plant diversity could alter the yield as well as the range of organic compounds that limit and thus control the composition as well as microbial community function.

1.5.1 Bacteria and Actinobacteria

The sustainability of soil function is the result of bacterial diversity. Endemism and clonality, which have an intrinsic spatial dimension (Grundmann and Normand

Table 1.1 Major roles of diverse soil microorganisms

Domain/phylum/ group of microorganism	Important species	Association with host	Major role of these species/ strains	References
Archaea	*Nitrososphaera viennensis*, *Methanosarcina* sp., *Methanosaeta* sp.,	No association	Contributing to ammonia oxidation in soil	Aislabie and Deslippe (2013)
			Weathering minerals as well as nutrient cycling in soil	
			Carry out N_2 fixation	
			Curtailment of atmospheric N_2 to NH_4^+	
Bacteria	*Rhizobium* sp., *Bradyrhizobium* sp., *Mesorhizobium* sp.,	Symbiotic	Fixation of atmospheric nitrogen in leguminous plant in root nodules	Giordano and Hirsch (2004)
			Present inside the host root system	
	Pseudomonas sp., *Bacillus* sp., *Klebsiella* sp., *Azotobacter* sp., *Azospirillum* sp., *Azomonas* sp.	Asymbiotic	Fixes atmospheric nitrogen usable form such as ammonia	Glick et al. (1999)
			Remain in close proximity of root system	
Actinobacteria	*Arthrobacter* sp., *Rhodococcus* sp.,	No association	Fixation of atmospheric nitrogen	Ahemad and Kibret (2014);
	Streptomyces sp., *Rubrobacter* sp., *Terrabacter* sp., *Acidimicrobium* sp., *Chloroflexi* sp., *Planctomycetes* sp., *Gemmatimonadetes* sp.		Solubilization of minerals	Bhattacharyya and Jha (2012) and Franco-Correa and Chavarro-Anzola (2014)
	Micromonospora sp., *Streptomyces* sp., *Streptosporangium* sp., *Thermobifida* sp.,	No association	Antagonistic efficiency against different fungal root pathogen	
	Frankia sp., *Nocardia* sp. *Kitasatospora* sp.,	No association	Efficient IAA producers (plant growth hormone)	
Verrucomicrobia	*Methylacidiphilum SolV*, *Methylacidiphilum Kam1*, *Verrucomicrobium spinosum*	No association	Nitrogen fixation and associative activity	Wertz et al. (2012)

Yeast	*Kluyveromyces waltii*, *Sccaromycopsis cataegensis*, *Pachytichospora transvaalensis Rhodotorula* sp., *Azotobacter* sp., *Cryptococcus* sp., *Lipomyces* sp., *Meyerozyma* sp.	Various association	Utilization of bacterial, plant root exudates for synthesis of plant protectants and other useful substances involved in plant growth	Vishniac (1995), Cho et al. (2001), Nakayan et al. (2009)
			Known producers of extracellular polymeric substances	
			Produces xylitol, phosphate solubilization and associated activities, and soil aggregation	
Cyanobacteria	*Nostoc* sp., *Anabaena* sp., *Leptolyngbya* sp.	Symbiotic and nonsymbiotic	Improved the soil C, soil N, and exopolymeric substance contents of the soil	Bano and Iqbal (2016)
			Releases amino acids and proteins, polysaccharides and carbohydrates, vitamins, and phytohormones as elicitor molecules for plant growth promotion	
			Increases resistance of plants against biotic and abiotic stresses	
Fungi	*Phoma* sp., *Trichoderma* sp., *Penicillium* sp., *Rhizoctonia* sp., *Pythium* sp.	Various association	Improve plant growth	Murali et al. (2012), Whipps (2001) and Mauchline et al. (2002)
			Induce systemic resistance (ISR) against plant pathogens	
			Enhances biomass production and promotes lateral root growth	
			Niche exclusion, antibiosis, predation, mycoparasitism, and ISR induction	

(continued)

Table 1.1 (continued)

Domain/phylum/ group of microorganism	Important species	Association with host	Major role of these species/ strains	References
AMF	*Acaulospora morrowiae*, *Glomus etunicatum*, *Rhizophagus irregularis*, *Gigaspora rosea*		Increases the soil nutrient availability	Ellouze et al. (2014) and Love-lock et al. (2004)
			Increase yield by enhancing host resource uptake by sharing	
			Improved water relations and increases antagonistism against plant pathogens	
			Phytoremediation of polluted soil	

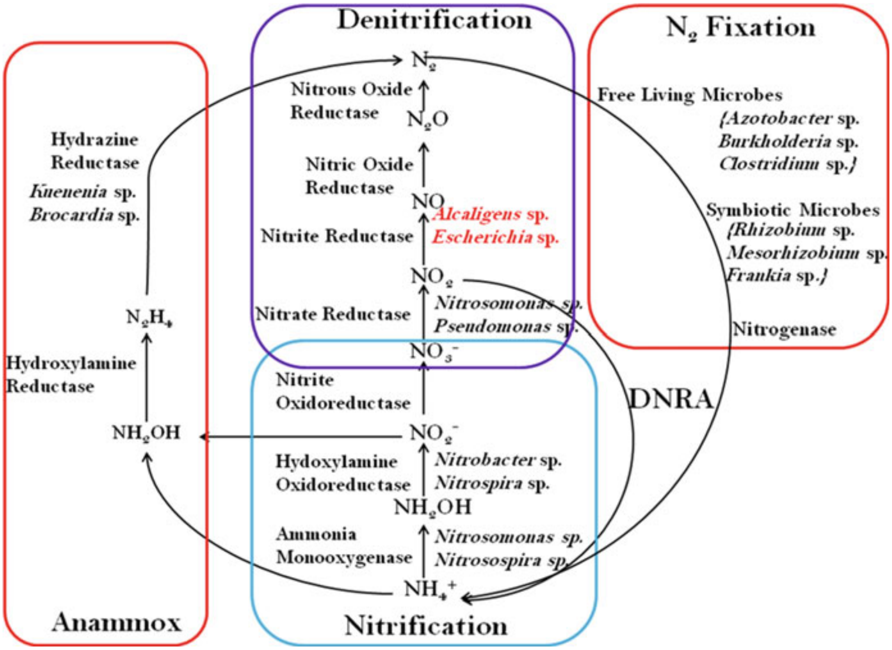

Fig. 1.2 Soil microbes involved in biological nitrogen cycles

2000), may have significant implications in soil function. Soil texture influencing bacterial community structure, even if the change is minor and with unchanged mineral composition of soil, probably results in the scattered arrangement of bacteria (Hattori and Hattori 1976). Bacterial diversity and community structure are influenced by a range of physicochemical properties of the soil matrix, including pore size, particle size, and the availability of water and carbon (Carson et al. 2009). At low pore connectivity, the maximal bacterial diversity is probably mediated by lots of interacting factors which favors the coexistence and decreases the competitive interactions (Carson et al. 2010).

Actinobacteria, being a slow grower in the soil, may colonize roots slowly but successfully. Mostly bacteria and actinobacteria bring rhizospheric change through altering the composition of small molecules like sugars, amino acids, fatty acids, flavonoids, and strigolactones leading to significant modification in the plant (Badri and Vivanco 2009) phenology. In turn, microbes inhabiting the rhizosphere release phytohormones, small molecules, or volatile compounds and regulate plant growth and root morphogenesis (Castro-Sowinski et al. 2007).

1.5.2 Fungi

Several advanced, independent soil microbiological methods for charactering the microbial biomass and soil microbial community structure uncovered that living and dead soil bacteria were associated with the clay fraction, whereas lower eukaryotes as fungi and their exoenzymes involved in the degradation of complex organic compounds were found in association with soil particulate organic matter. The plant species richness is also positively correlated with arbuscular mycorrhizal fungi (AMF) richness (Klironomos et al. 2000). AMF contribute positively to the plant productivity due to diverse relationship with increase in soil microbial diversity leading to an increase in per capita plant productivity (van der Heijden et al. 2008). The soil health is benefited by extensive mycelia networks of AMF with the glomalin secretion leading to the improvement of structural stability and quality of soil. At the instance of resource competition, AMF increases the yield by improving the resource uptake as phosphorous (P) along with carbon (C) and nitrogen (N) (Koide 1991). From an agroecological point of view, the ecological function imparted by AMF signifies the important impact these groups of symbiotic organisms have on the agricultural productivity and sustainability (Ellouze et al. 2014).

1.5.3 Archaea

There is abundant presence of archaea in soil, predominantly by the members of the phylum *Crenarchaeota*, mostly found and isolated below the topsoil. In general, these are grouped in the class of anaerobic soil microbes. Some members from *Euryarchaeota* phylum especially methanogens are active in the absence of O_2 created due to water logging (Angel et al. 2012). *Methanosaeta*, *Methanocella*, and *Methanosarcina* sp. comprising methanogens are widely found in soil microhabitat. Being strict anaerobes, they break down the organic molecules to CH_4 and CO_2 and participate in anaerobic food chain. Although, the pathways used by these methanogens for production of CH_4 from methylated compounds vary that include either reduction of CO_2 and methanol, cleavage of acetate, or reduction of methylated compounds from methane (Singh et al. 2017). Both *Methanosarcina* sp. and *Methanosaeta* sp. reduce acetate to produce methane. The oxidizing archaea like ammonia-oxidizing archaea (AOA) are more prominent at the subsoils (Di et al. 2010). Under high ammonia substrate concentrations, AOA dominates soil microbial community.

1.5.4 Cyanobacteria

In many agricultural fields, cyanobacteria are one of the vital inhabitants, where they efficiently contribute toward biological nitrogen fixation, help "P" solubilization, and improve crop productivity as well as soil fertility. The nitrogen-fixing cyanobacteria are helpful in crop production with saving partially or entirely mineralized nitrogen. Novel association between agriculturally important plants, N_2-fixing cyanobacteria, and cereal plants is now immerging (Spiller et al. 1993). Cyanobacteria, as inoculants in rice production, have enhanced soil fertility and improved soil structure, besides enhancing crop yields. Highest populations of *Anabaena* sp. (1×10^6 g^{-1} soil) and *Nostoc* sp. (9.1×10^4 g^{-1} soil) were recorded in paddy field soil, when supplimented with nitrogen. *Calothrix* sp., *Hapalosiphon* sp., and *Westiellopsis* sp. were among the other isolates from the rhizosphere region. Out of the nonheterocystous cyanobacteria from the rhizosphere, *Oscillatoria* sp. and *Phormidium* sp. were prevalent, but not in all rice cultivars, *Scytonema* sp. was found to be common in saline soil (El-Ayouty et al. 2012). Ninety-eight percent of Indian soils require inorganic phosphorus (chemical or biological) through phosphorus fertilization. Due to the low solubility and chemical fixation of phosphorus present in soil, only 0.1% is available to the crop plants. The soil microorganisms act as a biological combat system by solubilizing the insoluble inorganic phosphorous to its simplest form and making it available to the plants. The cyanobacteria involved in phosphate solubilization (PS) are *Anabaena* sp., *Calothrix* sp., *Nostoc* sp., *Scytonema* sp., and *Tolypothrix ceylonica*.

1.5.5 Yeast

Some selective variety of yeasts promote plant growth by means of pathogen suppression, phytohormone production, phosphate solubilization, N and S oxidation, siderophore production, and stimulation of mycorrhizal root colonization. Strains have been identified as biofertilizer yeasts (Eman et al. 2008). In vitro nitrification can be achieved through selective members of *Candida* sp., *Geotrichum* sp., *Rhodotorula* sp., *Saccharomyces* sp., and *Williopsis* sp. *Saccharomyces* sp. and *Williopsis* sp. were able to oxidize elemental sulfur in vitro for production of phosphate (PO_4^{3-}), sulfate (SO_4^{2-}), and tetrathionate ($S_4O_6^{2-}$) (Al-Falih and Wainwright 1995). Among yeasts, *Rhodotorula minuta*, *Saccharomyces cerevisiae*, and *Torula thermophila* cause inorganic phosphate solubilization. Other phosphate-solubilizing yeasts are *Hansenula* sp., *Klocker*a sp., *Rhodotorula* sp., and *Debaryomyces* sp., and the most efficient was *D. hansenii*. *Schwanniomyces occidentalis* exhibited PS activity on Mussoorie rock phosphate (Gaur 1990). Yeasts also synthesize antimicrobials and other metabolites required for plant growth, from polysaccharides and amino acids released by bacteria and root exudates. Yeasts are rich source of tryptophan a precursor of indole acetic acid (IAA) that stimulates cell elongation and division (Agamy et al. 2013).

1.6 Evaluation of Soil Fertility by Measuring Microbiological Activities

Various methods have been developed by researchers worldwide to determine the soil fertility on the basis of its microbiological activity.

1. A general mechanism of assessment of soil fertility is by adding moistened soil samples with 60 or 70% of water-holding capacity, with specific nutrient solution, followed by incubation at 20–30 °C for 7–30 days and observes biological changes.
2. The biological reactions involving metabolism of nitrogenous compounds are analyzed to evaluate the soil fertility. The common biological reactions like ammonification, nitrification, denitrification, and nitrogen fixation are used in soil fertility analysis.
3. The abundance of certain organisms in the soil and presence of other organisms can be examined by various microbiological culture methods. Measuring the changes in concentration of certain important plant nutrients in the soil with respect to microbial activity and abundance provides idea about soil fertility.

The major difficulty involved in the use of such methods is the dependency of soil microbial reaction on many variables in a natural scenario. This comprises of different intrinsic soil conditions, weather condition effects, and soil management.

1.7 Conclusion

Soil microbiology is a multidisciplinary branch of science which deals with the study of microorganisms associated with soil and their interaction. The soil, being the natural habitat for the survival and growth of microorganisms, has always given great emphasis to study its physicochemical and biological characteristic features. It is very important to understand the relationship of microorganisms with respect to higher plants as well as to exploit the ecto- and endo-microbial association for a sustainable soil microbial ecosystem. Soil microbiology defines a brief idea about microbes nurtured by nature and the chemical properties of the soil depending upon the geographical limits and climatic changes. It should make an exciting study in the field of agriculture and environmental sciences to create an intricate road map by extracting knowledge behind the complex microbiological activities, interacted with the environmental cues that would dramatically improve plant productivity and thus increase socioeconomical values.

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