Soil Community Composition and Ecosystem Processes

Arjita Punetha, Shailaja Punetha, and Amir Khan

Abstract Soil is defined as weathered rock material consisting of organic substances, minerals, air and water. Soil being a dynamic and large habitat sustains the growth of numerous organisms and endows us with innumerable functions. Soil can therefore be considered as a multi-habitat ecosystem rather than just a component of any ecosystem. Owing to its enormously high physical and chemical heterogeneity, soil hosts a multifaceted and varied biological community which offers myriad services to us. Right from soil formation to its management, soil community helps in weathering, nutrient cycling, water cycling, supporting agriculture, regulating climate, maintaining fertility and remediating the contaminants present in soil. However, anthropogenic activities like intensive agriculture, use of excessive chemicals and deforestation have significantly affected the soils and associated communities. Soil is the major hub of nutrients and water supply that directly govern the growth, nutrient status and productivity of crops thereby indirectly influencing the human health. Therefore, in order to maintain the proper functioning of soil and its community, soil restoration is the need of the hour. This requires reducing the use massive machinery for agricultural and other purposes, shifting to organic farming, syncing nutrient release and water availability with requirement of plants and monitoring the biological activity.

Keywords Soil microbial community · Soil management · Nutrient cycling

A. Punetha
CSIR-Central Institute of Medicinal & Aromatic Plants (CIMAP), Research Centre, Pantnagar, Uttarakhand, India

S. Punetha (✉)
GBPNIHE, Almora, Uttarakhand, India

A. Khan
Department of Microbiology, College of Basic Sciences and Humanities, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

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1 Introduction

Soils are a naturally produced intricate system made up of biotic and abiotic components that serve as the fundamental habitat for biological diversity and processes as well as a source of delivering a variety of ecosystem functions. The formation of soils takes place at the point of intersection of the lithosphere, biosphere, atmosphere and hydrosphere. The pedosphere (soil mantle of the Earth), which is made up of mineral, fluid, gaseous and biological elements, works as a facilitator of biogeochemical transformations and fluxes into and out of the contiguous spheres. Soils seem to be the most diverse natural material on the Earth and perhaps most crucial for human life because they impact food availability and its quality, purify and deposit water, detoxify pollutants and bring minerals and chemicals into human contact. Soils control most of the ecological processes in ecosystems and are home to a huge percentage of the world's biodiversity, and provide the structural foundation for a variety of human activities as well. Soils are a physically and chemically multifaceted ecosystem that supports a diverse microbiological and faunal taxonomic community. 10^9–10^{10} prokaryotic cells (bacteria and archaea), 10^4–10^7 protists, ~100 m of fungal hyphae and 10^8–10^9 viruses can be found in 1 g of surface soil (Srinivasiah et al., 2008, Bates et al., 2013; Bardgett & Van der Putten, 2014; Brady & Weil, 2014). In some soils, these values equate to prokaryotic biomass surpassing 5 tonnes per hectare, while fungal biomass ranges from 1 to 15 tonnes (Brady & Weil, 2014). These diverse communities of organisms perform vital roles in maintaining soil and ecosystem function, offering a slew of advantages to planetary cycles and human survival.

Numerous ecosystem activities are supported by the activities and dynamic interplay among soil organisms. Due to the several critical functions that soil performs, it is unquestionably one of the most important and strategic resources. Soil plays a pivotal role in (i) providing food, fibre and fuel; (ii) decay and decomposition of organic matter; (iii) recycling of vital nutrients; (iv) bioremediation of organic pollutants; (v) carbon capture and storage; (vi) regulation of water quality and its replenishment and (vii) habit formation for a wide range of organisms (Yang et al., 2020). Soil functions are dependent on soil features and interactions and are influenced by the use and management of soil. Various natural processes such as landslides and erosion diminish soil nutrients and biodiversity, eventually leading to soil degradation which poses a grave worldwide threat to food security and ecosystem sustainability (Godfray et al., 2010; Montgomery, 2010; Oldeman, 1998). Aside from this, anthropogenic activities such as the overuse of fertilizers and heavy equipment for agricultural purpose, livestock overgrazing and deforestation endanger the soil ecosystem's long-term sustainability. On a human life scale, soil is generally recognized as a non-renewable resource, since its recovery is an exceedingly sluggish process once it gets depleted (Camarsa et al., 2014; Lal, 2015). Considering the significance of soils for agriculture and livestock production, as well as delivering broader ecosystem services to local and global communities, retaining them in immaculate condition is crucial. In order to wisely manage the use of agricultural soils, decision-makers require science-based, convenient and cost-effective methods to analyze changes in soil quality and function.

2 Soil Organisms and Interlinkages Between Them

Soil harbors extremely rich and diversified biological community due to its exceptionally high physical and chemical variability at microscale and microclimatic properties that can support the establishment and maintenance of an enormously large number of niches (Tiedje et al., 2001; Ettema & Wardle, 2002). Based on their size, soil organisms are broadly classified as: microflora (1–100 μm, e.g. bacteria, fungi), microfauna (5–120 μm, e.g. protozoa, nematodes), mesofauna (80 μm–2 mm, e.g. collembola, acari) and macrofauna (500 μm–50 mm, e.g. earthworms, termites (Wall et al., 2001). The basic food web structure in soil is comparable to other food webs in that it also contains primary producers, consumers and detritivores, as in other food webs (Fig. 1). From the bottom to the top of the food chain, the number of soil organisms and their biomass per volume decreases by orders of magnitude. Soil food webs are perhaps more complex than other food webs, have longer food chains and greater cases of omnivory. Further, all fauna depend on primary producers (e.g. for litter). Debris of plants and other organic substances serves as habitat for soil organisms. Plants directly affect soil biota by producing organic matter above- and belowground and also indirectly influence soil organisms by providing them with shade, soil protection and source of water and nutrients. Energy and nutrients obtained by plants are ultimately integrated into detritus, which serves as the base of resources for a complicated soil food web.

Soil macrofauna disintegrate dead organic substance into smaller fragments, allowing soil bacteria and fungus to begin its degradation and convert it in the form of inorganic nutrients required for plant growth. This is followed by mineralization which is continued by organisms such as protozoa and nematodes that feed on bacteria and fungus, which are then eaten by first- and higher-order carnivores. Even in a distinct trophic classification, some species can be found "breaking the rules". Collembolans, for example, which are widely thought to consume fungus, include few species that feed on nematodes instead (Chamberlain et al., 2005). Studies indicate that soil ecosystems can have long and stable food chains unlike the other ecosystems which can generally sustain very small food chains. Digel et al. (2014), for example, evaluated food webs in 48 different forest soils comprising 89–168 species and discovered 729–3344 various feeding linkages. Unfortunately, our existing knowledge of trophic interactions is insufficient, and we require a more precise picture of the abundance and characteristics of prospective consumers at various trophic levels. For instance, viruses and enchytraeids are frequently overlooked out of these food web studies, and only mites and nematodes can be divided in distinct groups while diverse ecological groups of earthworms and collembolans are normally left out. This is significant since the presence or absence of a particular food source may alter the overall understanding of the soil food webs. Our

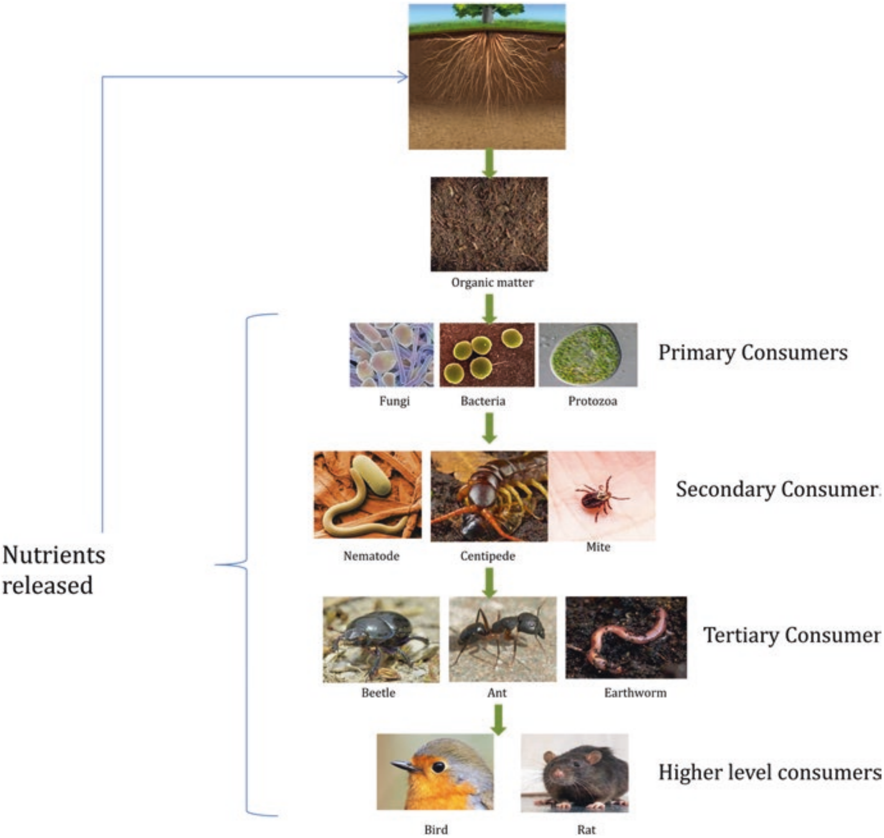

Fig. 1 Flow of energy between different trophic levels in soil ecosystem

understanding of nutrient cycles and flow of energy in the soil community and the linkage between dynamics of soil food chain and agro-ecosystem stability has been aided by soil food web analysis (Susilo et al., 2004; Van der Putten et al., 2004). Several obstacles are now inhibiting our ability to fully comprehend the performance of soil food webs, including (i) redundant nature of organisms (i.e. various organisms depending on same food source) and complement functional groups (Setala et al., 2005), (ii) the ability of certain soil organisms to keep changing their feeding sources or show diverse rate of feeding throughout their lifetime and (iii) density-dependent impacts on their feeding behavior (Kaneda & Kaneko, 2008). To offer a more realistic estimate of energy fluxes across the different trophic levels, they must all be included in food web analysis.

3 Ecosystem Services Provided by Soil and Soil Organisms

The organisms dwelling in the soil provide a number of functions to the other biota (Fig. 2). Services provided by soil organisms can broadly be classified into regulatory, supporting and provisional.

3.1 Regulating Services

Few of the regulatory services delivered by soil microorganisms chiefly involve the functions that ensure regulation of climate, water management and purification, disease and pest control and bioremediation of pollutants.

Fig. 2 Services provided by soil community

3.1.1 Climate Regulation

The biggest store of terrestrial carbon (C) reserves in the world is soil. Soils are a significant component of the global carbon cycle, containing both soil organic carbon (SOC) and soil inorganic carbon (SIC). Soil biodiversity is widely known for its function in limiting greenhouse gas emissions and regulating soil carbon storage (Jackson et al., 2017; de Graaff et al., 2015). The balance of C in soils is influenced by the interaction between climate, plant diversity and biodiversity of soil (Allison et al., 2010; Schimel & Schaeffer, 2012), and the short- and long-term fluxes and movements of carbon in and out of soils are ultimately controlled by the soil community.(Crowther et al., 2019). Litter breakdown and greenhouse gas emissions are also influenced by the soil community. Soil fauna enhance the surface area of litter by shredding leaves, which boosts the rate of its decomposition by microbes (Moore et al., 2004). The activity of earthworms can both stabilize soil C (Zhang et al., 2013) and augment greenhouse gas emissions (Lubbers et al., 2013) depending on the climate and conditions of local ecosystem.

3.1.2 Water Purification

Soil serves as a water purifier and reservoir, cleansing water as it flows through the soil and storing it for plant absorption. Better water infiltration also gives plants and soil organisms some additional opportunities to utilize dissolved and suspended nutrients like phosphates and nitrates, thereby lowering nutrient run-off into surface and groundwater. Phosphates and nitrates are recycled within terrestrial systems by the metabolic activity of soil microbes, which limits their export to aquatic systems (Elizabeth et al., 2020). Microorganisms play an important part in the filtration of water as it flows through soil because of their ability to breakdown a variety of pollutants. As an example, *Rhodococcus wratislaviensis*, a herbicide-degrading bacterium, has been found in soil as well as in groundwater samples that are contaminated with terbuthylazine indicating that it has the ability to detoxify contaminated soil and water systems. Additionally, soil microbes also have the ability to affect the quality and amount of soil organic matter, which can have an indirect effect on the rate of water infiltration (Turbé et al., 2010).

3.1.3 Disease and Pest Control

Biotic and abiotic components of soil can effectively inhibit plant diseases that are caused by soil-borne pathogens such as bacteria, filamentous fungus and oomycetes (Baker & Cook, 1974). Microbiota regulates the quality of soil organic matter (SOM) and availability of nutrients for plants growing in the respective soil, which is quite imperative for soil health maintenance (O'Donnell et al., 2005; Kibblewhite et al., 2008). Suppressive behavior is an inherent property of soil, which is widely recognized as a management technique for obtaining maximum agricultural output levels and ensuring low ecological footprints in systems that use intensive cropping techniques in presence of strong pathogen load (Kariuki et al., 2015). The biological activity of soil bacteria is thought to be the main mechanism driving this suppressive property of soil. Few examples of microorganisms that help in controlling of diseases include bacteria e.g. *Bacillus* and *Pseudomonas*, actinomycetes like *Streptomyces* and filamentous fungi such as *Trichoderma*, *Fusarium* and *Aspergillus*, which can elicit all mechanisms related to disease suppression and control.

3.1.4 Biodegradation of Organic Waste

One of the most serious risks to soil functions is pollution. Improper and unmanaged disposal of waste, industrial and mining activities, oil spills and agricultural practices are the main contributors of soil pollution. Microbial remediation of pollutants is recognized as a quick and cost-effective method that employs an extensive range of microbes to absorb organic contaminants as their carbon or nitrogen sources to support their growth (Chen et al., 2013; Mahmoud, 2016; Ortiz-Hernandez et al., 2018; Siles & Margesin, 2018; Zhan et al., 2018; Bhatt et al., 2020a). To support their growth and metabolic activity, microorganisms also use xenobiotic substances found in soil as their carbon or nitrogen sources (Mishra et al., 2021). Few examples of soil microorganisms involved in bioremediation of soil pollutants are bacteria like *Pseudomonas, Alcaligenes, Microbacterium, Methanospirillum, Bacillus, Sphingobium* and *Rhodococcus*, fungi such as *Aspergillus, Penecillium, Trichoderma* and *Fusarium* and yeasts like *Pichia, Candida, Aureobasidium* and *Exophiala* (Sathishkumar et al., 2008; Nzila, 2013; Sunita et al., 2013; Zhao et al., 2017; Bharadwaj, 2018; Yang et al., 2018a, b; Yu et al., 2019; Bhatt et al., 2020b). However, interaction between ecological parameters such as soil salinity, pH, temperature, carbon and nitrogen sources available and moisture content have significant impact on microbial biodegradation capacity (Megharaj & Naidu, 2010; Wu et al., 2014a, b; Bhatt et al., 2019).

3.2 Supporting Services

Supporting services are additional services which are not directly used by humans but are required for sustenance of ecosystem functioning. Soil microbial communities are involved in providing several supporting services such soil formation, nutrient and water cycling and primary production. In order to support and sustain plant growth, soil needs to be fertile and ensure sufficient supply of nutrients and adequate recycling of organic matter. Various species of bacteria and fungi are involved in the activities that lead to the breaking down and mineralization of nutrients and their cycling in the atmosphere. Soil microorganisms are identified as crucial drivers of plant diversity and primary production, and restoration of degraded terrestrial ecosystems can be done through manipulation of soil communities using microbes

(Wubs et al., 2016). A large portion of microbial diversity stimulates plant productivity through a variety of microbial methods. A variety of bacterial species including members of the *Actinobacteria, Proteobacteria* and *Firmicutes* genus have the ability to produce organic chemicals that affect plant root system proliferation (Haas & Defago, 2005; Doornbos et al., 2011). Soil microorganisms also help in nitrogen fixation. Symbiotic bacteria e.g. *Rhizobium* sp. and *Frankia* sp. and free-living bacteria such as *Azotobacter*, *Azospirillum*, *Bacillus* and *Klebsiella* spp. and some *Cyanobacteria* species notably add to atmospheric N fixation. Furthermore, numerous bacterial sp. like *Pseudomonas*, *Frankia* and *Streptomyces* and fungal sp. like *Aspergillus* have demonstrated the capability to create iron-chelating chemicals, hence boosting iron availability for plants. Siderophore-producing Streptomyces species have shown promise in biofertilization and microbial remediation of metal-contaminated soils (Dimkpa et al., 2008). Drought, excessive soil salinity, harsh temperatures, nutrient inadequacy and heavy metal toxicity can all be alleviated through plant–rhizobacteria interactions (Dimkpa et al., 2009). Identification of salt-and drought-tolerant microorganisms could be very useful in overcoming yield losses owing to water constraint around the world (Ali et al., 2014; Forni et al., 2017).

3.3 Provisioning Services

Provisioning services of soil refers to products formed by soil ecosystem services that can be brought to use by humans. Provisioning services encompass food, water, fibre, fuel, genetic resources, drugs and pharmaceuticals, all of which are derived from ecosystems. Soil bacteria are responsible for several of the benefits that soils offer to humans, including food production. This valuable soil service is produced by a healthy relationship between plants, microbes and soil, and humans rely on it for survival.

Many soil microbes assist the plants in obtaining inaccessible nutrients by transforming them into plant-available forms in exchange for energy from their host (Ango & Abdu, 2021). Several beneficial bacteria and fungi encourage plant growth by producing metabolites or by interacting physically with the host plant (Bender et al., 2016; Ragnarsdottir et al., 2015; Hayes & Krause, 2019). Antimicrobial agents and enzymes are also produced by soil microorganisms which are exploited in the field of biotechnology. Actinomycetes are one of the most abundant microbial groupings in the soil in nature. Species *Streptomyces* and *Micromonospora* are accountable for derivation of about 80% of the world's antibiotics (Sudha et al., 2011; Hassan et al., 2011; Brevik et al., 2020). Additionally, microbes can also be utilized to make bio-ethanol, biodiesel and bio-methane, which are all next-generation biofuels (Singh, 2015; Singh & Seneviratne, 2017; Peralta-Yahya & Keasling, 2010; Medipally et al., 2015).

4 Anthropogenic Activities Affecting Soil Community and Processes

4.1 Soil Pollutants

Maintenance of soil health and resilience to external conditions requires a healthy soil microbial community. Pollution has a significant impact on the growth and functioning of microorganisms, as well as the makeup and variety of the community in a soil ecosystem (Chen et al., 2014). Widespread incidence of organic pollution and its negative consequences have piqued popular interest. Many contaminants make their way to the soil, where they tend to accumulate over time, disrupting the soil ecosystem and processes.

4.1.1 Heavy Metals

Heavy metals, namely copper (Cu), chromium (Cr), nickel (Ni), lead (Pb), zinc (Zn) and manganese (Mn), garnered considerable attention due to their toxic and persistent nature and their tendency to bio-accumulate in ecosystems (Gan et al., 2017). While some of the heavy metals function as micronutrients for plants and are also required by microorganisms to maintain biological activities, copious amounts of heavy metals cause bio-toxicity, restrict microbial activity and disrupt the composition of soil community (Choppala et al., 2014; Khan et al., 2007). Heavy metals have the potential to alter the abundance and richness of microorganisms. (Tipayno et al., 2018; Zhang et al., 2019). Soil microorganisms can also interact with heavy metals and affect metal functional groups, resulting either in their mobilization (by dissolving, leaching or transforming them) or in their immobilization (by organic-metal binding and precipitation) (Gadd, 2004).

4.1.2 Antibiotics

Antibiotics are complex substances having different functional groups in their chemical structures and are categorized into several classes depending on their mode of action. Since most antibiotics are not entirely metabolized in the bodies of humans and animals, a significant amount of them is disposed into soil and water via municipal wastewater, livestock manure, sewage and organic wastes. (Bouki et al., 2013; Daghrir & Drogui, 2013; Wu et al., 2014a, b). Several studies have found that even low concentrations of antibiotics can alter a variety of soil processes facilitated by microbes. Soils containing sulfamethoxazole, sulfadiazine and trimethoprim demonstrated a significant reduction in soil respiration (SR) (Kotzerke et al., 2008; Liu et al., 2009) Antibiotic exposure is known to have an effect on nitrification and/or denitrification rates, and the effects are dependent on the type of antibiotic and the time of exposure. Antibiotics may also alter the rate of iron turnover in soil (Toth et al., 2011).

4.1.3 Agrochemicals

Agrochemical is a broad term used to define the chemical substances used for agricultural purposes, which comprise of pesticides, synthetic fertilizers, growth agents and raw manures. These agrochemicals may boost agricultural yields, but their widespread usage poses a significant harm to the environment, particularly soil biology. Some pesticides can disrupt association between plants and rhizobia, reducing the critical mechanism of biological nitrogen fixation. Pesticide-contaminated soils can also inactivate phosphorus-solublizing and nitrogen-fixing potential of bacteria (Hussain et al., 2009a, b). A substantial variation in microbial population has been detected between soils that were treated with pesticides and untreated ones, indicating that indiscriminate application of pesticides in the soil leads to reduction in microbial population and even their extinction (Ubuoh et al., 2012). Pesticides also affect microbial and enzymatic activities that underlie soil biochemical processes. (Demanou et al., 2004). In the literature, adverse effects of the use of agrochemicals on enzymatic activity of soil microbes have also been observed (Kalam et al., 2004; Menon et al., 2005; Gil-Sotres et al., 2005; Hussain et al., 2009a, b).

4.2 Intensive Agricultural Practices

One of the most prominent challenges of the twenty-first century is agricultural expansion. To keep up with the world's growing population, the total area under cultivation has been expanded by nearly 500% in the previous decades (FAO, 2018), with a 700% increase in fertilizer consumption and a several-fold increase in the use of agrochemicals (Tilman et al., 2002). Agricultural intensification has raised an extensive range of environmental concerns like chemical accumulation in soil and their leaching leading to groundwater eutrophication, increase in emissions of greenhouse gases, degradation of soil quality and soil erosion (Bender et al., 2016). Microbial communities play an indispensable role in ecosystems and render a wide range of services (Wall et al., 2001; Delgado-Baquerizo et al., 2016; Graham et al., 2016). Inadequate nutrient efficiency, increase in the amount of greenhouse gas emissions, groundwater eutrophication, loss of soil quality and soil erosion are all issues that have arisen as a result of agricultural intensification (Bender et al., 2016). Agricultural intensification, which involves high resource usage and limited crop diversification, can have an impact on soil- and plant-associated bacteria, as well as ecosystem services (de Vries et al., 2013). Current agricultural methods in many developing countries follow unsustainable practices, resulting in a massive volume of hazardous effluents being discharged directly or indirectly into the soil (Yanez et al., 2002). The introduction of nanotechnology and nanomaterials has complicated the picture of soil inputs and degradation even further (Mishra et al., 2017, 2018). Currently, numerous chemical fertilizers are used in an indiscriminate manner (Meena et al., 2016), causing harm to the soil biota. Furthermore, heavy machinery is a substantial contributor to soil compaction and change. Soil compaction reduces porosity, limiting oxygen and water delivery to soil microbes and plants, resulting in detrimental effects on soil ecology and forest productivity. Compaction has major repercussions in terms of runoff and erosion of the top soil, especially when restricted in ruts. In compacted soils, regeneration can be hampered or even blocked for lengthy periods of time, resulting in a significant reduction in microbial diversity in the soil and a negative impact on soil functioning.

4.3 Desertification

Desertification is a term used to describe the degradation of land in arid, semi-arid and sub-humid environments as a result of a variety of factors such as climatic changes and human activity. Desertification is mostly caused by overgrazing in many parts of the world. Other causes that contribute to desertification include urbanization, climate change, groundwater overdraft, deforestation, natural catastrophes and agricultural tillage practices. Desertification is one of the world's most serious social, economic and environmental problems. Total area impacted by desertification currently is 6–12 million km^2, and about 1–6% of residents live in these desertified areas (World Bank, 2009). The process of desertification introduces a significant alteration in the dominant species of the community, plant community structure and landscape pattern change. Desertification results in deficiency of several nutrients which also diminishes the carbon and nitrogen sources of microbes living in the soil, therefore hugely affecting their survival and decreasing their richness. As a result of which, the overall quality of soil deteriorates and soil functioning is severely affected.

5 Practices to Manage Soil and Achieve Optimum Functionality of Soil Community

Diverse, interacting forces shape soil microbial populations. Crop rotation, fertilizer and tillage practices all modify the physicochemical properties of soil, thereby influencing the variety and composition of soil bacterial and fungal communities (Francioli et al., 2016). Therefore, management of soil nutrients, promoting organic farming, practicing no tillage, using biological pest control methods etc. can hugely help in the maintenance of soil microbial community and ensuring soil sustainability.

5.1 Managing Soil Nutrients

Agricultural management influences microbial community composition and structure and their function of nutrient-cycling by establishing soil physicochemical features. Organic fertilizers improve soil microbial diversity and heterogeneity (Lupatini et al., 2017), and the bacterial and fungal community structure of organically managed soil systems is markedly different from that of conventional systems. (Francioli et al., 2016; Mader et al., 2002; Li et al., 2017; Wang et al., 2016). Organic fertilizers play a critical role in accumulation of soil organic matter and aggregate formation and hugely influence the composition of microbial community and their co-occurrence in microhabitats. Microbial communities provide nitrogen to plants in available forms through biological N fixation and mineralization of organic forms, and also limit N losses by immobilizing it in soil organic matter. The abundance, diversity and activity of soil microorganisms is hugely modified by the organic inputs such as compost and cover crop residues used for agriculture purpose (Li et al., 2017; Kong et al., 2010), while synthetic fertilizers mostly result in increased abundance of Acidobacteria (Francioli et al., 2016) and decrease the abundance of ammonia-oxidizing archaea (Muema et al., 2016). Synthetic fertilizers may affect microbial community structure by changing the soil pH and acidifying the soil, thereby indirectly increasing the abundance of acid-tolerant taxa. Modification in the structure and activity of microbial communities present in soil influences not only the rates but also the outcomes of agriculturally and environmentally important N-cycling processes like denitrification (Bhowmik et al., 2017).

5.2 Tillage Practices

No-tillage practices aid soil conservation by limiting the disturbance in soil and resulting negative carbon (C) mineralization, thereby acting as a C sink rather than being a source of carbon. In comparison to tillage systems, no tillage practice allows residue storage in soil itself, which provides additional benefits to the soil such as better soil fertility, minimized erosion and increased accessible moisture (West & Post, 2002; Lal, 2004; Franzluebbers, 2005). White and Rice (2007) concluded that in comparison to conventionally tilled soils, no-tillage soils showed higher microbial abundance. Crop rotation method and bio-covers can cause alterations in archaeal and bacterial composition and abundance (White & Rice, 2007). Agricultural conservation methods like crop rotations, animal manures and cover crops are said to preserve and enhance soil quality for long-term increase in agricultural output (DeBruyn et al., 2011). Cropping sequence diversity and crop rotations are also important factors in bacterial assemblages and species richness. Soybeans and legume cover crops with high protein content are said to create more fragile residues than cereals with a high C:N ratio, such as maize (Sarrantonio & Gallandt, 2003). In addition, increased diversity of cropping sequence and cover crops sustain more microbial biomass and encourage more fungal-based community structures, resulting in higher amounts of microbially derived organic matter (Six et al., 2006).

5.3 Biological Pest Management

Biopesticides are naturally occurring compounds that can be obtained from microorganisms, plants or other naturally occurring products to provide pest control (Lacey & Gerorgis, 2012). Biopesticides are important components of pest management strategies that aim to provide better and more environmentally friendly alternatives to conventional pesticides while avoiding soil pollution and contamination and preserving soil microbial ecosystems. While pathogenic microorganism-based biopesticides are particular to a target pest, biopesticides derived from beneficial interactors are a superior and more environmentally friendly option. Furthermore, unlike conventional chemical pesticides, biopesticides do not affect the ecosystem or soil bacteria (Gupta & Dikshit, 2010). Active substances released by several plants are also used as biocontrol agents. For example, strigolactones (a sesquiterpene) production promotes symbiotic associations by attracting *Glomeromycota* mycorrhizal fungi (Akiyama & Hayashi, 2006). The legumes produce flavonoids, which act as signalling molecules, attracting N-fixing bacteria to the rhizospheric zone and allowing rhizobial symbioses to form (Pathan et al., 2018). The release of organic acids by plant growth-promoting rhizobacteria (PGPR) benefits other soil microbes. For example, tomato roots emit citric and fumaric acids, which attract *Pseudomonas fluorescence* (Gupta, 2003). Another good example of a biopesticide is neem cake oil, which provides critical sustenance for soil microbes and enhances soil physicochemical qualities while also controlling a variety of pests (Gopal et al., 2007).

6 Conclusion

Soils support a diverse microbiological and faunal taxonomic community, which contributes to a wide range of ecosystem services that are critical for long-term viability of natural and agricultural ecosystems. These services have been classified as those related to the provision of products, the regulation of ecological processes and supporting services. The intricacy of demonstrating soil food webs under field conditions has been a major stumbling block to fully appreciating the contributions of soil microorganisms to soil processes and ecosystem services. As new analytical techniques and instruments become available, there is a continual need to identify, investigate and manage additional groupings of soil biota. For a better understanding of the links between soil biodiversity, their functioning and ecosystem services provided by them, multidimensional approaches that integrate new and existing information are required. However, there are also several natural and anthropogenic activities that pose serious threat to the survival of soil community, thereby hindering the ecosystem services provided by them. Therefore, there is also a pressing need to introduce and expand soil conservation methods in order to ensure appropriate soil functioning and long-term sustainability.

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