Bioremediation of Emerging Contaminants from Soils

Soil Health Conservation for Improved Ecology and Food Security

Edited by
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CHAPTER

Application of microphytes for soil reclamation

26

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Chapter outline

26.1 Introduction

A microalga or microphyte is a microscopic group of unicellular organisms containing eukaryotic protists, prokaryotic cyanobacteria, and blue-green algae. These plankton can be found in both seawater and freshwater. In addition to this, the soil of both coastal and freshwater environments also contains microphytes (Thurman, 1997). These organisms can live singly or in complex networks of interconnected communities called communities of communities. Their cell diameters vary from a few micrometers to a few hundred micrometers depending on

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[*] The authors have contributed equally to this chapter.

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the genus. Microalgae is autotrophic in nature. They have developed unique adaptations for living in a world where sluggish forces predominate. Photoautotrophic microalgae are crucial to Earth's biosphere because they generate roughly half of the oxygen we breathe and utilize the greenhouse gas (carbon dioxide) for growth. Microalgae, along with cyanobacteria, are generally referred to as phytoplankton; they are the primary contributors to respiration in the marine environment (Williams, 2013). Microalgae and bacteria comprise the food web's microbial foundation, supplying energy to higher trophic levels. The chlorophyll-a content of a microalgal biomass sample can indicate the microalgae's ability to contribute to future output (Sun et al., 2020; Thrush et al., 2006). Microalgae are an almost unexplored resource with a variety of species. Around 50,000 of the estimated 200,000–800,000 species across many distinct families are known (Starckx, 2012) and lots are yet to be identified. The molecular structures of more than 15,000 previously unknown substances found in algal detritus have been established. Several compounds are found in plants including carotenoids, antioxidants, fatty acids, enzymes, polymers, peptides, poisons, and sterols (Ratha & Prasanna, 2012). In addition to being a source of these useful by-products, microalgae have recently been recognized as a hopeful microbe in bioremediation and as a feedstock for biodiesel (Yuvraj, 2022). Different kinds of microalgae are cultivated in industrial laboratories for their many economical applications, such as human food, fuel, medicine, cosmetics, and fertilizer for crops (Mishra & Pabbi, 2004; Muller-Feuga, 2000; Wijesekara et al., 2011).

26.2 Useful microalgae and their associated characteristics for agriculture

Generally, the word "algae" does not apply to a specific taxonomic group but rather to a collection of oxygen-producing, chlorophyll-a-containing, photosynthetic creatures that may or may not have evolved from a shared progenitor. About half of the earth's photosynthetic output comes from these algae, which vary in size from single cells at the microscale to macroscopic clusters and the intricate leafy structures of seaweeds that can even reach 60 m in length (Barsanti & Gualtieri, 2014). Algae are commonly classified as macro- and microalgae. Microalgae can be found on virtually any surface, from water to earth (Olaizola, 2003; Tomaselli, 2004). Green algae, diatoms, euglenoids, and dinoflagellates are all examples of eukaryotic microalgae. Blue-green algae are not a true alga but types of bacteria, so presently these are known as cyanobacteria. These are present as free-living organisms or in symbiotic relationships with diatoms, ferns, lichens, cycads, sponges, plants, and other creatures (Adams & Duggan, 1999; Barsanti & Gualtieri, 2014; Rai et al., 2000; Sze, 1997). Microalgae can act as agricultural products, which may provide better crop yields (Fig. 26.1). After microalgae are added to the soil, it helps to add organic carbon (C), which is

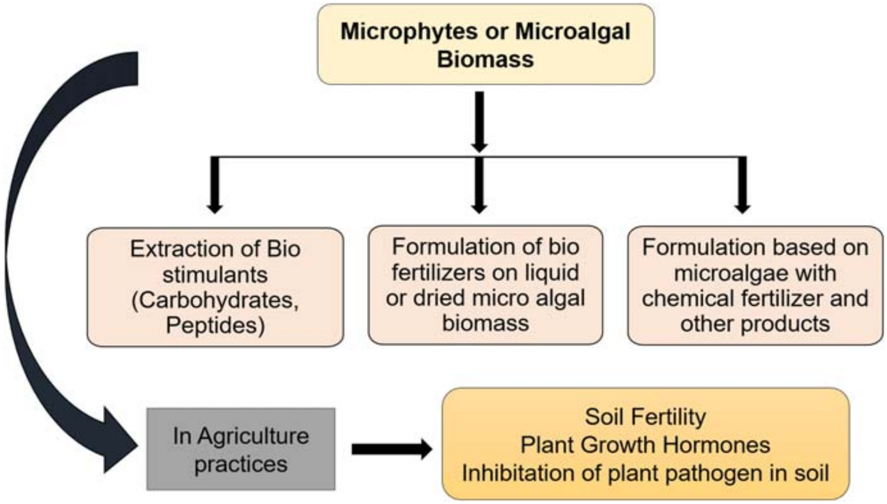

FIGURE 26.1

Different application products and uses of microphytes/microalgae in agricultural practices. Microalgae, sustainable agriculture, organic farming, biostimulator, and pathogen.

lacking in the traditional chemical nutrients (Ibraheem, 2007). The loss of soil organic carbon is an essential form of degradation in agricultural fields that leads to lower the soil quality and fertility, which can be recovered by using these microalgae (Fig. 26.1; Stavi & Lal, 2015) (Box 26.1).

26.3 Soil microbial dynamics, activity, and diversity

Soil aggregation, soil organic matter (SOM) degradation, and nitrogen cycling are all vital soil processes maintained by soil microbes and impact the global biogeochemical cycles (Dick et al., 1997; Kallenbach & Grandy, 2011). In the present time, intensification of agricultural activities characterized by excessive use of synthetic fertilizers, is one of the major causes of declining soil microbial diversity and soil quality. A robust and dynamic microbial community plays a vital role in ecosystem functioning and sustainable agriculture. Microbial communities that are both active and ecologically varied can help agricultural systems (organic farming) by providing nutrients through organic substrates to the plants (Tautges et al., 2016). Functions and markers of soil quality (Andrews et al., 2004; Doran & Zeiss, 2000) relies on the presence of soil microorganisms, which are crucial for soil preservation. To understand the soil quality, microbial biomass, microbial activity (soil enzymes), and microbial community composition and variety are frequently used as microbiological metrics (Benedetti & Dilly, 2006; Dai et al.,

Box 26.1 Use of several microalgal strains and their application method for plant growth enhancement in a greenhouse or in vitro condition (Microalgal strain: Fresh biomass or live cell suspension).

Microalgae use photosynthesis to integrate the organic carbon into their biomass, and the exopolysaccharides released to act as a source and reservoir for carbon for increasing soil fertility (Costa et al., 2018; Mager & Thomas, 2011;). Apart from affecting the plant growth, microalgae also affect the microbial population present in the soil (biomass, activity, community composition, and diversity) (Fig. 26.1; Marks et al., 2019; Nisha et al., 2018; Prasanna et al., 2016) by composting the material which yields different minerals. These minerals are then used by plants (Alobwede et al., 2019; Coppens et al., 2016; Mandal et al., 1992; Watanabe & Kiyohara, 1959). A number of farming products that are used for increasing soil fertility and crop production may be derived from microalgae for the wide variety of effects that microalgal biomass (or microalgal compounds) has on soils and plants. The microalgal biomass can be used as a soil conditioner (Fig. 26.2) for its characteristic to enhance the physical characteristics like soil structure and water retention ability (Ibraheem, 2007; Metting & Rayburn, 1983; Rossi et al., 2017). Microalgae are increasingly recognized as a type of biofertilizer, which is defined as a microbial inoculant that promotes plant growth (Fig. 26.2) when applied to soil, seeds, or the plant surface (Fig. 26.2). Biofertilizers accomplish this by increasing the supply or availability of nutrients to the plant through the activity of living microorganisms. Some examples of these processes are the absorption of nitrogen (N) and the solubilization of phosphorus (P) (Mahanty et al., 2017; Vessey, 2003). Even when adding nonliving microalgal biomass, such as oven-dry biomass, it is possible to classify these materials as organic additives or organic fertilizers (Barminski et al., 2016; Yoder & Davis, 2020). Recently, microalgae are also tested for their potential as future biostimulant sources for plants (Marks et al., 2019; Plaza et al., 2018; Ronga et al., 2019). A plant biostimulant is any substance, mixture, or microorganism that increases plant development, nutrient use efficiency, resistance to abiotic stress, quality characteristics, or the availability of limited nutrients in soil or the rhizosphere, regardless of the nutrient concentration of those soils or rhizospheres. Microalgae and the compounds produced from them are gaining attention as possible biopesticides and biocontrol agents, and the proof is mounting in their favor (Fig. 26.2). However, several microalgal/microphyte strains can be used for the growth of plants in controlled condition farming using different methods (Table 26.1). This strains may be added as fresh biomass or live cell suspension.

2018; Rice et al., 1996). Eukaryotic microalgae are seldom used as treatments in studies, but cyanobacterial biofertilizers are frequently examined for their effects on microbial biomass carbon and enzyme production. Soil microbial biomass acts as a nutrient source and sink and a catalyst for the change and rotation of SOM (through processes like organic C, N, and P mineralization) (Gregorich et al., 1994; Rice et al., 1996). The presence of microbes in the soil, helps the microbial biomass to be used as an initial predictor of alterations in soil conditions and management (i.e., Soil Organic Matter, SOM). Agricultural methods that can supply carbon and replenish the microbial biomass in farmed soils are needed when both the amount and quality of SOM diminish with agricultural expansions. Several enzymes present in the soil help in maintaining the biogeochemical (C, N, and P) cycles, and other than this, several enzyme assays indicate soil microbial activity (dehydrogenase and fluorescein diacetate (FDA) hydrolysis).

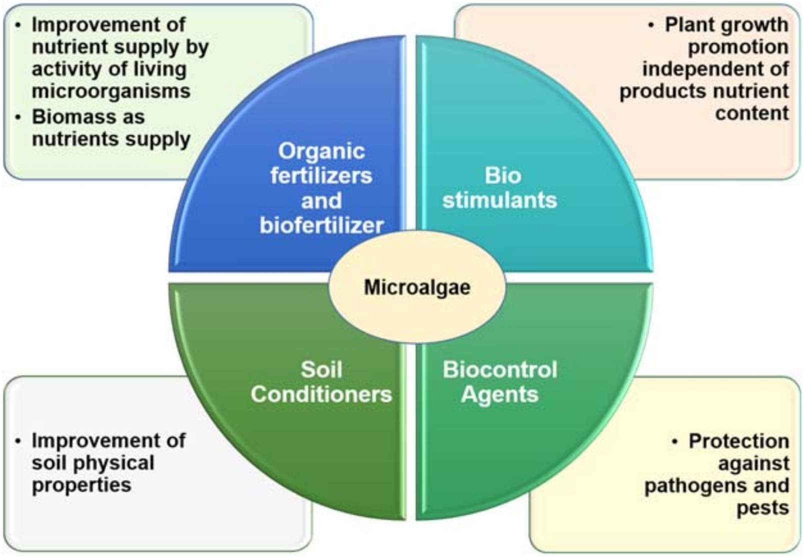

FIGURE 26.2

Products derived from agricultural microalgae that may improve soil quality and crop production, soil reclamation, green agriculture, plant growth, crop yield, and microalgal biomass.

Microalgae are a source of carbon, nitrogen, and other micronutrients when applied to soil, and for this reason, these inputs would have an effect on the microbial populations in the soil; however, the actual effect time is likely to be highly dependent on environmental conditions and inoculum establishment. Numerous studies on varied cyanobacterial species and agricultural plants have found that enzyme activities are substantially increased in modified samples compared to nonmodified samples. The following analyses provide the idea of soil condition: Dehydrogenase and FDA hydrolysis to represent the overall microbial activity, invertase data to represent carbon cycle metabolism, and phosphomonoesterase and alkaline phosphatase measurements to represent phosphorus cycle metabolism. In most cases, dehydrogenases are a good proxy for biomass produced by microorganisms, as they reflect the oxidative metabolic activity of viable, complete cells. Since FDA can be digested by a diverse array of nonspecific enzymes, including lipases, proteases, and esterases, it gives a comprehensive snapshot of the soil microbial activity. Soil invertase activity, which hydrolyzes sugar into glucose and fructose, is correlated with organic C levels (Frankenberger & Dick, 1983; Frankenberger & Johanson, 1983). Even though more field studies are needed to investigate the long-term effects of microalgal soil amendments, there is a general agreement that they positively affect soil microbiological parameters.

Table 26.1 Use of several microalgal strains and its application method for plant growth enhancement in greenhouse or in vitro conditions (microalgal strain: fresh biomass or live cell suspension).

Sl. no.	Plant	Microalgal strain	Method of application	Result	References
1.	Spinach, Chinese chives	*Chlorella fusca*	Irrigation in soil and foliar application	Enhanced productivity and market value	Kim et al. (2018)
2.	Wheat, sorghum, lentils	*Nostoc muscorum*	Incubation in laboratory and also applied to seeds	Enhanced total N, soluble protein, and amino acids	Adam (1999)
3.	Corn	*Nostoc* sp.	Applied on pot surface immediately after germination	Enhanced dry matter yield	Maqubela et al. (2009)
4.	Cumin, coriander	*Anabaena laxa*	Applying at time of soil mixing in pots	Enhanced peroxidase activity in root and shoot	Kumar et al. (2013)
5.	Corn	*Nostoc* spp.	Applied on pot surface at time of two leaf stage	Enhanced N uptake and content of N in tissue	Grzesik and Romanowska-duda (2014)
6.	Lettuce	*Chlorella vulgaris*	Applied in pots soil/greenhouse	Enhanced pigments in seedlings and total protein	Faheed and Abd-El Fattah (2008)
7.	Tomato	*Anabaena laxa*	Applied to carrier used at time of potting mix	Enhanced shoot Nin plants, Plant P	Prasanna et al. (2013)
8.	Wheat	*Calothrix ghosei*	Applied in pot soil near to root zone after 15 days of sowing	Enhanced grain yield	Karthikeyan et al. (2007)
9.	Rice	*Anabaena azotica*	Applied in pots/ greenhouse	Enhanced grain, straw, husk, and dry weight	Nagy and Pintér (2015)

26.4 Applications

26.4.1 Reclamation of Usar lands

Usar (sodic) soils are prevalent all over the Indian subcontinent and are characterized by a lack of fertility due to their high salinity and alkalinity. Plant development is stunted because of its impermeability, excessive hardness, and rare undesirable salts on the surface. The elevated pH level in the soil also acts as a barrier to better crop yield. The subsurface water table is mostly located between 3.0 and 4.5 m below the surface. These soils can be reclaimed during the rainy season (July−September) and the waning monsoon, by the technique (Singh, 1950) of growing the blue-green algae on the soil surface in the alkaline Usar soils of northern India, where other vegetation fails to thrive (December−January). These soils, which undergo an alkalization process, are recoverable by replacing sodium with calcium by applying chemical correctives like gypsum, with a high cost. Soil waterlogging, organic debris, and nitrogen could also facilitate the interaction of $CaCO_3$ with sodium clay. Blue-green algae, a plant capable of fixing the atmospheric nitrogen dioxide, grows prolifically in saturated soils, so it meets these criteria. The Usar lands can be revived using the following procedure: Initially the land was subdivided into parcels smaller than 0.4 hectares in May and June, just before the summer monsoon arrives. An earthen mound served as a boundary for the individual sections. A dense layer of nitrogen-fixing blue-green algae developed after the initial rains. Eventually, when the soil flooded, nitrogen-fixing forms typical of rice fields emerged and flourished as long as the soil remained saturated with water. Blue-green algae was one of the earliest identified nitrogen-fixing compounds in flooded paddy field. Numerous experiments have been tried to inoculate the soil with blue-green algae to boost rice production, due to the integral fertility of tropical paddy fields to these organisms. This method is known as "algalization" (Venkataraman, 1966).

26.4.2 Enhancement of soil vitality

Some cyanobacteria can fix ambient nitrogen into usable forms of nitrogen, but the oxygen produced by photosynthesis in the same cell is toxic to the nitrogen-fixing enzymes. Several unicellular, filamentous, nonheterocyst cyanobacterial strains have evolved strategies for escaping oxygen, including geographic division and cellular differentiation into nitrogen-fixing heterocysts, as well as time separation of oxygen generation in filamentous cyanobacteria and nitrogen fixation. The heterocyst cell core becomes anaerobic, primarily due to breathing, which allows the continuation of an oxygen-sensitive process of nitrogen fixation. In-depth research has been conducted into the mechanisms that control nitrogen fixation in the heterocyst system. All the energy needed for carbon and nitrogen fixation is provided by sunlight, for this reason, diazotrophic cyanobacteria only exist in sunlight. As a result, these cyanobacteria require less energy to produce the end products so it acts as good biofertilizers. The agricultural potentiality of the heterocystous cyanobacteria (free-living or symbiotic relationship with the aquatic fern *Azolla*) has long been known (EI Zeky et al., 2005). A major challenge to soil restoration in dry and semi-arid regions is its high salinity content. The impact of salt on plant and algae development, metabolism, and production has been the subject of research (Ibraheem & Abdel-Raouf, 2007). Improvements in plant salinity tolerance were achieved through the use of growth factors like gibberellic acid. During the use of higher concentrations, growth regulators are impractical and prohibitively costly. Under the right circumstances, algae can boost soil fertility and enhance plant growth conditions by playing an important economic role in soil restoration (Nisha et al., 2007; Pandey et al., 2005; Prabu & Udayasoorian, 2007).

26.4.3 Soil structure, erosion control, and water retention

Erosion, crusting, and compaction all results from a deteriorating soil structure, which in turn causes ground deterioration (Eswaran et al., 2001). Stable soil aggregates enhance ventilation and hydrodynamic characteristics and make the soil less vulnerable to erosive factors like wind and water, and aggregate stability is decided by soil agglomeration (Nimmo, 2004; Johnson et al., 2016). Soil microorganisms are essential for creating soil stability and the extracellular polysaccharide (EPS) present in the microorganisms functions as binding agents of soil particles (Rossi et al., 2018). There are different chemical makeups of EPS produced by different microalgae (Pereira et al., 2009; Xiao & Zheng, 2016). Additionally, the EPS makes a complicated extracellular matrix comprised of proteins, lipids, nucleic acids, and other substances, which shields the cells from damage and creates a nutrient-rich and hygienic microclimate (Mager & Thomas, 2011). The subject of biological soil crusts (BSCs), which includes cyanobacteria and eukaryotic microalgae, has conducted extensive research on the impact of EPS on soil physical characteristics like aggregation, aggregate stability, and water retention in dry and semiarid environments. Microalgae that produce EPS, on the other hand, have shown to enhance soil physical characteristics in farming contexts, suggesting a future role as soil cleansers (Maqubela et al., 2012; Metting & Rayburn, 1983; Nisha et al., 2018). The amphiphilic character of the EPS in BSCs allows cyanobacterial strands to intertwine in networks that support the soil and create extra holes during the early soil aggregation process (Rossi et al., 2018). Several experiments with agricultural soils have shown improved soil cohesion and durability. In a container trial with maize, inoculating low organic C soils with EPS-producing *Nostoc* sp. improved aggregate size and resilience in water, though this impact depended on the strain used and the presence of plants (Maqubela, Mnkeni, et al., 2010; Maqubela et al., 2012). Other examples include the increased water stability of soil aggregates observed with other cyanobacterial strains such as *Nostoc muscorum* (Rogers & Burns, 1994), *Tolypothrix tenuis* (Mulé et al., 1999), and a combination of *Aulosira fertilissima*, *T. tenuis*, *Anabaena*, *Nostoc*, and *Plectonema* (Roychoudhury et al., 1983). The collective stability of a saline-sodic soil was also enhanced by the administration of purified EPS from *N. muscorum* (de Caire et al., 1997). Aggregate stability in cold farming soils was boosted by the eukaryotic microalgae *Chlamydomonas mexicana* and *Chlamydomonas sajao* (Metting, 1987). Due to the increased rock stability, the soil is more resistant to wind and precipitation damage. Chamizo et al. (2012) reported reduced silt erosion following rain models in field tests. Hu et al. (2002)

showed that fine sand is more resistant to wind erosion in BSCs. For example, in abandoned farming areas, Sadeghi et al. (2020) found that field sections infected with *Nostoc* sp. and *Oscillatoria* sp. reduce soil loss by overflow by up to 36% after natural rains. Conversely, phytoplankton that produces EPS can enhance the soil hydrodynamic properties and soil water absorption. The EPS is hygroscopic, that absorbs water from both precipitation and nonprecipitation sources like clouds, mist, and even water vapor. While comparing with BSCs that had their EPS removed, undamaged BSCs can reduce evaporation losses and retain water for extended durations (Adessi et al., 2018). However, water losses are comparable in soils with and without BSCs or in crusts with and without EPS at very low soil wetness (6%–8%) during arid mild times. The water-holding capacity of farming soils has been improved by using different microalgal additives (Rossi et al., 2018).

26.4.4 Dust control and soil consolidation

BSCs are formed when soil microbes agglomerate soil particles in arid regions with inconsistent vascular plant dispersal and low water availability (Abdel-Raouf et al., 2004; Hawkes & Flechtner, 2002). In water and nutrient-deprived environments, biological crusts are formed by microalgae, cyanobacteria, lichens, microfungi, bacteria, and mosses with patchy vascular plant growth. Crusts will probably have both direct and secondary effects on plants due to the ways in which they change soil variables, such as water access, nutritional content, and weathering vulnerability (Hawkes & Flechtner, 2002; Stal, 2007). Soil stability is achieved by cyanobacteria and other surface creatures joining smaller fragments into bigger ones (Shields & Durrell, 1964). A variety of mechanisms are used for binding soil particles (Bar-Or & Danin, 1989), including physical binding by entangled filaments, adhesion to mucilaginous sheaths or slime layers formed by cyanobacterial trichomes and attachment along the cyanobacterial trichomes themselves. The surface organic matter composition increased due to this coupling (Danin et al., 1989), making the soil more resistant to wind and water runoff. Microorganisms are widely acknowledged as being crucial to the success of soils by increasing the strength of soil particles. (Eldridge & Leys, 2003). However, a greater tendency of soil aggregation was observed after soils were infected with algae or cyanobacteria, as shown by Bailey et al. (1973). Gelatinous materials secreted by cyanobacteria and microphytes bind or entangle the clay particles in the sand, bringing the microbes to the soil's surface. Crusts develop when algal and cyanobacterial filaments, moss and lichens, and soil fragments entangle (Chartres, 1992). The first few millimeters of soil are compacted into a shell by polysaccharides produced by filamentous algae and cyanobacteria and by the living organisms themselves (Campbell et al., 1989). It is well known that the development of a soil layer creates a vital role in the biological working of dry and semiarid areas (Harper & Marble, 1988). Numerous ecological, metabolic, and biological studies have been conducted on macrobiotic crust communities for its increasing interest in their potential involvement in nutrient cycling (Lewis & Flechtner, 2002). Cameron (1960, 1964) conducted one of the first comprehensive studies of macrobiotic crust creatures. Due to the biological impacts on both physical and chemical soil characteristics and their possible influence on vascular plants, these studies highlighted the importance of characterizing the geographic patterns of organisms within the crusts. The geographic variability of crust organisms may result from a combination of biotic and abiotic variables (Hawkes & Flechtner, 2002). The mucilaginous (palmelloid) green microalgae are used as soil conditioners in the United States to a limited extent (Skujins, 1991). Soil conditioning refers to practices and materials that improve the soil's structure through its formation and/or consolidation of sediments, in addition to the soil's physical qualities for agricultural use. Living bacteria fibers are thought to play a major role in aggregate stabilization through their ability to adsorb and bond particles from the environment (Burns & Davies, 1986). The introduction of mass-cultured *Chlamydomonas* and *Asterococcus* species (Chlorophyceae) into watered granular soils through a center pivot irrigation system has demonstrated a significant improvement in the structure of soil clumps (Hawkes & Flechtner, 2002).

26.4.5 Halting wind, water, and air degradation

Soil surface microphytes play a significant role in slowing down erosion due to wind and water. Microphytic crusts vary in cover over areas typically scanty in the region where vascular plant development and litter occurs, so there are high rates of natural erosion. Microphytes increase the roughness of the soil's surface, which likely plays a part in the nonuniform movement of water down an incline. More and more twists and turns in the water's course dissipate its erosive force. On a microscopic scale, the microphytes may create alternating aggravating and deteriorating surfaces, potentially altering the remaining outflow of silt from a hillside. Based on Stanley's (1983) hypothesis, microphytic crusts increase water erosion on the lower slopes of calcareous soils in semiarid rangelands because they generate higher surface flows on summits. There is some evidence that microphytes can delay erosion in dry and semiarid regions, even though they may not break the kinetic energy of falling and moving water as effectively as vascular plants do. Global increment in the wind-borne sediments resulting from human activity over the past 150 years may be the reason for the decline in microphytic crusts in dry to semiarid areas (Goudie, 1983; Kovda, 1980; Tsoar & Pye, 1987). There has been a suggestion that differences in soil surface crusts may explain some of the inexplicable changes in dust cyclone forecasting capacities of climatic and meteorological models (Brazel & Nickling, 1987; Gillette et al., 1982). For example, the Halutza sand sea, located on the Egyptian-Israel boundary, is partially stabilised by the growth of mosses and algae (Tsoar & Møller, 1986). They also explain the interactions between microphyte death and sand flow. Microphytic crusts are broken down by human, animal, and vehicular traffic, releasing the smaller particulates to be carried by wind (Marshall, 1972).

26.4.6 Heavy metal elimination

Presently, there has been a rise in heavy metals in the environment due to several anthropogenic activities like mining, energy production, fuel extraction, electroplating, effluent sludge, and cultivation. These contaminants are conservative in the sense that they cannot be broken down by microbes or any other natural means. As a result of this, the soil, water, and silt amount often exceed safer limits. Heavy metals such as arsenic, mercury, chrome, nickel, lead, cadmium, zinc, and iron can be fatal to living organisms in high concentrations. These heavy metal pollutants can then permeate deep into the aquifer and contaminate both the groundwater and the water near the surface. As these heavy metals enter the food chain through plants and eventually the human body, they become absorbed into the cells. For this reason, a significant risk to human health arises from heavy metals because they fundamentally alter the biological processes within the body (Krishnan et al., 2004). They can also move from one food chain to another because of their bioaccumulative nature (Pergent & Pergent-Martini, 1999). As a result, food output and human health have become major concerns in many established and emerging nations due to heavy metal contamination of agricultural soils. Trace metals such as As, Cr, Co, Cu, Ni, Se, Va, and Zn are essential for the survival of many species. However, at higher concentrations, these same metals become toxic. Heavy metals like Pb, Hg, Cd, U, Ag, and B have been shown to be neurotoxic and have no recognized nutritional benefit (Inthorn, 2001). Heavy metals are usually removed from polluted water using reverse osmosis, electrodialysis, ultrafiltration, ion exchange, chemical precipitation, phytoremediation, etc. However, these approaches have limitations, such as insufficient metal removal, excessive reagent and energy demands, and the production of poisonous sludge or other waste products that necessitate cautious dispersal (Ahalya et al., 2003). Using microalgae found naturally or by-products from the brewing industry can act as biosorbents. The term “biosorption” describes the process by which organic matter can take up and store ions from metallic ions. Biosorbents and detritus derived from various microbial sources, including moss, marine plants, and leaf-based adsorbents, were discovered (King et al., 2007; Niu et al., 1993;). Microorganisms showed exceptional metal-binding abilities (Schiewer & Volesky, 2000a; 2000b). Microalgae can accumulate metals because their cell walls are composed of carbohydrates, proteins, or lipids that contain functional groups like amino, hydroxyl, carboxyl, and sulfate (Yu et al., 1999). As a result, microalgal cell membranes can be used to store toxic metals. Because of this, microalgal biomass is widely regarded as an efficient and trustworthy means of detoxifying water of toxic metals (Volesky & Holan, 1995). For this reason, microalgae are not typically suggested as dietary products due to their propensity to absorb toxic metals. They are so effective at removing metals from polluted water, contaminated fertilizers, and atmospheric deposition into open wetlands that the resulting biomass may exceed safe levels for human consumption.

26.4.7 Biofertilizer

In modern agricultural practices, biofertilizers play several important roles in soil fertility, agricultural productivity, and production. Even though biofertilizers are favourable to the environment, they are in no way capable of replacing cannot replace artificial fertilizers, which are essential for achieving the highest possible crop harvests. The fermentation process yields biofertilizers, comprised of active, living earth microorganisms that are beneficial to plant growth. They increase the development and productivity of plants by supplying nutrients that the plants readily absorb. They are both cost-effective and environmentally friendly bioinoculants, and they have a significant potential to increase agricultural production in an environmentally responsible manner. The biofertilizers are nitrogen fixers, phosphate solubilizers, and phosphate activating. After the use of biofertilizers, the plant can absorb more minerals and water, produce more roots, experience more vegetative growth, and fix more nitrogen. Under ideal agronomic and insect control circumstances, they can only be able to reduce the number of artificial fertilizers they use (Asoegwu et al., 2020). To satisfy the comprehensive nutritional requirement of the soil, they are used in conjunction with artificial fertilizers. Some biofertilizers encourage the production of substances beneficial to plant development, such as vitamin B complex and indole acetic acid. They also assist in the biological control of diseases and the rehabilitation of contaminated soils by acting as adversaries and reducing the incidence of soil-borne plant infections. This contributes to the biocontrol of plant diseases. In contrast to artificial fertilizers, which frequently flow to the nearby water bodies and cause eutrophication and methemoglobinemia (also known as "blue baby syndrome") when the nitrate level exceeds 10 mg/L or higher, these fertilizers do not pollute the environment in any way and are therefore environmentally favorable (Self & Waskom, 2008). Biofertilizers are used to supplement the soil with additional nutrients and microorganisms, some of which may not be present in the soil or may be present in insufficient quantities. They also cut down on the overall amount of trash that is disposable. The environmental effect of artificial fertilizers can be mitigated by using biofertilizers, particularly on land and water. They contribute to an improvement in the soil's condition by delivering nutrients and maintaining a natural environment within the rhizosphere. Together with improved agricultural leftover management, this will contribute to a reduction in fertilizer overspill or pollution. Inoculants made of microorganisms will also contribute to a reduction in the quantity of artificial fertilizers used and an improvement in the utilization effectiveness of the fertilizers that are applied (Chauhan et al., 2012). The microorganisms that are found in biofertilizers are very essential because they are the ones that generate the nitrogen, potassium, and phosphorus, as well as the other nutrients that plants need. Most biological fertilizers release hormones, such as auxins, cytokinins, biotins, and vitamins, that are necessary for plant development. Plants protected by biofertilizers receive this benefit because the medications they produce are efficient against a wide variety of plant infections. In addition, biofertilizers shield plants from the damaging effects of saltwater and dehydration. The use of biofertilizers, which are low-cost and risk-free supplies, opens up a wealth of research opportunities in the fields of sustainable agriculture and the creation of stress-free environments (Sahoo et al., 2013). Generally, biofertilizers are long-lasting in the soil for agricultural practices due to its nature of more gradual discharge of nutrients which provides plants a better way to grow similar like the natural environment. Like this, the plants continue to receive a gradual and steady supply of the nutrients that biofertilizers provide for more than one growing season. Therefore, the continued use of biofertilizers results in the accumulation of nutrients in the soil, which ultimately leads to an increase in the productivity of the soil.

26.5 Conclusions

Microphytes incorporate several characteristics that are becoming increasingly important in a complex farming setting and the process of land reclamation. Microalgae/microphytes boost soil productivity and structure by adding minerals and improving microbial soil quality metrics and nutrient cycling. Protecting plants from disease, producing phytohormones and other bioactive compounds, and associating with plant roots are the ways through which microalgae contribute to plant development. These results are significant as they could lead to further advancements in the discovery of substances that can boost growth or the development of crops that do not need nitrogen. Microalgae have massive untapped capabilities as natural assets in agriculture and as sustainable answers for agricultural production, plant macro- and micronutrient enrichment, and soil preservation and regeneration due to their extensive range of available forms and functions. Future farming viability relies heavily on ecosystem functions like soil fertility, nutrient cycling, and controlling erosion. All these can be controlled by using microalgal resources. Microphytes not only improve soil and plant characteristics but also decrease the resulting waste supplied to the soil and plants. This involves implementing environmentally friendly and socially responsible practices to ensure long-term agricultural productivity and ecosystem health. These practices contribute to achieving the UN Goals of Sustainability by promoting sustainable agriculture, ensuring food security, reducing environmental impacts, and supporting the well-being of both present and future generations.

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Bioremediation of Emerging Contaminants from Soils

Soil Health Conservation for Improved Ecology and Food Security

Edited by Prasann Kumar, Arun Lal Srivastav, Veena Chaudhary, Eric D. van Hullebusch and Rosa Busquets

Bioremediation of Emerging Contaminants from Soils: Soil Health Conservation for Improved Ecology and Food Security deals with current challenges of sustainable soil health using eco-friendly approaches. This book provides ways of reducing the chemical burden on the soil by maintaining balance in terms of society, environment, and economy, which are considered basic pillars of sustainability.

Designed to highlight soil health best practices for both environmental and agricultural sustainability, these approaches are also considered important for improving global food security by ensuring safe growing conditions for crops for food and feed. Presented in two parts, this book first highlights emerging contaminants and their sources. The second part explores a variety of steps and tools for addressing contaminated soils, including bio- and phytoremediation options. Case studies in each part provide real-world insights for practical application.

Key features:

- Contains the latest practical and theoretical aspects of the soil health crisis and its management
- Presents collective information to ensure the remediation of soil from emerging contaminants
- Serves as baseline information for environmental issues in agriculture along with their alternative eco-friendly solutions

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