Chapter 17
Plant-Microbe Interactions for Bioremediation and Phytoremediation of Environmental Pollutants and Agro-ecosystem Development

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Abstract Development in both the industrial and agricultural sectors has resulted in excess production of hazardous substances which is ruining our environment. However several physicochemical technologies are available to treat such substances but require extra setup to deal with eco-friendly manner. Phytoremediation and bioremediation has emerged as a substitute of such technologies which is brought by the interaction among plant and microorganisms. PGPR (plant growth-promoting rhizobacteria) has an important contribution in remediation of environmental pollutants as well as agro-ecosystem development. Along with PGPR, several fungi, endophytes, mycorrhiza, and algae also form association with plants and contribute in sustainable development. Application of genetic engineering has resulted tremendous effect in increasing their efficiency of pollution control and plant growth regulation.

Keywords Environmental pollutants · Bioremediation · Phytoremediation · Plant-microbe interactions

1 Introduction

In the present era, our world is suffering through various economic and environmental problems, among which conventional energy depletion, global warming, and water pollution are of more concern. These problems are affecting the whole society in different ways. As per a report by WHO 2013, drinking water pollution is a major problem of half of the population worldwide. Such pollution is responsible for

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R. N. Bharagava, G. Saxena (eds.), *Bioremediation of Industrial Waste for Environmental Safety*, https://doi.org/10.1007/978-981-13-3426-9_17

around 250 million cases of waterborne disease and 0.005–0.01 billion deaths in a year. A vigorous development in agricultural as well as industrial sector has resulted in excess production of chemicals and its entrance into the environment as toxic contaminants (Sharma et al. 2014). Due to extreme presence of these potential toxicants, clean water and healthy soil have become scarce resulting in limited crop production (Kamaludeen et al. 2003).

There are a number of toxic agents which pose serious hazardous effect to our environment resulting in water, air, and soil pollution (Goutam et al. 2018; Bharagava et al. 2017a; b; Goutam et al. 2017; Saxena et al. 2016; Saxena and Bharagava 2015). The remediation of such pollution in water and soil often involves some technologies that are expensive, cost-effective, and labor-intensive and require site restoration either with physical or chemical methods. Due to drawbacks of these technologies, scientists have started to develop some new technology as an alternative to using plant and microorganism or both in an interaction for the removal of toxic contaminants in soil (Glick 2003).

Use of certain plants for removal or destruction of hazardous toxicants from environment for its cleanup is the recently developed method and termed as phytoremediation. The plants used in this method are called hyperaccumulators which grow best in metal concentration-rich soil (Glick 2003). Alkorta and Garbisu (2001) have reported phytoremediation to be an effective, nonintrusive, in situ, aesthetically pleasing, low-cost, and socially accepted technology for the remediation of polluted soil. This technology may remediate the pollutants in several forms: phytostabilization, rhizofiltration, phytoextraction, and phytovolatilization.

Bioremediation is the process which uses microorganisms like bacteria or fungi and yeast for the cleaning of polluted water and soil (Bharagava et al. 2017c; Saxena and Bharagava 2017; Kishor et al. 2018). In this technology, the growth of indigenous microbial consortia of polluted site is promoted for desired activity (Agarwal 1998) by controlling biotic and abiotic stresses.

Not only remediation of environmental pollutions but plant-microbe interaction contributes to sustainable development of agriculture also. Nowadays, there is a big challenge in crop production with reduced use of pesticides and chemical fertilizers. Therefore the use of PGPR for increase in crop yield has proved environmentally friendly approach as an alternative to such problems. The direct and indirect mechanism of plant growth promotion by these PGPR includes nutrient regulation and hormonal regulation in plants resulting in induced resistance against phytopathogens.

The current chapter is based on the elastration of available physicochemical technologies for environmental remediation and plant microbial interaction with special reference to phytoremediation and bioremediation for the sustainable development of agroecosystem.

2 Environmental Pollutants and Their Toxicity in Environment

Pollutants in the environment are of several categories like organic, inorganic, and radioactive and some other metals. Inorganic pollutants are mainly nitrate, sodium, arsenic, or ammonia, whereas metallic pollutants are characterized by cadmium, copper, mercury, chromium, and selenium. Uranium, strontium, and cesium are the main radioactive substances causing pollution in the environment. Organic pollutants are the main source of environmental pollution. It includes various compounds like bentazon and atrazine as pesticides; polycyclic aromatic hydrocarbons (PAHs); petroleum hydrocarbons such as toluene and benzene; and trichloroethylene which is a chlorinated solvent. There are some other very hazardous pollutants being released into the environment unintentionally or intentionally and posing global concern for their remediation. These lipophilic chemicals are called as persistent organic pollutants (POPs) because they get accumulated in different biological systems present in the environment like animal tissue and are resistant to photochemical and biodegradation resulting in longtime presence in the environment (Buccini 2003; Wong et al. 2005; Sharma et al. 2014). Recent advancement in day to day life of humans has led to the increase in the utilization of nanoparticles in cosmetics, but in most of the cases, besides their benefits, the negative effects observed on the environment requires mineralization or removal of these toxic chemicals (Landis and Yu 2003). According to Kuppusamy et al. (2016), there is a list of toxic pollutants mainly inorganic and organic (as demonstrated in Fig. 17.1.) which exert risk to health of more than 100 million people if exposure occurs.

The exposure to these toxic pollutants may have adverse health impacts like organ dysfunction, cancer, mental and physical disorders, neurological disorder, and reduced immune system and ultimately causes death (Godduhn and Duffy 2003; Perera and Herbstman 2011; Mates et al. 2010; Yu et al. 2011; Huang et al. 2012).

Since the adverse effects of various kinds of environmental pollutants, the demand has increased to develop a suitable technology for lowering the cost of pollutant treatment because the remedial sector plays an important role in strengthening the GDP. In this respect, the selection of already available technology for better applicability directly depends upon the characteristics of polluted site and task objectives. Therefore, a combination of all the adopted methods for remediation of pollutants such as biological and physicochemical means is the most promising option in present scenario (Kuppusamy et al. 2016).

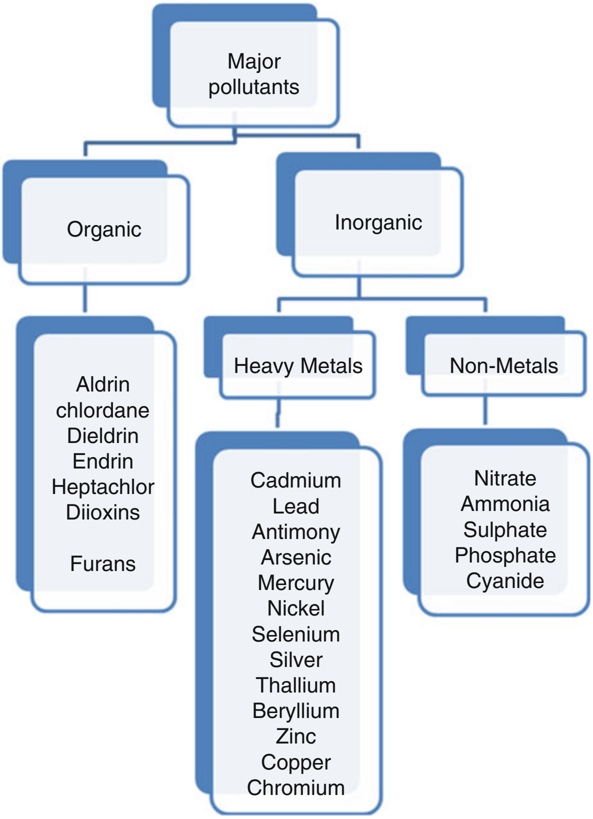

Fig. 17.1 Major organic and inorganic pollutants (Adapted from Kuppusamy et al. 2016)

3 Environmental Remediation Technologies

With the increase in human population, industries based on food production, health stability, automobiles, etc. have also expanded which results in more natural resources utilization like water, land, and air (Kumar et al. 2011). Various kinds of environmental pollutants are being used for this purpose and are having adverse effect on the environment. Hence, cleanup of the environment is necessary. Several biological and physicochemical remediation technologies (Fig. 17.2) can be adapted to cure the environment. These technologies are categorized as ex situ or in situ on the basis of site of treatment.

The transport and treatment of polluted media (soil, water) from contaminated site to a different location is called ex situ, whereas on-site treatment of pollutants is called in situ mode of remediation. Both ex situ and in situ methods of remediation have some advantages and disadvantages in their uses. The major advantage with the use of in situ is it does not require excavation and transport of contaminated soil from its site and also the cost of the treatment process and risk of exposure to pollutant are

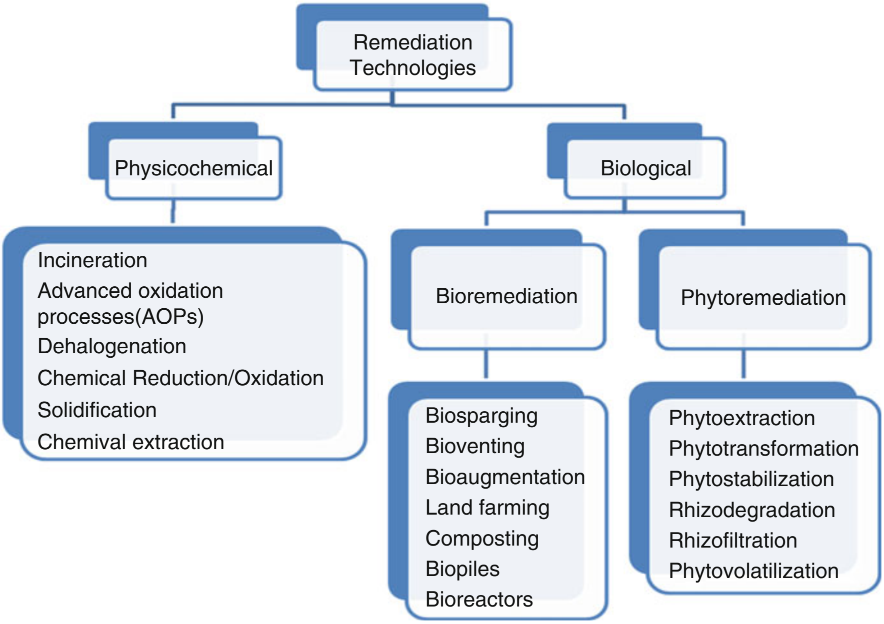

Fig. 17.2 Physicochemical and biological technologies for environmental remediation

minimal. The main disadvantage of this technique is less efficiency in pollutant removal than ex situ.

Generally, the cost of ex situ treatment process is very high, but the time requirement for this process makes it more applicable than in situ method. The soil treated by ex situ method can be further used for landscape purposes (Kuppusamy et al. 2016).

3.1 Physicochemical Remediation

Pollutant removal from water and soil can be achieved by several physical and chemical means which are as follows:

3.1.1 Incineration

It is the process which involves disposal of hazardous waste through exposing them to a very high temperature (750–1200 °C). Burning can be achieved in different types of experimental setup such as infrared combustors (infrared energy as heat source), fluidized bed combustors, circulating bed combustors, and rotary kilns, where temperature ranges in between 850 and 1010 °C depending upon the type of incineration chamber used (FRTR 2012).

Prime benefits of incineration are reduced bulky solids or wastes and the less amounts of greenhouse gases (CH_4 and CO_2) generation. Recovery of energy and aid into the economy is the other advantage in use of the incinerator. The main drawback of this technology is that it is very expensive both in construction and operation of this facility (Kuppusamy et al. 2016).

3.1.2 Advanced Oxidation Processes (AOPs)

This technology is basically based on the use of ozone along with UV or hydrogen peroxide and on the other hand UV with hydrogen peroxide. High cost of reagent (energy source, ozone, hydrogen peroxide) used in this process is the main disadvantage of the technology.

3.1.3 Dehalogenation

The technology is also called as dechlorination. In this process, halogen molecule like chlorine is replaced by hydrogen or a reducing radical containing a hydrogen donor for decomposition of contaminants in organic compounds. There are two dehalogenation processes:

1. Base catalyzed decomposition (BCD) – Where screened contaminated soil is crushed and mixed with sodium bicarbonate followed by its introduction in reactor for heating of mixture above 330 °C (630 °F) and volatilization or partial decomposition of pollutants.
2. Alkaline polyethylene glycol process – In this APEG process, polyethylene glycol (an alkaline reagent) is used to form glycol ether and/or a hydroxylated compound. An alkali metal salt also forms as by-products which are water-soluble.

3.1.4 Chemical Reduction/Oxidation

Chemical reduction/oxidation or redox reactions are the conversion of hazardous contaminants (viz., metals and inorganic, pesticides, cyanides, triazines, and formaldehyde-contaminated soils) to non-hazardous or less toxic compounds which are less mobile and so more stable. In this reaction, electrons are transferred from one compound to another, where the first compound losing electron is oxidized and the other one gaining the electron is reduced.

The most commonly used oxidizing agents are hypochlorite, chlorine, chlorine dioxide ozone, hydrogen peroxide, etc. To make the process more effective, mixture of the reagents can be used combining them with ultraviolet oxidation. In the reduction processes of unsaturated organic contaminants or high oxidation state metals like Cr (VI), metals with low oxidation potential or sodium borohydride are generally used.

The chemistry involved in this method is generally well known, and it has been used for years in related chemical processes. But the main drawback of this method is the requirement of excessive amount of reagents making it costly for high contaminant concentrations, and partial decontamination may result along with formation of intermediate contaminants.

3.1.5 Solidification

This is the method of stabilizing the contaminant by physical bound or enclosing within a low permeability mass, i.e., solidification. The mobility is reduced by the induction of chemical reaction between contaminant and stabilizing agent. This technique can be applied ex situ as well as in situ but requires additional setups. Inorganics, including radionuclides, are mostly treated by this method, whereas it has less effectiveness against organics and pesticides.

The main disadvantage in the application of this technique is generation of higher final mass of pollutants than the original contaminated soil, and contaminants are neither eliminated nor transformed into less toxic form, and only mobility is reduced.

3.1.6 Chemical Extraction

In this process, contaminants are separated from the soil to reduce the volume of contaminant. On the basis of the type of contaminants, two major chemical extraction processes are as follows:

1. Acid extraction – Acids are used to extract contaminants from soils. Additionally after decontamination, residual acid is neutralized by dewatering of soil followed by mixing it with fertilizer and lime.
2. Solvent extraction – To remove mixtures of metals and organic compounds, different solvents are used in the treatment of soil. Physical separation is generally required prior to chemical extraction, which can enhance the process by separating out particulate heavy metals.

An advantage of this technology is that it can be used for the extraction of a range of selected organic contaminants for the treatment such as SVOCs, VOCs, some fuels, explosives, and inorganics, heavy metals, etc. However, the effectiveness of this technology is limited on organics with high molecular weight (eugris.info).

3.2 *Biological Remediation*

Biological remediation is mainly of two types, i.e., bioremediation and phytoremediation.

3.2.1 Bioremediation

Bioremediation is the process for removal of environmental contaminants with the use of biological agents mainly microorganisms (Saxena and Bharagava 2016; Bharagava et al. 2019). Therefore, it is one of the best management tools for remediation and recovery of contaminated environment. Most importantly, for the success of various bioremediation technologies, the nature of contaminated site and complexity of organisms being used must be strategized prior to treatment process. Here, a list (Table 17.1) is being presented consisting of various microorganisms like fungi, anaerobes, and aerobes which have been used in environmental remediation.

These microorganisms used in bioremediation may be of indigenous nature to polluted site, or they may be isolated from elsewhere and introduced to the site

Table 17.1 Microbial agents reported in the degradation and detoxification of environmental pollutants

Microorganism	Toxic chemicals	References
Organic pollutants		
Leifsonia	Imidacloprid	Anhalt et al. (2007)
Scenedesmus obliquus, *Euglena gracilis*	DDT, parathion	Ardal (2014)
Chlamydomonas sp.	Lindane, naphthalene, phenol	
Chlorella sp.	Toxaphene, methoxychlor	
Chlamydomonas sp. *Chlorococcum* sp. *Dunaliella* sp.	Mirex	
Heavy metals		
Bacillus cereus strain XMCr-6	Cr (VI)	Dong et al. (2013)
Kocuria flava	Cu	Achal et al. (2011)
Bacillus cereus	Cr (VI)	Kanmani et al. (2012)
Sporosarcina ginsengisoli	As (III)	Achal et al. (2012)
Pseudomonas veronii	Cd, Zn, Cu	Vullo et al. (2008)
Aspergillus versicolor	Ni, Cu	Tastan et al. (2010)
Aspergillus fumigatus	Pb	Kumar et al. (2011)
Spirogyra spp. *and Spirulina* spp.	Cr Cu, Fe, Mn, Zn	Mane and Bhosle (2012)
Hydrodictyon, *Oedogonium*, and *Rhizoclonium* spp.	As, V	Saunders et al. (2012)

(Vidali 2001). Now, scientists from all over the world have started to put their energy to select or search new organism with more biodegradation ability for a number of pollutants from different environmental locations (Kumar et al. 2011). On the basis of applicability, bioremediation also can be categorized ex situ and in situ depending upon the experimental process involved.

In situ Biodegradation It is a type of bioremediation in which nutrients and oxygen are supplied into the contaminated site in the form of aqueous solution and degradation of organic contaminants is stimulated by native bacteria. This process is best applicable in case of polluted groundwater and soil.

(A) *Biosparging*

In this process, concentration of groundwater oxygen is increased by injecting pressurized air in the water, and contaminants are degraded biologically by native microorganisms. The injected air increases the contact between groundwater and soil so that saturated zone gets mixed. The requirement of less capital input in construction of the air injection system makes this process more flexible.

(B) *Bioventing*

It is the most commonly used in situ method which involves air supply with less flow rate than biosparging. Here, the nutrients and necessary oxygen are provided to indigenous bacteria through wells to stimulate biodegradation and minimize the chance of release of volatile contaminants into the environment. This process is best used for treatment of contaminants deep below the surface

(C) *Bioaugmentation*

It is the addition of potential microorganisms to the contaminated site with better degradation ability. The organism may be indigenous or exogenous.

Ex situ Bioremediation This technique involves the physical removal or excavation of polluted soil from a location. It involves:

(D) *Land Farming*

It is a very simple process which involves excavation of contaminated soil and spreading over a bed followed by periodical turning for complete degradation of contaminants by indigenous microorganisms through aerobic degradation. Advantage with this process is its reduced monitoring and maintenance cost, whereas limitation to treat superficial 10–35 cm of soil is the main drawback of this process.

(E) *Composting*

A rich microbial population for biodegradation of pollutants with a characteristic temperature of compost can be achieved by the mixing of contaminated soil with nonhazardous organic contents like agricultural wastes or manure. These organic contents support the growth or survivability of microorganisms which degrade the pollutants.

(F) *Biopiles*

A technique consisting property of both composting and land farming where cells are constructed to aerate the composted pile. Here, physical loss such as volatilization and leaching of contaminant is reduced.

(G) *Bioreactors*

In this ex situ technology of removal of pollutants, water and contaminated soil are treated in aqueous reactors or slurry reactors. Here, polluted materials are more manageable than in situ methods. The main disadvantage of this process is that it requires pretreatment like washing of soil.

3.2.1.1 Advantage of Bioremediation

It is the most natural and publically accepted process to treat pollutants. The residue produced after the practices is harmless which may include bacterial cells, water, and carbon dioxide.

It is less expensive and possesses almost complete degradation of pollutants.

3.2.1.2 Disadvantage of Bioremediation

The main disadvantage of this technology is the limitation of treatment of only biodegradable materials. Sometimes the bacterial metabolic process involved in the process is highly specific; hence a controlled environment is required for the successful degradation of contaminants. The longer time consumption and pretreatment of target media like soil contribute to the disadvantages of the process.

3.2.2 Phytoremediation

Plants are natural filter and metabolize naturally generated substances, and therefore, the use of plants for the removal of contaminants in water and soil is the emerging technology known as phytoremediation (EPA 1999, 2000; Raskin and Ensley 2000; Chandra et al. 2015; Saxena et al. 2019). This technology is further categorized in six different types of techniques (Table 17.2) which are classified on the basis of types of contaminants: phytovolatilization, phytotransformation, phytostabilization, rhizofiltration, rhizodegradation, and phytoextraction.

3.2.2.1 Phytoextraction or Phytoaccumulation

In this process, accumulation of contaminants in plant takes place in the root system and shoot or leaves present above the ground which ultimately saves economy

Table 17.2 An overview of different phytoremediation strategies for environmental decontamination

Phytoremediation techniques	Mechanism	Surface medium
Phytoextraction	Uptake and concentration of metal via direct uptake into the plant tissue with subsequent removal of the plants	Contaminated soils and wastewaters
Phytotransformation	Plant uptake and degradation of organic compounds	Surface water and groundwater
Phytostabilization	Root exudates cause metal to precipitate and become less available	Contaminated soils, ground-water, mine tailing waste
Rhizodegradation	Enhances pollutant degradation in rhizosphere	Remediation of contaminated soils and groundwater within rhizosphere
Rhizofiltration	Uptake of metals into plant roots	Surface water
Phytovolatilization	Plants evaportranspirate metals such as selenium, mercury, and volatile hydrocarbons	Contaminated soils and groundwater

Adapted from Vidali (2001)

invested in various costly remediation technologies. Contaminant like metals present even in low level can be removed from the site and accumulated in plants and further recovered by recycling from the biomass before its disposal.

3.2.2.2 Phytotransformation or Phytodegradation

It is the process in which highly toxic organic contaminants from a polluted site like water body or soil can be taken up and transformed to less toxic forms via plant system.

3.2.2.3 Phytostabilization

This process is the reduction of mobility of a contaminant and its migration into the ground level. Pollution-causing substances are leached out and absorbed to the surface of plant roots making it stable and avoiding its reentrance into the environment.

3.2.2.4 Rhizodegradation

A mutual relationship between plant root and microorganisms like bacteria and fungi residing in rhizosphere makes an environment where contaminants are broken down through the metabolic activity and secretion of enzymes and proteins from the root system of plant.

3.2.2.5 Rhizofiltration

With this remediation technology, contaminants present in the water can be filter out by the help of plant roots.

3.2.2.6 Phytovolatilization

This process is the uptake and conversion of contaminant into the gaseous state through plant system and release into the environment. Volatile organic compounds are the best candidate for this process to be treated by the help of evapotranspiration.

3.2.2.7 Disadvantages of Phytoremediation

There are several disadvantages associated with this technology. The foremost disadvantage is time consumption in treatment of a polluted site, whereas growth of plant used is also inhibited by the increase in metal level inside the plant body. Bioavailability of metal or any other contaminant is one of the major contributors in the disadvantages of this technology.

4 Plant-Microbe Interaction for Sustainable Agricultural Development and Environmental Cleanup

The interaction between plant and microbes has a very significant role in the development of agriculture as well as remediation of environment. Microbial interaction with plants may be both negative and positive, resulting in disease development or stimulation in growth of plant along with stress tolerance by the help of beneficial microbiota (Abhilash et al. 2012). In addition to it, the communication system to form an interaction between plant and microorganism also helps in resource distribution in below or above the ground across plant body and provides resistance against its competitors. This communication system modifies the physicochemical property of soil and diversity of biotic life which helps in plant growth promotion and pollutant removal from soil (Fig. 17.3). The secondary metabolites produced in form of exudates by the plant root and shoot system are responsible for the development of such communication system for the plant-microbe interaction. However, understanding the exact mechanisms of interaction is more or less difficult and complex as it takes place at different spheres of the plant system such as endosphere, phyllosphere, and rhizosphere. Therefore it is vital to understand the exact mechanisms of interaction between plant and microbes for the assessment of contribution of plant beneficial microbiota in sustainable agriculture, environmental cleanup, and restoration of ecosystem (Saleem and Moe 2014; Dubey et al. 2015).

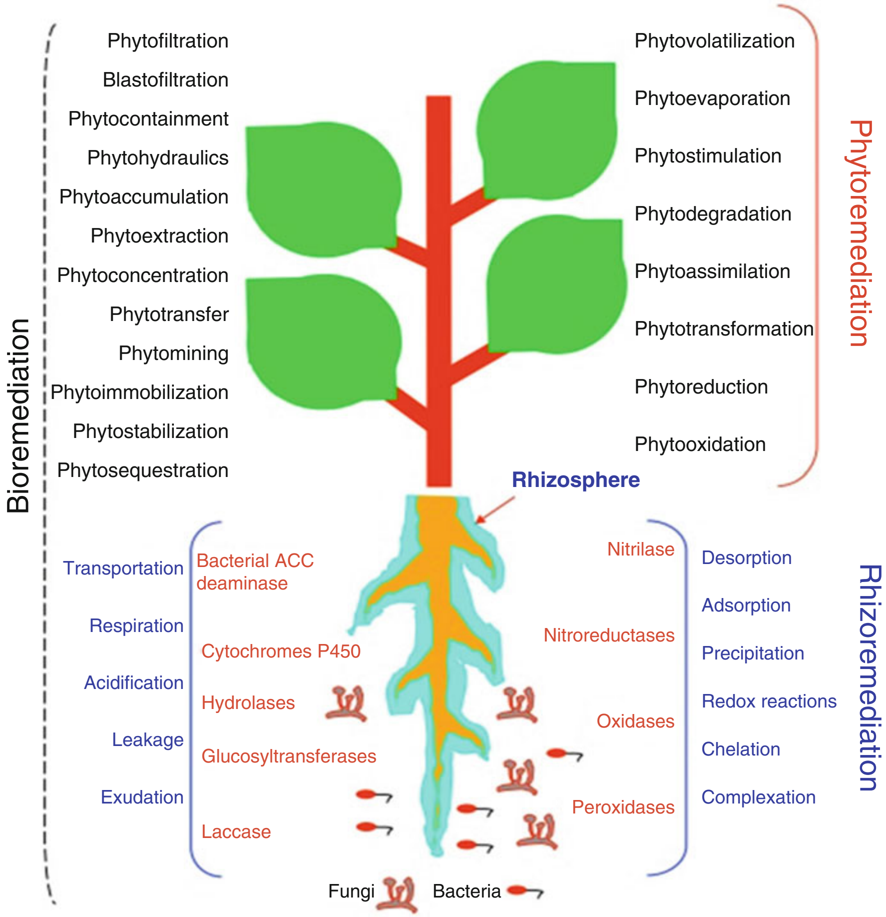

Fig. 17.3 Plant-microbe interaction and strategies to act against pollutants (Adapted from Ma et al. 2011)

Nowadays, sustainability of agriculture without a polluted environment is of major concern worldwide (Singh et al. 2011), and therefore the beneficial impact of plant-microbe associations can be a best alternative for this problem. In respect to this, several bioagents have gathered the attention of researchers for their use in biofertilizer and some other valuable effects such as healthy crop promotion and sustainable development of agroecosystem by alteration in physical, chemical, and biological factors involved in establishment of better interaction between plant and soil (Barea et al. 2005). For this purpose, studies are going on, and some species of bioagents have been commercialized like *Bacillus*, *Azospirillum*, *Pseudomonas*, *Azotobacter*, *Klebsiella*, *Enterobacter*, *Variovorax*, and *Serratia* sp. (Glick 2012).

On the other hand, microbes have role in environmental bioremediation as it is a natural process which is carried out by association of plants and microorganisms.

Therefore, bioremediation is a cost-effective tool for destruction of contaminants with the help of biological activity of microbes (Kamaludeen et al. 2003). This activity can be enhanced by the supplementation of nutrients (P and N) and other substrates like phenol, methane, and toluene (Baldwin et al. 2008; Akhtar et al. 2013). According to Weyens et al. (2009), plant-microbe interaction has a crucial role in phytoremediation by plant growth promotion and sequestration of pollutants, its detoxification, and degradation. These microbes have certain metabolic abilities and degradation pathways which results in degradation of organic pollutants and evapotranspiration of volatile organic contaminants in more effective way (Weyens et al. 2009). Some root endophytes are equipped by metal sequestration/resistance and can enhance the accumulation of these toxic metals in plant tissue even if they are present as trace element in soil (Rajkumar et al. 2012). Therefore, it is expected that microbes present in phyllosphere of the plant can resist the stress due to particulate matter contamination and promote the phytoremediation ability of plant. Growing indoor plants can increase humidity level in the air, and allelochemicals released into the environment through them can inhibit airborne harmful microbes (Berg et al. 2014; Wolverton 2008).

4.1 Role of Plant Growth-Promoting Rhizobacteria

Plant growth-promoting rhizobacteria have a very significant role in growth promotion of plants resulting in sustainable agricultural development. They aid in growth promotion of plant by two mechanisms, viz., direct and indirect mechanism. Fixation of atmospheric nitrogen, solubilization of phosphorus, synthesis of siderophore for iron chelation, and supplying siderophore-iron complex to plant so that plant may synthesize various phytohormones like gibberellins, cytokinins, and auxins come under direct mechanism, whereas indirect mechanism is brought about by control of disease-causing phytopathogens by producing antibiotics, depletion of iron in the soil, and ultimately stimulation of plant growth. On the basis of interaction with host plant, PGPR are categorized into two groups: (1) symbiotic rhizobacteria, which invade and infest the interior of the plant cell to survive (known as intracellular PGPR, e.g., bacteria forming nodule), and (2) free-living rhizobacteria that reside outside the plant and are also known as extracellular PGPR, e.g., *Azotobacter*, *Pseudomonas*, *Burkholderia*, and *Bacillus* (Babalola and Akindolire 2011; Khan 2005). Microorganisms like plant growth-promoting rhizobacteria can enhance the nutrients availability in rhizosphere (Choudhary et al. 2011). For example, nitrogen is the most limiting factor in plant growth as it is not easily available for plant, but *Azospirillum* present in cereal ecosystem can fix the free nitrogen and improve the crop yield (Tejera et al. 2005). Additionally, phosphate is also solubilized by PGPR (Wani et al. 2007), which is further taken up by plants. Vejan et al. (2016) decribe that Lavakush et al. (2014) conducted a study on PGPR strain like *Pseudomonas putida* and *Pseudomonas fluorescens* for their effect on nutrient uptake in rice.

4.2 Role of Endophytes

According to Schulz and Boyle (2006) and Lodewyckx et al. (2002), bacteria that colonize the intimate niche of plant (internal tissues) without any negative effects or infection to host are called endophytic bacteria. Except seed endophytes, the primary site to gain entry (or route of colonization) by endophytes into plants is via the roots which is now confirmed by several microscopic studies (Pan et al. 1997; Germaine et al. 2004). After getting entrance into the plant, endophyte resides in xylem or root cortex or transports through the vascular system to colonize the plant systematically (Mahaffee et al. 1997; Quadt-Hallmann et al. 1997). With interaction to plants, endophytes get carbohydrates, and in return, they provide resistance to plant from various abiotic and biotic stresses (Hamilton and Bauerle 2012; Hamilton et al. 2012). Endophytes can alter the structural community of plant (Clay and Holah 1999; Yuan et al. 2011), as well as they regulate the interaction between competitors and their host plant (Omacini et al. 2001; Clay and Holah 1999; Hyde and Soytong 2008; Guo et al. 2008)

A study of Chen et al. (2010), Shin et al. (2011), and Luo et al. (2011) describes that many endophytes are being used in phytoremediation because of metal resistance or organic pollutant degradation and plant growth promotion ability.

4.3 Role of Mycorrhiza

For plant growth development, mycorrhizae fulfil its role by providing mineral nutrients exclusively the uptake of phosphate to the plants (Moose 1972). According to Bagyaraj (1984), Entry et al. (2002), and Fomina et al. (2005), this effect is because of several key features of mycorrhiza such as (i) extra radical mycelium increases the absorbing surface and exploits large soil volume; (ii) hyphal diameter is small which leads to increase in P-absorbing surface area; (iii) P concentration is low in mycorrhiza by the formation of polyphosphates (poly P); and (iv) release of P is catalyzed by the production of phosphatases and organic acids. Hence mycorrhiza can help in sustainable development of agroecosystem by increasing plant survival rate and plant nutrients acquisition, and also it helps in increasing carbon and nitrogen deposition into the soil and reduces plant stress (Almas et al. 2004).

The infection by mycorrhiza helps in the increase of uptake of Pb and Mn by plant from soil solutions even in low concentrations (Heggo et al. 1990; Malcova and Gryndler 2003), and thus, they may play crucial role in the phytoremediation of contaminated site (Liao et al. 2003; Gohre and Paszkowski 2006; Orlowska et al. 2011; Zarei et al. 2010; Chanda et al. 2014). The association formed by ectomycorrhiza can perform a significant resistance against metallic toxicity in contaminated soil (Leyval et al. 1997) and petroleum-like compounds (Sarand et al. 1999) or polycyclic aromatic hydrocarbons (Leyval and Binet 1998).

Mycorrhiza enhance the growth of plant by improving nutrition, resistance, and tolerance against various stresses (Clark and Zeto 2000; Turnau and Haselwandter 2002). They can also be used as bioprotectants, biodegraders, and biofertilizers (Xavier and Boyetchko 2002). Several studies also report their phytoremediation potential for heavy metal-polluted soil (Chaudhry et al. 1998; Khan et al. 2000; Khan 2001; Jamal et al. 2002; Hayes et al. 2003; Khan and Ahmad 2006).

5 Genetically Engineered Microorganisms in Environmental Remediation

Genetic engineering technique which is also called as recombinant DNA technology is based on the natural genetic interchange in between microorganisms, and the organism formed is called genetically engineered microorganism (GEM) or modified microorganism (GMM). These engineered microorganisms have the capacity to bioremediate the soil, activated sludge, and groundwater by degrading varied chemical. Several researchers also suggest that the genetically modified organisms may have more potential to remediate the environment than wild ones.

Several gene complexes or plasmids are responsible for degradation of various environmental pollutants and generally for every compound, and one separate plasmid is required. According to Ramos et al. (1994), for better understanding, four categories are described:

1. OCT plasmid for degradation of hexane, decane, and octane.
2. Camphor is decomposed by CAM plasmid.
3. XYL plasmid can degrade xylene and toluenes.
4. NAH plasmid for naphthalene degradation.

The best GMM, for example, *Pseudomonas putida*, contains the NAH and XYL plasmid and a hybrid of CAM and OCT plasmid which can degrade camphor, salicylate, octane, and naphthalene. It can metabolize hydrocarbons more effectively and grow quickly on crude oil (Markandey and Rajvaidya 2004). This organism formed by the technology of genetic engineering is known as superbug (oil-eating bug).

According to Huang et al. (2004), there may be three recommended criteria for gene recombination and selection as a suitable strain: (1) after cloning, stability and expression of target gene should be confirmed for selected strains; (2) the strain should be contaminant tolerant or insensitive; and (3) strains should survive in plant rhizosphere.

Many rhizobacteria have only limited capability in degrading organic pollutants. With the use of advance molecular biology, rhizoremediation may get achieved by the construction of genetically engineered rhizobacteria with the contaminant-degrading gene (Glick 2010).

6 Future Prospects and Challenges

This chapter describes and presents lucrative information about available technologies especially for environmental bioremediation and agro-ecosystem development. However, information about organisms involved and the interaction formed with indigenous microbiota are less. In addition to it, study based on characterization of all the other microorganisms as well as increasing efficiency of these organisms with the help of new recombinant DNA technology is required. The matter of bioavailability of pollutants and longer time period required in the process like bioremediation and phytoremediation is of more concern.

7 Conclusion

The present chapter has mainly focused on the plant-microbe interaction in maintaining ecosystem sustainability along with remediation of environmental pollution. Accordingly, we first summarize key information on available remediation technologies. Then, we have discussed microorganism responsible for remediation of environmental pollutants and their interaction with plant to maintain sustainable ecosystem. Further, we have discussed on how to discover and manipulate the efficiency of these organisms with the help of genetic engineering. This chapter has a special emphasis on biological remediation technology and its superiority over physicochemical methods to treat environmental pollutants. Finally, we also outline the research required in the future.

Acknowledgment Authors are extremely grateful to Director, Defence Institute of Bio-Energy Research (DIBER), DRDO, Ministry of Defence, Government of India (GOI), India, for providing financial and infrastructural support.

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