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Review Article

# ADVANTAGEOUS OF BENEFICIAL MICROBES FOR BIOREMEDIATION OF ADULTERATED GLOBAL-CULTIVATED SOILS

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## ABSTRACT

The soil is one of the most valuable resources since it forms the foundation for many important life processes and ecosystem purposes. Worldwide, soil pollution is a result of human activities that are not sustainable, such as the use of dangerous inorganic chemicals. The mining, production, transportation, end-user use, disposal, and accidental discharge of chemicals all contribute to soil contamination, which in turn jeopardizes human life, livestock, wildlife, and entire ecosystems. Purifying and decontaminating soil with conventional procedures is labor-intensive and time-consuming and can modify the soil's physical, chemical, and biological properties. Furthermore, they do not always ensure that all impurities are eliminated. Sustainable and cutting-edge technology has developed over the last few decades. Biological soil remediation solutions, also known as soft remediation options, are being developed to integrate, namely efficient removal of soil contaminants, mitigation of soil ecotoxicity, and reduction of legally and ethically mandated hazards to the environment and human health. Soil remediation methods should not only repair soil health and provide necessary system services but also reduce noxious waste concentrations in the soil to below regulatory limits. The microorganisms have shown promise in the clean-up of soils contaminated with radioactive contaminants, heavy metals, chemical fertilizers in excess, trichlorethylene, trinitrotoluene, herbicides such as atrazine, and organophosphates. The cost of cleaning up environmental pollutants with eco-friendly technology is inexpensive when compared to other approaches, including conventional ones. The focus of the current manuscript is on using beneficial bacteria to clean up polluted farmland to ensure the longevity of the subsequent generation.

**Keywords:** Bioremediation, Heavy metal, Pesticides, Microorganism, Organophosphates.

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## INTRODUCTION

Soil remediation using the microbes has shown promise in cases where radioactive pollutants, heavy metals, excessive chemical fertilizer use, trichlorethylene, trinitrotoluene, herbicides such as atrazine, and organophosphates have affected soil health. Management of environmental toxins with eco-friendly technology is cost-effective in contrast to other procedures, including conventional ones. These methods, while often effective, can be time-consuming and costly, and they cannot always ensure that all traces of contaminants will be eliminated from the soil. Furthermore, they often result in substantial alterations to the soil's physical, chemical, and biological properties. Bioremediation methods were created to better clean contaminated environments. Considerable attention has been paid to bioremediation techniques, which involve the employment of microbes to remove soil pollutants. Several studies have been published on this topic. However, further study is needed to completely comprehend present procedures, make the necessary adjustments to improve their efficacy, and explore new possibilities based on everyday experiences.

### Soil quality

Soil health is typically defined as the degree to which a given soil can carry out its functions as a living system by maintaining biological productivity, enhancing environmental quality, and preserving plant and animal health [1]. Soil pollution is another deteriorating issue that can negatively affect soil health [2]. Due to its multifaceted and, at times, competing functions from both an ecological and a human perspective, measuring soil health requires investigating a wide range of factors. Specifically, to evaluate soil health properly: Since the physical, chemical, and biological processes in a soil ecosystem are not separate but interdependent on one another, it is imperative that chemical, (ecological) toxicological, and ecological approaches be incorporated into the evaluation, and (ii) the intended use of the contaminated site be carefully considered. The bioavailability of pollutants and, hence, the (eco) toxicity of the soil are strongly influenced by the soil's physicochemical features, such as its pH, redox potential, organic matter content, texture, and other components. The total concentration of contaminants is, unfortunately, the most important factor in environmental risk assessments of contaminated soils under most environmental legislation (ERA).

Overall soil contaminant concentration alone, however, is not sufficient for evaluating the potential adverse effects of contaminants on soil functioning [3]. It is true that the mobility and bioavailability of soil pollutants play critical roles in the uptake of these contaminants by organisms and, ultimately, in their ecotoxicity [4,5]. As bioavailability represents the fraction that can be taken up by soil organisms and/or leached to other environmental compartments, it is a much more significant element for effective soil protection and risk assessment than total contaminant concentrations. Soil properties, including pH, redox potential, moisture content, organic matter content, clay content, anionic molecule presence, and so on, have a significant impact on the bioavailability of metals [6]. Solubility, hydrophobicity, and interaction with the mineral and organic fractions of the soil matrix through physicochemical processes including sorption and complexation impact the bioavailability and mobility of organic contaminants [5].

Soil health assessments, including the selection of a soil remediation option and the monitoring of the performance of the chosen remediation technique, should always incorporate the evaluation of the bioavailable portion of the contaminants. Yet there is disagreement about how precisely to measure soil pollution's bioavailability. $NaNO_2$, $(NH_4)_2SO_4$, and $CaCl^2$ are only a few of the inorganic salts that are utilized in the most typical chemical extraction process for metal contaminants [7]. Nevertheless, in addition to total and bioavailable contaminant concentrations, biological indicators are crucial for a correct assessment of the impact of soil pollutants on soil health, as they depict the influence of contaminants on the soil biota in a very direct way [3]. Soil microbes play a critical role in a wide range of soil activities and the delivery of ecosystem services, and they also provide ecologically valuable information that combines a wide range of environmental factors [8]. In a similar vein, standardized (eco) toxicological bioassays have been developed and proposed for soil (eco) toxicity research using model organisms such as *Eisenia fetida* [9], *Vibrio fisheri* [10], *Lactuca sativa* [11], *Cucumis sativus,* etc.

### Source of soil pollution

Soil contamination implies the presence of poisons, chemicals, salts, radioactive elements, or disease-causing substances in soils at concentrations high enough to negatively impact plant growth and animal health. Seepage from a landfill, industrial waste discharge into the soil [12], contaminated water percolating into the soil [13], underground storage tank rupture, and the excessive application of pesticides, herbicides, or fertilizer are just some of the many causes of soil pollution [14]. Chemicals that is well-known for their role in soil contamination. There are many strategies being employed by environmentalists throughout the world to reduce the massive accumulation of contaminants in the soil.

## TECHNOLOGIES FOR SOIL BIOREMEDIATION

Physical and chemical methods of waste purification have traditionally been prohibitively expensive. There is also space area for storing things and throwing them away. Despite their high costs, conventional cleaning methods come with several drawbacks, including the fact that they may not always ensure that all contaminants are removed. Because of this, the quest for low-cost, environmentally friendly alternatives to standard trash compactors has increased over the past two decades. The study of waste as well as the creation and application of technologies to reduce waste have become three of the world's most rapidly expanding industries. The technology with the most potential is that which most closely mimics tried-and-true natural mechanisms that have effectively returned ecosystems to their natural condition after disturbances. Chemicals derived from natural sources (animals, plants, or minerals) are transformed, removed, or stabilized by natural processes so that they do not build up to dangerous concentrations and disrupt ecosystem stability. Governments and industries have worked together to provide secure and cost-effective waste management alternatives in response to rising public knowledge and concern about pollution of the environment. Bioremediation has emerged as a highly promising technology for eliminating various environmental pollutants. Bioremediation indicates the practice of employing naturally occurring biological activity to remove or render harmless a variety of contaminants. Hence, it employs low-tech, low-cost approaches that are popular with the general populace and are often performed on-site. Bioremediation is a technique for cleaning up polluted areas by using bacterial microbes and other living creatures to break down harmful substances. Hazardous contaminants can be degraded or detoxified using naturally occurring bacteria, fungi, or plants. It is possible that the microbes in question are native to the contaminated area, but it is also possible that they were isolated elsewhere and then moved there. Mutations and other metabolic processes in living things alter the chemical composition of contaminants [15]. The success of bioremediation depends on the ability of microbes to enzymatically digest pollutants and convert them into inert chemicals. Because bioremediation is only successful under specific environmental circumstances, it is often employed to accelerate the development and breakdown of microbes. The development and activity of microbes are affected by factors such as pH, temperature, and moisture [16]. Although certain microbes have been isolated in severe environments, most thrive in a specific temperature range, making it essential to simulate these conditions whenever possible. If the pH of the ground is too low, lime can raise it. Several biological responses are affected by temperature, with many doubling in velocity for every 10°C increase in temperature. On the other hand, each type of cell dies out at a predictable rate. Solar heating can be increased in the late spring, summer, and fall by using a plastic covering. Irrigation is required to reach the ideal moisture level because water is essential for all living things.

## SYSTEM FOR BIOREMEDIATION

Bioremediation entails the breakdown of organic pollutants into harmless by-products such as carbon dioxide, water, and biomass. The humic material could bind to certain pollutants, rendering them immobile. Degradation can happen in either aerobic or anaerobic settings. Bioremediation typically employs either an ex-situ or an in-situ aerobic approach. The ability to optimize biological activity, the accessibility of the contaminant to microbes, and the pollutant's susceptibility to biological transformation are the three fundamental ideologies that guide the assortment of the most appropriate technology from the wide range of bioremediation technologies developed to treat contaminants. Treatment costs can be reduced by hastening the degradation process through the application of appropriate technology and the modification of environmental conditions [17]. Soil and groundwater are analyzed using ex-situ techniques once they have been removed from their original environments by excavation (in the case of soil) or pumping (in the case of groundwater) (water). In situ belongs to non-disruptive treatments that are carried out directly on the ground or in the groundwater. These techniques are the most fashionable since they treat pollutants in situ, eliminating the need for costly and inconvenient excavation and transportation. However, the depth of soil that can be treated effectively limits in-situ treatment. Although many soils' optimal bioremediation rates are achieved at depths of a few centimeters to around 30 centimeters due to the presence of adequate oxygen diffusion, soils at depths of 60 centimeters and deeper have also been effectively treated [15].

### *Ex-situ* methods

Land farming, often termed land treatment or land application, is an above-ground method of soil remediation that uses biodegradation to lower the concentrations of organic contaminants. Aeration and/or the addition of minerals, fertilizers, and water are commonly employed to disseminate excavated contaminated soils in a thin coating over the ground surface and increase aerobic microbial activity inside the soils. Contaminated soil is typically treated in layers as thin as 0.4 m; hence, a substantial area is required for the process. Frequent plowing, harrowing, or milling helps accelerate deterioration by increasing the oxygen supply and mixing. This treatment method is practical if adequate land is available at a reasonable cost [17].

### Biopiles

The method combines organic composting with conventional gardening. When excavated soils are mixed with soil additives and spread out on a treatment area, forced aeration is utilized to facilitate bioremediation. When pollutants are degraded, they release carbon dioxide and water. A treatment bed, an aeration system, an irrigation/nutrient system, and a leachate collection system make up the core components of a biopile system. Covering soil mounds with plastic can reduce runoff, evaporation, and volatilization while maximizing solar heating. Mounds can reach heights of 20 feet. Before being released into the atmosphere, VOCs are cleaned up if necessary [18]. Biopiles provide an optimal environment for both aerobic and anaerobic microorganisms to thrive.

### Bioreactors

The bioreactor approach can be used in either a solid or slurry state to treat contaminated soil. Mechanical soil deterioration, through attrition and vigorous component mixing in a closed container, is the basis for the operation of solid-phase reactors. Hence, pollution, germs, nutrients, air, and water are continually exchanging information with one another. By combining contaminated soil with biomass (typically indigenous microorganisms) capable of degrading target contaminants in water slurry, a slurry bioreactor creates a three-phase (solid, liquid, and gas) mixing condition to accelerate the bioremediation rate of soil-bound and water-soluble pollutants. Compared to in situ or solid-phase systems, the rate and volume of biodegradation in a bioreactor are greater because the contained environment is more manageable and, hence, more regulated and predictable. Nevertheless, contaminated soil must be pre-treated (e.g., excavated) before being placed in a bioreactor. Soil washing or physical extraction (e.g., vacuum extraction) can be used to remove the contaminant from the soil [15].

### Composting

The presence of metallic pollutants in organic residues, trash, and by-products can be mitigated using bioremediation, which employs this method to degrade potentially harmful organic molecules. Akin to the way soil naturally decomposes organic matter through the action of microorganisms, composting is a method for processing such waste. Composts have a higher temperature than soils, which increases metabolic activity and the solubility of pollutants. Composts with a high concentration of substrates are more likely to facilitate the co-metabolization of organic pollutants. Mechanically processing biodegradable materials, such as grinding, mixing, and sieving, to remove undesirable or non-degradable constituents, including metals, plastics, glass, and stones, creates a conducive environment for biological treatment. The compost mechanism's efficacy is influenced by several factors, including the specific organic pollutant, the composting setting and methods, the composition of the microbe population, and the passage of time [19].

## *IN-SITU* METHODS

### Biosparging

Organic waste is decomposed by local bacteria, which are activated and utilized in waterlogged soil. Introducing air into the saturated zone via boreholes enhances oxygen dissolution and the activity of the soil's indigenous microbes. More oxygen speeds up the natural process of aerobic biodegradation of pollutants in soil or groundwater. Biosparging can lessen the number of petroleum chemicals that are absorbed by soil at the capillary fringe or below the water table. Because lighter petroleum molecules volatilize rapidly and are removed swiftly through sparging, biosparging is commonly utilized in areas where mid-weight petroleum compounds are used, such as diesel fuel. The permeability of the soil is crucial to the success of the technology [15,17].

### Bioventing

*In-situ* remediation employs native bacteria to decompose organic matter stuck in the unsaturated zone of the soil. The system relies on a combination of vacuum boosting and soil vapor extraction. Subterranean pressure shifts attract atmospheric air and other oxygen sources, which are essential for the aerobic breakdown of pollutants. Used for cleaning diesel, kerosene, jet fuel, and gasoline, among other petroleum products. If the pollutants to be treated are volatile, the extracted soil vapor must be treated by adsorption of the contaminants on activated carbon, followed by biodegradation in a biofilter [17].

### Bioaugmentation

Microbes, either foreign or indigenous, are introduced to contaminated areas. Most soils that have been exposed to biodegradable waste for an extended period contain indigenous microbes that are good degraders if the land treatment unit is managed properly, and nonindigenous cultures rarely compete with indigenous populations well enough to develop and maintain viable population levels, both of which limit the usefulness of using additional microbial cultures in a land treatment unit [15].

### Bioremediation of organic contaminants

Whenever contaminated areas are likely to contain a wide variety of organic pollutants, it will be necessary to employ a wide range of microorganisms to remove them (Table 1). In 1947, the first biological remediation agent to get trademark protection was a strain of *Pseudomonas putida.* As reported by Prescott *et al.* [20]. There have been many more additions to the collection since then, representing at least 11 distinct prokaryotic classes [21]. Microorganisms may degrade organic contaminants in two ways: with oxygen (respiration) or without it (anaerobic conditions) (denitrification, methanogenesis, and sulfidogenesis). Almost all environmental pollutants are more quickly and completely degraded under aerobic conditions. An essential enzymatic step in aerobic biodegradation is oxidation, which is catalyzed by oxygenase and peroxidase. Incorporating oxygen into a substrate is the job of oxygenases, a class of oxidoreductases. Both the first assault on the substrate and the latter phases of the respiratory chain, which are essential for the survival of degradative organisms, require oxygen. In anaerobic environments, soluble carbon molecules are degraded sequentially to methane, carbon dioxide, ammonia, and hydrogen sulfide by a synoptic interaction of fermentative and acetogenic bacteria with methanogens or sulfate reducers. In terms of kinetics and capabilities, anaerobic degradation has long been seen as second-best to aerobic degradation. Anaerobic approaches have been demonstrated to be more successful and less expensive than aerobic treatment when dealing with significant loads of organic contaminants that can be quickly decomposed.

**Table 1: Microbes recognised for metabolism of organophosphates in culture and in field conditions**

| S. No. | Organophosphates | Bacteria | Fungi |
|---|---|---|---|
| 1. | Chlorpyrifos | *Bacillus* sp.<br>*Kurthia* sp. | *Aspergillus niger*<br>*Claviceps* sp. |
| 2. | Diazinon | *Anthrobacter* sp.<br>*Pseudomonas diminutum* | *Aspergillus oryzae*<br>*Trichoderma* sp. |
| 3. | Dimethonate | *Pseudomonas putida*<br>*Rhizobium* sp. | *Claviceps* sp.<br>*Penicillium notatum* |
| 4. | Dichlorvos | *Bacillus coagulans*<br>*Pseudomonas melophthora* | *Aspergillus niger*<br>*Penicillium notatum* |
| 5. | Malathion | *Bacillus subtilis*<br>*Rhizobium japonicum* | *Aspergillus spp.*<br>*Trichoderma viride* |

### Pesticides

The organic herbicides atrazine and organophosphate are two of the most widely utilized. While using conservation tillage, atrazine is by far the most common herbicide employed. First used in the 1950s, its primary function has been weed control in the production of staple crops including sugar cane, sorghum, and maize. Atrazine is resistant to biodegradation because of its solubility of only approximately 30 mg/l and its half-life of more than 170 days in soils with atrazine-degrading bacteria [22]. Atrazine is a persistent pesticide that is often detected in water samples taken from the surface and the ground, posing a direct threat to humans who drink this water. Atrazine, like other triazine herbicides, kills plants by binding to the plastoquinone-binding protein of photosystem II, a protein that is absent in mammals. Inadequate nutrition and oxidative stress brought on by a breakdown in the electron transport pathway kill plants. Ultraviolet radiation has a multiplicative effect on oxidative stress [23]. Claimed endocrine disruptor effects, possible carcinogenic impact, and epidemiological relation to lower sperm counts in males have led to calls for its ban in the United States [14]. The atrazine-degrading bacteria Pseudomonas sp. ADP has been studied the most extensively. Atrazine is biodegraded by Pseudomonas sp. ADP using the AtzA, B, and C enzymes. This process ultimately yields cyanuric acid. After being metabolized by AtzA, atrazine becomes hydroxy atrazine, which is then deamidated hydrolytically to produce N-isopropylammelide. In the end, AtzC, a hydrolytic deamidase comparable to AtzB, converts N-isopropylammelide to cyanuric acid. Cyanuric acid is mineralized by enzymes produced by soil microorganisms into carbon dioxide and ammonia. To wit [13,24].

More than a hundred OP pesticides are in use, accounting for 38% of all pesticides [25]. Insecticides and CW agents both include organophosphates, which are very toxic neurotoxins. The organophosphate family includes paraoxon, parathion, chlorpyrifos disulfoton, ruelene, carbophenothion, and dimeton. The ability of this family of drugs to block acetylcholinesterase, preventing it from decomposing acetylcholine at the synaptic junction, is the primary cause of their neurotoxicological effects. These chemicals have also been linked to abnormalities and chromosome damage in people who have bladder cancer. Phosphotriesterases are a class of enzymes found in bacteria, humans, and other animals and plants that break down OP. Insight into OP degradation has progressed dramatically thanks to years of study into OP biodegradation. As the issue has been better understood, its applicability has expanded into several industrial contexts [25].

## BIOREMEDIATION OF INORGANIC CONTAMINANTS

### Heavy metals

Heavy metals are the most widespread inorganic pollutants, and they have polluted a large swath of land due to mining, industrial, agricultural, and military activities. Metals are found in the earth's crust in varying amounts, and many of them, including copper, iron, manganese, nickel, and zinc, are essential for cellular function, but at larger concentrations, they become toxic. A "contaminant" may be any metal (or metalloid) species that have been found in an undesirable location, pose a threat to human health or the environment, or are present in excessive amounts [26]. Soil metal concentrations typically fall between 1 and 70,000 mg/kg. Regardless of the source of the metals in the soil, high concentrations of various metals may cause soil degradation, decreased crop production, and subpar quality in the resulting agricultural products [27]. Heavy metals represent a long-term threat to human and environmental health since they are not biodegradable and may accumulate in dietary sources [28]. Arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), and zinc are some of the metals or metalloids mentioned (Zn). Aluminium (Al), cesium (Cs), cobalt (Co), manganese (Mn), molybdenum (Mo), strontium (Sr), and uranium (U) are all examples of less frequent metallic species that might be considered contaminants [26].

It has been found that high concentrations of Pb may stay in the soil for up to 150 years following sludge application, making it one of the most persistent metals with a soil retention period of 150–5,000 years [29,30]. CD has a half-life of around 10 years in the human body and an average biological half-life of 18 years [31]. Harmful heavy metals are problematic because they may enter the food chain and accumulate in the bodies of animals and people, where they can damage DNA and have cancerous consequences owing to their mutagenic qualities [31]. For instance, Cd, Cr, and Cu have all been linked to anything from dermatitis to cancer in humans [29]. In high quantities, metal ions may entirely restrict the microbial population by blocking a range of metabolic activities, including protein denaturation, cell division suppression, and the destruction of cell membranes. Conversely, organisms may adapt to survive in environments with elevated metal concentrations. Metals are everlasting because they cannot be removed physiologically, even though environmental conditions may create changes in species composition and bioavailability [18]. It is the dissociation of metal ions from their native binding sites or their interactions with ligands that causes metal toxicity in microorganisms [32,33]. Metal ions such as $Hg^{2+}$, $Cd^{2+}$, and $Ag^{2+}$ have the propensity to attach to SH groups, which may block the action of sensitive enzymes [32]. Metals may also affect enzyme specificity, damage cell membranes, and disrupt cellular processes when present in high enough amounts [33]. Because of this, bacteria have evolved components involved in maintaining metal ion homeostasis and determinants of metal resistance [32,33].

There are six potential pathways for a metal resistance system: exclusion via a permeability barrier, intra- and extra-cellular sequestration, active efflux pumps, enzymatic reduction, and decreased sensitivity of cellular targets to metal ions [32-36]. Table 2 lists some of the resistance mechanisms that allow microorganisms to thrive in metal-contaminated environments. Both inorganic redox conversions and conversions from inorganic to organic form and vice versa, most often methylation and demethylation, are examples of metal microbial transformations that execute a wide range of activities in harsh settings. Microbes may generate energy by oxidizing iron, sulfur, manganese, and arsenic. Yet metals may also be reduced by a process called dissimilatory reduction, which occurs when microorganisms utilize them as terminal electron acceptors during anaerobic respiration. Oxyanions of As, Cr, Se, and U, as discovered by Tebo and Obraztsova [37], may be employed as final electron acceptors in anaerobic respiration by microorganisms. In addition, it is thought that microorganisms possess reduction pathways unrelated to respiration that provide metal resistance. Common detoxification mechanisms among microorganisms include the aerobic and anaerobic reduction of Cr (VI) to Cr (III), the reduction of Se (VI) to elemental selenium [38], the reduction of U (VI) to U (IV) [38], and the reduction of Hg (II) to Hg (0) [39]. Since methylated substances are generally volatile, microbial methylation plays a significant role in the biogeochemical cycle of metals. Biomethylation by various bacteria (Pseudomonas sp., Escherichia sp., Bacillus sp., and Clostridium sp.) of mercury (Hg [II]) results in the production of gaseous methylmercury, the most poisonous and easily accumulated form of mercury [35,40]. Biomethylation of arsenic to gaseous arsines, selenium to volatile dimethyl selenide, and lead to dimethyl lead has been observed to occur in a variety of soil environments [40-42].

**Table 2: Microbe utilizes heavy metals**

| S. No. | Elements | Microorganism |
|---|---|---|
| 1. | Cadmium | *Aspergillus niger*<br>*Ganoderma applantus* |
| 2. | Cobalt | *Phormedium valderium*<br>*Zooglea* sp. |
| 3. | Chromium | *Desulfovibrio vulgaris*<br>*Desulfovibrio fructosovorans* |
| 4. | Nickel | *Chlorella vulgaris*<br>*Zooglea* sp. |
| 5. | Mercury | *Chlorella vulgaris*<br>*Rhizopus arrhizus* |
| 6. | Silver | *Aspergillus niger*<br>*Geobacter metallireducens* |
| 7. | Zinc | *Aspergillus niger*<br>*Pleurotus ostreatus* |

## AM FUNGI IMPROVE BIOREMEDIATION

The complete ability that AM fungi can play in agriculture, phytoremediation habitat loss, and whilst complete to attain healthier lawns are currently being investigated. The ability to restore regions affected by industrial processes ought to enhance the effective value of the area by promoting the revegetation of the area and rebuilding the soil of the disturbed area. Similarly, the ability to enhance agricultural yields, if it no longer enhances plant survival, through inoculating the soil with AM fungi ought to prove to be a beneficial strategy in the future to ensure food security.

Pollution from heavy metals reduces the efficiency of soil microorganisms and microbial activities. Long-term impacts on the soil and the high toxicity of heavy metals to soil microorganisms and microbiological processes are accepted as established truths. Tolerance, the capacity to survive in the presence of high internal metal concentrations, and avoidance, the ability to restrict metal absorption, both contribute to the heavy metal resistance shown by all microorganisms, including AM fungus. Recently, phytoremediation, the practice of using plants to clean polluted soils, has emerged as a promising strategy for safe and environmentally sound soil cleaning. Rumor has it that AM fungi have developed mechanisms that may mitigate the dangers of heavy metals in co-culture settings. Surface-active polysaccharides are incorporated into the fungal cell wall, metal compounds are immobilized, polyphosphate granules are precipitated from the soil, and AM fungi chelate heavy metals [43].

The capacity of AM fungus to trap metal and protect plants is related to the number of external hyphae generated by the fungi. Nevertheless, this is contingent on whether AM fungus species have evolved biological defenses against toxic metals. The mycorrhizal fungus *Glomus caledonium* seems to be useful in the bioremediation of heavy metal-contaminated soil.

### Carbon cycling

A significant quantity of carbon flows via AM fungal mycelia to extraordinary additives in soils. The production of glycoproteins, inclusive of glomalin, which might be involved in the formation and strength of soil aggregates, ought to have added an essential influence on extraordinary microorganisms associated with the AM fungal mycelium [16,43-45].

### Phytoremediation

Disturbance of native plant groups in desertification-threatened regions is frequently accompanied by degradation of physical and biological soil properties, soil structure, nutrient availability, and organic matter. When restoring disturbed land, it is crucial to replace not only the above-ground vegetation but also biological and physical soil properties [46,47]. A particularly new technique for restoring land is to inoculate the soil with AM fungi while reintroducing vegetation in ecological restoration. It has enabled host plants to establish themselves on degraded soil and enhance soil quality and health [16,44,48,49]. Soil's quality parameters had been considerably improved over the long term when a mixture of indigenous AM fungal species was introduced compared to non-nodulated soil and soil inoculated with a single exotic species of AM fungi [47]. The benefits had been elevated PG, enhanced P uptake [46], soil N content, higher soil organic matter, and soil aggregation, attributed to higher legume nodulation in the presence of AM fungi, higher water infiltration, and soil aeration because of soil aggregation [43,47]. Native strains of AM fungi improve the extraction of heavy metal(s) from polluted soils and make the soil healthy and appropriate for crop production [50].

The vital and useful symbiotic relationship between plants and AM fungi cannot be taken for granted. Life without AM fungi might be extensively different because the beneficial relationship between AM fungi and the plant is of utter significance for their survival. Their role in the ecosystem, in addition to agriculture, might be impossible to replace.

## PROSPECTS AND IMPORTANCE OF BIOREMEDIATION

Bioremediation is a strategy for cleaning up polluted ecosystems. This includes things like polluted soil, water, and seas. Many types of vegetation, algae, fungus, and bacteria may all be found in these webs. When exposed to a harmful substance, they may break it down chemically, immobilize it, or absorb it into their bodies. One of the key benefits is that these systems do less damage to the environment and produce fewer or no by-products. Physical and chemical therapies have conventionally been both costly and ineffectual. Hence, by analyzing previous bioremediation research, the development of more efficient and useful bioreactors or products is possible. These tools could also be able to rid the world of all contaminants. By-products include several valuable chemicals.

## CONCLUSION

Sustainable biological soil remediation methods are being developed to successfully remove pollutants from soil, minimize their bioavailability, mobility, (eco)toxicity, and potential threats to the environment and human health, and restore soil health and ecosystem services at the same time. When it comes to decontaminating polluted areas, bioremediation is quickly displacing traditional physicochemical approaches. Given its usefulness, labor intensity, safety, and environmental friendliness, this field has seen significant growth during the 1990s. Nevertheless, since bioremediation sometimes requires many treatment processes, may extend for years or even decades, and is often coupled with other treatments, estimating its efficacy can be challenging. Further interdisciplinary study into process optimization, validation, environmental effects, and the efficacy and predictability of the method is needed to make it a commonly utilized technology.

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