The Pharma Innovation Journal 2022; 11(12): 3644-3647

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(12): 3644-3647

www.thepharmajournal.com
Received: 08-10-2022
Accepted: 14-11-2022

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Phytoremediation: A remedy for problematic soil-review paper

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Abstract
Phytoremediation, the use of plants and their associated microbes for environmental cleanup, has gained acceptance in the past 10 years as a cost-effective, noninvasive alternative or complementary technology for engineering-based remediation methods. Plants can be used for pollutant stabilization, extraction, degradation, or volatilization. The use of plants (directly or indirectly) to remediate contaminated soil or water is known as phytoremediation. This technology has emerged as a more cost effective, noninvasive, and publicly acceptable way to address the removal of environmental contaminants. Plants can be used to accumulate inorganic and organic contaminants, metabolize organic contaminants, and encourage microbial degradation of organic contaminants in the root zone. Widespread utilization of phytoremediation can be limited by the small habitat range or size of plants expressing remediation potential, and insufficient abilities of native plants to tolerate, detoxify, and accumulate contaminants. A better understanding and appreciation of the potential mechanisms for removing contaminants from the root zone and the interaction between plants, microorganisms, and contaminants will be useful in extending the application of phytoremediation to additional contaminated sites.

Keywords: Phytoremediation, problematic soil, rhizofiltration

1. Introduction
In the modern age of rapid industrialization, it is not possible to avoid the toxic chemicals and metals in the environment. Especially heavy metals pollution has become a serious threat to the environment and food security because of rapid growth in industries and agriculture and disturbance of natural ecosystem due to enormous increase in world population. Unlike organic pollutants, biodegradation of heavy metals is just out of question and hence are continuously accumulating in the environment (Sarwar *et al.*, 2010) [1]. Accumulation of these heavy metals in agricultural soils and water resources poses a great threat to human health due to potential risk of their entry into food chain (Sarwar *et al.*, 2010) [1].
A major environmental concern due to dispersal of industrial and urban wastes generated by human activities is the contamination of soil. Controlled and uncontrolled disposal of waste, accidental and process spillage, mining and smelting of metalliferous ores, sewage sludge application to agricultural soils are responsible for the migration of contaminants into non-contaminated sites as dust or leachate and contribute towards contamination of our ecosystem. A wide range of inorganic and organic compounds cause contamination, these include heavy metals, combustible and putriscible substances, hazardous wastes, explosives and petroleum products. Major component of inorganic contaminates are heavy metals [Adriano (1986)] [2] they present a different problem than organic contaminants. Soil microorganisms can degrade organic contaminants, while metals need immobilisation or physical removal. Although many metals are essential, all metals are toxic at higher concentrations, because they cause oxidative stress by formation of free radicals. Another reason why metals may be toxic is that they can replace essential metals in pigments or enzymes disrupting their function [Henry (2000)] [3]. Thus, metals render the land unsuitable for plant growth and destroy the biodiversity.

2. Mechanisms of Phytoremediation
Area that absorbs and accumulates water and nutrients essential for growth along with other non-essential contaminants. Six mechanisms by which plants can affect contaminant mass in soil, sediments, and water. Although many similarities can be observed between some of these mechanisms, and the nomenclature varies.

Each of these mechanisms will have an effect on the volume, mobility, or toxicity of contaminants, as the application of phytoremediation is intended to do [23].

2.1 Phytoextraction

This also called phytoaccumulation, it refers to the uptake of metal contaminants in the soil by plant roots into the above ground portions of the plants. Phytoextraction is primarily used for the treatment of contaminated soils. This approach uses plants to absorb, concentrate, and precipitate toxic metals from contaminated soils into the above ground biomass (shoots, leaves, etc.). Discovery of metal hyperaccumulator species demonstrates that plants have the potential to remove metals from contaminated soils. A hyperaccumulator is a plant species capable of accumulating 100 times more metal than a common non-accumulating plant. Metals such as nickel, zinc and copper are the best candidates for removal by phytoextraction because it has been shown that they are preferred by a majority of plants (approximately 400) that uptake and absorb large amounts of metals. There are several advantages of phytoextraction. The cost of phytoextraction is fairly low, when compared to conventional methods. Another benefit is that the contaminant is permanently removed from the soil. In addition, the amount of waste material that must be disposed of is substantially decreased [26] (up to 95%) and in some cases, the contaminant can be recycled from the contaminated plant biomass. The use of hyperaccumulator species is limited by slow growth, shallow root system, and small biomass production. In addition, the plant biomass must also be harvested and disposed of properly. There are several factors limiting the extent of metal phytoextraction including: • Metal bioavailability within the rhizosphere • Rate of metal uptake by roots • Proportion of metal "fixed" within the roots • Rate of xylem loading/translocation to shoots • Cellular tolerance to toxic metals The method is also usually limited to metals and other inorganic compounds in soil or sediment. In order for this clean-up method to be feasible, the plants must (1) extract large concentrations of heavy metals into their roots, (2) translocate the heavy metal into the surface biomass, and (3) produce a large quantity of plant biomass. In addition, remediative plants must have mechanisms to detoxify and/or tolerate high metal concentrations accumulated in their shoots [27].

2.2 Rhizofiltration

This is used to remediate extracted groundwater, surface water, and wastewater with low contaminant concentrations. It is the adsorption or precipitation onto plant roots or absorption of contaminants surrounding the root zone. Rhizofiltration is typically exploited in groundwater (either in situ or extracted), surface water, or wastewater for removal of metals or other inorganic compounds. Rhizofiltration can be used for Pb, Cd, Cu, Ni, Zn, and Cr, which are primarily retained within the roots. Rhizofiltration is similar to phytoextraction, but the plants are used contaminated ground water rather than soil. To acclimatize the plants, once a large root system has been developed, contaminated water is collected from a waste site and brought to the plants where it is substituted for their water source. The plants are then planted in the contaminated area where the roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested. Sunflower, Indian mustard, tobacco, rye, spinach, and corn have been proved for their ability to remove lead from water, with sunflower having the greatest ability. The advantages associated with rhizofiltration are the ability to use both terrestrial and aquatic plants for either in situ or ex situ applications. Another advantage is that contaminants do not have to be translocated to the shoots. Thus, species other than hyperaccumulators may be used. Terrestrial plants are preferred because they have a fibrous and much longer root system, increasing the amount of root area. Disadvantages include the constant need to adjust pH, plants may first need to be grown in a greenhouse or nursery; there is periodic harvesting and plant disposal; and a good understanding of the chemical speciation/interactions is needed.

2.3 Phytovolatilization

This involves the use of plants to take up contaminants from the soil, transforming them into volatile forms and transpiring them into the atmosphere. Phytovolatilization may also refer the diffusion of contaminants from the stems or other plant parts that the contaminant travels through before reaching the leaves. Phytovolatilization can occur with contaminants present in soil, sediment, or water. Mercury is the primary metal contaminant that this process has been used for. It has also been found to occur with volatile organic compounds, including trichloroethene, also as well as inorganic chemicals that have volatile forms, such as selenium, and arsenic. The advantage of this method is that the contaminant, mercuric ion, may be transformed into a less toxic substance. The disadvantage to this is that the mercury released into the atmosphere is likely to be recycled by precipitation and then redeposited back into lakes and oceans, repeating the production of methylmercury by anaerobic bacteria.

2.4 Phytostabilization

This is also referred to as in-place inactivation. It is used for the remediation of soil, sediment, and sludge. It is the use of certain plant species to immobilize contaminants in the soil and ground water through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants (rhizosphere). This process decreases the mobility of the contaminant and prevents migration to the ground water and it reduces bio-availability of metal into the food chain. This technique can also be used to re-establish vegetation cover at sites where natural vegetation fails to survive due to high metals concentrations in surface soils or physical disturbances to surface materials. Metal-tolerant species is used to restore vegetation at contaminated sites, thereby decreasing the potential migration of pollutants through wind erosion and transport of exposed surface soils and leaching of soil contamination to ground water. Phytostabilization can occur through the sorption, precipitation, or metal valence reduction. It is useful for the treatment of lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn). Advantage of this method is the changes that the presence of the plant induces in soil chemistry and environment. These changes in soil chemistry may induce adsorption of contaminants onto the plant roots or soil or cause metals precipitation onto the plant root. Phytostabilization has been successful in addressing metals and other inorganic contaminants in soil and sediments. Some of the advantages associated with this technology are that the disposal of hazardous material/biomass is not required and it is very effective when rapid immobilization is needed to preserve ground and surface waters [28]. The presence of plants also reduces soil erosion and decreases the amount of water available in the system. However, this clean-up technology has several major disadvantages including: contaminant remaining in soil, application of extensive fertilization or soil amendments, mandatory monitoring is required, and the stabilization of the contaminants may be primarily due to the soil amendments.

2.5 Phytodegradation

This is also referred to as phytotransformation. It involves the degradation of complex organic molecules to simple molecules or the incorporation of these molecules into plant tissues [29]. In the Phytodegradation mechanism contaminants are broken down after they have been taken up by the plant. As with phytoextraction and phytovolatilization, plant uptake generally occurs only when the contaminants' solubility and hydrophobicity fall into a certain acceptable range. Phytodegradation has been showed to remediate some organic contaminants, such as chlorinated solvents, herbicides, and munitions, and it can address contaminants in soil, sediment, or groundwater.

2.6 Rhizodegradation

This is also referred to as phytostimulation. Rhizodegradation refers to the breakdown of contaminants within the plant root zone, or rhizosphere. It is believed to be carried out by bacteria or other microorganisms. Studies have documented up to 100 times as many microorganisms in rhizosphere soil as in soil outside the rhizosphere. Microorganisms may be so prevalent in the rhizosphere because the plant exudes sugars, amino acids, enzymes, and other compounds that can stimulate bacterial growth. The roots also provide additional surface area for microbes to grow on and a pathway for oxygen transfer from the environment. The localized nature of rhizodegradation means that it is primarily useful in contaminated soil, and it has been investigated and found to have at least some successes in treating a wide variety of mostly organic chemicals, including petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), chlorinated solvents, pesticides, polychlorinated biphenyls (PCBs), benzene, toluene, ethylbenzene, and xylenes. It can also be seen as plant-assisted bioremediation, the stimulation of microbial and fungal degradation by release of exudates/enzymes into the root zone (rhizosphere) [3].

Advantages of phytoremediation

Phytoremediation is an effective, in situ, non-intrusive, low-cost, ecologically benign and socially accepted technology for cleaning up contaminated soils. It also prevents the destruction of the landscape and enhances the activity and diversity of soil microorganisms to support healthy ecosystems, which is therefore considered a more attractive alternative to the methods presently used to treat heavy metal pollution [3, 7]. Phytoremediation takes advantage of the unique, selective, and natural absorption capacity of plant root systems, as well as the translocation, bioaccumulation, and contaminant storage/degradation capacity of the complete plant body. Many plant species, both terrestrial and aquatic, have significant hyperaccumulation capacity that can be used for soil and water phytoremediation. The ease of application and applicability to a large variety of metals, radionuclides, and organic substances. In addition, the wide applicability of the technology allows it to be used at sites that cannot be easily remediated by other methods. For example, large sites with low concentrations of widely dispersed pollutants at low depths represent an interesting challenge for which phytoremediation is particularly suited.

Conclusion

Phytoremediation is a fast developing field, since last ten years lot of field application were initiated all over the world, it includes Phytoremediation of Organic, Inorganic and Radionuclides. This sustainable and inexpensive process is fast emerging as a viable alternative to conventional remediation methods, and will be most suitable for a developing country like India. Most of the studies have been done in developed countries and knowledge of suitable plants is particularly limited in India. In India commercial application of Phytoremediation of soil Heavy metal or Organic compounds is in its earliest phase. Fast growing plants with high biomass and good metal uptake ability are needed. In most of the contaminated sites hardy, tolerant, weed species exist and phytoremediation through these and other non-edible species can restrict the contaminant from being introduced into the food web. However, several methods of plant disposal have been described but data regarding these methods are scarce. Composting and compaction can be treated as pre-treatment steps for volume reduction, but care should be taken to collect leachate resulting from compaction. Between the two methods that significantly reduce the contaminated biomass, incineration seems to be least time consuming and environmentally sound than direct burning or Ashing.

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