Indian J.Sci.Res. 14 (1): 127-130, 2017
ISSN: 0976-2876 (Print)
ISSN: 2250-0138 (Online)

REVIEW ON PHYTOREMEDIATION TECHNOLOGY FOR REMOVAL OF SOIL CONTAMINANT

G. SREELAL[a1] AND R. JAYANTHI[b]

[a]Research Scholar, Department of Civil Engineering, Periyar Maniammai University, Thanjavur, India
[b]Dean (School of Engg. & Tech.), Department of Civil Engineering, Periyar Maniammai University, Thanjavur, India

ABSTRACT

Phytoremediation technology utilizes the use of plants to clean up the contaminated environment and is sturdily budding at recent times. Various researchers clearly established that plant species hold the potential to eliminate, degrade, metabolize, or immobilize contaminants. In spite of having this incredible potential, Phytoremediation still exists as a non-commercial technology due to the poor understanding of the effect of agronomic practices. Phytoremediation potential depends upon the interaction of various biotic and abiotic factors and hence practitioners should own right perceptive on plant biology, and the effect of agronomic practices on plant/soil/contaminant. This study reviews the general Phytoremediation processes and plant mechanisms for removing contaminants from the soil and confers the effects of agronomic practices on these processes.

KEYWORDS: Phytoremediation, Contaminated Soil, Agronomic Practice, Contaminant Removal, Toxic Metals, Green Technology.

The Greek word phyto (plant) and the Latin word remedium (to correct) together constitutes the generic term Phytoremediation [Cunningham et al., 1996. Cunningham S.D. and Ow D.W., 1996]. Mechanical cleanup technologies that require high capital cost and labor can be used along with or could be ideally replaced with the conventional Phytoremediation technology. Phytoremediation technology utilizes the inherent plant abilities and is said to be a non destructive and in-situ remediation technology for the cleanup of contaminated soil. Its concept of using nature to clean nature makes it an eco- friendly cleanup technology [UNEP (Undated)].

Since 1991 the term Phytoremediation has been used to describe the usage of plants to reduce the volume and toxicity of contaminants from any contaminated media [USEPA, 2000]. Plants help to clean up pollution caused by metals, oil, pesticides and explosives. Plants prevent the transfer of the pollutant from one site to the other through groundwater, wind and rain. Tropical areas that stimulate microbial activity and that which favor plant growth are ideal for this technology and Phytoremediation potential on these areas were observed high [Zhang et al., 2010].

Plants ability to remove contaminant has been recognized and has been applied in wasteland farming since 1700. These uses of plants in the removal of contaminants lead to the evolution of constructed wetlands and in the usage of plants in air pollution monitoring. The damage resulting due to industrial growth and extensive chemical usage lead to the recognition to find technologies that could address the contamination by residues, among them phytoremediation has been used in recent years [USEPA, 2000].

METHODS OF PHYTOREMEDIATION

Ex-situ Method

This method needs contaminated soil removal for treatment either onsite or offsite and returning the soil back to the restored site. This method involves the destruction of contaminant either chemically or physically and relies on detoxification and excavation. After treatment, the contaminant finally undergoes stabilization, immobilization, solidification, destruction or incineration.

In-situ Method

In this method excavation of the contaminant site is not needed. This method involves immobilization, destruction, separation or transformation of contaminant from the bulk soil [Reed et al., 1992]. Due to reduced ecological impact and reduced cost in-situ techniques are preferred over ex-situ technique. Normally, Ex-situ technique involve the burial of heavy metal contaminated soil in the landfill site and henceforth this method is not the best option for remediation as this technique simply transfer the contaminant elsewhere together with the hazards during its transport [Smith B., 1993].

MECHANISMS OF PHYTOREMEDIATION

The soil property, bioavailability and the type of contaminant determine the efficiency and mechanism of Phytoremediation [Cunningham S.D. and Ow D.W., 1996].Primary uptake of contaminants in the plant occurs in the root system as it accumulates water and absorbs nutrients essential for growth along with non-essential contaminants [Raskin I. and Ensley B.D., 2000]. The contaminant mass on soil, water and sediments were affected by the following plant mechanisms.

Phytodegradation

In this process, complex organic molecules are degraded to simple molecules and are incorporated into plant tissues. Fall in the solubility and hydrophobicity of contaminants tends the occurrence of plant uptake. Sites contaminated with herbicides, chlorinated solvents were remediated through the process of phytodegradation

[1]Corresponding author

[EPA (2000)]. It is also referred to as phytotransformation.

Phytovolatilisation

In this process, the contaminants taken up by plants from soil were transpired into the atmosphere after converting them into volatile form [USEPA, 2000].Before reaching the leaves these contaminants are diffused through stem or other plant parts [Raskin I. and Ensley B.D., 2000].Mercury contaminated sites can be recovered in this process. Transformation of highly toxic mercury ion into less toxic elemental mercury can be considered as the best advantage of this process.

The main disadvantage is that the diffused mercury into the atmosphere through this process could be recycled through precipitation thereby repeating the formation of methyl mercury by anaerobic bacteria [USEPA, 2000].

Phytoextraction

This refers to the translocation or the uptake of hazardous contaminants present in the soil by the roots of hyper accumulating plants above ground biomass (leaves, shoots, etc). This sub-process of Phytoremediation can also said to be phytoaccumulation. The majority of hyperaccumulating plants (Approximately 400) has the unusual ability to absorb and uptake large quantities of nickel, zinc and copper and are said to be the best metals for removal by phytoextraction.

Phytoextraction has several advantages. When compared to conventional methods, the phytoextraction process is fairly economical. Another benefit is the permanent removal of the contaminant from the soil thereby decreasing the amount (up to 95%) of waste that is needed to be disposed of. In addition, the contaminant can be recycled from the contaminated plant biomass [USEPA, 2000].

Table I: Phytoremediation Process & Mechanism

No.	Process	Mechanism	Contaminant
1.	Phytotransformation	Degradation	Organic
2.	Phytovolatilization	Volatilisation	Organic/ Inorganic
3.	Phytoextraction	Hyperaccumulation	Inorganic
4.	Phytostabilisation	Complexation	Inorganic
5.	Rhizofiltration	Rhizosphere accumulation	Organic/ Inorganic

Phytostabilisation

This method depends on the ability of roots to limit contaminant bioavailability and mobility in the soil and is used mostly for soil, sludge and sediment remediation [Mueller et al., 1999]. The primary purpose of the plant is to decrease the water amount percolating through the soil matrix which results in hazardous leachate formation thus preventing soil erosion and toxic metal distribution to other areas [Berti W.R. and Cunningham S.D., 2000]. This method is effective at places where biomass disposal is not required and wherever ground and surface water need to be preserved with rapid immobilization of contaminants.

Rhizofiltration

This refers to the adsorption or absorption of low contaminant concentrations of groundwater, surface water and wastewater surrounding root zone. Lead, Cadmium, Zinc, Nickel, Chromium are primarily retained within the roots [USEPA, 2000]. The only difference between Rhizofiltration and phytoextraction is that in rhizofiltration process plants address contaminated groundwater rather than soil.

The ability to use both aquatic and terrestrial plants for both ex-situ and in-situ applications are the major advantages of rhizofiltration. Translocation of the contaminant into the shoot system can be completely avoided by choosing terrestrial plants of longer root system [Raskin I. and Ensley B.D., 2000]. The need for constant adjustment of Ph and the requirement of well- designed tank system are considered as the limiting factors of rhizofiltration.

PHYTOREMEDIATION WITH AGRONOMIC PRACTICES

Although Phytoremediation technology has an incredible potential in remediating contaminated sites, it still exists as a non- commercial technology due to the poor understanding of agronomic practices. It is very important for the practitioners to own right perceptive on the following agronomic practices on plant/ soil/ contaminant. Phytoremediation is essentially an agronomic approach and its success depends ultimately on agronomic practices applied at the site. The importance of employing effective agronomic practices has been discussed by [Chaney et al., 2000].

Plant Selection

One of the most important factors affecting the removal of metal is the selection of suitable plant species. Although, the extraction of the metal potential of the plant is of prime importance, the criteria to ensure the protection of the environment should also be considered while choosing plants for remediation.

Selection of exotic species could possibly endanger the harmony of the ecosystem. Hence it is very important to select native plants as a choice in remediation. Crops should be preferred in general to avoid propagation of weedy species. Crops that are too palatable need to be carefully handled as they might pose grazing animals under serious risk. The amount of biomass harvested and the concentration of metals within the harvested biomass ensure the rate of metal removal.

Hyperaccumulator plants are limited with small size and slow growth but have the potential to concentrate high metal level. Nonaccumulator plants produce significant amount of biomass [Ebbs D.S. et al., 1997]. Nonaccumulator plants have a low potential to bio-concentrate metals and will not remove enough metals to support phytoextraction [Chaney et al., 2000]. It is identified that maize could possibly accumulate high levels of cadmium [Hinesly T.D., Alexander D.E., Ziegler E.L. and Barrett G.L., 1978] and are not supported to remediate sites with zinc toxicity [Chaney et al., 2000]. Handling of contaminated biomass is a tedious process and henceforth hyperaccumulating plants that produce low biomass need to be chosen if proper disposal is of major concern.

There have been no identified hyperaccumulator species to remediate the Lead contaminated site. However, species such as Asiatic dayflower (Commelina communis), ragweed (Ambrosia artemisiifolia) have superior Pb accumulating properties [Berti W.R. and Cunningham S.D., 1993].

For profound contamination deep-rooted plants need to be selected for remediation. Surface contaminated sites could be remediated with the usage of shallow-rooted species.

Conditioning and Soil Fertilization

To acidify soil for greater bioavailability of metals and to provide essential nutrients such as nitrates and sulfates for greater yield (NH4)2SO4 is used as a soil additive [Chaney et al., 2000]. To resume normal farm uses and for the development of the ecosystem, it is necessary to elevate the pH value of the soil to a near neutral value. The capacity of the soil to bind metals is ensured by premature liming and with the addition of organic fertilizers.

Production of biomass could be increased with the addition of Phosphate fertilizers since Phosphorus is one of the major nutrients required for plant growth. The addition of Phosphate fertilizers is not effective on lead contaminated site as it precipitates metal into pyromorphite and chloro-pyromorphite [Chaney et al., 2000]. Hence it is important to find out a new approach for Phosphate application on lead contaminated soil.

Sowing

Plant density (number of plants/m^2) is an important factor to control biomass production. Both yield/hectare and yield/plant get affected with density. Growth and development pattern of the plant gets affected with density. Plants tend to compete for light on high density. Plant capacity to absorb and accumulate metal depends on its growth period. Longer the growth period greater will be the level of metal absorption. Metal uptake and the architecture of the root system get affected with the distance between plants.

Crop Rotation

The yield of crops used in Phytoremediation gets affected by means of predators, diseases and by the proliferation of weeds. This problem can be addressed through the process of crop rotation. In general, before 30 years crops were rotated more frequently than today. For Phytoremediation of metals short-term (2 to 3 years) monoculture (use of same species on all seasons) is acceptable. For long term applications cleanup of metals can be successfully achieved with only one remediation species.

Table II: Merits & Demerits of Phytoremediation

No.	Merits	Demerits/ Limitations
1.	Suitable for both organic & inorganic contaminated sites.	Shallow contaminated sites are restricted.
2.	In-Situ/Ex-Situ application possible	Remediation of contaminated site may take up several years to complete.
3.	Amount of soil disturbance is less compared with conventional Methods.	Sites with low contaminants are restricted.
4.	Further utilization of metals in the form of bio- ore.	Harvested plant biomass generate hazardous waste
5.	Decrease in spread of Contaminants via air and water.	Climatic conditions are a limiting factor.
6.	Highly skilled and expensive equipments are not required.	Biodiversity gets affected due to the introduction of foreign species.

Crop Maintenance

Proper irrigation and control of weed stand out as the important practices for crop maintenance. Chemical and physical methods control weed growth. Control of weed during the initial growth of selected plants could be observed through the application of pre-emergent herbicides. Post-emergent herbicides control weed growth establishment that occurs after the plant growth. Soil solution movement from soil to root ensures metal uptake by plant and hence adequate moisture is required in the soil considering the volume the water to be delivered. Evaporation and transpiration losses need to be calculated and the delivered water needs to compensate all such losses. Metal extraction rate and root growth get restricted on excessive water delivery together inflating the operational cost. Evaporation loss could be kept minimal by low-pressure delivery to the soil or through dripping there by leaving a very little effect on air humidity. Air humidity gets elevated on high-pressure delivery by nozzles thereby minimizing the loss through transpiration.

Handling and Disposal

The need to handle and dispose of the contaminated biomass is said to be the drawback of this technology as it ensures additional cost requirement to proceed. Landfill is considered to be one option for the disposal of contaminated biomass.

Chemical, physical, thermal and microbial degradation of biomass ensures reduction of waste volume thereby decreasing the cost requirement for processing and handling of waste. Bio-ore gets concentrated by means of biomass incineration [Chaney et al., 2000.] thus the recovered metal value offsets the technology cost.

CONCLUSION

Phytoremediation technology is fast emerging and many field tests on Phytoremediation of Organic/ Inorganic/ Radionuclide has been conducted day by day. This sustainable, fast emerging, inexpensive process is the best alternative to conventional remediation methods. Being a developing country this technology is highly suitable for a country like India. Optimization of agronomic practices is necessary to maximize cleanup thereby converting it to a commercial technology.

Phytoremediating species of greater metal extracting potential need to be identified and should be used for crop rotation. New hyperaccumulator plants need to be explored and there is a high need to know about their physiology. Proper optimization of crop harvesting time and information regarding heavy metal uptake by plants need to be addressed. Handling of contaminated biomass waste and its safe disposal requires further study.

REFERENCES

Berti W.R. and Cunningham S.D., 1993. Remediating soil Pb with green plants. Presented at The Internatl Conf Soc Environ Geochem Health. July 25-27, New Orleans, LA.

Berti W.R. and Cunningham S.D., 2000. In Phytoremediation of Toxic Metals: Using Plants to Clean Up the Environment. (ed. Raskin, I.) – Wiley-Interscience, John Wiley and Sons, Inc. New York, NY.; pp 71- 88.

Cunningham et al., 1996. Phytoremediation of soils contaminated with organic pollutants. Adv. Agron., **56**: 55-114.

Cunningham S.D. and Ow D.W., 1996. Promises and prospect of phytoremediation. Plant Physiol., **110**: 715-719.

Chaney et al., 2000. In Phytoremediation of contaminated soil and water. (ed Terry N. and G. Banelos) – Lewis Publishers, Boca Raton, FL.pp. 129–158.

EPA (2000). A Citizen's Guide to Phytoremediation. EPA 542-F-98-011. United States Environmental Protection Agency, p. 6.

Ebbs D.S. et al., 1997. Phytoextraction of cadmium and zinc from a contaminated site. J. Environ. Qual., **26**:1424-1430

Hinesly T.D., Alexander D.E., Ziegler E.L. and Barrett G.L., 1978. Zinc and Cd accumulation by corn inbreds grown on sludge amended soil. Agron J **70**:425-428

Mueller et al., 1999. Phytoremediation Decision Tree. – Prepared by - Interstate Technology and Regulatory Cooperation Work Group; pp 1-36

Raskin I. and Ensley B.D., 2000. Recent developments for in situ treatment of metal contaminated soils. In: Phytoremediation of Toxic Metals: Using Plants to Clean Up the Environment. John Wiley & Sons Inc., New York.

Reed et al., 1992. – In Environmental Remediation Removing Organic and Metal Ion Pollutants. pp. 1-19.

Smith B., 1993. Remediation update funding the remedy. – Waste Manage Environ. **4**:24-30.

UNEP (Undated). Phytoremediation: An Environmentally Sound Technology for pollution Prevention,Control and Remediation, United Nations Environment Programme Division of Technology, Industry, and Economics.

United States Environmental Protection Agency (USEPA). (2000). Introduction to Phytoremediation. EPA 600/R-99/107, U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

Zhang et al., 2010. Potential of four forage grasses in remediation of Cd and Zn contaminated soils. Bioresour. Technol., **101**:2063-2066.