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– A REVIEW

ROLE OF HIGHER PLANTS IN REMEDIATION OF METAL CONTAMINATED SITES

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ABSTRACT

Due to rapid industrialization, modern agriculture and other anthropogenic activities, heavy metal pollution in soil and water has become a serious threat to the human and animal health and well-being of a nation. The use of higher plants in remediation of metal contaminated sites, known as phytoremediation, is gaining worldwide importance due to its low cost involvement and eco-friendliness of the method. A great body of literature exists in this aspect and quite a good number of plants have been identified worldwide which are hyper accumulators of various heavy metals. This paper discusses different remediation techniques with special emphasis on phytoremediation and its relative advantage over others. Phytoremediation is an energy efficient, aesthetically pleasing method of remediating sites with low to moderate levels of contamination and it can be used in conjunction with other more traditional remedial methods as a finishing step to the remedial process.

Key words: Heavy metals, Phytoremediation, Bioremediation, Soil pollution, Contaminated sites.

INTRODUCTION

Heavy metal pollution is an important worldwide problem due to its toxic behavior even at low concentrations. At higher level, heavy metals form free redicals, which cause the oxidative stress. They can also replace the essential metals. The accumulation, mobility and toxicity of heavy metals are influenced by nature of soil and environmental factors. Some metals are essential and nontoxic in small amount and naturally present in soil, and they are known as 'trace elements' or 'micro nutrient', but the non essential metals are toxic and called as 'toxic elements'. Due to several anthropogenic activities metals are posing serious threat, because it is not only a source of nutrients for plant but also a sink for contaminants. Aerosols, smelting plants, coal fired power plants, pesticides, fertilizers, sewage sludge and mine wastes are the main source of heavy metal pollution in soil. Out of these, industrial activities and agricultural practices are more responsible for soil pollution (Table 1), as these have increased in last few decades due to the large scale of industrialization and newer methods of farming. According to Central Statistical Organization[1] the use of fertilizers and pesticides in agriculture has increased by 80% (7.7-13.9 million tones) and 240% (24305-85030), respectively since 1984 to 1996.

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Remediation techniques

To cleanup the contaminated soil, remediation is a worldwide accepted method. It can be physical, chemical or biological that may achieve either the partial/complete removal of metal from soil or reduction of its bioavailability in order to minimize toxicity. Large varieties of methods have been developed to remediate metal-contaminated sites and are grouped into physical, chemical and biological methods. The selection and adoption of these technologies depend on the extent and nature of metal-contamination, type of soil, characteristics of the contaminated site, cost of operation, availability of materials and relevant regulations.

Table 1: Heavy metals and their source of contamination in soil

Heavy metal	Sources of contamination in soil
Pb	Batteries, metal products
Cd	Electroplating, batteries and fertilizers
As	Timber treatment, paints and pesticides
Cr	Timber treatment, leather tanning, pesticides and dyes
Cu	Timber treatment, fertilizers, fungicides, electrical and pigments
Mn	Fertilizer
Zn	Dyes, paints, timber treatment, fertilizers and mine tailings
Hg	Instruments, fumigants and fertilizers
Ni	Alloys, batteries and mine tailings
Mo	Fertilizer

Physical remediation

It is the oldest remediation method for soil. In this technique, through the capping, soil mixing, soil washing, solidification and excavation process, soil can be cleaned. Contaminated site can be cleaned up rapidly through this method but due to the high cost and risk in contaminant shifting, it is not a good remedial technique for the removal of heavy metals from a large area.

Chemical remediation/ in situ fixation

In chemical remediation, heavy metals of contaminated soil are transformed with added chemicals to a less toxic form, which is not easily absorbed by plants. So, in stabilization process heavy metals remains in the soil but in a less harmful form. Due to the high rate of success this method is becoming popular. It is a periodical treatment method and requires special equipments and operators and can affect the physical structure and biological activity of the treated medium at low level. So it is also not applicable on large scale for heavy metal remediation.

Biological remediation

This technique are broadly grouped into two categories-

(a) Bioremediation (using microorganism)

(b) Phytoremediation (using higher plants)

Bioremediation

In this process native or introduced microorganisms and biological material i.e., compost and animal manures are used to detoxify the contaminants. It is an eco-friendly technique, which does not require any chemical amendments other than microbial cultures and biological wastes.

Phytoremediation

The use of plant to remove the heavy metals was first introduced in 1983 and is often called phytoremediation[2]. It consists of the Greek prefix ‘phyto’ meaning ‘plant’ and the Latin root ‘remedium’ meaning ‘to correct or remove an evil’. It is an economically feasible, environmentally viable and largely accepted technology for the remediation of heavy metals from the contaminated soil. The cost of this method is very less than the costs of excavation and in situ fixation (Table 2).

Table 2: Comparative costs for different types of heavy metal soil remediation[6]

Type of remediation	Cost/ cubic meter (Rs.)	Time required
Excavation and removal	5000-20000	6-9 months
In situ fixation (including soil amendments)	4500-10000	6-9 months
Phytoremediation	750-2000	18-60 months

There are various categories of phytoremediation:

Phytostabilization

In phytostabilization, transcription and root growth are used to immobilize metal contaminants by reducing leaching, controlling erosion, creating an aerobic environment in the root zone, and adding organic matter to the substrate that binds metals. The stabilization of metals in the root zone could be achieved through the addition of organic matter as well as soil amendments.

Rhizofiltration

In rhizofiltration, the root of plants are used to adsorb or absorb the metal, which are subsequently removed by harvesting the whole plant. In this case metal tolerance and translocation of the metal to aerial parts are largely irrelevant.

Phytoextraction / Phytoaccumulation

In phytoextraction, plants can be grown on contaminated soil and the aerial parts enriched with metal harvested. In this case, plants need to be tolerant only if the soil metal content is very high, but they need to accumulate very high concentrations in their aerial parts. Phytoextraction involves repeated cropping of plant until the metal concentration in the soil has reached the acceptable (targeted) level. In most cases even under optimal conditions, phytoextraction could take a long time to cleanup metal-polluted soils to accepted target values.

Phytovolatilization

It is an inherent process of the phytoremediation of organically-contaminated soils. However, phytovolatilization as applied to inorganic contaminants is still in its infancy. Phytovolatilization has some potential for remediating soils contaminated with Hg, Se, B and possibly other elements.

Plants have developed three basic strategies for growing on contaminated soil (Fig. 1), these are:

Metal excluder

These plants contain large amount of heavy metal in their roots but prevent the entering of the metal in their aerial part.

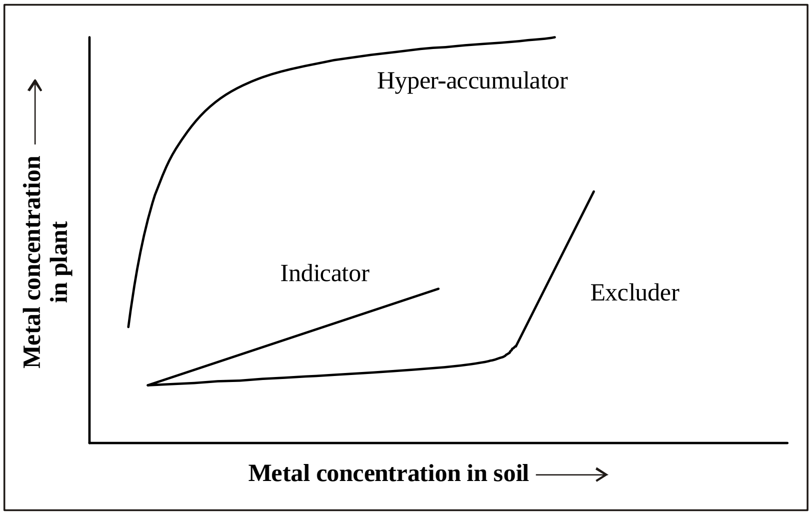

Fig. 1: A schematic diagram of different strategies of plants to adapt to higher metal contamination in soil

Metal indicators

These plants accumulate metals in their above-ground tissues, which are reflected by the metal levels in the soil.

Metal accumulators

These plants (hyperaccumulators) concentrate the metals in their above ground tissues to levels for exceeding those present in the soil.

The plants, which contain more than 0.1% of Ni, Co, Cu, Cr or Pb and 1% of Zn in its leaves on a dry weight basis is called a hyperaccumulator, irrespective of the metal concentration in the soil. At present there are 400 species of known hyperaccumulator. Some selected hyperaccumulator plants are given in Table 3. Jaffery et al.,[3] Baker and Walker[4] and Brown et al.,[5] studied the accumulation level of heavy metals in "Harvestable" material of some known hyperaccumulator plant species (Table 4).

Table 3: Metals and their hyperaccumulators plant species

Metal	Plants
Pb	*Brassica juncea*, Water hyacinth (*Eichhornia crassipes*), Hydrilla (*Hydrilla verticillata*), Sunflower (*Helianthus annuus*), *Lemna minor*, *Salvinia molesta*, *Spirodela polyrhiza*.
Cd	Alpine pennycrest (*Thlaspi cacrulescens*), *Cardaminosis helleri*, Eel grass (*Vallisneria spiralis*), Water hyssop (*Bacopa monnieri*), Water hyacinth (*Eichhornia crassipes*), Hydrilla (*Hydrilla verticillata*), Duck weed (*Lemna minor*), Giant duckweed (*Spirodela palyrhiza*).
As	Chinese brake fern (*Pteris vittata*), Fern (*Pteris cretica*).
Cr	Duck weed (*Lemna minor*), *Ceratophyllum demersum*, Giant reed (*Arundo donax*), Cattail

	(*Typha angustifolia*), Alfo albo (*Medicago sativa*), Water hyssop (*Bacopa monnieri*), Pista stratiotes, Water fern (*Salvinia molesta*), *Spirodela polyrhiza*.
Cu	*Aeolanthus bioformifollus*, *Lemna minor*, *Vigna radiate*, Creosote bush (*Larrea tridentate*), Water hyssop (*Bacopa monnieri*), Indian mustard (*Brassica juncea*).

Cont…

Metal	Plants
Mn	*Alyxia rubricaulis*, *Macademia neurophylla*
Zn	Alpine pennycrest (*Thlaspi caerulescens*), *Brassica juncea*.
Hg	Lemna minor, Water lettuce (*Pistia stratiotes*), Water hyacinth (*Eichhornia crassipes*), Hydrilla (*Hydrilla verticillata*).
Ni	*Phyllanthus serpentines*, *Lemna minor*, *Salvinia molesta*, *Brassica juncea*, *Spirodela polyrhiza*.
Co	Eel grass of Africa (*Haumaniastrum robertii*).

Table 4: Metal concentration (on a dry weight basis) in known hyperaccumulators. For reasons of logistics and potential "worker exposure", root tissue (in which concentrations can be significantly higher in some species) are not considered as "harvestable" here

Metal	Plant species	Concentration in "Harvestable" material from plants grown in contaminated soil (dry wt. basis)
Cd	*Thlaspi careulenscens*	1,800 mg Kg^{-1} in shoots[a]
Cu	*Ipomea alpine*	12,300 mg Kg^{-1} in shoots[a]
Co	*Haumaniastrum robertii*	10,200 mg Kg^{-1} in shoots[a]
Pb	*T. rotundifolium*	8,200 mg Kg^{-1} in shoots[a]
Mn	*Macadamia neurophylla*	51,800 mg Kg^{-1} in shoots[a]
Ni	*Psychotria douarrie Sebertia accuminata*	47,500 mg Kg^{-1} in shoots[a] 25% by wt. of dried sap[b]
Zn	*T. careulenscens*	51,600 mg Kg^{-1} in shoots[c]

[a]Baker and Walker[4]
[b]Jaffery et al.[3]
[c]Brown et al.[5]

Natural remediation

The use of unenhanced (or non-invasive) natural processes as part of a site remediation strategy is called natural attenuation. Natural remediation is well estabilished as a remedial strategy for a few organic chemicals, primarily BTEX (Benzene, Toulene, Ethylene, Xylene). However, these processes cannot destroy metals but in some cases can immobilize them. This remediation can be managed for both organic and inorganic contaminants.

CONCLUSION

Phytoremediation is the use of living green plants for in situ risk reduction and/or removal of contaminants from contaminated soil, water, sediments, and air. Specially selected or engineered plants are used in the process. Risk reduction can be through a process of removal, degradation of, or containment of a contaminant or a combination of any of these factors. Phytoremediation is an energy efficient, aesthetically pleasing method of remediating sites with low to moderate levels of contamination and it can be used in conjunction with other more traditional remedial methods as a finishing step to the remedial process. One of the main advantages of phytoremediation is that of its relatively low cost compared to other remedial methods such as excavation.

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