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Phytoextraction and Stabilization of Lead in Contaminated Soils using Plants

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ABSTRACT

Lead is a toxic heavy metal contaminant that poses a serious threat to human health. It is present everywhere in the environment including agricultural, industrial and residential areas. To remediate lead from the contaminated soil, phytoremediation approaches are used. Phytoextraction and Phytostabilization are methods of phytoremediation which has been successfully used to remediate lead contaminant from the soil. Phytoextraction involves the use of hyperaccumulators; to accumulate lead contaminant within the shoots by using the uptake mechanism. Whereas, Phytostabilization involves the stabilization or maintenance of lead in the rhizosphere of the soil to reduce its harmful impact on the environment. Lead phytoextraction could be enhanced by adding chelating agents, such as EDTA, to increase the bioavailability of lead contaminant in the plants. Lead phytostabilization is an effective method to remediate lead contaminant. This method tolerates lead exposure and prevents it in or around the root zone which can restrict the movement of lead into other plants, avoiding resuspended dust and mitigating lead exposure. These approaches are cost effective, simple; ecofriendly and do not require a huge amount of labour.

Keywords: contaminant, EDTA, hyperaccumulator, lead, phytoextraction, phytoremediation, phytostabilization

1. INTRODUCTION

Soil pollution is a major concern throughout the world and affects all living beings, mainly humans and animals. Soil pollution entails the presence of heavy metals in the soil. These metals are produced by various anthropogenic activities, such as mining, industrial waste, chemical pesticides, fertilizers, and waste water irrigation. Cadmium, arsenic, mercury, chromium, thallium, and lead are prime examples of heavy metals. These metals are toxic to human health, even if ingested in a small concentration. Some of the heavy metals have a biological role in the soil, except lead. Lead (Pb) is the most wide spread inorganic pollutant and is released in the environment by electrical batteries, lead containing paints, and gasoline, among others [1]. It is the second most toxic metal that causes serious environmental damage in agricultural soil and also causes many illnesses to human beings, for example weakness, anemia, nervous disorders and renal disorder. It can also harm pregnant women by crossing the placental barrier and affecting the unborn child [2].

Lead is not physiologically important in plants. Although, it can be accumulated in edible tissues by plants growing in lead contaminated soil, which poses a significant danger to foodstuffs. It slows various metabolic processes, such as

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photosynthesis, respiration, water absorption, metabolism of nitrogen, and nutrient absorption. It also creates oxidative stress by creating reactive oxygen species (ROS) in plants [3].

Lead mainly exists as a divalent cation, that is, Pb^{2+} in contaminated soil which is vulnerable to cation exchange and solubility/sorption phenomenon related with most soils. The activity of free Pb^{2+} in soil therefore varies, and depends on the solubility of controlled lead phase. In a previous research, it was recorded that most agricultural soils demonstrate exceptionally low lead activity at 10–8.5 M or 0.5 µg / kg. While lead exposure is greater in contaminated soil then in normal soil, it would still be important to increase the soluble lead level to eliminate it from infected soil and decrease its accumulation [4].

Due to its widespread distribution, stability and toxicity in relation to human health, lead is deemed as the target pollutant of remediation studies. Lead pollution in soil can cause a number of environmental problems, including loss of vegetation, contamination of groundwater and toxicity in plants, animals and humans. So, to prevent contamination from highly toxic heavy metals, different techniques have been used to remediate or degrade them for centuries[4].

The remediation of lead-contaminated soil is crucial, and several conventional methods are employed to eliminate lead from the soil. These methods include soil washing with chemicals, containment technologies and electro-kinetic remediation. Furthermore, physiochemical techniques, such as immobilization or extraction of heavy metals, have been reported. However, these technologies have many drawbacks which include the requirement for skilled workers, costly methods, specialized equipment, and adverse effects on other important elements of the soil. These methods are also ineffective and not ecofriendly [5]. So, to overcome all these drawbacks phytoremediation approaches have been used to treat such contaminated soil. Phytoremediation is a green technology which is defined as a process in which different varieties of plants are used to degrade, remediate or remove the contamination from soil by using different methods. This technology is cost effective, ecofriendly, and simple. Phytoremediation uses metal accumulating plants to remove metals from plants through their roots and to accumulate these metals in above-ground plant parts. The process of metal concentration is greatly reduced by the amount of contamination which is required to be disposed of, thereby reducing the associated disposal charges. Metal rich plants can safely be harvested and removed from the particular site. There are different types of phytoremediation, namely phytostabilization, phytoextraction, phytodegradation, rhizofilteration and phytovolatilization. Among these technologies phytoextraction and phytostabilization are widely used to remediate lead from the contaminated soil. Researchers have discovered that there are some plants that have the ability to take up highly toxic metal including lead through their root system and are able to clean up the contaminated soil and water [5,6].

1.1. Sources of Lead Contamination

Lead is an important but harmful metal present in the environment. It can cause serious damage to human health. It is released in the environment through various anthropogenic activities, such as smelting, chemical pesticides used by farmers to kill herbs and insects, industrial wastes that contain different heavy metals, and from lead batteries, as shown in Figure 1. Lead paints and lead water piping used in the water distribution system are also major sources of lead [6].

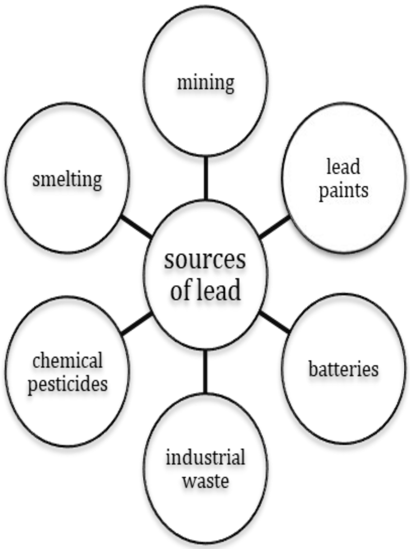

Figure 1. Sources of lead

2. METHODS TO REMOVE LEAD CONTAMINATION FROM SOIL

2.1. Phytoextraction

Phytoextraction is a process of phytoremediation in which plants are able to remediate, remove or degrade toxic contaminants usually metals that are toxic to organisms even at low concentration in soil or water. The plants belonging to the *Brassicaceae* and *Fabaceae* families have a high capacity to absorb heavy metals [7,8].

The aim of lead phytoextraction is to reduce its concentration in a soil within a suitable time span, that is, 3-20 years. The time is site dependent and based on the initial and final soil lead concentration, use of land in future, and the degree of risk posed by the land to the environment and human health. In this method, hyper accumulators are used to uptake lead from the soil through their roots. Studies conducted on hyper accumulating species found that *Brassicaceae* and *Fabaceae* families have a high ability to uptake heavy metals from the soil [9]. *Thlaspi rotundifolium* is a hyper accumulating plant that is able to accumulate a lead concentration level of 130-8200 mg kg^{-1} with a mean value of 1100 mg kg^{-1} through its shoots. According to the literature, due to slow growth and a small biomass, this plant species is not suitable for lead phytoextraction. It was found that hyper accumulating species do not have a high biomass. So, a screening program is needed to examine the physiological factors of lead accumulation in more than 50 plants species by growing them on lead contaminated land. It was also found that corn and pea plants are able to uptake lead through their shoots more than *Thlaspi rotundifolium* [10].

In another research, a new hyperaccumulator plant with the ability to accumulate lead from the soil namely *Bidens maximowicziana* was studied. *B.maximowicziana* has a high biomass, wide ecological amplitude, and strong roots which are easily harvested. Therefore, the use of *B.maximowicziana* has a greater potential to remediate lead from contaminated soil and is also a native resource for the analysis of lead hyperaccumulation and detoxification of chemical pathways. *B. maximowicziana* has a strong ability to accumulate and tolerate lead from the soil. *Coronopus didymus* is a wild herb that belongs to *Brassicaceae* family which has good lead accumulating ability as well, probably through its roots [11].

Sesuvium portulacastrum species belongs to the family *Aizoaceae* and it is able to decontaminate lead contaminated soil. Its ability to uptake contaminants through the roots is enhanced by adding chelating agents, such as EDTA (Ethylenediamine tetraacetic acid), to the contaminated soil. Adding EDTA to the soil increases the movement of lead in it. In the same way, green onions (*A. fistulosum*) were also shown to be a possible candidate for lead phytoremediation. PDTA (Propylenediamine tetraacetate) is used as a chelating agent for green onions, rather than EDTA. According to a research without adding the chelating agent to the soil, green onions are not able to extract the proper amount of lead from it. Indeed, they extract less than 25mg/kg of lead. When EDTA is added to the soil, it greatly increases lead accumulation from the soil through their stems at the concentration of about 225mg/kg [12]. PDTA could not significantly increases phytoextraction without the chelating agent. So, according to different researches, EDTA plays an important role in the accumulation of lead from the soil and is more effective than PDTA.

Different salt tolerant plant species are able to accumulate lead from lead contaminated soil including *S. portulacastrum*. It is a rapidly growing halophyte specie used as a hyperaccumulators and is able to accumulate lead from the soil [13]. Phytoextraction offers several benefits. It is a cost effective and ecofriendly technique that does not harm the soil structure and does not demand high technical expertise. However, it is a time intensive process, and the plants employed for phytoextraction may contain pollutants, which may result in pollution when they are disposed of after harvesting.

The desirable characters of plant species involved in phytoextraction include rapid growth rate, high biomass production, and extended root system (required for the exploration of high volume of soil). They should also have the ability to tolerate high concentrations of metals in plant tissues, as well as the ability to adapt to specific environments and sites.

Phytoextraction is the most suitable for lead extraction when it is bioavailabe. This method is less costly than traditional methods but it is more costly than phytostabilization and it could take years for lead remediation. Furthermore, the use of chelating agents to mobilize lead is usually required, although the production of biodegradable compounds minimizes the effect on the environment. Major research and commercialization of phytoremediation technologies for lead remediation is planned to occur in the future and it would have a great impact [14].

Plants that have a high biomass are able to accumulate lead from the soil, while chelating agents are added to the surface of the soil so that the solubility of lead may increase. The roots of the plants uptake the soil lead in the harvested part of the plant. After harvesting, biomass may be processed for the extraction and recovery of metals, which is known as phytomining (Figure 2).

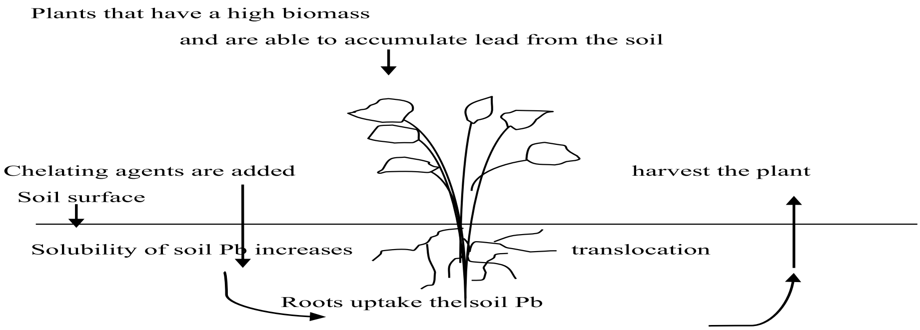

Figure 2. Schematic Representation of the Process of Phytoextraction [14]

2.2. Phytostabilization

Phytostabilization is also a type of phytoremediation. It is also known as in-place activationwhich involves the use of green plants to stabilizes or localizes the soil metal contaminants within their roots or near the rhizosphere, so that human exposure to them is reduced. The plants used for phytostabilization are able to stabilize the soil and prevent soil erosion, act as a barrier to reduce human exposure to the contaminated soil, and reduce the leaching of contaminants through the soil. The treatment of soil for phytostabilization involves the inactivation of soil contaminants rapidly and irreversibly with simple applications and without inducing any other environmental impact. All of this is achieved at a relatively low cost. Phytostabilization not only remove the contaminants from the soil but it also inactivates and immobilizes the potential ions by preventing the biomagnification of the contaminants to the food chain [15].

The most widely used soil amendments for lead includes phosphate products which are able to react with lead and form insoluble phosphate minerals, for example, lead pyromorphite. So, to reduce the solubility of lead, a large amount of application rates, that is, 5000 mg phosphorus/ kg soil are required. Phytostabilization forms a barrier between the environment and the contaminated soil. This method is effective when soil lead is present in the form of chemical and is not available to the roots of plants or where lead soluble compounds may be converted into comparatively -inert substances [16]. It requires the presence of a well-established plant species on a contaminated site and its perpetual maintenance. Phytostabilization is a cost effective method and it reduces the bioavailability of contaminants that may able to enter the human circulatory system through inhalation, ingestion and skin contact. Although, ingestion remains the main source of entry in the human body. Dense canopy plants and rooting systems, such as grass species, physically strengthen the soil against the effects of rain and erosion or leaching, and also prevent the migration of pollutants off-site [17].

The major aims of phytostabilization is that it should have the ability to modify the speciation of trace elements in the soil, with the objective of reducing the solubility and the exchangeable fraction of those elements. The canopy of plants is stabilized by restricting the uptake of trace elements by crops, while the ecosystem is enhanced by restricting the mobility of plants [18]. Figure 3 shows the schematic representation of the process of phytostabilization.

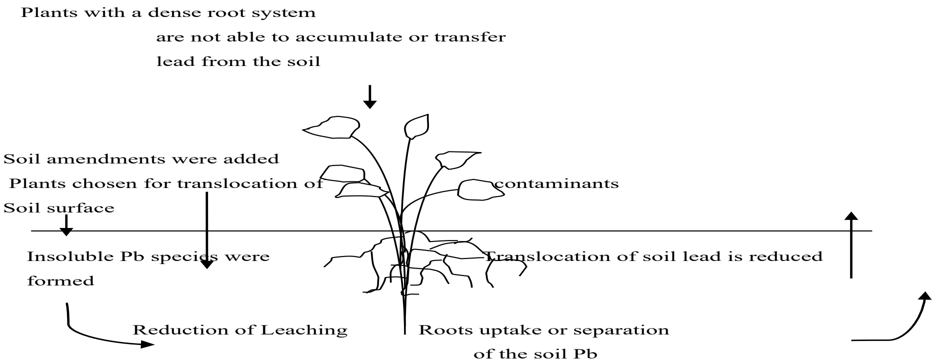

Figure 3. Schematic Representation of the Process of Phytostabilization [14]

In the presence of high concentrations of heavy metals, plants should have a comprehensive root system and sufficient biomass to become fit for phytostabilization, while the translocation of metals from roots to shoots should be as low as possible. Therefore, the bioconcentration factor of root (BCFR) is an additional assessment index for phytostabilization in comparison to the criterion for hyperaccumulators. While the study of the total heavy metal content in the soil can provide some information on heavy metal accumulation in the particular soil, it cannot show the bioavailability of these metals as well as the capacity to translocate them, nor does it provide an adequate criterion to determine their effects on living organisms. However, as metals enter the soil, plants are directly influenced by the available heavy metal content. So, the potential of resistance and root accumulation might be represented by the root bioconcentration factor [19].

Acer wardii has the ability to accumulate and stabilize lead in its roots. It has the ability to accumulate lead in its rhizosphere soil. It was found that in its root surroundings 310 mg/kg lead is present and is 17 times higher than the non-rhizosphere part of the soil. *A. Wardii* is the most promising candidate for lead accumulation in the roots of the studied plants, and could be used in lead-polluted soils for phytostabilization. *Juncus effusus* also has the ability to accumulate lead in its tissues of shoots and roots via adding chelating agents, for example, modified EDTA enhances the accumulation of lead [20].

Phytostabilization is a cost effective and ecofriendly method when immobilization is needed to preserve ground water and no contaminants waste is required. However, it is a time consuming method, requires soil amendments, and contaminants remain in the soil [21].

3. CONCLUSION

Phytoextraction and phytostabilization are the emerging technologies used to remediate lead from the lead contaminated soil by using plants. Phytostabilization is a promising technology and has been employed to reduce lead bioavailability and risks to human health. Whereas, phytoextraction is a viable technology increasingly needed to remediate lead contaminations from the soil by using plants. Hyperaccumulator plant species are used in phytoextraction which is a time consuming process. So, to overcome this drawback, genetic engineering may be used to develop transgenic plants. These plants may have fast growing ability, high biomass production, ability to tolerate metal toxicity, may have greater metal accumulation ability, and might be more beneficial. Genetic engineering method helps to improve phytoextraction and phytostabilization abilities of plants and these methods are more effective, time saving, and ecofriendly.

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