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Review

Phytoremediation of heavy metals: Recent techniques

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The current remediation technique of heavy metal from contaminated soil-water are expensive, time consuming and environmentally destructive. Unlike organic compounds, metals cannot degrade, and therefore effective cleanup requires their immobilization to reduce or remove toxicity. In recent years, scientists and engineers have started to generate cost effective technologies that include use of microorganisms/biomass or live plants to clean polluted areas. Phytoremediation is an emerging technology for cleaning up contaminated sites, which is cost effective, and has aesthetic advantages and long term applicability. It is best applied at sites with shallow contamination of organic, nutrient or metal pollutants that are amenable to one of the five applications; phytotransformation, rhizosphere bioremediation, phytostabilization, phytoextraction and rhizofiltration. The technology involves efficient use of plants to remove, detoxify or immobilize environmental contaminants in a growth matrix (soil, water or sediments) through the natural, biological, chemical or physical activities or processes of the plants. A brief review on phytoremediation of heavy metals and its effect on plants have been compiled to provide a wide applicability of phytoremediation.

Key words: Heavy metals, phytoremediation, uptake, metals toxicity.

INTRODUCTION

Human evolution has led to immense scientific and technological progress. Global development, however, raises new challenges, especially in the field of environmental protection and conservation (Bennett et al., 2003). Nearly every government around the world advocates for an environment free from harmful contamination for their citizens. However, the demand for a country's economic, agricultural and industrial development outweighs the demand for a safe, pure, and natural environmental. Ironically, it is the economic, agricultural and industrial developments that are often linked to polluting the environment (Ikhuoria and Okieimen, 2000). Since the beginning of the industrial revolution, soil pollution by toxic metals has accelerated dramatically. According to Nriagu (1996) about 90% of the anthropogenic emissions of heavy metals have occurred since 1900 AD; it is now well recognized that human activities lead to a substantial accumulation of heavy metals in soils on a global scale (e.g. 5.6 – 38 x 106 kg Cd yr-1). Man's exposure to heavy metals comes from industrial activities like mining, smelting, refining and manufacturing processes (Nriagu, 1996). A number of chemicals, heavy metals and other industries in the coastal areas have resulted in significant discharge of industrial effluents into the coastal water bodies. These toxic substances are released into the environment and contribute to a variety of toxic effects on living organisms in food chain (Dembitsky, 2003) by bioaccumulation and bio-magnification (Manohar et al., 2006). Heavy metals, such as cadmium, copper, lead; chromium, zinc, and nickel are important environmental pollutants, particularly in areas with high anthropogenic pressure (United States Environmental Protection Agency, 1997). The soil has been traditionally the site for disposal for most of the heavy metal wastes which needs to be treated. Currently, conventional remediation methods of heavy metal contaminated soils are expensive and environmentally destructive (Bio-Wise, 2003; Aboulroos et al., 2006).

GLOBAL ENVIRONMENTAL PROBLEM

Heavy metals are known to cause toxicities around the

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world. There are documented cases of many different metals causing toxicity issues. The world's most polluted places threaten the health of more than 10 million people in many countries, according to a report released by a U.S. environmental action group (ENS, 2006). According to report, the Chinese city of Linfen, located in the heart of the country's coal region is as an example of the severe pollution faced by many Chinese cities; Haina, Dominican Republic, is the site of a former automobile battery recycling smelter where residents suffer from widespread lead poisoning; the Indian city of Ranipet, where some 3.5 million people are affected by tannery waste, contains hexavalent chromium and azodyes. Mailuu-Suu, Kyrgyzstan, home to a former Soviet uranium plant and severely contaminated with radioactive uranium mine wastes; the Russian industrial city of Norilsk, which houses the world's largest heavy metals smelting complex is where more than 4 million tons of cadmium, copper, lead, nickel, arsenic, selenium and zinc emissions are released annually; the Russian Far East towns of Dalnegorsk and Rudnaya Pristan, residents suffer from serious lead poisoning from an old smelter and the unsafe transport of lead concentrate from the local lead mining site; and in the city of Kabwe, Zambia, mining and smelting operations have led to widespread lead and cadmium contamination. Tannery runoff in India is polluting the water supply of some 3.5 million people (ENS, 2006).

Mining for precious metals, coal, and other commodities forms an important part of many countries' economies. Developing countries (Brazil, China, India and Peru) contribute a large proportion of the world's mining products. For example, of the total world production of iron ore (1,020,000 metric tons), 21% is produced by China, 19% by Brazil and 7% by India (USA National Mining Association, 2002). The largest producer of copper is Chile (30% of total world production), while Mexico produces the largest proportion of silver (16% of world production). While large producers have modern 'mega-mines', small-scale or surface mining is common in many countries. Mining activities affect health via water through: the method of extraction; contamination of local water sources as well as having harmful effects on the environment such as beach erosion from sand mining or by longer term effects on reducing biodiversity or fish populations (WHO, 2008).

A number of chemicals, heavy metals and other industries in the coastal areas have resulted in significant discharge of industrial effluents into the coastal water bodies. These toxic substances are released into the environment and contribute to a variety of toxic effects on living organisms by food chain (Dembitsky, 2003). Heavy metals, such as cadmium, copper, lead; chromium, zinc, and nickel are important environmental pollutants, particularly in areas with high anthropogenic pressure (United States Environmental Protection Agency, 1997). According to their chemical properties and biological function, heavy metals form a heterogeneous group; toxicity varies by metals and concentrations. Many of them (Hg, Cd, Ni, Pb, Cu, Zn, Cr, Co) are highly toxic both in elemental and soluble salt forms. Their presence in the atmosphere, soil and water, even in traces can cause serious problems to organisms. Heavy metals bioaccumulation in the food chain especially can be highly dangerous to human health. The most common route of human exposure to heavy metals is through ingestion from both food and water sources (Pickering and Owen, 1997)

SOURCES OF METAL POLLUTION

Geological and anthropogenic activities are sources of heavy metal contamination (Dembitsky, 2003). Sources of anthropogenic metal contamination include industrial effluents, fuel production, mining, smelting processes, military operations, utilization of agricultural chemicals, small-scale industries (including battery production, metal products, metal smelting and cable coating industries), brick kilns and coal combustion (Zhen-Guo et al., 2002). One of the prominent sources contributing to increased load of soil contamination is disposal of municipal wastage. These wastes are either dumped on roadsides or used as land fills, while sewage is used for irrigation. These wastes, although useful as a source of nutrients, are also sources of carcinogens and toxic metals. Other sources can include unsafe or excess application of (sometimes banned) pesticides, fungicides and fertilisers (Zhen-Guo et al., 2002). Additional potential sources of heavy metals include irrigation water contaminated by sewage and industrial effluent leading to contaminated soils and vegetables (Bridge, 2004).

METAL TOXICITY

All plants have the ability to accumulate "essential" metals (Ca, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Se, V and Zn) from the soil solution. Plants need different concentrations for growth and development. This ability also allows plants to accumulate other "non-essential" metals (Al, As, Au, Cd, Cr, Hg, Pb, Pd, Pt, Sb, Te, Tl and U) which have no known biological function (Djingova and Kuleff, 2000). Moreover, metals cannot be broken down and when concentrations inside the plant cells accumulate above threshold or optimal levels, it can cause direct toxicity by damaging cell structure (due to oxidative stress caused by reactive oxygen species) and inhibit a number of cytoplasmic enzymes (Assche and Clijsters, 1990). In addition, it can cause indirect toxic effects by replacing essential nutrients at cation exchange sites in plants (Taiz and Zeiger, 2002). Baker (1981) proposed, however, that some plants have evolved to tolerate the presence of large amounts of metals in their environment by the following three ways:

1. Exclusion, whereby transport of metals is restricted and constant metal concentrations are maintained in the

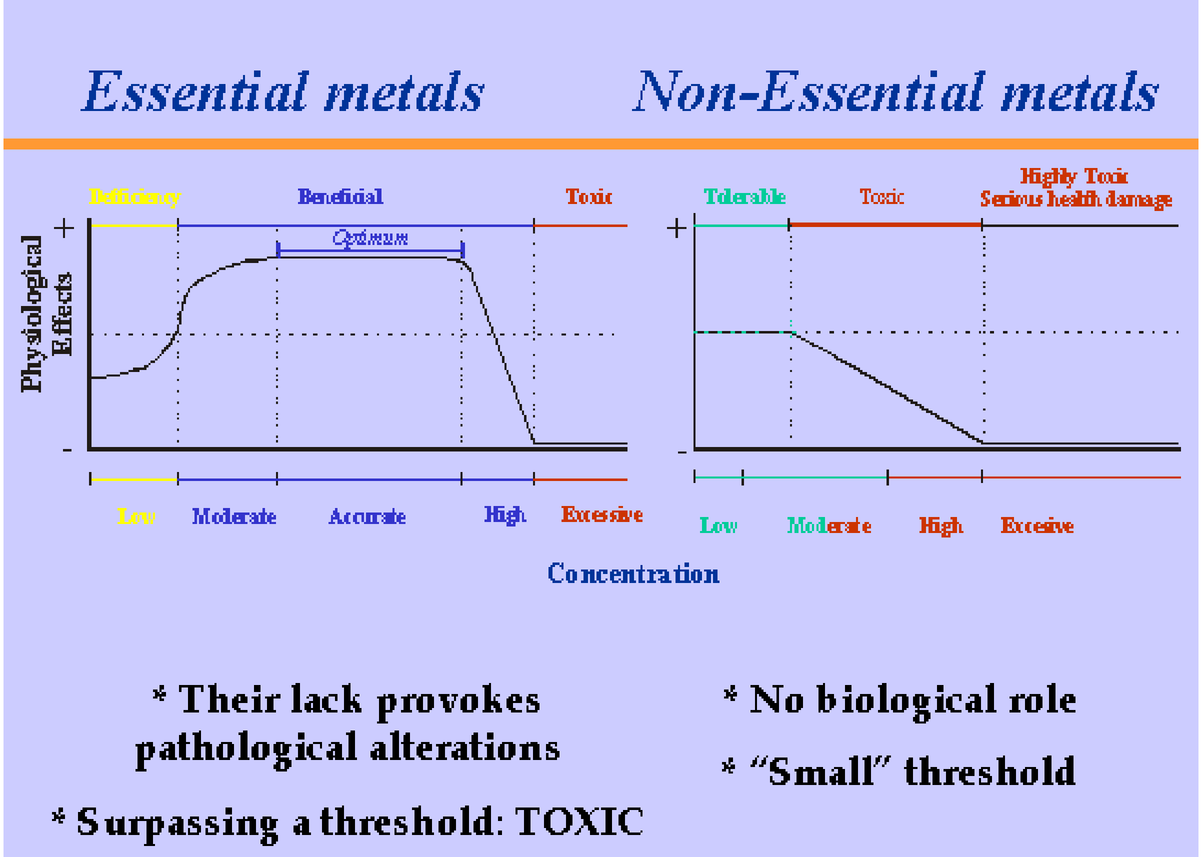

Figure 1. Conceptual response strategies of metal concentrations in plant tops in relation to increasing total metal concentrations in the soil.

shoot over a wide range of soil levels. 2. Inclution, whereby shoot metal concentrations reflect those in the soil solution in a linear relationship. 3. Bioccumulation, whereby metals are accumulated in the roots and upper plant parts at both high and low soil concentrations (Figure 1).

Schmidt (2003) reported that elevated heavy metal concentrations in the soil can lead to enhanced crop uptake and negative affect on plant growth. At higher concentrations, they interfere with metabolic processes and inhibit growth, sometimes leading to plant death (Schaller and Diez, 1991). Excessive metals in human nutrition can be toxic and can cause acute and chronic diseases (Schmidt, 2003). Zn is an essential trace nutrient to all high plants and animals. Zinc is required in a large number of enzymes (Mengel and Kirkby, 1982) and plays an essential role in DNA transcription. Zinc toxicity often leads to leaf chlorosis (Cobbett and Goldsbrough, 2002).

Cu is essential micronutrient for plants, but it can be toxic at higher concentrations. Copper (Cu) contributes to several physiological processes in plants including photosynthesis, respiration, carbohydrate distribution, nitrogen and cell wall metabolism, seed production including also disease resistance (Kabata-Pendias and Pendias, 2001). The higher concentration of Cu may account for the suppressed root growth, leaf chlorosis observed among plants (Baker and Walker, 1989). Kuzovkina et al., (2004) mentioned that cadmium is not an essential element for plant metabolism and can be strongly phytotoxic, causing rapid death. It is known to disturb enzyme activities, to inhibit the DNA-mediated transformation in microorganisms, to interfere in the symbiosis between microbes and plants, as well as to increase plant predisposition to fungal invasion (Kabata-Pendias and Pendias, 2001). Khan and Moheman, (2006) reported that Ni is considered to be among non essential element needed for the healthy growth of plants, animals and soil microbes. However, the recent literature survey available is suggesting that nickel is an essential element in many species of plants and animals. It interacts with iron found in haemoglobin and helps in oxygen transport, stimulate the metabolism as well as being regarded as a key metal in several plants and animals enzymes systems. Ni is readily transported from roots to overground plant tissues. However at higher concentrations it can be toxic. Pb is a nonessential element in metabolic processes and may become toxic or lethal to many organisms even when absorbed in small amounts. Boonyapookana et al. (2005) showed that Pb caused phytotoxic effect including chlorosis, necrosis, stunt growth of root/shoot, and less biomass production on *Helianthus annuus*, *Nicotiana tabacum* and *Vetiveria zizanioides.*

REMEDIATION MEASURES

Soil remediation is defined by Allen (1988) as the return of soil to a condition of ecological stability together with the establishment of plant communities it supports or supported to conditions prior to disturbance. Conventional technologies involve the removal of metals from polluted soils by transportation to laboratories, soil washing with chemicals to remove metals, and finally replacing the soil at its original location or disposing of it as hazardous waste (Francis et al., 1999). This decontamination strategy is an ex situ approach and can be very expensive and damaging to the soil structure and ecology (Salt et al., 1995a). Immobilization of heavy metals through the addition of lime (Krebs et al., 1999), phosphate (Ebbs et al., 1998) and calcium carbonate (CaCO3) (Chen et al., 2000) have been suggested as remediation techniques. These remediation technologies have the advantage of immediately reducing the risk factors arising from metal contamination, but may only be considered temporary alternatives because the metals have not been removed from the soil environment.

In response to a growing need to address environmental contamination, many remediation technologies have been developed to treat soil, leachate, wastewater, and ground-water contaminated by various pollutants, including in situ and ex situ methods (Aboulroos et al., 2006). A particular contaminated site may require a combination of procedures to allow the optimum remediation for the prevailing conditions. Biological, physical, and chemical technologies may be used in conjunction with one another to reduce the contamination to a safe and acceptable level. Conventional methods to remediate metal-contaminated soils (soil flushing, solidification/ stabilization, vitrification, thermal desorption, encapsulation) (Bio-Wise, 2003) can be used at highly contaminated sites but are not applicable to large areas. These remediation methods require high energy input and expensive machinery (Schnoor, 1997). At the same time they destroy soil structure and decrease soil productivity (Leumann et al., 1995).

RECENT TECHNIQUES

Some micro-organism-based remediation techniques, such as bioremediation, show potential for their ability to degrade and detoxify certain contaminants. Although these biological systems are less amenable to environmental extremes than other traditional methods, they have the perceived advantage of being more cost-effective (Cunningham et al., 1997).

Bioremediation is most applicable for sites that have been contaminated with organic pollutants, and as such, this condition has been the focus of the majority of bioremediation research. Because heavy metals are not subject to degradation, several researchers have suggested that bioremediation has limited potential to remediate metal-polluted environments (Marschner, 1995). The use of natural materials to remediate contaminated waters and soils has been investigated for the past thirty years. Scientists and engineers have been investigating the ability of live plants and inactivated biomaterials as remediation alternatives. Over the past decade there has been increasing interest for the development of plant-based remediation technologies which have the potential to be low-cost, low-impact, and environmentally sound (Cunningham and Ow, 1996), a concept called phytoremediation. In phytoremediation (uptake), the roots of established plants absorb metal elements from the soil and translocate them to the above-ground shoots where they accumulate. After sufficient plant growth and metal accumulation, the above-ground portions of the plant are harvested and removed, resulting in the permanent removal of metals from the site (Nandakumar et al., 1995). Some researchers suggest that the incineration of harvested plant tissue dramatically reduces the volume of the material requiring disposal. In some cases valuable metals can be extracted from the metal-rich ash and serve as a source of revenue, thereby offsetting the expense of remediation (Cunningham and Ow, 1996).

Phytoremediation is an integrated multidisciplinary approach to the cleanup of contaminated soils, which combines the disciplines of plant physiology, soil chemistry, and soil microbiology (Cunningham and Ow, 1996). Phytoremediation has been applied to a number of contaminants in small-scale field and/or laboratory studies. These contaminants include heavy metals, radionuclides, chlorinated solvents, petroleum hydrocarbons, PCBs, PAHs, organophosphate insecticides, explosives, and surfactants (Khan et al., 2004). Certain species of higher plants can accumulate very high concentrations of metals in their tissues without-showing toxicity (Klassen et al., 2000; Bennett et al., 2003). Such plants can be used successfully to clean up heavy metal polluted soils if their biomass and metal content are large enough to complete remedi¬ation within a reasonable period (Ebbs and Kochian, 1998). 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. In the natural setting, certain plants have been identified which have the potential to uptake heavy metals. At least 45 families have been identified to hyperaccumulate heavy metal; some of the families are Brassicaceae, Fabaceae, Euphorbiaceae, Asteraceae, Lamiaceae and Scrophulariaceae. Brassica juncea, commonly called Indian mustard, has been found to have a good ability to transport lead from the roots to the shoots (United States

Protection Agency, 2000). Indian mustard (B. juncea) is a high biomass, rapidly growing plant that has an ability to accumulate Ni and Cd in its shoots. It is a promising plant for phytoremediation (Terry et al., 1992). Aquatic plants such as the floating Eichhornia crassipes (water hyacinth), Lemna minor (duckweed), and Pistia have been investigated for use in rhizofiltration (Karkhanis et al., 2005). Recently, a fern Pteris vitatta has been shown to accumulate as much as 14,500 mg kg–1 arsenic in fronds without showing symptoms of toxicity (Ma et al., 2001). Corn, sunflower and sorghum (Jadia and Fulekar, 2008) were found to be effective due to their fast growth rate and large amount of biomass (Pilon-Smits, 2005; Schmidt, 2003; Tang et al., 2003). Gardea-Torresdey et al. (2000) have shown that alfalfa is a potential source of biomaterials for the removal and recovery of heavy metal ions.

PHYTOREMEDIATION CASE STUDIES

Phytoextraction

This technology involves the extraction of metals by plant roots and the translocation thereof to shoots. The roots and shoots are subsequently harvested to remove the contaminants from the soil. Salt et al. (1995a) reported that the costs involved in phytoextraction would be more than ten times less per hectare compared to conventional soil remediation techniques. Phytoextraction also has environmental benefits because it is considered a low impact technology. Furthermore, during the phytoextraction procedure, plants cover the soil and erosion and leaching will thus be reduced. With successive cropping and harvesting, the levels of contaminants in the soil can be reduced (Vandenhove et al., 2001). Researchers at the University of Florida have discovered the ability of the Chinese brake fern, P. vittata to hyperaccumulate arsenic. In a field test, the ferns were planted at a wood-preserving site containing soil contaminated with from 18.8 to 1,603 parts per million arsenic, and they accumulated from 3,280 to 4,980 parts per million arsenic in their tissues (Ma et al., 2001). Sunflower, H. annus have proven effective in the remediation of radionuclides and certain other heavy metals. The flowers were planted as a demonstration of phytoremediation in a pond contaminated with radioactive cesium-137 and strontium-90 as a result of the Chernobyl nuclear disaster in the Ukraine. The concentration of radionuclides in the water decreased by 90% in a two-week period. According to the demonstration, the radionuclide concentration in the roots was 8000 times than that in the water. In a demonstration study performed by Phytotech for the Department of Energy, H. annus reduced the uranium concentration at the site from 350 parts per billion to 5 parts per billion, achieving a 95% reduction in 24 h (Schnoor, 1997).

Phytostabilization

Phytostabilization, also referred to as in-place inactivation, is primarily used for the remediation of soil, sediment, and sludges (United States Protection Agency, 2000). It is the use of plant roots to limit contaminant mobility and bioavailability in the soil. The plants primary purposes are to (1) decrease the amount of water percolating through the soil matrix, which may result in the formation of a hazardous leachate, (2) act as a barrier to prevent direct contact with the contaminated soil and (3) prevent soil erosion and the distribution of the toxic metal to other areas (Raskin and Ensley, 2000). Phytostabilization can occur through the sorption, precipitation, complexation, or metal valence reduction. It is useful for the treatment of lead (Pb) as well as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn). Some of the advantages associated with this technology are that the disposal of hazardous material/biomass is not required (United States Protection Agency, 2000) and it is very effective when rapid immobilization is needed to preserve ground and surface waters. The presence of plants also reduces soil erosion and decreases the amount of water available in the system (United States Protection Agency, 2000). Phytostabilization has been used to treat contaminated land areas affected by mining activities and Superfund sites. The experiment on phytostabilization by Jadia and Fulekar (2008) was conducted in a greenhouse, using sorghum (fibrous root grass) to remediate soil contaminated by heavy metals and the developed vermicompost was amended in contaminated soil as a natural fertilizer. They reported that growth was adversely affected by heavy metals at the higher concentration of 40 and 50 ppm, while lower concentrations (5 to 20 ppm) stimulated shoot growth and increased plant biomass. Further, heavy metals were efficiently taken up mainly by roots of sorghum plant at all the evaluated concentrations of 5, 10, 20, 40 and 50 ppm. The order of uptake of heavy metals was: Zn>Cu>Cd>Ni>Pb. The large surface area of fibrous roots of sorghum and intensive penetration of roots into the soil reduces leaching via stabilization of soil and capable of immobilizing and concentrating heavy metals in the roots.

Rhizofiltration

Rhizofiltration is primarily used to remediate extracted groundwater, surface water, and wastewater with low contaminant concentrations (Ensley, 2000). It is defined as the use of plants, both terrestrial and aquatic, to absorb, concentrate, and precipitate contaminants from polluted aqueous sources in their roots. Rhizofiltration can be used for Pb, Cd, Cu, Ni, Zn, and Cr, which are primarily retained within the roots (United States Protection Agency, 2000). Sunflower, Indian mustard, tobacco, rye, spinach, and corn have been studied for their ability to remove lead from water, with sunflower having the greatest ability. Indian mustard has a bioaccumulation coefficient of 563 for lead and has also proven to be effective in removing a wide concentration range of lead (4 mg/L -500 mg/L) (Raskin and Ensley, 2000; United States Protection Agency, 2000). 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 (Raskin and Ensley, 2000). Sunflower (Asteracaea spp.) have successfully been implemented for rhizofiltration at Chernobyl to remediate uranium contamination. Dushenkov et al. (1995) observed that roots of many hydroponically grown terrestrial plants such as Indian mustard (B. juncea (L.) Czem) and sunflower (H. annuus L.) effectively removed the potentially toxic metals, Cu, Cd, Cr, Ni, Pb and Zn, from aqueous solutions.

An experiment on rhizofilteration by Karkhanis et al. (2005) was conducted in a greenhouse, uisng pistia, duckweed and water hyacinth (Eichornia crassipes) to remediate aquatic environment contaminated by coal ash containing heavy metals. Rhizofilteration of coal ash starting from 0, 5, 10, 20, 30, 40%. Simultaneously the physicochemical parameters of leachate have been analyzed and studied to understand the leachability. The results showed that pistia has high potential capacity of uptake of the heavy metals (Zn, Cr, and Cu) and duckweed also showed good potential for uptake of these metals next to pistia. Rhizofiltration of Zn and Cu in case of water hyacinth was lower as compared to pistia and duckweed. This research shows that pistia/duckweed/ water hyacinth can be good accumulators of heavy metals in aquatic environment.

Phytovolatilization

Phytovolatilization involves the use of plants to take up contaminants from the soil, transforming them into volatile forms and transpiring them into the atmosphere (United States Protection Agency, 2000). Mercuric mercury is the primary metal contaminant that this process has been used for. The advantage of this method is that the contaminant, mercuric ion, may be transformed into a less toxic substance (that is, elemental Hg). 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 methyl-mercury by anaerobic bacteria.

In laboratory experiments, tobacco (*N. tabacum*) and a small model plant (*Arabidopsis thaliana*) that had been genetically modified to include a gene for mercuric reductase converted ionic mercury (Hg(II)) to the less toxic metallic mercury (Hg(0)) and volatilized it (Meagher et al., 2000). Similarly transformed yellow poplar (*Liriodendron tulipifera*) plantlets had resistance to, and grew well in, normally toxic concentrations of ionic mercury. The transformed plantlets volatilized about ten times more elemental mercury than did untransformed plantlets (Rugh et al., 1998). Indian mustard and canola (*Brassica napus*) may be effective for phytovolatilization of selenium, and, in addition, accumulate the selenium (Bañuelos et al., 1997).

PLANT-METAL UPTAKE

Plants extract and accumulate metals from soil solution. Before the metal can move from the soil solution into the plant, it must pass the surface of the root. This can either be a passive process, with metal ions moving through the porous cell wall of the root cells, or an active process by which metal ions move symplastically through the cells of the root. This latter process requires that the metal ions traverse the plasmalemma, a selectively permeable barrier that surrounds cells (Pilon-Smits, 2005). Special plant membrane proteins recognize the chemical structure of essential metals; these proteins bind the metals and are then ready for uptake and transport. Numerous protein transporters exist in plants. For example, the model plant thale cress (*A. thaliana*) contains 150 different cation transporters (Axelsen and Palmgren, 2001) and even more than one transporter for some metals (Hawkesford, 2003). Some of the essential, non-essential and toxic metals, however, are analogous in chemical structure so that these proteins regard them as the same. For example arsenate is taken up by P transporters. Abedin et al. (2002) studied the uptake kinetics of as species, arsenite and arsenate, in rice plants and found that arsenate uptake was strongly suppressed in the presence of arsenite. Clarkson and Luttge (1989) reported that Cu and Zn, Ni and Cd compete for the same membrane carriers. For root to shoot transport these elements are transported via the vascular system to the above-soil biomass (shoots). The shoots are harvested, incinerated to reduce volume, disposed of as hazardous waste, or precious metals can be recycled (phytomining). Different chelators may be involved in the translocation of metal cations through the xylem, such as organic acid chelators [malate, citrate, histidine (Salt et al., 1995b; von Wiren et al., 1999), or nicotianamine (Stephen et al., 1996; von Wiren et al., 1999)]. Since the metal is complexed within a chelate it can be translocated upwards in the xylem without being adsorbed by the high cation exchange capacity of the xylem (von Wiren et al., 1999).

CONCLUSION

The pollution of soil and water with heavy metals is an environmental concern today. Metals and other inorganic contaminants are among the most prevalent forms of contamination found at waste sites, and their remediation in soils and sediments are among the most technically difficult. The high cost of existing cleanup technologies led to the search for new cleanup strategies that have the potential to be low-cost, low-impact, visually benign, and environmentally sound. Phytoremediation is a new cleanup concept that involves the use of plants to clean or stabilize contaminated environments.

Phytoremediation is a potential remediation strategy that can be used to decontaminate soils contaminated with inorganic pollutants. Research related to this relatively new technology needs to be promoted and emphasized and expanded in developing countries since it is low cost. In situ, solar driven technology makes use of vascular plants to accumulate and translocate metals from roots to shoots. Harvesting the plant shoots can permanently remove these contaminants from the soil. Phytoremediation does not have the destructive impact on soil fertility and structure that some more vigorous conventional technologies have such as acid extraction and soil washing. This technology can be applied "in situ" to remediate shallow soil, ground water and surface water bodies. Also, phytoremediation has been perceived to be a more environmentally-friendly "green" and low-tech alternative to more active and intrusive remedial methods.

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