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PHYTOSTABILISATION FOR CONTAMINANT CONTAINMENT – REVIEW

***M. Suganthi[1], P. Muthukrishnan[2], C. Chinnusamy[3] and H. Gopi[4]**

[1]Assistant Professor, Post Graduate Research Institute in Animal Sciences, Kattupakkam, Tanuvas

[2,3]Professor, Department of Agronomy, Tamilnadu Agricultural University, Coimbatore

[4]Professor and Head, Post Graduate Research Institute in Animal Sciences, Kattupakkam, Tanuvas

E-mail: agrisuganthi@yahoo.com (**Corresponding Author*)

Abstract: Plants represent a more environmentally compatible and less expensive method to site restoration compared to physico-chemical approaches, even if the time scale required to reach the target end-points is often a limiting factor. Plants are already cleaning our environment constantly, everywhere, acting as "green livers", even if we do not recognize or know it. Phytoremediation is the *in situ* use of plants and their associated microorganisms to decontaminate a polluted site. The processes for the phytoremediation of organic pollutants, petroleum hydrocarbons in particular, are primarily by Phytodegradation, Phytostimulation, Phytovolatilization and Phytostabilization. In phytostabilization process plants are used to stabilize the soil and the contaminant resulted in clean environment.

Keywords: Phytostabilisation, Phytoremidiation, Contaminant, Phytoextraction.

Introduction

There is an increasing trend in areas of land, ground water and surface Water affected by contaminants by the industrial military or agricultural pollutants either due to ignorance lack of awareness and carelessness. Build up of toxic elements results in destruction of natural resources and also it creates strain to environment. Conventional practices such as "pump and treat" "dig and dump" technique are expensive so plant are widely used in remediation process. The use of plants specifically chosen or tailored for the rehabilitation of polluted land and brown fields, water purification, and even removal of indoor or outdoor air contaminants, is becoming essential to achieve sustainable development (Conesa *et al*., 2007).

Phytostabilisation

Phytostabilization uses plants to stabilize the soil and the contaminant. The pollutant is sorbed to the root tissue and therefore unable to move through the soil or into the groundwater. Ideal ideotypes of plants for phytostabilization should be

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- It should develop an extensive root system and
- Produce a large amount of biomass in the presence of high concentrations of metals
- Keeping root to-shoot metal translocation as small as possible (Wong, 2003).

Nevertheless, mine soils are frequently unfavorable environments for plants due to the presence of many growth-limiting factors, such as high levels of available metals, soil acidity, a lack of organic matter (OM) and its associated nutrients, and poor substrate Structure (Tordoff *et al*., 2000; Wong, 2003). The use of organic amendments is a common practice in phytostabilization procedures because organic residues are able to improve soil properties by raising pH, increasing OM content, adding essential nutrients for plant growth, increasing water holding capacity, and modifying/ reducing metal bioavailability (Alvarenga *et al*., 2009a, 2009b).

In most of the legislative scheme require that a soil be remediated when the total concentration of one or more contaminants is exceeded in a designated part (topsoil, subsoil). But in an ideal phytostabilisation process the total concentration of metal contaminants should be remain unchanged. So now the regulators following some risk based system which is based on the effect of the contaminants.

Higher plants immobilize metal by the rhizosphere effect. Root exudates stimulate microbial activity and biochemical transformation and enhancement of mineralization of metal in rhizosphere which helps in phytostabilisation (Paterson, 2003).

The chemical and biological reactions occurring in the rhizosphere play an important role in the bioavailability of metal to plants. Plants may be identified and engineered that exude compounds capable of immobilizing contaminants using redox processes of insoluble compounds in the rhizosphere. Pb is precipitated as phosphate and Cd form sulphur complexes with sulfide in the roots and the rhizosphere of *Agrostis capillaries* and *Silene vulgaris* respectively. Plants reduce mobility and transport of pollutants in the environment either by uptake or immobilization (Pulford and Watson, 2003). Soil amendments can also be used for this process. Volatilization of contaminants in to the atmosphere via plants is an important process where high concentration of contaminants present. Recent efforts have concentrated on developing transgenic species with increased potential for volatilizing Hg and selenium (Robinson *et.al*., 2007).

Processes involved in phytostabilisation

Contaminant removal

Plant removal of contaminants may play a role in this technology. Fassler *et.al*.,(2010) showed that agricultural crops could enhance the phytostabilisation of a metal contaminated soil while producing Zn-rich biomass that could be used as nutritious fodder. Repeated cropping of plants that take up contaminants from soil should lower the soil's contaminant concentrations to acceptable levels, provided the harvested amounts of contaminants exceed further inputs. Each cropping would remove contaminants from the area. The metal-rich biomass would be burned, fermented or used in gasification to reduce its volume. Residual material that is rich in the contaminating heavy metals could be reprocessed to recover metals or stored in an appropriate area, such as a contained landfill, that does not pose a risk to the environment.

Phytoextraction requires that plants accumulate large amounts of contaminants into the above-ground biomass. Hyper accumulator plants do have this property, but most of them produce little biomass so that their extraction efficiency is usually limited. In addition, agronomic cultivation techniques would still need to be developed for these plants. As an alternative strategy it has been proposed to use high biomass crop plants for which agricultural techniques exist and increase the accumulation of the contaminating metals by the application of amendments that increase their bioavailability. The addition of chelants such as EDTA can dramatically increase plant metal uptake (Hoagland and Arnon, 1950). The combination of phytoremediation and profitable crop production is known as phytomanagement (Robinson *et al*., 2007; Domı´nguez *et al*., 2010). Potential plant products such as biofuel, fibre, wood are depending on the contamination level, animal feed.

Fassler *et.al*., 2010 from his study concluded that the long-term effectiveness of phytomanagement (the combination of profitable crop production with the gradual reduction of soil contamination by phytoextraction) to deal with moderately metal-contaminated agricultural land. In a 6-year field experiment, we grew maize (*Zea mays* L.), sunflower (*Helianthus annuus* L.) and tobacco (*Nicotiana tabacum* L.) in crop rotation. The addition of elemental sulphur (2136 kg ha^{-1} yr^{-1}) decreased the soil pH from 7.4 to 6.7, increased the Zn accumulation by maize, sunflower and tobacco by factors of 1.3, 1.4 and 1.2, respectively, and increased the Cd accumulation by tobacco 1.3-fold. Neither the addition of ammonium sulphate (129 kg /ha/year) nor nitrilotriacetic acid (NTA, 430 kg/ ha/yr) significantly increased phytoextraction. The results show that phytoextraction for soil cleansing would require centuries. However, this land could be used to generate profitable crops, including the production of safe (low Cd) stock fodder fortified with Zn, green manure for micronutrient-deficient soils.

Plant based processes involved in the containment of contaminant

Contaminant	Substrate	Plant species	Containment process
Hg	Base metal tailing	*Brassica juncea*	Phytovolatalisation and phytoextraction
Cd	Variable charge soil	*Brassica juncea*	Phytoimmobilisation
Cu	Soil	*Brassica napus*	Chelation followed by uptake
As and Mo	Tailing	*Brassica juncea*	Phytoextraction
Pb,Cd,Cu	Artificially contaminated with 600 mg/kg 40 mg/kg Cd,and 100 mg/kg Cu	*Echinochloa crus-galli*	Phytoextraction
Cd,Cr,Cu,Pb and Zn	Multply metal contaminated soil	*Brassica juncea*	Chelation followed by uptake

Inoculation with specific mycorrhizal fungi has been considered to increase the uptake of nutrients and pollutants by phytoextractor species. Inoculation of *Melilotus officinalis* and *sorghum sudanense* with vesicular arbuscular mycorrhizae increased the uptake of ^{137}Cs by 30 Bq/g ash. The association of *Pteris vittata* with mycorrhizal fungi increased its capacity to uptake As up to 1031 mg As /Kg dry weight compared to 527 mg As/kg in the non mycorrhizal plants (Leung *et.al*., 2010). The mechanisms of plant nutrient uptake by the fungi and their subsequent translocation into the root may be more specific than the corresponding plant uptake mechanisms reducing the amount of toxic metal than enter the plant.

Soil cover

Vegetative cover also plays a vital role in stabilization by reducing the water flux through the soil profile and mechanically stabilizing the soil through root growth. Vegetation reduces the wind velocity, thereby mitigating the dispersion of soil and sediments. The vegetation induced reduction in soil erosion is likely to reduce the movement of contaminants and subsequent off-site contamination. Vegetative cover increased infiltration there by reducing the runoff which helps in reduction in leaching of contaminants. Vegetative cover in rehabilitated mined land increased infiltration rate and declined erosion from stimulated storm from 30-35 t/ha at 0% vegetative cover to 0.5 t/ha at 47% cover (Loch, 2000).

Rhizosphere modification

Rhizosphere induced changes in soil biochemical properties regulate the transformation, mobility and bioavailability of metal there by affecting the phytostabilisation of contaminated sites. Major rhizosphere impact is acidification, release of organic acids and increased microbial activity. The plants receiving NH4+ will counterbalance the corresponding excess of positive charges by releasing equivalent amounts of H+ in the rhizosphere, thereby decreasing rhizosphere pH. Apart from this, nitrogen transformation and nitrate leaching in the nitrogen cycle have been suggested to be major causes of soil acidification (Bolan and Hedley, 2003)**.**

Acidification affect the solubility and speciation of metal in several ways such as modification of surface charge in variable charge soils, Altering the speciation of metal and influencing the redox reactions of the metal (Adriano,2001). Acidification will control the adsorption of heavy metal. Desorption of heavy metal is also is higher in acid soils. Both adsorption and desorption controls the bioavailability of metals thereby it increases the chance for leaching due to desorption and metals moves into groundwater.

Adsorption of metal almost invariably decreases with increasing soil acidity (Yang *et.al.*, 2006). In soils with low oxide content increasing pH had little effect on adsorption while in highly acidic soils adsorption decreased with increasing pH. Carbon compound and nutrients are released by plant root into the rhizosphere by rhizodeposition. Rhizodeposits which mostly consist of carbohydrates, carboxylic acids and amino acids which are responsible for enhanced microbial activity. Among the carboxylate malate, citrate and oxalate are expected to have the most dramatic effect. Some prokaryotic and eukaryotic microorganisms excrete extracellular polymeric substances (EPS) such as polysaccharides, glycoprotein, lipopolysaccharide and soluble peptide. Microbes involved in EPS production are *Bacillus megaoterium, Acinetobacter, Pseudomonas aeruginosa and Cyanobacteria*

Hydraulic control

The plants are effectively acting as natural hydraulic pump. Which when a dense root network has been established near the water table in the soil can transpire large volume of water per day(6 lit /plant/day)Hydraulic control system can be utilized to decrease the migration of contaminants (Ashwath and Venkatraman, 2010). Hydraulic control is regulation of movement of contaminants through leaching and surface runoff by controlling the flow of water in soil. Phytocapping of contaminated soil involves placing the layer of soil material and growing of dense vegetation. Soil layer act as 'sponge' as the time of rain activity and reduce the infiltration rate .vegetation act as a ‘bio-pump’ so that the contaminants move in to the stream of plants and become inactive.

An alternative landfill capping technique known as ‘Phytocapping’ (establishment of plants on a layer of soil placed over the waste) was trialled at Rockhampton, Australia. Twenty one tree species were grown for 3 years on two types of phytocaps (thick cap; 1400 mm and thin cap; 700 mm and their growth, transpiration loss, canopy rainfall interception and methane oxidation were studied. The results show that the canopy of the trees grown on the phytocaps intercepted, on an average, 30% of the rainfall thus preventing a significant proportion of the rain water from entering the soil. The long-term sap flow monitoring data showed that the 2 to 3 year-old trees could remove 0.9 to 2.1 mm day^{-1}. The phytocaps were also found very effective in oxidising methane. The methane concentrations were 4 to 5 times lower in phytocaps than in the adjacent non-vegetated landfill sites. Overall, results of this study demonstrate that the phytocaps are effective in limiting percolation of water into the waste at Rockhampton which has a semi-arid climate. (Barton *et. al*. 2005) noticed that *Pinus taeda* and *Pinus virginiana* has resulted in a decrease in the drainage volume by facilitating water loss through transpiration. Phytoremediation can also affect metal fluxes via plant-induced physico-chemical changes in the soil. Vegetation affects the fate of trace elements in soil (Robinson *et. al.,* 2006). Increase in transpiration rate will increase the uptake of metals. An increase in Pb and Zn uptake by lettuce and wheat respectively with increase in transpiration rate.

Conclusion

Phytostabilisation is primarily aimed at containing the mobility of contaminants through their immobilization within the root zone of plants and “holding” soil and sediments, thereby preventing off-site contamination through their migration via wind and water erosion and leaching, and soil dispersion. The main advantage of this technology is that it reduces the mobility and therefore the risk of contaminants without necessarily removing them from their source location. Further this technology does not generate contaminated secondary waste that needs treatment and also provides ecosystem development to achieve biodiversity corridors. However, since the contaminants are left in place, the site enquires regular monitoring in order to maintain the stabilizing conditions. If the soil amendments are used to enhance immobilization, they may need to be periodically reapplied to maintain the effectiveness of the phytostabilisation. Hence the plants are the best option for remediating the environmental pollution.

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