

PHYTOREMEDIATION: PROCESSES AND MECHANISMS

N AHALYA AND T V RAMACHANDRA

ENERGY AND WETLANDS RESEARCH GROUP CENTRE FOR ECOLOGICAL
SCIENCES, INDIAN INSTITUTE OF SCIENCE, BANGALORE 560 012

(Received 5-1-2004; revised 1-3-04; accepted 10-3-04)

ABSTRACT

Heavy metal contamination of soil and water due to agricultural and industrial activities is a matter of serious concern, which ultimately reaches humans in the food chain. The sources of these heavy metals can be from both point and non-point sources. The heavy metals when discharged into aquatic ecosystems are easily assimilated by planktonic organisms at the base of the aquatic food chain. Through the process of biomagnification, minute concentrations of heavy metals are passed up in the food chain, increasing to levels that pose a serious threat to higher order organisms. The conventional treatment systems have many disadvantages like high cost, incomplete metal removal, etc. In this context, phytoremediation is being increasingly adopted wherein certain plants are used to adsorb or degrade the pollutants. These plant are found in the Brassicaceae, Euphorbiaceae, Asteraceae, Lamiaceae and Scrophulariaceae families.

Key words : Phytoremediation, Processes, Mechanisms.

INTRODUCTION

The discharge of heavy metals in the environment has been a matter of concern with rapid industrialization and intensification of agricultural activities over the last few decades. The pollutants are introduced into the environment without appropriate treatment in most localities. Heavy metals released into the environment today comes from uncontrolled emissions by metal smelters and other industrial activities, unsafe disposal of industrial wastes and lead in water pipes, paint, and gasoline.

Heavy metals that are hazardous are lead, mercury, cadmium, arsenic, copper, zinc and chromium. Such metals are found naturally in the soil in trace amounts. Increased concentrations due to anthropogenic activities in particular areas pose serious threat to all living organisms. Arsenic and cadmium, for instance, can cause cancer. Mercury can cause mutations and genetic damage, while copper, lead, and mercury can cause brain and bone damage.

Metal ions are commonly removed from dilute aqueous streams through chemical precipitation, reverse osmosis and solvent extraction.

These techniques have disadvantages such as incomplete metal removal, high reagent and energy requirements, generation of toxic sludge or other waste products that again require disposal.

The search for alternate and innovative treatment techniques has focused attention on the use of biological materials for heavy metal removal and recovery technologies (Biosorption) and has proved efficient in the removal of heavy metals and economically viable compared to conventional treatment. Metal accumulative bioprocesses generally are divided into two categories, biosorptive (passive) uptake by non-living biomass and bioaccumulation by living cells. Among the various resources of biological wastes, both dead and live biomass of microorganisms (bacteria, yeasts, fungi & algae) and some plants exhibit metal-binding capabilities (Wong 2003).

Phytoremediation: Phytoremediation is a general term used to clean up contaminants using plants, or *remediate sites* by removing pollutants from soil and water (Chandra Shekar *et al* 2003). Plants can break down or degrade organic pollutants or contain and stabilize metal contaminants by acting as filters or traps. Phytoremediation involves growing plants in a contaminated matrix, for a required growth period to remove contaminants from the matrix or facilitate immobilization or degradation (detoxification) of the pollutants. The plants can be subsequently harvested, processed and disposed off in an environmentally sound manner.

A phyto remediation system capitalizes on the synergistic relationships among plants, microorganisms, water and soil that have evolved naturally in wetlands and upland sites over millions of years. In the biological sequences that transform contaminants to neutral compounds, plants contribute inherent enzymatic and uptake processes that can recycle or sequester the organic molecules they encounter.

Plants act as hosts to aerobic and anaerobic microorganisms, supplying them with both physical habitat and chemical building blocks. Plant roots and shoots increase microbial activity in their direct environment by providing additional colonisable surface area, increasing readily-degradable

carbon substrates by organic exudates and leachates and by decomposition of part of their mass and creating temporally and spatially varying oxygen regimes.

Physically, plants slow the movement of contaminants in soil (reduced run-off), increase evapotranspiration and adsorb compounds through their roots. Once a wetland or upland phytoremediation system is in place, its biological components would be naturally self-sustaining (due to photosynthesis).

Phytoremediation can be applied in terrestrial and aquatic environments. It can be used as a preparative or finishing step for other clean-up technologies. Plants are aesthetically pleasing and these systems are relatively self-sustaining and cost-effective. Plants have evolved a great diversity of genetic adaptations to handle the accumulated pollutants that occur in the environment. Growing, and in some cases harvesting the plants on a contaminated site as a remediation method is a passive technique that can be used to clean up sites with shallow, low to moderate levels of contamination. Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons and landfill leachates. It can also be used in river basin management through the hydraulic control of contaminants.

Mechanism of phytoremediation: There are several ways by which plants clean up or remediate contaminated sites. The uptake of contaminants in plants occurs primarily through the root system, in which the principal mechanisms for preventing toxicity are found. The root system provides an enormous surface area that absorbs and accumulates the water and nutrients essential for growth along with other non-essential contaminants (Yin Ouyang 2002). Plant roots cause changes at the soil-root interface as they release organic and inorganic exudates in the rhizosphere. These root exudates affect the number and activity of microorganisms, the aggregation and stability of the soil particles around the root, and the availability of the contaminants. Root exudates by themselves can increase or decrease (immobilize) the availability of the contaminants in the root zone of the plants through changes in soil characteristics, release of organic substances, changes in chemical composition and/or increase in plant assisted microbial activity.

Phytoremediation Processes: At metals contaminated sites, plants are used either to stabilise or remove the metals from the soil and ground water through mechanisms such as phytoextraction, rhizofiltration, and phytostabilization (UNEP 2002).

Phytoextraction also called phytoaccumulation, refers to the uptake and translocation of metal contaminants in the soil by plant roots into the aboveground portions of the plants. Certain plants, called hyperaccumulators, adsorb unusually large amounts of metals in comparison to other plants. One or a combination of these plants is selected and planted at a particular site based on the type of metals present and other site conditions. After the growth period of the plants, they are harvested and either incinerated or composted to recycle the metals. This procedure may be repeated if necessary, to bring soil contaminant levels down to permissible limits. If plants are incinerated, ash is disposed off in a hazardous waste landfill. The volume of ash will be less than 10% of the volume that is created, if the contaminated soil itself were dug up for treatment.

Metals such as nickel, zinc and copper are the best candidates for removal by phytoextraction because it has been shown that they are preferred by a majority of the (approximately 400) plants that uptake and absorb unusually large amounts of metals.

Rhizofiltration (rhizo- means root) is the adsorption or precipitation onto plant roots or absorption of contaminants in the solution surrounding the root zone. Rhizofiltration is similar to phytoextraction, but the plants are used primarily to address contaminated ground water rather than soil. The plants to be used for cleanup are raised in greenhouses with their roots in water rather than in soil. To acclimatize the plants, once a large root system has been developed, contaminated water is collected from a waste site and brought to the plants where it is substituted for their water source. The plants are then planted in the contaminated area where the roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested.

Phytostabilization is the use of certain plant species to immobilize contaminants in the soil and ground water through absorption and

accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants (rhizosphere). This process reduces the mobility of the contaminant and prevents migration to the ground water, and it reduces bio-availability of metal into the food chain. This technique can also be used to reestablish vegetation cover at sites where natural vegetation fails to survive due to high metals concentrations in surface soils or physical disturbances to surface materials. Metal-tolerant species is used to restore vegetation at contaminated sites, thereby decreasing the potential migration of pollutants through wind erosion and transport of exposed surface soils and leaching of soil contamination to ground water.

Thus, phytoremediation is a low cost, solar energy driven and natural cleanup technique, which are most useful at sites with shallow, low levels of contamination. They are useful for treating a wide variety of environmental contaminants and are effective with or in some cases, in place of mechanical cleanup methods. Environmentally sound technologies (ESTs) encompass technologies that have significantly improved environmental performance relative to other technologies. ESTs protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products, and handle all residual wastes in an environmentally sustainable manner. The development and application of phytoremediation as an environmentally sound technology involves a number of challenges that include capacity building and establishment of regulatory framework (John B Williams 2002). Mostly, there is a lack of data, performance standards and cost-benefit analysis regarding phytoremediation technologies. Hence there is a need for:

- appropriate phytoremediation technologies and techniques applicable to different geographic regions with varied climatic conditions;
- site characterization, clean-up and technology selection criteria;
- assessment and evaluation methods that can determine the applicability of various phytoremediation techniques; and
- capacity-building on the planning and implementation of phytoremediation technology.

REFERENCES

Chandra Shekar K, Kamala C T, Chary N S and Anjaneyulu Y 2003 Removal of heavy metals using a plant biomass with reference to environmental control. *Int. J. Mineral Processing*. 68:1-4 :37-45

Journal of Ecobiology Vol.18 (2006)

- Wong M H 2003 Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. *Chemosphere* 50(6) : 775-780.
- Williams J B 2002 Phytoremediation in wetland ecosystems: Progress, problems and potential. *Critical Rev. Plant Sci.* 21(6) : 607-635.
- Yin Quyang 2002 Phytoremediation: modeling plant uptake and contaminant transport in the soil-plant-atmosphere continuum. *J. Hydrology* 260: 1-2 :66-82.
- UNEP 2002 Phytoremediation: An environmentally sound technology for pollution prevention, control and remediation - An Introductory guide for decision makers. Freshwater Management Series No. 2
- <http://www.clu-in.org/products/citguide/phyto2.htm>
- E-Mail: cestvr@ces.iisc.ernet.in
energy@ces.iisc.ernet.in