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Phytoremediation: Green Technology: A Review

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Abstract:
Polluted water is major environmental and human health problem, which may be solved by the phytoremediation technology. It is cost effective and environmental friendly technique in which plants are used to absorb the pollutants from air , water or soil. There are five types of phytoremediation techniques: 1) rhizofiltration, a water remediation technique involving the uptake of contaminants by plant roots; 2) phytoextraction, a soil remediation technique involving uptake of contaminants from soil; 3) phytotransformation, applicable for both soil and water, involving the degradation of contaminants through plant metabolism, 4) phyto-stimulation or plant-assisted bioremediation, also applicable for both soil and water, which involves the stimulation of microbial biodegradation through the activities of plants in the root zone, and 5) phytostabilization, using plants to reduce the mobility and migration potential of contaminants in soil.

Keywords: Phytoremediation, Rhizofiltration, phytoextraction, phytotransformation, phyto-stimulation, phytostabilization.

I. INTRODUCTION

The godfather of phytoremediation and the study of hyperaccumulator plants may very well be R. R. Brooks of New Zealand. The first article on phytoremediation was written by scientists at Rutgers University, about the use of specially selected and engineered metal-accumulating plants used to clean polluted soils. In 1993, a United States patent was filed by a company called Phytotech. Titled "Phytoremediation of Metals", the patent disclosed a method to remove metal ions from soil using plants.[1]. The phytoremediation is a broad term which has been used since 1991 to describe the use of plants to reduce the volume, mobility or toxicity of contaminants in soil, groundwater or other contaminated media[2]

What is phytoremediation

Phytoremediation is basically defined as removal or degradation or detoxification of harmful environmental pollutants with the help of green plants and their associated microorganisms, soil amendments or agronomic techniques. Phytoremediation, an emerging cleanup technology for contaminated soils, groundwater, and wastewater, is both low-tech and low-cost.

Phytoremediation of heavy metals-Concepts and applications

The mobilization of heavy metals by man through extraction from ores and processing for different applications has led to the release of Phytoremediation defined as the engineered use of green plants, including grasses, forbs, and woody species, to remove, contain, or render harmless such environmental contaminants as heavy metals, trace elements, organic compounds, and radioactive compounds in soil or water. This definition includes all plant-influenced biological, chemical, and physical processes that aid in the uptake, sequestration, degradation, and metabolism of contaminants, either by plants or by the free-living organisms that constitute the plant's rhizosphere.[3] The health hazards associated with soil contamination with trace elements having toxic effects together with high cost of removal and replacement of polluted soil have prompted to develop alternative and cheaper technologies to recover the degraded land. Current research in this area now includes plants to remediate polluted soils and to facilitate improvement of soil structure, the innovative technique being known as phytoremediation .[4] Phytoremediation is the direct use of living green plants in situ, or in place, for removal, degradation, or containment of contaminants in soils, sludges, sediments, surface water and groundwater. Phytoremediation is:

- A low cost, solar energy driven cleanup technique.
- Most useful at sites with shallow, low levels of contamination.
- Useful for treating a wide variety of environmental contaminants.
- Effective with, or in some cases, in place of mechanical cleanup methods. [5]

Assessments of plants for phytoremediation of arsenic-contaminated water and soil.

Phytoremediation is an innovative technology that uses plants in order to remediate polluted water and soil. A 10 week study in flower pots was performed in order to determine the arsenic (As) removal potential of Shoenoplectus americanus, Eleocharis macrostachya and Baccharis salicifolia and also to evaluate their tolerance capacity to increasing doses of As. The experiment involved five different treatments with distinct As concentrations (1, 2, 3, 4 and 5 mg L^{-1}) and a control (tap water) to determine the acclimatization capacity of the species to the different concentrations. The number of plants and their height were determined during the experiment. The values for the factors of translocation, accumulation and enrichment were obtained at the end of the experiment; the maximum values for these factors were, respectively, 1.86, 92.13 and 1.63 for E. macrostachya, 1.73, 59.74 and 0.56 for S. americanus and 8.96, 27.94 and 6.72 for B. salicifolia. The maximum growth value belonged to the S americanus. The maximum concentration of As in water tolerated by E. macrostachya and B. salicifolia were 2 and 3 mg L^{-1} respectively. B. Salicifolia, has no tolerance for environments with high concentrations of arsenic.

S. americanus showed the highest As accumulation capacity and the greatest tolerance in the tested concentrations. E. macrostachya proved to be translocator plants and S. americanus was confirmed to be a stabilizer plant with a high potential for phytostabilization and rhizofiltration techniques.[6]

Phytodegradation

The phytodegradation of organic compounds can take place inside the plant or within the rhizosphere of the plant. Many different compounds and classes of compounds can be removed from the environment by this method, including solvents in groundwater, petroleum and aromatic compounds in soils, and volatile compounds in the air. Although still a relatively new area of research, there are many laboratories studying the underlying science necessary for a wide range of applications for plant-based remediation of organic contaminants .[7]

Phytodegradation of total petroleum hydrocarbon (TPH) in diesel-contaminated water using Scirpus grossus

Phytoremediation using the perennial plant Scirpus grossus has been suggested as an environmentally friendly and economical method for treating contaminated water. In this study, a pilot-scale constructed wetland with a sub-surface batch system was adapted for the phytoremediation of contaminated water with different diesel concentrations, i.e., 0%, 0.1%, 0.175%, and 0.25% (V_{diesel}/ V_{water}), using S. grossus for a period of 72 days under greenhouse conditions. The degradation of total petroleum hydrocarbons (TPH) from the water by S. grossus after 72 days of diesel exposure was recorded as 81.5%, 71.4%, and 66.6% for 0.1%, 0.175%, and 0.25% diesel (v/v) treatments, respectively. S. grossus was extracted, and the results show that the maximum TPH was 223.56 mg kg?1in stem + leaf samples with 93.72% n-alkanes C20–C34. In the batch biodegradation experiment, the rhizobacteria of S. grossus played a role in diesel degradation in the rhizosphere zone. Hence, a sub-surface batch constructed wetland using S. grossus could be a promising solution for the phytoremediation of industrial contaminated water with diesel. [8]

Phytostabilization

Soils have become contaminated by metals over centuries of human industry. Mining and smelting have caused extensive soil contamination in most countries. Many countries are working to limit environmental and human risks from the contaminated soils under regulatory programs such as the US (Superfund). The extent of contamination varies from statistically detectable to severe such that no plants can grow on the contaminated soils and the contamination erodes to disperse and worsen the environmental effects of the site. The simplest method to address such sites is to require placing all contaminated soil materials in a secure landfill, usually on site, and cover the landfill with clean topsoil. For some small areas of contaminated soils, that may be the most cost effective solution. But for extensive mine waste and smelter contaminated sites, the cost would be massive. But most of this land area was near neutral pH, well vegetated, and actively farmed or gardened with no evidence of adverse effects to plants, wildlife, soil organisms or humans. Small areas with >10,000 mg Ni kg-1 were removed based on possible soil ingestion risk as a protective measure before any governmental decision about the requirement for soil remediation was completed. Diagnosis of metal phytotoxicity is best done using agronomic soil analysis methods such as the diethylenetriaminepenta acetate extraction. In this method, the chelating agent DTPA. extracts metals in a soil solution matrix buffered at pH 7.3. In order to test contaminated soils the ratio of solution to soil must be increased markedly. The original method used 20 mL per 10 g of air dry soil. This is fine for diagnosis of potential Fe or Zn deficiency. But for contaminated soils the metals which are strongly chelated (Fe, Zn, Cu, Pb, Cd, Ni, Mn) can saturate the DTPA causing false low estimates of DTPA-extractable potentially toxic metals. In testing of Zn-Cd contaminated soils at Palmerton, PA, USA, found that they needed to use 50 mL g^{-1} soil to avoid DTPA saturation and underestimation of available metals. In testing of Ni contaminated soils at Port Colborne, Ontario, Canada, Kukier and Chaney (2001) found they had to use at least 30 mL g^{-1} soil to avoid saturation. [9]

Phytostabilization: A Green Approach to Contaminant Containment

Phytostabilization involves the establishment of a plant cover on the surface of the contaminated sites with the aim of reducing the mobility of contaminants within the vadose zone through accumulation by roots or immobilization within the rhizosphere, thereby reducing off-site contamination. The process includes transpiration and root growth that immobilizes contaminants by reducing leaching, controlling erosion, creating an aerobic environment in the root zone, and adding organic matter to the substrate that binds the contaminant. Microbial activity associated with the plant roots may accelerate the degradation of organic contaminants such as pesticides and hydrocarbons to nontoxic forms. Phytostabilization can be enhanced by using soil amendments that immobilize metal(loid)s combined with plant species that are tolerant of high levels of contaminants and low-fertility soils or tailings. Although this technology is effective in the containment of metal(loid)s, the site requires regular monitoring to ensure that the stabilizing conditions are maintained. Soil amendments used to enhance immobilization may need to be periodically reapplied to maintain their effectiveness. We critically examine the applicability of this technology to manage metal(loid)s contaminated soils and identify fertile areas for future research.[10]

Rhirofiltration

Heavy metal pollution of aqueous streams is a major environmental problem facing the modern world. Several methods of removing heavy metals from water based on ion exchange or chemical and microbiological precipitation have been developed and used with some success .These technologies have different efficiencies for different metals and may be very costly if large volumes, low metal concentrations, and high cleanup standards are involved. Recently, there has been some research into the use of living and nonliving bacteria and algae for the bioremediation and recovery of heavy metals from aqueous streams . In addition, live or dead cultured cells of Datura innoxia, a higher plant, can be used to remove Ba2+ from solution . Commercial applications of this research are still hampered by the high cost of growing pure cultures of cells and microorganisms and by the need for their immobilization or separation from the aqueous stream. Metal-accumulating fungi and Azolla filiculoides, an aquatic fern ,were also proposed as metal biosorbers capable of remediating industrial effluents. Aquatic higher plants have also been utilized for water purification. Water hyacinth (Eichhornia crassipes) can remove various heavy metals from solution. However, the efficiency of metal removal by these plants is low because of their small size and small, slow-growing roots. The high water content of aquatic plants also complicates their drying, composting, and incineration. In contrast, terrestrial plants develop much longer, fibrous root systems covered with root hairs, which create an extremely high surface area. These roots are easily dried in the open air. Here, we demonstrate that hydroponically grown roots of a terrestrial plant Brassica junceu (Indian mustard) effectively remove heavy metals from aqueous solutions. We refer to this process as rhizofiltration, which is defined as the use of plant roots to absorb, concentrate, and precipitate heavy metals from polluted effluents. Our estimates indicate that in many cases the efficiency of removal compares favorablywith currently employed water treatment technologies. The commercialization of rhizofltration will be driven by economics as well as by such technical advantages as applicability to many "problem" metals, ability to treat high volumes, lesser need for toxic chemicals, reduced volume of secondary waste, possibility of recycling, and the likelihood of regulatory and public acceptance. B. junceu was chosen as a model plant for rhizofltration because it accumulated high levels of Pb and other heavy metals in a screen that used a number of commercially cultivated plant species . In addition, several members of the Brassicaceae family have been shown to accumulate unusually high concentrations of heavy metals in both shoots and roots Lead (Pb), cadmium (Cd), copper.[11]

Rhirofiltration: The Use of Plants To Remove Heavy Metals from Aqueous Streams

Heavy metal pollution of water is a major environ-mental problem facing the modern world. Rhizofiltration-the use of plant roots to remove heavy metals from water-is an emerging environmental cleanup technology. Roots of many hydroponically grown terrestrial plants, e.g., Indian mustard (Brassica juncea (L.) Czern.), sunflower (Helianthus annuus L.), and various grasses, effectively removed toxic metals such as Cu2+, Cd2+, C P , Ni2+, Pb2+, and Zn2+ from aqueous solutions. Roots of B, juncea concentrated these metals 131-563-fold (on a DW basis) above initial solution concentrations. Pb removal was based on tissue absorption and on root-mediated Pb precipitation in the form of insoluble inorganic compounds, mainly lead phosphate. At high Pb concentrations, precipitation played a progressively more important role in Pb removal than tissue absorption, which saturated at approximately 100 mg of Pb/g DW root. Dried roots were much less effective than live roots in accumulating Pb and in removing Pb from the solution.[11]

Rhizofiltration using sunflower (Helianthus annuus L.) and bean (Phaseolus vulgaris L. var. vulgaris) to remediate uranium contaminated groundwater

The uranium removal efficiencies of rhizofiltration in the remediation of groundwater were investi-gated in lab-scale experiments. Sunflower (Helianthus annuus L.) and bean (Phaseolus vulgaris L. var.vulgaris) were cultivated and an artificially uranium contaminated solution and three genuine ground-water samples were used in the experiments. Morethan 80% of the initial uranium in solution and genuine groundwater, respectively, was removed within 24h by using sunflower and the residual uranium concentration of the treated water was lower than 30g/L (USEPA drinking water limit). For bean, the uranium removal efficiency of the rhizofiltration was roughly 60–80%. The maximum uranium removal via rhizofiltration for the two plant cultivars occurred at pH 3–5 of solution and their uranium removal efficiencies exceeded 90%. The lab-scale continuous rhizofiltration clean-up system delivered over 99% uranium removal efficiency, and the results of SEM and EDS analyses indicated that most uranium accumulated in the roots of plants. The present results suggested that the uranium removal capacity of two plants evaluated in the clean-up system was about 25mg/kg of wet plant mass. Notably, the removal capacity of the root parts only was more than 500mg/kg. [12]

Rhizodegradation

Rhizodegradation, also called phyto-stimulation or plant-assisted bioremediation/degradation, is the breakdown of contaminants in the rhizosphere (soil surrounding the roots of plants) through microbial activity that is enhanced by the presence of plant roots and is a much slower process than phytodegradation. Micro-organisms (yeast, fungi, or bacteria) consume and digest organic substances for nutrition and energy. Certain micro-organisms can digest organic substances such as fuels or solvents that are hazardous to humans and break them down into harmless products in a process called biodegradation. Natural substances released by the plant roots – sugars, alcohols, and acids – contain organic carbon that provides food for soil microorganisms and the additional nutrients enhance their activity. Biodegradation is also aided by the way plants loosen the soil and transport water to the area. [13]

Effect of Rhizodegradation in Diesel-contaminated Soil under Different Soil Conditions

In order to develop a cultivation technique for the practical use of phytoremediation of diesel-contaminated soil, we evaluated the rhizodegradation of diesel-contaminated soil using Italian ryegrass. Experiments were conducted under two different soil conditions that were expected to reduce the influence of diesel on the plant. Under the first condition, the initial diesel concentration which is expressed in the total petroleum hydrocarbon (TPH) concentration was set to 0.80%. The concentration was almost half the upper limit for the growth of Italian ryegrass. Under the second condition, zeolite was added to the experimental soil to improve the cation exchange capacity (CEC). In 152 days experiments, we evaluated the plant growth variables, TPH concentration, soil dehydrogenase activity (DHA) that is reflective of the rhizosphere microbial activity, and the aerobic bacterial count. The results suggest that the TPH concentration in first condition (0.80%) could not bring about a significant recovery of plant growth. The plant growth observed in first condition was equal to that observed in the case of the upper limit TPH concentration used in our previous study. However, under the second condition, it is suggested that the addition of zeolite could increase plant growth, which can in turn improve the rhizodegradation effect. [14]

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