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POPULAR ARTICLE

PHYTOREMEDIATION: A GREEN TECHNOLOGY TO CLEAN UP CONTAMINATED SOIL

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ABSTRACT

Phytoremediation, or the use of green plants to clean and regulate pollutants in water, soil, and air, is a critical component of the emerging area of ecological engineering. Site's soil and water parameters, nutrient sustainability, meteorological, hydrology, viable ecosystems, and pollutant characteristics determine in situ and ex-situ uses. In many applications, phytotoxicity and mass transport restrictions or bioavailability are crucial. Most applications are affordable since they rely on sunshine and in-situ nutrient recycling, however, treatments across vast land areas and longer treatment durations are mainly confined to root zones and shallow water. Wetlands, grasslands, crops, and tree plantations have been used successfully to treat a range of pollutants, often present in low quantities and are not highly phytotoxic.

INTRODUCTION

Heavy metal contamination has been identified as one of the key abiotic pressures causing environmental degradation in recent decades. Although heavy metals occur naturally in soil, geologic and human activities raise their concentration to levels that may be hazardous to both plants and animals due to their potential toxicity, which disrupts their physiology and development.

Metals are taken up by plant roots and translocated to the shoot system, where they can endanger human health when they reach the food chain. The phytoremediation process involves using plants and the bacteria that live on them to clean up the environment. This method uses natural mechanisms in plants and the microbial rhizosphere flora to break down and store organic and inorganic contaminants. A reliable method of cleaning up different organic and inorganic toxins is phytoremediation. Most organic contaminants in the environment are artificial and toxic to living things. Some of them are carcinogenic and many are poisonous. Through spills (fuel, solvents), military operations (explosives, chemical weapons), agriculture (pesticides, herbicides), industry (chemical, petrochemical), wood treatment, etc., organic pollutants are discharged into the environment. Depending on their qualities, organic materials may be taken up by plants or degraded in the root zone before being degraded, sequestered, or volatilized. Successful phytoremediation has been used to treat a variety of organic pollutants, including the most prevalent groundwater pollutant, TCE, herbicides like atrazine, explosives like TNT, petroleum hydrocarbons like oil, gasoline, benzene, toluene, and PAHs, the fuel additive MTBE, and polychlorinated biphenyls (PCBs). It is normal for inorganic contaminants to exist in the earth's crust or atmosphere. Their release into the environment is facilitated by human activities including mining, industry, transportation, agriculture, and military, which causes toxicity. Although inorganics cannot be broken down, they can be stabilised or sequestered in plant tissues that can be used for harvest through phytoremediation. Plant macronutrients like nitrate and phosphate, plant trace elements like Cr, Cu, Fe, Mn, Mo, and Zn, non-essential elements like Cd, Co, F, Hg, Se, Pb, V, and W, and radioactive isotopes like 238U, 137Cs, and 90Sr are examples of inorganic pollutants that can be remedied by phytoremediation. For solid, liquid, or gaseous substrates, phytoremediation is one option. At military sites (TNT, metals, organics), agricultural fields (herbicides, pesticides, metals, selenium), industrial sites (organics, metals, arsenic), mine tailings (metals), and wood treatment sites, for instance, contaminated soils and sediments have been phytoremediated (PAHs). Sewage and municipal wastewater (nutrients, metals), agricultural runoff/drainage water (nutrients from fertilisers, metals, arsenic, selenium, boron, organic pesticides, and herbicides), industrial wastewater (metals, selenium), coal pile runoff (metals), landfill leachate, mine drainage (metals), and groundwater plumes are examples of polluted waters that can be treated by phytoremediation (organics, metals).

Additionally, plants can filter out airborne contaminants, including NOx, SO2, ozone, CO2, nerve gases, dust or soot particles, or halogenated volatile hydrocarbons inside and outside. In the last 10 years, business and governmental organisations have been more interested in phytoremediation. Due in part to the comparatively low cost of phytoremediation and the restricted funding for environmental cleaning, this practice has become increasingly popular. Environmental clean-up comes with astronomical prices. Currently, $6-8 billion and $25-50 billion respectively are spent yearly on environmental cleaning in the US. Phytoremediation is, on average, ten times more affordable than engineering-based remediation techniques such as soil excavation, soil washing or burning, or pump-and-treat systems since biological processes are ultimately solar-driven. Additionally, the cost-effectiveness of phytoremediation is enhanced by the fact that treatment is often done in place. It could lessen how much of the contaminated substrate is exposed to people, animals, and the environment. Phytoremediation offers benefits but also has its drawbacks.

The plants that handle the cleaning need to be close to the contaminant and capable of responding to it. Soil characteristics, toxic levels, and climate should all promote plant development. If soils are toxic, they can be improved using amendments, as explained below, to make them more conducive to plant development because the plants need to be able to reach the pollution, phytoremediation is likewise constrained by root depth. For herbaceous plants, the normal root depth is 50 cm, whereas, for trees, it is 3 m. Pollutant breakdown by plants and flow via phytoremediation systems both function fairly quickly (days or months), while soil cleaning by plant accumulation sometimes takes years, limiting application. The contaminants' bioavailability may also put a cap on phytoremediation. Phytoremediation is not appropriate if just a small portion of the pollutant is bioavailable yet the legal cleaning criteria demand that all of the contaminants be eliminated. However, adding soil amendments—as explained below—can increase pollutant bioavailability. However, certain phreatophytes have been seen to tap into groundwater at depths of 15 metres or more, particularly in dry conditions. Bio/phytoremediation does not preclude non-biological remediation techniques. The most successful and economical remediation method may involve a mix of multiple methods, such as digging the most polluted areas and polishing the site with plants, because pollutant distribution and concentration are heterogeneous at many sites. A diverse team of skilled scientists is necessary for such an integrated remediation endeavour.

PHYTOREMEDIATION METHODS

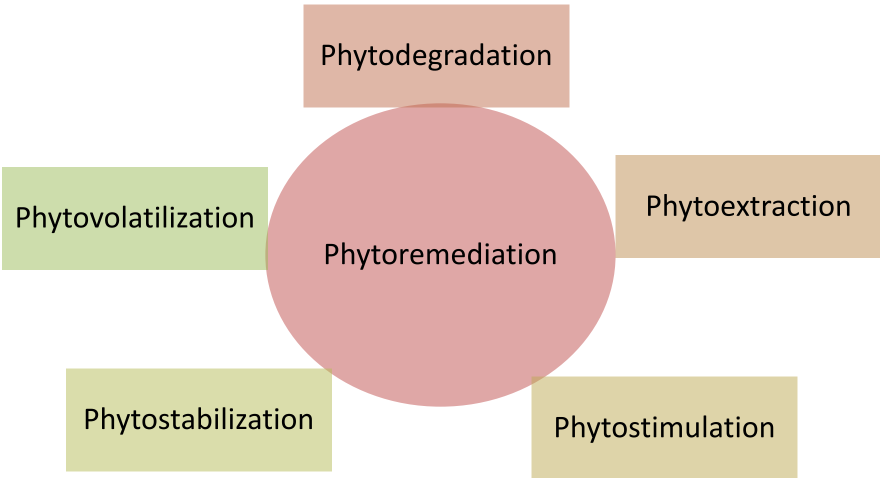
There are several ways to employ plants and creatures in their rhizosphere for phytoremediation. They can be employed as filters in hydroponic systems, such as rhizofiltration, or artificial wetlands. In order to prevent pollution from seeping below or from spreading horizontally, trees can be employed as hydraulic barriers to producing an upward water flow in the root zone. In hydroponic systems, referred to as rhizofiltration, plants and the creatures in their rhizosphere can act as filters.

Trees can be employed as hydraulic barriers to induce an upward water flow in the root zone, stop pollution from seeping downward, or stop a contaminated groundwater plume from spreading horizontally. Rhizofiltration is conceptually similar to phytoextraction, however, it focuses on treating dirty groundwater as opposed to polluted soils. Either the plant roots absorb the pollutants or they are adsorbed onto the root surface. Plants used for rhizoliltration are first acclimated to the pollutant before being planted at the intended location. Plants are hydroponically cultivated in clean water instead of dirt until they have a substantial root system. After the plant has established a thick root system, a contaminated water source is switched out for it to help the plant adjust. Once the plants have adapted, they are placed in the polluted region, where the roots absorb the contaminated water. Pollutants may be stabilised or decomposed in the rhizosphere, sequestered or degraded inside the plant tissue, or volatilized during phytoremediation.

The process of using plants to stabilise pollutants in soil—either by merely avoiding erosion, leaching, or runoff or by changing contaminants into less bioavailable forms—is known as phytostabilization (e.g., via precipitation in the rhizosphere).

This lessens or even stops pollutant mobility, reducing migration into the groundwater or air and contaminant bioavailability, inhibiting transmission through the food chain. The process through which soil-borne metal pollutants are ingested by plant roots and transferred to their tissues above the soil surface is known as phytoextraction. Many different plants can be employed since they all have varying capacities for absorbing and resisting high concentrations of contaminants.

This is especially crucial for sites that have been contaminated with several metal contaminants. The plants are collected and carefully disposed of once they have grown and absorbed the metal contaminants. This process is done numerous times to bring the contamination level down to acceptable limits. The metals can occasionally be recycled by a procedure called phytomining, but this is often only done with valuable metals. Zinc, copper, and nickel have all been successfully phytoextracted, but there is also interesting research being done on lead and chromium absorption plants. Phytodegradation is the breakdown or degradation of organic pollutants caused by a plant's internal and external metabolic activities. Ex-planta metabolic activities hydrolyze organic substances into smaller fragments that the plant may absorb. Some pollutants can be taken up by plants and subsequently degraded by plant enzymes. As the plant matures, it may utilise these smaller pollution molecules as metabolites, which would subsequently be integrated into the tissues of the plant. It has been shown that some plant enzymes break down organic pesticides, chlorinated solvents like TCE (trichloroethane), and waste from the manufacture of weapons. Plants absorb water soluble contaminants and release them into the atmosphere when they transpire water. This process is known as phytovolatilization.



As water moves from the roots to the leaves through the plant's vascular system, the pollutant may change along the journey and evaporate or volatilize into the air around the plant. Plants have various degrees of effectiveness as phytovolatilizers, with one research finding that poplar trees may volatilize up to 90% of the TCE they ingest. In the past ten years, phytoremediation—the use of plants and the bacteria that live on them—has gained popularity as an economical, non-intrusive substitute for or in addition to engineering-based remediation techniques. Utilizing plants for pollution extraction, degradation, or volatilization is possible. The case studies that are presented here in this chapter will help readers better understand the various phytoremediation techniques.

NEW DEVELOPMENTS IN PHYTOREMEDIATION

- One of the most dangerous pollutants endangering human health and ecosystems is mercury (Hg), which has been introduced from both natural and man-made sources. Recent calculations show that yearly global emissions range from 4800 to 8300 tonnes.
- An extremely poisonous organomercurial molecule called methyl Mercury is created when anaerobic sulfate-reducing bacteria methylate mercury, which is often discharged as metal or ionic form and accumulates in sediments.

- The form of mercury found in the environment has a significant impact on its toxicity. The fact that inorganic mercury forms bond tightly to soil constituents that lessen their availability and absorption helps explain why they are often less dangerous than organic mercury forms. Because of increasing tissue accumulation at higher trophic levels, the harmful effects of methyl mercury are further amplified. Organomercurials are strong neurotoxins that enter the bloodstream through the digestive tract at a rate of over 90%, whereas mercury salts and elemental mercury absorb less than 10% and 0.1%, respectively.
- Mercury tends to harm membrane transporters like aquaporins at the plasma membrane of plants, which disrupts the flow of nutrients and water.
- Organomercurials localise quickly to plastids where they build up and impair critical metabolic processes such as electron transport, oxygen evolution, photorespiration, the Hill reaction, and chlorophyll content.
- Mercury cannot be effectively detoxified or converted by plants into more benign forms. Genes from other species can be incorporated into plants through genetic engineering to improve their capacity for phytoremediation. MerAB is a well-characterized phytoremediation method built via the nuclear genome that uses the bacterial merA (mercuric ion reductase) and merB (organomercurial lyase) genes to genetically modify plants for Hg remediation.
- Organomercurial lyase promotes the protonolysis of organic-Hg to Hg2+, whereas mercuric ion reductase converts Hg2+ to Hg0, which is volatilized from plants.

CONCLUSIONS

A major problem for agricultural production and food safety is heavy metal contamination because of its harmful effects and quick buildup in the environment. A number of methods have been developed to stop or lessen heavy metal pollution and replant the contaminated soil.

Compared to other physicochemical procedures, phytoremediation offers several benefits and has been shown to be a potential method for replanting heavy metal-contaminated soil. The simplest method for phytoremediation is the use of heavy metal hyperaccumulators, and hundreds of these plants have already been discovered. molecules and signalling pathways will be crucial for creating the best plant species for genetically engineered phytoremediation.

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