POTENTIAL OF PHYTOREMEDIATION, AN EMERGING GREEN TECHNOLOGY

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Abstract
Phytoremediation has been defined as the use of green plants and their associated microorganisms, soil amendments and agronomic techniques to remove, contain or render harmless environmental pollutants. The possible use of green plants to remove organic pollutants and toxic metals from wastewater and contaminated soils is described, with its limitations and advantages.

Keywords bioremediation, contaminated sites, green plants, organic pollutants, phytoremediation, toxic metals, wastewater
We often think of plants primarily as a source of food, fuel and fiber. However, recognition has been made recently of the potential of plants to serve as environmental counterbalance to industrialisation processes, but not only as a sink for the increased atmospheric CO₂. Indeed, over the last century, the content of xenobiotic compounds in ecosystems has increased considerably. Many organic synthetic substances, which include pesticides, solvents, dyes, by-products of chemical and petrochemical industries, are eventually transported to natural vegetation and cultivated crops, where they can either be harmful to the plant itself; totally or partially degraded; transformed; or accumulated in plant tissues and organs. In the latter case, xenobiotics are concentrated in food chains and finally in man, with possible detrimental effects on his health. Such a situation also occurs with heavy metals. Actually, anthropogenic sources of toxic metals in environment are numerous: metalliferous mining and smelting, electroplating, energy and fuel production, gas exhausts, agriculture or waste disposal. Reports on plants growing in polluted stands without being seriously harmed indicate that it should be possible to detoxify contaminants using agricultural and biotechnological approaches. Higher plants possess a pronounced ability for the metabolism and degradation of many recalcitrant xenobiotics and can be considered as "green livers", acting as an important sink for environmentally damaging chemicals. On the other hand, different plant species are able to hyperaccumulate toxic metals in their tissues. It thus appears that crops and cultivated plants can be developed and used for the removal of hazardous persistent organic compounds and toxic metals from industrial wastewaters and for phytoremediation purposes. Phytoremediation has been defined as the use of green plants and their associated microorganisms, soil amendments and agronomic techniques to remove, contain or render harmless environmental pollutants.

Contaminated soils and waters pose a major environmental and human health problem, which may be partially solved by the emerging phytoremediation technology. The use of plants for the removal of xenobiotics and heavy metals from spillage sites, sewage waters, sludges and polluted areas has become an important experimental and practical approach over the last 15 years. Knowledge of the physiological and molecular mechanisms of phytoremediation have begun to emerge together with biological and engineering strategies designed to optimise and improve the phytoremediation process. Numerous plant species have been explored and treatment systems have been set up, most of them without exact knowledge of the mechanisms involved. Interestingly enough, the systems established over the world seem to
fulfil their task properly and remove pollutants from various matrices with good efficiency and at comparatively low cost. Woody plant species, shrubs, other perennials, but also annual plants have been found to be suitable for this technique, but it has to be admitted that in most cases the associated microflora plays an important if not the decisive role in the treatment of the polluted sites. Hence, stimulation of micro-organisms by plant exudates and leachates, and by fluctuating oxygen regimes has also to be considered.

Several types of phytoremediation can be defined:

- **Phytoextraction**, the use of pollutant-accumulating plants to remove metals or organics from soil by concentrating them in harvestable plant parts;
- **Phytotransformation**, the degradation of complex organic molecules to simple molecules or the incorporation of these molecules into plant tissues;
- **Phytostimulation**, or plant-assisted bioremediation, the stimulation of microbial and fungal degradation by release of exudates/enzymes into the root zone (rhizosphere);
- **Phytovolatilization**, the use of plants to volatilize pollutants or metabolites;
- **Rhizofiltration**, the use of plant roots to ab/adsorb pollutants, mainly metals, but also organic pollutants, from water and aqueous waste streams;
- **Pump and tree**, the use of trees to evaporate water and thus to extract pollutants from the soil;
- **Phytostabilisation**, the use of plants to reduce the mobility and bioavailability of pollutants in the environment, thus preventing their migration to groundwater or their entry into the food chain;
- **Hydraulic control**, the control of the water table and the soil field capacity by plant canopies.

Besides metabolisation, one of the most striking features of all phytoremediation techniques is the extensive evaporation of water from plant-covered sites. This high consumption of water that may almost equal the amount of water added to an area via precipitation prevents pollutants wash out and slows down the possible migration in the soil and into the ground water. Furthermore, upward movement of water will also transport soluble pollutants into the plants.
Whereas the removal of heavy metals seems to be governed by the processes of ion transport and hyperaccumulation in tolerant plants after mobilizing the metals in the rhizosphere, phytodegradation and phytovolatilisation of organic xenobiotics have both to rely on the metabolism of foreign compounds in the plant. Even more complicated, organic pollutants under consideration are often lipophilic or covalently bound to soil components which causes a severe problem to the uptake of the compound into the plant. Once in the plant rhizosphere, the pollutants have to migrate into the root, then become translocated into other tissues and organs of the plant, where detoxification and metabolisation will take place.

When developing bioremediation strategies based on phytoremediation, both pre-harvest parameters (including contaminant level, plant selection, treatability, agronomic techniques, groundwater capture zone, transpiration rate, uptake rate and required cleanup time) and post-harvest evaluation parameters (including collection, left-over, underground residues disposal and treatment of the contaminated plant material) must be considered.

Phytoremediation presents many advantages, as compared to other remediation techniques: it can be performed with minimal environmental disturbance; it is applicable to a broad range of contaminants, including many metals with limited alternative options; possibly less secondary air and/or water wastes are generated than with traditional methods; organic pollutants may be degraded to CO₂ and H₂O, removing environmental toxicity; it is cost-effective for large volumes of water having low concentrations of contaminants; topsoil is left in a usable condition and may be reclaimed for agricultural use; soil can be left at site after contaminants are removed, rather than having to be disposed or isolated; it is cost-effective for large areas having low to moderately contaminated surface soils; plant uptake of contaminated groundwater can prevent off-site migration. However, several drawbacks and limitations of phytoremediation also exist: a long time is often required for remediation; the treatment is generally limited to soils at a meter from the surface and groundwater within a few meters of the surface; climatic or hydrologic conditions may restrict the rate of growth of plants that can be utilized; ground surface at the site may have to be modified to prevent flooding or erosion; contaminants may still enter the food chain through animals/insects that eat plant material containing contaminants; soil amendments may be required.
Phytoremediation is expected to be complementary to classical bioremediation techniques, based on the use of micro-organisms only. It should be particularly useful for the extraction of toxic metals from contaminated sites and the treatment of recalcitrant organic pollutants, like chlorinated pesticides, organophosphate insecticides, petroleum hydrocarbons (BTEX), polynuclear aromatic hydrocarbons (PAHs), sulphonated aromatics, phenolics, nitroaromatics and explosives, polychlorinated biphenyls (PCBs) and chlorinated solvents (TCE, PCE). Plant biomass or agricultural vegetal wastes could also be used efficiently for the removal of organic pollutants or toxic metals from contaminated waters. Such innovative biotreatments should be particularly useful in countries like China.

At the present time, phytoremediation is still a nascent technology that seeks to exploit the metabolic capabilities and growth habits of higher plants: delivering a cheap, soft and safe biological treatment that is applicable to specific contaminated sites and wastewaters is a relatively recent focus. In such a context, there is still a significant need to pursue both fundamental and applied research to provide low-cost, low-impact, visually benign and environmentally sound depollution strategies.