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Phytoremediation of Municipal Solid Waste Landfill Site: A Review

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ABSTRACT

Phytoremediation, collectively referring to all species-based technologies using green plants to remediate and rehabilitate municipal solid waste landfill sites, has emerged as a potential candidate. Phytoextraction using hyper accumulating plants is seen as a promising technique; a lack of understanding of the basic physiological, biochemical, and molecular mechanisms involved in the removal of heavy metal from environment. The discovery of hyper accumulator plants, which contain high levels of heavy metals that would be highly toxic to other plants, prompted the idea of using certain plant species to extract metals from the soil and, in the process, clean up soil for other less tolerant plants. Among the techniques used to cleanup affected sites, Phytoremediation has recently emerged as a new, cost-effective, environment-friendly alternative. After a short introduction to the types of plant-based cleanup techniques, this review focuses on metal hyperaccumulator plants and their potential use in phytoextraction technology. Research and development activities relating to different aspects of phytoremediation are keeping the interest of scientists and engineers alive and enriching the literature. Being a subject of multi-disciplinary interest, findings of phytoremediation research has resulted in generation of enormous data. Collating data from such diverse sources would help understand the dynamics and dimensions of dumpsite rehabilitation.

Keywords: Phytoremediation, Biochemical, Phytoextraction.

INTRODUCTION

Natural or planted vegetation on a landfill has an important role in erosion control and removal of contaminants, besides imparting aesthetic value. Moreover, it may also be used in leachate treatment Maurice[47]. Landfill vegetation often shows signs of damage commonly caused by the presence of landfill gas (LFG) in the root zone. The goal for the reconstruction of a suitable medium for landfill revegetation is to provide a capping that is deep and as favorable to root growth as is necessary to achieve desired plant performance, Vogel[77], Nagendran R. *et al*.[51].

Although reviews on phytoremediation of sites contaminated with a variety of contaminants are readily available (Siciliano and Germida[68], Lasat[39], Schwitzguebel *et al*.[71]. The present review, an off-shoot of studies on rehabilitation of municipal solid waste dumpsites, attempts to fill this gap by leaning on research findings, especially those reported in the last two decades, Nagendran R. *et al*.[51].

At many hazardous waste sites requiring cleanup, the contaminated soil, groundwater, and/or wastewater contain a mixture of contaminant types, often at widely varying concentrations. These may include salts, organics, heavy metals, trace elements, and radioactive compounds. The simultaneous cleanup of multiple, mixed contaminants using conventional chemical and thermal methods are both technically difficult and expensive; these methods also destroy the biotic component of soils. Phytoremediation, an emerging cleanup technology for contaminated soils, groundwater, and wastewater that is both low-tech and low-cost, is 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, traceelements, organic compounds, and radioactive compounds insoil or water Hinchman and Negri[27], Hussain *et al*.[28]. Several comprehensive studies have been done,summarizing many important aspects of this novel plant basedtechnology Meagher[44], Navari-Izzo and Quartacci[50], Lasat[39], McGrath *et al.*[42], McIntyre[43], Singh *et al*.[62], Prasad and Freitas[52], Alkorta *et al*.[1], Ghosh and Singh[26], Pilon Smits[53], Padmavathiamma and Li[54]. Present work shall give a general guidance, recommend for using phytoremediation technique highlighting the process associated with applicants and identifying biological mechanisms.

PHYTOREMEDIATION

"Phytoremediation", is an emerging technology in which the plants are employed to absorb and bio-magnify elements from a polluted environment and metabolize them into various biomolecules in their tissues, Pant Pandey *et al*.[55]. Phytoremediation, collectively referring to all plant based technologies, uses green plants to remediate contaminated sites, Sadowsky[64]. This technology draws its inspiration from the myriad of physical, chemical and biological interactions occurring between plants and the environmental media. Phytoremediation is evolving into a cost-effective means of managing wastes, especially excess petroleum hydrocarbons, polycyclic aromatic hydrocarbons, explosives, organic matter, and nutrients. Applications are being tested for cleaning up contaminated soil, water, and air. Several features make phytoremediation an attractive alternative to many of the currently practiced in situ and ex situ technologies. These include: low capital and maintenance costs, non-invasiveness, easy start-up, high public acceptance and the pleasant landscape that emerges as a final product, Boyajian and Carreira[10], Nagendran R. *et al*.[51].

In the last several decades, phytoremediation strategies have been examined as a means to clean up a number of organic and inorganic pollutants, including heavy metals, Kumar *et al.*[36], Salt *et al.*[65], Chaney *et al.*[19], chlorinated solvents Walton *et al.*[78], Haby and Crowley[30], agrochemicals Anderson *et al.*[4], Hoagland *et al.*[31], Kruger *et al.*[37], polycyclic aromatic hydrocarbons, Aprill and Sims[5], Reilly *et at.*[60], polychlorinated biphenyls Brazil *et al.*[7], Donnelly and Fletcher[20], munitions Schnoor *et al.*[66] and radio nuclides, Entry *et al.*[23]. These soluble organic and inorganic contaminants, which move into plant roots or rhizosphere by the mass flow process of diffusion, appear to be most amenable to the remediation process Schnoor *et al.*[66], Cunningham *et al.*[14]. In several instances, plants and/or their attendant rhizosphere microbes have been shown to transform some chemical compounds to some degree Walton *et al.*[78], Crowley *et al.*[17], Siciliano and Germida[68], Nagendran R. *et al*.[51].

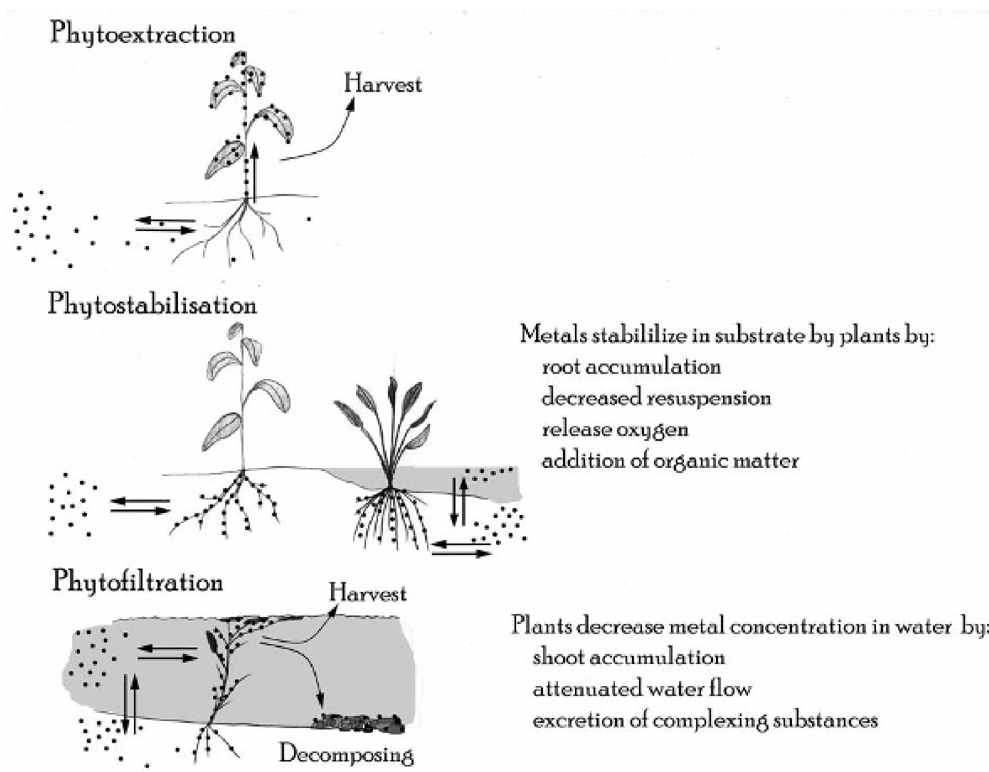

Figure 1. Principles of phytoextraction, phytostabilization and phytofiltration (Source: Jitendra *et al.*, 2011)

METHODS OF PHYTOREMEDIATION

The use of green plants to remove pollutants from the environment or render them harmless is defined as phytoremediation, Cunningham and Berti[15]. Phytoextraction, phytostabilization and phytofiltration are three processes involved in phytoremediation Salt *et al*.[70], processes which can help reduce metal content of respective environment. The general process of phytoremediation is depicted in Figure-1 (Jitendra *et al*.[34].

Table: 1. Types and processes involved in Phytoremediation (Nagendran R. *et al*. 2006)

S.No.	Type	Contaminant	Process
1.	Phytoextraction	Heavy metals: arsenic, cadmium, chromium, copper, mercury, lead, zinc	High biomass, metal hyperaccumulators extract metals from soil and accumulate them in shoots
2.	Rhizofiltration		Plant roots growing in polluted water precipitate and concentrate metals
3	Phytostabilization		Heavy-metal tolerant plants stabilize the metal in soil and render them harmless
4	Phytovolatilization		Plants extract volatile metals like Hg and Se from the soil and volatilize them from the Foliage
5	Phytodegradation		Plants absorb the contaminants and degrade them within the plant system
6	Rhizosphere biodegradation		Plants release exudates and enzymes which directly degrade the pollutant and/or induce the microbes which are involved in degradation
7	Hydraulic pumping		Plant roots grow to the water table, take up water and prevents the migration of polluted water
8	Phytovolatilization		Plants take up the pollutants along with water, pollutants pass through xylem and are released from foliage
9	Phytosorption		Adsorption of pollutants by plant roots and leaves and prevention of the pollutant Movement
10	Phytocapping		Plants consume water from the rainfall and reduce leaching and pollutant movementR

Phytoextraction

This technique reduces soil metal concentrations by cultivating plants with a high capacity for metal accumulation in shoots. Plants used for this purpose should ideally combine high metal accumulation in shoots and high biomass production. Many hyperaccumulator species fulfill the first, but not the second condition. Therefore, species that accumulate lower metal concentrations but are high biomass producers may also be useful, Joan Barceló *et al*.[35].

Rhizofiltration

This technique is used for cleaning contaminated surface waters or wastewaters by adsorption or precipitation of metals onto roots or absorption by roots or other submerged organs of metal-tolerant aquatic plants. For this purpose, plants must not only be metal-resistant but also have a high adsorption surface and must tolerate hypoxia Dushenkov *et al*.[22], Horne *et al*.[32], Joan Barceló *et al*. [35].

Phytostabilization

Plants are used for immobilizing contaminant metals in soils or sediments by root uptake, adsorption onto roots or precipitation in the rhizosphere. By decreasing metal mobility, these processes prevent leaching and groundwater pollution. Bioavailability is reduced and fewer metals enter the trophic web (Joan Barceló *et al*., 2003).

Phytodegradation

Elimination of organic pollutants by decomposition through plant enzymes or products (Joan Barceló *et al*., 2003).

Rhizodegradation

Decomposition of organic pollutants by means of rhizosphere microorganisms (Wenzel *et al*., 1999, Joan Barceló *et al*., 2003).

Phytovolatilization

Organic pollutants absorbed by plants are released into the atmosphere by transpiration, either in their original form or after metabolic modification. In addition, certain metals can be absorbed and volatilized by certain organisms. Several species of the genus Astragalus accumulate and volatilize Se. Uptake and evaporation of Hg is achieved by some bacteria. The bacterial genes responsible have already been transferred to Nicotiana or Brassica species, and these transgenic plants may become useful in cleaning Hg-contaminated soils (Bañuelos *et al*., 1998, Meager *et al*., 2000, Joan Barceló *et al*., 2003).

Hydraulic control

This technique uses plants that absorb large amounts of water and thus prevent the spread of contaminated wastewater into adjacent uncontaminated areas. Phreatophytes can be used for cleaning saturated soils and contaminated aquifers (Quinn *et al*., 2001, Joan Barceló *et al*., 2003).

Phytorestauration

Revegetation of barren areas by fast-growing resistant species that efficiently cover the soil, thus preventing the migration of contaminated soil particles and soil erosion by wind and surface water run-off. This technique reduces the spread of contaminants and also visual impact. However, previous soil conditioning is required (e.g. liming or berengeriteamend-ments) to enable plants to colonize the polluted substrate (Mench *et al*., 2000, Vangronsveld *et al*., 1998, Vangronsveld *et al*., 2000, Joan Barceló *et al*., 2003).

Table: 2 Advantage and Disadvantage/ Limitations of Phytoremediation (Source: Jitendra *et al.*, 2011, Schwitzguébel (2000); Ghosh and Singh, 2005).

S. No.	Advantages	Disadvantage/Limitations
1.	Amendable to a broad range of organic and inorganic contaminants including many metals with limited alternative options.	Restricted to sites with shallow contamination within rooting zone of remediative plants; ground surface at the site may have to be modified to prevent flooding or erosion.
2.	In Situ / Ex Situ application possible with effluent/soil substrate respectively; soil can be left at site after contaminants are removed, rather than having to be disposed or isolated.	A long time is often required for remediation; may take up to several years to remediate a contaminated site.
3	In Situ applications decrease the amount of soil disturbance compared to conventional methods; it can be performed with minimal environmental disturbance; topsoil is left in a usable condition and may be reclaimed for agricultural use; organic pollutants may be degraded to CO_2 and H_2O, removing environmental toxicity.	Restricted to sites with low contaminant concentrations; the treatment is generally limited to soils at a meter from the surface and groundwater within a few meters of the surface; soil amendments may be required.
4	Reduces the amount of waste to be landfilled (up to 95%), can be further utilized as bio-ore of heavy metals.	Harvested plant biomass from phytoextraction may be classified as a hazardous waste hence disposal should be proper.
5	In Situ applications decrease spread of contaminant via air and water; possibly less secondary air and/or water wastes are generated than with traditional methods.	Climatic conditions are a limiting factor; climatic or hydrologic conditions may restrict the rate of growth of plants that can be utilized.
6	Does not require expensive equipment or highly specialized personnel; it is cost-effective for large Schwitzguébel (2000); Ghosh and Singh (2005). volumes of water having low concentrations of contaminants; it is cost-effective for large areas having low to moderately contaminated surface soils.	Introduction of non-native species may affect biodiversity.
7	In large scale applications the potential energy stored can be utilized to generate thermal energy; plant uptake of contaminated groundwater can prevent off-site migration.	Consumption/utilization of contaminated plant biomass is a cause of concern; contaminants may still enter the food chain through animals/insects that eat plant material containing contaminants.

Metal hyperaccumulator plants

Hyperaccumulators are metallophytes and belong to the natural vegetation of metal-enriched soils (Ernst *et al*. 2000, Pollard *et al*., 2000). These species have evolved internal mechanisms that allow them to take up and tolerate large metal concentrations that would be extremely toxic to other organisms (Clemens *et al*., 2001, Lasat *et al*., 2002). These plants are perfectly adapted to the particular environmental conditions of their habitat and high metal accumulation may contribute to their defense against herbivores and fungal infections (Boyd *et al*., 1998, Martens *et al*., 2002, Tolrà *et al*., 2001). However, usually, the metabolic and energetic costs of their adaptation mechanisms do not allow them to compete efficiently on uncontaminated soil with non metallophytes (Joan Barceló *et al*., 2003).

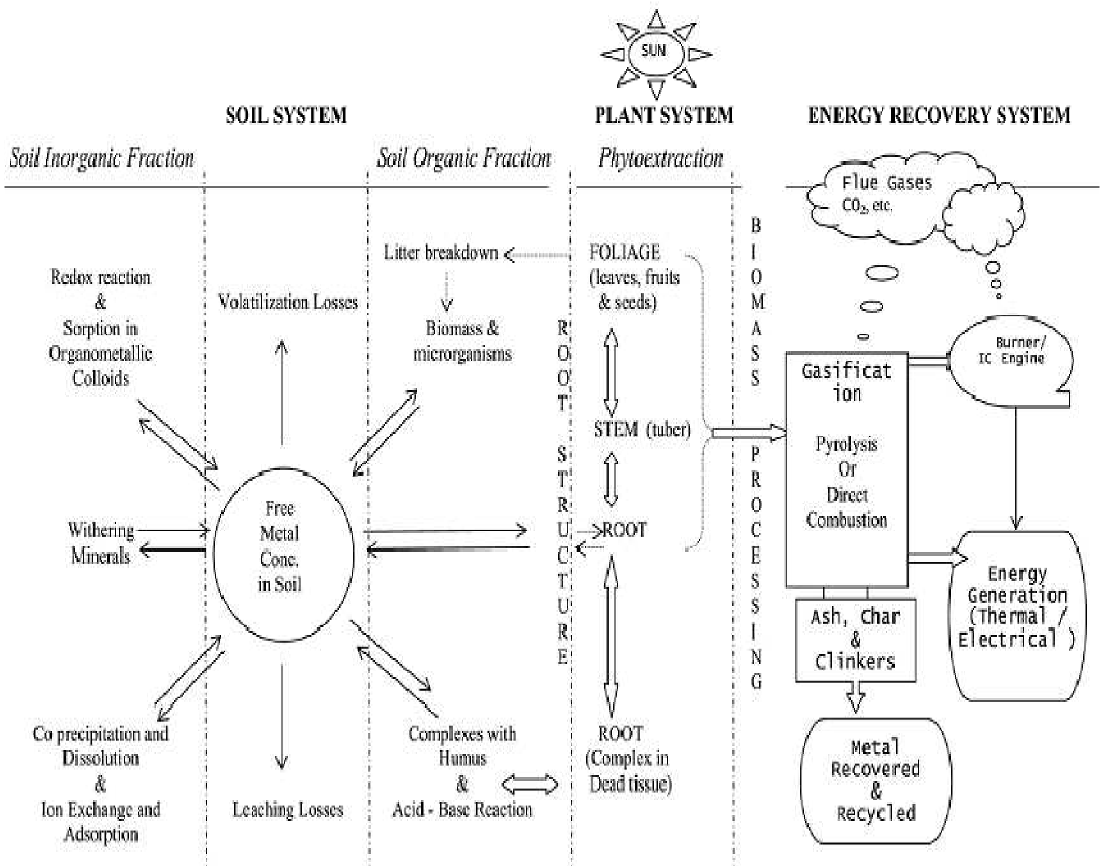

Figure 2. Overview of some phytoremediation process (Source: Ghosh and Singh (2005), Jitendra *et al*., 2011).

Mechanisms of metal tolerance and hyperaccumulation in plants

Metal hyperaccumulators are highly specialized models of plant mineral nutrition. Seventeen elements are considered essential for all higher plants (C, H, O, N, S, P, K, Ca, Mg, Fe, Mn, Cu, Zn, B, Mo, Cl, and Ni). Macronutrients are those necessary in high concentrations (mM level) while micronutrients are required only in µM tissue concentrations. Hyperaccumulators concentrate, in a specific way, certain trace metals or metalloids that may be essential (Cu, Mn, Zn, or Ni) or not (e.g. Cd, Pb, Hg, Se, Al, As) at amounts that would be extremely toxic to other plants (Assunçao *et al*., 2001, Baker *et al*., 1989, Brooks *et al*., 1998, Hall *et al*., 2002, Jansen *et al*., 2002, Marschner *et al*., 1995, McNeill *et al*., 1992, Tolrà *et al*., 1996).

Vegetation at Landfill site

Plants are known to increase nutrient availability by secreting cationic chelators, organic acids, or specific enzymes such as phosphatase into the soil systems. Competition for these nutrients by degrading and non-degrading species will influence the amount of contaminant degraded (Steffensen and Alexander, 1995). Increases in nutrient availability brought about by plant growth may be one mechanism by which plants stimulate biodegradation. Supporting this, Cheng and Coleman (1990) found that living roots and fertilizers had equivalent stimulatory effects on straw decomposition. Furthermore, atrazine degradation by an inoculated consortium was similar in treatments receiving fertilizer and those in which corn plants were grown (Alvay and Crowley, 1996, Nagendran R. *et al*. 2006).

Maurice *et al*. (1995) have reported that plants belonging to four families viz., Poaceae, Asteraceae, Polygonaceae and Chenopodiaceae dominate, while other species occur only sporadically in Stockholm, Malmo and Helsingborg landfills of Sweden. Their observations further indicate that the species diversity decreases with the age of the landfill. Dwyer *et al*. (2000) have quantified the plant species occurring in Albuquerque, USA, with reference to different landfill covers. According to them, the perennial grass and annual weeds were abundant in different landfill covers (Nagendran R. *et al*. 2006).

Leachates on vegetation

A complex of sequences mediated by physical, chemical and biological events occurs within a landfill. As a consequence, refuse is degraded or transformed. As water percolates through the landfill, contaminants are leached from the solid waste. Mechanisms of contaminant removal include leaching of inherently soluble materials, leaching of soluble biodegradation products of complex organic materials, leaching of soluble products of chemical reactions and wash out of fines and colloids (Reinhart and Grosh, 1998). The quality of the leachate produced is highly variable and depends on the composition of the solid waste, depth of waste, site hydrology, compaction, waste age, interaction of leachate with the environment, landfill design and operation, available oxygen and temperature. Moisture content is an important limiting factor of plant growth and development in landfills, especially in tropical climates. In tropical climates, rainfall is the primary source of moisture and hence supports the drought tolerant vegetation and determines the species diversity in landfills. In such cases, mono species Phytoremediation aided by leachate circulation may be carried out to maintain the growth, accelerate the degradation and stabilize the wastes. Moreover, leachate circulation prevents the pollutants from entering the groundwater. Toxic components in leachates such as heavy metals may reduce the growth and development of plants (Nagendran R. *et al*. 2006).

Heavy Metals Concentration

The amount of metal available for phytoremediation is estimated on the basis of the distribution of metal between the fractions of a sequential extraction. The results are interpreted with the understanding that the extracted fractions are operationally defined and not necessarily specific soil components. For example, the carbonate fraction consists of soluble compounds at pH 5 and is not limited solely to carbonate compounds. Chelating agents have been used to estimate metal bioavailability and are the basis for the DTPA (diethyl trinitrile penta acetic acid) soil test for micronutrient and heavy-metal availability (Lindsay and Norvell, 1978; Amacher, 1996, Nagendran R. *et al*. 2006).

Metals targeted by this process include Cd, Pb, Zn, Cu, Cr, Ni, Se and Hg. Phytoextraction using hyper accumulating plants is proving to be one of the most effective Phytoremediation methods to clean up metal contaminated sites. Several plant species, including Thlapsi sp., have been shown to accumulate very high levels of Ni, Zn and Cd from soils (Baker and Brooks, 1989; Kramer *et al*., 2000). Brassica juncea has been found to be an excellent accumulator plant for metals such as Cd, Cr, Ni, Zn and Cu in soils (Kumar *et al*., 1995; Salt *et al*., 1995), and several plant species have been shown to accumulate Pb (Dushenkov *et al*., 1995; Cunningham *et al*., 1997). The enormous literature available on plant–metal interaction needs to be oriented towards the application in landfill remediation (Nagendran R. *et al*. 2006).

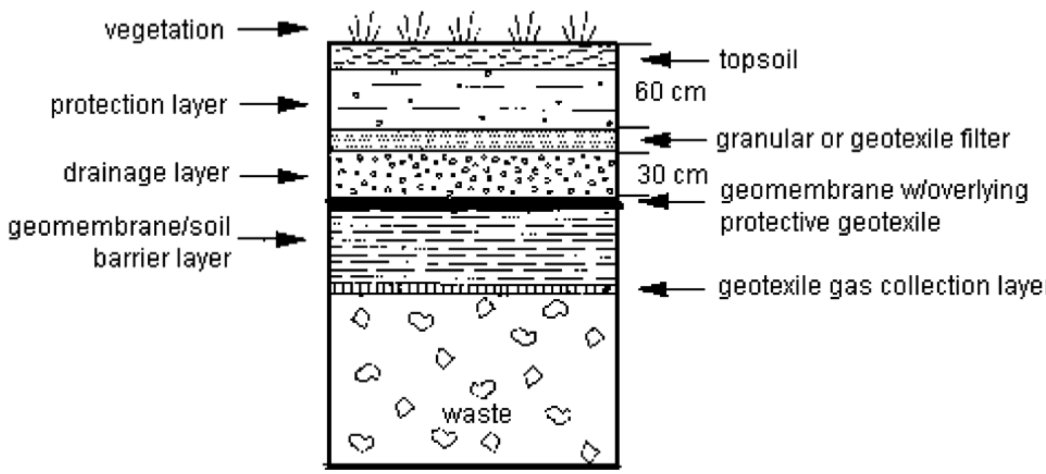

Fig. 2. Typical landfill cap system.
Source: Platinum International, Inc. 2002, Nagendran R. et al. 2006.

Landfill capping

Landfills are usually required to have clay caps and impermeable synthetic membranes to minimize the infiltration of rainfall and generation of leachate. Landfill capping is the most common form of remediation because it is generally less expensive than other technologies and effectively manages the human and ecological risks associated with a remediation site (Nagendran R. *et al*. 2006).

According to Platinum International, Inc. (2002), landfill caps can be used to

- Minimize exposure on the surface of the waste facility;
- Prevent vertical infiltration of water into wastes that would create contaminated leachate;
- Contain waste while treatment is being applied;
- Control gas emissions from underlying waste;
- Create a land surface that can support vegetation and/or be used for other purposes (Nagendran R. *et al*. 2006).

Evapotranspiration landfill covers

Vegetative caps are also called ‘‘alternative covers’’ and ‘‘evapotranspiration landfill covers’’. Their purpose is to increase evapotranspiration from the surface of the landfill and enhance bioremediation. A further advantage of the alternative vegetative cap is more rapid ‘‘stabilization’’ of the wastes, decreased gas production after 5–20 years, and earlier access to the site for alternative uses (parkland, municipal building construction). Disadvantages include the possibility of phytotoxicity, pests, or weather destroying the trees and decreasing the efficiency of the alternative cap. Other disadvantages are that it is a less proven system, and state regulations sometimes do not allow alternative caps (Schnoor, 2002, Nagendran R. *et al*. 2006).

Limitation of phytoremediation of Landfill site

Root contact is a primary limitation in Phytoremediation applicability. Remediation with plants requires that the contaminants be in contact with the root zone of the plants. Either the plants must be able to extend their roots to the contaminants or the contaminated media must be moved to the rhizosphere of plants (Nagendran R. *et al*. 2006).

CONCLUSION

Phytoremediation is a new, attractive technique that has emerged over recent years. This technique offers excellent perspectives for the development of plants with the potential for cleaning metal-contaminated soils, at least under certain, favorable conditions and for using adequate crop management systems. Phytoremediation have to be changed to adopt to landfill conditions. Thus, tremendous scope exists for investigating different facets of this technology and its application to real-world conditions such as municipal solid waste landfills and dumpsites. The mechanisms of metal uptake, accumulation, exclusion, translocation, osmoregulation and copartmentation vary with each plant species and determine its specific role in Phytoremediation. In order to develop new crop species/plants having capabilities of metal extraction from the polluted environment, traditional breeding techniques, hybrid generation through protoplast fusions, and production of mutagens through radiation and chemicals are all in progress. To date the available methods for the recovery of heavy metals from plant biomass of hyper accumulators are still limited. Traditional disposal approaches such as burning and ashing are not applicable to volatile metals; therefore, investigations are needed to develop new methods for effective recovery of metals from the hyper accumulator plant biomass.

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