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Phytoremediation

Management of Environmental

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 **Phytoremediation Using Microbial**

**Communities: II**

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**15.1 Introduction**

Phytoremediation is a novel green technology that uses

specialized plants and associated soil microbes to remove,

destroy, sequester or reduce the concentrations or toxic

effects of contaminant in polluted environment especially

soil and water. It refers to a group of plant-based technologies

that use either naturally occurring or genetically

engineered plants to clean contaminated environments. This

technology depends on the ability of both the plant and associated

microorganisms to adapt to or survive in high-metal

environments. Polluted soil poses a severe problem to both

ecosystem health and land development. Soil pollution

threatens the health of human, plant and animal. Soil pollution

can spread to other parts of the natural environment

because soil is at the confl uence of many natural systems. For

instance, groundwater that percolates through a polluted soil

can carry soil contaminants into streams, rivers, wells and

drinking water. Plants growing on polluted soil may contain

harmful levels of pollutants that can be passed on to the animals

and people that eat them. Dust blown from polluted soil

can be inhaled directly by passers-by. Additionally, polluted

soil renders valuable open land unusable for parks, recreation

or commercial development. The fact that both soil minerals

and soil pollutants carry small electric charges that cause

each to bond with each other makes polluted soil very hard to

clean. A range of technologies such as fi xation, leaching, soil

excavation, chemical treatment, vitrifi cation, electrokinetics

and landfi ll of the top contaminated soil, bioventing, thermal

desorption, soil vapour extraction, biopiles, etc., have been

used for the removal of metals. Many of these methods have

high maintenance costs and may cause secondary pollution

(Haque et al. 2008 ). Excavation of p olluted soil for off-site

treatment or disposal is labour intensive, consumes a lot of

time and requires the use of heavy machinery hence very

expensive (Danh et al. 2009 ). Therefore, cheaper on-site, or

in situ, remediation techniques have recently become the

focus of research. One of the most interesting and promising

of these in situ techniques is phytoremediation. Using plants

to remediate soil pollution comprised of two components,

one by the root-colonizing microbes and the other by plants

themselves which absorb, accumulate, translocate, sequester

and detoxify toxic compounds to non-toxic metabolites.

Plants frequently lack metabolic capacity for the degradation

of many pollutants hence the need to utilize degradation ability

of soil organisms. Metal tolerance of plants is generally

increased by symbiotic, root-colonizing, arbuscular mycorrhizal

fungi (AMF), through metal sequestration in the AMF

hyphae. More also excretion of the glycoprotein glomalin by

AMF hyphae can form complex metals in the soil. Exposure

of plants to microorganisms within the rhizoplane protects

the plants from the toxic effect of the contaminants and also

takes part in phytoremediation. Resistant plants can thrive on

sites that are too toxic for other plants to grow. They in turn

give the microbial processes the boost they need to remove

organic pollution more quickly from the soil.

The mechanism responsible for the phytoremediation

of contaminated soil has been proved to be as a result of

increase in microbial activity. Organic toxins, those that

contain carbon such as the hydrocarbons found in gasoline

and other fuels, can be broken down by microbial processes.

Soil fungi, for example, improve phytoremediation

ability of plants by increasing the absorptive area of the

roots of plants. The effi ciency of *Tithonia diversifolia* and

*Helianthus annuus* in remediating soils contaminated with

zinc and lead nitrates could be improved by introducing

mycorrhizal fungi in order to increase the absorptive area of

the roots of these plants ( Adesodun et al. 2010 ). Plants on

the other hand play a key role in determining the size and

health of soil microbial populations. All plant roots secrete

organic materials that can be used as food for microbes,

and this creates a healthier, larger, more diverse and active

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microbial population, which in turn causes a faster breakdown of pollutants. Phytoremediation reduces contaminant levels through microbial degradation in the rhizosphere. Phytoremediation systems increase the catabolic potential

of rhizosphere soil by altering the functional composition

of the microbial community (Siciliano et al. 2003 ). Plants,

through their “rhizosphere effects”, support hydrocarbondegrading

microbes that assist in phytoremediation in the

root zone (Nie et al. 2009 ). For example, root activities in

perennial ryegrass and alfalfa increase the number of rhizobacteria

capable of petroleum degradation in the soil

(Kirk et al. 2005 ). In turn, healthy microbial communities

enhance soil nutrient availability to the plants (Wenzel

2009 ). Phytoremediation process can also be enhanced by

the addition of specifi c inocula of microorganism to contaminated

soils (bioaugmentation). Also, plants that are relatively

tolerant to various environmental contaminants are

often stunted in the presence of the contaminant. Therefore,

plant growth-promoting microorganisms can be added to the roots of plants to remedy this situation. The best bioaugmentation performance can be achieved by the use of microorganisms that are already present in the soil, since indigenous microorganisms are well adjusted to their own

environment. Inoculating plants with genetically engineered

strains of bacteria that degrade a specifi c contaminant has

shown promising results. Biostimulation, a process which

involves manipulating the nutrient and pH levels of the

soil to increase microbial populations, can also be used to

amplify the population of soil organism responsible for biodegradation.

Hence, fertilizers can be used together with

bioaugmentation to facilitate degradation of pollutants.

**15.2 Advantages of Phytoremediation**

**Using Microbes**

1. Low-cost: It is less expensive than alternative

engineering- based solutions such as soil excavation,

incineration or land fi lling of the contaminated

materials.

2. Aesthetically pleasing and appealing to the public. Trees

and smaller plants used in phytoremediation make a site

more attractive, reduce noise and improve surrounding

air quality.

3. Site use and remediation can occur simultaneously.

4. In situ approach: It treats the contamination in place so

that large quantities of soil, sediment or water do not have

to be dug up or pumped out of the ground for treatment.

5. Environmentally friendly: Poses no health risk to neither

plant, human nor animal.

6. Enhance soil nutrient availability to the plants.

7. It takes advantage of natural plant processes and requires

less equipment and labour than other methods since

plants do most of the work.

8. Saves energy since the site can be cleaned up without

digging up and hauling soil or pumping groundwater.

9. Trees and smaller plants used in phytoremediation help

control soil erosion.

10. Creates a more fertile soil as soil organic matter is

increased as a result of root secretions and falling stems

and leaves.

11. Phytoremediation does not degrade the physical or

chemical health of the soil as compared to soil excavation

method that removes the organic-matter-rich topsoil

and, because of the use of heavy machinery, compacts

the soil that is left behind.

12. Its by-product can fi nd a range of other uses. Some of

the plants used for phytoremediation produce metabolites

or phenolic compounds that are of commercial

value in the pharmaceutical industry.

13. The roots of plants used create pores through which

water and oxygen can fl ow.

**15.3 Limitations of Phytoremediation**

**Using Microbes**

1. A long time period is required for remediation. It is a slow

process that may take many growing seasons before an

adequate reduction of pollution is achieved, whereas soil

excavation and treatment clean up the site quickly.

Multiple metal-contaminated soils require specifi c metal

accumulator species and therefore require a wide range of

research prior to the application. The cadmium/zinc

model hyperaccumulator *Thlaspi caerulescens* , for example,

is sensitive towards copper (Cu) toxicity, which is a

problem in remediation of Cd/Zn from soils in the presence

of Cu by application of this species.

2. Scientifi c understanding of mechanisms is still limited;

this is because the technique is still in its infancy state.

3. Hyperaccumulators can be a pollution hazard themselves.

For instance, animals can eat the hyperaccumulators and

cause the toxins to enter the food chain. If the concentration

of contaminant in the plants is high enough to cause

toxicity, there must be a way to segregate the plants from

humans and wildlife, which may not be an easy task.

**15.4 Environmental Contaminants**

The following compounds have been reported as contaminants

in soil and water:

Pesticides; explosives; oil; heavy metal such as arsenic

(As), cadmium (Cd), chromium (Cr), mercury (Hg), nickel

(Ni), lead (Pb), selenium (Se), uranium (U), vanadium (V)

and wolfram (W); polychlorinated biphenyls; polycyclic aromatic

hydrocarbons (PAHs); chlorinated solvents; xenobiotics;

munitions; semi-coke solid wastes (which contain several

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organic and inorganic compounds such as oil products,

asphaltenes, phenols, PAHs, sulphuric compounds); oil

shale; and organic synthetic compounds.

**15.5 Factors that Affect Phytoremediation**

Certain factors affect the uptake, distribution and transformation

of contaminants. Some of these factors include the

following:

1. Level of contamination: They work best where contaminant

levels are low because high concentrations may

limit plant growth and take too long to clean up.

2. Plant species used for phytoremediation: Certain plants

are better at removing contaminants than others. This

may be due to differences in root exudate patterns, differences

in root architecture as well as differences in

genetic composition of the plant. Tall fescue with fi brous

root system, for example, increases the potential of soil

microbial community to degrade hydrocarbons, whereas

rose clover with a coarse, woody root system decreases

it (Siciliano et al. 2003 ). Plants used for phytoremediation

must be able to tolerate the types and concentrations

of contaminants present. They also must be able to grow

and survive in the local climate. Chemical, physical and

microbiological plants with low biomass yield and

reduced root systems do not support effi cient phytoremediation

and most likely do not prevent the leaching of

contaminants into the aquatic system.

3. Depth of contamination: Small plants like ferns and

grasses have been used where contamination is shallow.

Because tree roots grow deeper, trees such as

poplars and willows are used for hydraulic control or to

clean up deeper soil contamination and contaminated

groundwater.

4. Plant growth and development stage. Phytoremediation

is most effective during the vegetative growth stages of

plants. Plant vegetative growth stage is the most important

phase for phytoremediation (Nie et al. 2011 ).

5. Type and properties of inoculum used for

bioaugmentation.

6. Soil condition: Soil abiotic and biotic factors may determine

the survival and activity of the introduced microorganisms

(Juhanson et al. 2007 ). Some of the abiotic

factors include temperature, soil pH, soil organic matter,

soil moisture, cation exchange capacity, etc.

7. Bioavailability of contaminant to the microbial community

is another factor infl uencing biodegradation of

pollutants.

8. Age of the contaminants.

9. Physical and chemical properties of the contaminant.

Contaminants that are soluble in water may pass by the

root system without being accumulated.

10. Climatic factors. Plant survival and growth are adversely

affected by extreme climatic factors.

11. Toxicity of soil.

12. Bioavailability of contaminant to plants. Metal that is

tightly bound to the organic portions of the soil may not

be available to plants.

13. Contaminant source.

**15.6 Phytoremediation Strategies**

These technologies to be discussed below are based on the

plant’s ability to absorb, accumulate, sequester and detoxify

toxic metals:

1. *Hydraulic control* : In this process of phytoremediation,

plants act like a pump, drawing the groundwater up through

their roots to keep it from moving. It reduces the movement

of contaminated groundwater towards clean areas off-site.

2. *Phytoaccumulation* ( *phytoextraction* ) : Plants absorb,

accumulate and transport pollutants from the soil to

aboveground plant parts (shoots). Removing the metals is

as simple as pruning or cutting the plant aboveground

mass. Plants, and their associated soil microbes, can release

chemicals that act as biosurfactants in the soil that increase

the uptake of contaminants. The aboveground plant parts

rich in accumulated metal can be easily and safely processed

by drying, ashing or composting. The plants used in

a phytoextraction scheme should ideally have large biomass

production and accumulate high concentration of

metals in the aboveground portions (Adesodun et al. 2010 ).

Over 500 plant species (101 families) and approximately

0.2 % of angiosperms have been reported to possess metal

hyperaccumulation ability (Krämer 2010 ).

3. *Phytostabilization* involves the use of plants to reduce the

mobility and bioavailability of contaminants in soil either

through precipitation or adsorption onto roots. Plants

adsorb contaminants onto their roots where microorganisms

that live in the soil break down the adsorbed contaminants

to less harmful chemicals. Mycorrhizal

association, for example, is known to inhibit transport of

metallic cations into plant roots. Some plant species such

as *Combretum* and *Rhus* (Anacardiaceae) have the ability

of in situ stabilization of some metals (Regnier et al.

2009 ; Mokgalaka-Matlala et al. 2010 ).

4. *Phytodegradation* is the breaking down of contaminants

into less toxic substances in the soil through the activities of

microorganisms in the rhizosphere of plant roots or externally

through metabolites produced by plants. For instance,

exudates (peptides) from the bacterium *Pseudomonas*

*putida* can decrease cadmium (Cd) toxicity in plants.

Natural exudates such as siderophores, organic acids and

phenolics released by the roots of certain plants can form

complexes (chelates) with metals in the rhizosphere.

6. High level of tolerance to waterlogging and extreme

drought condition.

7. High level of accumulation, translocation and uptake

potential of contaminant.

8. Habitat preference of plant, e.g. terrestrial aquatic or semiaquatic.

**15.9 Effects of the Metals**

**on the Phytoremediators**

Plants that have been successfully used as phytoremediators

were able to tolerate, accumulate or translocate the metals by

reasons of the following effects of the metals on the plants:

1. The plant physiology: Metals affect the physiology of

plants either by promoting or inhibiting the growth of the

plant. Some develop metal tolerance characteristics

through apoplastic or symplastic detoxifi cation mechanisms

(Pilon-Smits et al. 2009 ). Some are absorbed from

soil solution through passive transport. Hg, for example,

may preferentially bind with sulphur- and nitrogen-rich

ligands (amino acids) and enter inside the cells. Cd can

induce changes in lipid profi le (Ouariti et al. 1997 ) and

can also affect the enzymatic activities associated with

membranes such as the H + ATPase (Fodor et al. 1995 ).

2. Biomass production of the plants that have been successfully

used as phytoremediators.

**15.10 Responses of Microbial Communities**

**to Phytoremediation**

Different plant species have different effects on microorganisms

in the soil. For instance, *Alyssum corsicum* , *Alyssum*

*murale* and *Brassica juncea* (Ni hyperaccumulators) have

been reported to increase both the population and biomass of

soil microorganisms. By absorbing nickel from the soil and

excreting root exudates, the plants reduced nickel toxicity

and improved the living environment of the microbes (Cai

et al. 2007 ). Phytoremediation increased the number of

phenol- degrading bacteria as well as metabolic diversity of

microbial community in semi-coke polluted soil (Truu et al.

2003 ). Perennial ryegrass supports a general increase in

microbial activity and numbers in the rhizosphere, some of

which have catabolic activity towards petroleum hydrocarbons

in petroleum-contaminated soil. Alfalfa, on the other

hand, seems to specifi cally increase the number of microorganisms

capable of degrading more complex hydrocarbons

(Kirk et al. 2005 ). Plant-dependent changes in microbial

functionality are the result of some form of communication

between the associated microorganisms and the plant. For

example, bacterial products, such as lumichrome, stimulate

root respiration and thereby increase the availability of root

exudates for bacteria (Phillips et al. 2009 ).

**15.11 Sources of Environmental Pollution**

1. Increased toxic waste from increased population

2. Anthropogenic activities such as agriculture

3. Metal purifi cation procedure, which includes mining,

smelting and the tailings from industries

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