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Phytoremediation approaches to PAH contaminated soil

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Abstract

Petroleum based products are the current major source of energy and their transport across the world frequently result in oil spillage, contaminating the soil and water alike. There is an overwhelming need for *in situ* technologies that can efficiently remediate persistent contaminants from soil in a cost-effective, environmentally friendly method. In phytoremediation, plants are utilized to clean up contaminated soil, taking advantage of their natural ability to take up, accumulate and/or degrade constituents of their soil and water. Phytoremediation processes and techniques suggest their applicability to a broad range of contaminants including various organic compounds such as chlorinated solvents, BTEX (Benzene, toluene, ethylene & xylene), polycyclic aromatic hydrocarbons (PAHs), nutrients and surfactants offering a low-cost method of soil remediation technology. Chemical nature of organic contaminants, sources of contamination, microbial processes associated with plants and role of plants in PAH contaminated soil reclamation have been discussed to decipher the strategies to accomplish remediation to a large extent over short durations of exposure based on multi-process integration approaches.

Keywords: Phytoremediation, pollution, polycyclic aromatic hydrocarbons, oil spillage.

Introduction

Petroleum and its products are of specific concern in pollution studies due to their structural complexity, slow biodegradability, bio-magnification potential and above all the serious health hazards associated with their release into the environment. Plants are used successfully in the remediation of a wide range of contaminated soils, mainly due to their 2 way functioning-creating favorable conditions for microbial degradation and roots assessing the contaminants in the soil.

Nature & types of organic contaminants: Organic pollutants differ in charge and solubility. Non-polar compounds such as hydrocarbons are poorly soluble in water and sorbs readily to hydrophobic soil particles like soil organic matter. Organic contaminants include petroleum hydrocarbons, often introduced into the environment via the oil and gas explorations. Crude oil is a complex mixture of aliphatic, aromatic, heterocyclic and asphaltene/tar hydrocarbons, ranging in size from C6 to > C50. Total petroleum hydrocarbons (TPHs) are classified into different fractions. Fractions 1 (C6–C10) and 2 (C10–C16) are volatile or semi-volatile, whereas fractions 3 (C16–C33) and 4 (C34–C50) are hydrophobic and recalcitrant. Compounds from fractions 3 and 4 can be highly toxic and are regulated due to their mutagenicity and carcinogenicity. These hydrocarbons can be degraded by various processes, including photo oxidation, microbial action and natural rhizosphere action (Greenberg *et al.,* 2007).

Petroleum or crude oil, a naturally occurring flammable liquid found in rock formations in Earth's crust consists of a complex mixture of hydrocarbons of various molecular weights and organic compounds. The proportion of these hydrocarbons is highly variable and ranges from as much as 97% by weight in the lighter oils to as little as 50% in the heavier oils and bitumens. The hydrocarbons in crude oil are mostly alkanes (C_nH_{2n+2}), cycloalkanes or naphthenes (C_nH_{2n}) in addition to various aromatic hydrocarbons or asphaltenes (C_nH_n) while the other organic compounds contain nitrogen, oxygen and sulfur along with trace amounts of metals such as iron, nickel, copper and vanadium. The most common products of petroleum distillations are fuels which include: ethane and other short-chain alkanes, diesel fuel (petrodiesel), fuel oils, gasoline (petrol), jet fuel, kerosene and liquefied petroleum gas (LPG). Certain types of resultant hydrocarbons may be mixed with other non-hydrocarbons, to create other end products like alkenes (olefins) which can be manufactured into plastics or other compounds, lubricants which produce light machine oils, motor oils and greases, wax (used in the packaging of frozen foods), sulfur or sulfuric acid useful as industrial materials, petroleum coke used in solid fuel, paraffin wax etc. Bioremediation of oil components is restricted by their volatility, toxicity and bioavailability; which in turn depends on the length of the carbon chain. Oil components with a short length carbon chain can easily evaporate; whereas molecules with longer carbon chains or complicated (eg. branched or cycle) molecular structures persist in the soil due to less susceptibility to degradability, extractability and other related processes in a time-dependent manner.

Common sites of PAH contaminants: The typical contaminated sites are: unregulated former disposal sites (areas associated with spills, leaks, open storage areas); filling stations; electrical facilities, leaks and spills, fire-fighter training areas, ports and waterways where past industrial discharges contaminated sediment; lagoons used to store or "treat" industrial effluents, mine tailings; ponds, above and below ground fuel storage sites;

municipal landfills; military training areas; abandoned buildings with inventory of fuel, transportation routes where spills or spraying of oil or chemicals have occurred and wood preserving sites (Site remediation technologies, 1997). Petroleum is also the raw material for many chemical products such as plastics, paints and cosmetics.

Phytoremediation: Phytoremediation is the green technology that uses plants to remediate contaminated soil, sediment and surface water. Pradhan et al 1998) \It is a cost-effective, ecologically compatible tool for the environmental clean-up of a wide array of contaminants such as petroleum hydrocarbons, chlorinated solvents, pesticides and metals (Anderson *et al.,* 1993; Cunningham & Lee 1995; Schwab *et al.,* 1995). Plants preserve the natural structure and texture of soil using solar energy and hence this technology is suitable to diverse regions and climates.

Phytoremediation process

(a) Uptake of organic compounds from soil and water; (b) Accumulation or processing of these chemicals via lignification, volatilization, metabolization, mineralization; (c) Use of enzymes to break down complex organic molecules into simpler molecules (ultimately carbon dioxide & water) and (d) Increase the carbon and oxygen content of soil around roots (and so promote microbial/fungal activity) and decay of root tissues.

Phytoremediation techniques

There are 5 basic phytoremediation techniques:

1) Rhizofiltration, a water remediation technique involving the uptake of contaminants by roots of plants.

2) Phytoextraction, a technique involving uptake of contaminants from soil. 3) Phytotransformation, applicable to both soil and water and involves the degradation of contaminants through plant metabolism. 4) Phyto-stimulation, (plant-assisted bioremediation) used for both soil and water and involves stimulation of microbial biodegradation at the root zone. 5) Phytostabilization, using plants to reduce the mobility and migration potential of contaminants in soil (Ralinda & Miller, 1996).

Metabolism inside plants

Organic pollutants cause hindrance to uptake of compound in a plant as they are lipophilic and covalently bound to the soil components where log Kow is important for transport of substances in the transpiration stream. After reaching the plant rhizosphere contaminants migrate into the root, where lipophilic compounds either limit the uptake or cause accumulation in the partly suberised root cortex. Before the pollutant is translocated by the transpiration stream in the xylem into other tissues of the plant (root & shoot), it has to enter the symplast to overcome the barriers of suberised casparian strips in the root endodermis where detoxification and metabolism occur (Schroder *et al.,* 2002). P-450 enzymes catalyse phase-I transformation reactions like hydroxylation, sulfoxidation and N and O-dealkylation and Glutathione-S-transferases are responsible for conjugation reations which play a central role in detoxification in plants. Phase-III of plant xenobiotics metabolism involves storage and compartmentation of soluble conjugates in the cell wall (Komossa *et al.,* 1995). Transformation of contaminants may occur outside the plant in the rhizosphere, inside the plant or sorbed to the leaf surface (photolysis) (Trapp & Karlson, 2001).

Microbial processes associated with plants: Plant enzymes aid in the degradation of contaminants during phytoremediation, but during natural attenuation or bioaugmentation, indigenous microbial population performs the degradation. However the hydrocarbon assemblage is resistant to soil micro-organisms under normal conditions and persist in the subsurface for decades. Since plant roots can supply readily available carbon sources for microorganisms they influence the soil microbial community by increasing microbial numbers, improve physical and chemical conditions of soil, increase humification and adsorption of pollutants onto the rhizosphere. Since different plants have varying effects on microorganisms, their degradation rate is dependent on individual composition of plant exudates (Merkl *et al.,* 2005).

Filamentous fungi of the genera *Fusarium, Penicillium, Trichoderma, Aspergillus, Neosartorya, Pseudallescheria, Cladosporium, Pestalotiopsis, Phoma and Paecillomyces* have the ability to synthesize extracellular oxidative enzymes which can relate lignin degrading enzyme systems with crude oil contaminants (Naranjo *et al.,* 2007). White-rot fungi contain all three lignin-modifying enzymes (LMEs): lignin peroxidase, manganese dependent peroxidase, and laccase enzymes and hence are able to breakdown and mineralize several environmental pollutants into nontoxic forms. Through intensive study of lignolytic fungi, it has been established that these organisms produce extracellular enzymes with very low substrate specificity. Petroleum hydrocarbon pollution severely effects the species composition and density of indigenous microalgae in polluted soil (Megharaj *et al.,* 2000). D'Annibale *et al.* (2006) explain that external nutritional supply like saw dust, fertilizers or plant debris is always required in conjunction with fungus unlike bacteria. He isolated nine fungal strains from an aged and heavily contaminated soil, identified and screened to assess their degradative potential. Among them, *Allescheriella* sp. strain DABAC 1, *Stachybotrys* sp. Strain DABAC 3, and *Phlebia* sp. strain DABAC 9 were selected for remediation trials on the basis of Poly R-478 decolourization associated with lignin-modifying enzyme (LME) production. These autochthonous fungi were tested for the ability to grow under nonsterile conditions and to degrade various aromatic hydrocarbons in the same contaminated soil. The autochthonous fungi made a significant decrease in soil toxicity, as assessed by both the *Lepidium sativum* L. germination test and the Collembola mortality test. The large quantity of residual

Table 1. Studies on phytoremediation with PAH contaminants in soil.

Common name of plant	Scientific name of plant	Research findings	References
Cocks foot Tall fescue Red fescue Rye grass Birdsfoot-trefoil Red clover White clover	*Dactylis glomerata* *Festuca arundinacea* *Festuca rubra* *Lolium perenne* *Lotus carniculatus* *Trifolium pretense* *Trifolium repens*	Naphthalene decreased to about 20% & other PAHs decreased with an increase in molecular weight, except with pyrene, the only PAH not to show any significant decrease.	Smith *et al.,* 2006
Cat claw	*Mimosa monancistra*	Dissipation of benzo[a]pyrene significantly faster in vegetated soil.	Bernal *et al.,* 2007
Baby bear	*Cucurbita pepo* ssp *pepo*	As soil moisture, plant density increased rates of contaminant accumulation by plant roots were increased. Concentrations of the compound in plant roots were inversely related to plant age whereas no change in the bioavailability of the compound was observed in successive generations of plants grown in the same contaminated soil.	Kelsey *et al.,* 2006
Annual ryegrass Tall Fescue Yellow Sweet Clover	*Lolium multiflorum* *Festuca arundinacea* Schreb. *Melilotus officinalis* Lam.	Maturity of plant root contributes to reduction in the bioavailability of target PAHs.	Parrish *et al.,* 2005
Sunflower Bermuda grass Southern crabgrass	*Helianthus annuus* L. *Cynodon dactylon* L. *Digitaria ciliaris* (Retz.)Koeler.	Vegetation increases total numbers of beneficial fungi and bacteria in contaminated soil.	Olson & Fletcher, 2000
Maize	*Zea mays* L.	Increase in hydrocarbon bioavailability, stimulates bacterial population.	Radwan *et al.,* 1995 Chaineau *et al.,* 2000
Switch grass Little bluestem grass Alfalfa	*Panicum virgatum* *Schizachyrium scoparium* *Medicago sativa* L.	Reduction in total PAH concentration after six months of treatment.	Pradhan *et al.,*1998 Wiltse *et al.,* 1998
Rice Naked Spinach Devil's beggartick	*Oryza sativa* L.cv. *Spinacia oleracea* L.cv.Ohrai. *Pueraria lobata* (Willd.) Ohwi *Bidens frondosa* L.	Significant decrease in TPH concentration under vegetated conditions.	Kaimi *et al.,* 2007
Slender oat	*Avena barbata*	A large phenanthrene degrader population in rhizosphere is related to root debris & soil exudates.	Miya & Firestone, 2001
Alfalfa Alpine blue grass	*Medicago sativa* L. *Poa alpine* L.	Stimulation of bioremediation around plant roots due to higher number of organic chemical degraders indicates potential.	Nichols *et al.,* 1997
Tall fescue	*Festuca arundinacea*	Greater total bacterial numbers & PAH-degrading bacteria in rhizosphere soil.	Ho & Banks, 2006
Alflalfa Reed	*Medicago sativa L.* *Phragmitis australis*	Rhizosphere microflora of alfalfa was less inhibited by hydrocarbon contamination with higher degradative potential compared to reed.	Muratova *et al.,* 2003

oil in microcosms with plants and fungi may suggest, however, that plants were able to take up greater quantities of nutrients with the assistance of fungi, intensifying competition between plants and bacteria (Vavrek *et al.,* 2001).

Based on the hypothesis that root exudates not only increase the rhizosphere microbial numbers but also community composition. Binet *et al.* (2000) investigated the significance of plant microbial interactions in the degradation of PAH. Dead and decaying roots (result of normal root turnover) produce air filled macro-pores in soil which facilitate oxygen diffusion in the subsurface. As a result biodegradation of many organic chemical contaminants is stimulated by plants. Certain organic chemicals can be passively taken up through the roots and transported in the plant's vascular system (Ferro *et al.,* 1999). More efficient degradation of contaminant is reported in phytoremediation systems when plants associated themselves with endophytes. Plant endophyte partnerships are beneficial to improve phytoremediation of a mixture of contaminants (Weyens *et al.,* 2009).

Table 2. Studies on phytoremediation with spent oil contaminants in soil.

Common name of plant	Scientific name of plant	Research findings	References
Smooth brome grass Wheat Flax	*Medicago truncatular* *Bromus mermis* *Secale cereale* *Triticum aestivum* *Linum ussitasimum* *Agropyron desertorum*	Reduction in germination, above ground height & biomass for all species.	Sharifi *et al.,* 2007
Chilly Tomato	*Capsicum annum* L. *Lycopersicum esculentum*	Germination percentage, mean height, mean leaf area reduced. Premature death with all strengths of oil.	Anoliefo & Vwioko,1995
Castor	*Ricinus communis* L.	Stimulation of growth parameters- plant height, stem girth, leaf area, fresh and dry weights, and root length.	Vwioko & Fashemi, 2005
Slim amaranth	*Amaranthus hybridus* L.	Decrease in the total chlorophyll and protein levels.	Odjegba & Sadiq, 2002
Cowpea	*Vigna ungiculata* L. Walp)	Reduction in germination time, increase in germination percentage, plant height, leaf number and total biomass.	Ataga & Adedokun, 2007

Wolf *et al.* (2007) attribute rhizosphere effect to the very characteristics of the roots. The contribution of the rhizosphere microbes in the degradation of pollutants is referred to as rhizoremediation (Anderson *et al.,* 1993; Schwab *et al.,* 1995). However when trees establish rhizosphere colonization, the hydrocarbons become amenable to biodegradation (Phillips, 2004). This emerging technology has been reviewed by a number of authors (Salt *et al.,* 1998; Schnoor 2002; Joner & Leyval, 2003a, b; Suresh & Ravi Shankar, 2004; Okoh, 2006). Nichols *et al.* (1997) and Radwan *et al.* (1998) demonstrated increase in hydrocarbon-degrading microorganisms under the influence of "rhizosphere effect" in the root zone of the plants which are utilized in the phytoremediation of hydrocarbon-contaminated soil.

Siciliano *et al.* (2003) demonstrated that phytoremediation systems that substantially decrease aged Total Petroleum Hydrocarbons (TPH) in soil do so mainly by increasing bacteria and that bacteria contain a bulk of hydrocarbon catabolic genes. However, promotion of catabolic activity by plants is strongly influenced by site factors that include available nutrients. Their results suggest that phytoremediation systems are better optional methods for increasing the potential of soil to degrade hydrocarbons.

Role of plants in soil reclamation: Though annual, biennial and perennial plant species were found during the survey of contaminated sites, annuals and biennials would be less useful for phytoremediation than perennial species since they require low management inputs (Godwin & Thorpe, 2000). When benzene and octane were absorbed through root cells there were concentration dependent variations in the level of sub cellular organelles structure in alfalfa and rye grass root cells. Destruction in cell homoeostasis was observed at the basic metabolism enzyme levels in annual and perennial plants (Sadunishvili *et al.,* 2009). The role of plants in remediation of PAHs, spent oil and crude oil contamination is presented in Table 1-3.

Aprill and Sims (1990) established a mix of eight grasses in sandy loamy soil to demonstrate whether the degradation of four PAH (benzo[*a*]pyrene, benzo[*a*]anthracene, dibenzo [*a, h*] anthracene & chrysene) was stimulated by plant growth. The eight grasses included *Andropogon gerardii, Schizachyrium scoparium, Sorghastrum nutans, Panicum virgatum, Elymus canadensis glaucifolius, Bouteloua curtipendula, Bouteloua gracilis and Pascopyrum smithii. Vicia faba* plants (broad beans) are suggested as tools for the phytoremediation of oily desert areas because these can grow in poor soils and tolerate crude oil concentrations up to 10 % w/w (Radwan *et al.,* 1998). Their rhizospheres are rich in hydrocarbon utilizing microorganisms which could affect oil attenuation in sand (Radwan *et al.,* 2000).

Alfalfa recorded an increase in the number of both culturable, aerobic heterotrophic and petroleum degrading bacteria in the rhizosphere by 7 weeks, though its rhizosphere effect was not as substantial as perennial ryegrass due to varying root morphologies. *Lolium perenne* seemed to support an increase in microbial numbers as the rhizosphere effects were similar for both heterotrophic bacteria and petroleum degrading bacteria. In addition there was a large increase in hexadecane degrading bacteria (Kirk *et al.,* 2005). Muratova *et al.* (2003) observed increase in total microbial numbers and high rate of PAH degradation in PAH-contaminated soil which was planted with *Medicago sativa L.* and reeds when compared with unplanted soil. Mangroves found in the areas with most industrial and shipping activity are subjected to the effects of PAH contamination. There are limited reports on phytoremediation of organic pollutants affected by mycorrhiza during the last decade. Most of these studies were concentrated on ectomycorrhizal fungi in pure culture, rather than in symbiosis with plants (Joner & Leyval, 2003b). A number of changes take place in soil in the presence of roots which could be mistaken as changes in its chemical characteristics, modified microbial composition and enhanced microbial activity. It has thus been demonstrated that ectomycorrhizal fungi may degrade several compounds such as 2,4-

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Table 3: Studies on phytoremediation with crude oil contaminants in soil

Common name	Scientific name of plant	Research findings	References
Alfalfa	*Medicago sativa* L.	Light crude oil at 1%-10% prevents normal growth and germination of Alfalfa in soil.	Dariush Minai-Tehrani *et al.*, 2007
Maize	*Zea mays* *Psoralea esculenta* Pursh.	Inhibited germination and growth at high concentrations.	Ogboghodo *et al.*, 2004
Prairie turnip Crested Wheat Grass Yellow sweet clover White clover Timothy Prairie sagewort Pennsylvania Cinquefoil	*Lathyrus venosus* Muhl. *Agropyron pectiniforme* R. & S. *Melilotus officinalis* (L.) Lam. *Trifolium repens* L. *Phleum pretense* L. *Artemisia frigida* Willd. *Potentilla pensylvanica* L.	Lowest seedling mass in contaminated soil.	Robson *et al.*, 2004
Guinea corn	*Sorghum bicolor*	Inhibition of germination and growth in guinea corn, serves as a bio-indicator of crude oil polluted areas.	Akaninwor *et al.*, 2007
Maize Alfalfa Ryegrass Wheat Soybean Winter vetch	*Zea mays* *Medicago sativa* *Lolium perenne* *Triticum aestivum* *Glycine max* *Vicia villosa*	*Z. mays* and *G. max* seedlings possess greater potential to enhance remediation based upon percent emergence and plant biomass production in contaminated soil.	Issoufi *et al.*, 2006
Bahia grass Dallis grass Pearl millet Centipede grass Brown top millet Weeping love grass Sudan grass American joint vetch Winter vetch Annual ryegrass Tall fescue Wheat Slender oat Crimpson clover Arrow leaf clover	*Digitaria sanguinalis* (L.) Scop *Paspalum notatum* Flugge *P. dilatatum* Poir. *Pennisetum glaucum* (L.)R.Br. *Eremochloa ophiuroides* (Munro) Hack). *Brachiaria ramosa* L. *Eragrostis curvula* (Schrad.) Nees. *Sorghum sudanense* (Piper) Stapf *Lespedeza cuneata* (Dumont) G.Don. *L .stipulacea* Maxim. *L.striata*(Thunb.)H.&A.(Marion) *Aschynomene americana* L. *Vicia villosa* Roth *Lolium multiflorum* L.(Marshall) *Festuca arundinacea* Schreb.(KY31) *Triticum aestivum* L.(Roane) *Avena sativa* L.(Chapman) *Trifolium incarnatum* L.(Dixie) *T. vesiculosum*	Optimum Nitrogen application increased plant root growth and extends rhizosphere potential. Nitrogen requirement for growth varies based on plant species.	Kirkpatrick *et al.,* 2006
	Sorghum bicolor L.	All vegetated treatments resulted in higher remediation efficiency.	Banks *et al.,* 2003
	Brachiaria brizantha	The medium fertilizer concentration resulted in best root growth and highest absolute oil dissipation.	Merkl *et al.*, 2005
Cowpea	*Vigna unguiculata*	Total amylase, starch phosphorylase and mitotic activities were inhibited.	Achuba, 2006
	Phaseolus vulgaris	Can sustain growth in an oil polluted soil; Good candidate for phyto-remediation.	Nwoko *et al.,* 2007
Inflated-scale flat sedge Indian goose grass	*Brachiaria brizantha* (Hochst. ex. A. Rich.) Stapf *Cyperus aggregatus* (Willd.) Endl. *Eleusine indica* (L.) Gaertn.	Developed coarser roots larger specific root surface area in contaminated soil.	Merkl *et al.,* 2005
Broad beans	*Vicia faba*	Co-inoculation of *V. faba* plant roots with nodule bacteria and PGPR enhanced plant growth and nitrogen fixation.	Radwan *et al.,* 2005
Okra	*Abelmoschus esculetus*	Combination of crude oil, microbes and fertilizers stimulated germination, growth, biomass, microbial population and rate of degradation.	Ogbonna *et al.*, 2007

dichlorophenol, 2,4,6-trinitrotoluene, atrazine, polychlorinated biphenyls and some 3-5 ring PAHs. In a pot study, Joner and Leyval, (2003a) found that in PAH-contaminated soil planted with a mix of clover-ryegrass, PAH concentrations decreased as a function of proximity to the roots, and that mycorrhiza generally enhanced plant growth and favoured growth of clover than that of ryegrass.

Wang and Zhao (2007) from their studies on uptake and biodegradation of PAHs by marine seaweed *Laminaria japonica* reported that 0.1 mg/l conc. of PAH levels, less than 90% of phenanthrene and pyrene were removed from the seawater and that 70-90% of phenanthrene and 65-90% of pyrene which accumulated in the seaweed tissues were metabolised after 10 d of incubation. Therefore they suggest that in coastal waters contaminated with PAHs, *Laminaria japonica* could play an important role in removing PAHs and possibly other organic pollutants from sea water, thus serving as an environmentally-friendly' bioremediation system that protects ecological health and marine life. Their results also indicate that there is lower bioaccumulation of these PAHs in the seaweed tissues and get biodegraded rapidly to less or non-toxic forms of compounds by oxidant enzymes. This is an important public health factor considering the large quantities of seaweed consumption in China and other Asian countries.

Frick *et al.* (1999) stated that *Triticum aestivum, Andropogon gerardii, Bouteloua curtipendula, Bouteloua gracilis, Buchloe dactyloides, Chloris gayana, Cynodon spp., Daucus carota, Elymus canadensis, Festuca aurundinacea, Festuca rubra, Glycine max, Lemna sp., Lolium multiflorum, Lolium perenne, Medicago sativa L., Panicum coloratum L., Panicum virgatum, Phaseolus vulgaris, Populus sp., Schizachyrium scoparium, Sorghastrum nutans, Sorghum vulgare, Sorghum bicolor subsp. drummondii and Zoysia japonica* indicated significant phytoremediation potential for *in-situ* remediation of oil contaminated soils.

One commonly used plant for phytoremediation is tall fescue (*Festuca arundinacea)*, a robust, broad-leaf grass. This plant is effective for enhancement of PAH dissipation in the rhizosphere (Banks *et al.,* 1999; Chen *et al.,* 2003; Chen & Banks, 2004; Huang *et al.,* 2004; Parrish *et al.,* 2005). These identified species provide the initial guidelines for remediation strategies in other tropical countries because phytoremediation of oil-contaminated soils is dependent on the ability of the selected species to enhance the degradation of petroleum hydrocarbons (Merkl *et al.,* 2004).

Challenges and future prospects

One component that has hindered widespread use of phytoremediation is the production of stress ethylene which results due to chemical toxicity, nutrient deficiency and/or water stress in impacted soils. However, Multi-process phytoremediation system (MPPS) which can utilize plant/PGPR (plant growth promoting rhizobacteria) interactions to mitigate the effects of stress ethylene is developed by plant biomass get enhanced particularly in the rhizosphere (Greenberg *et al.,* 2007). Stressors and physical restrictions, heterogeneity in initial contaminant levels, root structure, soil structure, organic composition of soil, soil pH, moisture content and microbial activity and regulatory restrictions are the limiting factors in the use of genetically modified organisms for successful field trails. Yet, strategies to minimize ecological risks and improve methods for monitoring, sampling and analyzing experimental field data by addressing the inconsistencies in experimental protocols are needed for adequate performance of remediation systems at the field level (Gerhardt *et al.,* 2009). Exploiting the natural biodiversity by recognizing suitable natural species that grow in the contaminated sites and understanding the mechanisms involved in the soil plant interactions may widen the scope of remediation attempts.

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References

1. A´ lvarez-Bernal D, Contreras-Ramos S, Marsch R and Dendooven L (2007) Influence of Catclaw *Mimosa monancistra* on the dissipation of soil PAHs. *Int. J. Phytoremed*. 9, 79-90.
2. Achuba FI (2006) The Effect of sub lethal concentrations of crude oil on the growth and metabolism of Cowpea (*Vigna unguiculata*) seedlings. *Environmentalist*. 26, 17-20.
3. Akaninwor JO, Ayeleso AO and Monoga CC (2007) Effect of different concentrations of crude oil (Bonny Light) on major food reserves in guinea corn during germination and growth. *Sci. Res. Essays*. 2(4), 127-131.
4. Anderson TA, Guthrie EA and Walton BT (1993) Bioremediation in the rhizosphere: plant roots and associated microbes clean contaminated soil. *Environ. Sci. Technol*. 27, 2630-2636.
5. Anoliefo GO and Vwioko DE (1995) Effects of spent lubricating oil on the growth of *Capsicum annum* L. and *Lycopersicon esculentum* Miller. *Environ. Pollut*. 88, 1361-364.
6. Aprill W and Sims RC (1990) Evaluation of the use of prairie grasses for stimulating polycyclic aromatic hydrocarbon treatment in soil. *Chemosphere*. 20 (1-2), 253-265.
7. Ataga AE and Adedokun OM (2007) Effects of amendments and bioaugmentation of soil polluted with crude oil, automotive gasoline oil, and spent engine oil on the growth of cowpea (*Vigna ungiculata* L. Walp). *Sci. Res. Essays*. 2 (5), 147-149.
8. Banks MK, Kulakow P, Schwab AP, Chen Z and Rathbone K (2003) Degradation of crude oil in the rhizosphere of *Sorghum bicolor*. *Int. J. Phytoremed*. 5(3), 225-234.
9. Banks MK, Lee E and Schwab AP (1999) Evaluation of dissipation mechanisms for benzopyrene in the rhizosphere of tall fescue. *J. Environ. Qual*. 28, 294-298.
10. Binet P, Portal JM and Leyval C (2000) Dissipation of 3-6-ring polycyclic aromatic hydrocarbons in the rhizosphere of ryegrass. *Soil. Biol. Biochem*. 32, 2011-2017.

11. Chaineau CH, Morel JL and Oudot J (2000) Biodegradation of fuel oil hydrocarbons in the rhizosphere of maize. *J. Environ. Qual.* 29, 569-578.
12. Chen YC and Banks MK (2004) Bacterial community evaluation during establishment of tall fescue (*Festuca arundinacea*) in soil contaminated with pyrene. *Int. J. Phytoremed*. 6, 227-238.
13. Chen YC, Banks MK and Schwab AP (2003) Pyrene degradation in the rhizosphere of tall fescue (Festuca arundinacea) and switchgrass (*Panicum virgatum* L.). *Environ. Sci. Technol*. 37, 5778-5782.
14. Cunningham SD and Lee CR (1995) Phytoremediation: Plant-based remediation of contaminated soils and sediments. In: Bioremediation. Skipper HA (ed), Society of Soil Science, American Society of Agronomy. Special publication. 43, 145-156.
15. D'Annibale A, Rosetto F, Leonardi V, Federici F and Petruccioli M (2006) Role of autochthonous filamentous fungi in bioremediation of a soil historically contaminated with aromatic hydrocarbons. *Appl. Environ. Microbial*. 72(1), 28-36.
16. Dariush Minai-Tehrani, Malek-Hossein Shahriari, Gholamreza Savaghebi-Firoozabadi, Mahdie Azizi and Faeze Kalantari (2007) Study of growth and germination of *Medicago sativa* (Alfalfa) in light crude oil-contaminated soil. *Res. J. Agric. Biol. Sci.* 3(1), 46-51.
17. Ferro AM, Rock SA, Kennedy J, Herrick JJ and Turner DL (1999) Phytoremediation of soils contaminated with wood preservatives: greenhouse and field evaluations. *Int. J. Phytoremed*. 1(3), 289-306.
18. Frick CM, Farrell RE and Germida JJ (1999) Assessment of phytoremediation as an in-Situ technique for cleaning oil-contaminated sites. Petroleum Technology Alliance Canada: Calgary, Canada.
19. Gerhardt KE, Huang XD, Glick BR and Greenberg BM (2009) Phytoremediation and rhizoremediation of organic soil contaminants: Potential and challenges. *Plant Sci*. 176, 20-30.
20. Godwin B and Thorpe J (2000) Assessment of Phytoremediation as an In-situ technique for cleaning oil-contaminated sites- phase ii final report, Petroleum technology alliance of Canada (PTAC). p:7.
21. Greenberg BM, Xiao-Dong Huang, Karen Gerhardt, Bernard R. Glick, Jola Gurska, Wenxi Wang, Mark Lampi, Aaron Khalid, David Isherwood, Pearl Chang, Haitang Wang, Shan Shan Wu, Xiao Ming Yu, and D. George Dixon and Perry Gerwing (2007) field and laboratory tests of a multi-process phytoremediation system for decontamination of petroleum and salt impacted soils In: Proc. 9th Int. in situ and on-site remediation symp. Batelle press.
22. Ho Ch and Banks MK (2006) Degradation of polycyclic aromatic hydrocarbons in the rhizosphere of *Festuca arundinacea* and associated microbial community changes. *Biorem. J*. 10(3), 93-104.
23. Huang XD, El-Alawi Y, Penrose DM, Glick BR and Greenberg BM (2004). A multi-process phytoremediation system for removal of polycyclic aromatic hydrocarbons from contaminated soils. *Environ. Pollut*. 130, 465-476.
24. Interstate technology and regulatory cooperation (ITRC) (1999) Work group-Phytoremediation decision tree. Phytoremediation work team. p:8.
25. Issoufi I, Rhykerd RL and Smiciklas KD (2006) Seedling growth of agronomic crops in crude oil contaminated soil. *J. Agronomy Crop Sci*. 192, 310–317.
26. Joner EJ and Leyval C (2003a) Rhizosphere gradients of polycyclic aromatic hydrocarbon (PAH) dissipation in two industrial soils and the impact of arbuscular mycorrhiza. *Environ. Sci. Technol*. 37, 2371-2375.
27. Joner EJ and Leyval C (2003b) Phytoremediation of organic pollutants using mycorrhizal plants: a new aspect of rhizosphere interactions. *Agronomie.* 23, 495-502.
28. Kaimi E, Mukaidani T, Miyoshi S and Tamaki M (2007) Screening of twelve plant species for phytoremediation of petroleum hydrocarbon contaminated soil. *Plant Prod. Sci.* 10(2), 211-218.
29. Kelsey JW, Colino A, Koberle M and White JC (2006) Growth conditions impact 2,2-bis (p-chlorophenyl)-1,1-dichloroethylene (p,p'-DDE) accumulation by *Cucurbita pepo. Int. J. Phytoremed*. 8, 261-271.
30. Kirk JL, Klironomos JN, Lee H and Trevors JT (2005) The effects of perennial ryegrass and alfalfa on microbial abundance and diversity in petroleum contaminated soil. *Environ. Pollut*. 133, 455-465.
31. Kirkpatrick WD, White Jr. P, Wolf DC, Thoma GJ and Reynolds CM (2006) Selecting plants and nitrogen rates to vegetate crude-oil-contaminated soil. *Int. J. Phytoremed*. 8, 285-297.
32. Komossa D, Langebartels C and Sandermann jr H (1995) Metabolic processes for organic chemicals in plants. In :Trapp S, Mc Farlane C, Eds., Plant contamination-modeling and simulation of organic chemical processes. Lewis Pub., Boca Raton, Florida, USA. pp:69-103.
33. Megharaj M, Singleton I, McClure NC and Naidu R (2000) Influence of petroleum hydrocarbon contamination on microalgae and microbial activities in a long-term contaminated soil. *Arch. Environ. Contam. Toxicol*. 38(4), 439-445.
34. Merkl N, Kraft S and Infante C (2004) Phytoremediation of petroleum-contaminated soils in the tropics - assessment of the potential of plant species from eastern Venezuela. *J. Appl. Bot. Food Qual.* 78 (3), 185-192.
35. Merkl N, Schultze-Kraft R and Infante C (2005) Phytoremediation of petroleum-contaminated soils in the tropics - assessment of tropical grasses and legumes for enhancing oil-degradation. *Water Air Soil Pollut*. 165, 195-209.
36. Miya RK and Firestone MK (2001) Enhanced phenanthrene biodegradation in soil by slender oat root exudates and root debris. *J. Environ. Qual*. 30, 1911-1918.
37. Muratova A, Hübner Th, Narula N, Wand H, Turkovskaya O, Kuschk P, Jahn R and Merbach W (2003) Rhizosphere microflora of plants used for the phytoremediation of bitumen-contaminated soil. *Microbiol. Res*. 158, 151-161.
38. Naranjo L, Urbina H, De Sisto A and Leon V (2007) Isolation of autochthonous non-white rot fungi with potential for enzymatic degrading of Venezuelan extra-heavy crude oil. *Biocatal. Biotransform*. 25(2-4), 341-349.
39. Nichols TD, Wolf DC, Rogers HB, Beyrouty CA and Reynolds CM (1997) Rhizosphere microbial populations in contaminated soils. *Water Air Soil Pollut*. 95, 165-178.
40. Nwoko CO, Okeke PN, Agwu OO and Akpan IE (2007) Performance of *Phaseolus vulgaris* L. in a soil contaminated with spent-engine oil. *Afr. J. Biotech*. 6 (16), 1922-1925.
41. Odjegba VJ and Sadiq AO (2002) Effects of spent engine oil on the growth parameters, chlorophyll and protein levels of *Amaranthus hybridus* L. *Environmentalist.* 22, 23-28.
42. Ogboghodo IA, Iruaga EK, Osemwota OI and Chokor JU (2004) An assessment of the effects of crude oil pollution on

soil properties, germination and growth of maize (Zea mays) using two crude oil types-Forcados light and Escravos light. Environ. *Monit. Assess*. 96, 143-152.
43. Ogbonna DN, Iwegbue CMA, Sokari TG and Akoko IO (2007) Effect of bioremediation on the growth of Okro (*Abelmoshus esculetus*) in the Niger Delta soils. *Environmentalist*. 27, 303-309.
44. Okoh (2006) Biodegradation alternative in the cleanup of petroleum hydrocarbon pollutants. *Biotechnol. Mol. Biol. Rev.* 1(2), 38-50.
45. Olson PE and Fletcher JS (2000) Ecological recovery of vegetation at a former industrial sludge basin and its implications to phytoremediation. *Environ. Sci. Pollut. Res*. 7, 1-10.
46. Parrish ZD, Banks MK and Schwab AP (2005) Effect of root death and decay on dissipation of polycyclic aromatic hydrocarbons in the rhizosphere of yellow sweet clover and tall fescue. *J. Environ. Qual.*34, 207-216.
47. Phillips KJ (2004) Handbook of complex environmental remediation problems. The McGraw-Hill Company, NY. pp: 2-11.
48. Pradhan SP, Conrad JR, Paterek JR and Srivastava VJ (1998) Potential of Phytoremediation for Treatment of PAHs in Soil at MGP Sites. *Soil Sediment Contam*. 7(4), 467-480.
49. Radwan SS, Narjes Dashti and El-Nemr IM (2005) Enhancing the growth of *Vicia faba* plants by microbial inoculation to improve their phytoremediation potential for oily desert areas. *Int. J. Phytoremed*. 7(1), 19-32.
50. Radwan SS, Al-Awadhi H and El-Nemr IM (2000) Cropping as phytoremediation practice for oily soil with reference to crop safety as food. *Int. J. Phytoremed*. 2, 383-396.
51. Radwan SS, Al-Awadhi H, Sorkhoh NA and El-Nemr IM (1998) Rhizospheric hydrocarbon utilizing microorganisms as potential contributors to phytoremediation for the oily Kuwaiti desert. *Microbiol. Res*. 153, 247-251.
52. Radwan SS, Sorkhoh NA and El-Nemr IM (1995) Oil biodegradation around roots. *Nature.* 376, 302.
53. Ralinda R and Miller PG (1996) Phytoremediation. Ground-Water Remediation Technologies Analysis Center, pp: 3.
54. Robson DB, Germida JJ, Farrell RE, Knight JD (2004) Hydrocarbon tolerance correlates with seed mass and relative growth rate. *Biorem. J.* 8(3-4), 185-199.
55. Sadunishvili T, Kvesitadze E, Betsiashvili M, Kuprava N, Zaalishvili G and Kvesitadze G (2009) Influence of Hydrocarbons on plant cell ultrastructure and main metabolic enzymes. World academy of science. *Engg. Technol*. 57, 271-276.
56. Salt DE, Smith RD and Raskin I (1998) Phytoremediation. *Annu. Rev. Plant Physiol. Plant Mol. Biol*. 49, 643-668.
57. Schnoor JL (2002) Technology evaluation report: Phytoremediation of soil and groundwater. Remediation technologies analysis center, Pittsburg (GWRTAC) series TE-02-01.
58. Schroder P, Harvey PJ and Scwitzguebel JP (2002) Prospects for the phytoremediation of organic pollutants in Europe. *Environ. Sci. Pollut. Res*. 9(1), 1-3.
59. Schwab AP, Banks MK and Arunachalam M (1995) Biodegradation of polycyclic aromatic hydrocarbons in rhizosphere soil. In: Hinchee RE, Anderson DB, Hoeppel RE (ed) Bioremediation of Recalcitrant Organics. Battelle Memorial Institute, Columbus, OH, U.S.A. pp:23-29.
60. Sharifi M, Sadeghi Y and Akbarpour M (2007) Germination and growth of six plant species on contaminated soil with spent oil. *Int. J. Environ. Sci. Tech*. 4(4), 463-470.
61. Siciliano SD, Germida JJ, Banks K and Greer CW (2003) Changes in Microbial Community Composition and Function during a Polyaromatic Hydrocarbon Phytoremediation Field Trial. *Appl. Environ. Microbiol*. 69(1), 483-489.
62. Site remediation technologies: A reference manual (1997) contaminated sites management working group, water technology international corp., Burlington, Ontario. pp:2-3.
63. Smith MJ, Flowers TH, Duncan HJ and Alder J (2006) Effects of polycyclic aromatic hydrocarbons on germination and subsequent growth of grasses and legumes in freshly contaminated soil and soil with aged PAHs residues. *Environ. Pollut*. 141, 519-525.
64. Suresh B and Ravishankar GA (2004) Phytoremediation—A novel and promising approach for environmental clean-up. *Crit. Rev. Biotechnol*. 24(2-3), 97-124.
65. Trapp S and Karlson U (2001) Aspects of phytoremediation of organic pollutants. *J. Soils Sediments*. 1-7.
66. Vavrek MC, Colgan M and Campbell WJ (2001) The role of plant-fungal interactions in remediation of oak-hickory pine systems. Technical report series. pp:1-15.
67. Vwioko DE and Fashemi DS (2005) Growth response of *Ricinus communis* L (Castor Oil) in spent lubricating oil polluted soil. *J. Appl. Sci. Environ. Manage*. 9(2), 73-79.
68. Wang XC and Zhao HM (2007) Uptake and biodegradation of polycyclic aromatic hydrocarbons by marine seaweed, *J. Coastal Res*. Special Issue 50.
69. Weyens N, Lelie D, Taghavi S and Vangronsveld J (2009) Phytoremediation: Plant-endophyte partnerships take the Challenge. *Curr. Opin. Biotechnol.* 20, 248-254.
70. Wilste CC, Rooney WL, Chen Z, Schwab AP and Banks MK (1998) Greenhouse evaluation of agronomic and crude oil phytoremediation potential among alfalfa genotypes. *J. Environ. Qual*. 27, 169-173.
71. Wolf DC, Thompson OA, Mattice JD and Thoma GA (2007) Influence of nitrogen addition and plant root parameters on phytoremediation of pyrene-contaminated soil. *Water Air Soil Pollut*. 189(1-4), 37-47.