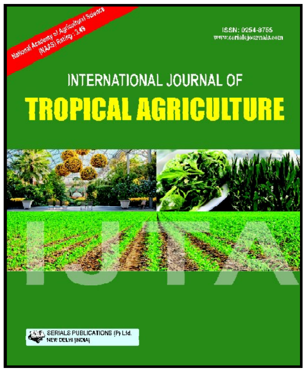

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Phytoremediation of Xenobiotics using Arbuscular Mycorrhiza from Contaminated Soil

Awadhesh Kumar Shukla*

Department of Botany, K. S. Saket P.G. College (Dr RMLU), Ayodhya-224123, Uttar Pradesh, India
**E-mail: awadhkshukla@gmail.com*

Abstract: Phytoremediation is accepted as one of the most promising and cost effective approach for the removal of pollutants from contaminated soils. Arbuscular mycorrhizal fungi (AMF) are often present in association with the roots of approximately 90 % of higher vascular plants. AMF is considered as better microorganism for enhancing the phytoremediation process. It possesses intermingled hyphae that create wide area network and made connection in between plant roots and soil rhizospheric microorganisms. This article is focused on the role and significance of AMF in phytoremediation of hydrocarbon contaminated sites and metabolite formation during bioremediation of organic compounds. Furthermore the factor affecting the bioremediation process is also summarized.

INTRODUCTION

Organic soil and heavy metal pollution have become a global concern due to rampant industrialization, sewage, oil spills accidents and oil processing etc. is the leading contributors of hydrocarbon in the environment (Khade and Adholeya, 2007; Gan *et al.,* 2009; Małachowska-Jutsz *et al.,* 2011; Rajtor and Piotrowska-Seget, 2016). Contamination by xenobiotics poses huge threats to the soil quality, crop plants, food chain and ultimately creates health hazards to the human beings. Hence, remediation of soil is warranted in order to protect the environment from deterioration and improve yields of the crop plants for food quality that met the demand of increasing human population.

Till dates, there are various conventional physico-chemicals techniques have been developed and applied for the remediation of hydrocarbons. Conventional remediation methods are usually highly efficient, however, they are costly and having potential to alter the soil structure, decrease the soil microbial activity and consequently leads to the depletion of the nutrients essential for plant growth and yield (Khan *et al*., 2000; Gan *et al*., 2009). In recent past the researchers are paying their attention on the utilization of biological means for detoxification of the contaminated environment. The most promising biological method proposed for clean-up of contaminated environment is phytoremediation. This technology involves the plants and their associated microorganisms for removal of toxic organic compounds from the environmental components contaminated with it. It has been established that phytoremediation is one of the most cost effective, eco-friendly and promising technology for the removal of pollutants from the soils (Gao *et al*., 2011). Effective degradation of pollutants in the soil is achieved due to the plant-stimulated microbial degradation in the rhizosphere (Joner *et al*., 2001). It has been demonstrated that involvement of the catabolic potential of both, microorganisms and plants is the most effective approaches for decontamination of pollutants from the environmental components like soil. The earlier researchers have also pointed out that the surface area adjoining the root, soil contact and microbial activity of rhizosphere are the major drawback in the phytoremediation process. However, these limitations are theoretically overcome by the mycorrhizal associations with the plants.

Arbuscular mycorrhizal fungi (AMF) show symbiotic association with higher plants which is an integral part of terrestrial ecosystems. It is reported that the exploitation of mycorrhizal fungi offers a potential advantage in bioremediation and phytoremediaiton due to that they get the direct supply of carbon source from their host in order to support growth into contaminated environment (Finlay, 2008). AMF hyphae have potential to create a extensive underground network of mycelium that are directly connected through plant roots, soil and adjoining microflora (Parniske, 2008; van der Heijden and Horton, 2009). It is established that the surface area created by fungal hyphae is approximately 100 fold greater the area covered by the root system while, the length can be several orders of magnitude larger than that of the plant root, and hence the fungal hyphae occupy larger area of soil than plant roots (Khan *et al*., 2000). Such an extensive network of fungal mycelium helps to release nutrients and organic contaminants from soil particles thus facilitates nutrients and water uptake by plants (Leyval *et al*., 2002; Rabie, 2005).

Khan *et al*. (2000) and Liao *et al*. (2003) have suggested through their studies that AM have shown positive effects on potential stabilization of plant and ability to detoxify the hydrocarbons in the contaminated soils. This article highlights the diversity of arbuscular mycorrhiza and their potential exploitation in phytoremediation of organic and inorganic pollutants from the contaminated soils.

MECHANISMS OF BIODEGRADATION AND METABOLITE FORMATION

Monika Rajtor and Zofia Piotrowska-Seget (2016) have described the application of AMF may improve the phytoremediation efficacy via plant growth, enhance the biodegradative activity of roots and rhizospheric microorganisms and also promotes the adsorption and bioaccumulation of hydrocarbons by roots. Further they suggested that dissolved organic carbon (DOC) released by the AMF hyphae stimulates the development and increase the enzymatic activity of hydrocarbon-degrading microorganisms. Mycorrhizal colonization has potential to alter the root exudation pattern and enhance the enzymatic activity of oxidoreductases that directly involved in oxidative degradation of aromatic hydrocarbons. Besides this they also protect the plants against oxidative stress, elevate the lipid content, increase volume of the root system in order to create large area for absorption and consequently contribute to enhance the absorption of hydrophobic hydrocarbons.

Earlier reports of Binet *et al*. (2001) suggested the anthraquinone was identified as a metabolite of anthracene through GC-MS. They observed that the concentration of anthracene was found to be in large amount in the soil planted with ryegrass than in unplanted controls. Similarly the concentration of anthracene was significantly smaller in the mycorrhizal associated plant than nonmycorrhizal plant. Another study reported the presence of atrazine metabolites in roots of *Zea mays* grown in pots contaminated with deethylatrazine and deisopropylatrazine. Furthermore, they observed that AMF colonization enhanced the metabolization of atrazine (Huang *et al*., 2007; Lenoir *et al*., 2016). It is confirmed that in the hyphosphere and mycorhizosphere zones high enzymatic activities such as dehydrogenase, catalase, dioxygenase etc. were observed (Rabie, 2005; Corgi_e *et al*., 2006; Huang *et al*., 2009).

BIODEGRADATION OF POLYAROMATIC HYDROCARBONS AND HEAVY METAL

Hydrocarbons affect the root colonization and rhizosphere microorganisms. Phytoremediation of soils contaminated with pyrene and phenanthrene in the presence of arbuscular mycorrhiza with host plant *Medicago sativa* have been studied in detail by Gao *et al*. (2011). They experimentally proved that more than 88.1% and 98.6% of pyrene and phenanthrene were degraded after incubation for70 days at initial concentrations of 74 and 103 mg/kg, respectively. Later on Aranda *et al*. (2013) studied the effects of PAH on the mycorrhizal associated with *Dacus carota* roots. They observed the increase in dry weight of mycorrhizal roots in the absence of PAH. They determined experimentally that in the presence of phenanthrene and dibenzothiophene at concentration of 60 μM the root biomass of mycorrhiza got reduced upto 60% of initial concentration. Further increase in the concentration from 60 to 120 μM the biomass drastically decreased to 80 to 92%, respectively in the presence of phenanthrene and dibenzothiophene. Details of some studies related to mycorrhiza associated phytoremediation are summarized in Table 1.

Earlier studies reported that soils contaminated with heavy metals such as As, Cu, Cd, Pb, U and Zn can be removed using mycorrhiza (Marques *et al*., 2006; Wang *et al*., 2007; Chen *et al*., 2008 ; Chibuike, 2013). It is well established that heavy metal removal depends on the types of plant and fungal species colonizer. Earlier it is reported that mycorrhiza was effectively involved in removal of Cu from contaminated soil planted with one legume and two different native plants (Chen *et al*., 2007). Later it is established that the fungal species isolated from polluted soil having more potential for remediation of the heavy metal compared to other species introduced from a different sources. It may be due to the high adaptability of the indigenous species (Orlowska *et al*., 2012).

FACTORS AFFECTING PHYTOREMEDIATION

Microorganisms possess inherent properties for the decontamination of numerous inorganic and organic pollutants having their own metabolic machinery and potential capacity to adapt into inhospitable environments. It is well proven that the microorganisms are the best players on site remediation process. However, their efficacy depends on various factors like chemical nature and the concentration of pollutants, their ease of availability to microorganisms, and the physicochemical characterization of the environment (Fantroussi and Agathos, 2005). Basically there are two important factors that influences the rate of pollutants degradation by microorganisms are; 1) the microbes present in the habitat have potential to withstand with pollution load, nutrients requirements and environmental condition. Furthermore the abiotic factors like temperature, moisture content, pH and organic matter content, aeration, nutrient content and soil type also determine the efficiency of phytoremediation.

A biotic factor determines the metabolic activity of microorganisms. It may include inhibition of enzymatic activities and the proliferation processes of degrading microorganisms. The rate of hydrocarbon degradation is generally dependent on the concentration of the pollutants and the total number of microorganisms containing enzymes for decontamination. The development of huge amount of hyphae may also obstruct the nutrient translocation and aeration for mycorrhiza during bioremediation.

Table 1
A summary of mycorrhizal mediated phytoremediation of pollutants

No.	*Pollutants*	*Fungus*	*Inferences*	*References*
1.	Anthracene	*Glomus mosseae*, *Glomus intraradices*	Inoculation of fungal strain with jute (*Corchorus capsularis*) enhanced anthracene removal and also improved the plant growth	Cheung *et al*., 2008
2.	Phenanthrene, pyrene	*Glomus mosseae G. etunicatum*	High rate of hydrocarbon degradation were observed in the presence of inoculation with mycorrhiza	Gao *et al*., 2011
3.	Phenanthrene and pyrene	*Glomus mosseae*	High degradation rates were observed in rhizospheric zone compared to near rhizosphere and bulk soil	Wu *et al*., 2011
4.	Phenanthrene and pyrene	*Glomus mosseae* and bacterium Acinetobacter sp.	Significant removal of PAH was observed bacteria fungi and rye grass	Yu *et al*., 2011
5.	Phenanthrene, pyrene, dibenz(a,h)-anthracene	*Glomus intraradices*	Removal of hydrocarbons were found to be dominant and their accumulation was negligible	Zhou *et al*., 2013
6.	anthracene, phenanthrene and dibenzothiophene	*Rhizophagus custos*	The presence of anthracene have shown root growth of mycorrhiza while phenanthrene and dibenzothiophene inhibited the development of mycorrhizal roots	Aranda *et al*., 2013
7.	Polycyclic aromatic hydrocarbons (PAHs)	*Glomus caledoniun*	PAHs degradation was found to be highest in combination with *Glomus caledoniun*, *Festuca arundinacea* and earthworm	Lu and Lu, 2015

CONCLUSION AND FUTURE PROSPECTS

It is demonstrated that soils contaminated with pollutants possess very limited diversity of indigenous AM fungi hence, it is essential to enrich and isolate microorganisms from the contaminated environment and their potential could be exploited for decontamination of the hydrocarbons heavy metal. Emphasis should be given on the selection of plant types and indigenous AMF strain that would be better choice to enhance the phytoremediation process. Special attention should be given on the interaction between plants roots and mycorrhizal colonization so that enhance the production of enzymes responsible for the bioremediation of xenobiotic. AMF mediated phytoremediation highlights a great potential for the remediation of hydrocarbon polluted soil additionally, more comprehensive experiments are required in exhaustive way to optimize the methods and overcome its limitations. In order to fully elucidate the influence of hydrocarbons on mycorrhizal interactions, there is need to investigate the molecular characterization of microorganisms in response to hydrocarbons. However, in future more focused research is required in order to fully understand the mechanisms tracing of degradation pathway.

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