

Review

Use of mycorrhiza in soil remediation: A review

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Mycorrhiza-assisted remediation (MAR) is a sustainable method of remediation that uses natural organisms for soil remediation. It is a technique that not only ensures the removal of soil pollutants but also improves the structure of the soil and helps in plant nutrient acquisition. Thus, it helps in vegetation/revegetation of polluted soils after treatment. MAR can be used for the removal of both organic and inorganic soil pollutants. However, its efficiency may be influenced by the species and origin of the mycorrhizal fungi, the type of plants colonized, and the type and concentration of the pollutant. Various soil organisms interact with mycorrhizal fungi to improve the efficiency of MAR. However, more research is needed in order to fully understand the mechanisms of MAR.

Key words: Mycorrhiza-assisted remediation (MAR), mycorrhiza, pollutants, soil remediation, soil organisms

INTRODUCTION

Soil pollution has become a global problem due to increase in industrialization and mining activities. One major area that suffers from the impact of soil pollution is agriculture – crop production. Crops do not grow well on polluted soils because these soils contain toxic elements that hinder their growth. Soil remediation is therefore essential to not only create a healthy environment but also to increase the food demand of the ever increasing human population.

Soil remediation can be achieved via various methods. Some of these methods involve the physical excavation and transport of the polluted soil to landfills for disposal. Others involve the use of solvent extraction techniques, electrokinetic separation, chemical oxidation, soil stabilization/solidification and bioremediation (Bento et al., 2005; Gong et al., 2005; Collins et al., 2009; Roach et al., 2009). Each method has its own advantages and disadvantages and the choice of any method would depend on the type of pollutant to be remediated, the proposed use of the polluted site, available time and finance.

Mycorrhiza-assisted remediation (MAR) is an aspect of bioremediation that can be used for the treatment of both organic and inorganic pollutants. It has received much

attention in recent years because it enhances the establishment/re-establishment of vegetation on the remediated soil and can equally be achieved at a reasonable cost even though it is relatively time consuming. This paper discusses the different mechanisms employed by mycorrhizal fungi for the treatment of both organic and inorganic soil pollutants. Interactions between mycorrhiza and other soil organisms were highlighted. Recommendations on the best approach to MAR were made after examination of various case studies.

PROPERTIES OF POLLUTED SOILS

Soil properties are adversely affected by the presence of toxic elements. For instance, soils with high concentrations of heavy metals such as Cd, Pb and Zn show a decline in microbial biomass and nitrogen fixation (Fliessbach et al., 1994; Giller et al., 1998). However, the rate at which the soil is affected by these metals will depend on the soil's pH, temperature, organic matter, clay mineral and inorganic ion content (Bååth, 1989; Giller et al., 1998).

Organic pollutants affect soil properties in diverse ways. The hydrophobic nature of most organic pollutants influences soil physical properties such as water holding capacity (WHC) and hydraulic conductivity (HC). Trofimov and Rozanova (2003) reported a reduction in WHC and HC of soils polluted with petroleum hydrocarbon. On the other hand, increases in structural stability of hydrocarbon polluted soils have also been documented (McGill et al., 1981). Due to the structural composition of organic pollutants, the soils they come in contact with gain a high amount of organic carbon; this increases the activities of the microorganisms not affected by these pollutants (Tiquia et al., 2002; Trofimov and Rosanova, 2003; Robertson et al., 2007). However, continued growth of these organisms lead to depletion of soil nutrients which eventually results in poor plant growth (Xu and Johnson, 1997).

SOIL REMEDIATION TECHNIQUES

Polluted soils can be treated on-site (*in situ* remediation) or they can be transported to another location for treatment (*ex situ* remediation) or disposal. The method adopted would depend on the proposed use of the site, the type of pollutants involved and the available resources. Soil remediation can be achieved by the physical excavation and transport of the polluted soil to landfills. Apart from the risk of pollutant dispersal during transport of polluted soils, this method is also time consuming and expensive (Bellandi, 1995). Scarcity of landfills also makes this method undesirable. Capping of the polluted soil with a surface layer that supports vegetation is another physical method of soil remediation. However, this method is temporal and most times complete soil remediation is not achieved (Smith and Hayward, 1993; Bellandi, 1995).

A more common method of soil remediation is the use of chemicals. This method has received much attention because it can be used for the treatment of soils polluted with organic and inorganic pollutants. It also achieves remediation within a relatively short time. However, chemical remediation is a rather expensive method of soil remediation and some chemicals may interfere with the soil's ability to support plant growth. Chemicals that have been used for soil remediation include oxidants such as ozone, KMnO_4 , H_2O_2 and Fenton's reagent (Masten and Davies, 1997; Ferrarese et al., 2008). Chemical soil stabilizers such as lime and apatite have also been used for the remediation of polluted soils (Collins et al., 2009; Venäläinen, 2011).

Solvent extraction technique is a physical/chemical method that can be used for the removal of organic soil pollutants. It involves washing the soil with water and organic solvents. Solvents such as surfactants, cyclodextrins and vegetable oil have been used for the removal of pollutants via this method (Li and Chen, 2002; Gong et al., 2005; Viglianti et al., 2006). Electrokinetic

separation is another physical/chemical method of soil remediation that can be used for both organic and inorganic pollutants when minimum disturbance of the surface soil is required (Wang et al., 2007). Thermal techniques such as soil incineration (*ex situ* treatment) and conductive heating (*in situ* treatment) can also be used for the removal of volatile and semi-volatile soil pollutants (Bellandi, 1995; Baker and Heron, 2004; Gan et al., 2009).

Another common method of soil remediation is bioremediation. It involves the use of organisms (microorganisms and/or plants) for the treatment of polluted soils. It is a generally accepted form of remediation because it involves the use of natural substances rather than the introduction of artificial chemicals/materials. Thus, it eliminates the risks associated with handling chemicals. It can also be used for the remediation of soils polluted with organic and inorganic pollutants (Salunkhe et al., 1998; Li et al., 2008). It is relatively cheap compared to most types of soil remediation techniques, even though complete soil remediation can be achieved within a longer time.

Phytoremediation (bioremediation that involves the use of plants) is widely used for the remediation of soils polluted with heavy metals (Ebbs et al., 1997; Bani et al., 2007). However, it can also be used to remediate soils polluted with organic pollutants (Aprill and Sims, 1990; Chaineau et al., 2000). Plants use various mechanisms for the remediation of polluted soils. Some of these mechanisms involve the accumulation of pollutants by plant structures (phytoextraction); reduction in pollutant mobility/bioavailability (phytostabilization); release of pollutants/metabolites into the atmosphere (phytovolatilization) and degradation of pollutants (phytodegradation and rhizodegradation). Whichever mechanism is employed, complete remediation of polluted soils via phytoremediation takes a considerable amount of time to be accomplished (McCutcheon and Schnoor, 2003).

MYCORRHIZA-ASSISTED REMEDIATION (MAR)

MAR is an aspect of bioremediation that uses mycorrhiza for the treatment of polluted soils. Mycorrhiza is the symbiotic association between fungi and the roots of vascular plants. The plant supplies the fungi with carbohydrate, while the fungi - known as mycorrhizal fungi - extends the surface area of the plant's roots and thus increases their ability to absorb more nutrients (especially phosphorus) and water from the soil. Mycorrhiza increases the plant's ability to resist diseases (Harrier and Watson, 2004). It also provides a stable soil for plant growth via production of glomalin - a substance that binds soil aggregates (Wright et al., 2007).

Mycorrhizal fungi are also able to detoxify toxic substances; hence they have been used for the remediation of both organic and inorganic pollutants in

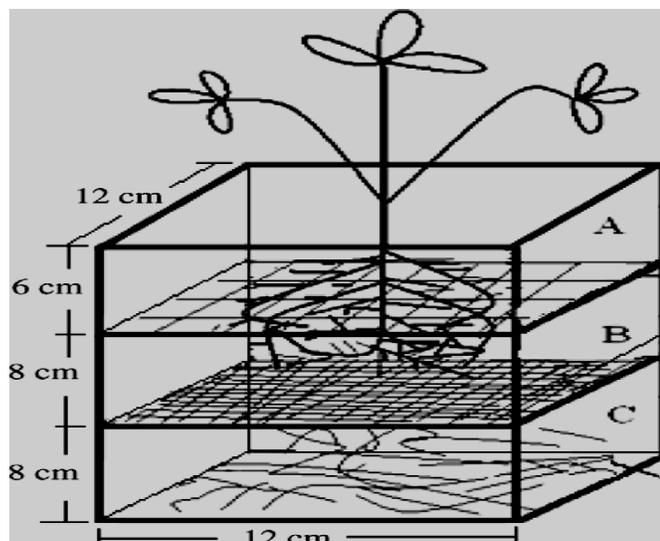


Figure 1. Area covered by mycorrhizal fungi hyphae. This figure shows how mycorrhizal fungi increase the surface area of plant roots and thus help in remediation. The ordinary plant root did not go farther than compartment B; however the fungi hyphae extended into compartment C (Adapted from Gao et al., 2010).

soils. Remediation of polluted soils can be done by the two common types of mycorrhizae – ectomycorrhiza (ECM) and arbuscular mycorrhiza (AM). However, AM is used in most remediation exercises because it colonizes almost all types of plants unlike ECM that colonizes mostly woody species.

Mycorrhiza cannot exist without a plant; therefore MAR can be described as a modified form of phytoremediation that exploits the benefits derived from mycorrhizal fungi. It uses some of the techniques of phytoremediation such as phytoextraction and phytostabilization. However, it is different from phytoremediation because remediation can be achieved at a faster rate since the area covered by plant roots - through the fungi hyphae - in MAR is larger than the area covered in phytoremediation (Gao et al., 2010) (Figure 1).

Rufyikiri et al. (2004) observed that MAR reduced the translocation of pollutants from the roots to the shoots of plants. Thus, MAR increases the secondary value of plants used for phytoremediation (especially phytoextraction) because the plants that would normally be harvested and incinerated could be used to check erosion on the remediated soil. Furthermore, as the fungi spores remain in the soil for up to six years (Nguyen et al., 2012), they easily colonize and support the growth of any crop planted on the soil after remediation. Thus, MAR ensures the rapid vegetation of remediated soils.

REMEDICATION OF INORGANIC POLLUTANTS IN SOILS

Mycorrhizal fungi occur naturally in roots of plants

growing on heavy metal polluted soils (Turnau, 1998). Thus, they have been used for the remediation of these soils; though in most cases, the fungi are inoculated in order to speed up the remediation process. The basic mechanisms of MAR employed in the remediation of inorganic pollutants are phytoextraction and phytostabilization (Table 1).

Studies have shown that soils polluted with various heavy metals including As, Cu, Cd, Pb, U and Zn can be remediated via MAR (Chen et al., 2005; Janouskova et al., 2006; Marques et al., 2006; Trotta et al., 2006; Wang et al., 2007; Chen et al., 2008). The ability of MAR to effectively remove heavy metals depends on the plant species the fungi colonizes. Chen et al. (2007) reported that the effect of MAR was significant when a legume (*Trifolium repens*) and two native plants (*Coreopsis drummondii* and *Pteris vittata*) were planted on a soil with high Cu concentration. On the other hand, using turf grass (*Lolium perenne*) did not produce significant results. Thus, it can be deduced that some phytoremediation plants have greater tolerance to heavy metals than others and would thus produce better results when used in MAR. The origin of the mycorrhizal fungi also determines the amount of heavy metal removed from a soil. Orłowska et al. (2012) found that fungi species isolated from polluted soil are able to accomplish more remediation than others introduced from a different source; this is mainly due to the high adaptability of the indigenous species.

Soils polluted with multiple heavy metals can be treated via MAR (Liao et al., 2003; Vogel-Mikus et al., 2005; Chen et al., 2006). This is achieved through phytoextraction with appropriate plant species. Vogel-Mikus et al. (2005) used MAR with *Thlaspi praecox* (Brassicaceae) for treatment of a soil polluted with Zn, Cd and Pb. It is widely known that most plants in the Brassicaceae family do not form mycorrhizal associations (Marschner, 1995). Some researchers have argued that their exudates may even be toxic to the mycorrhizal fungi (Cardoso and Kuyper, 2006). Thus, the work of Vogel-Mikus et al. (2005) indicates that there may be more species of the mycorrhizal fungi - which are yet to be discovered - that may have the ability to colonize these group of plants. MAR can also be used for the treatment of soils polluted with radionuclides such as ^{137}Cs and ^{90}Sr through phytoextraction as demonstrated by Entry et al. (1999); though the feasibility of this method under field conditions is yet to be determined.

There are conflicting reports about the use of MAR. Joner and Leyval (1997) observed that uptake of Cd by *Trifolium subterraneum* was not significantly influenced by the mycorrhizal status of the plant. Similarly, Diaz et al. (1996) reported that at lower concentrations of Pb and Zn, plants inoculated with *Glomus mosseae* and *Glomus macrocarpus* accumulated an equal or greater amount of these metals compared to the control. However, at higher concentrations of these metals, the control accumulated

Table 1. MAR of inorganic pollutants in soils.

Pollutant	Mechanism	Reference
As	Phytoextraction, Phytostabilization	Trotta et al., 2006; Dong et al., 2008; Leung et al., 2010; Orłowska et al., 2012
Cd	Phytostabilization	Janouskova et al., 2006
Cu	Phytostabilization	Cheng et al., 2007; Wang et al., 2007
Pb	Phytostabilization	Chen et al., 2005
U	Phytostabilization	Chen et al., 2008
Zn	Phytoextraction	Marques et al., 2006
As and U	Phytoextraction	Chen et al., 2006
¹³⁷ Cs and ⁹⁰ Sr	Phytoextraction	Entry et al., 1999
Cu and Cd	Phytoextraction	Liao et al., 2003
Zn, Cd and Pb	Phytoextraction	Vogel-Mikus et al., 2005

Table 2. MAR of organic pollutants in soils.

Pollutant	Mechanism	Reference
Atrazine	Phytoextraction and Biodegradation	Huang et al., 2007
DDT	Phytoextraction and Biodegradation	Wu et al., 2008
<i>p, p'</i> -DDE	Phytoextraction	White et al., 2006
Fluorene and Phenanthrene	Phytostabilization and Biodegradation	Gao et al., 2010
Phenanthrene and Pyrene	Phytostabilization and Biodegradation	Gao et al., 2011
Anthracene, Chrysene, Dibenz(a,h)anthracene	Biodegradation	Joner et al., 2001
Anthracene, Phenanthrene, Fluoranthene, Chrysene, Benzo[a]anthracene, Benzo[k]fluoranthene, Dibenz[a,h]anthracene, Benzo[g,h,i]perylene	Phytoextraction and Biodegradation	Binet et al., 2000

more of these metals than plants inoculated with *G. mosseae*, but this was not so for the *G. macrocarpus* plants which accumulated similar or higher amounts of metal compared to the control. Some other researchers have shown that heavy metals can inhibit mycorrhizal activities (Chao and Wang, 1990; Del Val et al., 1999). The above experiments indicate that MAR of soils polluted with heavy metals may be influenced by the concentration of the metal and the species of the mycorrhizal fungi used for remediation. Thus, when using MAR, appropriate fungi species should be selected. Determining the tolerable limits of the fungi species before they are used for MAR will also ensure that good results are produced. Addition of a layer of non-contaminated soil to the polluted soil before use of MAR may reduce the concentration of these pollutants and thus enhance MAR. Studies have shown that combining MAR with other methods of remediation such as addition of soil amendments like phosphate rock and organic materials enhances the remediation of soils polluted with heavy metals (Leung et al., 2010; Alguacil et al., 2011).

REMEDICATION OF ORGANIC POLLUTANTS IN SOILS

The mechanisms involved in MAR of soils polluted with

organic pollutants are similar to that of inorganic pollutants except that for most organic pollutants e.g. polycyclic aromatic hydrocarbons (PAHs), remediation is also accomplished through biodegradation (Binet et al., 2000; Gao et al., 2011) (Table 2). Mycorrhizal fungi favour the activities of some soil microorganisms (Harrier and Watson, 2004). Thus, the amount of pollutants remediated via MAR is increased due to activities of these microorganisms.

The rate of pollutant removal by MAR may be influenced by the structure of the organic pollutant. Pollutants with high molecular weight and hence low water solubility are degraded (or are taken up by plants) at a slower rate than those with lower molecular weight. This is evident in the work of Gao et al. (2010) where the remediation of fluorene and phenanthrene with AM were compared. The authors observed that due to the lower molecular weight of fluorene, its translocation by the fungal hyphae was greater than that of phenanthrene; thus fluorene was easily removed from the soil.

Soils polluted with organic pollutants can also be remediated through the other mechanisms of MAR – phytostabilization and phytoextraction (White et al., 2006; Gao et al., 2010). However, phytostabilization is mostly used on soils with low concentrations of pollutants. MAR of organic pollutants can be accomplished through the

combination of two mechanisms (Table 2). Reductions in the rate of organic pollutant translocation from the root to the shoot of plants used in MAR have been recorded (Huang et al., 2007; Wu et al., 2008).

MAR does not always support the removal of organic pollutants from soil. Genney et al. (2004) and Joner et al. (2006) attributed this negative result to the mineral nutrient status of the polluted soil. They argued that the absence of nutrients (especially N and P) hinders the activities of the fungi and thus their ability to assist in remediation is adversely affected. Based on above finding, one may be tempted to add fertilizers in order to aid the remediation process. However, this should be done with caution as excess P hinders mycorrhizal fungi activities (Smith and Read, 2008). It is better to add organic materials since they release these nutrients at a slower rate than the mineral fertilizers. The above researchers (Genney et al., 2004; Joner et al., 2006) used ECM for the remediation of soils polluted with recalcitrant organic pollutants such as chrysene, anthracene and fluorene. Other researchers have used ECM for the remediation of soils polluted with easily biodegradable pollutants such as 3-chlorobenzoic acid and effective remediation was accomplished (Heinonsalo et al., 2000; Dittmann et al., 2002). Thus, this further accentuates the fact that the efficiency of MAR depends on the type of pollutant and the fungi species. AM fungi adapt in a wide variety of soils and have achieved the expected results in various remediation studies (Joner et al., 2001; Joner and Leyval., 2003; Huang et al., 2007). Therefore, various species of AM fungi could be employed for the remediation of soils polluted with organic pollutants to ensure effective clean-up of the polluted soils. Combining MAR with other remediation methods such as introduction of other microorganisms or surfactants that facilitate biodegradation would also aid in the removal of organic pollutants (Alarcón et al., 2008; Wu et al., 2008; Yu et al., 2011; Xiao et al., 2012).

INTERACTION BETWEEN MYCORRHIZA AND OTHER SOIL ORGANISMS: EFFECTS ON SOIL REMEDIATION

Mycorrhizal fungi interact with some other beneficial soil organisms in order to achieve complete clean-up of polluted soils. These organisms include earthworms, and various species of bacteria and fungi (Table 3).

Earthworms

Earthworms are important soil organisms that contribute to the maintenance of soil properties. They are known to survive in soils with high concentrations of heavy metals because they are able to accumulate these metals into their tissues (Morgan et al., 1989). They have the ability to increase metal availability in soil (Cheng and Wong,

2002) and thus, they have been used to improve the efficiency of phytoremediation (Ma et al., 2002).

Interaction between earthworm and mycorrhiza results in rapid remediation of heavy metal contaminated soils. Yu et al. (2005) reported a rapid colonization rate of rye grass by mycorrhizal fungi as a result of earthworm activities. This interaction significantly increased the amount of Cd removed from the soil. The authors linked this result to the production of phytohormones by earthworms which may have stimulated mycorrhizal infection. Earthworms also contribute to the effective dispersal of the fungi propagules through their feeding habits. Gange (1993) showed that earthworm casts contain more than ten times the number of infective mycorrhizal propagule in surrounding soils. On the other hand, earthworms may also contribute to the disconnection of mycorrhizal fungi from plant root as they feed and burrow through the soil (Ma et al., 2006). The combined effect of earthworm and mycorrhiza on soil remediation is complex; the mechanism involved in this relationship is not fully understood. However, Lebron et al. (1998) argue that the relationship depends on the plant species the fungi colonizes.

Microorganisms

Most microorganisms used for the remediation of organic pollutants have the ability to biodegrade these pollutants; hence, when they are used together with mycorrhiza, remediation is faster and more efficient. Both the filamentous fungus, *Cunninghamella echinulata* and the bacterium, *Sphingomonas paucimobilis* have been used in conjunction with AM for the remediation of a soil polluted with petroleum hydrocarbon (Alarcón et al., 2008). The authors reported that the combined use of these microorganisms resulted in the highest amount of pollutant degradation compared to when the microorganisms were not used simultaneously. Another soil bacterium capable of remediating polluted soils is *Bacillus subtilis*. It does this by producing biosurfactants which are capable of enhancing biodegradation of organic pollutants (Cameotra and Bollag, 2003; Xiao et al., 2012). *Bacillus subtilis* also enhances mycorrhization of plant roots by increasing the growth of the fungi hyphae. Thus, when both microbes are used for remediation, greater amounts of the pollutant are removed at a faster rate than with ordinary MAR (Xiao et al., 2012).

Acinetobacter is known for its ability to biodegrade PAHs (Kanaly and Harayama, 2000). Miya and Firestone (2001) reported that biodegradation of PAH by *Acinetobacter* can be stimulated by root exudates. Therefore, since mycorrhizal fungi ensure the production of more root exudates - through extended root growth, combining both organisms would enhance the removal of PAH from polluted soils. Yu et al. (2011) reported that more PAH was removed from a polluted soil through the

Table 3. Soil remediation via interaction between mycorrhiza and other soil organisms.

Organism	Pollutant	Mechanism	Reference
<i>Acinetobacter sp.</i>	Phenanthrene and Pyrene	Biodegradation and Phytoextraction	Yu et al., 2011
<i>Bacillus subtilis</i>	Phenanthrene	Biodegradation and Phytoextraction	Xiao et al., 2012
Earthworm	Cd	Phytoextraction	Yu et al., 2005
Earthworm and <i>Rhizobium</i>	Pb/Zn mine tailings	Phytostabilization	Ma et al., 2006
<i>Fusarium concolor</i> and <i>Trichoderma koningii</i>	Cd and Pb	Phytoextraction	Arriagada et al., 2004, 2005, 2007
<i>Sphingomonas paucimobilis</i> and <i>Cunninghamella echinulata</i>	Crude oil	Biodegradation	Alarcón et al., 2008

combined use of *Acinetobacter* and mycorrhiza.

A number of saprobes have the ability to biodegrade soil pollutants; thus they have been used in several remediation studies (Wainwright, 1992; Arriagada et al., 2004; Madrid et al., 2005). *Fusarium sp.* and *Trichoderma sp.* are two saprobes that have been used in conjunction with MAR for the remediation of soils polluted with heavy metals (Arriagada et al., 2004, 2005, 2007). These studies show that the combined effect of these fungi in MAR resulted in the removal of larger amounts of pollutants compared to when they were not combined. The interaction between these fungi species is not well understood. However, the amount of pollutant removed depends on the species of saprobe and mycorrhizal fungi used for remediation (Arriagada et al., 2007).

Due to the extensive root system of leguminous plants, they have been used in many phytoremediation studies (Palmroth et al., 2002; Smith et al., 2006). Therefore, *Rhizobium*, the nitrogen fixing bacterium in the root nodules of legumes can be found in most soils remediated with legumes. *Rhizobium* improves the growth of mycelia in mycorrhizal fungi, while the fungi supplies phosphorus that aids nitrogen fixation (Ma et al., 2006). Therefore, this symbiotic association between these organisms indirectly enhances the remediation of polluted soils.

Advantages of MAR

1. MAR enhances the vegetation/revegetation of a soil after clean-up. This is basically because of the other benefits (that is, increased nutrient and water uptake, disease resistance and soil stabilization) derived from mycorrhizal fungi.
2. It is achieved through a natural process and thus is perceived to be environmentally friendly.
3. Remediation is carried out *in situ*, thus eliminating the risks involved in transporting polluted soils to other locations for treatment.
4. It is used for the remediation of a wide range of pollutants (both organic and inorganic).
5. It achieves complete soil remediation, since the fungal

spores can remain in the soil for a long time. Thus, they colonize any introduced plant and continue the remediation process.

6. It is assumed to be relatively cheaper and easier to accomplish compared to other methods of soil remediation (such as chemical and thermal remediation), since it does not require sophisticated technologies.

7. It can be safely combined with other remediation techniques to achieve the desired results. For instance, MAR can be combined with chemical remediation whereby the chemicals are used to achieve faster remediation while MAR helps to restore the soil properties for better crop establishment.

Disadvantages of MAR

1. It is a relatively slow method of remediation. It may take months for complete soil remediation to be accomplished.
2. Some species of mycorrhizal fungi are pollutant-specific. Thus, the wrong species may be used for a particular pollutant and the desired results may not be obtained.
3. Its efficiency depends on the type of plant used. Some plants do not form mycorrhizal association; hence, remediation may not be accomplished when these plants are used.

RESEARCH NEEDS

1. MAR has been used to remove several soil pollutants. However, in few other cases, effective soil remediation was not achieved (Joner et al., 2006). The reason for these negative results is not well understood. It has been attributed to the nutrient status of the soil. However, more research is needed in order to arrive at a definite conclusion so as to enhance the efficiency of MAR.
2. Most MAR have focused on the use of AM fungi. Some other researchers who used ECM did not achieve the expected result (Joner et al., 2006). More research is therefore needed in order to discover other species of ECM fungi that can be used for soil remediation because

this group of fungi colonize tree species that control erosion; thus, they indirectly reduce further soil degradation.

3. MAR has been improved by interactions between the fungi and other soil organisms. There are millions of other soil organisms whose interaction with mycorrhizal fungi has not been explored. There is need to focus research in this area so that MAR would be achieved at a faster rate.

4. Studies on the use of MAR for the treatment of soils polluted with both organic and inorganic pollutants are rare in literature. Therefore, both laboratory and field trials should be conducted to ascertain the efficiency of MAR for this type of soil pollution. Incorporating various species of mycorrhizal fungi may be one way of achieving this.

CONCLUSION

The benefits derived from mycorrhizal fungi make MAR a suitable method for the clean-up of soils whose intended use is crop production. MAR effectively detoxifies both organic and inorganic pollutants. However, the efficiency of this method of remediation depends on the species and origin of the fungi used, the type of plant colonized, and the type and concentration of the pollutants. Combining MAR with other methods of remediation help improve its efficiency. However, more research is needed in order to harness the benefits of this method of soil remediation.

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