

Mycorrhizae: hidden gold beneath the soil

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Abstract

Mycorrhiza are symbiotic associations that forms between the roots of most plant species and fungi. Mycorrhizal fungi are involved with a wide variety of other activities that benefit plant establishment and growth. Mycorrhiza as a factor of soil quality, can perhaps be viewed to be important for three main mechanisms: influences on plant physiology, soil ecological interactions, and soil engineering. Mycorrhizae also plays important role in phytoremediation of polluted lands. Inoculation of host plants with indigenous AMF may play an important role in plant protection from metal toxicity by binding metals and consequently restricting their translocation to the shoots, therefore contributing to successful phytostabilization. In addition, the recently discovered mycorrhizal colonization of hyperaccumulating plants may represent a potentially important biotechnological tool for phytoextraction, another branch of modern phytotechnologies. Thus, Symbiosis of mycorrhiza offers important benefits for Plants, soil, humans and environment and is important at the individual plant level, in community ecology, and in influencing processes at the ecosystem scale, respectively.

Keywords: Mycorrhizae, AMF, Phytoremediation, Soil engineering, Plant nutrients.

1. Introduction

The roots of almost all higher plants are known to form mutualistic symbioses with fungi. These are termed mycorrhizas (fungus roots, from the Greek: mykes = mushroom or fungus and rhiza = root). Allen (1991)^[1] defined a mycorrhiza as and fungus localised in a root or root-like structure in which energy moves primarily from plant to fungus and inorganic resources move from fungus to plant. Mycorrhiza formation is required for the survival and growth of many forest tree species. In the mycorrhizal literature, the term symbiosis is often used to describe these highly interdependent mutualistic relationships where the host plant

receives mineral nutrients while the fungus obtains photosynthetically derived carbons^[13, 14]. These fungi grow either inside of a plant's roots or attach to the surface of a root. The fungi benefit from the plant's food and nutrients and in turn send their hyphae (like small roots) out into the surrounding soil to absorb nutrients and water^[40, 36]. So, mycorrhiza actually enhance a plant's ability to take up nutrients and water. Various studies has shown that Mycorrhiza are the most common association between microorganisms and higher plants. Early fossilized plants were mycorrhizal and 95% of all plant families are mycorrhizal.



Fig1: The roots of a tree colonized by mycorrhizal fungi

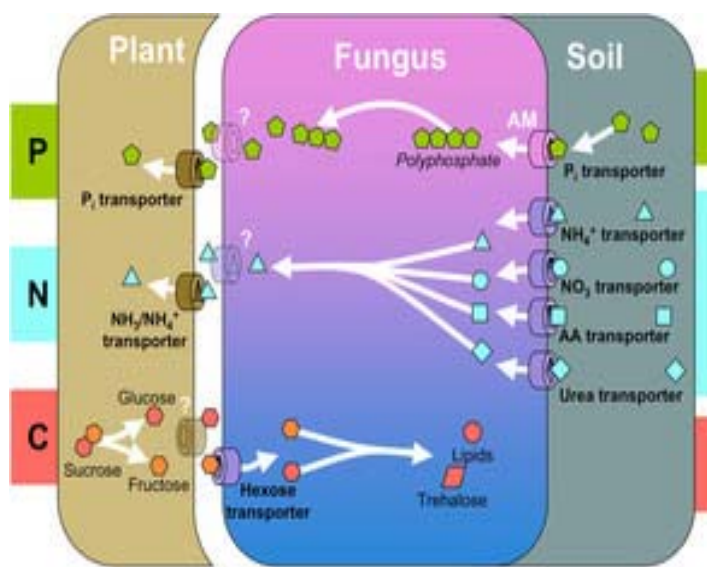


Fig 2: Exchange of nutrients between the plant and the fungus

1.1. Types of mycorrhizal association

Seven different types of mycorrhizal associations have been reported.

1. Endo-mycorrhiza
2. Ectomycorrhiza
3. Ectendo-mycorrhiza
4. Arbutoid –mycorrhiza
5. Monotropoid- mycorrhiza
6. Ericoid-mycorrhiza
7. Orchid- mycorrhiza

Table 1: Types of Mycorrhizae

Root structures	VAM	ECM	Ectendo	Arbutoid	Monotropoid	Ericoid	Orchid
Septate hyphae	- (+)	+ -	+ -	+	+	+	+
Hyphae in cells	+	- (+)	+	+	+	+	+
Hyphae coils	+ -	-	+	+	-	-	-
Arbuscules	+	-	-	-	-	-	-
Fungal sheath	-	+ (-)	+ (-)	+	+	-	-
Hartig net	-	+	+	+	+	-	-
Vesicles	+ -	-	-	-	-	-	-
Host plants	Vascular plants	Gymnosperms, Angiosperms	Gymnosperms Angiosperm	Ericales	Monotropaceae	Ericales	Orchidaceae
chlorophyll	+	+	+	+ -	-	+	+ -
Fungi	Zygo-Glomales	Most Basid-, but some Asco – and Zygo-	Most Basid-, but some Asco – and Zygo	Most Basid-, but some Asco – and Zygo	Most Basid-, but some Asco – and Zygo	Asco- (Basid-	Basid-

Notes: - = absent, + = present, (+) sometimes present, (-) = sometimes absent, + - = present or absent, Basid- = Basidiomycete, Asco- = Ascomycetes, Zygo = Zygomycetes

Among all the types Endo mycorrhiza is most abundant type. It is also called VAM (Vesicular Arbuscular mycorrhizal) or AM (Arbuscular mycorrhizal). Arbuscular mycorrhizal fungi belong to the phylum Glomeromycota^[33] and form symbiosis with about 250,000 species of plants worldwide^[36]. They propagate in soil as spores, hyphae, or colonized root fragments. During the plant-AMF symbiosis, the fungus penetrates the root cortical cell walls and forms highly branched intracellular fungal structures called arbuscules. Arbuscules are specialized hyphae formed as intercalary structures between coil hyphae. They are thought to be the main site of nutrient exchange between fungus and plant^[15]. The hyphae of AMF provide roots with increased surface to explore a greater soil volume for nutrients and water. Arbuscular mycorrhizal fungi influence plant growth in a number of ways^[20].

2. What do mycorrhiza do??

2.1 Roles for the plants:

2.1.1 Plant Nutrition

Arbuscular mycorrhizal fungi influence plant growth in a number of ways^[20]. The extraradical hyphae of AMF extend several centimetres into the soil and help the plants in uptake of mineral nutrients especially the immobile nutrients such as P, Zn and Cu^[24]. Their role in N uptake has also been demonstrated^[37, 38, 39, 11, 2]. The soil has tiny spaces in which minerals important for plant growth are found but plant roots are just too big to penetrate. Mycorrhiza are able to access these soil spaces, absorb the minerals and deliver them to the plant roots.

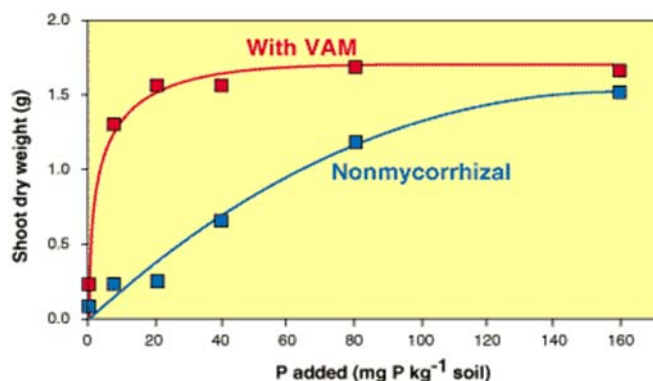


Fig 3: Response curve produced by growing mycorrhizal and nonmycorrhizal plants of the Australian native *Cassia pruinosa* at a range of soil P levels. (data from Jasper et al. 1994).

2.1.2 Plant Physiology

VAM actually change the physiology of the plant producing chemicals that the plant absorbs, or even influencing the plant's own hormones enhancing plant functions and growth^[28].

2.1.3 Drought Resistance

VAM help plants cope with droughts both directly and indirectly. Water loss is slowed by effects of the mycorrhiza on pores in plant leaves and stems through which water vapor escapes. Mycorrhiza also cause the soil to hold water better so that soil moisture is maintained longer during dry spells. The hyphae of AMF also play an important role in stabilization of

soil aggregates. The soil fungal mycelium entangles soil particles within the hyphae network and cements particles together through exudation of extracellular polysaccharide compounds such as glomalin^[31, 41].

2.1.4 Plant Protection

Plants are susceptible to bacterial invasions through their roots. When fungi combine with plant roots to form VAM, the roots are changed in a way that can help prevent soil bacteria from invading the plant. Mycorrhizal fungi protect plants against pathogen attack^[8, 16]. They enhance plant resistance to pathogens^[22] and tolerance to environmental stresses^[28]. Slezack *et al.* (2000)^[35] showed that bioprotection of *Pisum sativum* roots against *Aphanomyces euteiches* is related to mycorrhiza-related chitinolytic enzymes which appeared to depend on fully established mycorrhizal symbiosis.

2.1.5 Pollution Resistance

Various VAM have been found to alleviate toxic concentrations of heavy metals, such as zinc and copper. Some of the fungi involved in VAM associations have been found to uptake and accumulate the metals in plant roots, where the metals are tolerable, instead of the stems and leaves, which could lead to disease or death.

2.1.6 Production of special glycoprotein

Glomalin is a glycoprotein produced mainly on hyphae and spores of arbuscular mycorrhizal fungi (*Glomus*) in soil and in roots. It is a glycoprotein, a sugar-protein compound that might trigger the formation of soil^[31, 41].

Glomalin may also provide a secure vault for soil carbon. By helping to form and stabilize small soil particles called "aggregates," glomalin reduces the decomposition of the labile (unstable) organic carbon compounds within the aggregates. For this reason, the carbon within the glomalin molecule may resist decomposition for up to 100 years.

As a glycoprotein, glomalin stores carbon in the form of proteins and carbohydrates (glucose, in particular). It permeates organic substance tiding it up with sand, silt and clay particles^[4, 27]. Glomalin contains approx. 30- 40% of carbon and forms small soil clumps. This granulated material mellows the soil and binds carbon in the ground. It also increases soil air permeability and water storage. The More Glomalin, the Better Soil's Feel The higher a soil's glomalin level, the better its tilth, or feel and structure, the less its susceptibility to erosion by either wind or water, and the better it is for the growing plants.

2.2 Important roles of mycorrhizal fungi in natural and managed ecosystems

Soil hyphae are likely to have an important role in nutrient cycling by helping to prevent losses from the system, especially at times when roots are inactive^[23]. Hyphae are conduits that may transport carbon from plant roots to other soil organisms involved in nutrient cycling processes. Thus, cooperating with other members of the decomposition soil food-web. Soil hyphae may have an important role in nutrient cycling by acquiring nutrients from saprophytic fungi^[21]. Hyphae of VAM fungi are considered to contribute to soil structure. Their role in mechanical aggregation has been questioned^[7], but secretions such as glomalin may be more important^[42]. Hyphal mats produced by ECM fungi

considerably alter soil structure^[12]. Mycorrhizal fungi contribute to carbon storage in soil by altering the quality and quantity of soil organic matter^[32]. It is further suggested that the potential of phytoremediation of contaminated soil can be enhanced by inoculating hyper-accumulator plants with mycorrhizal fungi most appropriate for the contaminated site. Mycorrhizal fungi by management to increase their effectiveness in promoting plant growth. Suggest an economic analysis approach to assessing the potential benefits of this increase in effectiveness.

3. Prospects

The prospect of AM fungi existing in heavy metal-contaminated soils has important implications for phytoremediation. High concentrations of heavy metals (HM) in the soil have detrimental effects on ecosystems and are a risk to human health as they can enter the food chain via agricultural products or contaminated drinking water. Phytoremediation, a sustainable and inexpensive technology based on the removal of pollutants from the environment by plants, is becoming an increasingly important objective in plant research.

However, as phytoremediation is a slow process, improvement of efficiency and thus increased stabilization or removal of HMs from soils is an important goal. Arbuscular mycorrhizal (AM) fungi provide an attractive system to advance plant-based environmental clean-up. During symbiotic interaction the hyphal network functionally extends the root system of their hosts. Thus, plants in symbiosis with AM fungi have the potential to take up HM from an enlarged soil volume. Since HM are not biodegradable and may enter the food chain, they are a long-term threat to both the environment and human health^[19].

There are two main strategies that use plants either to bind HM in the soil (phytostabilization) or to import and store HM in the plant's above-ground tissues (phytoextraction). Arbuscular mycorrhizal (AM) fungi occur in the soil of most ecosystems, including polluted soils. By acquiring phosphate, micronutrients and water and delivering a proportion to their hosts they enhance the nutritional state of their hosts. Similarly, HM are taken up via the fungal hyphae and can be transported to the plant. Thus, in some cases mycorrhizal plants can show enhanced HM uptake and root-to-shoot transport (phytoextraction) while in other cases AM fungi contribute to HM immobilization within the soil (phytostabilization).

3.1 Roles in ecosystems

Carbon transport: The fungal/plant interface provides a conduit for the movement of carbon from the plant to the fungus, and for movement between plants linked by mycelia^[43]. It is generally believed that mycorrhizal plants direct more of their photosynthates into the soil than nonmycorrhizal plants. This extra carbon accumulates in patches and at the edge of hyphal mats^[44], and boosts the energy supply to the detrital food web, benefiting saprophytic microbes and other soil organisms^[3].

3.2 Nutrient cycling and nutrient conservation

The potential of mycorrhizal fungi to capture and deliver nutrients to their host comes from studies using inoculated eucalypts in field trials. Most of the land available for

plantation forestry have been degraded over recent centuries with Extensive loss of the A horizon caused by population pressure, inadequate management and over-harvesting. Topsoil crusting is common, contributing to enhanced erosion, reduced soil water storage, compaction and poor root development. Low soil organic matter (SOM) content (<2%) also restrains productivity.

3.3 Value to people

Sporocarps of fungi, mostly basidiomycetes, have traditionally been collected for local consumption and trade [5]. Many of these fungi, especially members of the Amanitaceae, Boletaceae, Russulaceae, and Tricholomataceae, form ectomycorrhizal associations with trees in the families Dipterocarpaceae, Fagaceae and Pinaceae and are important for maintaining ecosystem function. The highest diversity of edible fungi is collected from mixed forests. Forest fungi are also valued for medicine, for their aesthetics, as bio-indicators of environmental quality and for bio-remediation. Epigeous and hypogeous sporocarps of ECM and VAM fungi are important food sources for placental and marsupial mammals [25, 18, 30, 26, 6]. Mycorrhizal roots and fungus fruit bodies are important as food sources and habitats for invertebrates [9, 29]. Mycorrhizal fungus hyphae are an important food source for soil invertebrates [34, 17].

4. Conclusion

Mycorrhiza are very important association to plants, animals, soil, ecosystem and for humans also. So far more than 170 species of AM fungi have been recorded and described (<http://invam.caf.wvu.edu/>) and many more still awaits discovery. In spite of such importance limited researches have been conducted in the field of discovery and proper application. Its wide spread application has intrigued many researchers these days. Much more researches should be conducted for exploiting the benefits of mycorrhiza. Its role in soil stabilization is catching pace in the countries like Nepal. Nepal is very prone to soil erosion and is susceptible to sediment disasters mainly caused by slope failure, land slides, debris and bank erosion. There is an urgent need to control erosion and prevent potential sediment disaster in Nepal. Therefore mycorrhizae are essential for the establishment of tree seedlings and for their good growth and development in soils in low nutrients. In Nepal systematic application of mycorrhiza in drought effected and eroded land site can prosper the Agriculture and also prevents soil erosion with lots of benefits in global scale. Studying and realizing the importance of mycorrhiza in various fields, they can be considered as hidden gold inside the soil and open treasure ready to be mined and explored for the future benefits.

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