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BENEFICIAL ASPECTS OF ARBUSCULAR MYCORRHIZAL FUNGI

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ABSTRACT
Substantial metal contamination of soil is a huge ecological issue and has its negative effect on human health and agriculture. Rhizosphere, as a vital interface of soil and plant, assumes a critical part in phytoremediation of defiled soil by heavy metals, in which, microbial populaces are known to influence substantial heavy metal versatility and accessibility to the plant through arrival of chelating operators, fermentation, phosphate solubilization and redox changes, and consequently, can possibly improve phytoremediation processed. The comibined association of mycorrhizal fungi and Rhizobium, with legume plants, as a symbiotic association, increased the beneficial aspects comparatively more than their single associations with the host plants. This review focuses on all beneficial aspects of AM fungi, regarding plant growth.

KEYWORDS: AM fungi, rhizobium, glomus messae, phytoremediation, symbiosis.

REVIEW OF LITERATURE
Arbuscular mycorrhizal fungi are ubiquitous in soil habitats and form beneficial symbiosis with more than 80 per cent of the vascular flowering plants. The AM fungi are obligate symbiotic, relies on carbon provided by the plant and in return, it improves the mineral nutrition of the plant, especially uptake of phosphorus and to some extent nitrogen. Also, AM fungi play a significant role in suppression of soil–borne plant pathogens, tolerance to drought stress and heavy metal pollution, production of plant growth hormones and mobilization of carbohydrates from one plant to another. Furthermore, AM fungi are able to bind soil into semi – stable aggregates and hence improving the soil structure.

The terminology of vesicular arbuscular mycorrhiza has been changed to arbuscular mycorrhiza, since the members of the family Gigasporaceae do not form vesicles (Morton and Benny, 1990). Approximately 160 fungal taxa of the order *Glomales* (Glomeromycota) have been described on the basis of their spore morphology (Schubler *et al.*, 2001). However, recent molecular analysis indicates that the actual number of AM taxa may be much higher (Daniell *et al.*, 2001; Vandenkoornhuyse *et al.*, 2002).

Occurrence of AM Fungi
Ever since the description at the endophyte from populus *Rhizophagus poulinus* (Dangeard, 1900), reports are accumulating on the occurrence of AM fungi in the plant system. The occurrence of AM fungi has been reported in over 90 per cent of the plant species and in most soils (Schenick and Perez, 1987). Also, AM fungi have been found to associate with bryophytes (Mukerji et al., 1986), pteridophytes (Nishida, 1956; Hepden, 1960; Girija and Nair, 1988) and Gymnosperms (Muthukumar and Udaiyan, 1998). They also occur in the gametophytes of some mosses, lycopods and psilotales which are all rootless (Mosse *et al*., 1973; Pocock and Duckett, 1984). They have also been found in aquatic plants (Beck-Nielsen and Medsen, 2001), marshes and temperate grasslands (Evans et al., 1990).

The association of AM fungi has been reported in several cultivated crops such as *Glycine max, Eleusine coracana, Zea mays, Pennisetum purpureum, Pennisetum typhoides, Vigna sinensis, and Capsicum annum* (Godse *et al*., 1976), *Pennisetum pedicillatum* (Ammani *et al*., 1986), *Sorghum biclor* (Mukerji et.,1986), Sugarcane (Ammani *et al.*, 1986), *Eletaria cardamomum, Piper betle*, and *Piper nigrum* (Manjunath and Bagyaraj, 1982), *Amorphophallus*, *Colacasia esculenta* and *Solanum melangena* (Bhaskaran et.,al 1996).

In addition, the AM fungi are known to associate with fruit crops like apple (Mosse, 1957) and mango (Sukhado, 1990). The occurrence of AM fungi has been reported in ornamental plants like *Impatiens balasamia* (Dwivedi *et al.*, 2003) and medicinal plants (Mukerji et al, 1984; Barthakur and Bardoli, 1990). Sukhado, (1987) have reported six AM fungl species from rhizosphere soils of maritime strand plants of point calimare, among the six, spore types of *Glomus fasciculatum*, *Glomus macrocarpum* and S*clerocystis rubriformis* were the most abundant. (Sengupta and

Chauduri, 1990) reported that dominate members of mangrove plant community were all arbuscular mycorrhizal plants.

Colonization of AM fungi

Arbuscular Mycorrhizal (AM) fungi in soil exist as thick walled chylamydospores or as vegetative propagules in roots. Spore germination may be induced either by root exudates containing primary phenolic compounds such as flavonoids and isoflavonoids (Schreiner, 1997) or organic acids produced by mycorrhization-helper bacteria (Garbaye, 1994). After germination, the germ tube grows towards the root. The right signals coming from the roots of host plants promote a differential morphogenesis consisting of profuse hyphal branching (Gianinazzi Vand Gianinazzi, 1995). Immediately after contacting their hosts, fungi form appresoria indicating that some kind of recognition occurs at this stage (Giovannetti and Mosse, 1980). From the appresoria, a hypha penetrates in to the root cortex, where inter-intracellular proliferation of mycelium takes place (Gianinazzi-Pearson et al., 1994). The intercellular hyphae branched in to the parenchymatous host cells as intracellular miniature tree like structures called arbuscules. During the arbuscules development, the plant plasma membrane is not branched but grows so that the invading hyphae and all their branches remain surrounded by it (Smith, 1987). The arbuscule formation increases the metabolic activity of the host cell due to the bidirectional transfer of metabolites and minerals between the plant cells and the AM fungal symbiont (Smith, 1990). Arbuscules are ephemeral structures that live for 4-15 days, after which they begin to senesce (Mason et al., 1992). After the arbuscule formation, AM fungi form inter and intracellular hyphal swellings called vesicles. These structures contain lipids and serve as the reserve food material for the fungus. After the establishment of the fungus in the root, hyphae grow out of the root and in the rhizosphere soil. Extra radical hyphae of the AM fungi play a key role in nutrient acquisition from the soil and for the transport of nutrients to the roots. Reproductive structures of the AM fungi (Chlamydospores) are formed within 6-8 weeks after the colonization, depending on the species.

Uptake of Nutrients and Plant growth

The arbuscular mycorrhizal fungi stimulate the uptake of nutrients by plants especially immobile elements such as P, Zn, and Cu and hence enhancing the plant growth and biomass. The beneficial effect of mycorrhizae on plant growth is mediated by the uptake of nutrients especially phosphorus (Bolan, 1991). Further, the mycorrhizal fungi are known to enhance the mobiliztion of nutrients and play a significant role in tree seedling growth (Muthukumar and Udaiyan, 1998). In addition, AM fungi also enhance the mobilization of other nutrients such as Zn, Cu, S, Mg, Ca and K (Gildon and Tinker, 1983; Faber *et al*., 1990) Also, mycorrhizal fungi are found to improve the uptake of N from nitrogenous fertilizers from soil and transporting it to the host plant (Ames *et al.*, 1984;). Further, its absorption and transport increased the biomass production in soils with low K, Ca and Mg (Liu *et al.,* 2002).

The AM association is known to improve the plant growth through uptake of nutrients in crop plants such as wheat (Azocn and Ocampo, 1981), *Pennisetum americanum* (Krishna Bagyaraj, 1982), barley (Black and Tinker (1979), chickpea (Satyaprasad, 1982). *Capsicum annum* (Suresh, 2000), groundnut (Champawat, R.S. 1988), soybean (Schenck *et al.,* 1989), maize (Gerdemann, 1964), and Sorghum (Raju *et al*., 1990).

Similar AM – induced plant growth has been reported in plants like citrus (Antones and Cardou, 1990), onion (Manjunath and Bagyaraj, 1981; Ojala *et al*., 1983), lavender and bell pepper , tomato (Azcon *et al.*, 1986; Pond *et al*., 1984), Potato (Porter *et al*., 1987a; 1987b), papaya, *Acorus calomus*, and *Talinum indicum* (Mahesh and Selvaraj, 2008).

Heavy-Metal Tolerance

Since heavy metal up take and tolerance depend on both the plant and soil factors including soil microbes, AM colonization of roots results in an increase in root surface area for nutrient acquisition. The extra material fungal hyphae can extend several cm in to the soil and uptake large amounts of nutrients, including heavy metals, to the host root. Mycorrhiza has been reported in plants from heavy metal contaminated sites (Shetty *et al.,* 1995). They evolved a heavy metal tolerance and play vital role in the phytoremediation. have shown that AM fungal infected` in prairie grasses in iron ore.

Several heavy metals tolerant AM fungal spores distributed in heavy metal polluted soil. *Glomus mosseae* has been isolated from high concentrations of Cd in the rhizosphere soil (Weissensenhorn *et al*., 1995). Sambandan *et al*., (1992) have reported that fifteen AM fungal species from heavy metal contaminated soils from India, among the fifteen, spore type *Glomus geosporum* was the most abundant in all the sites. Griffioen et al., (1994) have shown that the community of AM fungi in rhizosphere of *Fragaria vesca* in Zn-contaminated soil. Seventy percent of the root samples were found to be colonized by *G. mosseae*. Similarily, Griffioen *et al.,* (1994) have shown that the another unique AM fungal species, *Scutellospora dipurpurascens* from the rhizosphere of *Agrostis capillaris* in Zn contaminates soils of Netherlands. Selvaraj *et al*., (2005) have reported fifteen AM fungal species from industrial polluted soil; among the fifteen *Glomus fasciculatum* was the most predominant in the tested plants.

External mycelium of AM fungi spreads beyond the root exploration and provides access to greater volume of heavy metals present in the rhizosphere. The absorption and accumulation of Cu in the extradical mycelium of

Glomus spp (Gonzalez-Chauez *et al.*, 2002). A greater volume of metals also stored in the mycelial roots and in the spores (Chen *et al.*, 2001).

The accumulation of heavy metals in the fungal structures is considered to be the biological barrier in the transport of heavy metals to the host plants. Reduced Cd translocation from roots to shoots in the presence of *Trifolium subterraneum* is a clear cut evidence for this view. Similarly, retention of Zn in the roots of AM plants has been reported in several instances (Chen *et al*., 2001; 2003; Zhu *et al*., 2001). However, under Zn limitation mobilization of Zn and transfer to the shoot in improved by the AM symbiosis reflecting the role of Zn as a micronutrient.

The endomycorrhizae form special structures namely vesicles and arbuscules in the host plant. The vesicles are oval (or) round and attached to the internal hyphae in terminal position. They contain oil and are believed to function as storage organs. Arbuscules are born on side branches of distributive hyphae which run parallel to the root axis. The internal hyphae are connected to the entry points by zigzagging or coiling hyphae. The entry points extend form the appressoria. The appressoria connect the infection inside the root and the external mycelium which travels along the root surface forming more infection points and also extends into the surrounding soil. In the soil it forms large resting spores and secondary spores.

In metallophyte plants *Viola calaminaria* is the most tolerated plant whose roots are associated with *Glomus sp* colonization. Also, four different *Glomus sp* were found in the *V. calaminaria* rhizosphere has been reported by Hilde Brandt *et al.*, (2001).

Weissenhorn *et al.*, (1995) have reported that the AM fungi tolerated and colonize at high Cd (1220 mg kg^{-1}) and Pb (895 mg kg^{-1}) concentrations. High mycorrhizal colonization (90%) in *Plantago lanceolata* in calamine soil mounds rich in Cd, Pb and Zn of Southern Poland. Turnav *et al*., (1996) revealed that the higher mycorrhizal colonization in *oxalis acetosellg* acidic forest soil low pH and high Cd, Zn and Pb. Del val *et al*., (1999) have shown that the AM fungal diversity in a long term experiment amended with sewage – sludge containing heavy metals such as Zn, Cu, Cd, Ni and Pb. The total number of AM fungal spores decreased with long term sludge application and with increasing amounts of heavy metals, but the AM fungal spores never disappeared completely in the soils amended with the highest rates of sludge. *Glomus claroideum* has been reported that the potentially adapted to increased metal concentration in the soil. This fungi produced a significant root colonization level (20% in *Allium porrum* and 15% in *Sorghom bicolor*) in the growth in the heavy metal contaminated soil Leyval *et al.*, (1995) have studied that the spores from naturally polluted soils to germinate better in heavy metal polluted soil compared to spores from non-polluted soils. They germinated in soils contains 6060 $mgkg^{-1}$ Pb, 24, 410$mgkg^{-1}$ Zn and 1630 $mgkg^{-1}$Cu.

Heavy Metal Detoxification Mechanism

In general, arbuscular mycorrhizal (AM) fungi occur in the soil of most ecosystems, including polluted soils. The fungi play significant role in nutrient uptake and heavy metals are taken up via the fungal hyphae and can be transported to the plant. In some cases mycorrhizal plants can shows enhanced heavy metal uptake and root – shoot – transport (phytoextraction) while in other cases arbuscular mycorrhizae fungi contribute to heavy metal immobilization within the soil (phytostabilization). The mycorrhizal colonization on clean-up contaminated soil depends on the plant – fungus – heavy metal combination and is influenced by soil conditions. The significance of arbuscular mycorrhizal fungi in soil remedition has been recognized.

The AM fungi contribute to the immobilization of heavy metal in the soil beyond the plant rhizosphere and thereby improve phytostabilization. The fungus employs strategies similar to those of its host. Among theseareimmobilization of metals by compound secreted by the fungus, precipitation inpolyphosphate granules in the soil, adsorption to fungal cell walls, and chelation of metals inside the fungus (Gaur and Adholeya, 2004).
Glomalin is an insoluble glycoprotein that is produced and released by AM fungi and binds heavy metals in the soil (Gonzalez-Chavez *et al*., 2004; Wright and Upadhyaya, 1996; 1998). The fungal strains secretes significant quantity of glomalin should be more suitable for biostabilization efforts. Furthermore, Glomalin attaches to soil help stabilize aggregates and the fungi do great work for the survival of plants at heavy metal polluted soils.

Disease suppression

The AM fungi are known to reduce soil – borne diseases caused by fungal pathogens such as *Phytopthora*, *Apanomyces*, *Fusarium and Verticillium* (Azeon – Aguilor and Barea, 1996). Carnon *et. al.*, (1998) observed a reduction in *Fusarium* population in the soil surrounding mycorrhizal tomato. Also, AM fungi have been found to protect the plants from root pathogen like *Phytopthora parasitica* and nematodes (Dodd, 2000). Pozo *et al*., (2002) have reported that *G.mosseae* is found induce local and systemic resistance to *Phytopthora parasitica* and hence reduce the symptoms produced by the pathogen.

Evidences have shown that mycorrhizal fungi are capable of protecting plants against bacterial pathogens like *Erwinia caratovora* and *Pseudomonas syringae* (Garcia-Garrido and Occampo, 1989). In contrast, AM colonization did not protect roots of wheat from damage by root pathogens. Similar non-protective role of *G.mosseae* against *Aphanomyces euteichus* has also been reported.

Drought stress

Drought stress is considered to be one of the most important factors limiting plant growth and yield in many areas. However, inoculation of AM fungi can protect the plants against the detrimental effects of drought stress and improve the productivity of crop plants. Colonization of roots by AM fungi affords host plants greater resistance to drought by several mechanisms. One of the mechanisms for drought tolerance is the improved uptake of nutrients. Subramanian and Charest (1997) have shown that AM colonization improved the uptake of N, P, K, Mg, Mn in to the grains of maize than non- mycorrhizal plants under drought conditions. Also, these authors found early emergence of tasseled and silks in mycorrhizal plants than non-mycorrhizal plants under drought conditions. In addition, improved stomatal conductance and leaf water potential (Auge, 2001), extensive hyphal systems for absorbing and conducting water and soluble ions over along distances (Elias and Safir 1987; Auge *et al.*, 2001), changes in plant hormones (Allen *et al.*, 1982;), cell wall elasticity (Auge *et al*., 1989;) enhanced activity of antioxidant enzymes (Ruiz-Lozano *et al.*, 1995) and improved water potential, transpiration and photosynthesis, have been associated with AM colonization in plants under drought conditions.

Mycorrhizal colonization with *Gigaspora margarita* was found to inhibit biosynthesis in plants by blocking the 1-aminocyclopropane-1 carboxylic acid (ACC) conversion to ethylene. Studies on metabolic changes in maize under drought have revealed that AM plants had higher total sugars, reducing sugars and protein content in leaves, but not the chlorophyll content, as compared to non-mycorrhizal plants (Subramanian and Charest, 1997).

Other biochemical changes

Allen *et al.*, (1980) reported an increase cytokinin and chlorophyll content of plants associated with AM fungi. Also, considerable differences between mycorrhizal and non- mycorrhizal plants were found in total carbohydrates (Krishna et al 1985), amino acids (Necme and Meridith, 1981; Selvaraj 1998), lipids (Cooper and Tinker, 1978), phenolics (Krishna et al, 1981), and plant hormones (Allen *et al.*, 1982; Danneberg *et al.*, 1992).

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