Bioefficacy and Characterization Effect of *Arbuscular mycorrhizae* Fungi on Defence Response Diseases and Soil Sickness In Crop Plants (Review)

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**Abstract:** *Arbuscular mycorrhizal* fungi (AMF) are multipurpose organisms with complex ecological ramifications in the soil system that has been difficult to study and understand. The most common group of mycorrhizal fungi are the arbuscular mycorrhizal fungi (AMF) which colonise the roots of over 80% of land plant families but they cannot be cultured, as yet, away from the host plant. AMF are primarily responsible for nutrient transfer from soil to plant but have other roles such as soil aggregation, protection of plant against drought stress and soil pathogens and increasing plant diversity. This is achieved by the growth of their fungal mycelium within a host root and out into the soil beyond. There is an urgent need to study the below-ground microbiology of soils in agro- and natural ecosystems as AMF are pivotal in closing nutrient cycles and have a proven multi-functional role in soil-plant interactions. More information is also needed on the biodiversity and functional diversity of these microbes and their interactions with crops and plants. The phytocentric concept of AMF that has prevailed since the naming of these organisms is being replaced by a holistic vision recognizing that AMF are a key element of soil functioning and health rather than a plant root component. Recent advances in knowledge brought about by new techniques for soil microbiology research open the way to AMF management in crop production. Arbuscular mycorrhizal fungi may influence crop development, even in phosphorus-rich soils. However, growing crops in soil with lower fertility would optimize the expression of the multiple beneficial effects of AMF in agro-ecosystem and reduce nutrient seepage to the environment. The consideration of the soil mycorrhizal potential within the framework of soil testing and fertilization recommendations, the development of improved inoculants and signal molecules to manipulate AMF and the development of cultivars with improved symbiotic qualities would insure the production of good crop yields while improving agroecosystems’ sustainability.

**Key words:** *Arbuscular mycorrhizal* Fungi · Bio-Control · Field Crop Production · Agriculture · Soil Health · Beneficial Effect

**INTRODUCTION**

The crop is being affected by various diseases caused by bacteria, fungi and viruses. Among these, fungal diseases contribute heavy loss in yield and diseases such as blight, stalk and ear rot and smut have been reported with localized yield losses of about 11-50% (Nankam 1991; Ngoko 1994; Cardwell et al. 1997). *Arbuscular mycorrhiza* (AM) is a group of obligate fungi that lives in a symbiotic relationship with the roots of most agricultural crops (Smith and Read, 1997; Giovannetti et al., 2006; Javaid, 2007; Javaid et al., 2007; Avaid and Riaz, 2008). These fungi form essential components of sustainable soil-plant systems and improve crop growth and productivity (Van Der Heijden et al., 1998; Schreiner et al., 2003; Kapoor et al., 2004; Cavagnaro et al., 2006).

Arbuscular mycorrhizal fungi play a key role in natural ecosystems and influence plant productivity, plant nutrition and plant resistance (Demir and Akkopru 2007).

Biological control preserves environmental quality by a reduction in applying chemical inputs and is characteristic of sustainable management practices (Altieri 1994, Barea and Jeffries 1995). AMF have potential...
to reduce disease caused by fungal pathogens i.e., *Phytophthora, Sclerotinia, Rhizoctonia, Pythium, Verticillium* and *Aphanomyces* (Azcon-Aguilar and Barea 1996, Demir and Akkopru 2007 and Aysan and Demir 2009).

Effective management strategies have not been developed so far as the disease is considered to be more complex in nature. Biological control could be the best alternative and may be helpful, especially against soil borne pathogens (Hajieghrari et al. 2008). It is evident from several studies that arbuscular mycorrhizal (AM) fungi associations have been shown to reduce damage caused by soil-borne plant pathogens (Aguilar and Barea 1996).

*Glomus fasiculatum* and *Gigaspora margarita* decrease root rot diseases caused by *Fusarium oxysporum* in Asparagus (Matsubara et al. 2001), *Glomus clarum* was able to reduce the root necrosis caused by *Rhizoctonia solani* in cow pea (Abdel-Fattah and Shabana 2002) and *Glomus mossae* was shown to systemically reduce disease infection caused by *Gaeumannomyces graminis* in Barley (Khaosaad et al. 2007). Therefore, in the present study an effort was made to evaluate the effect of three AM fungi (*Glomus fasiculatum* (GF), *Glomus mossae* (GM) and *Acaulispora laevis* (AL) on the management of black bundle disease caused by *C. acremonium* in poly house condition.

Establishing of the same crops in long term at the same site can cause a problem known as replant disease (Utkhede 2006). Soilborne plant pathogen control by fumigation, chemical pesticide and soil solarization is intensively investigated.

They benefit their host plants by improving nutrient uptake like phosphorus (P), nitrogen (N) and micronutrients (Barea et al., 1991; Clark and Zeto, 2000; Ward et al., 2001; Javaid, 2009). AM fungi also provide their host plants with protection against environmental abiotic stresses (Augé, 2001; Javaid, 2007; Azcón et al., 2009) as well as, biotic stress (Khaosaad et al., 2007). The benefits of artificially inoculating a wide variety of agronomic plant species with AM fungi have been documented in numerous studies.

According to Artursson et al. (2006), VAM can increase growth and phosphorus content of many crops. On the other hand, VAM significantly decreased disease incidence and severity compared to Rhizoctonia-infected plants. This could be due to the direct antagonistic effect of VAM on the pathogen and/or the improvement of the growth conditions of the host plant. Generally, application of VAM improved the plant growth by its direct effect on improving the internal status of the crop or indirectly by reducing the harmful effect of the pathogen.

Inoculation with arbuscular mycorrhizal (AM) fungi decreases disease incidence caused by *Fusarium* sp. In asparagus (Wacker et al., 1990), tomato (*Lycopersicon esculentum* Mill.) (Caron et al., 1986; Datnoff et al., 1995) and potato (*Solanum tuberosum* L.) (Niemira et al., 1996).

Datnoff et al. (1995) found that both *T. harzianum* and AM fungal inoculums reduced crown and root rot disease (determined by percent of plants having necrosis of the stem and root) caused by *F. oxysporum* f. sp. *radicis-lycopersici* in tomatoes.

Sivan and Chet (1986) found that application of *T. Harzianum* with AM fungi reduced disease caused by *Fusarium* sp. in cotton, wheat and muskmelon.

Nowadays, their application as a biofertilizer in crop production is recommended with the aim of increasing productivity and reducing fertilizer use (Schwartz et al., 2006). Benefits, however, are not guaranteed and the factors that determine the efficiency of this fungal association are still unclear. Some of these factors were suggested to be AM and plant species, competition with other soil micro-organisms as well as, the nutrient status of the soil (Sylvia et al., 2005).

However, research is needed to develop cultural and biological control methods to induce resistance of host plant. The use of AMF to protect crops from soilborne disease eventually inducing healthy growth of plants with high yields at lower cost and minimum risk to humans and environment is a promising strategy.

The Function of AMF: There are four broad groups of soil microorganisms: soil animals, prokaryotes, fungal saprotrophs and endophytes. Animals are involved in predation and comminution of soil organic matter. Prokaryotes are a very diverse and versatile group. They are responsible for much of the oxido-reduction reactions taking place in the soil and are also largely involved in soil organic matter mineralization, along with fungal saprotrophs. In contrast to these later groups, AMF are biotrophic endophytes that do not use soil organic matter as a source of carbon and energy but, rather, depend on a host plant for their supply. In return, AMF stimulate plant growth, improve the physical quality of their soil environment and protect them against soil-borne pathogens. Arbuscular mycorrhizal fungi form extensive hyphal networks in the top soil layer onto which most plants of an ecosystem are connected (Read and Birch 1988).
As much as 30 m of AMF hyphae can be found per gram of soil (Leake et al. 2004). In nature, AMF networks are involved in the distribution of nutrients in the top layer of the soil and among plants within a community (Marschner and Dell 1994; George et al. 1995; He et al. 2003; Neumann and George 2004; Simard and Durall 2004) and influence plant community structure (Hartnett and Wilson 1999; Stampe and Daehler 2003; Urcelay and Diaz 2003).

The nature of AMF networks has been well described recently (Giovannetti et al. 2004; de la Providencia et al. 2005). These networks are involved in the distribution of photosynthesis-derived carbon in soil (Staddon et al. 2003a; Zhu and Miller 2003). Arbuscular mycorrhizal hyphae, which may account for 3-20% of root weight (Smith and Read 1997).

Thus, considerable amounts of carbon are distributed in the soil via AMF networks, potentially influencing soil microorganisms (Marschner et al. 2001; Soderberg et al. 2002; Marschner and Baumann 2003) and the accumulation of soil carbon (Rillig et al. 2001; Lovelock et al. 2004). Our understanding of the soil systems has improved and it has become clear that AMF are multipurpose key components of soil functioning and sustainability (Leake et al. 2004).

Plants, AMF and the soil matrix are essential parts of the soil system and all these components must be considered to understand the soil systems. Harris and Paul (1987) estimated that 40-50% of photosynthesis-derived carbon is channelled to AMF; more conservative values of 10-20% were reported by Jakobsen et al. (2002). Although the carbon cost of AMF to plants varies with the organisms involved and the environmental conditions, it is certainly an appreciable drain on a host plant. The carbon cost related to AMF maintenance is offset by the positive effects AMF have on plant growth and soil quality. This beneficial impact of AMF is well documented (Smith and Read 1997).

The AMF effect on plant growth promotion is most often attributed to improved uptake of water and nutrients, in particular P, which has low mobility in soil (Bieleski 1973) and which is required in large amount by plants. Better nutrition, improved water relations and increased carbon sink size have been proposed to explain the high photosynthetic activity of AMF colonized plants, of which the symbiotic condition would oscillate between mutualistic and parasitic, depending on nutrient availability (Bethlenfalvay et al. 1987). Although they are most often beneficial, AMF have reduced plant productivity in nutrient-rich agricultural soils (Ryan and Graham 2002; Stewart et al. 2005).

Arbuscular mycorrhizal fungi are associated with, but clearly distinct from plants and appear as the backbone of soil ecosystems rather than as a plant part of foreign origin. Evidence for the key role of AMF in soil systems comes from the revelation of the very ancient origin of AMF. Fossil records indicate that the Glomites, which existed 400 million years ago, were very similar to modern AMF and experts believe that the association of plant and AMF may have helped land colonization by plants (Pirozinsky and Dalpé 1992; Taylor et al. 1995; Schussler et al. 2001).

The fact that AMF have remained largely unchanged throughout the co-evolution of plants and soil, testifies to their importance to soil functioning and quality. The soil is an integrated and complex evolutive system with physical and biological components (Crawford et al. 2005). Since evolution proceeds through the replacement of less performant systems with performant ones, AMF, which have persisted through time, appear as a performant multipurpose component in soil ecosystems. As exposed by Barea et al. (2002), AMF help plants produce more biomass with lower levels of soil available nutrients and at the same time are photosynthesis-driven soil quality builders.

AMF are involved in the maintenance of soil quality (Barea et al. 2002). The physical soil entrapping effect and contribution to soil organic matter of AMF hyphae directly influence soil aggregation and structural stability (Jastrow et al. 1998; Wright and Anderson 2000). Arbuscular mycorrhizal mycelium and spores produce a cell surface glycoprotein, glomalin, which improves soil physical quality (Rillig 2004). Glomalin was found to be closely related to stable soil aggregate formation (Wright and Upadhyaya 1998), except in high carbonate soils where soil aggregate stability depends on carbonates rather than on soil organic materials (Franzluебbers et al. 2000).

Glomalin and its degradation products appear to be recalcitrant to decomposition in soil, where they accumulate, as determined by their long-lasting detection with a monoclonal antibody. Glomalin is often (Franzluебbers et al. 2000) but not always related to soil organic matter (Rillig et al. 2001). It appears, however, that glomalin is an important source of organic matter in soil. These fungi form abundant mycelial networks, have a fast turnover rate and the glomalin they produce seems to by-pass the microbial processing imposed on fresh organic matter, thus contributing directly to the stable soil organic matter pool. The Bradford-reactive soil-protein (BRSP) pool extracted from tropical soils was shown to have a minimum residence time of 6 to 42 yr, according to
carbon dating and the abundance of immunoreactive glomalin has seemingly reached 3-10 mg cm\(^{-2}\) in their A and O horizons (Rillig et al. 2001).

All this suggests that glomalin-related soil proteins’ contribution to the stable soil organic matter pool is important. Thus, AMF hyphal networks possess the ability to modify the physical quality of plant habitats through their important contribution to soil organic matter build-up and stabilization of soil aggregates. Extra radical AMF hyphae also influence the soil biological environment and, hence, may influence soil biochemical processes and the incidence of disease outbreaks. Arbuscular mycorrhizal fungi-soil microbial interactions are complex and cannot be generalized. The zone of soil immediately surrounding AMF hyphae, the hyphosphere, hosts selected rhizosphere bacteria (Vancura et al. 1990).

These bacteria may require amino acid and growth factors provided by AMF and their populations may fluctuate as AMF hyphae turnover throughout the soil volume. The AMF impact on the overall microbial community has varied. AMF were also shown to have little effect (Olsson et al. 1996) or negative impact (Christensen and Jakobsen 1993) on the number and activity of total soil bacteria. Marschner and Baumann (2003) observed a significant effect of AMF on the structure of the soil bacterial community.

Numerous researchers report AMF-related changes in the quality of the soil microbial community (Marschner and Baumann 2003) and variation in the size of specific microbial populations (Green et al. 1999), but no general trend for an AMF effect on soil microorganisms emerges, most likely due to the complexity and wide biodiversity of the soil environment.

The AMF cytoplasm may also host bacterial endophytes, in particular plant growth promoting rhizobacteria (PGPR) (Ruiz-Lozano and Bonfante 2000; Minerdi et al. 2002; Bianciotto et al. 2004). The role of the endophytes living within AMF spores and hyphae still needs to be clarified, but some evidence suggests that they could be involved in nutrient exchange between the partners of this consequently tri-partite symbiosis (Minerdi et al. 2002) and stimulate AMF spore germination (Bianciotto et al. 2004).

Important advances are being made in the field of AMF ecology with molecular tools such as polymerase chain reaction (PCR) (Kowalchuk et al. 2002; Vandenkoonhuysse et al. 2003; Gollotte et al. 2004; Hunt et al. 2004); and fatty acid methyl ester (FAME) (Olsson et al. 1999; Balser et al. 2005; Nilsson et al. 2005) based techniques that now allow us to track these fungi in plants and soils. AMF ecology has recently become an active field of research, which should provide important knowledge for the management of AMF in agricultural fields.

The “Mycorrhizal Effects”: AMF influence crop production in commercial farms although it is not always recognized, this influence being confounded with that of other soil factors. The creation of non-mycorrhizal controls through the chemical destruction of native AMF (Gazey et al. 2004) or their repression using non-host crops (Vestberg et al. 2005), fallow (Abu-Zeyad et al. 1999) in rotation, or deep tillage (Drijber et al. 2000; Miller 2000) have revealed that AMF influence crop development. Considering the profound influence of AMF on many aspects of plant physiology and the complexity of the soil system, it is virtually impossible to pinpoint the mechanisms responsible for the AMF effect in any particular case. However, we know that the expression of this AMF effect in crop growth depends on three factors: environmental conditions including soil type and plant and fungal genotypes.

AMF were considered as a monolithic group of non-specific fungi. We now recognize that considerable variation in plant growth response can be triggered by different AMF isolates (Stewart et al. 2005). The symbiosis is more complex than it was first thought and there is no such thing as an all purpose AMF isolate; the effect of an AMF is plant (Hart and Klironomos 2002) and soil (Rivera et al. 2007) dependant.

Considerable interaction between the AMF and plant species isolated from a woodland site illustrated well the ability of different AMF to enhance P uptake and growth in different plant species and to colonize their roots (Helgason et al. 2002). Inoculants contain one of a few AMF strains identified as effective, in monospecific AMF inoculants. The different strains formulated are recommended for use in different soil types (Rivera et al. 2007). Thus, the mycorrhizal effects depend on the plant and AMF genotypes interaction, as well as on soil conditions.

Plant genotype is a determinant of the AMF effect in two ways. First, plant species have a specific influence on AMF development and it appears that plant species determine, to a large extent, the composition of AMF populations flourishing in a soil (Eom et al. 2000). Some AMF are even denied access in some plant species, even if they are good colonizers on other species.

(Helgason et al. 2002; Sanders 2003) and cannot reproduce. This specificity suggests that crop species in rotations may influence the quality of the AMF population in the soil of a following crop. Second, the genotype of a plant can also influence the response of this plant to specific AMF. For example, Liu et al. (2000) demonstrated the differential response of three maize hybrids to inoculation with one AMF.

Stewart et al. (2005), working with different strawberry cultivars in a P-rich field, also found large intraspecific variation in plant response to mycorrhizal inoculation, with the growth of some cultivars being largely decreased by inoculation with a given AMF inoculant, while the growth of another was largely increased. It makes no doubt that plant and AMF genotypes influence the effect of AMF on crop development in agricultural fields.

Most often, AMF effects were sought and found in plant development. It has been overlooked, but mycorrhizal effects are also related to soil quality. Plant genotype could indirectly modify soil physical quality or the risk of disease outbreak, through its effects on AMF development or population composition. Plants, AMF and soil are three interacting components of a system. In this system, plant genotype could have an important effect on soil quality both through direct and indirect modifications of the soil environment. Vegetation is an important soil-forming factor (Brady and Weil 2001).

Plants directly influence soils in their quality as the main source of metabolically active and soil organic matter C, as well as through their influence on soil water. Plants indirectly modify the soil environment, as they are the determinant of the AMF networks development and, thus, of their influence in soil.

It is well known that high soil P decreases AMF development (Linderman and Davis 2004a). This sometimes led to the conclusion that AMF cannot enhance plant growth in high P soils. However, soil fertility is not the only determinant of AMF development and effectiveness. The AMF effect depends also on the plant and AMF genotypes and AMF-related growth enhancement at high soil P levels has occurred (Singh et al. 2002).

Arbuscular mycorrhizal fungi are present in agricultural fields, even in soils under intensive management. Intensive management decreases AMF biodiversity and selects for slow colonizing-fast sporulating species, but the examination of AMF biodiversity throughout the soil profile revealed that genotypes presumably less fit in intensively managed soil were found at greater depths (50-70 cm) in a soil zone unaffected by cultural practices (Oehl et al. 2005).

Arbuscular mycorrhizal fungi at greater depths can be seen as a bank of biodiversity that can feed the top soil inhabiting population when the conditions change in surface soil, improving the adaptability of the AMF population of cultivated soils. Furthermore, poor taxonomic AMF diversity in intensively cropped systems may not be indicative of poor AMF functional biodiversity, as pointed out by Munkvold et al. (2004) who found a large intraspecific functional diversity in AMF. Thus, the management of AMF native to agricultural soils appears possible even in soil modified by a history of intensive crop management.

**Enhancing Mycorrhizal Effects in Field Crops:** It is clear that AMF effects are less prominent in soil with high or excessive P fertility. The buildup of excessive soil P fertility levels is not desirable as P loss to the environment may reduce water quality in rural areas (Beauchemin and Simard 1999) and excessively rich soils do not produce higher yields than well-managed P poor, sufficient or rich soils. The best scenario for both farmers and society is the one where the efficiency of P fertilizer applied at lower rates is enhanced by AMF.

In this way, soil P fertility would not diminish potential beneficial AMF effects other than plant P nutrition and yields would be optimized. In soils excessively rich in P, following repeated application of high rates of P fertilizers, manure or compost, manufactured signal molecules may be able to stimulate AMF development and optimize AMF contribution to crop production and soil quality. Different molecules were found to stimulate AMF development (Cruz et al. 2004; Dong and Zhao 2004).

Manufactured signal molecules stimulating AMF are currently being tested and will soon enter the market. These new biotechnological products could be advantageously integrated with known practices optimizing AMF contribution to crop productivity, such as cover cropping (Sorensen et al. 2005), crop rotation (Johnson et al. 1992) reduced tillage (Miller et al. 1995) and moderate fertilization (Miller 2000). Such tools could be also useful to enhance AMF effects in crop species less receptive to AMF and allow the expression of AMF-related benefits on soil quality and on the development of a possibly mycorrhizae-dependent subsequent crop. Current P fertilization recommendations are very imprecise.
Most soil test P used only estimate the available P in the mineral fraction of the soil and ignore P potentially available in the organic fraction of soils and the mycorrhizal potential of soils. In order to implement strategies of reduced fertilization and AMF management in agricultural soils with no undue risk of yield loss, P fertilization recommendations could be based on a soil test estimating both the amount of soil P potentially available to a crop and the soil mycorrhizal potential, which represents the potential contribution of indigenous AMF populations to the recovery of this P. A few methods have been proposed to evaluate the status of AMF populations of soils: the most probable number or MPN (Porter 1979), the mycorrhizal soil infectivity (MSI) (Plenchette et al. 1989) and the undisturbed core (Brundrett et al. 1994) methods were the most favourably considered by the scientific community.

These methods all generate estimations of the extent of the soil ability to produce mycorrhizal root colonization, but provide no information on the quality of the AMF populations. Furthermore, all these methods are bioassays involving growing trap plants for weeks, which cannot be used for routine soil testing. It may be possible to develop a convenient soil test to estimate the potential contribution of AMF to crop nutrition based on molecular methods. Theoretically, DNA analysis could produce estimates of the quality (Kowalchuk et al. 2002; de Souza et al. 2004) and amounts of AMF in a soil. Real-time PCR was used to quantify AMF (Filion et al. 2003) and PCR probes were used to enumerate AMF isolates in ecosystems (Gollotte et al. 2004). Although the analysis of phospholipids FAME extracted from soil gives no information on AMF biodiversity, it can estimate AMF abundance in soil (Nilsson et al. 2005). These analytical techniques could be used in soil-testing laboratories to improve the accuracy of soil P supply power estimates and fertilization recommendations. The results of the test would be entered into models specific to the crop to be grown, after calibration.

Fertilization using such an approach would maximize the expression of AMF benefits to soils and crops, reduce agricultural reliance on fertilizers and reduce the risk of nutrient loss to the environment. Attempts are currently being made to develop such analytical techniques. Soil mycorrhizal potential may well end up being modelled if we finally achieve development of a practical methodology to measure it and develop models; this would considerably reduce the cost of AMF monitoring. A DNA-based analysis production of crops with fertilizer levels favouring AMF development also brings AMF-related benefits in the form of reduced disease incidence, improved crop tolerance to drought and other stresses and improved soil physical quality, which translate into reduced soil erosion and improved aeration and water infiltration, providing a better environment for plant growth.

Crop production relies heavily on agrochemicals because these products are reliable and easy to use on large highly mechanized farms although they may have negative impacts on the environment. Concerns related to the environmental impacts of crop production effluents are now an incentive for the development of AMF technologies also in these countries. At the same time, scientific and technological progresses are coming to a point where it may be possible to integrate AMF management into intensive cropping systems. The adoption of crop production practices considering the management of AMF would lead the improvement of the quality of agricultural soil and crop resistance to stresses. Experts predict that global climate change will increase the frequency of extreme climatic events (Patz et al. 2005), thus increasing risks of crop failure. The temperate latitudes, which are projected to warm disproportionately, are among the potentially vulnerable regions. Stress-resistant crop plants growing in high-quality soils will certainly be an asset in the future. Arbuscular mycorrhizal fungi have a place amongst the biotechnologies of tomorrow’s agriculture.

Effect of Soil Sterilization and Fungicide Treatments on Mycorrhizal Infection: Although large number of experiments studied the effect of different sterilization methods on soil pathogenic fungi, little information were reported about their effect on useful soil fungi.

Fungicide Treatment: The effects of biocide use on non target organisms, such as VA-fungi, are of interest to agriculture, since inhibition of beneficial organisms may counteract benefits derived from pest and disease control. Most of the fungicides which have been used to study their effect on VA mycorrhizal fungi were found to be deleterious, but some were quite compatible with VA mycorrhizal fungi. Sreenivasa and Bagyaraj (1989) were studied the effect of nine fungicides on root colonization with VA mycorrhizal fungi and indicated that reduction from 10 to 20% of root infection percentages were recorded when the recommended level of fungicides were used. While some fungicides were significantly increased the percentage root colonization at half the recommended level.
In an experiment studied the effect of different fungicides on VA-fungi infection and population, it was concluded that application of fungicide to soil reduced sporulation and the root length colonized by VA-fungus, although interaction of VA-fungi and fungicide were observed to be highly variable depending on fungus fungicide combination and on environmental conditions.

**Solarization Treatment:** Soil solarization was shown to be cost reducing, compatible with other pest management tactics, readily integrated into standard production systems and a valid alternative to preplant fumigation with methyl bromide (Chellami et al., 1997). It also reported that soil solarization induced better growth response in plants even when no pathogen is present in the soil (Stapleton et al., 1986). In field experiment, it was reported that solarization of soil by covering it with transparent plastic sheets resulted in reduction or complete elimination of soil pathogens between 0 and 25 cm depth in soil covered for 30-60 days (Mansoori et al., 1996).

In other experiment it was observed that covering the soil with a clear plastic sheet resulted in complete elimination of endomycorrhizal fungi at 10 and 20 cm soil depths (Al-Mommi et al., 1988). It was also reported that root nodulation, infection by mycorrhizal fungi and yield of cowpea were higher in plants grown in solarized soil when compared to control treatment without solarization (Alloush et al., 2000). Stapleton and DeVay (1986) indicated that the beneficial response of plant growth to soil solarization might have resulted from the effects of better root nodulation, enhanced VA mycorrhizal association and the increased availability of some of the macro and micro nutrients in soil solution due to solarization.

**Methyl Bromide Treatment:** Although there was a grave environmental concern about the application of methyl bromide and it’s toxicity to mammals, it is still recommended for soil disinfection. Great reduction or complete elimination of all living organisms in the soil after methyl bromide gas fumigation of soil is well documented (Chllami et al., 1997). Soil disinfection by methyl bromide fumigation or steam is often used to eliminate soil-borne plant pathogens, but such treatments can reduce VA mycorrhizal fungi as well (Mange, 1983). Several studies have indicated that plant stunting following soil fumigation treatments may be due to elimination of VA mycorrhizae (Alten et al., 1993; Aggangan et al., 1996).

**Protection Against Toxic Methals and Pathogen:** Few investigations were made about the importance of endomycorrhizal and ectomycorrhizal fungi in protecting host plants from phytopathogens and mineral elements toxicity. Still it was indicated that ectomycorrhizal fungi protect trees from high concentrations of toxic heavy metals, because these tend to be accumulated and immobilized in the mycorrhizal sheath (Jackson et al., 1984).

**Effect of Soil Fertility on Mycorrhizal Infection:** Most authors report extensive colonization to occur mainly in plants growing in soils of low fertility (Khalil et al., 1991). Field and greenhouse studies demonstrated that crops growing in nutrient-poor soils had higher levels of mycorrhizal colonization than crops growing in better soils (Gehring et al., 1994). Vesicular-arbuscular mycorrhiza inoculation in combination with phosphorus increased dry and fresh shoot weight, leaf area and leaf number of strawberry compared to application of phosphorus alone (Khanizadeh et al., 1995).

**Effect of Soil Amendment with Organic Wastes on Mycorrhizal Colonization:** The materials we refer as organic wastes are merely those which are not put to use in our existing technological system. Once we begin to use them, they will no longer be called wastes and if they are in demand, we may even seek to increase their production. Organic wastes are really resources out of place. Farmers historically have applied animal manure and human wastes to the land, both treated and untreated, for crop production.

Animal and crop plant wastes are different in their chemical and biological composition depending on the source of the material. Kale et al., (1992) found that mycorrhizae in roots of a summer crop was 2.85% in soil previously received chemical fertilizers compared to 10% in the soil with half the recommended dosage of chemical fertilizers and organic matter (OM) amendment. Inoculation with VA-fungus did not significantly affect seed yield of pea (Pisum sativum L.) plants in soil which is rich in OM and phosphorus. On the contrary, seed yield was significantly enhanced with VA-fungi inoculation in soil which is poor in OM and phosphorus (Bethlenfalvay et al., 1994).

**Exudates and Mycorrhiza Bio-Soil Against Soil-Borne Disease:** Symbiotic interaction between plant root and microbes depends on secondary metabolites in the root exudates for beneficial association initiation and
development (Vigo et al., 2000). The pathogenic interaction depends on understanding the chemical warfare mediated by plant secretion of phytoalexins, defense protein and other unknown chemical compounds (Flores et al., 1999; Bais et al., 2004, 2003). The protective effect of mycorrhizal symbioses against root pathogenic fungi has been tested by many researchers (Caron, 1989; St-Arnaud and Vujanovic, 2007; Oger et al., 2004).

Disease decrease within plants colonized by mycorrhizal species is the result of the complex interactions between pathogens, AMF and plant (Harrier and Watson, 2004). Mycorrhizal symbiosis has been shown to lessen the damage caused by soil-borne pathogens (Azcon-Aguilar and Barea, 1996). Phytophthora parasitica proliferation was greatly considered an interesting alternative to synthetic Phytophthora parasitica products for the control of fungal diseases in plants is mycorrhizal tomato roots (Cordier et al., 2004). Mycorrhizal symbiosis has reduced conidial germination of Trichoderma harzianum, had no effect on C. michiganensis and reduced conidial germination of Fusarium oxysporum f. sp. chrysanthemi (Filion et al., 1999). The use of natural products for the control of fungal diseases in plants is considered an interesting alternative to synthetic fungicide due to their less negative impact on the environment (Brunelli, 1995).

Root exudates are considered as one of the mechanisms that explain the ability of AMF to suppress or increase the soil-borne diseases (Mukerji et al., 2002). Root exudates vary between different hosts and the composition of the exudates changes in the same plant at different conditions (Marschner, 1995; Tahat et al., 2011). The current knowledge about the importance of exudates in AM fungus-host interactions was recently developed in in vitro culture technique and in situ compartmental systems. Although it is believed that root exudates play a major role in the infection and colonization of hosts by AMF, the actual role or mode of action of exudates was elucidated only recently (Nagahashi, 2000; Smith and Read, 2008).

The germination of Fusarium oxysporum f. sp Lycopersici was inhibited in the presence of root exudates from the tomato plant (Scheffknecht et al., 2006). Root exudates can have direct defensive qualities. Pathogen-activated plant defenses can result in root secretion of antimicrobial compounds. It was shown that root-derived anti-microbial metabolites from Arabidopsis confer resistance to a variety of P. syringae pathovars (Bais et al., 2005). In another study, it was also predicted that transgenic plants that produce antimicrobial proteins can influence rhizosphere microbial communities (Glandorf et al., 1997). Sugars and amino acids in the root exudates stimulate the germination of chlamydomospores and other fungi resting spores. The hyphal length of G. mosseae was greatly affected by the exudates of mycorrhizal tomato root exudates and mycorrhizal corn root exudates. The growth of Ralstonia solanacearum was suppressed due to G. mosseae spores germination (Tahat et al., 2010b).
The effect of parasitic nematode in the rhizosphere root exudates was studied (Foster, 1986; Griffiths, 1989; Horiuch et al., 2005). Root feeding nematode could participate in the interaction with root and soil ‘S’ microorganisms (Bais et al., 2006). Most information of microbe-nematode interaction in mycorrhizosphere and rhizosphere has been derived from rhizobi, mycorrhiza and plant pathogen researches (Khan, 1993). Horiuch et al. (2005) found that Caenobabditis elegans may arrange understanding of these fungi. However, technologies are now in place for the development of the tools required for the management of AMF in crop production as well as to increase knowledge on the ecology of these fungi. With better understanding of AMF in agricultural soil and with tools to monitor and manage AMF, we will be able to optimize the contribution of AMF to agricultural production and finally move toward the management of more sustainable cropping systems, for the benefit of societies and agro-industries.

Mycorrhizal inoculation tended to increase macro-and micronutrient and increased growth of crop plants, which was comparable to NP fertilizer application. Here, the benefits obtained from indigenous AM fungi surpassed those of commercial types. Thus, use of AM fungi economizes on fertilizer use in plant production providing a sustainable and environmentally safer substitute. Further research is imperative for field appraisal of these fungi.

CONCLUSION

Mycorrhizal fungi associated with plant roots have existed for hundreds of millions of years. The role of mycorrhizal fungi in improving plant nutrition and their interactions with other soil biota have been investigated with reference to the host plant growth, but little is known about how these interactions affect soil structure. The combination of these organisms in natural, undisturbed ecosystems would seem to contribute to the successful growth and health of plants. Several factors influenced the production of root exudates such as plant type, age, light, soil microflora, soil fertilizer and soil pH. This view has attempted to characterize qualitative changes in populations of rhizobacteria associated with plants with mycorrhizae in what is called the “mycorrhizosphere”. Microbial populations in the mycorrhizosphere can change dynamically over time and are influenced by what microbes are present in the background soil or growth medium. The process of selective enrichment of specific functional groups of microbes from that medium is due to root and arbuscular mycorrhizal fungus, hyphal exudates.

The real nature of AMF and the important contribution of these fungi to soil quality maintenance and proper function are just being realized. Research on AMF has progressed slowly due largely to the biotrophic nature of AMF, which limited our ability to study and understand these fungi. However, technologies are now in place for the development of the tools required for the management of AMF in crop production as well as to increase knowledge on the ecology of these fungi. With better understanding of AMF in agricultural soil and with tools to monitor and manage AMF, we will be able to optimize the contribution of AMF to agricultural production and finally move toward the management of more sustainable cropping systems, for the benefit of societies and agro-industries.

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