Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 9 (5): 241-248, 2010
ISSN 1682-3974

Mycorrhiza and Organic Farming

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Abstract: Arbuscular Mycorrhizal Fungi (AMF) are key components of the soil microbiota that play an essential role in plant growth, plant protection and soil quality. These fungi are widespread in agriculture systems and are especially relevant for organic farming because they can act as natural fertilisers and enhance plant yield. Data on the interaction between organic practices and AMF populations are limited and inconsistent. Here, we explore the various roles that AMF play in organic farming systems with special emphasis on their contribution to crop productivity. Present results highlight that organic low-input systems have a high potential to maintain the mycorrhizas, keeping the soil fertile and productive and point the need to incorporate VAM technology in organic farming to stop deterioration of agricultural and forest land and other adverse factors.

Key words: Arbuscular mycorrhizal fungi, benefits, crop productivity, interactions, organic farming

INTRODUCTION

Mycorrhiza are the rule in nature, not the exception. In a mycorrhizal association, the fungus may colonize the roots of a host plant, either intracellularly or extracellularly. Mycorrhizae are present in 92% of plant families (80% of species) (Wang and Qiu, 2006), with endomycorrhizae or Arbuscular Mycorrhizae (AM) being the ancestral and predominant form and indeed the most prevalent symbiotic association found in all the plant kingdom. Arbuscular Mycorrhizae (AM) are formed only by fungi in the division Glomeromycota. AM fungi lives in association with approximately 85% of herbaceous plants and produce microscopic arbuscules within cells of the root. Symbiotic associations between Arbuscular Mycorrhiza (AM) fungi and plant roots are widespread in the natural environment and can prove range of benefits to the host plant.

AM fungi play an important role in plant health by improving nutrient (especially inorganic P) and water uptake by their host plant and providing protection against soil-borne pathogens (Kurle and Pfleger, 1994; Siddiqui and Mahmood, 1996; Ryan and Graham, 2002). In return, the fungi receive carbohydrates (sugars) and growth factors from the host plant. Other benefits include: increased resistance to foliar-feeding insects (Gange and West, 1994), improved drought resistance (Auge *et al*., 1994) and increased tolerance of salinity and heavy metals. Increased uptake of macronutrients other than P, including N, K and Mg has also been measured as well as increased uptake of some micronutrients maintaining soil aggregate stability. Many agricultural practices including use of fertilizers and biocides, tillage, monocultures and the growing of non-mycorrhizal crops are detrimental to AM fungus communities (Kabir *et al*., 1998; Thingstrup *et al*., 1998). As a result, agroecosystems are impoverished in AMF and may not provide the full range of benefits to the crop. In natural environments, the diversity of AM fungi is a key contributor to the diversity and productivity of plant communities (Van der Heijden *et al*., 1988). AM fungi are strongly affected by anthropogenic activities (Giovannetti and Gianinazzi-Pearson, 1994). A variety of agricultural practices are known to impact on AMF, with fertilizers, cultivation, crop monocultures and non-mycorrhizal crop plants known to reduce inoculum (Kurle and Pfleger, 1994; Helgason *et al*., 1998; Daniell *et al*., 2001).

Organic farming is the only sustainable farming system that is legally defined. It is a crop production system that avoids the use of synthetic and chemical inputs like fertilizers, pesticides, growth regulators and live stock feed additives. Indiscriminate use of synthetic chemicals and the problems arising from them forced us to think about the alternative means. To the maximum extent feasible, organic farming systems rely on the management of soil organic matter to enhance the chemical, biological and physiological properties of the soil, in order to optimize crop production. Soil management controls the supply of nutrients to crops and subsequently to live-stock and humans (Watson *et al*., 2002). Organic manures such as farmyard manure, compost, vermicompost, biofertilizers, biopesticides etc. can be used at least as complement, if not a substitute.

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Organic systems have longer-term solutions at the systems level. An example of this system is the importance of crop rotation design for nutrient cycling and conservation and weed, pest and disease control (Stockdale *et al*., 2001). Organic fertilizer sources were shown to have major positive effects on the physical properties of soil. This effect is due to the role of mycorrhiza on soil structure formation (Celik *et al*., 2004). Soil microbial communities are considered a vital factor for the functioning of agroecosystems and success in organic farming (Gosling *et al*., 2006). Organic farming systems utilize highly complex and integrated biological systems to achieve their goal and most, if not all, management practices used in this system affect more than one component of the system, for example, cultivation may be beneficial for weed control but may stimulate mineralization of nitrogen when the crop does not require it. Thus, the interaction between soil management practices and different aspects of production and environmental impact will continue to challenge the nature and development of organic farming in the nature.

INTERACTIONS

AM interaction with soil and crops: Mycorrhizal root systems increase the absorptive area of roots 10 to 1000 times thereby greatly improving the ability of the plants to utilize the soil resource. AM fungi are able to absorb and transfer all of the 15 major, macro and micro nutrients necessary for plant growth (Lester, 2009). This behaviour is particularly evident with soil nutrients that are more immobile such as P, Zn and Cu. The fungal soil network is able to maintain P transport to plant for longer periods (Hodge, 2000; Jeffries and Barrea, 1994; Lange and Vlek, 2000).

Mycorrhizal fungi release powerful chemicals into the soil that dissolve hard to capture nutrients such as P, Fe and other tightly bound soil nutrients (Lester, 2009). This extraction process is particularly important in plant nutrition. AM fungi forms an intricate web that captures and assimilates nutrients conserving the nutrient capital in soils. The same extensive network of fungal filaments important to nutrient uptake are also important in water uptake and storage.

AM interaction with agricultural practices: Crop management involves a range of practices which have impact on the AM association, both directly, by damaging or killing AMF and indirectly, by creating conditions either favourable or unfavourable to AM fungi. In general, agricultural practices have a negative impact on the AM association and agricultural soils are AMF impoverished, particularly in terms of number of species (Helgason *et al*., 1998; Menendez *et al*., 2001). For example, high levels of P fertilization have been found to slow down or inhibit mycorrhizal efficiency in soybean fields (Ezawa *et al*., 2000). Higher soil infectivity was observed under reduced or no tillage practices (Mozafar *et al*., 2000) and limited increased mycorrhizal colonization of barley root and soil infectivity (Hamel *et al*., 1996). Relative to conventional management, there is evidence that organic farming practices can enhance the amounts of AMF inoculum (Bending *et al*., 2004; Mader *et al*., 2000).

AM interaction with other soil micro-organisms: As well as interacting with disease causing agents, AM fungi also interact with a whole range of causal organisms in soils. AM fungi might provide a means of biocontrol of plant disease in organic systems (Siddiqui *et al*., 1998; Harrier and Watson, 2004; Whipps, 2004). Bacterial communities and some strains promote germination of AM fungal spores which will increase the rate and extent of root colonization (Johansson *et al*., 2004). These interactions suggest that AM might affect plant and soil microbial activity by stimulating the production of root exudates, phytoalexins and phenolic compounds (Morandi, 1996; Norman and Hooker, 2000).

ROLE OF AM COLONIZATION ON PLANT NUTRITION AND GROWTH

The relationship between the development of arbuscular mycorrhizas and increased growth of the host was recognized by Asai (1944) in his studies of AM colonization and nodulation in a large number of legumes. He concluded that colonization was important both in plant growth and in the development of nodules. The C economy of AM plants needs to be considered in the context of the effects of AM colonization on mineral nutrition and the relative costs of fungal C use, in relation to benefits derived from increased nutrient uptake.

AM plants have two potential pathways of nutrient uptake, directly from the soil or via an AM fungal symbiont. The AM pathway depends on three essential processes: uptake of the nutrients by the fungal mycelium in the soil; translocation for some distance within the hyphae to the intraradical fungal structures (hyphae, arbuscules and coils) within the roots and transfer to the plant cells across the complex interface between the symbionts. The fungal mycelium in soil can absorb nutrients beyond the zone depleted through uptake by the roots themselves, so that they increase the effectiveness with which the soil volume is exploited. Consequently, the effects of AM colonization on P nutrition are often large and may have indirect effects on other aspects of plant metabolism, so that direct effect of the symbiosis on the other nutrients are masked (Smith and Read, 2008).

AM FUNGAL CARBON METABOLISM

AM fungi are completely dependent on an organic C supply from a photosynthetic partner. Between 4 and 20% of net photosynthate is transferred to the fungus and used in production of both vegetative and reproductive structures and in respiration to support growth and maintenance, including nutrient uptake (Smith and Read, 2008).

Carbon is deployed in growth of the intra and extra radical mycelium and in respiration to support both growth and maintenance, representing a considerable increase in C flux to the soil. At this stage, there is little indications of the reasons for the variations in the estimates, but they are likely to include species of plant and fungus, fungal biomass and rate of colonization, as well as the metabolic activity of the fungus.

AM FUNGI IN ORGANIC FARMING SYSTEMS

Arbuscular Mycorrhizal Fungi (AMF) are potential contributors to plant nutrition and pathogen suppression in low input agricultural systems, although individual species of AMF vary widely in their functional attributes. Organic farming has developed from a wide number of disparate movements across the world into a more uniform group of farming systems, which operate broadly within the principles of the International Federation of Organic Agricultural Movements (Stockdale *et al*., 2001). Though the exact production methods vary considerably, general principles include the exclusion of most synthetic biocides and fertilizers, the management of soils through addition of organic materials and use of crop rotation (IFOAM, 1998). The use of readily soluble fertilizers and biocides are severely restricted in organic farming. As a result, organic systems often have lower concentrations of total and available soil P than equivalent conventional systems (Gosling and Shepherd, 2005). Biocontrol agents that may used in organic systems to control pathogenic fungi do not appear to damage the AMF association (Ravnskov *et al*., 2002; Gaur *et al*., 2004).

In organic plant production, the supply of Phosphorus is a bottle neck as P is the only macronutrient that cannot be obtained through biological fixation or weathering of parent rock minerals. Farmers thus rely upon recycling of nutrients from plant residues and manure, or addition of superphosphate to meet plant's demand for Phosphorus. The mycorrhizal fungi form hyphae in soil as the extension of the roots, transporting nutrients from the soil to the plant. Regarding organic nutrients, mycorrhiza has been shown to improve the utility of both N and P in plant material, as its wide distribution makes more frequent contact with sites where organic matter is mineralized. This scavenging of the soil is the main mechanism for plant supply of P and some other plant nutrients in agroecosystems where these are not a soluble salts (Joner, 1996).

It is widely acknowledged that AM technology can improve soil and crop productivity by allowing farmers to produce their inputs of chemical fertilizers and/or by enhancing plant survival, thus offsetting ecological and environmental concerns. Mycorrhizal fungi have particular value for legumes because of their need for an adequate phosphorus supply, not only for optimum growth but also for nodulation and nitrogen fixation (Azcon-Aguilar *et al*., 1979; Hayman, 1986).

Both improved nitrogen fixation in legumes by Rhizobium and increased uptake of phosphorus from AM fungal associations can indirectly reduce the chemical fertilizer requirement and the problems related to water and air pollution by chemicals as residuals to the soil-root zone. The reduction of fertilizer requirements by using efficient isolates of *Rhizobium* and AM fungi with different leguminous agricultural crops grown in Bangladesh is of great value (Mridha and Xu, 2001).

Some of the agronomically important trees, which have AM fungi association include citrus, tea, coffee, rubber and oil-palm where these plants are grown in nurseries, AMF inoculation may greatly facilitate establishment and early growth after transplanting to the field site. Nursery production of ornamental seedlings and cuttings by treating the rooting and growing media with appropriate inocula is another important area where VAM can be used.

DOES ORGANIC FARMING FAVOUR AM FUNGI?

Recent studies have indicated that one important contributor to plant productivity in low input systems, Arbuscular Mycorrhizal Fungi (AMF) have very low inoculums in conventional management systems (Mader *et al*., 2000). In organic farming, a package of actions is applied such as the use of crop rotation, inter and intra cropping and manuring. The soil fertility was enhanced by organic farming and the healthy crops were produced more efficiently with respect to energy and nutrient use. It was found that organically managed soil had greater AMF spore numbers and root colonization potential and therefore higher AMF inoculum potential, than conventionally managed soil (Galvez *et al*., 2001; Oehl *et al*., 2003; Ozaki *et al*., 2004; Shrestha-Vaidya *et al*., 2008), although, low input practices used in such management system do not always allow the level of biodiversity to increase, even after a long time (Franke-Snyder *et al*., 2001; Bedini *et al*., 2008). In a number of studies, organic management has been shown to stimulate AM fungi communities, with the effect attributed to reduced soil P under organic management (Ryan *et al*., 1994; Mader *et al*., 2000). This suggests that other practices such as the use of fertility building crops, a greater variety of cash crops, non-chemical weed control and non-use of fungicides may be important; all these factors are known to influence AMF populations (Kurle and Pfleger, 1994). The relative difference in AMF spore numbers between organic and conventionally managed fields increased with time since conversion. Gryndler *et al*. (2009) studied that the mycelia of AM fungi are influenced by organic matter decomposition both via compounds released during the decomposition process and also by secondary metabolites produced by micro-organisms involved in organic matter (pure cellulose and alfalfa shoot and root material) decomposition.

BENEFITS

Soil structure: Arbuscular mycorrhizae are important factors of soil quality through their effects on host plant physiology, soil ecological interactions and their contributions to maintaining soil structure (Rillig, 2004). Mycorrhizal filaments produce humic compounds and organic glues (extracellular polysaccharides) that bind soil into aggregates and improves soil porosity. Soil porosity and soil structure positively influence the growth of plants by promoting aeration, water movements into soil, root growth and distribution. In sandy or compacted soils, the ability of mycorrhizal fungi to promote soil structure may be more important than the seeking out of nutrients.

Plant growth hormones: Certain AMF spores or seeds of the fungus have been selected for their establishment and growth-enhancing abilities. Mycorrhizal inoculants can be sprinkled onto roots during transplanting, worked into sed beds, blended into potting soil, watered in via existing irrigation systems, applied as a root dip gel or probed into the root zone of existing plants. AM fungi also increase the production of plant growth hormones such as cytokinins and gibberellins.

Plant roots: AM fungi increase overall absorption capacity of roots due to morphological and physiological changes in the plant. There is increased absorption surface area, greater longevity of absorbing roots, better utilization of low-availability nutrients and better retention/storage of nutrients, thus reducing reaction with soil colloids or leaching losses. Nodulation and atmospheric nitrogen fixation capacity in legumes were also increased by AM fungi.

Crop yield: Mycorrhizal fungi improve crop yields (Siddiqui and Mahmood, 2001), especially in infertile soil (Hayman, 1982). Many crops are grown in acid soil, where their establishment is frequently limited by low availiability of phosphorus. In this case, appropriate mycorrhizal fungi can greatly improve crop yields by increasing the phosphorus uptake by plants (Howeler *et al*., 1987). When the availability in soil is low, non-mycorrhizal root systems may be unable to absorb P effectively and the plants become P deficient and grow poorly. AM colonization and P uptake lead to relief of this nutrient stress and, in consequence, plant growth is increased. This is the well-known mycorrhizal growth response (the big and little plant effect) which has been demonstrated for an enormous number of species mainly in pot experiments.

Nutrient uptake: It is now established that the fungal partner can make a considerable contribution to nutrient uptake. VAM fungi can mediate inter-plant transfer of phosphorus (Francis *et al*., 1986; Newman and Ritz, 1986), carbon (Newman, 1988; Read *et al*., 1985) and nitrogen (Read *et al*., 1985; Kessel *et al*., 1985; Haystead *et al*., 1988; Barea *et al*., 1988; McNeil and Wood, 1990). The largest effect of AM formation is on P nutrition. In addition to phosphorus uptake, VAM fungi can also enhance the uptake of relatively immobile micro nutrients, particularly zinc and copper (Killham and Firestone, 1983; Lambert *et al*., 1979; Gnekow and Marschner, 1989; Gildon and Tinker, 1983; Pacovsky, 1986).

Disease and pathogen: AM fungi are recognized as high potential agents in plant protection and pest management (Quarles, 1999; Sharma and Dohroo, 1996; St-Arnaud *et al*., 1995). Mycorrhizal roots have a mantle that acts as a physical barrier against the invasion of root diseases AMF secretes antibiotics that competes or antagonizes pathogens, thus aiding in disease suppression. AM fungi can decrease the severity of diseases caused by root pathogenic fungi, bacteria and nematodes (Jalali and Chand, 1988; Siddiqui and Mahmood, 1995a, b; Bhat and Mahmood, 2000; Shafi *et al*., 2002). In several cases direct biocontrol potential has been demonstrated, especially for plant diseases caused by *Phytophthora*, *Rhizoctonia* and *Fusarium* pathogens (Siddiqui and Mahmood, 1996;

Abdelaziz *et al*., 1996; St-Arnaud *et al*., 1997; Siddiqui *et al*., 1998; Dalpe and Monreal, 2004).

Weed control: Mycorrhizal fungi can contribute to weed control also. They suppress the competitive ability of weeds relative to sunflower (Van der Heijden *et al*., 2008). AM fungi have the potential to be a much more environmentally sound method of *Poa annua* (weed of temperate zone golf) control in sports turf than the currently used chemicals (Gange *et al*., 1999). Btehlenfalvay *et al*. (1996) studied that mycorrhizal fungi enhance weed control and crop growth in a soybean-cocklebur association treated with herbicide bentazon*[1].

Land rehabilitation: The effective role of VAM fungi in land rehabilitation has been well documented (Allen and Allen, 1988; Sylvia and Will, 1988; White *et al*., 1989). The AM fungi, by maintaining the uptake of slowly diffusing nutrients under water stress conditions, can help plants resist drought stress (Azcon *et al*., 1988). VAM fungi can help plants become established in saline soils (Hirrel and Gerdemann, 1980; Pond *et al*., 1984) and in nutrient deficient soil or degraded (eroded) habitats, in coal wastes, eroded desert and disturbed soils (Hall and Armstrong, 1979; Khan, 1981). Mycorrhizal fungi appear to have beneficial effects on soil aggregation and may be an important means of controlling soil erosion. Extramatrical mycelia of AM fungi have been reported to bind soil grains in sandy soils and dunes and many sand dune plants are known to be mycorrhizal.

CONCLUSION

Mycorrhizal fungi are one of the more important groups of soil organisms and play a critical role in nutrient cycling, mediating plant stress and protection against pathogens. They are also cornerstones in the ability of plants to survive transplant shock. Plants have co-evolved mutualistic relationships with symbiotic mycorrhizal fungi such that their survival and fitness depends upon the healthy functioning of these fungi and vice-versa. The evidence suggests that the organic farming system leads to increase the inoculum levels of AMF with greater crop colonization that resulted in enhanced nutrient uptake and therefore Arbuscular Mycorrhizal Fungi (AMF) may be used as a substitute to reduced fertilizers.

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