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Plant and Soil Relationship between Fungi

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Abstract: *There are two types of mycorrhizae: ectomycorrhizae and endomycorrhizae. Ectomycorrhizae form an extensive dense sheath around the roots, called a mantle . Hyphae from the fungi extend from the mantle into the soil, which increases the surface area for water and mineral absorption. This type of mycorrhizae is found in forest trees, especially conifers, birches, and oaks. Endomycorrhizae, also called arbuscular mycorrhizae, do not form a dense sheath over the root. Instead, the fungal mycelium is embedded within the root tissue. Endomycorrhizae are found in the roots of more than 80 percent of terrestrial plants We concluded that The relationship between plants and fungi is symbiotic because the plant obtains phosphate and other minerals through the fungus, while the fungus obtains sugars from the plant root. The long extensions of the fungus, called hyphae, help increase the surface area of the plant root system so that it can extend beyond the area of nutrient depletion. Ectomycorrhizae are a type of mycorrhizae that form a dense sheath around the plant roots, called a mantle, from which the hyphae grow; in endomycorrhizae, mycelium is embedded within the root tissue, as opposed to forming a sheath around it. In endomycorrhizae, mycelium is embedded within the root tissue, as opposed to forming a sheath around it; these are found in the roots of most terrestrial plants.*

Keywords: *Mycorrhizal fungi, mineral nutrients, plant root*

1. Introduction

Mycorrhizal fungi can protect the roots from disease organisms, through simple spatial interference, by improving nutrient uptake, and by producing glomulin and other metabolites that inhibit disease. Stress in plants can be reduced because the mycorrhizal fungi can solubilize mineral nutrients from plant not-available forms to plant available forms, and translocate those nutrients to the root system in exchange for sugars provided by the plant.

Mycorrhizal fungi played an integral role in the success of plants in the environment of early Earth as plants moved from water to land, by providing efficient nutrient absorption from the low organic matter mineral soil, and assisting in the formation of soil aggregates. Arbuscular mycorrhizal (AM) fungi occur over a wide range of agro climatic conditions and are geographically ubiquitous. Among important plants that associate with mycorrhizal fungi are corn, carrots, leek, potatoes, beans, soybeans, other legumes, tomatoes, peppers, onions, garlic, sunflower, strawberries, citrus, apples, peaches, grapes, cotton, coffee, tea, cocoa, and sugarcane. For some plant species, the association with mycorrhizal fungi is indispensable. The degree of dependence varies with plant species, particularly the root morphology, and conditions of soil and climate. Plants with thick roots, poorly branched and with few root hairs, are usually more dependent on mycorrhizae for normal growth and development. The fungi do not disperse with the wind like mold fungi, but instead move by growing from root to root, or by moving with quantities of soil. Unless your site is within a few feet of healthy native vegetation, mycorrhizal fungi are very unlikely to show up fast enough to benefit your plants in the critical early stages. There are confirmed cases of native plants that sat three years (surviving only with artificial maintenance) before native mycorrhizal fungi moved to the site.

Arbuscular mycorrhizal fungi is the medium of soil structure, it determines the flow of water, nutrients, and air, directs the pathways of root growth, and opens channels for the movement of soil animals. As the moderator of the microbial community, it determines the metabolic processes of the soil. In other words, the mycorrhizal network is practically synonymous with ecosystem function. The tremendous advances in research on mycorrhizal physiology and ecology over the past 40 years have led to a greater understanding of the multiple roles of AMF in the ecosystem.

Fig 1. *Show mycorrhizal (AM) fungi*

Arbuscular mycorrhizal (AM) fungi are the **most abundant type of fungi in the soil**, and are one of the most dominate and important organisms in the soil, comprising 5–50% of the total microbial biomass in soils. Mycorrhizae tend to be the **largest component in the ecosystem** primarily because both the fungi and the associated roots are turned over rapidly. Many species of mycorrhizal fungus spores exist naturally in most soils. If plant roots are present when soil conditions prompt the fungal spore to germinate, the newly developing fungal "roots" (or hyphae) link with the cell walls of the plant roots and grow into them, creating structures that allow for the transfer of nutrients between the two organisms. In this symbiosis, the plant provides the mycorrhizal fungi the sugars they need to keep growing (since fungi can't photosynthesize to make their own sugars), and the fungi provide the plants with soil nutrients, particularly phosphorus, which their hyphae can extract from the soil more efficiently than the plant roots can.

When a large, vigorous network of mycorrhizal hyphae is associated with a plant's roots, it exponentially expands the "reach" and surface area of those roots, giving the plant greater access to the nutrients the soil has to offer. This symbiosis is, of course, great for plants, because the extra nutrients can fuel better growth and increase resistance to drought and disease. There are only two instances in which mycorrhizal fungi do not provide benefits to plants: (a) when the soil already has such ideal nutrient and moisture levels that the plants can scavenge enough on their own, or (b) when the plants are brassicas (members of the mustard family), which do not allow the mycorrhizal fungi to colonize their roots.

2. HYPHAE

The mycorrhizal fungi hyphae are much smaller than plant roots, so they can easily penetrate into small spaces between soil particles.

The thread-like hyphae, are structured such that there are linear cytoplasmic units that can extend for a meter or more, fan out into the soil to scavenge even highly immobile nutrients, efficiently absorb the maximum amount of available nutrients and deliver these nutrients back to the plant inside the root cell wall.

In studying differences in the architecture and wall thickness of extraradical hyphae, two types or morphologies were recognized: the larger and thicker, more mellanized hyphae which is part of the ‘permanent’ fungal network and acts as ‘conduit’ or runner hyphae, and the thin-walled, very fine, ephemeral hyphae which is the ‘absorptive’ hyphae and will fan out into nutrient-rich microsites in the soil. The ephemeral hyphae are decomposed in days or weeks while the turnover of runner hyphae may be years

3. MUTUALISTIC SYMBIOSIS

A mycorrhizae is a mutualistic symbiosis between plant and fungus localized -In return, the mycorrhizal fungi receive sugars and other compounds from plants to fuel mycorrhizal activities. Both agricultural plant and fungus benefit from the "symbiotic relationship. These fungi receive carbon (about 12–27%) from the plant host in the form of simple hexose sugars, which are used for fungal growth and exuded into the mycorrhizosphere

4. NUTRIENT MOBILIZATION

Increased mobilization and transfer of nutrients (P, N, S, micronutrients Cu, Zn) from the soil to the plant. Mycorrhizal fungi have been estimated to "substitute" up to 500 lb/acre of Phosphorus for citrus and 170 lb/acre for soybeans in tropical areas. They secrete powerful extracellular enzymes that dissolve tightly bound minerals like phosphorus, and iron. Their hair-like filaments function as pipes to funnel more water and nutrients, particularly phosphorus, and other mineral nutrients, such Cu, and Zn, back to the plant roots. Recent research by the Agricultural Research Service has documented the importance of mycorrhizae for the uptake of nitrogen. They were shown to enhance root absorption area up to 47-fold.

5. PHOSPHORUS

Better development of Phosphorus solubilizing bacteria in the mycorhizosphere. Some crops that are poor at seeking out nutrients in the soil are very dependent on AM fungi for phosphorus uptake. For example flax, which has poor chemotaxic ability, is highly dependent on AM mediated phosphorus uptake at low and intermediate soil phosphorus concentrations (Thingstrup et al. 1998).

6. AM INTERACTION WITH OTHER ORGANISMS

AM fungi influence bacterial, fungal, and microarthropod communities by providing them substrates in the forms of decomposing fine, ephemeral hyphae and the deposition of hyphal biomolecules, and by influencing soil structure Mycorrhizal fungi exude (photosynthetically-derived) carbon into the mycorrhizosphere which attract soil organisms, these microorganisms (use these) exudates to transform organic matter and soil minerals into plant-available nutrients which also stabilize soil aggregates

7. PATHOGENS

Modification of plant-pathogen relations: mycorrhizae influence the colonization of roots by other microorganisms, reduce the susceptibility (or increase the tolerance) of roots to soil-borne pathogens such as nematodes or phytopathogenic fungi. Secretion of antibiotics and support of a community that competes or antagonizes pathogenic microorganisms, thus aiding in disease suppression;

8. PLANT GROWTH HORMONES

AM increased production of plant growth hormones such as cytokinins and gibberelins;

9. WATER

Modification of soil-plant-water relations, promoting better adaptation of plant to adverse environment conditions (drought, metals). At elevated heavy metal concentrations in soils, mycorrhizal fungi have been shown to detoxify the environment for plant growth. Bidirectional movement of nutrients characterizes these symbionts where carbon flows to the fungus and inorganic nutrients get transported through mycorrhizal network to the plant

10. PLANT DEPENDENCY

Plant species differ in the extent and dependence on colonization by certain AM fungi and some plants may be facultative mycotrophswhile others may be obligate mycotrophs.

Host plant species differ in the degree to which they depend on the symbiosis. That is, some (mostly weedy) species benefit little, even though they are capable of becoming mycorrhizal. Other species are mycotrophic: they depend upon the symbiosis and make little growth without it unless heavily fertilized. Perennial grasses are often strongly mycotrophic.

Other factors such as root surface area, root hair abundance and length, growth rate, response to soil conditions and exudations can be related to the plant dependency on AM symbiosis for nutrient uptake. Some crops are considered as facultative mycotrophs, while others are seen as obligate mycotrophs (Smith and Read, 1997). Various plants, such as leek or corn, are highly dependent on mycorrhizae to meet their basic P requirements, while others like wheat, barley and oat, benefit from the symbiosis but are less dependent (Plenchette, 1983; Ryan and Angus, 2003).

11. Colonization Levels

Given that mycorrhizal fungi can influence so many aspects of plant growth, and documenting all these benefits is usually extremely expensive and difficult, they have not been documented. Therefore, probably the best that can be done is to say that perhaps as low as 12% colonization might be documented to be beneficial (work by Moore and Reeves in the mid-1990's), but more likely a minimum level of 40% colonization is required, as suggested by Mosse, and St. John in various publications and comments.

If the plant does not require mycorrhizal colonization, there probably is no reason to assess the roots for mycorrhizal colonization. Although the Allens showed that one way for certain plants to exclude non-mycorrhizal plants from a community was to make sure the mycorrhizal fungi were present, because the mycorrhizal fungi pulled nutrients from the non-mycorrhizal plants. This is a probable mechanism for mycorrhizal crop plants being able to out compete weeds and earlier successional plant species.

When mycorrhizal colonization is low, or less than the desired range, given that the desired plant requires VAM or ectomycorrhizal colonization or ericoid mycorrhizal fungi, then check how low the colonization is. If less than perhaps 10 to 15%, then addition of mycorrhizal spores would be a good idea. If it is an annual plant, placing VAM spores near or on the seed or seed pieces is the simplest way to get the roots colonized as soon as the roots area produced. With permanent turf, adding VAM spores into the compost mixed into the aeration cores gets the VAM spores into the root system without destroying the turf.

With perennial plants, verti-mulching and adding the VAM or ecto- spores into the compost mixed in the vertimulch is the simplest way to get the spores next to the root system. In cases where we have added inoculum in this fashion, roots have gone from 0% colonization to 25 to 30% within a year, and to 50 to 60% in two years, with addition of humic acids through the season to help the mycorrhizal fungi grow rapidly (see next section)

If colonization is between 15% and 40%, then all that is needed is additional fungal foods to help the mycorrhizal fungi improve plant growth, reduce plant stress, and improve root protection.

There is a dose response relationship to humic acids additions. Typically addition of 2 to 4 pounds of dry product, or 1 to 2 gallons of liquid product per acre are adequate to improve fungal growth. But, if there are toxic chemical residues to overcome, additional humics of fulvics may be needed. It is best to check periodically to see that colonization is improving as desired. Be aware that that most humic acid products contain 10 to 12% humic acids. If the product you are considering is less expensive, please check the concentration of humic acid. Half the concentration of the humic acid means they can drop the price, but your fungi get less benefit. Check colonization periodically to make sure the fungi are growing and colonization is increasing. Weather can cause problems with colonization, and severe drought, floods, burns, compaction causing by over-grazing, heavy machinery, herds of people walking on the lawns or turf can reduce colonization. If that happens, additional applications of fungal foods will be needed to help resuscitate the damage. Fungi are just like any other organism. If they are harmed, they need care to recover. Triage for fungi includes adding foods they love (humic acid is like chocolate to a choc-a-holic, but they'll also accept any woody, wide C: N ratio fungal food), and putting on a mulch or litter layer on the soil surface. If colonization is above 40%, then the plants are getting the help they need from the fungi. Periodically check to make sure nothing has harmed them.

What if colonization seems too high? This is extremely rare, but does happen, and seems to be associated with the fungi taking more than their fair share of the plant's resources. Stop applying fungal foods. Consider helping the bacteria compete with the fungi for a bit.

12. Corn/Maize

Maize is an obligate mycotroph, which means it is heavily dependent upon the symbiosis with AM and makes little growth without it unless heavily fertilized. Maize is also a trap plant with ability to attract mycorrhizal propagules even when present in low amounts, a likely event in the tropical soils. A 90 day fallow in corn can reduce AM active hyphae by 57%.

13. WEEDS

Most weeds are not AM, so this might mean that inoculated with AM would favor AM plants over weeds. Soil with little inoculum selects against most natives and favors the plant species that do not need to become mycorrhizal early in life. These plants are better known as weeds.

14. SOIL pH

Most of the mycorrhizal isolates were able to germinate at pH 3.8, Mycorrhizae lower the rhizosphere pH due to selective uptake of NH4+ (ammonium-ions) and release of H+ ions. Decreased soil pH increases the solubility of phosphorus precipitates. The hyphal uptake of NH4+ also increases the flow of nitrogen to the plant as NH4+ is adsorbed to the soil's inner surfaces and must be taken up by diffusion.

15. INTERACTION WITH NITROGEN FIXING BACTERIA

Nodulating - legumes require an optimum level of phosphorus in their tissue for nodulation and nitrogen fixation by the bacterial symbiont, because these processes are phosphorus dependent. Arbuscular mycorrhizal fungi provide aid to these processes with the bacterial symbionts by satisfying the host nutritional needs. Recent research has shown that AM fungi release an unidentified diffusional factor, known as the myc factor, which activates the nodulation factor's inducible gene mtENOD11. This is the same gene involved in establishing symbiosis with the nitrogen fixing, rhizobial bacteria(Kosuta et al. 2003).

When rhizobium bacteria are present in the soil, mycorrhizal colonization is increased due to an increase in the concentration of chemical signals involved in the establishment of symbiosis (Xie et al. 2003).

16. LIMITING FACTORS

There is a lower incidence of mycorrhizal colonization in very arid or nutrient rich soils. When the level of soil fertility and humidity are increased, the dependence on the mycorrhizal condition decreases to a point where the plant becomes immune to colonization. The addition of fertilizers containing easily soluble phosphorus, including non-composted manure, will greatly reduce VAM colonization. An important consideration in AM fungus production is the level of available Phosphorus in the media in which the plant hosts are grown. Plants growing in high P situations limit colonization of their roots by AM fungi. In effect, they are deciding to limit the “cost” (in terms of sugar) of the symbiosis in the absence of benefit (in this case, improved uptake of phosphorus) since the roots can function well enough on their own in the high nutrient situation. A 90 day fallow in corn can reduce AM active hyphae by 57%, root colonization by crops which are not AM can reduce AM colonization by 37%. **Plants which are not mycorrhizal** Those include members of the Brassicaceae family, like cabbage and cauliflower, and the mustard family, like canola and crambe. "When you grow those crops, it's like a fallow period, because glomalin production stops," says Wright. "You need to rotate them with crops that have glomalin-producing fungi."

17. INCREASING FACTORS

Levels were maintained or raised by no-till, cover crops, reduced phosphorus inputs, and the sparing use of crops that don't have arbuscular mycorrhizal fungi on their roots. Seedlings become mycorrhizal very quickly if the soil is full of mycorrhizal hyphae, but more slowly if the soil contains only dormant spores (fungal reproductive structures). The living mycelial network favors the diverse native species that must become mycorrhizal quickly. Seedlings that germinate on soil with an existing mycorrhizal network can very quickly become mycorrhizal. Seedlings that germinate on soil without a mycorrhizal network become colonized much more slowly. Within the last decade, inventories of the soil’s productive capacity indicate severe degradation and loss of arable lands as a result of soil erosion, cultivation, salinization, over-grazing, land clearing, desertification, soil pollution, and atmospheric pollution. Loss of topsoil, at a rate of 10 million hectares per year, is a serious problem in agroecosystems and has resulted in an estimated loss of nearly one-third of the world’s arable land during the last 40 years (Pimentel et al., 1995) Liebig found that switchgrass fields had an average of about seven tons more soil carbon per acre than nearby corn and wheat fields. Greater soil carbon under switchgrass was observed at all depths, but it was most pronounced at one to three feet down—a depth in the soil profile where switchgrass has more root biomass than corn or wheat. Switchgrass roots grow as long as eight feet, compared to three to six feet for corn and wheat.

18. PROPAGATION

International Culture Collection of (Vascular) Arbuscular Mycorrhizal Fungi (INVAM) has excellent information on propagating mycorrhizal spores-

http://invam.caf.wvu.edu/methods/cultures/trapcultures.htm

http://invam.caf.wvu.edu/cultures/faqs/faqtraps.htm

A hard-to-understand, and even harder to override, characteristic of AM fungi limits the ways in which inoculum may be produced. Arbuscular mycorrhizal fungi are obligate symbionts, that is they must colonize plant roots to grow and reproduce. Endomycorrhizal fungi have to be multiplied through a host plant. For this reason, widespread inoculations are difficult and better field success is obtained through management of the symbiosis (i.e., nutrient conditions of the soil/substrate of plant growth). Only the phase of the fungus inside the root ("intraradical hyphae") can absorb sugar and express certain metabolic pathways necessary for growth, such as the synthesis of fats. Therefore, the fungus has a very limited ability to grow asymbiotically, i.e. without living in symbiosis. Failure by researchers to overcome these limitations has prohibited the growth of these organisms in pure culture on Petri dishes or in fermenters for inoculum production. It is a myth that arbuscular fungi behave similar to many other fungi by initiating sporulation after nutrient deprivation (host stress in obligate symbionts). Timing of onset of sporulation varies with species and also growing conditions (affecting fungus directly and indirectly through host physiology). It often occurs within 3-4 weeks after onset of mycorrhizal colonization under almost any conditions except high phosphorus in soil (which inhibits all phases). We, and researchers in Lyn Abbott's lab, have experimental results indicating sporulation occurs only after a critical threshold level of fungal biomass is established in roots. Sporulation then progresses asynchronously thereafter along with continued mycorrhizal development.

Arbuscular fungi are obligate biotrophs that are unable to sustain growth and reproduction apart from a plant host. This restrictive niche appears to be balanced by an extremely wide host range, so that ample opportunities exist for any dispersed fungal propagule to establish a new individual somewhere else. The filamentous habit characteristic of this and other fungi affords organisms considerable versatility in their life cycles, with the capability of indefinite growth as long as carbon from a host plant source is available. Intraradical hyphae originated from a single entry point appear to have limited growth, forming an "infection (or colonization) unit" of a size regulated by host-fungus interactions. The external hyphae are of various morphologies and functions, ranging from "infective" hyphae to "absorptive" hyphae to "fertile" (spore-bearing) hyphae. Duration of growth, senescence, etc. and other properties of each hyphal form is poorly understood at this time. It is the infective hyphae which initiate new points of colonization on the same root, other roots of the same plant, or roots of adjacent plants. Work with pot cultures indicates external hyphae (fragments or attached to mycorrhizal roots) are most infective in the families Glomaceae and Acaulosporaceae.

Topsoil should be collected during a dormant season: the dry part of the year in warm climates, or the cold part of the year if there is no distinct dry season. For very small jobs, you can collect topsoil from the root zone of a known mycorrhizal host. For AM inoculum, try a late-successional native shrub or tree, or a perennial grass. Mycorrhizal propagules settle out quickly in water and must be continuously agitated to remain in suspension. Inoculum suspensions have been recommended for application through drip irrigation systems with hundreds of yards of pipe and tubing. AM inoculum is singularly unsuited for such use

19. EVOLUTION OF MYCORRHIZAE

Arbuscular mycorrhizal (AM) fungi are ancient microorganisms appeared between 460 and 400 million years ago as plants started to colonize the land. Mycorrhizal fungi are ancient microorganisms which played an integral role in the success of plants in the environment of early Earth as plants moved from water to land, by providing efficient nutrient absorption from the low organic matter mineral soil, and assisting in the formation of soil aggregates.

Fig 2. *Ectomycorrhizae form sheaths, called a mantle, around the roots of plants, as shown in this image*

20. CORRECT TERMINOLOGY

In the last 10 years, some researchers have suggested that some mycorrhizal fungi do not produce vesicules under all conditions, and so VA mycorrhizal fungi should be called arbuscular mycorrhizal fungi, not vesicular-arbuscular mycorrhizal fungi. Just be aware that sometimes, people say VAM, sometimes AM.

See -The Instant Expert Guide to Mycorrhiza by Ted St. John

Do not speak of a mycorrhizae plant. The adjectival form is mycorrhizal. Speak of a mycorrhizalplant.

The mycorrhiza is not the fungus - the mycorrhiza is the symbiotic combination of plant and fungus, the term mycorrhiza refers to a combined structure. This subtlety is elusive enough that even specialists have lapses from time to time, and say mycorrhiza when they really mean the fungus. Even if you occasionally slip, be sure you grasp the central idea that a mycorrhiza is the combination, which includes the mycorrhizal fungus and the mycorrhizal host plant.

The term Infected vs. Colonization: Until the 1970s, mycorrhizal plants were said to be infected by mycorrhizal fungi. Since infection sounded too pathological, we began saying colonization instead. Today, hard looks will befall those who speak of mycorrhizal infection. AM or VAM??? AM fungal species form arbuscules (branched structures inside the root cells) at some point in the colonization cycle, but not all form vesicles (oil storage organs in the roots). Thus, the current trend to drop the V part of VAM. Among mycorrhizal specialists, those who still say VAM are thought to be badly out of date, and there has been a stampede to the more current term. Say VAM at your peril.

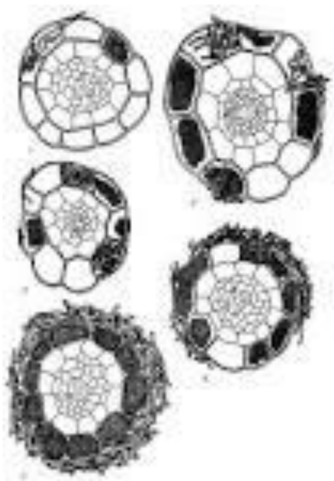

Fig 3. *Estimation of* ***mycorrhizal***

21. Conclusion

A nutrient depletion zone can develop when there is rapid soil solution uptake, low nutrient concentration, low diffusion rate, or low soil moisture. These conditions are very common; therefore, most plants rely on fungi to facilitate the uptake of minerals from the soil. Mycorrhizae, known as root fungi, form symbiotic associations with plant roots. In these associations, the fungi are actually integrated into the physical structure of the root. The fungi colonize the living root tissue during active plant growth. Through mycorrhization, the plant obtains phosphate and other minerals, such as zinc and copper, from the soil. The fungus obtains nutrients, such as sugars, from the plant root. Mycorrhizae help increase the surface area of the plant root system because hyphae, which are narrow, can spread beyond the nutrient depletion zone. Hyphae are long extensions of the fungus, which can grow into small soil pores that allow access to phosphorus otherwise unavailable to the plant. The beneficial effect on the plant is best observed in poor soils. The benefit to fungi is that they can obtain up to 20 percent of the total carbon accessed by plants. Mycorrhizae function as a physical barrier to pathogens. They also provides an induction of generalized host defense mechanisms, which sometimes involves the production of antibiotic compounds by the fungi. Fungi have also been found to have a protective role for plants rooted in soils with high metal concentrations, such as acidic and contaminated soils.

Acknowledgments

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References

[1] Mycorrhizae: An Overview Zaki A. Siddiqui and John Pichtel

[2] The Molecular Components of Nutrient Exchange in Arbuscular Mycorrhizal Interactions Ruairidh J.H. Sawers, Shu-Yi Yang, Caroline Gutjahr, and Uta Paszkowski

[3] Arbuscular Mycorrhizal Fungi as Potential Bioprotectantsagainst Plant Pathogens Mohd. Sayeed Akhtar and Zaki A. Siddiqui

[4] Arbuscular Mycorrhizae and Alleviation of Soil Stresses on Plant Growth Philippe Giasson, Antoine Karam, and Alfred Jaouich

[5] Arbuscular Mycorrhizal Fungi Communities in Major Intensive North American Grain ProductionsM.S. Beauregard, C. Hamel, and M. St.-Arnaud

[6] Arbuscular Mycorrhizae: A Dynamic MicrosymbiontRestoration in Native Ecosystems for Sustainable Agriculture Jitendra Panwar, R.S. Yadav, B.K. Yadav, and J.C. Tarafdar

[7] Indirect Contributions of AM Fungi and Soil Aggregation to Plant Growth and Protection Kristine A. Nichols

[8] Arbuscular Mycorrhizae and their Role in Plant Restoration in Native Ecosystems Krish Jayachandran and Jack Fisher

[9] Effects of Interactions of Arbuscular Mycorrhizal Fungi and Beneficial Saprophytic Mycoflora on Plant Growth and Disease ProtectionFungi and Beneficial Saprophytic Mycoflora on Plant M.G.B. Saldajeno, W.A. Chandanie, M. Kubota and M. Hyakumachi

[10] The Mycorrhizosphere Effect: A Multitrophic Interaction Complex Improves Mycorrhizal Symbiosis and Plant Growth R. Duponnois, A. Galiana, and Y. Prin

[11] Ectomycorrhizae and their Importance in Forest Ecosystems Kazuyoshi Futai, Takeshi Taniguchi, and Ryota Kataoka

[12] Ectomycorrhizal Associations Function to Maintain Krista L. McGuire

[13] The Use of Mycorrhizal Biotechnology in Restoration of Disturbed Ecosystem Ali M. Quoreshi

[14] In vitro Mycorrhization of Micropropagated Plants: Studies on Castanea sativa Mill Anabela Martins

[15] Effective and Flexible Methods for Visualizing and Quantifying Endorhizal Fungi Susan G.W. Kaminskyj