Benefits and Opportunities with Mycorrhizal Fungi in Nursery Propagation and Production Systems©

Fred T. Davies, Jr.
Dept. of Horticultural Sciences, Texas A&M University, College Station, Texas 77843-2133

[email: f-davies@tamu.edu]

INTRODUCTION

Mycorrhiza means "fungus root" and is a symbiotic association between specific fungi and the fine, young roots of higher plants. The majority of plants strictly speaking do not have roots, rather they form mycorrhizas. There are seven different types of mycorrhiza. The two most important are the endomycorrhiza and ectomycorrhiza. Endomycorrhizal plants are typically herbaceous plants, shrubs, many ornamental, fruit and nut trees, vegetables and agronomic crops, and turf grasses. More than 85% of higher plants form endomycorrhizal associations. The ecotomycorrhizal fungi form associations with conifers such as fir and pines, and hardwoods such as birch, beech, eucalyptus, oak, willow, and magnolia. Ectomycorrhiza fungi colonize around 10% of higher plants. Some plants such as eucalyptus will form both endo- and ectomycorrhizal associations.

Endomycorrhiza. Endomycorrhiza are characterized by arbuscules (arbuscular mycorrhiza), and some endomycorrhiza will form both arbuscules and vesicles — these are referred to as vesicular arbuscular mycorrhiza. Mycorrhizal hyphae penetrate into the host root cortical cells and extend outward into the surrounding soil, thus increasing the roots surface area. Vesicles are used for food storage, and arbuscules are involved in exchange of soil mineral ions (phosphorus, magnesium, iron, etc.) which the mycorrhiza gives to the host plant. With this symbiotic association, the mycorrhiza help the host plant more efficiently absorb soil mineral ions and soil water, while the host plant gives the fungi carbon (carbohydrates), since mycorrhiza can not photosynthesize.

Ectomycorrhiza. The hyphae of ectomycorrhizas form a network (Hartig net) between the root cortical cells and also extend outward into the surrounding soil. The hyphae also form a sheath or fungal mantle on the root surface. Ectomycorrhiza can be seen without magnification, whereas endomycorrhiza are observed with tissue-staining techniques and a compound microscope. Ectomycorrhiza can be produced synthetically in Melin-Norkrans medium. This allows easier production, minimizes contamination, and produces very clean cultures.

Mycorrhizal fungi are unique in that their hyphae do not penetrate the vascular stele of the host plant, unlike vascular wilt fungi such as *Verticillium*, *Fusarium*, etc. Mycorrhizas exist naturally in many commercial production systems. Examples include field rose production in East Texas where rose bushes are produced in 2-year cycles. High mycorrhizal colonization occurs in these low phosphorus, sandy-loam soil field conditions (Davies, 1987).

Challenges Facing the Nursery Industry. There are opportunities for the utilization of mycorrhizal fungi with the challenges facing the nursery industry and the incorporation of Best Management Practices [BMP] (Yeager et al., 1997).

Industry challenges include increased production costs and greater governmental regulations. Irrigation water usage needs to be curtailed. Reducing irrigation run-off, limiting the usage of soluble fertilizers, fungicides, and pesticides are being addressed. There is also a need to produce and market more stress-efficient plants that use less water and fertilizer and have greater resistance to environmental stress and diseases and insects.

The BMP changes occurring in the nursery industry are highly conducive for mycorrhizal usage. For instance, a greater proportion of slow-release fertilizers are being used today than soluble fertilizers, which is beneficial for mycorrhizal associations. There will also be fewer pesticides available in the future, which are causing changes in cultural practices, i.e., the future usage of methyl bromide is very uncertain and most likely will be fazed out. Water is a key limiting environmental factor. This has led to recycling of irrigation water and other BMP programs. With these changes in cultural practices, use of slow-release fertilizers and reduction in pesticide usage, there are opportunities for utilizing mycorrhizal fungi.

Benefits of Mycorrhiza. Mycorrhizal fungi can enhance efficiency of plant roots to absorb water and macro- and microelements from the soil or container media. This helps reduce fertility and irrigation requirements, increases drought resistance and plant resistance to pathogens. Mycorrhizal fungi enhance plant health and vigor and minimize stress. Minimizing stress is particularly important because with less stress there is greater plant resistance to pathogens and pests and a reduction in pesticide usage. In regard to pathogen resistance, there can be biotic responses with certain compounds produced by the mycorrhizal fungi to ward-off pathogens; there can also be mycorrhizal-stimulated changes that cause the host plant biochemistry to change (Pfleger and Linderman, 1994). The germination of *Fusarium* spores will trigger the germination of mycorrhizal spores. The fungal mantle of ectomycorrhiza forms a physical barrier between roots and pathogens.

Mycorrhizal fungi enhance the drought resistance of plants by causing changes in the host plant biochemistry (greater osmotic adjustment, lower production of abscisic acid), changes in root morphology (more new root initiation for better water absorption), and greater extraradical hyphae development which allow the root system to have better contact with soil water. The plant is more efficient in surviving drought conditions. Other benefits include enhanced seedling growth, increased adventitious root formation of cuttings (Davies et al. 2000), and enhanced plant transplant establishment (Davies and Call, 1990).

We have been able to demonstrate in very severe coal revegetation sites that mycorrhizal fungi will enhance the survivability and growth of endo- and ectomycorrhizal plants (Call and Davies, 1988; Davies and Call, 1990). Disturbed sites can also be found in the construction of houses with changes in soil structure, soil compaction, and subsequent drainage and aeration problems. There are opportunities in incorporating mycorrhiza during the nursery production cycle of a plant so that when the ornamental shrub or tree is transplanted into the landscape it has greater stress resistance, survivability and re-growth.

Mycorrhiza and Propagation. In regards to adventitious root formation, both endo- and ectomycorrhizal fungi can enhance adventitious root formation of cuttings (Hartmann et al., 1997). There can be enhanced root initiation and root development. The ectomycorrhizal fungi are capable of producing auxins, gibberellins, and other phytohormones. With some of the more difficult-to-root plant species it may be useful to try combinations of mycorrhizal fungi and auxins to stimulate better root formation. The endomycorrhizal fungi, *Glomus intraradices*, increased adventitious rooting of softwood cuttings and liner plant development of desert willow (*Chilopsis linearis*) (Davies et al., 2000a).

How to Apply Mycorrhizal Fungi. Mycorrhizal fungi can be applied as:

- a layer of spores, mycelium, and colonized roots banded into the container media,
- pre-incorporated in commercial peat-based mixes,
- placed in the dibble hole of the container prior to sticking the liner (it is ideal to let the new roots grow into the mycorrhizal fungi),
- gel or liquid drench system,
- injected or mixed with backfill, or
- incorporated with pelleted seed.

Utilization of Mycorrhizal Fungi in Commercial Production Systems. Mycorrhizal fungi can survive in nursery production systems. In a study that we conducted in a commercial nursery in Texas, four species were used as host plants [*Nandina domestica* 'Moon Bay', *Loropetalum chinense* var. *rubrum* 'Hines purple leaf' Plumb delight® fringe flower, *Salvia gregii*, and *Photinia* ×*fraseri*] (Davies et al., 2000b). Plants were inoculated with arbuscular mycorrhizal fungi, *Glomus*

Table 1. Fungicidal effects on endomycorrhiza [source: D. Marx, S. Parent].

No reported negative effect	Inhibitory effect*
Carbamate (Fermate, Ferbam)	Aliette* (Fosetyl - Al)
Carbendazim (Bavistin)	Benomyl* (Benlate,Tersan-1991)
Bravo (Chlorothalonil)	Captan* (Orthocide)
Chloroneb (Tersan, Demosan)	Copper Oxychloride Sulfate* (CDCS)
Chlorothalonil (Bravo, Daconil-2787, Exotherm)	Easout* (Thiophanate methyl)
Difolatan (Sulfonimide, Difosan, Captafol)	Formalin* (Formaldehyde)
Lesan (fenaminosulf)	Metalaxyl* (Subdue, Ridomil)
Mancozeb (Dithane M-45)	PCNB* (Terraclor, Tri-PCNB)
Maneb (Dithane M-22, Manzate)	Phaltan* (Folpet)
No-Damp(Oxine benzoate) (sol)	Terrazole* (Truban, ETMT, Etridiazol)
Rovral (Chipco-26019)	Tilt* (CGA-65250)
Soufre -92 %	Thiophanate Methyl * (Cleary-3336)
Thiabendazole (Mertect)	Triadimefon (Bayleton)*
Thiram (Tersan 75, Arasan)	Vitavax* (Carboxin, DCMO)
Topsin-M (Easout, Fungo, Duosan)	
Triforine (Funginex)	

Table 2. Fungicidal effects on ectomycorrhiza [source: D. Marx].

No reported negative effect	Inhibitory effect*
Aliette (Fosotyl Al)	Banrot*
Benomyl (Benlate, Tersan-1991)	Chlorothalonil* (Daconil-2787, Bravo)
Captan (Orthocide)	Mancozeb* (Dithane)
Carbamate (Fermate, Ferbam)	PCNB* (Terraclor, Tri-PCNB)
Carbendazim	Triadimefon* (Bayleton)
Dexon	Zineb* (Ziram, Zerlate)
Difolatan (Sulfonimide, Difosan, Captafol)	
Fuberidizole	
Metalaxyl (Subdue, Ridomil)	
Thiophanate Methyl (Cleary 3336)	
Thiram (Arasan)	

intraradices, and grown in a commercial nursery in Texas. The commercial inoculum of *Glomus intraradices* only enhanced growth of *N. domestica*. However, intraradical hyphae development and colonization (total arbuscules, vesicles/endospores, hyphae) of *L. chinense*, *N. domestica*, and *S. gregii* increased at the higher fertility levels. *S. greggii* had the greatest mycorrhizal development and a 216% increase in hyphae development and colonization at the higher fertility level. This was important since there was not a decrease in colonization occurring at the higher fertility levels.

We need to change our mentality that we are just looking for greater growth and higher phosphorus uptake with mycorrhizal fungi. Under high fertility conditions, it is not realistic to see growth differences with mycorrhiza. In a nursery setting, a more realistic goal is to achieve good mycorrhizal colonization so that the ornamental shrub or tree can be transplanted into a stressful landscape environment — and survive, and reestablish growth more quickly than a nonmycorrhizal plant. One should not be so concerned about differences in plant growth during nursery production, since water and fertility are normally not limiting factors. However, greater growth and establishment following transplanting is an important value-added asset of mycorrhizal landscape plants.

Fungicides and Mycorrhiza. Fungicides will decrease development of mycorrhizas for a short time, depending on the persistence of the fungicide. Most foliar applications of fungicides, except those that are systemic such as Triadimefon (Bayleton) do not affect mycorrhizas because the fungicide doesn't come in contact with the mycorrhizal fungi in soil. Soil drenches do come in contact with mycorrhizal fungi, and may or may not have an influence depending on the mycorrhizal species and the fungicide. Fungicide can inhibit, have no effect, or actually stimulate mycorrhiza development. There are differences in mycorrhiza response, i.e., Benomyl

(Benlate, Tersan-1991) will depress endomycorrhiza, but enhance ectomycorrhiza development. For optimal mycorrhiza response it is best to delay fungicidal application during the first 3 weeks of colonization. Mycorrhizal colonization can occur within the first 3-5 days of treatment, depending on the inoculum source. See the tables on fungicides affecting endomycorrhiza (Table 1) and ectomycorrhiza (Table 2). In these tables a fungicide was listed as inhibitory if it was reported to inhibit mycorrhizal development, regardless of other reports to the contrary. In general, pesticides and herbicides do not inhibit mycorrhiza and are not a problem, except for a few exceptions (Table 3).

Proliferation of Commercial Sources of Mycorrhiza. There are a number of commercial companies now selling mycorrhizal inoculum (Table 4). It is important to determine if your host plant species is ecto- or endomycorrhizal dependent. There

Table 3. Insecticidal effects on endomycorrhiza*

No reported negative effect	Inhibitory effect*
Agribrom (bromine source)	Diazinon* (Diazinon)
Ambush 25 wp	Savon insecticide*
Ambush (Permetrin)	Malathion *(malathion)
Cygon (Dimethoate)	Oxamyl *
Kelthane (Dicofol)	
Morestan (Chinomethionat)	
Metasystox (Oxydemeton-methyl)	
Pentac (Dienochlor)	
Pirimor (Pirimicarb)	
Vendex (Fenbutatin-oxide)	
Talstar-Attain (Bifenthrin)	
Dursban (Chlorpyrifos)	
Trumpet-Dycarb (Bendiocarb)	
Enstar (Kinoprene)	
Margoson (Azateractin)	
Mavrik (Fluvinate)	
Orthene (Acephate)	
Sevin (Carbaryl)	
Avid (Abamectin)	
Citation (Cyromazine)	
Marathon (Imidacloprid)	

*source: S. Parent

Table 4. Partial list of commercial sources of mycorrhizal fungi in North America*

Company	Contact
Accelerator Horticultural Products (Ohio)	Ph: 888-442-5811, e-mail webber@siscom.net
AgBio Inc. (Westminster, Colorado)	Ph: 303-469-9221 FAX: 303-469-9598 Toll free: 877-268-2020
Becker-Underwood (Ames, IO)	Ph: 800-232-5907, FAX: 515-232-5961
BIONET (Marina, CA)	Ph: 831-582-3477, FAX: 831-582-3488, e-mail sgruman@mycorrhiza.cc
BioScientific, Inc. (Avondale, AZ)	Ph: 602-932-4588
BioTerra Technologies, Inc. (Las Vegas, NV)	Ph: 702-256-6404, FAX 702-255-2266
EcoLife Corporation (Moorpark, CA)	Ph: 805-553-9200, FAX 805-553-9300
Ectomycorrhizal Inoculums Spore Supply	e-mail matsutake@cavenet.com
First Fruits (Triadelphia, WV)	Ph: 888-489-0162
Horticultural Alliance, Inc. (Sarasota, FL)	Ph: 800-628-6373, FAX: 888-386-4047, e-mail jquinn@hortsorb.com
J.H. Biotech, Inc. (Ventura, CA)	Ph: 805-650-8933
Mikro-Tek Inc. (Timmins, Ontario, Canada)	Ph: 705-268-3536
Mycorrhizal Applications (Grants Pass, OR)	Ph: 541-476 3985 and FAX 541 476-1581
Plant Health Care, Inc. (Pittsburgh, PA)	Ph: 1-800-421-9051
Premier Horticulture (Red Hill, PA)	Ph: 800-525-2553, FAX 215-679-4119
Premier Tech (Québec, Canada)	Ph: 800-606-6926 ext. 563 or 418-867-8883
Reforestation Technologies (Salinas, CA)	Ph: 800-784-4769
Roots Inc., (Independence MO)	Ph: 800-342-6173
T & J Enterprises (Spokane, WA)	Ph: 509-327-7670, FAX 509-326-4707
TIPCO, Inc. (Knoxville, TN)	Ph: 423-633-5400, FAX: 423-633-6624
Tree of Life Nursery (San J.Capistrano, CA)	Ph: 714-788-0685, FAX: 714-728-0509
Tree Pro (West Lafayette, IN)	Ph: 800-875-8071

*source: D. Sylvia's Web Resources (e-mail dmsylvia@ufl.edu).

can be advantages to working with mixed isolates of more than one mycorrhiza that come in a "cocktail," however, there is a diminishing return to having more than three mixed mycorrhizal species in a single inoculum (J. Morton, pers. commun.). It would be best to try a small test with several commercial isolates, making sure to include a nonmycorrhizal control.

Commercial Advantages of Producing Mycorrhizal Plants. Advantages of utilizing mycorrhizal fungi during propagation and production include:

- Producing more stress-resistant plants during production, which leads to reduced pesticide application during production;
- more drought- and nutrient-tolerant plants in the landscape;
- potentially higher transplanting success and faster establishment; and
- marketing higher value landscape plants.

What Mycorrhizal Fungi Will Not Do. Mycorrhizal fungi are not a panacea or silver bullet for solving all nursery production challenges. The use of mycorrhizal fungi along with other improved cultural practices, including BMP, can improve propagation and production efficiency and the development of more stress-resistant plants for the landscape. Mycorrhizal fungi can enhance transplanting establishment and success. Mycorrhizal fungi are not for all plant systems, i.e., in general they work better with more coarse rooted, perennial plants that may be subjected to production problems, transplanting problems, or that may be subjected to stressful landscape sites. The potential exists for marketing mycorrhizal plants that command higher prices.

Information on Mycorrhiza. The following web sites offer excellent information on mycorrhiza:

- Mycorrhizal Information Exchange - Bob Augé, University of Tennessee: http://mycorrhiza.ag.utk.edu;
- David Sylvia's Web Resources - University of Florida:http://dmsylvia.ifas.ufl.edu. and
- Joe Morton, INVAM—International Culture Collection of Vesicular Arbuscular Mycorrhizal Fungi: http://invam.caf.wvu.edu

SUMMARY

- Mycorrhizal fungi can be incorporated with media composed of bark, peat, sand, vermiculite, perlite, calcined clays;
- Optimum results occur when a media contains at least a 10% mineral soil component;
- The most efficient and economical time to apply is during propagation or when transplanting liners;
- Mycorrhizal fungi work best with slow release fertilizers, however they can be managed in liquid fertilizer regimes;
- Avoid using fungicides within the first three weeks of mycorrhizal fungi inoculation;
- In general, insecticides and herbicides do not effect mycorrhiza development;
- The greatest opportunity with mycorrhiza are generally with coarse-rooted perennials, shrubs and trees.

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