Significance of Mycorrhizal Management in the Production of Trees and Shrubs

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INTRODUCTION

Another paper in this Proceedings described the basic biology and the important roles that mycorrhizal associations play in normal growth and development of forest plants. It also emphasized that all commercially important plants, especially woody plants, regardless of where they are grown still have the genetic requirements their species have acquired from the forests over millions of years of evolution. One such biological requirement is abundant mycorrhizal development on their root systems. The purpose of this paper is to discuss factors affecting mycorrhizal development and to present a few examples of some of the worldwide research done on mycorrhizal manipulations of commercially important forest and landscape plants. There are hundreds of publications that could be used in this discussion. However, only a few are used here to show the importance of managing mycorrhizae—the missing part of the forest—in propagation and productivity of these plants in our man-made environments.

FACTORS AFFECTING MYCORRHIZAL DEVELOPMENT

Many factors affect mycorrhizal development and they must be considered in any commercial application. It is necessary, however, to distinguish between factors that affect the plant and those that affect the mycorrhizal fungi. Generally, any soil or above-ground plant condition that affects root growth (i.e. carbon allocation to roots) also influence mycorrhizal development. The first prerequisite to mycorrhizal development is that the plant must produce a susceptible feeder root. Second, viable inoculum of a mycorrhizal fungus must be present in the rhizosphere or immediate rhizoplane. Third, chemical, physical, and biological soil conditions must favor successful root colonization. Photosynthetic potential, soil fertility, and soil water appear to be the main factors affecting susceptibility of roots to mycorrhizal colonization. High light intensity, moderate soil fertility and soil water promote development; low light intensity and excessive amounts of nitrogen and phosphorus and irrigation tend to reduce development. Research has shown that it takes 10 to 15 times the N and P ordinarily found in most forest soils to significantly suppress mycorrhizal development. In other words, it may take over 150 $\mu g\ g^{-1}$ of P and 450 $\mu g\ g^{-1}$ of N in soil solution to significantly reduce development (Cline and Marx, 1995). Mechanical defoliation that reduces photosynthetic surfaces reduces mycorrhizal development. Increased photosynthesis due to CO_2 enrichment of the atmosphere increases development. Light intensity, fertility, and soil water influence the carbohydrate status of roots and the synthesis of new roots. Both of these cases are manifestations of carbon allocation. Rapidly growing roots in highly fertile soil contain little available soluble carbohydrates which are needed by the fungi to successfully establish mycorrhizae. Photosynthates supplied to the fungi by the plant are essential to the development, function, and maintenance of mycorrhizae.

Many factors regulate the survival of the fungi in the soil or their growth on roots. Extremes of soil temperature, pH, moisture, etc. and the presence of antagonistic soil microbes can reduce the survival of certain propagules (spores or mycelia) of these fungi, and thereby, their inoculum potential in the soil. Certain fungicides stimulate mycorrhizae while others inhibit the development. Rarely have other pesticides been reported to directly affect mycorrhizal development (Marx, 1991).

MYCORRHIZAL MANIPULATION TO IMPROVE PLANT PERFORMANCE

Most of the published research on mycorrhizae has been done on forest trees and it dates to the early 1900s. In the early 1970s, research began in southern bareroot and container nurseries to produce tree seedlings with specific mycorrhizae for the purpose of improving their survival and growth on clear-cut forest sites, and on adverse sites, such as coal-mined lands, borrow pits, and severely-eroded areas. Research in the South was successful and research soon spread worldwide. Most of the research on pine and oak was done with *Pisolithus tinctorius* (Pt), a puffball-producing ectomycorrhizal fungus, with a very broad tree host range. Subsequent research has shown this fungus to have unique characteristics that aid trees of all ages to deal with environmental stresses. Over 25 species of other ectomycorrhizal fungi have also been used to successfully inoculate a wide variety of tree species.

Table 1. Response of 10- to 12-month-old pine seedlings to *Pisolithus* (Pt) or naturally occurring ectomycorrhizae in bareroot tree nurseries.

Treatment	Height (cm)	Stem diameter (mm)	Total fresh wt. (g)	Culls (%)
Pinus echinata (shortleaf pine)				
Pt	20.50	6.20	26.70	38.00
Natural	19.30	5.80	21.30	70.00
P. taeda (loblolly pine)				
Pt	28.30	4.70	15.30	16.00
Natural	23.20	4.40	12.20	30.00
P. ponderosa (ponderosa pine)				
Pt	24.20	7.50	37.90	28.00
Natural	22.10	7.10	31.40	42.00
P. strobus (Eastern white pine)				
Pt	18.80	5.70	23.20	19.00
Natural	15.00	5.30	18.90	41.00

Nursery Propagation. In the mid-1970s, research by the U.S.D.A. Forest Service began to develop a commercial inoculum of Pt. For over a decade, research on various commercial formulations was compared to research-grade inoculum for efficacy in over 45 bareroot and container nurseries belonging to forest product industries, and various federal and state agencies throughout the U.S. Table 1 shows representative results from bareroot nursery tests in fumigated soils. (Marx et al., 1984). Ectomycorrhizal development by Pt increased seedling size and reduced the percentage of cull seedlings. Similar results have been obtained with 23 other pine species. An important point to remember in this and other research on ectomycorrhizae is that the noninoculated controls in fumigated soil or containers always have *naturally occurring ectomycorrhizae from airborne spores of local fungi. In no tests,* therefore, are nonmycorrhizal seedlings ever compared to ectomycorrhizal seedlings. The comparisons are between different species of fungi. Table 2 shows the effects of Pt ectomycorrhizae on container-grown oak seedlings in Missouri (Dixon et al., 1984). All of the oaks with Pt ectomycorrhizae were taller, had thicker stems, weighed more, and had larger leaf areas that did control seedlings. All of these oaks were grown under high soil fertility and irrigation protocols. Similar data has been published on six other oak species.

Table 2. Response of 20-week-old container-grown English, black and white oaks to *Pisolithus (Pt)* or naturally occurring ectomycorrhizae.

Treatment	Height (cm)	Stem diameter (mm)	Total wt. (g)	Leaf area (cm)
Quercus robur (English oak)				
Pt	34.00	8.00	17.30	334.00
Natural	23.00	6.00	8.50	272.00
Q. velutina (black oak)				
Pt	15.00	5.00	6.70	181.00
Natural	13.00	4.00	4.30	115.00
Q. alba (white oak)				
Pt	16.00	5.00	6.00	201.00
Natural	13.00	4.00	4.50	162.00

A considerable amount of nursery research has been published on the response of various hardwoods to endomycorrhizae, i.e., vesicular arbuscular mycorrhizae (VAM). An example is the work by Kormanik et al. (1982) shown is Table 3. These results clearly show that in soils containing normal forest soil amounts of available P (i.e., 10 to 15 $\mu g\ g^{-1}$), these eight species of hardwoods have an absolute requirement for VAM, i.e., they could never be competitive in a forest without VAM. Without VAM, they rarely grow beyond the primary leaf stage. Similar research is published on over 35 other hardwood tree species.

Field Performance. The ultimate value of mycorrhizal manipulation is to increase plant growth during nursery propagation, as just discussed, and to improve their field performance on their final planting site. Table 4 shows 8-year results with loblolly pine on an old-field reforestation site in Georgia. The differences in survival and growth was related to yearly rainfall. *During 4 dry years, trees with Pt* ectomycorrhizae grew at rates comparable to their growth rates during wetter years. Trees with only naturally occurring ectomycorrhizae slowed growth considerably during the dry years. There are numerous other publications presenting even more dramatic responses of trees to specific ectomycorrhizae formed by Pt and other fungi on mined lands, borrow pits, reforestation sites, and afforestation sites in Latin

Table 3. Response of eight hardwood tree species to VA mycorrhizae after 10 months in a bareroot nursery.

Treatment	Height (cm)	Diameter (mm)	Total wt. (g)
Prunus serotina (black cherry)			
VAM	70.00	6.90	29.30
Control	12.80	1.50	0.40
Acer negundo (boxelder)			
VAM	45.10	10.10	23.70
Control	12.80	3.20	0.70
Fraxinus pennsylvanica (green ash)			
VAM	37.40	8.60	23.00
Control	6.70	2.00	0.40
Acer rubrum (red maple)			
VAM	35.80	6.60	10.40
Control	8.30	2.40	0.40
Acer saccharum (sugar maple)			
VAM	9.30	3.30	3.06
Control	7.10	2.50	0.80
Liquidambar styraciflua (Sweetgum)			
VAM	29.60	7.0	12.10
Control	4.40	2.0	0.40
Platanus occidentalis (sycamore)			
VAM	66.60	12.90	71.30
Control	19.90	4.20	3.60
Juglans nigra (black walnut)			
VAM	24.80	7.90	85.60
Control	21.00	5.70	17.00

America, Asia, and Africa (Marx, 1991, Marx and Ruehle, 1989). Recently, mature oak and pecan trees in stressed urban landscapes have been inoculated by soil injection with ectomycorrhizal fungi which significantly stimulated root and mycorrhizal development.

There are numerous reports on the significance of VAM to field performance of a variety of plants including hardwood trees, desert shrubs and grasses, and woody ornamentals, grasses and flowers. Table 5 shows the response of yellow poplar after 4 years on three reforestation sites in Tennessee (Hay and Rennie, 1989). Survival and growth were significantly improved by preforming the VAM on seedling roots prior to outplanting.

CONCLUSIONS

Much is known about the biological value of mycorrhizae to plants. Research on the response of a variety of commercially and ecologically important plants to inoculation with diverse mycorrhizal fungi has shown the potential practical value of the mycorrhizal technology. Today, there are commercial inoculants of both

Table 4. Response of *Pinus taeda* (loblolly pine) after 8 years on an old-field site to *Pisolithus* (Pt) or naturally occurring ectomycorrhizae.

Treatment	% Survival	Height (m)	Volume/ha (m^3)
Pt	72.00	8.10	854.00
Natural	58.00	7.70	540.00

Table 5. Response of yellow poplar (*Liriodendron tulipifera*) after 4 years to VAM on three field sites (averaged) in Tennessee.

Treatment	Survival (%)	Height (cm)	Diameter (mm)	Plot vol. (cm^3)
VAM	66.00	108.00	22.50	363×10^4
Control	46.00	70.00	14.80	71×10^4

ectomycorrhizal and VAM fungi available for use to improve the biological quality of plants in various applications. By inoculating with the proper mycorrhizal fungi, we are bringing back that biologically essential part of the forest missing from our plants on man-made landscapes.

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