Mycorrhizae in Forest Tree Nurseries

Michelle M. Cram and R. Kasten Dumroese

Mycorrhizae are symbiotic fungus-root associations. The colonization of roots by mycorrhizal fungi can benefit the host by improving nutrient and water uptake. In exchange, the host plant provides the mycorrhizal fungi carbohydrates (carbon) from photosynthesis. A substantial portion of this carbon is ultimately transferred to the rhizosphere and is estimated to account for up to 15 percent of the organic matter in forest soils. Under most environmental conditions, trees and other plants are naturally colonized by mycorrhizal fungi. These mycorrhizal associations are highly complex and dynamic, a result of the great diversity of mycorrhizal fungi, hosts, and terrestrial systems that interact and evolve with changes in hosts and environmental conditions.

Two types of mycorrhizae are found on trees: ectomycorrhizae and arbuscular mycorrhizae (syn. endomycorrhizae). Ectomycorrhizal fungi enter the root between cortex cells and often form a thick mantle outside of the short feeder roots that is visible to the naked eye (fig. I.6). Forest tree species with ectomycorrhizae include pine, firs, spruce, hemlock, oak, hickory, alder, and beech.

Arbuscular mycorrhizal fungi enter the root cells and cannot be seen without the aid of a microscope (fig. I.7). Arbuscular mycorrhizae are especially effective at transferring carbon to soil in the form of glomalin, a sticky glue-like substance that is estimated to provide 30 to 40 percent of the carbon found in soils. Forest tree species with arbuscular mycorrhizae include cedars, cypress, junipers, redwoods, maple, ash, dogwoods, sycamore, yellow-poplar, and sweetgum. Agricultural crops used by forest nurseries as cover crops also form arbuscular mycorrhizae.

The intensive commercial seedling production for reforestation typically suppresses or delays colonization of seedlings by mycorrhizal fungi. Fumigation used to control pests can limit and sometimes remove mycorrhizal fungi from the upper 15 to 30 cm (6 to 12 in) of soil for weeks to several months. Some fungicides have also been found to suppress mycorrhizae development, especially systemic fungicides (for example, triadimefon) and fungicides applied as soil drenches (for example, azoxystrobin, iprodione). High fertilization rates have also been known to suppress mycorrhizae development, particularly when the fertilizer is high in phosphorus (greater than 150 ppm). Despite the negative effect these common nursery treatments have on mycorrhizae, the benefits of fertilization and pest control often outweigh the delay of mycorrhizae formation on seedlings.

Figure I.6—Pisolithus tinctorius *forms a yellow-brown (ocher) mantle on pine feeder roots.* Photo by Michelle M. Cram, USDA Forest Service.

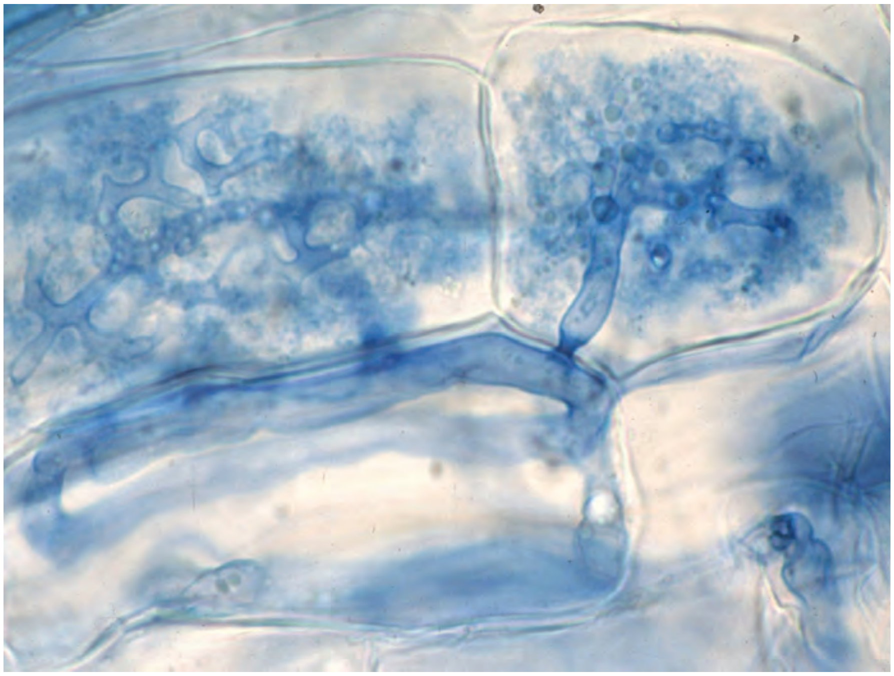

Figure I.7—*Arbuscular mycorrhizal fungi within western redcedar root cells.* Photo by Michael P. Amaranthus, Mycorrhizal Applications, Inc.

Ectomycorrhizal fungi are able to infest fumigated fields or containers via windblown spores produced by mushrooms and puffballs growing within or near the nurseries. These ectomycorrhizal fungi are often well-adapted to intensive nursery systems. *Thelephora terrestris* is common in most North American nurseries (fig. I.8). In the Pacific Northwest, *Laccaria laccata* and *Inocybe lacera* are also common forest nursery colonizers. In contrast, arbuscular mycorrhizal fungi produce soilborne spores that are unlikely to colonize container growing media and can be slower to recolonize fumigated soils. This delay in colonization can limit production of species highly dependent on arbuscular mycorrhizae.

Artificial inoculation with mycorrhizal fungi can be beneficial for a variety of tree seedlings and sites; however, there are many documented cases in which artificial inoculation resulted in no measurable benefit or significant losses in seedling survival and growth. The symbiotic association between plants and mycorrhizal fungi requires a balanced exchange of carbon to expanded nutrient and water uptake to be mutually beneficial. If the environmental conditions that plants are growing in are fully adequate for growth, then mycorrhizal fungi may add little benefit to offset their carbon use. Rapid colonization of seedlings by mycorrhizal fungi naturally present in the nursery or at a typical outplanting site may also render artificial inoculation unnecessary. Results of artificial inoculation will vary greatly depending on the host, species or strain of mycorrhizal fungi, and environmental conditions of the nursery and outplanting sites. The complexity of interactions between mycorrhizal associations and environmental conditions requires careful testing of a particular mycorrhizal inoculant to ensure a positive benefit-to-cost ratio before operational use.

Artificial inoculation with mycorrhizal fungi in the nursery is used to increase seedling performance in situations known by researchers and managers to have consistently positive results. *Pisolithus tinctorius*, an ectomycorrhizal fungus, has been known to increase survival and growth of pine and oak seedlings on strip mine spoils in the Eastern United States (fig. I.9). Artificial inoculation with arbuscular mycorrhizal fungi (for example, *Glomus intraradices*) for species such as incense cedar, redwood, giant sequoia, and western redcedar significantly increase seedling density and growth in the nursery, and survival and early growth after outplanting on some sites. Many other examples exist of nurseries that use artificial inoculation of mycorrhizal fungi in hardwood beds following fumigation, container operations, or as requested by their clients.

Mycorrhizal fungi may be purchased, usually in the form of spore inoculum. These products typically are applied in the nursery as a dry granular to soil or media before sowing or as a drench after germination. Some container media are sold with mycorrhizal fungi or spores incorporated. It may be difficult to find commercial products that contain only one species of mycorrhizal fungi. Many products often combine multiple species of mycorrhizal fungi, other biological organisms (for example, bacteria and *Trichoderma* spp.), and nutrients, making each ingredient's benefit difficult to assess. When testing mycorrhizal products that also contain nutrients, it is imperative to include a nutrient control to determine if seedling response is caused by the fungi

Figure I.8—Thelephora terrestris *fruiting bodies on slash pine.* Photo from USDA Forest Service Archive.

Figure I.9—Pisolithus tinctorius (Pt) *fruiting bodies form under a Virginia pine originally inoculated with Pt and planted on a strip-mine spoil.* Photo by Michelle M. Cram, USDA Forest Service.

or the nutrients. Managers interested in using or testing a particular mycorrhizal species may have to special order a single species product.

Some nurseries produce their own mycorrhizal inoculum. Ectomycorrhizal inoculum is made by grinding up the fruiting bodies (puffballs, truffles, etc.) and adding the spores to soil, dusting seeds, or mixing the inoculum with water and drenching containers or beds after germination (fig. I.10). Nurseries that use pesticides known to suppress mycorrhizae should delay artificial inoculation until after the pesticide applications are finished. The primary limitation to producing ectomycorrhizal inoculum is finding sufficient quantities of fruiting bodies. In contrast, arbuscular mycorrhizal inoculum can be grown in pots with fast growing host plants. Original inoculum is collected in the field from soil under desired tree species and mixed with container media before sowing host seeds, such as alfalfa and grasses. After the host plants have matured and are well infected (assistance from university or State extension services may be required to determining the presence and species), the soil and host roots can be cut up and added to container media (10 percent by volume) or applied to beds before sowing.

Common cover crops used in bareroot forest nurseries for 1- to 2-year rotations can help boost arbuscular mycorrhizae populations and increase organic matter content. This increase in mycorrhizal fungi, however, will most likely be lost if fumigation occurs between cover cropping and seedling production. Many nurseries that fumigate in the fall will use a winter cover crop, such as rye grass and oats, as living mulch. Winter cover crops in other agriculture systems increase arbuscular mycorrhizae levels in the subsequent summer crops. In forest tree nurseries, more information is needed on the interactions of mycorrhizae, cover crop, tree species, and application timing to deploy a rotational cropping system for managing seedlings dependent on arbuscular mycorrhizae.

The potential of mycorrhizae to positively affect seedlings survival and growth will continue to draw efforts at using artificial and cultural techniques to produce a superior mycorrhizal seedling. A better understanding of the mycorrhizal system for each nursery, tree species, and outplanting site is needed to determine the best cultural or artificial inoculation practices. Ultimately, any practices used in forest nurseries must increase seedling performance and have an acceptable benefit-to-cost ratio.

Figure I.10—*Puffball fruiting body of* Pisolithus tinctorius. Photo by Michelle M. Cram, USDA Forest Service.

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