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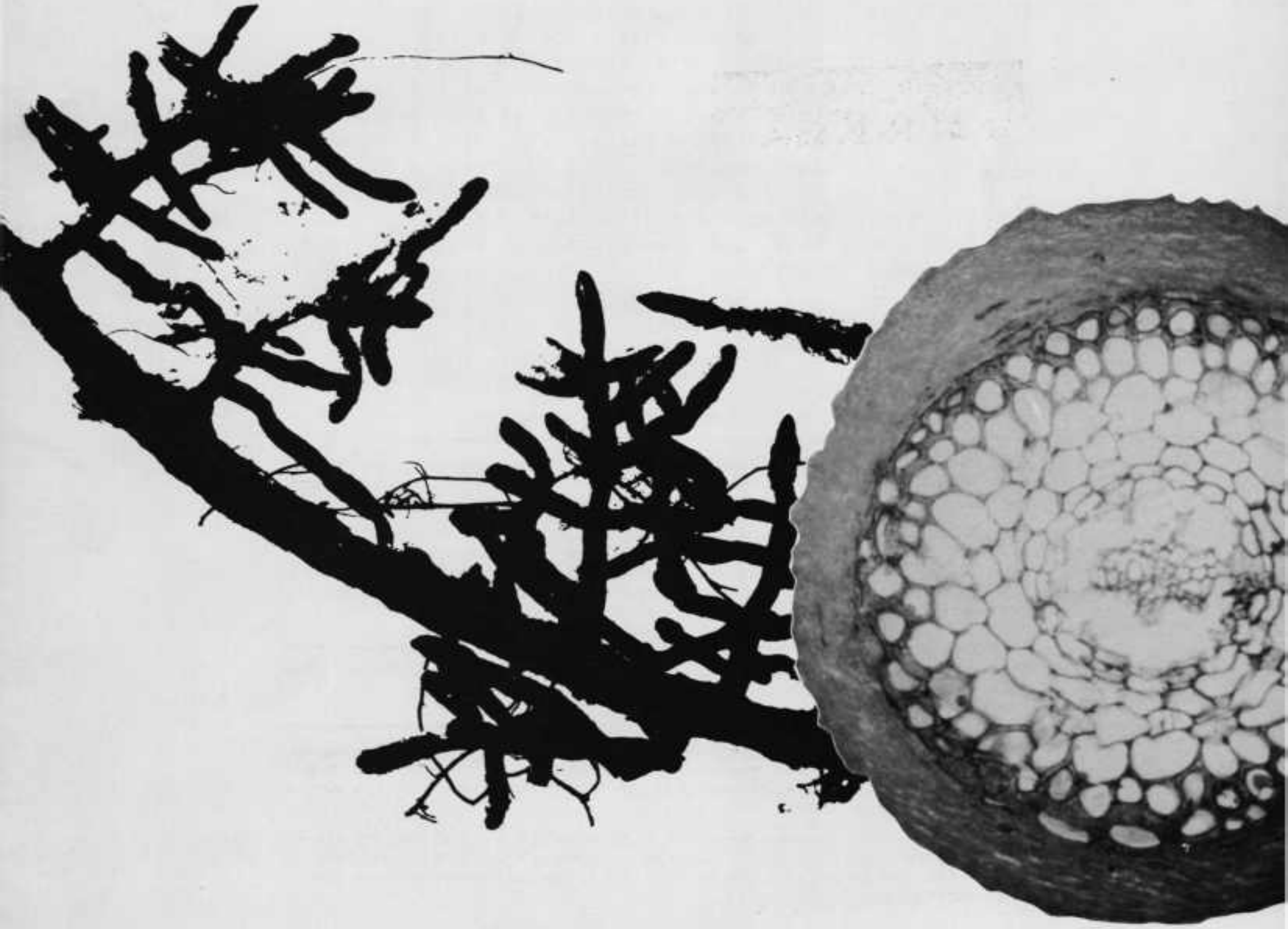
Mycorrhizae
A Hidden Benefactor to Forest Trees



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Cover:

The partial circle is a cross section of a Douglas-fir root colonized with mycorrhizea. The fine hyphal strands form a dense sheet around the root tip and probe the intercellular spaces of the outer root cortex. This intimate, symbiotic interaction between the roots and the mycorrhizal fungi provides food for the fungi by means of the tree and more efficient acquisition of water and nutrients for the tree by means of the fungi. A subdued representation of a mycorrhizal root extending out from the cross section depicts how a colonized root appears under slight magnification. Most of the fine hyphal strands, which radiate out from the sheet and are responsible for mining the soil or litter for water and nutrients, were lost during excavation of the seedling. (See figure 1 in text.)

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MYCORRHIZAE - A HIDDEN BENEFACTOR TO FOREST TREES

by David R. DeYoe and Kermit Cromack

Introduction

This report introduces you, the forest manager, to mycorrhizae, a special type of fungi that develops a unique and highly beneficial relationship with roots of forest trees. Its objective is to help you better understand mycorrhizae and the role they play in enabling forest trees to survive and grow and to describe the efforts being made by forest researchers to see how mycorrhizae might be used to improve reforestation success.

What Are Mycorrhizal Fungi?

Fungi are plants that cannot manufacture their own food because they are unable to convert sunlight into energy used for producing food sugars. Consequently, fungi must acquire food from other plants, including forest trees. Many fungi are detrimental to tree vigor and parasitize trees' roots to acquire the food they need. Another large group of fungi, known as mycorrhizae, form a mutually beneficial (symbiotic) relationship with the tree. Mycorrhizal fungi colonize roots of forest trees, forming extensive "root-like" fungal strands, called hyphae. Hyphae permeate the soil, increasing the surface area for absorption (Fig. 1). This helps the tree acquire water and nutrients more efficiently from the soil and even from humus and litter layers. In return, the tree provides a substantial allotment of food to the fungi for this service.

Why Are They Important?

Achieving success in your reforestation venture requires that you pay close attention to each of four components that comprise the reforestation process: seed quality and processing, nursery practices, seedling care and handling and the environment [climate, soils, living creatures (including humans) and geography]. Mycorrhizae are a select group of living creatures in the environment that are important to seedling establishment. As research accumulates, it is becoming clear that these symbiotic fungi are, in fact, essential to tree survival and growth. Survival of planted seedlings depends on rapid development of a root system capable of efficient use of the soil environment for uptake of water and nutrients. Mycorrhizae are more effective than tree roots at accumulating water and nutrients and can store excess nutrients, thus minimizing their loss from the root zone by leaching. The nutrients in this reserve cache can then be more efficiently allocated to the tree as they are needed. Although the presence of mycorrhizae on root tips slows root growth because the tree's food reserves are used for mycorrhizal growth and reproduction, this is not detrimental to the tree because the "thread-like" mycorrhizal hyphae better exploit the soil than do "rope-like" tree roots (Fig. 1). Colonization by mycorrhizae actually extends the life of individual root tips from days or weeks to months or years. In addition, mycorrhizae protect tree roots from invasion by damaging fungi. Beneficial mycorrhizal fungi are continually in competition with fungi that damage the tree. The protective advantage to the tree depends on root interaction with mycorrhizal fungi first. If damaging fungi infect the roots first they will seriously retard mycorrhiza development.* Mycorrhizae can also act upon organic matter and soil mineral complexes by releasing weak acids which increases the solubility of soil nutrients making them more available for absorption by hyphae and ultimately by tree roots.

The advantages that mycorrhizae provide to tree seedlings (soil exploitation, active enhancement of nutrient availability, uptake and allocation efficiency, increased root tip life span and root tip protection) manifest themselves in improved seedling survival and growth (Fig. 2A and 2B). Seedling height and diameter growth both are enhanced by the presence of compatible mycorrhizal species, being increased 10 to 1,000 percent or more, above that of non-mycorrhizal seedlings under identical conditions. Depending on the species (tree and mycorrhizae) and/or site conditions, the absence of mycorrhizae for an extended period (2-10 weeks depending on site severity) during seedling establishment can result in mortality.

These beneficial manifestations of mycorrhizae on seedling vigor may occur on any forest plantation regardless of site quality. However, the positive effects of mycorrhizae are most dramatic on low site class lands or on plantations that have been severely disturbed. This is because stress conditions disrupt tree root development and the acquisition of water and nutrients to a far greater extent than is the case with mycorrhizal hyphae. High site class lands, although frequently able to supply water and most nutrients** in amounts sufficient to meet the needs of trees and competing vegetation, support large mycorrhizal populations, indicating that mycorrhizae are important, but their effect is expressed in a more subtle fashion.

What Do Mycorrhizae Look Like?

The most common form of mycorrhiza in western forests, ectomycorrhiza (Fig. 3A), occurs on roots of trees such as Douglas-fir, western hemlock, most pines and some deciduous hardwood species, forming a dense mat of interwoven hyphae around the feeder root tips. Fungal hyphae radiating from this compact network of fibrous strands become an extension of the tree's root system (Fig. 1). This fungal mat and, to a lesser degree, the extending hyphal threads are usually easy to see with a hand lens.

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*The inhibition of one fungus type by another can be due to one or more of the following conditions: hoarding of tree foods so little is left for invading fungi, forming a physical barrier (hyphal mat) to entry by competing hyphae and producing substances which are toxic to other fungi.

**The mycorrhizal association with forest trees is necessary for absorption of adequate phosphorous from the soil, even on the best sites.

Other important coniferous tree species such as cedar and redwood have a symbiotic relationship with endomycorrhizae (Fig. 3B), a type of mycorrhiza that penetrates the root and resides within root cells limiting detection to examination with a microscope.

Most mycorrhizal fungi produce mushrooms as their visible, above-ground reproductive structures (Fig. 4A). Other mycorrhizae produce underground reproductive structures known as truffles (Fig. 4B).

How Do Mycorrhizae And Trees Get Together?

Colonization begins when the root tip comes in close proximity to hyphae in the soil or the mycorrhizal fungus spore (reproductive cells), triggering spore germination. Hyphae emerging from the spore tap into the tree's food supply and then rapidly colonize the root tip (Fig. 3).

Spores of the mycorrhizal fungus must be deposited on or within the soil where roots of the host tree will be available for colonization by the fungus. Spores from mushrooms are disseminated primarily by wind. Therefore mushrooms must be relatively close to the seedlings to insure that the symbiotic relationship between tree and mycorrhizae will be initiated.

Mycorrhizae producing truffles depend on mammals for spore dispersal. The truffles are eaten primarily by the small mammals, and to a lesser extent by deer, and the spores are spread in the fecal material. The Townsend chipmunk and the California red-backed vole, that inhabit numerous sites in our Pacific Northwest forests, have been found to be very important as "carriers" of truffle spores. The role these and other mammals play in spore dispersal is important to seedling establishment on forest sites and should be considered whenever control alternatives are being evaluated for animal damage to seedlings in new plantations.

Does Satisfactory Colonization Occur Under Natural Conditions?

Colonization of tree roots by mycorrhizal fungi is an integral part of the natural operation of a forest community. Most natural disturbances, such as wildfire, winds, ice storms, seasonal flooding, etc., do not interfere with the mycorrhizal population unless the disturbances are severe or prolonged. Hence, the likelihood that seedlings will be colonized by mycorrhizae when entering gaps* created by natural disturbances is high.

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*Gap is an ecological term used to refer to open areas created in young to mature forests by any type of disturbance. For example, openings caused by windthrow (or fire) can be large or small, and depending on gap size, the season in which the disturbance occurs and the developmental stage of the existing community, can alter stand structure (its physical appearance) and/or composition (its resident biological community).

At any point in time, and certainly over a period of time, many different species of mycorrhizae interact with a given tree species. One or a few are responsible for colonizing a young seedling, others join in after the tree is established and growing well. This suggests that the beneficial tree-fungus interaction is important enough to the forest community for nature to have invested considerable effort to insure a life-long association between the two plant types. This is manifested in the intricate and often obligatory interactions between the tree, its fungal associate and the mammals that inhabit the forest community.

It is important to remember that mycorrhizae are but one of many biological entities in the environment that are critical to seedling establishment in areas that have been disturbed. Climate, soil conditions and other biological factors, like competing vegetation, detrimental fungi, animals and insects, all blend together to affect an individual seedling's chances for survival in a given spot. Some make it, some don't; it's all part of the natural selection (survival of the fittest) process of plant succession, which rarely occurs fast enough to accommodate human reforestation needs. As a result, current investigations are evaluating the feasibility of colonizing seedlings artificially in the nursery, or possibly in old grass/brush fields, to help improve reforestation success, particularly on harsh sites.

Is Artificial Inoculation Of Seedlings Necessary?

Currently, we do not know if artificial inoculation in nurseries, or in the field, is cost effective. We do know that many disturbances caused by humans, either in managing seedlings in nurseries or harvesting and preparing forest sites for reforestation, can be damaging to mycorrhizae. If seedlings that have not been adequately colonized in the nursery are planted on harsh sites or in areas that have been disturbed severely enough to hinder natural mycorrhizal colonization, then the chances of plantation failure will increase substantially.

Nurseries frequently are located on sites that were, for many years, used in production of agricultural crops (grains and domestic animals). Eventually these sites became unable to support mycorrhizal communities, much the same as old grass/brush fields, because mycorrhizae depend on trees for existence. This, coupled with nursery soil fumigation practices to control undesirable fungi and bacteria, hindered natural re-entry of mycorrhizal fungi. In addition, the seedlings in nurseries are often heavily fertilized, which tends to suppress mycorrhizal colonization. The existence of such unfavorable conditions suggests a need for artificially inoculating seed beds with a compatible mycorrhizal species to aid seedling survival and growth.

Artificial inoculation of seedlings in nurseries does produce a more vigorous product. Whether the additional cost of artificial inoculation can be returned through increased survival and growth after planting, however, remains to be seen. A point involving reforestation costing that should be kept in mind is that the inoculation of seedlings and mycorrhiza in the nursery (even if only on a limited basis for difficult sites) can be cheaper, per acre, than the costs associated with re-entry after a full or partial plantation failure. This point, coupled with the known benefits of mycorrhiza may help fuel establishment of an operational inoculation program in the near future.

Another important point requires that you disturb the "future" plantation as little as possible during harvesting and site preparation treatments. Forest land manipulation practices known to reduce seedling survival or growth do so, in part, because they inhibit the ability of mycorrhizae to colonize seedling roots or create conditions that prevent site occupancy by seedling or mycorrhizae. Conditions that are particularly damaging to mycorrhizal populations, and to seedlings, include:

1) reduced soil oxygen (soil compaction from improper use of heavy equipment),

2) altered soil pH (improper use of fertilizers or lime, and failure to check pH of water used for any chemical treatments),

3) hydrophobic, "water-hating", soil conditions (intense field or slash burning),

4) prolonged flooding (soil compaction or harvesting in areas with poor drainage), and

5) chemical toxicity (improper use of fertilizers and herbicides or introduction of grasses or herbs that release inhibitory substances from their roots).

All of these conditions can easily be avoided if you pay close attention to the forest environment with which you are working and to the "potentially harmful" methods being employed.

What Can I Do As A Woodland Manager?

First of all, realize that mycorrhizae are a critical component of that forest system and their relationship with forest tree species is often essential to tree survival and growth.

Be aware that researchers are seeking information to better understand how mycorrhizae and trees can be manipulated to our advantage. Also, realize that nature's constraints, which are inherent to each forest system and are responsible for maintaining the integrity and smooth operation of any ecosystem, must not be compromised.

Be patient, because the operational use of mycorrhizae in seedling nurseries, for rehabilitation of old grass/brush fields or for helping to heal severely disturbed sites is not likely to occur until researchers can show that doing so is cost effective.

Hopefully, the answers needed will be obtained within the current decade.

What Are The Key Points To Remember About Mycorrhizae?

- Mycorrhizae are integral components of all forest ecosystems.

- Mycorrhizae form a mutually beneficial interaction (symbiotic) with forest trees that is essential to survival and development of both the mycorrhizae and the tree.

- Mycorrhizae must become associated with the tree to acquire needed foods they cannot produce on their own.

- Mycorrhizal reproductive structures, mushrooms above-ground or truffles below-ground, contain the spores that are disseminated by wind and small mammals.

- Any artificial methods of colonization begin with the collection of mushrooms or truffles, followed by processing of spores or growing of cultures in whatever fashion seems best suited for successful artificial inoculation of trees by the mycorrhizae.

- Mycorrhizal spores initiate colonization of tree root tips, resulting in development of "thread-like" hyphae that permeate the soil and litter in search of water and nutrients.

- The tree's association with mycorrhizae improves its chances for survival and vigorous growth through a) more effective exploration of the soil environment for water and nutrients, b) more efficient use of nutrients (time release from mycorrhizae to tree), c) increasing above-ground growth and improving competition for light and resistance to physical abuse (both biological and climatic) and d) retarding infection by damaging fungi.

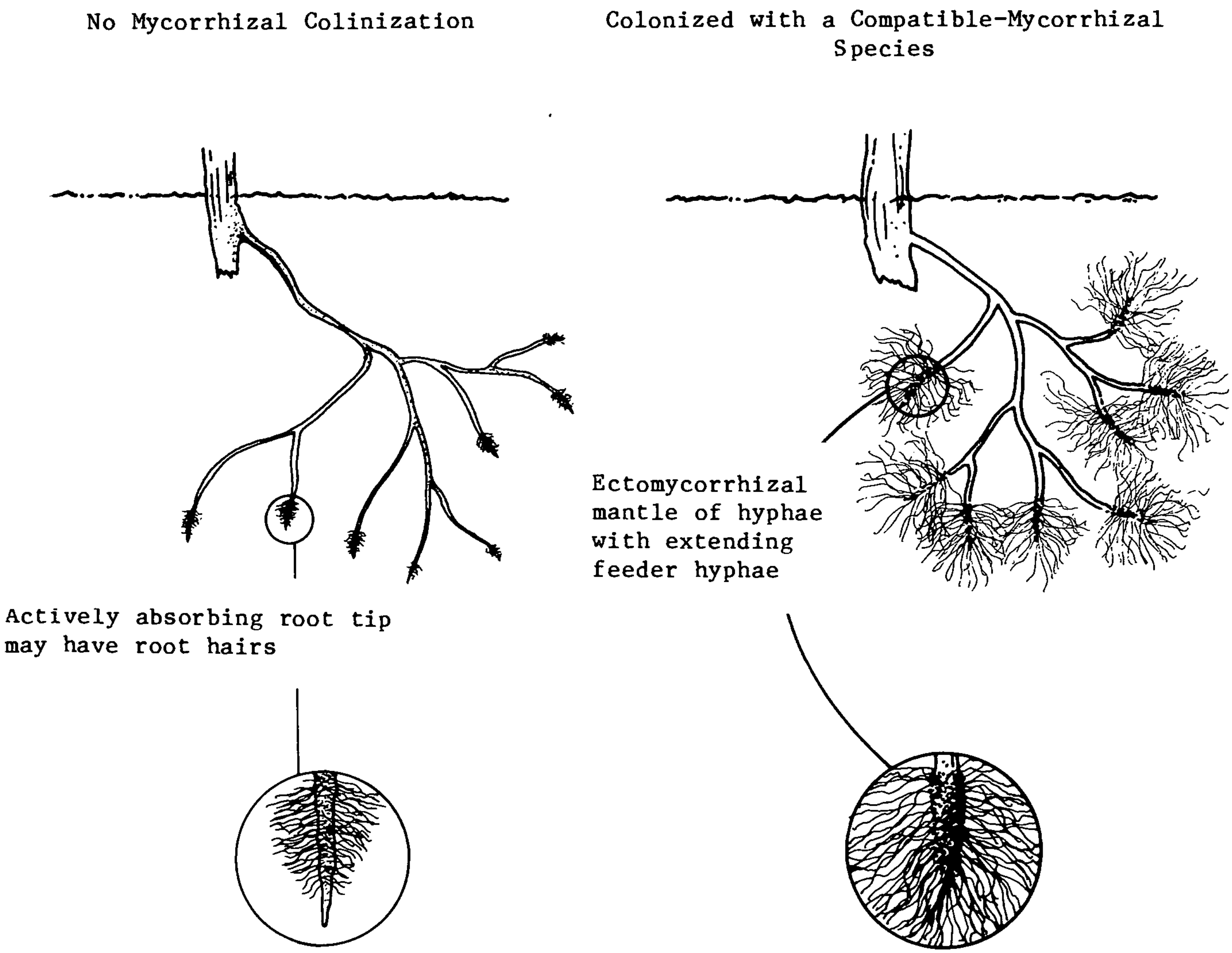
- Different mycorrhizal species interact with the tree at different stages of the tree's development, hence the species responsible for initial seedling establishment must be present, either naturally or artificially, to avert a regeneration failure.

- The mycorrhizal fungus-tree relationship occurs on all forest sites, good or bad. However, the positive benefits of the association are most obvious on sites of low quality.

- A disturbance--natural or human-induced--that creates any of the following conditions: low soil oxygen, altered soil pH, hydrophobic soils, presence of mycorrhizal toxins or flooding, will adversely affect mycorrhizal populations and site occupancy by the seedling.

The use of mycorrhizal fungi, ecologically adapted to a planting site, can increase the survival and growth of forest trees, particularly on low quality sites (nurseries, brush fields or sites severely disturbed). Management of mycorrhizal fungi may prove to be a valuable silvicultural tool because efficient uptake and dissemination of nutrients and water, protection from damaging fungi and superior seedling vigor all help enhance probability of reforestation success.

Figure 1: Mycorrhizal and non-mycorrhizal tree roots.



Do you see a difference in the amount of soil surface area capable of being exploited by the colonized tree roots?

Figure 2A and 2B.

2A: Douglas-fir 1-0 seedlings growing in a Willamette Valley nursery bed which was recently converted from a grass field. Initially the beds were largely devoid of mycorrhizal species capable of assisting seedlings because the absence of trees prevented survival of mycorrhizae. Consequently, healthy seedlings occur only in small pockets where roots were colonized by sporadic invasion of spores from distant sources. Several years may be required after conversion for nursery soils to become populated with beneficial species of mycorrhizae.

Note: Similar, or more devastating, results could also occur in brush field conversion or in areas severely disturbed by improper execution of site preparation methods.

2B: Survival and growth information for mycorrhizal (cross-hatched) and non-mycorrhizal (open) 1-0 Douglas-fir seedlings growing in this Willamette Valley nursery.

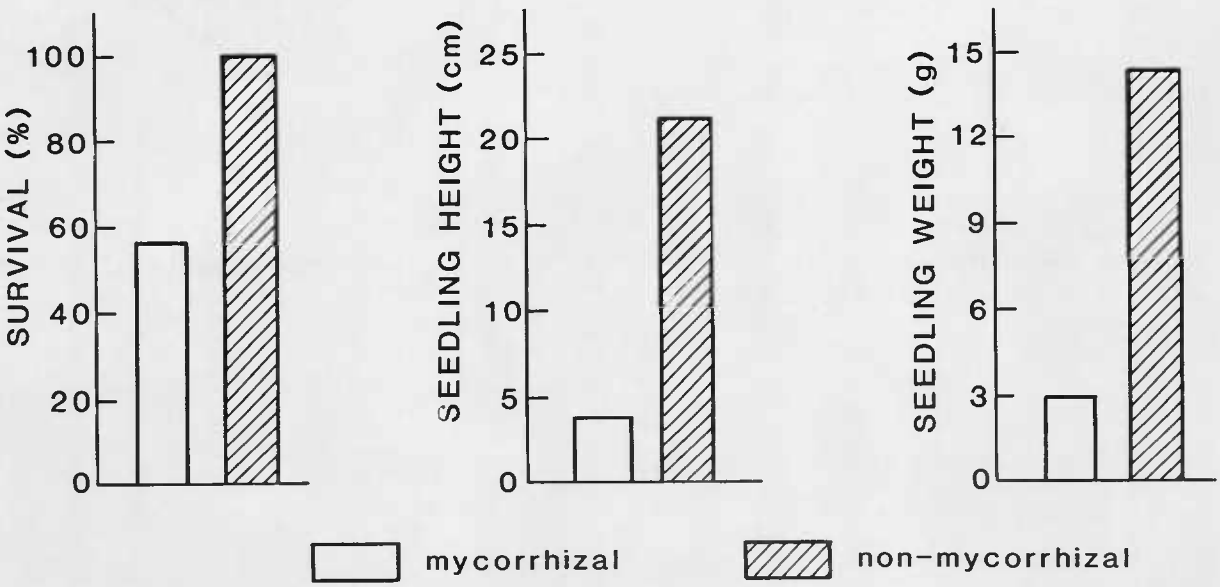
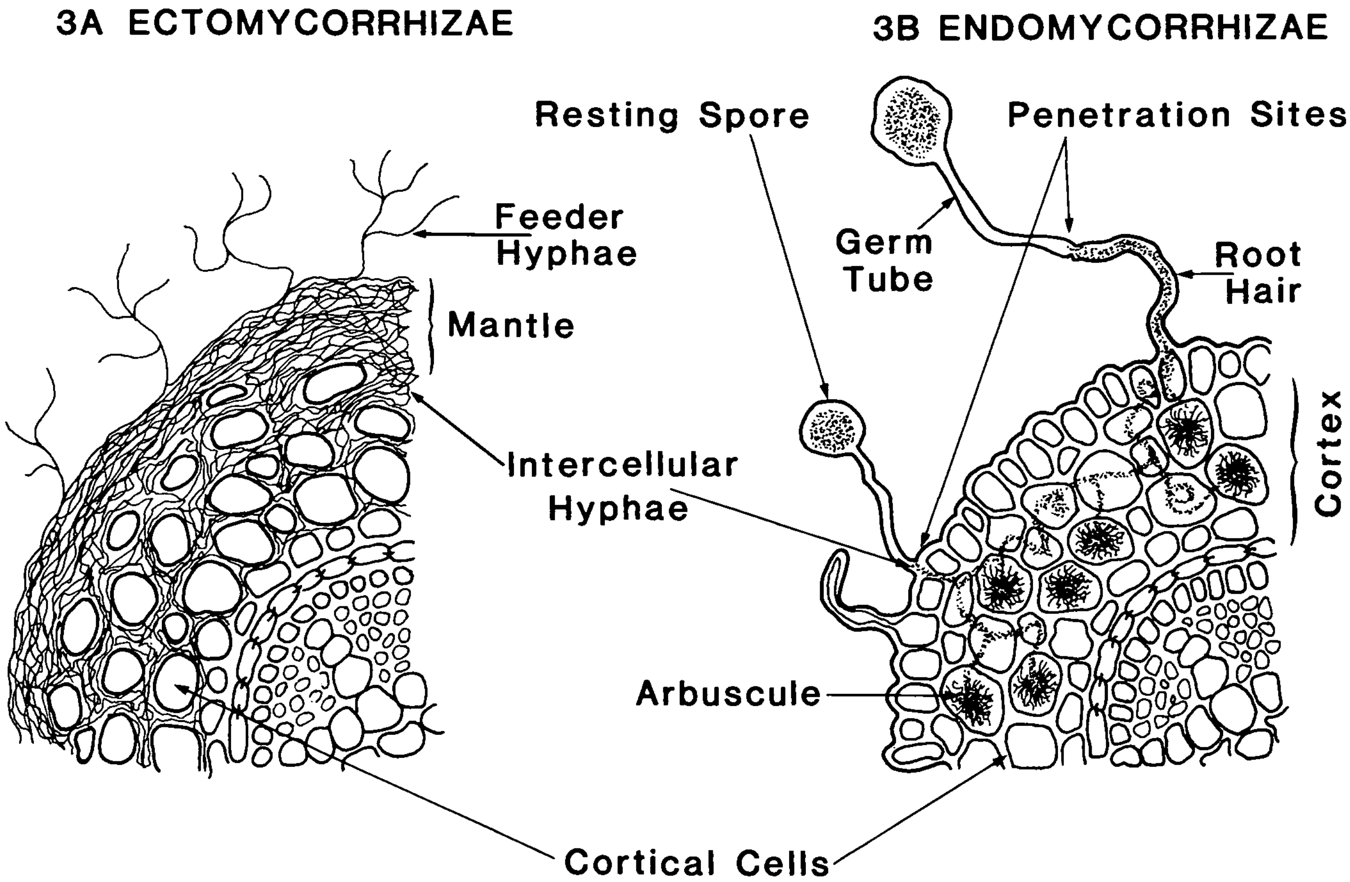


Figure 3A and 3B: Symbiotic association between tree roots and ectomycorrhizae (A) and endomycorrhizae (B).



Spores or resting hyphae of ectomycorrhizae are stimulated to germinate or grow, respectively, by approaching host root tips. After penetrating the root tip, an extensive intercellular (between the cells) network of hyphae is formed which provides a large surface area for exchange of food and nutrients between the symbiotic partners.

Resting spores of endomycorrhizae endure soil microclimate adversities while waiting for a compatible root tip to grow close enough to trigger spore germination. The germ tube penetrates the host root and invades the root cells. An arbuscule, a mass of intertwined, highly branched hyphae, develops inside the cells (intracellular), becoming rich with nutrients acquired from feeder hyphae in the soil. Eventually the arbuscules are digested by host cells, releasing their nutrient reserves and aiding the tree root.

Figure 4A and 4B: Reproductive structures of mycorrhizal fungi.

4A • Mushrooms are above-ground structures, with spores being wind disseminated.

4B • Truffles are below-ground structures. Spores are disseminated in the fecal matter of small mammals that feed on truffles.