BENEFITS AND APPLICATION OF ECTOMYCORRHIZAE IN SOUTHERN FOREST TREE NURSERIES

Charles E. Cordell[1/] and Donald H. Marx[2/]

Abstract.--Extensive laboratory and field studies by the USDA Forest Service have revealed practical techniques for applying the ectomycorrhizal fungus P. tinctorius (Pt) in container and bare-root nurseries, and demonstrated the benefits in forestation and mineland reclamation. Benefits include significant increases in nursery seedling quality (reduced culls) along with increased survival and growth in field plantings. Types of commercial inoculum include mycelium, bulk spores, spore pellets, and spore-encapsulated seed. A machine has also been developed to apply mycelial inoculum in bare-root nurseries. Considerable interest in use of Pt has been expressed by several forest and mineland reclamation agencies. Operational bare-root nursery inoculations have been conducted in the Southern and Central United States.

Additional keywords: Ectomycorrhizae, P. tinctorius, forest tree nurseries, seedling quality, field forestation, mineland reclamation, alternative inoculation techniques.

Roots of all forest tree seedlings form mutually beneficial associations called mycorrhizae with specific soil fungi. These symbiotic associations are the rule rather than the exception in nature; they are required for the successful production of the majority of, if not all, conifer and hardwood species. The two general types of mycorrhizae found in forest tree nurseries are ecto- and endomycorrhizae. The ectomycorrhizal fungi occur primarily on conifer species, while the endomycorrhizal fungi occur primarily on hardwood species.

During the past several years, the USDA Forest Service and a large number of cooperating forestry agencies have conducted extensive laboratory and field studies of mycorrhizae in forest tree nurseries and outplantings. This work has centered around the practical use of one ectomycorrhizal fungus, Pisolithus tinctorius (Pt). This fungus was selected because of its availability, ease of manipulation, wide geographic and host range, and demonstrated benefits to tree seedling hosts.

1/ National Mycorrhizae Applications Coordinator, Forest Pest Management, State and Private Forestry, Region 8, USDA Forest Service, Asheville, N.C.

2/ Director, Institute for Mycorrhizal Research and Development, Southeastern Forest Experiment Station, USDA Forest Service, Athens, Ga.

BENEFITS

Nurseries

Pt has been artificially inoculated into seedling containers and prefumigated nursery seedbeds producing many conifer and some hardwood species on a variety of nursery sites. Effective Pt vegetative inoculum has consistently improved the quality of nursery seedlings. National container and bare-root nursery evaluations have demonstrated the effectiveness of different formulations of Pt inoculum on selected conifer seedling species (Marx, Ruehle, and others, 1982; Marx, Cordell, and others, 1984). During the past 8 years, over 100 bare-root nursery tests have been conducted in 38 states. A companion evaluation of container seedlings also demonstrated the effectiveness of commercial Pt vegetative inoculum in 18 nurseries in 9 states (including Hawaii) and Canada (Marx, Ruehle, and others, 1982). These inoculations have increased feeder root ectomycorrhizal development and seedling quality, and significantly decreased plantable seedling losses (25% - nursery cull reduction). Negative results have been correlated with such factors as ineffective Pt inoculum, adverse environment and cultural management practices (both bare-root and container nurseries), and pesticide toxicity.

Field Plantings

Inoculated seedlings have been planted on a variety of sites--routine forestation sites, strip-mined areas, kaolin wastes, and Christmas tree farms, etc.--in locations scattered over the United States. Currently, over 100 Pt ectomycorrhizal outplantings involving 12 species of conifers are being monitored in 20 states. Over 75 of these outplantings involve southern pine species (primarily loblolly [*Pinus taeda* L] and slash pines [*P. elliottii* var. *elliottii* Engelm]) in the Southern United States. Most of these outplantings have been established since 1979 and, consequently, tree survival and growth results are preliminary. However, in outplantings of several conifer species in widespread locations tree survival and early growth have been improved by Pt inoculation in nurseries. A significant increase (25+%) in tree growth is also still being observed on eastern white (*P. strobus* L.), loblolly, and Virginia (*P. virginiana* Mill.) pines after 10 years in western North Carolina. Outplantings established by the Ohio Division of Mineland Reclamation on mineland reclamation sites in southern Ohio during 1982 and 1983 showed average survival increases of 18% and 59%, respectively, for Pt-inoculated Virginia and eastern white pine seedlings over routine nursery seedlings after 1 year in the field.

COSTS

The estimated costs of three primary types of commercial Pt inoculum are summarized in Table 1.

Table 1.--Commercial Pt inoculum costs[a/]

Pt inoculum type	Inoculum cost per 1,000 seedlings	Inoculum cost per planted hectare
Mycelium	$13.33	$23.91
Spore-encapsulated seeds	$ 2.22	$ 3.98
Spore pellets	$ 2.75	$ 4.93

a/ Above cost estimates are for loblolly and slash pine bare-root nurseries (269 seedlings/m^2) and forestation plantings (1.8 x 3.0 m spacing; 1794 trees/ha) in the Southern United States.

The commercial Pt ectomycorrhizal inoculum costs per unit of forest product will vary with such factors as inoculum costs, inoculum type, application rate, nursery seedling density, seed size (encapsulated seed), and field planting spacing.

NURSERY INOCULATIONS

During the past 10 years, the USDA Forest Service has been cooperating with private companies in the development of several types of commercial Pt inoculum (mycelium and spores), along with equipment needed for tailoring container-grown and bare-root seedlings. Alternative types of Pt inoculum that are or soon will be commercially available include mycelium from Sylvan Spawn Laboratories, Kittanning, Pa., and spore pellets, spore-encapsulated seeds, and bulk spores from either International Tree Seed Co., Odenville, Ala., or South Pine, Inc., Birmingham, Ala.

Container Nurseries

For container-grown seedlings, Pt spore or vegetative mycelium inoculum can be added directly into the rooting medium before containers are filled. In addition, spores can either be drenched or dusted onto the growing medium or applied as spore pellets after sowing seeds. Spores can also be attached to seedcoats, and these spore-encapsulated seeds can be sown by conventional techniques.

Bare-root Nurseries

In bare-root nurseries, Pt mycelium inoculum can be placed in prefumigated seedbeds before sowing (Fig. 1-a). Spores can also be drenched or dusted onto seedlings, pelletized and applied to seedbeds (Fig. 1-c), attached to seedcoats (Fig. 1-b) as with container-grown stock, or applied with commercial hydromulch (Fig. 1-d). The Pt spore inoculum has not generally been as effective as the mycelium inoculum, but it can be used operationally in some nurseries.

Ectomycorrhizal Mycelium Inoculum Applicator

A machine has been developed to apply Pt mycelium inoculum to nursery seedbeds (Fig. 1-a) (Cordell and others, 1981). It bands the inoculum into the seedling root zone at desired soil depths for maximum inoculation effectiveness and efficiency. During the past 5 years, the machine has performed well in 20 Southern and Central U.S. nurseries on six species of pines and more than 2 million seedlings. Use of this machine reduces inoculum requirements by 67% and significantly reduces labor and time requirements in comparison with the alternative broadcast application.

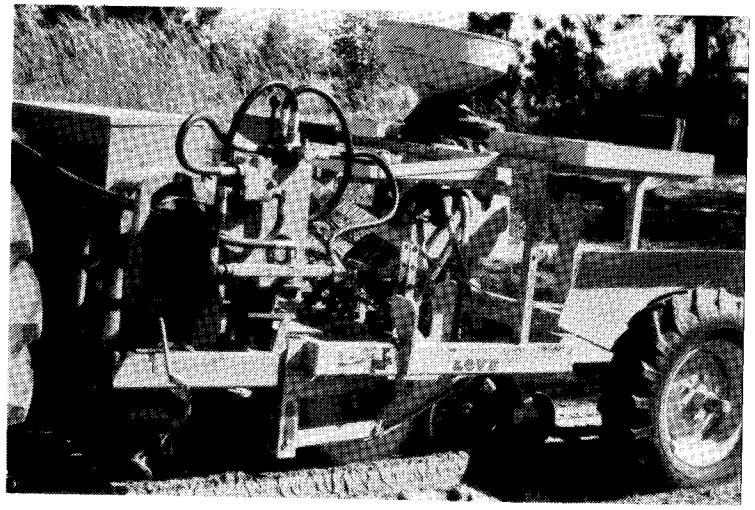
OPERATIONAL APPLICATIONS

Mineland Reclamation

Interest in use of Pt ectomycorrhizae in mineland reclamation has increased greatly in the past 4 years (Wolf, Cordell, and Keller, 1981). The Ohio Division of Reclamation has requested approximately 200,000 Pt-inoculated pine seedlings annually for reclamation sites in southern Ohio. Field tests are underway with Pt-inoculated and uninoculated seedlings on surface-mined land with soils that have been amended in various ways. High fertility and intensive site reclamation may reduce the positive effects of Pt ectomycorrhizae. However, Pt could significantly reduce reclamation costs by limiting site reclamation efforts to initial grass establishment, erosion control, and permanent plantings with trees tailored with Pt ectomycorrhizae.

Forestation

During the past 4 to 5 years, considerable interest has also been expressed by National Forests, several state forestry agencies, and a number of private companies in use of Pt ectomycorrhizae on selected field forestation sites in the Southern and Central United States. A private company with relatively large forest holdings in western North Carolina and northwestern South Carolina has scheduled the annual production of 500,000 eastern white and loblolly pine bare-root nursery seedlings inoculated with Pt spore pellets. These seedlings will be used in all the company's forest plantings. National Forests in Ohio and South Carolina have also scheduled the annual production of Pt-tailored bare-root seedlings for selected reclamation and forestation sites. Operational Pt inoculations were established in five Southern and one Central United States bare-root nurseries involving seven conifer and one hardwood species and over 1 million seedlings during the spring of 1985.



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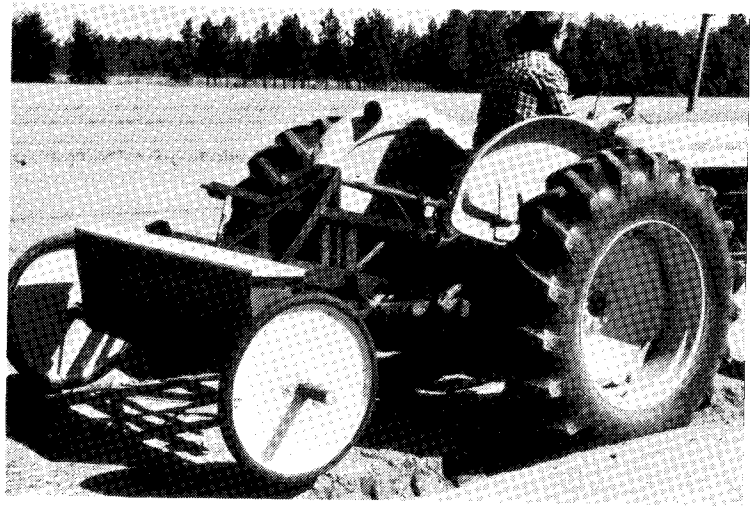

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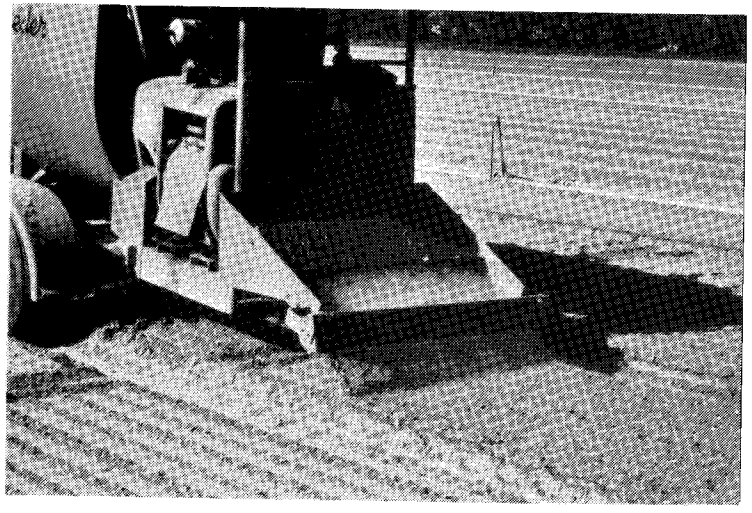

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Figure 1.--Alternative Pt inoculation techniques for bare-root nurseries - (a) mycelium inoculum applicator-nursery seeder, (b) spore-encapsulated seed, (c) spore pellets applied with a fertilizer applicator, and (d) spores applied with a hydromulch machine.

High-value Forest Products

The use of Pt in high-value plantings such as Christmas tree farms and custom-tailored southern pine species for forestation also appears promising (Ruehle, Marx, and Cordell, 1982; Kais, Snow, and Marx, 1981).

Technology Transfer

In a special program, the USDA Forest Service is providing mycorrhizae technology to forest tree nurserymen, field foresters, mineland reclamation specialists, and other concerned land managers (Cordell and Webb, 1980; Cordell, 1985). The present Pt effort emphasizes use in selected forestation and mineland reclamation programs. The techniques and procedures derived from this pioneering program should also be applicable to additional ectomycorrhizal fungi and expanded uses.

DISCUSSION

Several types of effective Pt inoculum can be used, and a machine for mycelium inoculations in bare-root nurseries is commercially available. These recent developments provide the nurserymen and land managers alternatives in planning Pt applications. The need for higher-quality nursery seedlings for successful field forestation and disturbed site reclamation by Federal, State, industry, and private forest land managers is becoming increasingly apparent. Although seedling costs represent a minor portion of forestation expense (less than 10%), seedling quality is the most significant factor in successful forestation and mineland reclamation. Consequently, the benefits of producing Pt-tailored seedlings for selected forestation and reclamation sites should greatly exceed the costs.

CONCLUSIONS

The Pt ectomycorrhizal fungus can be used operationally in container and bare-root seedling nurseries for the production of higher-quality seedlings with significantly improved survival and growth capabilities in field plantings. Overall, the best field planting results have been obtained on adverse sites such as coal spoils and poor reforestation sites. In addition, results are best when planted seedlings have Pt indices > 50 (Pt incidence greater than other natural ectomycorrhizae incidence on seedling feeder roots).

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