Table 1. — Comparative morphology of typical and atypical trees.

Character	Typical trees	Atypical trees	Fig.no.
Crown	Wide and flat-topped	Narrow, elliptical, pyramidal or conical	A-E
Bole	Short clear bole	Long clear bole	F
Stem surface	Kough	Smooth	G
Branches	Long, irregular, heavy, persistent	Short, regular thin, deciduous	B-E
Bark colour	Dark	Light	B,C,G
Foliage	Leaf sprays shorter,blunt at the tip, scale leaves broader, not closely appressed to axis; dark green in colour	Leaf sprays longer, finer and pointed at the tip, scale leaves narrower closely appressed to axis; glaucous green in colour	-

Discussion

In many North Temperate species of conifers narrow-crowned varieties have long been known and described by taxonomists under appropriate varietal names such as *pyramidalis, columnaris, fastigiata, pendula* etc. (see DALLIMORE and JACKSON, 1954). The narrow-crowned variants of Mulanje Cedar reported here probably represent a similar true-breeding variety of this native Central African conifer.

Recently Finnish tree breeders obtained a 1:1 segregation of narrow-crowned and normal trees in open pollinated progeny of a 90-year old narrow-crowned tree of Scots pine (KARKI, 1986) and two 'pendula' trees of Norway Spruce (LEPISTO, 1984) suggesting that the parent trees they investigated were heterozygous for a single gene dominant mutation with pleiotropic effects. The same could also be true of the narrow-crowned atypical Mulanje Cedar trees described here. Further investigations are continuing.

KARKI (1980, 1985) enumerated the several possible advantages of using genetically narrow-crowned tree ideotypes in plantation forestry. The narrow-crowned Mulanje Cedar variants reported here could potentially have similar advantages in future Silviculture and Arboriculture of this valuable native conifer.

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Table 2. — Comparative measurements of typical and atypical trees for six characters.

Character	Typical Trees									Atypical Trees								
	I	II	III	IV	V	VI	VII	VIII	Average	I	II	III	IV	V	VI	VII	VIII	Average
Total height (m)	32.3	29.6	30.1	29.9	32.6	32.8	28.8	35.1	31.4	31.8	32.6	31.6	31.8	32.1	33.1	33.6	33.6	32.5
Height of clear bole (m)	14.8	12.3	14.3	14.3	14.8	13.8	13.8	11.1	13.7	17.6	17.3	19.1	17.6	16.6	14.3	17.8	18.6	17.4
Crown height (m)	17.5	17.3	15.8	15.1	17.8	19.0	15.0	24.0	17.7	14.2	15.3	12.5	14.2	15.5	18.8	15.8	15.0	15.2
Crown width (m)	8.6	15.8	10.5	8.6	10.1	10.0	8.3	12.2	10.5	3.2	2.6	3.6	4.0	4.4	4.6	2.5	5.4	3.8
DBH OB (cm)	57	57	61	53	52	54	48	71	56.6	34	35	40	34	34	32	32	37	34.8
Bark thickness (cm)	1.4	1.2	1.3	1.4	1.6	1.5	1.6	1.3	1.412	0.4	0.6	0.6	0.7	0.6	0.6	0.6	0.5	0.575

Growth and Ectomycorrhizal Development of Loblolly Pine Progenies Inoculated with Three Isolates of Pisolithus tinctorius

By R. K. DIXON, H. E. GARRETT and H. E. STELZER

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The authors are, respectively, Associate Professor, School of Forestry, Auburn University, Auburn, AL 36849-4201, USA; Professor, School of Forestry, Fisheries, and Wildlife University of Missouri, Columbia, MO 65211, USA; and Graduate Instructor, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907, USA.

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Summary

Loblolly pine (*Pinus taeda* L.) progenies from an Oklahoma, USA, tree improvement program were inoculated with different isolates of the fungal symbiont *Pisolithus tinctorius*. Seedlings showed genetic variation in ectomycorrhizal development, shoot height, component dry weights, and net assimilation rate. Rapid growing progenies exhibited superior mycorrhizal colonization and a positive correlation between infection and total dry weight. Net assimilation rates of seedlings from each family inoculated with selected strains of *P. tinctorius* were superior to con-

trol seedlings during ontogeny. Both fungal and host genotype influence mycorrhizal symbiosis and subsequent seedling growth.

Key words: Pisolithus tinctorius, Pinus taeda, ectomycorrhizae, symbiosis, tree seedlings.

Zusammenfassung

Nachkommenschaften kontrollierter Kreuzungen von *Pinus taeda* L. des Baumzüchtungsprogrammes in Oklahoma, USA, wurden mit verschiedenen Isolaten des symbiontischen Pilzes *Pisolithus tinctorius* geimpft. Die Sämlinge zeigten genetische Variationen in der Entwicklung ihrer Ektomycorrhiza, sowie in Triebhöhe, Trockengewicht der Komponenten und ihrer Nettoassimilationsrate. Die schnellwachsenden Nachkömmlinge zeigten eine bessere Besiedlung durch die Mycorrhiza und eine positive Korrelation zwischen Infektion und Gesamttrockengewicht. Die Nettoassimilationsrate der Sämlinge aus jeder Familie, die mit ausgesuchten Linien des Pilzes *P. tinctorius* geimpft wurden, war während der Ontogenie besser als die der Kontrollsämlinge. Sowohl der Pilz- als auch der Wirtgenotyp beeinflussen die Symbiose mit dem Pilz und das darauffolgende Sämlingswachstum.

Introduction

Previous investigations have revealed that seed source may influence the degree of ectomycorrhizal infection and subsequent growth of tree seedlings following inoculation (Linneman 1960). For example, Wright and Ching (1962) reported that ectomycorrhizal formation of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seedlings varied with seed source in the nursery. In provenance trials with Scots pine (*P. sylvestris* L.) *in Sweden,* Lundeberg (1968), observed that the relative susceptibility of seedlings to infection by ectomycorrhizal fungi varied significantly among provenances following outplanting. These early studies suggested that provenances or cultivars will differentially enter into mycorrhizal symbiosis with a given species or strain of fungi.

Recent research has examined variation in ectomycorrhizal formation and early growth of half-sib progenies of *Pinus* spp. inoculated with different fungal symbionts. Marx and Bryan (1975) observed that slash pine genotypes (*P. elliottii* var. *elliottii* Engelm) regulate the degree of ectomycorrhizal development by *Pisolithus tinctorius* (Pers.) Coker and Couch, as well as the early shoot growth following ectomycorrhizal colonization. Host genotype of loblolly pine (*P. taeda* L.) also influenced ectomycorrhizal formation by a single isolate of *Pisolithus tinctorius* (Long 1973). In contrast to earlier studies, Cline and Reid (1982) observed that the benefit received by different provenances of lodgepole pine (*P. contorta* var. *latifolia* Engelm) and ponderosa pine (*P. ponderosa* var. *scopulorum* Engelm) following ectomycorrhizal colonization was influenced by the amount of ectomycorrhizal infection rather than host genotype. However, provenance genotype did indirectly affect seedling growth by influencing ectomycorrhizal colonization of the root system.

Few studies have examined the role of fungal genotype in the ectomycorrhizal infection process or subsequent growth response to colonization. Laiho (1970) reported that isolates of *Paxillus involutus* Batsch ex Fr. differ in their ability to form ectomycorrhizae with various tree species. Isolates of *Pisolithus tinctorius* also vary widely in ability to infect and colonize root systems of loblolly pine seedlings from an open-pollinated seed source (Marx 1981). Selected strains of *Rhizopogon luteolus* Fr. and Nordh. impart significantly greater growth responses in radiata pine (*P. radiata* D. Don) than to others (Theodorou and Bowen 1970). These studies suggest that fungal genotype does influence ectomycorrhizal development and early seedling growth. However, the complex relationship between host genotype and fungal genotype has not been evaluated.

Table 1. — Sources and date of isolation of three isolates of *Pisolithus tinctorius* used to inoculate container-grown loblolly pine.

Isolate No.	Source and isolation date
29	Quercus - Pinus, Georgia, USA, isolated in 1959 by B. Zak from sporocarp tissue.
145	Quercus acutissima, Kentucky, USA, isolated in 1974 by D. Marx from sporocarp tissue.
270	Pinus taeda, Georgia, USA, isolated in 1980 by D. Marx from sporocarp tissue.

The purpose of this study was to evaluate: 1) the ectomycorrhizal development of nine open-pollinated progenies of loblolly pine inoculated with three isolates of *Pisolithus tinctorius* and 2) the net assimilation rate and morphological characteristics of seedlings following ectomycorrhizal colonization.

Materials and Methods

Fungal isolates and inoculum preparation

Three isolates of *Pisolithus tinctorius* were used (*Table 1*). These isolates represent a range of ability to infect loblolly pine and impart a growth response (Marx 1981). The isolates were grown as stock cultures in test tube slants of modified-Melin-Norkrans (MMN) medium and stored in darkness at 5° C until inoculum preparation (Marx 1969). Vegetative mycelial inoculum for each isolate was grown in two-liter glass jars using procedures described by Marx and Bryan (1975). After 10 weeks, the inoculum was removed from the jars and leached repeatedly with deionized water to remove unused nutrients, and stored at 5° C until used.

Seed source and seedling culture

Open-pollinated seed were collected from nine loblolly pine selections currently under evaluation by the Department of Forestry at Oklahoma State University (personal communication, Dr. Charles Tauer, Oklahoma State University, Stillwater, OK, USA). The nine selections were chosen based on their BV-20 value. A BV-20 value is an estimate of a selection's breeding value, in a percent form, at age 20 (personal communication, Mr. Thomas Byram, Western Gulf Forest Tree Improvement Cooperative, College Station, TX, USA). The baseline BV-20 value of the genetic test sites under evaluation is considered to be 100; this can be viewed as the plantation average. Superior selections will have a BV-20 value greater than 100, while inferior selections will have values less than the baseline value. Nursery-run check selections included in these genetic tests have a BV-20 value of 92.

As can be seen from *Table 2*, selections 1, 2, and 3 with BV-20 values of over 120, are considerably better than the test plantation average, and have been incorporated into second generation orchards. Selections 4, 5, and 6 are slightly below average with a breeding value of approximately 95, and are being maintained in first generation orchards. Finally, selections 7, 8, and 9 with BV-20's of less than 90 have been rogued from the program.

Seed were stratified and stored using standard procedures (Schopmeyer 1974). Following 90 days of stratification,

Table 2. — Breeding values at age 20 (BV-20) of the selections under investigation. Baseline value is 100; check selections possessed a BV-20 of 92.

Selection	BV-20 Value
(Superior)	
1	124
2	122
3	121
(Average)	
4	97
5	95
6	93
(Inferior)	
7	87
8	86
9	81

seed of uniform weight were pre-germinated aseptically using procedures outlined by DUNLAP and BARNETT (1983).

A 1:1 sphagnum moss-vermiculite mixture, fumigated with methyl bromide (Dowfume MC-2, Dow Chemical Co., Midland, MI, USA) for 48 h, was the potting substrate (DIXON *et al.* 1984). Mycorrhizal treatments were implemented by mixing one part inoculum with 20 parts sterile potting substrate. Noninoculated seedlings from each selection were grown in sterile sphagnum moss-vermiculite drenched with inoculum leachate. Four-cavity (500 cc capacity) rootrainers (Spencer-LeMaire Industries, Ltd. Edmonton, Alberta, Canada) were filled with the appropriate medium and pregerminated seed were planted one per cavity. The rootrainers, each containing one seedling, were arranged in a completely randomized block design. Within each of five blocks a given fungal × half sib family treatment combination (4 × 9) consisted of 14 rootrainers of four seedlings each.

Seedlings were grown in a glasshouse for 20 weeks from May through September, 1982. Glasshouse ambient temperature ranged from 22—34° C, and a photoperiod of 16 h was maintained with supplemental sodium vapor lights (750 $uE \cdot m^{-2} \cdot s^{-1}$). Seedlings were watered with tap water on alternate days or as needed. All seedlings received 75 ml of full-strength HOAGLAND's solution on a weekly basis following seedling emergence (HOAGLAND and ARNON 1939).

Seedling analysis

Four seedlings per treatment per block were harvested at random on an alternate week basis throughout the study period. After 20 weeks, 16 additional seedlings per treatment per block were harvested.

Root systems were gently washed free of potting substrate and visually examined for ectomycorrhizal colonization by each test fungus. To further verify mycorrhizal development approximately 10 percent of the suspected short roots were free-hand sectioned, mounted, and examined at 100 × for fungus mantle and Hartig net development. Percent ectomycorrhizal colonization was determined by methods described by DIXON *et al.* (1981).

Oven dry (80° C, 24 h) weights of roots, shoots, and needles were recorded. Shoot length and root collar diameter of each seedling were also measured. Weight measurements were used to compute net assimilation rates, root/shoot ratios, and leaf/total weight ratios (EVANS 1972).

All data were subjected to analysis of variance, and where appropriate, differences among treatment means were compared with the least significant difference test (LSD) ($P \leq 0.05$). Mean values of shoot length, total dry weight, and ectomycorrhizal colonization for each of the nine families are presented in *Appendix 1.* These results indicate that families with similar BV-20 values responded similarly to treatments imposed in this experiment. In the interest of brevity, extensive results for three families representing superior (family 2), average (family 5), and inferior (family 8) BV-20 values will be presented and discussed.

Results

Ectomycorrhizal infection

All isolates tested formed ectomycorrhizae with loblolly pine (*Table 3*). However, significant differences among families in ectomycorrhizal colonization were only observed on seedlings inoculated with *Pisolithus tinctorius* isolate 270. Generally, progeny 2 formed the most ectomycorrhizae, followed by progenies 5 and 8. Control seedlings were not contaminated with ectomycorrhizae.

Inoculation with isolate 270 resulted in abundant coralloid and bifurcate ectomycorrhizae yellow to gold in color. The Hartig net developed to the endodermis and mantles were 30 to 50 u thick. Approximately 50 percent of seedling laterals were infected with *P. tinctorius* ectomycorrhizae 12 weeks after inoculation with isolate 270. Sporocarps of *P. tinctorius* developed in the containers of seedlings inoculated with isolate 270 in the eighteenth week of the study.

Inoculation with isolate 145 resulted in significantly less ectomycorrhizae than observed for isolate 270 for progenies 2 and 5 but not for 8. Ectomycorrhizae of isolate 145 were yellow in color and Hartig net and mantle development on short roots were incomplete. When present, mantle thickness ranged from 10 to 20 u.

Significantly fewer laterals were infected with isolate 29 for all three progenies. Ectomycorrhizae were golden brown and mantle development was visible on only a few short roots.

Shoot length and root collar diameter

Shoot length and root collar diameter were greatest for progeny 2, followed by 5 and 8, respectively (*Table 3*). Inoculation of progenies 2, 5, and 8 with isolate 270 stimulated

Table 3. — Shoot length, root collar diameter, and percent ectomycorrhizal laterals of three 20-week old loblolly pine progenies inoculated with four ectomycorrhizal fungal treatments.

Progeny	Fungal isolate	Shoot[1/] length (cm)	Root[1/] collar diameter (cm)	Ectomycorrhizal[1/] laterals (%)
2	control	13.2cde	4.4cd	0a
	29	15.1ef	4.1bc	18b
	145	14.3de	4.0b	51c
	270	17.9f	5.3e	86e
5	control	12.0bc	4.2bc	0a
	29	13.0cd	4.6d	23b
	145	13.2cde	4.1b	42c
	270	14.7de	4.5cd	71de
8	control	9.9ab	3.2a	0a
	29	10.4ab	3.6a	16b
	145	8.9a	4.0b	45c
	270	13.4cde	4.3bcd	56cd
Main Effects				
Fungi		*	*	*
Progeny		*	*	*
Fungi x Progeny		*	ns	ns

[1/] Means within a column not sharing a common letter differ significantly ($P \leq 0.05$) by LSD test.

* Significant differences as determined by F-test ($P \leq 0.05$).

Appendix 1. — Shoot length, total dry weight, and percentage of ectomycorrhizal laterals of nine 20-week-old loblolly pine progenies inoculated with four ectomycorrhizal treatments.

Progeny	Fungal isolate	Shoot length (cm)	Total dry weight (g)	Ectomycorrhizal laterals (%)
1	control	13.0	4.0	0
	29	14.9	4.4	20
	145	14.5	4.0	49
	270	18.1	6.6	87
2	control	13.2	4.1	0
	29	15.1	4.4	18
	145	14.3	4.0	51
	270	17.9	6.6	86
3	control	12.8	4.1	0
	29	14.9	4.3	21
	145	14.7	4.2	56
	270	18.2	6.7	89
4	control	11.9	4.0	0
	29	13.0	4.0	22
	145	13.3	4.0	45
	270	14.7	5.1	68
5	control	12.0	4.3	0
	29	13.0	4.4	23
	145	13.2	5.2	42
	270	14.7	5.1	71
6	control	12.0	4.3	0
	29	13.1	4.4	25
	145	13.2	5.0	44
	270	14.6	5.2	72
7	control	9.9	2.4	0
	29	10.0	3.0	19
	145	9.0	3.5	48
	270	13.5	4.3	53
8	control	9.9	2.3	0
	29	10.4	3.1	16
	145	8.9	3.4	45
	270	13.4	4.4	56
9	control	10.0	2.4	0
	29	10.1	2.9	10
	145	9.4	3.3	49
	270	13.6	4.4	51
Fungi		*	*	*
Progeny		*	*	*
Fungi x Progeny		*	ns	ns

*Significant differences as determined by F-test ($P \leq 0.05$).

significant increases in height over control seedlings. Plants in family 2 inoculated with isolate 270 were 36 percent taller than noninoculated control seedlings. Generally, inoculation with isolates 29 and 145 did not impart a significant height growth response in any family. Root collar diameter was significantly stimulated following inoculation of progenies 2 and 8 with isolate 270. Inoculation of family 5 with isolate 29 and family 8 with isolate 145 also resulted in significant increases in root collar diameter.

Total dry weight

Total dry weight of progenies 2 and 8 were significantly increased compared to control seedlings following inoculation with isolate 270 (*Table 4*). Inoculation with isolate 270 resulted in a 61 percent increase in dry weight over control seedlings in progeny 2 and a 91 percent increase in progeny 8. Inoculation with isolates 29 and 145 did not result in significant dry weight gains. Again, inoculation of family 8 with isolate 270 yielded results not significantly different from noninoculated family 2 or 5.

Root/shoot and leaf/total weight ratios

Inoculation of progenies 2 and 5 with isolate 270 significantly decreased root/shoot ratios relative to control seedlings (*Table 4*). In contrast, leaf/total weight ratios increased in progenies 2 and 5 following inoculation with isolate 270. As before, family 8 inoculated with isolate 270 and noninoculated family 2 did not differ significantly for either parameter.

Net assimilation rate

Inoculation with isolate 270 significantly increased net assimilation rates over controls in progenies 2 and 5 over the final 12 weeks of the experiment (*Figure 1*). Moreover, the relative decrease in net assimilation rates of seedlings inoculated with isolate 270 was less when compared to the other fungal treatments. Inoculation of seedlings in family 8 with isolates 29, 145, and 270 significantly improved net assimilation rates over control seedlings.

Discussion

Ectomycorrhizal development was greatest on seedlings inoculated with *Pisolithus tinctorius* isolate 270 and least with isolates 29 and 145. The latter two isolates were poor symbionts on loblolly pine in a previous study (Marx 1981). Although original host and age in culture may significantly reduce virulence, both of these fungi grew rapidly in pure culture. The relationship between *in vitro* growth of ectomycorrhizal fungi and the ability to enter a symbiotic relationship remains unclear (Marx 1981; Dixon *et al.* 1984). Differential formation of ectomycorrhizae suggests that fungal genotype influences ectomycorrhizal formation. Our results agree with previous studies which indicate that a single strain of fungus may infect a range of host genotypes (Theodorou and Bowen 1970).

The superior growth response of seedlings inoculated with isolate 270 and relatively poor growth of seedlings inoculated with isolates 29 and 145 suggests differential ability of strains to benefit seedling growth. Several workers have demonstrated that ectomycorrhizal strains within a species differ in element uptake efficiency (Bowen 1973; Harley and Smith 1983), adaptation to water stress (Mexal and Reid 1973), plant growth regulator production (Crafts and Miller 1974, and host carbon consumption (Hacskaylo 1973; Harley and Smith 1983). Because the seedlings in this study were grown in a uniform environment and received equal amounts of mineral fertilizer and water, strain superiority in mineral nutrition or water uptake may be discounted. Other factors such as substantial host carbon con-

Table 4. — Total dry weight, root/shoot ratio and leaf/total dry weight ratio of three 20-week old loblolly pine progenies inoculated with four ectomycorrhizal fungal treatments.

Progeny	Fungal isolate	Total[z] dry weight (g)	Root/[z] shoot ratio	Leaf/[z] total weight ratio
2	control	4.1bc	1.0bc	0.3a
	29	4.4bc	0.9abc	0.4ab
	145	4.0bc	0.8ab	0.5ab
	270	6.6d	0.7a	0.6b
5	control	4.3bc	1.1c	0.3a
	29	4.4bc	0.9abc	0.4ab
	145	5.2cd	1.0bc	0.4ab
	270	5.1cd	0.7a	0.6b
8	control	2.3a	0.8ab	0.3a
	29	3.1ab	0.8ab	0.4ab
	145	3.4ab	0.9abc	0.4ab
	270	4.4bc	0.8ab	0.5ab
Main Effects				
Fungi		*	ns	ns
Progeny		*	*	*
Fungi x Progeny		ns	ns	ns

[z] Means within a column not sharing a common letter differ significantly ($P \leq 0.05$) by LSD test.

* Significant differences as determined by F-test ($P \leq 0.05$).

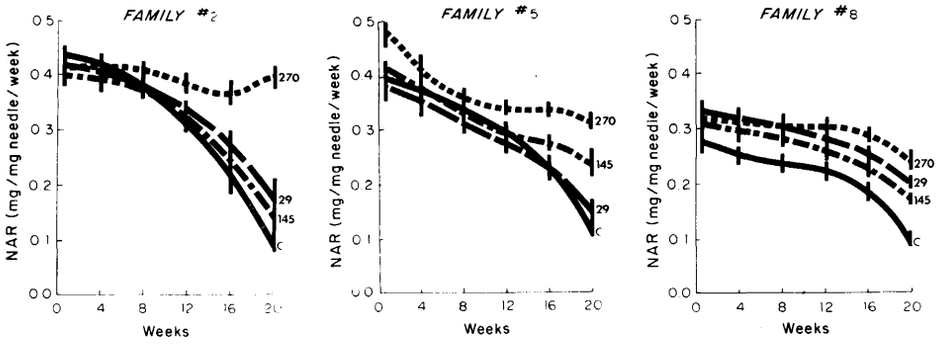

Figure 1. — Mean variation in net assimilation rate (NAR, mg/mg needle/week) over a 20 week period for three loblolly pine families inoculated with *P. tinctorius* 270 (— — — — — —), 145 (—— — —— — ——), 29 (———— ————), and noninoculated control (————————). Vertical bars indicate ± one standard error.

sumption by isolate 29 may have resulted in the large seedling growth differences (Bevege *et al.* 1975).

The degree of ectomycorrhizae formation by isolate 270 on progeny 8 was low, while formation of progeny 2 was relatively high. Similar colonization patterns were observed for isolates 145 and 29. Root systems of seedlings (e.g., number of laterals and short roots) harvested from these two progenies were similar. Thus, the potential sites for ectomycorrhizal infection were similar in both. Other factors such as host susceptibility to infection, phenology of short root formation, fungal specificity, or rhizosphere compatibility of the host and fungi may have influenced mycorrhizal formation (Harley and Smith 1983). Differential ectomycorrhizae formation by some strains of *P. tinctorius* on different progenies suggest the influence of host genotype on ectomycorrhizal formation is significant. Previous studies have shown that potential for mycorrhizae formation was highly dependent on seed source (Moser 1958; Wright and Ching 1962; Lundeberg 1968; Marx and Bryan 1971). However, ectomycorrhizal colonization by some symbionts such as *Thelephora terrestris* Ehr. ex Fr., seemingly are not influenced by host genotype (Marx and Bryan 1971).

Total dry weight of seedlings in progenies 2 and 8 was significantly increased following inoculation with *P. tinctorius* isolate 270. Significant increases in root collar diameter were observed in selected progenies following inoculation with isolates 145 and 29. Moreover, seedling dry weights in progeny 2 were positively correlated with percent ectomycorrhizal colonization by isolates 145 and 270 ($r = 0.86$ and 0.84, respectively). This growth response was generally found when ectomycorrhizal infection was 50 percent or greater, suggesting that a minimal level of root system colonization is necessary for a virulent symbiont to impart a growth response. Marx *et al.* (1982) also concluded that a threshold infection level of approximately 50 percent was necessary to improve the growth of southern pines.

Growth responses following ectomycorrhizal formation on loblolly pine were strongly influenced by host genotype. Superior growth of hosts, such as progeny 2, remained superior regardless of fungal partner. Long (1973) and Marx and Bryan (1971) also suggested that loblolly pine genotype controls the benefit seedlings obtained from ectomycorrhizal relationships. In contrast, Cline and Reid (1982) concluded that the benefit received by lodgepole and ponderosa pine was directly controlled by the amount of mycorrhizal colonization rather than the host genotype. Our study suggests host genotype indirectly influences seedling growth by controlling the rate and degree of mycorrhizal colonization.

Evaluation of net assimilation rate revealed that seedlings inoculated with isolate 270, and to a lesser degree isolate 145, were superior in dry weight gain per unit of needle dry weight relative to controls. Inoculation with isolate 29 did not significantly influence net assimilation rate in progenies 2 and 5. Net assimilation rates were high initially and declined during seedling ontogeny. Other investigators have observed similar patterns of net assimilation rate for loblolly pine (Ledig and Perry 1969). The general decline in net assimilation rate by all seedlings may be attributed to: 1) self-shading of needles as total needle surface area increases or 2) a decrease in needle photosynthetic efficiency or capacity during ontogeny. The superior net assimilation rate of the inoculated seedlings during ontogeny suggests that ectomycorrhizal symbionts may increase photosynthesis and/or decrease respiration rates of the seedlings (Reid *et al.* 1983). The influence of ectomycorrhizae on photosynthesis and respiration rates may be related to improved water relations (Dixon *et al.* 1983), mineral uptake (Harley and Smith 1983) or changes in plant growth regulator metabolism (Crafts and Miller 1974).

In all seedling variables measured, inoculation of an inferior host family with fungal isolate 270 resulted in growth comparable to a noninoculated superior host family. While we do not propose that inoculating trees with mycorrhizal fungi supercedes the need for forest tree improvement, we do suggest that mycorrhizae research should be integrated into tree improvement programs. Such considerations could result in retaining co-called borderline genotypes within a breeding program which would in turn maintain a broader genetic base for advanced generation breeding.

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The Effect of Water Spray Cooling Treatment on Reproductive Phenology in a Douglas-Fir Seed Orchard

By A. M. K. Fashler[1]) and Y. A. El-Kassaby[2])*)

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Abstract

The effectiveness of reproductive bud cooling on the genetic efficiency in a Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] seed orchard was tested by comparing the reproductive bud phenology in three cooled and three uncooled years. The cooling system was found to influence two major elements affecting seed orchard genetic efficiency, namely pollen contamination levels and panmictic equilibrium, as well as a number of additional factors, including insect infestation, frost damage, seed yield, and management effectiveness. Based on these results, a solid-set overhead irrigation/cooling system is recommended for Douglas-fir seed orchards.

Key words: *Pseudotsuga menziesii*, seed orchards, overhead cooling systems, panmictic equilibrium, contamination.

Zusammenfassung

In einer Douglasien-Samenplantage wurde die Auswirkung der Kühlung reproduktiver (Blüten-)Knospen auf die genetische Effizienz geprüft, indem die Phänologie der Blütenknospen in drei Jahren mit Kühlbehandlung mit der in drei Jahren ohne Kühlbehandlung verglichen wurde. Es wurde gefunden, daß die Kühlung zwei Hauptelemente beeinflußt, nämlich das Niveau der Pollenkontamination und das panmiktische Gleichgewicht, außerdem eine Anzahl zusätzlicher Faktoren, wie Insektenbefall, Frostschaden, Samenausbeute und Effizienz der Bewirtschaftung. Auf diesen Ergebnissen basierend, wird ein dauerhaft eingebautes Beregnungssystem für Douglasien-Samenplantagen empfohlen, das über Gipfelhöhe der Pflanzen sprüht.

Introduction

The advantages of seed orchards for production of consistent and abundant yields of genetically-improved seed for reforestation programs are recognized (cf. Faulkner 1975). The resulting seed crop is expected to reflect both the genetic superiority and broad genetic base present among the orchard trees. The degree to which a seed orchard achieves this expectation is called the "genetic efficiency" (Adams and Joly 1980). Several conditions are required to achieve maximum genetic efficiency in wind-pollinated seed orchards. These include: a) parental reproductive balance, b) isolation from background pollen, c) minimal rates of selfing, d) random mating with equal compatibility, and e) reproductive synchronization (Woessner and Franklin 1973). In short, if a seed orchard crop is to reflect its expected theoretical genetic gain, the orchard itself must represent a nearly perfect, closed, panmictic population.

Several management practices have been implemented in seed orchards to increase the genetic efficiency. These in-

[1]) Forest Consultant, 2188 West 46th Avenue, Vancouver, B.C., Canada V6M 2L1 (formerley with Pacific Forest Products Ltd., Victoria, B.C.).

[2]) Tree Improvement Supervisor, CIP Inc., Tahsis Pacific Region, Saanich Forestry Centre, 8067 East Saanich Road, RR # 1, Saanichton, B.C., Canada V0S 1M0 and Adjunct Professor, Department of Forest Sciences, Faculty of Forestry, University of British Columbia, Vancouver, B. C., Canada V6T 1W5.

*) To whom reprint requests should be addressed.