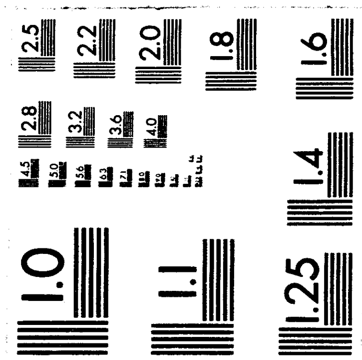
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DOE/SR/15122--T1

Department of Energy and U.S.D.A. Forest Service
Interagency Agreement DE-AI09-86SR15122

FINAL REPORT
1986-1991

RESEARCH IN SUPPORT OF FOREST MANAGEMENT

by

Institute of Tree Root Biology (SE-4551), Athens, GA
Diseases of Southern Forests (SE-4502), Athens, GA
Utilization of Southern Timber (SE-4701), Athens GA
Forest Soil Productivity in the Southeast (SE-4102),
Research Triangle Park, NC

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December 1991

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PROJECT SUMMARY

This final research report on Research in Support of Forest Management for the Savannah River Forest Station covers the period 1986 thru 1991. The original 5-year Interagency Agreement (DE-AI09-86SR15122) was extended one year to complete certain studies. Total 6-year funding from DOE to the Southeastern Forest Experiment Station (SEFES) was $666,000.

This report provides a budget breakdown by year, a list of publications resulting from research accomplished by SEFES scientists and their cooperators, and a list of continuing research study titles. Output is 22 research publications, 23 publications involving technology transfer of results to various user groups, and 11 manuscripts in pre-publication format. DOE funding contributed approximately 15 percent of the total cost of the research; the remainder was funded by the SEFES through the following research work units:

I. SE-4551, Institute of Tree Root Biology (formerly Institute for Mycorrhizal Research and Development), Athens, GA - 14 research publications, 21 technology transfer publications, and 8 pre-publications.

II. SE-4502, Diseases of Southern Forests, Athens, GA - 4 research publications, 1 technology transfer publication, and 1 pre-publication.

III. SE-4701, Utilization of Southern Timber, Athens, GA - 2 research publications.

IV. SE-4102, Forest Soil Productivity in the Southeast, Research Triangle Park, NC - 2 research publications, 1 technology transfer publication, and 2 pre-publication.

The research is an extension of that reported in the Final Report (December 1990) for Interagency Agreement DE-AI09-76SR00870. Some long-term studies initiated during the period of that Agreement (1975 thru 1989) are reported here; this shows the continuum of forest management research activities by scientists in the SEFES. A total of twenty-two studies funded by these Agreements are still continuing and will not be completed for several years.

Following Forest Service policy, all research studies had a written comprehensive study plan that was reviewed both inside and outside the SEFES prior to initiation of research. This involved not only the evaluation of the merits of the science but, also, the validity of the experimental design and statistical evaluation. The study plan with its supporting research data, maps, and other information is a permanent record of the specific research study until the study is closed.

The research accomplished can be summarized as follows:

1. Nursery protocols were developed for ectomycorrhizal fungus manipulation, for increasing root fibrosity, and for increasing seedling quality which, after field validation, increased survival and growth of loblolly and longleaf pines (SE-4551).

2. Determined the biological, genetical, and practical significance of first-order lateral roots on pine and hardwood seedlings for maximizing their competitive abilities under natural forest conditions (SE-4551).

3. Investigated the significance of pyrophosphate-dependent sucrose metabolism to tree vigor and overall physiology (SE-4551).

4. Determined that genetic lines of loblolly pine selected for fusiform rust resistance were no more sensitive to air pollution than routine commercial lines (SE-4502).

5. The systemic insecticide carbofuran decreased the incidence of tip moth damage and also decreased the incidence of fusiform rust disease on young loblolly pines (SE-4502).

6. Municipal sewage sludge applied to a good-quality forest site increased growth, lowered fusiform rust disease, did not significantly affect the proportion of biomass in wood, bark or foliage, but did decrease tracheid length in loblolly pine (SE-4502 and SE-4701).

7. Developed a conceptual stand-level model using mutual negative feedbacks between aboveground carbon allocation and soil organic matter. Increased organic matter is linked to increased available water and nutrients (SE-4102).

DOE Funding to Southeastern Forest Experiment Station:
Research in Support of Forest Management

FY86	$100,000
FY87	105,000
FY88	110,000
FY89	114,000
FY90	117,000
FY91[1]	120,000
	$666,000

[1] Original Agreement (DE-AI09-86SR15122) covered a 5-year period of research funding from FY86 to FY90. In order to complete certain ongoing studies, the Savannah River Forest Station allocated $120,000 for FY91 to the Southeastern Forest Experiment Station. Thus, the actual budget to the SEFES was $666,000 for 6 years and not $549,000 for 5 years as decribed in the original Agreement.

COMPLETED RESEARCH

I. Research by Institute of Tree Root Biology (SE-4551).

A. Research on Mycorrhizae and Reforestation

1. Marx, D.H., Cordell, C.E. and France, R.C. 1986. Effects of triadimefon on growth and ectomycorrhizal development of loblolly and slash pines in nurseries. Phytopathology 76:824-831.

Three or four sprays with the systemic fungicide triadimefon (Bayleton) each at 0.56 kg a.i./ha applied in May and June to control fusiform rust disease significantly suppressed ectomycorrhizal development by artificially introduced *Pisolithus tinctorius* and naturally occurring fungi by two- to threefold on loblolly and slash pine seedlings throughout the growing season compared with seedlings sprayed (17-41 times) with the fungicide ferbam. The average indices of *P. tinctorius* ectomycorrhizae in the three nurseries after triadimefon and ferbam sprays were 2 and 69, respectively. Basidiocarp production by ectomycorrhizal fungi in triadimefon-treated plots occurred later in the growing season (September) and was 3-10 times less than in ferbam-treated plots. Residues of triadimefon and its metabolite triadimenol were detected in roots and tops of seedlings. These residues, especially triadimenol, were detected in one nursery up to 116 days after the last triadimefon spray in amounts sufficient to strongly inhibit growth of *P. tinctorius* and *Thelephora terrestris* in pure culture. The ED_{50} of triadimefon on growth of *P. tinctorius* and *T. terrestris* was 0.98 and 1.66 mg/L, respectively; the ED_{50} of triadimenol was 0.40 and 0.25 mg/L, respectively. Triadimenol residues ranging betweeen 0.4 and 4.5 µg/g of root were detected up to 116 days after the last triadimefon spray.

2. Marx, D.H. and Cordell, C.E. 1987. Triadimefon affects *Pisolithus* ectomycorrhizal development, fusiform rust, and growth of loblolly and slash pines in nurseries. USDA For. Serv. Res. Paper SE-267, 14 pp.

Three triadimefon sprays of 0.14, 0.21, 0.28, or 0.42 kg a.i./ha plus seed soaking significantly suppressed ectomycorrhizal development by introduced *Pisolithus tinctorius* on slash and loblolly pine seedlings in two nurseries in comparison with control seedlings with or without fermate spray. All dosages effectively controlled fusiform rust disease. Mycorrhizal suppression was dose-related. Triadimefon seed soaking alone did not suppress *Pisolithus* ectomycorrhizal development, but it did reduce seedling density by 16 percent. Residues of triadimefon and triadimenol were detected in seedcoats, endosperm, primary needles, radicals, and roots after seed soaking and seed germination of both pine species. Seedlings of both pine species were significantly smaller after spraying with 0.42 kg a.i./ha than control seedlings. Highest doses of triadimefon significantly reduced viability of inoculum of *P. tinctorius* buried in nursery soil for 2.5 months. Loblolly pine seedlings assayed 15 days after the last spray were less susceptible to colonization by fresh inoculum of *P. tinctorius* at the higher dose of triadimefon than were control seedlings. All triadimefon sprays at both nurseries suppressed naturally occurring ectomycorrhizal development throughout the growing season. Residues of triadimefon and triadimenol in roots were consistently correlated with suppression of ectomycorrhizal development in all instances.

3. Marx, D.H., Cordell, C.E., Maul, S.B. and Ruehle, J.L. 1989. Ectomycorrhizal **development on pine by Pisolithus tinctorius in bare-root and container seedling** nurseries. I. Efficacy of various vegetative inoculum formulations. New Forests 3:45-56.

A commercial pure culture, vegetative inoculum of Pisolithus tinctorius (Pt) produced by Sylvan Spawn Laboratory (now MycorrTech, Inc.) that does not require leaching and drying was formulated and tested on pine seedlings in operational bare-root nurseries, on seedlings in microplots and on container-grown seedlings. Incorporation of inoculum with C:N ratios of 50 to 60 into nursery beds at 0.33 liter/m^2 of soil, or into container medium in the ratio 1:10 (v/v) with rooting medium provides effective ectomycorrhizal development by Pisolithus tinctorius on southern pine seedlings.

4. Marx, D.H., Cordell, C.E., Maul, S.B. and Ruehle, J.L. 1989. Ectomycorrhizal development on pine by Pisolithus tinctorius in bare-root and container seedling nurseries. II. Efficacy of various vegetative and spore inocula. New Forests 3:57-66.

Vegetative inoculum produced by Sylvan Spawn Laboratories (now MycorrTech, Inc.) and machine-applied at a rate of 0.16 liter/m^2 of soil produced abundant Pisolithus tinctorius (Pt) ectomycorrhizae (Pt index >50) on pine seedlings. Approximately 0.6 to 0.7 liter of inoculum is required to produce 1,000 seedlings at a bed density of 270 seedlings/m^2. Using current methods of application, spore inoculum in different forms will consistently produce Pt ectomycorrhizae but not in the amounts formed by effective vegetative inoculum.

5. Marx, D.H. 1990. Soil pH and nitrogen influence Pisolithus ectomycorrhizal development and growth of loblolly pine seedlings. For. Sci. 36:224-245.

Five families of loblolly pine were grown from April to February in fumigated soil at pH 4.8, 5.8, and 6.8. All microplots received vegetative inoculum of Pisolithus tinctorius (Pt) and three, six, or nine applications of NH_4NO_3 at 50 kg N/ha/application through August, which totaled 150, 200, or 450 kg N/ha. Vegetative inoculum of Pt buried in soil lost significant viability after 54 days at soil pH 6.8. Inoculum viability declined in all treatments after 81 days, but it was only a little over a third as viable at pH 6.8 as at lower pH levels. Up to three applications of NH_4NO_3 at 50 kg N/ha each did not affect inoculum viability.

The five families of loblolly pine reacted similarly to soil treatments. Seedling height, root-collar diameters, and top dry weights were more affected by soil pH than by application of N. As soil pH increased, seedling growth decreased. Dry weight of roots, total length of lateral roots, and number of short roots were not significantly influenced by either soil treatment. Total Pt ectomycorrhizal ratings (combining number of mycorrhizae and proportion of different morphological types) were about one-fourth as much at pH 6.8 as in more acid soil conditions. Applications of NH_4NO_3 resulting in soil concentrations of NO_3-N ranging from 60 to 120 kg/ha and NH_4-N ranging from 90 to 130 kg/ha at pH 4.8 and 5.8 were associated with the most abundant Pt ectomycorrhizal development. Increased N applications increased Pt development at pH 5.8 and 6.8. Calcium equivalent treatments, using $CaSO_4$ at similar Ca concentrations, suggested seedling response was due to soil pH and not Ca concentrations.

6. Marx, D.H. and Hatchell, G.E. 1991. Specific nursery cultural practices that affect field performance of longleaf pine seedlings. pp. 113-122 in Proceedings Southern Forest Nursery Association Meeting, July 1990, Biloxi, MS.

Longleaf pine seedlings were grown at the South Carolina Coastal Nursery at a density of 9 seedlings/ft^2 with vegetative inoculum of Pisolithus tinctorius (Pt) or no inoculation, and with or without vertical root pruning in mid-August and again in late September. Evaluation of seedlings at lifting showed that vertical root pruning decreased shoot/root ratio and increased Pt index of inoculated seedlings. Average root collar diameters (RCD) ranged from 10.1 to 11.2 mm and were not affected by the treatments.

Representative seedlings ($\geq$8 mm RCD) were outplanted by machine on three sites at the Savannah River Forest Station, Aiken, SC. Site 1 is an Americus loamy sand (site index 65), site 2 is a Lakeland sand (site index 60), and site 3 is a Troop sand (site index 65). All sites were prepared by shearing, raking, and bedding. After 3 years, Pt ectomycorrhizae and vertical root pruning significantly increased survival, total height, percentage of seedlings in active height growth, and RCD, as well as seedling and plot volumes. Site 1 supported the best growth of seedlings.

Seedlings were also grown in Athens, GA, at four bed densities (6, 9, 12, and 15 seedlings/ft^2) with and without vertical root pruning, and with and without vegetative inoculum of Pt. Evaluation of seedlings at lifting showed that cull percent ($\leq$8 mm RCD) increased with increasing bed densities (9.5 to 55.7%) and that seedling sizes (RCD and weight) and Pt ectomycorrhizal development decreased with increasing densities. Root pruning significantly increased Pt ectomycorrhizal development at all densities. Representative seedlings ($\geq$8 mm RCD) from each nursery treatment were outplanted by machine on site 1 described above. After 4 years, low bed density, lateral root pruning, and Pt ectomycorrhizae significantly improved seedling survival, total height, percent seedlings in active height growth, RCD, and seedling and plot volumes. The best treatment combination (6 seedlings/ft^2, Pt ectomycorrhizae, and vertical root pruning) increased plot volumes by over 2.6 times compared to the worst treatment combination (15 seedlings/ft^2, natural ectomycorrhizae and no vertical root pruning).

7. Gruhn, C.M., Roncadori, R.W. and Kormanik, P.P. 1987. Interaction between a vesicular-arbuscular mycorrhizal fungus and phosphorus fertilization on sweetgum growth in loamy sand and kaolin spoil. Reclam. Reveg. Res. 6:197-206.

The effect of the vesicular-arbuscular mycorrhizal fungus, Gigaspora margarita, on the growth and development of sweetgum (Liquidambar styraciflua) at two phosphorus levels in a loamy sand soil and in kaolin mine spoil is reported. Total biomass production, growth rate, foliar nutrient content and mycorrhizal development in 161-day-old seedlings are presented.

Non-mycorrhizal seedlings grew best in a loamy sand soil supplemented with 100 μg P g^{-1}, but in kaolin spoil did not respond to this rate of fertilization unless they were mycorrhizal. In soil receiving 25 μg P g^{-1}, growth rate of mycorrhizal seedlings was significantly greater than that of non-mycorrhizal seedlings and foliar levels of P, Mg and Ca were enhanced by both mycorrhizal colonization and P fertilization. Mycorrhizal development and spore production were suppressed at the high P level.

B. Research on Lateral Root Configuration and Reforestation.

1. Kormanik, P.P. 1986. Lateral root morphology as an expression of sweetgum seedling quality. For. Sci. 32:595-604.

Sweetgum seedlings from four open pollinated mother trees were grown in nursery beds infested with one of four vesicular-arbuscular mycorrhizal (VAM) fungi, and with available soil P levels (Bray II) adjusted to 50 ppm. Comparable beds had no VAM fungi present but had their available soil P levels adjusted to about 75, 100, 200, and 300 ppm. When lifted, the seedlings were placed in one of three morphological grades based upon number of permanent lateral roots exceeding 1 mm in diameter. Grade 1 seedlings had more than six roots; grade 2 between four and six roots; grade 3 had fewer than four roots. Approximately 50 percent of all seedlings fell within the inferior root grade 3 classification. Nursery mycorrhizal condition and phosphorus fertilization had no affect upon lateral root morphology of seedlings from the four seedlots. No significant biological differences in seedling heights were observed among the different root grades at lifting, but root collar diameter (RCD) varied significantly among the grades in order: grade 1 > grade 2 > grade 3. One year after outplanting on the Savannah River Site, Aiken, SC, effects of root grade were significant for both height and RCD: grade 1 > grade 2 > grade 3. Early first year seedling dieback and first year survival varied significantly among grades. Dieback percentages for grades 1, 2, and 3 were 41, 67, and 89 percent; survival averages for grades 1, 2, and 3 were 79, 67, and 51 percent, respectively. These data suggest that number of lateral roots on a sweetgum nursery seedling is an indicator of probable performance after outplanting.

2. Ruehle, J.L. and Kormanik, P.P. 1986. Lateral root morphology: a potential indicator of seedling quality in northern red oak. USDA For. Serv. Res. Note SE-344, 6 pp.

Success of northern red oak plantings might be improved if a suitable measure of seedling quality could be developed. Numbers of first-order lateral roots on nursery seedlings may be such a measure. In lifted seedlings in 10 families, this variable was significantly correlated with height, stem diameter, and top and root weight but was not strongly correlated with number or length of stem flushes.

3. Kormanik, P.P., Ruehle, J.L. and Muse, H.D. 1989. Frequency distribution of lateral roots of 1-0 bare-root white oak seedlings. USDA For. Serv. Res. Note SE-353, 5 pp.

Frequency distributions of seedlings from three white oak mother trees were similar when seedling populations were stratified by first-order lateral roots with diameter ≥ 1 mm at proximal end. The root-collar diameter, height, and top and root weights of trees increased from the lowest lateral root class (0 to 3 roots) to the highest class (>21 roots). There were no significant differences among the three families in root-collar diameter, height, or average number of first-order lateral roots.

4. Kormanik, P.P., Ruehle, J.L. and Muse, H.D. 1990. Frequency distribution asnd heritability of first-order lateral roots in loblolly pine seedlings. For. Sci. 36:802-814.

Frequency distributions and heritability of first-order lateral roots (FOLR) were computed for seedling progeny of loblolly pine mother trees in different years in a nursery. Seeds were from 12 mother trees the first year and from 25 different mother trees the second year. The theoretical frequency distribution of FOLR in these loblolly pine seedlings was best approximated by a truncated normal distribution for untransformed FOLR >0. Family mean heritability estimates (h^2) for the 12 and 25 half-sib seedlots were 0.769 $\pm$ 0.17 and 0.766 $\pm$ 0.11 and combined data produced an h^2 of 0.767 $\pm$ 0.09. Seedlings were also stratified into four FOLR categories: 0-3, 4-5, 6-7, and $\geq$8. The aboveground dimensions of seedlings in the 0-3 category were consistently and significantly smaller than in the other three grades for all families. Seedlings in this category represented 39% of all seedlings tested over 2 years. In four families 57% of the progeny were in the lowest category, while in four other families only 25% of the seedlings were in this category. All measured seedling parameters increased significantly from the smallest to the largest FOLR category. These data suggest that mother trees could be selected for FOLR development by some standard nursery procedure.

C. Research on Root Physiology and Reforestation

1. Xu, D.-P, Sung, S-J. S., Alvarez, C.A. and Black C.C. 1986. Pyrophosphate-dependent sucrose metabolism and its activation by fructose 2,6-bisphosphate in sucrose importing plant tissues. Biochemical and Biophysical Res. Communications 141:440-445.

In the presence of pyrophosphate and uridine diphosphate, sucrose was cleaved to form glucose 1-phosphate and fructose with soluble extracts from sucrose importing plant tissues. The glucose 1-phosphate then was converted through glycolysis to triose phosphates in a pyrophosphate-dependent pathway which was activated by fructose 2,6-bisphosphate. Much less activity, <5%, was found in sucrose exporting tissue extracts from the same plants. These findings suggest that imported sucrose is metabolized in the cytoplasm of plant tissues by utilizing pyrophosphate and that sucrose metabolism is partially regulated by fructose 2,6-bisphosphate.

2. Sung, S-J. S., Xu, D.-P, Galloway, C.M. and Black, C.C. 1988. A reassessment of glycolysis and gluconeogenesis in higher plants. Physiol. Plant. 72:650-654.

Sucrose is the starting point of glycolysis and end point of gluconeogenesis in higher plants. During both glycolysis and gluconeogenesis alternative enzymes are present at various steps to carry out parallel pathways; alternatives are available for utilizing nucleotide triphosphates and pyrophosphate; fructose 2,6-bisphosphate serves as a strong internal regulator; and plants use these cytoplasmic alternatives as they develop and as their environments change.

3. Sung, S.-J. S., Xu, D.-P. and Black, C.C. 1989. Identification of actively filling sucrose sinks. Plant Physiol. 89:1117-1121.

Certain actively filling plant sucrose sinks such as a seed, a tuber, or a root can be identified by measuring the uridine diphosphate and pyrophsophate-dependent metabolism of sucrose. Sucrolysis in both active and quiescent sucrose sinks was tested and sucrose synthase was found to be the predominant sucrose breakdown activity. Sucrolysis via invertases was low and secondary in both types of sink. Sucrose synthase activity dropped markedly, greater than fivefold, in quiescent sinks. The tests are consistent with the hypothesis that the sucrose filling activity, i.e. the sink strength of these plant sinks can be measured by testing the uridine diphosphate and pyrophosphate-dependent breakdown of sucrose. Measuring the initial reactions of sucrolysis shows much promise for use in agriculture crop and tree improvement research as a biochemical test for sink strength.

4. Sung, S-J., Loboda, T. and Black, C.C. 1990. Sucrose, pyrophosphate, and plastid metabolism in relation to cellular communication. In Perspectives in Biochemical and Genetic Regulation of Photosynthesis, (I. Zelitch, ed). Plant Biology 10:55-68.

Signal sensing and transduction within a plant or between organs or cells or between cellular compartments, such as between the cytoplasm and the plastid, comprise diverse sets of mechanisms that we only grasp at an elementary level in plant biology. Even so, we glimpse some of these relationships because of their functional importance. Two central topics that involve cellular communication in plants are the roles of sucrose and the biosynthetic roles of pyrophosphate (PPi).

To help focus these considerations, an axiom for plant biology should be integrated with our elementary understanding of signal sensing and transduction. The axiom is: "Plants have developed alternative or multiple pathways or routes for conducting nearly every life process." This has been illustrated with alternative routes for feeding sugars into plant cells, with alternative biochemical pathways for sucrose breakdown, and with alternatives in the biosynthetic utilization of PPi in plant cells. Two theses will be developed here: (1) that sucrose is a signal molecule and (2) that the metabolic roles of sucrose are intertwined with the biosynthetic roles of PPi.

D. Technology Transfer of Research Information.

1. Cordell, C.E. and Marx, D.H. 1986. Benefits and application of ectomycorrhizae in southern forest tree nurseries. pp. 244-250 in Proc. International Symposium on Nursery Management Practices for the Southern Pines. (D.B. South, ed.), Auburn University, Auburn, AL.

2. Hatchell, G.E. 1986. Nursery cultural practices affect field performance of longleaf pine. pp. 148-156 in Proc. International Symposium on Nursery Management Practices for the Southern Pines. (D.B. South, ed.), Auburn University, Auburn, AL.

3. Cordell, C.E., Marx, D.H. and Owen, J.H. 1987. Pt - the beneficial fungus for your nursery. pp. 201-217 in Proc. Southern Forest Nursery Association, July 1986. Pensacola, FL.

4. Dixon, R.K. and Marx, D.H. 1987. Mycorrhizae, Chapter 18. pp. 336-350 in Cell and Tissue Culture in Forestry, Vol 2. Specific Principles and Methods: Growth and Developments. (J.M. Bonga and Don J. Durzan, eds.), Martinus Nijhoff Publishers, Dordrecht.

5. Marx, D.H. and Cordell, C.E. 1987. Ecology and management of ectomycorrhizal fungi in regenerating forests in the eastern United States. pp. 69-71 in Mycorrhizae in the next decade, Practical applications and research priorities, (D.M. Sylvia, L.L. Hung and J.H. Graham, eds.), 7th NACOM, May 1987, Gainesville, FL.

6. Cordell, C.E., Marx, D.H., Maul, S.B. and Owen, J.H. 1987. Production and utilization of ectomycorrhizal fungal inoculum in the eastern United States. pp. 287-289 in Mycorrhizae in the next decade, Practical applications and research priorities, (D.M. Sylvia, L.L. Hung and J.H. Graham, eds.), 7th North American Conference on Mycorrhizae, May 1987, Gainesville, FL.

7. Cordell, C.E., Marx, D.H. and McFee, D. 1988. Pt ectomycorrhizal fungus operational inoculations and management in southern forest nurseries - 1988. pp. 187-199 in Proc. Southern Forest Nursery Association, July 1988, Charleston, SC.

8. Marx, D.H. and Cordell, C.E. 1989. Operational ectomycorrhizal fungus inoculations in forest tree nurseries: 1989. In Proc. Intermountain Forest Nursery Association, Bismarck, ND. USDA For. Serv. Gen. Tech. Report RM-184:86-92.

9. Cordell, C.E., Marx, D.H. and Omdal, D. 1990. Pt ectomycorrhizal fungus operational inoculations and management in forest tree nurseries - 1989. pp. 131-136 in "Roots - foundation of quality seedlings," Proc. 1989 Northeastern Area Nurserymen's Conf., July 1989, Peoria, IL.

10. Marx, D.H. 1991. Forest application of the ectomycorrhizal fungus Pisolithus tinctorius. Marcus Wallenberg Prize Lecture, Sept. 1991, Stockholm, Sweden. 23 pp.

11. Kormanik, P.P. 1986. Lateral root development - Seedling quality - Field performance. pp. 15-18 in Proc. Northeastern Area Nurserymen's Conference, July 1986, State College, PA.

12. Kormanik, P.P. and Muse, H.D. 1986. Lateral roots as a potential indicator of nursery seedling quality. pp. 187-190 in Proc. TAPPI Research and Development Conf., Raleigh, NC.

13. Kormanik, P.P. and Ruehle, J.L. 1987. Lateral root development may define nursery seedling quality. In Proc. Fourth Biennial Southern Silvicultural Research Conf., Nov. 1986, Atlanta, GA. USDA For. Serv. Gen. Tech. Report SE-42:225-229.

14. Kormanik, P.P., Ruehle, J.L. and Muse, H.D. 1989. Frequency distributions of seedlings by first order lateral roots: A phenotypic or genotypic expression. pp. 181-189 in Proc. 31st Northeastern Forest Tree Improvement Conf. and 6th Northcentral Tree Improvement Association Meeting, July 1988, University Park, PA.

15. Kormanik, P. P. 1989. Frequency distribution of first-order lateral roots in forest tree seedlings: Silvicultural implications. In Proc. 5th Biennial Southern Silvicultural Research Conf., Nov. 1988, Memphis, TN. USDA For. Serv. Gen. Tech. Report SO-74:101-105.

16. Kormanik, P.P. and Ruehle, J.L. 1989. First-order lateral root development: Something to consider in mother tree and progeny assessment. pp. 220-227 in Proc. 20th Southern Forest Tree Improvement Conf., June 1989, Charleston, SC.

17. Kormanik, P.P. 1989. Importance of first-order lateral roots in the early development of forest tree seedlings. pp. 157-168 in Interrelationships between Microorganisms and Plants in Soil (Vancura, V. and Kunc, F., eds.), Academia, Publ. House of Czechoslovak Academy of Sciences, Praha.

18. Marx, D.H., Cordell, C.E. and Kormanik, P.P. 1989. Mycorrhizae: Benefit and practical application in forest tree nurseries. pp. 18-21 in Forest Nursery Pests, USDA For. Serv., Agric. Handbook No. 680.

19. Kormanik, P.P. 1990. Grading seedlings: Importance and long term impact. pp. 40-54 in "Roots - foundation of quality seedlings," Proc. 1989 Northeastern Area Nurserymen's Conf., July 1989, Peoria, IL.

20. Black, C.C., Xu, D.P., Sung, S.S., Mustardy, L., Paz, N., and Kormanik, P.P. 1987. PP_i metabolism and its regulation by fructose 2,6-bisphosphate in plants. pp. 264-268 in Phosphate Metabolism and Cellular Regulation in Microorganisms. Am. Soc. Microbiology, Washington, DC.

21. Black,C.C., Xu, D.P., Sung, S.S. and Calloway, C.M. 1988. Alternative routes in the biology of plants; illustrated with pyrophosphate metabolism and sucrose nutrition. pp. 206-214 in Proc. Symposium on Photosynthesis and Plant Mineral Nutrition, Sept. 1987, Varna, Bulgaria.

22. Loboda, T., Sung, S.S. and Black, C.C. 1990. Comparative kinetic analysis of sucrose metabolizing enzymes. Supplement to Plant Physiol. 93:41.

E. Manuscripts in Pre-publication

1. Marx, D.H., Maul, S.B. and Cordell, C.E. Application of specific ectomycorrhizal fungi in world forestry. Chapter 7 in Frontiers of Industrial Mycology, Chapman-Hall Publ., New York.

2. Marx, D.H. Utilization of the ectomycorrhizal technology in worldwide forestation practices. Biotechnology in Forestry: Mycorrhizae. Applications to Forest Management, Soil Erosion Control and Agriculture Course, Valencia, Spain, Oct. 1991.

3. Marx, D.H. The basics of ectomycorrhizae and their practical application in reforestation practices. Reforestation and Ectomycorrhizae Workshop, Krefeld, Germany. Oct. 1991.

4. Marx, D.H. The practical significance of ectomycorrhizae in forest establishment. Marcus Wallenberg Prize Symposium, Stockholm, Sweden, Sept. 1991.

5. Cordell, C.E. and Marx, D.H. Operational application of specific ectomycorrhizal fungi in forest tree nurseries. Proc. NE Area Federal, State and Provincial Nurserymen's Conference, Marietta, OH. July 1991.

6. Cordell, C.E., Marx, D.H. and Omdal, D. Identification, management, and application of ectomycorrhizal fungi in forest tree nurseries. International Union of Forest Research Organizations (IUFRO), Vancouver, Canada. Aug. 1990.

7. Muse, H.D. and Hatchell, G.E. A preliminary identification of morphological indicators of field performance in bare-root nursery stock. Submitted to Forest Science.

8. Kormanik, P.P., Muse, H.D. and Sung, S.S. Impact of nursery management practices on heritability estimates and frequency distributions of first-order lateral roots of loblolly pine. Proc. 21st Southern Forest Tree Improvement Conf., Knoxville, TN. June 1991.

II. Research by Diseases of Southern Forests (SE-4502)

A. Research Publications

1. Powers, H.R., Jr. and Matthews, F.R. 1987. Five fusiform rust-resistant seed sources in coastal South Carolina. South. J. Appl. For. 11:198-201.

Bulk collections of seeds from five fusiform rust-resistant sources of loblolly and slash pines were tested for disease resistance and growth potential on the Savannah River Site, Aiken, SC. Texas and Arkansas loblolly had significantly less rust than trees from other seed sources, although all five resistant sources had significantly less rust infection than commercial checks. Arkansas loblolly, although excellent for rust resistance, attained the least height. Trees from the loblolly and slash pine rust-resistant orchards also had good growth and rust resistance. Livingston Parish (Louisiana) loblolly seedlings, which have been widely planted in the South, were not significantly different from the rust-resistant loblolly orchard seedlings in either growth or rust infection. Survival of all seed sources in the test was satisfactory; however, the Livingston Parish and slash commercial check had significantly fewer surviving trees.

2. Winner, W.E., Cotter, I.S., Powers, H.R. and Skelly, J.M. 1987. Screening loblolly pine seedling responses to SO_2 and O_3: Analysis of families differing in resistance to fusiform rust disease. Environ. Pollut. 47:204-220.

Open pollinated families of loblolly pine differing in resistance to fusiform rust disease were screened in laboratory studies for responses to gaseous air pollutants. Twenty families were given acute exposures (2 fumigations for 4 h each) to SO_2 (0.4-1.0 ppm), O_3 (0.25 ppm), SO_2 (0.4-1.0 ppm) + O_3 (0.25 ppm), and control. Analyses of variance were performed to evaluate the treatment effects of these air pollutants on percent foliar injury, and to determine whether the families responded differentially to the air pollution treatments. Treatment effects were significant, with the combination treatment of SO_2 + O_3 producing a higher percentage of foliar injury than the controls; however, injury levels were very low and may not be of biological significance.

Subsequently, twelve families were grown in two soil types for exposure to chronic levels of SO_2 (0.06 ppm), O_3 (0.07 ppm), SO_2 (0.06 ppm) + O_3 (0.07 ppm), and control. The families were then ranked for decreased primary shoot growth, shoot dry weight, root dry weight, total plant dry weight and root/shoot ratio after exposure to air pollution treatments. Air pollution treatments as a main effect were significant for only one of the five growth parameters measured, that of primary shoot growth. The main effect of family, and the interaction of family and air pollution treatments were significant for most growth parameters measured. In general, O_3 alone and in combination with SO_2 reduced growth more than SO_2 alone. Fumigation with O_3 reduced growth of two families in comparison with control groups, whereas SO_2 alone produced decreased growth in one family and stimulated growth in three families. Treatment with O_3 alone produced higher root/shoot ratios than fumigation with charcoal-filtered air in two families. Overall, families which were fast growers under control conditions maintained their ranking after exposure to air pollution. Families producing less growth in charcoal-filtered air also produced less growth under various air pollution regimes. Results indicated that these families exhibited a high degree of resistance to air pollution injury. Growth responses of seedlings may not reflect family differences in long-term productivity. No relationship was apparent between fusiform rust resistance and growth reductions due to air pollutants.

3. Powers, H.R., Jr. and Stone, D.M. 1988. Control of tip moth by carbofuran reduces fusiform rust infection on loblolly pine. USDA For. Serv. Res. Paper SE-270, 5 pp.

The systemic insecticide carbofuran was applied to the soil under planted loblolly pines in studies on the Savannah River Site, Aiken, SC, at ages 2 through 5. As expected, the insecticide sharply reduced tip-moth damage and increased the height of 5-year-old saplings, compared with untreated controls. Untreated trees not only had more tip-moth injury but also had significantly more fusiform rust infections. Carbofuran itself did not have any fungicidal effect which could have been responsible for the lower incidence of rust among the treated trees. Since carbofuran treatment not only reduced damage from tip month but also decreased rust infection, these results may prompt new interest in the economics of tip-moth control.

4. Stone, D.M. and Powers, H.R. 1989. Sewage sludge increases early growth and decreases fusiform rust infection of nursery-run and rust-resistant loblolly pine. South. J. Appl. For. 12:68-71.

An intensively prepared site in a high rust-hazard area on the Savannah River Site, Aiken, SC, was fertilized with municipal sewage sludge to provide 300 or 600 lb/ac total nitrogen before planting nursery-run and fusiform rust-resistant seedlings. Rust-resistant seedlings had significantly greater first-year survival and significantly lower rust infection at age 6. The sludge treatments increased 6-year diameter and volume growth and decreased rust infection significantly; there were no differences between the two sludge levels. Sludge fertilization significantly increased average height, diameter, and stem volume of the largest 300 trees/ac and has begun to stimulate crown class differentiation. The greater growth of the larger trees did not alter the proportion infected by rust. Results indicate that even in areas of high-rust hazard, intensive site preparation and sludge fertilization can increase early growth and accelerate stand development of loblolly pine if rust-resistant stock is planted.

B. Technology Transfer of Research Information

1. Powers, H.R., Jr. and Stone, D.M. 1985. Incidence of fusiform rust infection on loblolly pine related to tip moth damage. pp. 129-134 Proc. Joint Conf. International Union of Forest Research Organizations (IUFRO), Working Parties on Forest Gall Midges and Rusts of Pines, Sept. 1985, Seoul, Korea.

C. Manuscripts in Pre-Publication

1. Powers, H.R., Belanger, R.P., Pepper, W.D. and Hastings, F.L. Provenance of loblolly pine affects susceptibility to the southern pine beetle in South Carolina submitted to Southern Journal of Applied Forestry.

III. Research by Utilization of Southern Timber (SE-4701)

A. Research Publications

1. Clark, A., III and Saucier, J.R. 1988. Biomass response of loblolly pine to applied sewage sludge four years after treatment. pp. 126-138 in Proc. 1987 Southern Forest Biomass Workshop (R.A. Daniels, W.F. Watson and I.W. Savelle, eds.), June 1987, Biloxi, MS.

Liquid sewage sludge that has been anaerobically digested was applied to 8-year-old loblolly pine plantations growing on sandy Coastal Plain soils, Savannah River Site, Aiken, SC. Sludge was applied at 0, 402, or 804 Kg N/ha on 0.212 ha plots replicated three times on each of two soil types. Both sludge applications significantly increased stemwood biomass compared to controls. Four years after treatment, dry biomass of stemwood had increased by 377 percent in control trees, 455 percent in trees getting light sludge, and 456 percent in trees getting heavy sludge applications. Sludge treatments did not significantly affect the proportion of biomass in wood, bark, or foliage.

2. Saucier, J.R. and Clark, A. 1988. Effets d'applications de boues d'epandage sur la croissance et les proprietes du bois de Pinus taeda de 8 ans dans le sud-est Etats-Unis. pp. 209-216 in Sciences et Industries du Bois, Apr. 1987, Nancy, France.

Sewage sludge in the form of liquid anaerobic material was applied to 8-year-old loblolly pine plantations at the Savannah River Site, Aiken, SC, to test the effect of waste disposal on forest growth. Sludge was applied at 0, 402 and 804 kg of N/ha on 0,212-ha plots replicated three times on each of two soil types. After 4 years, volume growth was increased by 23 percent by low-level sludge and 33 percent by high-level sludge compared with nontreated plots. Specific gravity of stemwood produced after treatment differed significantly between nontreated trees and high-level sludge trees (0.421 vs. 0.409) but was not significantly different between non-treatment and low-level sludge trees (0.421 vs. 0.412). Average annual tracheid length decreased 4 percent in treated trees compared with nontreated trees.

IV. Research by Forest Soil Productivity in the Southeast (SE-4102)

A. Research Publications

1. Craig, J.R. and Ruark, G.A. 1991. An evaluation of nitric and hydrofluoric acid digestions following dry combustion of pine foliage. Commun. In Soil Sci. Plant Anal. 22:1215-1223

Pine foliage samples of 1.00, 0.50, and 0.25 g were ground in either a Wiley mill or a shatterbox, ashed, subjected to either HF or HNO_3 digestions, and analyzed for element concentrations. Grinding methods had little effect on estimated mean element concentrations. The 1.00 g sample size was preferable, but few differences were observed with the 0.50 g sample. However, the 0.50 g weight is probably approaching the minimum for conventional grinding and analytical methods. Both acid digestions were equally effective in dissolving major elemental constituents, but the HF method was superior for the micro-nutrients, especially Mn. Variability associated with the major elements was similar for all combinations of grinding, acids, and the two larger sample weights. For analysis of the minor elements, the best combination was the 1.00 g sample, shatterbox grinding, and HF digestion. Analysis of 1.00 g samples of National Institute of Standards and Technology (NIST) pine needles, Standard Reference Material No. 1575, digested in HF acid compared very well with the NIST certified values.

2. Ruark, G.A. and Blake, J.I. 1991. Conceptual stand model of plant carbon allocation with a feedback linkage to soil organic matter maintenance. pp. 187-198 in Long-term field trials to assess environmental impacts of harvesting (W.J. Dyck and C.A. Mees, eds.), Proc. IEA/BE T6/A6 Workshop, Feb. 1990, Florida. Forest Research Institute, Rotorua, New Zealand, FRI Bulletin No. 161.

A conceptual stand-level model, predicated on mutual negative feedbacks between aboveground carbon allocation and soil organic matter (SOM), is described. In the model, increasing SOM heightens available water and possibly nutrients. This, in turn, increases total stand growth, but also proportionally shifts growth away from roots towards the shoot, leading to a subsequent reduction of carbon input to the SOM pool. However, since decomposition of SOM continues, the result is a cycling of SOM and shoot/root equilibrium levels. In the model, feedback is limited to only the labile SOM fraction, while the recalcitrant SOM pool is assumed invariant. The degree to which labile SOM can be increased is constrained by the carbon allocation limits of the plant species (i.e., nutrient and water uptake capacity per unit of root tissue) and the site. The model predicts that the labile SOM pool will increase to an equilibrium value for a plant/soil combination. Labile SOM levels will then fluctuate around this equilibrium as annual precipitation varies.

B. Technology Transfer of Research Information

1. Ross, S. 1991. Effect of forest floor removal, prescribed burning and nitrogen fertilizers. Symposium on Minority Participation in Forestry and Forest Related Sciences, Nov. 1991, Huntsville, AL.

C. Manuscripts in Pre-publication

1. Ruark, G.A. and Zarnoch, S.J. Sampling a mature pine stand for soil nitrogen, soil carbon, and fine root biomass. Submitted to Soil Science Society American Journal.

2. McKee, W.H., Jr., Wells, C.G., Craig, J.R., McKevlin, M.R., McLeod, K.W. and Davis, C.E. Distribution of nutrients from liquid and solid sludge applied to loblolly pine stands in soil and forest floor. To be submitted to Journal of Environmental Quality.

CONTINUING STUDIES

1. The feasibility of growing hardwood species on a borrow pit amended with either fertilizer and lime or sewage sludge. FS-SE-4551-69. P.P. Kormanik. Installed March 1982.

2. Interactions of subsoiling and solid sludge on soil physical and chemical factors and growth of *Pinus taeda* L. and a *Festuca* sp. FS-SE-4551-55. D.H. Marx. Installed December 1978.

3. Comparison of sludge and fertilizer applications on establishment and growth of seedlings of two sweetgum ecotypes endomycorrhizal with *Glomus mosseae* and *G. etunicatus*. FS-SE-4551-54. P.P. Kormanik. Installed February 1978.

4. Interaction of endomycorrhizae and soil phosphorus on the nursery development of black walnut seedlings. FS-SE-4551-78. P.P. Kormanik. Installed April 1984.

5. Reforestation of borrow pits by use of specific mycorrhizal fungi, soil amendments, and site preparation. FS-SE-4551-31. D.H. Marx and P.P. Kormanik. Installed December 1978.

6. Effects of morphological attributes of longleaf pine seedlings on field performance. FS-SE-4551-97. D.H. Marx. Installed December 1985.

7. Fiber yield and affect of *Botryosphaeria* spp. on recurrent coppicing of 11-year-old sweetgum. FS-SE-4551-107. P.P. Kormanik. Installed 1978.

8. Interaction of vesicular-arbuscular mycorrhizae, sweetgum family, and root grade on plantation development. FS-SE-4551-70. P.P. Kormanik. Installed 1978.

9. Effects of subsoiling, sewage sludge, and vesicular-arbuscular mycorrhizae on growth of sweetgum on a high quality site. FS-SE-4551-88. P.P. Kormanik. Installed February 1984.

10. Lateral root morphology of nursery-grown white oak seedlings. FS-SE-4551-99. P.P. Kormanik. (Several studies.)

11. Development of strong, first-order lateral roots on loblolly seedlings and their field performance as influenced by top shearing in the nursery. FS-SE-4551-100. P.P. Kormanik. (Several studies.)

12. Sweetgum field study comparing morphological root grade among swamp and upland ecotypes. FS-SE-4551-101. P.P. Kormanik. (Several studies.)

13. Modification of existing nursery practices to improve field performance of southern pines. FS-SE-4551-105. P.P. Kormanik. Several studies.)

14. Effect of top clipping and mycorrhizal symbiont on first-order lateral root development and subsequent field performance of loblolly pine. FS-SE-4551-110. P.P. Kormanik. (Several studies.)

15. Effect on FOLR development and plantation performance when loblolly pine seedling nursery development is limited by regulation of seedling metabolism. FS-SE-4551-111. P.P. Kormanik and S.S. Sung. (Several studies.)

16. Carbohydrate metabolism in transplanted loblolly pine seedlings. FS-SE-4551-108. S.S. Sung and P.P. Kormanik. (Several studies.)

17. Effect of forest floor removal, prescribed burning, and nitrogen fertilization. FS-SE-4102-186. W.H. McKee. Installed November 1986.

18. Study of natural resistance of several geographical sources of planted loblolly and slash pine to fusiform rust. FS-SE-4502-35. G. Kuhlman. Installed 1990.

19. Tip moth-fusiform rust interaction on loblolly pine. FS-SE-4502-50. G. Kuhlman. Installed 1980.

20. Comparison of rust resistant and improved loblolly and slash pine seedlings. FS-SE-4502-68. G. Kuhlman. Installed yearly from 1986 thru 1989.

21. Testing of loblolly stecklings for rust resistance. FS-SE-4502-80. G. Kuhlman. Installed 1988.

22. Comparison of Texas loblolly for resistance to fusiform rust and southern pine beetle. FS-SE-4502-20.55. G. Kuhlman. Installed 1990.

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