Literature Cited

ADELMAN, I. 1958. A new approach to the construction of index numbers. Rev. Econ. Stat. 40:240–249.

ALLEN, R.G.D. 1975. Index numbers theory and practice. Aldine, Chicago. 278 p.

DICKS, M.R., F. LLACUNA, AND M. LINSENBIGLER. 1988. The Conservation Reserve Program—implementation and accomplishments, 1986–87. Stat. Bull. No. 763. USDA Econ. Res. Serv., Washington, DC. 119 p.

GOUSEN, S., K. MONK, AND I. GERDUK. 1986. Producer price measurement—concepts and methods. USDL Bureau of Labor Statistics, Washington, DC. 160 p.

GULDIN, R.W. 1983. Regeneration costs for industrial landowners using hand vs. machine planting. South. J. Appl. For. 7:104–108.

HANSEN, B., AND E.F. LUCAS. 1984. On the accuracy of index numbers. Rev. Inc. Wealth 30:25–38.

MENDENHALL, W., AND J.E. REINMUTH. 1978. Statistics for management and economics. Ed 3. Duxbury Press, New Scituate, MA. 789 p.

OSBORN, C.T., F. LLACUNA, AND M. LINSENBIGLER. 1989. The Conservation Reserve Program—enrollment statistics for 1987–88 and signup periods 1–7. Stat. Bull. No. 785. USDA Econ. Res. Serv., Washington, DC. 138 p.

STRAKA, T.J., W.F. WATSON, AND M.R. DUBOIS. 1989. Costs and cost trends for forestry practices in the South. For. Farmer 27th Manual Edition 48:8–14.

USDA FOREST SERVICE. 1989. 1988 Annual fire report, Southern Region, State and Private. USDA Forest Service, Atlanta, GA.

USDL BUREAU OF LABOR STATISTICS. (Annual.) Employment and wages—annual averages (annual). Bulletin (various). Washington, DC.

USDL BUREAU OF LABOR STATISTICS. 1988. The producer price index. Published monthly. Washington, DC.

Benomyl Root Dips Adversely Affect First-Year Performance of Stored Loblolly Pine Seedlings

Nancy J. Stumpff *and* **David B. South,** *School of Forestry and Alabama Agricultural Experiment Station, Auburn University, AL 36849-5418.*[1]

ABSTRACT. Dipping loblolly pine roots into a clay slurry containing benomyl (1.25% active ingredient) at the time of packing did not improve survival of seedlings stored (near 3°C) for 1 to 4 weeks. In some situations, benomyl decreased outplanting survival. Regardless of lifting date or storage length, benomyl slightly decreased first-year height growth (by 12 to 17%). Although previous research has demonstrated that a benomyl treatment can improve the ability of March-lifted seedlings to withstand prolonged storage, a beneficial response is not yet predictable for loblolly pine seedlings lifted between October and February.

South. J. Appl. For. 15(3):133–137.

Long-term cool storage of loblolly pine (*Pinus taeda* L.) seedlings lifted before mid-December is rarely successful (Garber and Mexal 1980, Venator 1985, Boyer and South 1986). Lack of storability in the fall has been attributed to insufficient chilling needed to satisfy the release of bud dormancy (Garber and Mexal 1980). Boyer and South (1986) found that while some chilling can occur before successful long-term storage, the amount required is less than that needed for maximum speed of bud break. Thus, successful early storage may not be as dependent on chilling hours and the complete release of bud dormancy as once believed (Carlson 1985, Boyer and South 1986).

During the fall, physiology of loblolly pine seedlings changes in a variety of ways, some of which are not directly related to the level of bud dormancy. For instance, root respiration rates, root suberization, root and shoot carbohydrate contents, and levels of other substrates may be undergoing rapid changes (Chung and Barnes 1980a, 1980b, Venator 1985). Changes in certain substrate levels might cause seedlings to be more susceptible to damage by fungi and other pathogenic organisms.

Even though cool storage (2°C ± 1°C) can slow the growth of certain microorganisms, certain fungi can develop during long-term cool storage. Studies incorporating the fungicide benomyl (Benlate®) into seedling root dips prior to storage have shown mixed results in improving storability of loblolly pine seedlings. Research by Barnett et al. (1988) indicated that benomyl can improve storability of loblolly seedlings lifted in March. Like early lifted seedlings, March-lifted seedlings rarely do well in long-term storage. Studies with loblolly pine seedlings lifted during December and January have shown either no beneficial effect from treatment with benomyl (Barnett et al. 1988) or decreased survival (Boyer and South 1987). An ob-

[1] The authors are most grateful to John Blake and Hans Williams for assistance in the design and layout of the study. Acknowledgments are also extended to Bobby Childree and Phil Clayton who helped to plant the seedlings. Thanks are also expressed to the Stauffer Nursery for providing the seedlings and to Mead Coated Board for providing the outplanting site. Funding for this research was provided by the Auburn University Southern Forest Nursery Management Cooperative. This paper is Journal Series No. 9-902658P of the Alabama Agricultural Experiment Station. Use of trade, firm, or corporation names is for the reader's information and convenience. Such use does not constitute official endorsement by Auburn University of any product or service to the exclusion of others that may be suitable. Discussion of pesticides in this paper does not constitute recommendation of their use.

jective of this study was to test the effectiveness of benomyl in improving storability of fall-lifted (October-December) loblolly pine seedlings.

MATERIALS AND METHODS

In 1988, loblolly pine seedlings (from an orchard-mix seedlot; AFC-86-Med-A) were grown at Stauffer Nursery in Opelika, AL. Seedlings were top-pruned in August and were undercut, fertilized (with potassium chloride and ammonium nitrate) and top-pruned again in September. Weather during the late summer and early fall was near normal. However, average monthly temperatures at the nursery were slightly above normal for August (27°C) and November (13°C) but were below normal in September (23°C), October (15°C), and December (8°C). Rainfall was above normal during August (103 mm), September (181 mm), and November (178 mm) but was below normal during October (42 mm) and December (57 mm). Prior to initiating the study, four replicate plots were designated in the nurserybeds. Approximately 200 seedlings per replicate were hand-lifted every 2 weeks from October 27, 1988, through February 1, 1989. After transportation to Auburn, AL, cull seedlings [defined as grade 3 seedlings by Wakeley (1954)] were removed, and the roots of the remaining seedlings were rinsed to remove soil. Twenty-five seedlings per replicate plot were prepared for each treatment. One treatment involved dipping the seedlings in a clay slurry (450 g kaolinite per 1.5 l water), while the other treatment involved dipping in a clay slurry plus 1.25% a.i. benomyl (438.75 g kaolinite + 11.25 g Benlate WP50 in 1.5 l water). Seedlings were placed in Kraft-Polyethylene bags and kept in cool storage (3°C ± 1°C) either overnight or for 1 or 4 weeks.

After storage, seedlings were hand-planted in randomized complete blocks on a Piedmont site (Cecil sandy clay loam) near Opelika, AL. Site preparation consisted of an application of hexazinone, followed by chopping and burning. Rainfall at the site was recorded, and soil moisture at time of planting was determined gravimetrically. Seedling heights were recorded at time of planting. First-year survival and heights were recorded in April 1990. Plot means were subjected to analysis of variance techniques using SAS's GLM procedure (SAS Institute 1985). Prior to analysis, survival data were transformed using arcsine transformation.

RESULTS AND DISCUSSION

Survival

Although rainfall during November was above average, the winter months (December, January, and February) had below-normal rainfall. The only sudden, hard freezes occurred during February (Figure 1). Apparently due to adequate soil moisture at time of outplanting, adequate hand-planting techniques, and frequent

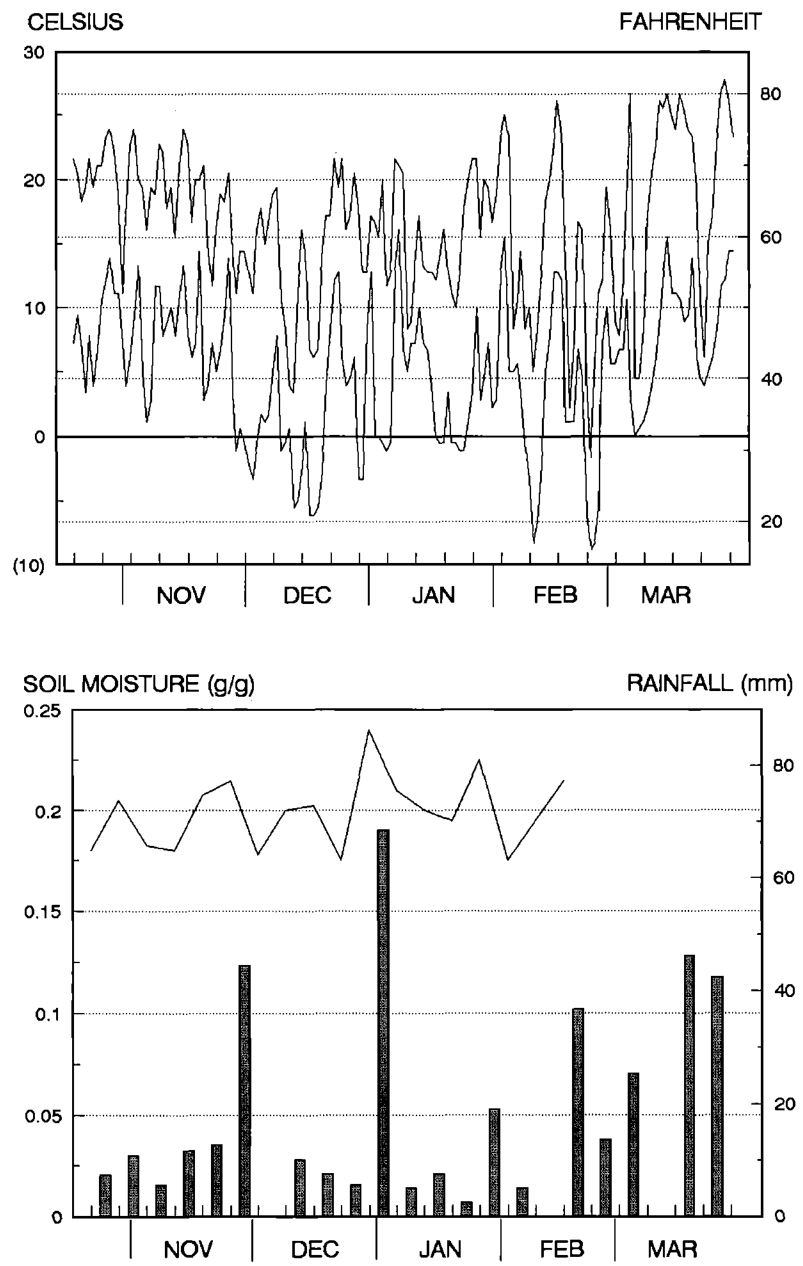

Figure 1. Maximum and minimum temperatures, weekly rainfall (bars), and soil moisture at the outplanting site during the 1988–89 planting season.

rainfall, overall seedling survival was good. The average survival for freshly lifted control seedlings was 92%, with only three dates (the first two and last) below this value (Figure 2). As expected, storage decreased survival of control seedlings. On the average, 1 and 4 weeks of storage decreased survival of control seedlings by 4 and 15 percentage points, respectively. The relatively good survival of seedlings lifted in late October and early November and stored for 4 weeks supports the contention that successful cool storage of loblolly pine seedlings may not be as directly related to chilling as once believed.

The reduction in survival of seedlings lifted on November 22 and December 7 and stored for 4 weeks does not appear to be related to environmental conditions at time of planting (Figure 1). Apparently, these seedlings were less suited for withstanding stresses that occur during storage. It is unclear whether this reduction in storability was due to a change in internal physiology or was due to a change in pathogenic fungi present on the roots. However, a "December dip" in survival of loblolly pine seedlings has also been reported for nonstored seedlings (Wakeley 1954, Switzer 1969) which would suggest a physiological response instead of a pathological effect. The "December dip" in survival appears to occur when terminal buds of loblolly pine are in the deepest phase of dormancy (Boyer and South 1989). This would support the theory that a seedling's resistance to stress is low when the terminal buds are in deep dormancy (Lavender 1985). Although a relationship between bud dormancy and stress resistance may exist, the reason for the observed decline in storability remains unknown.

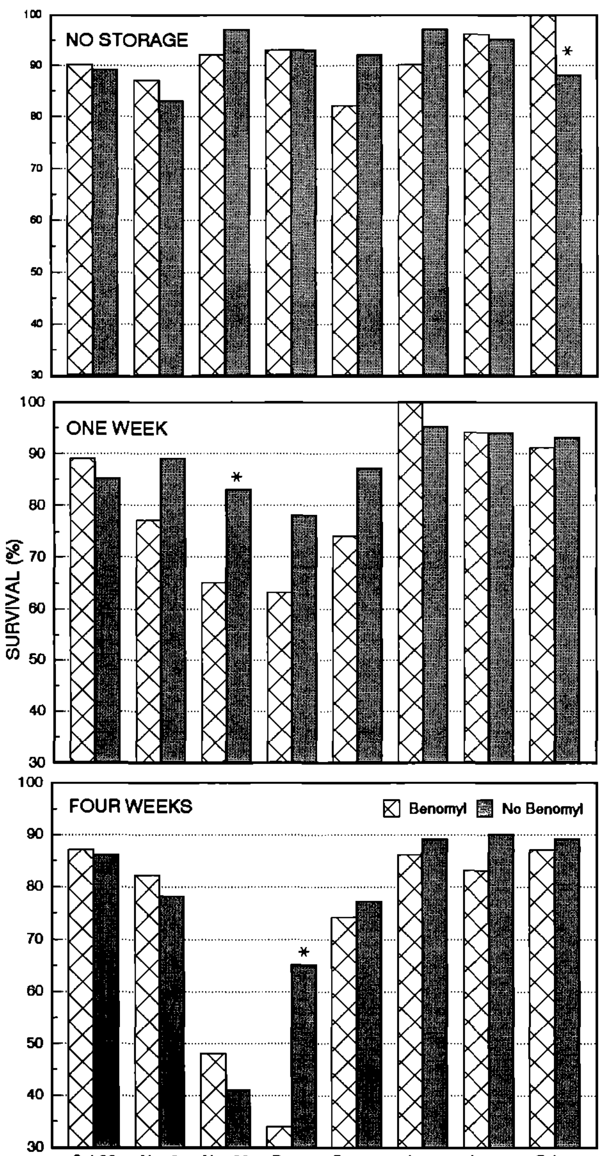

Figure 2. First-year survival of loblolly seedlings by lift date and storage. A significant treatment effect (5% level of probability as determined by Duncan's new multiple range test) is indicated by an asterisk (*).

Average survival of control seedlings was slightly higher than that for seedlings treated with benomyl (84.8% vs. 81.8%). Although this difference was not statistically significant, there was a significant three-way interaction (Table 1). Benomyl significantly improved survival for only 1 of the 24 lift-date-storage combinations (nonstored seedlings lifted on February 2). Instead of improving storability, benomyl decreased survival for seedlings lifted in November and December, and stored for 1 and 4 weeks, respectively (Figure 2).

Barnett et al. (1988) found that benomyl (1.25% a.i.) improved storability of loblolly pine seedlings lifted in March. Seedlings that were stored for 6 weeks and not treated with benomyl suffered nearly 80% mortality, while survival of seedlings treated with benomyl was near 90%. When lifted in January and stored for 6 weeks, survival of untreated loblolly pine seedlings was near 100%. Thus, adding benomyl to the clay slurry had no beneficial effect on January-lifted seedlings. Regardless of lift date, benomyl had little or no effect on seedlings stored for less than 1 week.

In our study, as in the study by Barnett et al. (1988), benomyl did not significantly affect the survival of seedlings lifted in January. However, in contrast, benomyl exhibited no statistically significant benefits to stored seedlings regardless of lift date. In fact, there

Table 1. Analysis of variance table for first-year survival and height growth of loblolly pine seedlings from the benomyl root-dip study.

Factor	df	Survival		Height growth	
		F value	PR > F	F value	PR > F
Block	3	23.72	0.0001	30.09	0.0001
Lift date	7	14.19	0.0001	6.51	0.0001
Storage	2	39.62	0.0001	23.39	0.0001
Benomyl	1	2.45	0.1199	20.69	0.0001
Storage*benomyl	2	0.97	0.3818	0.19	0.8232
Lift*storage	14	4.43	0.0001	1.34	0.1938
Lift*benomyl	7	1.72	0.1097	0.77	0.6133
Lift*storage*benomyl	14	1.80	0.0447	1.22	0.3466
error	141	(0.042176)		(38.51106)	

Numbers in parentheses represent the mean square error.

were two lift-date-storage treatments for which benomyl significantly decreased survival.

A benomyl/clay slurry (2% a.i.) treatment is currently registered for use on loblolly pine in order to improve survival through control of diseases caused by *Fusarium* and *Rhizoctonia*. In addition, it has been suggested that the storability of loblolly pine seedlings can be improved with benomyl, because this fungicide is active against *Pythium* (Barnett et al. 1988). The fact that benomyl did not improve survival for any of the lift-date-storage combinations in this study suggests several possibilities: (1) that a pathogenic fungus was not responsible for the reduction in storability in November and December, (2) that if a pathogen was involved, it was not controlled by the benomyl concentration used in this study, or (3) the benefit of the dip is primarily for loblolly seedlings lifted after mid-February.

There have been several reports on the negative effects of benomyl on survival of southern pines. Boyer and South (1987) found that a root dip of benomyl (5% a.i.) decreased survival of loblolly seedlings that were lifted in December, cool stored for 12 weeks, and outplanted in sand. However, the observed decrease was limited to seedlings with excessively high shoot/root ratios. When applied in a gel slurry, Rowan (personal communication 1990) observed a decreased in survival of loblolly pine (1% a.i.), slash pine (*Pinus elliottii* Engelm.) (4% a.i.) and longleaf pine (1% a.i.). Longleaf pine (*Pinus palustris* Mill.) seedlings lifted in January and treated with benomyl (10% a.i.) root dip had lower survival than clay dipping alone if stored for 0, 3, 6, or 12 weeks (Cordell et al. 1985). Kais et al. (1986) reported that benomyl (5% a.i.) decreased survival of longleaf pine planted in sand in Florida. They suggested that seedling phytotoxicity may result when excessive adsorption of the "fungitoxicant" occurs on sandy soils. Therefore, when outplanting longleaf pine on soils with more than 90% sand, field foresters should be aware that treating the roots with benomyl (5% a.i.) may result in a reduction in survival.

Growth

When benomyl was added to the clay slurry root dip, all three storage treatments resulted in a slight decrease in first-year height growth. Overall, height growth for benomyl-treated seedlings averaged 4 cm less than for seedlings dipped in clay slurry alone (Table 2). Height growth data have not been reported in other published studies where a benomyl root dip was tested on loblolly pine (Boyer and South 1987, Barnett et al. 1988). However, there are reports of decreased root growth potential (*RGP*). Barnett et al. (1988) found that *RGP* of seedlings with roots dipped in a benomyl (5% a.i.) clay slurry was decreased by up to 65%. Studies at Auburn University (unpublished) have also shown benomyl to decrease *RGP* of longleaf pine. Therefore, the decreased shoot growth seen in this study may be partially due to a reduction in *RGP*. Several studies have shown a positive correlation between *RGP* and first-year height growth (Larsen et al. 1988, Mexal and South 1991, Feret and Kreh 1985). Although *RGP* may be decreased by applying benomyl to the roots as a clay slurry, a soil drench of benomyl can increase mycorrhizal development when growing bareroot loblolly pine (Marx and Rowan 1981) or container-grown shortleaf (*Pinus echinata* Mill.) and longleaf pine (Pawuk et al. 1980, Pawuk and Barnett 1981).

In contrast to our findings with loblolly pine, height growth of longleaf pine seedlings has been improved by use of a benomyl treatment (Kais et al. 1981, 1986, Barnett et al. 1988). On some sites, earlier emergence from the grass stage probably results in part from control of brown-spot needle blight (*Scirrhia acicola* [Dearn.] Siggers). However, this disease seldom affects loblolly pine.

CONCLUSIONS

The potential for benomyl to decrease RGP, survival, and first-year height growth implies that loblolly seedlings are more sensitive to benomyl than are longleaf pine seedlings. In view of the variation in results from this and other studies with benomyl, it is not possible to predict at what time an increase in field survival will result from treating loblolly pine roots with benomyl prior to storage. Results from this study do not support the use of benomyl (1.25% a.i.) to improve storability

Table 2. First-year height growth (H1–H0) of loblolly pine seedlings.[1]

Treatment	Length of cool storage			Means
	Overnight	1 wk	4 wk	
	(cm)			
Clay slurry	27.1 a	23.9 a	20.2 a	23.7 a
Clay-benomyl slurry	23.8 b	19.2 b	16.8 b	19.9 b

[1] Within each column, the values differ significantly at the 0.05 level of probability.

of fall-lifted (October to December) loblolly pine seedlings. More research is needed to determine the exact mechanisms responsible for the improved survival reported in previous storage studies with March-lifted seedlings. □

Literature Cited

BARNETT, J.P., ET AL. 1988. Improving field performance of southern pine seedlings by treating with fungicides before storage. South. J. Appl. For. 12:281–285.

BOYER, J.N., AND D.B. SOUTH. 1986. Dormancy, chilling requirements, and storability of container-grown loblolly pine seedlings. P. 372–383. *in* Proc. Internat. Symp. on Nursery Management Practices for the Southern Pines, South, D.B., (ed.). Ala. Agric. Exp. Stn., Auburn University.

BOYER, J.N., AND D.B. SOUTH. 1987. Excessive seedling height, high shoot-to-root ratio, and benomyl root dip reduce survival of stored loblolly pine seedlings. Tree Plant. Notes 38(4):19–22.

BOYER, J.N., AND D.B. SOUTH. 1989. Seasonal changes in intensity of bud dormancy in loblolly pine seedlings. Tree Physiol. 5:379–385.

CARLSON, W.C. 1985. Effects of natural chilling and cold storage on budbreak and root growth potential of loblolly pine seedlings. Can. J. For. Res. 15:651–656.

CHUNG, H.H., AND R.L. BARNES. 1980a. Photosynthate allocation in *Pinus taeda.* II. Seasonal aspects of photosynthate allocation to different biochemical fractions in shoots. Can. J. For. Res. 10:338–347.

CHUNG, H.H., AND R.L. BARNES. 1980b. Photosynthate allocation in *Pinus taeda.* III. Photosynthate economy: Its production, consumption and balance in shoots during the growing season. Can. J. For. Res. 10:348–356.

CORDELL, C.E., ET AL. 1985. Effects of benomyl root storage treatments on longleaf pine seedling survival and brown-spot disease resistance. P. 84–88. *in* Proc. 1984 South. Nursery Conf., Lantz, C.W. (ed.). USDA For. Serv., Atlanta, GA.

FERET, P.P., AND R.E. KREH. 1985. Seedling root growth potential as an indicator of loblolly pine field performance. For. Sci. 31:1005–1011.

GARBER, M.P., AND J.G. MEXAL. 1980. Lift and storage practices: Their impact on successful establishment of southern pine plantations. N.Z. J. For. Sci. 10:72–82.

KAIS, A.G., G.A. SNOW, AND D.H. MARX. 1981. The effects of benomyl and *Pisolithus tinctorius* ectomycorrhizae on survival and growth of longleaf pine seedlings. South. J. Appl. For. 5:189–195.

KAIS, A.G., C.E. CORDELL, AND C.E. AFFELTRANGER. 1986. Benomyl root treatment controls brown-spot disease on longleaf pine in the southern United States. For. Sci. 32:506–511.

LARSEN, H.S., D.B. SOUTH, AND J.N. BOYER. 1988. Foliar nitrogen content at lifting correlates with early growth of loblolly pine seedlings from 20 nurseries. South. J. Appl. For. 12:181–185.

LAVENDER, D.P. 1985. Bud dormancy. P. 7–15 *in* Evaluating seedling quality: Principles, procedures, and predictive abilities of major tests. Duryea, M.L. (ed.). For. Res. Lab., Oregon State Univ., Corvallis.

MARX, D.H., AND S.J. ROWAN. 1981. Fungicides influence growth and development of specific ectomycorrhizae on loblolly pine seedlings. For. Sci. 27:167–176.

MEXAL, J.G., AND D.B. SOUTH. 1991. Bareroot seedling culture. *In* Regeneration manual for the southern pines. Duryea, M.L., and P.M. Dougherty (eds.). Nijhoff/Junk, The Hague, The Netherlands. (In press.)

PAWUK, W.H., J.L. RUEHLE, AND D.H. MARX. 1980. Fungicide drenches affect ectomycorrhizal development of container-grown *Pinus palustris* seedlings. Can. J. For. Res. 10:61–64.

PAWUK, W.H., AND J.P. BARNETT. 1981. Benomyl stimulates ectomycorrhizal development by *Pisolithus tinctorius* on shortleaf pine grown in containers. USDA For. Serv. Res. Note SO-267. 3 p.

SAS INSTITUTE, INC., 1985. SAS User's Guide, 1985 ed. SAS Institute, Inc., Cary, NC.

SWITZER, G.L. 1969. Planting date and survival of loblolly pine seedlings. Mississippi State Univ. Agric. Exp. Stn. Inf. Sheet 1090. 2 p.

VENATOR, C.R. 1985. Evidence of the presence of a lifting window for loblolly pine nursery seedlings. P. 184–191 *in* 1984 Proc. South. Nursery Conf. Lantz, C.W. (ed.). USDA For. Serv., Atlanta, GA.

WAKELEY, P.C. 1954. Planting the Southern Pines. USDA Agric. Monogr. No. 18. U.S. Gov. Print. Off., Washington, DC. 233 p.