Fungicides Improve Field Performance of Stored Loblolly and Longleaf Pine Seedlings

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ABSTRACT. *Seedlings of loblolly and longleaf pine lifted in December, January, and February were treated with either benomyl or ridomil before cold storage. Along with an untreated control, they were planted after cold storage of less than 1 wk, 3 wk, and 6 wk. Survival was measured in mid-June after planting, and after 1 and 4 yr in the field. Total height was measured after 4 yr. The fungicide application increased survival of both species lifted in December or February and was beneficial to longleaf pine seedlings regardless of storage duration. Fungicide-treated longleaf pine seedlings had greater mean 4 yr height than the controls, but fungicides did not affect the height of loblolly pine. South. J. Appl. For. 20(1): 5–9.*

Most southern pine seedlings are stored for a period of days or weeks between lifting at the nursery and planting at the reforestation site. Typically, lifting and storing occur between late November and mid-February (Wakeley 1954, May 1985). Root growth potential (RGP) is greatest during that period and peaks in January for many southern pine seed sources (Brissette et al. 1988). It is also during this early winter period that seedlings can best endure the rigors of lifting, storing, and transplanting (Garber and Mexal 1980). Although the biological basis is not defined, there is a positive relationship between RGP and the ability of seedlings to withstand stress (Ritchie and Tanaka 1990).

For several years, we have studied the effects of fungicides applied to seedling roots just before cold storage. In general, fungicide treatment improved field survival, presumably because of altered fungal populations found on the roots of stored seedlings. Results from a number of studies since 1986 show that the relative frequencies of fungi in the genera *Trichoderma*, *Pestalotia*, and *Pythium* on the roots of pine seedlings change during cold storage; in most years *Pythium* developed rapidly during storage (Jones et al. 1992).

A mixture of benomyl and kaolin clay to form a slurry with 5% active ingredient (ai) of the fungicide improved survival of longleaf pine (*Pinus palustris* Mill.) cold-stored for 1, 3, or 6 weeks (Barnett et al. 1988). Barnett et al. (1988) also reported a beneficial effect from clay and benomyl at 1.25% ai for loblolly pine (*P. taeda* L.) and slash pine (*P. elliotii* Engelm.) lifted in March and stored for 6 wk before planting.

However, benomyl can reduce RGP of southern pine seedlings (Barnett et al. 1988, Hallgren 1992). Furthermore, in a study with loblolly pine, Stumpff and South (1991) found that a 1.25% ai clay-benomyl slurry reduced initial survival and first-year height growth of seedlings lifted approximately biweekly between late October and February 1 and stored for either 1 or 4 wk.

The objective of the present study was to examine the effects both benomyl and ridomil (a fungicide more specifically targeted against *Pythium* than the broad spectrum benomyl) on survival and growth of loblolly and longleaf pine seedlings.

NOTE: This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate state and federal agencies before they can be recommended. CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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Materials and Methods

The seedlings originated from bulked seed orchard lots of loblolly and longleaf pine adapted to the Western Gulf Coastal Plain region. The seedlings were grown under operational conditions at the USDA Forest Service W.W. Ashe Nursery near Brooklyn, Mississippi. Seedlings of both species were hand-lifted on December 7, 1987, January 19, 1988, and February 29, 1988. They were culled to a uniform size; that is, both very small and very large seedlings were removed. The roots were washed to remove nursery soil, packaged in kraft-polyethylene bags, and transported to the Southern Forest Experiment Station laboratory in Pineville, Louisiana.

One of three fungicide treatments was applied; kaolin clay slurry (1,514 g clay plus 3.785 L water) with no fungicide (the control), a slurry of clay and enough 50% wettable powder benomyl to make a mixture with 1.25% ai, and a slurry of clay mixed with water containing 10 ppm ridomil. After treatment, the seedlings were rebagged (about 250 seedlings per bag) and put into cold storage (approximately 3°C) at the Alexandria Forestry Center in Pineville, Louisiana.

Three durations of cold storage were compared; less than 1 wk, 3 wk, and 6 wk. Within 4 days of lifting, seedlings from each species × fungicide treatment were planted. The remaining seedlings were left in cold storage for the specified times, then planted. Seedlings were machine-planted at a spacing of approximately 1.5 × 2.5 m on an old field site at the J.K. Johnson Tract of the Palustris Experimental Forest in central Louisiana. The soil is Beauregard silt loam (Plinthaquic Paleudults, fine-silty, siliceous, thermic), and the slope is 1% to 3%.

The study used a randomized, complete block experimental design with 4 blocks. Within the blocks, each species × lift date × storage duration × fungicide treatment was represented by 50 seedlings. The area required for this study was more than 4 ha, and blocking was intended to control variation due to edaphic differences at the site.

A number of weather variables were measured and recorded electronically by equipment located about 300 m from the planting site. Of particular interest in this study were the temperature during the planting season and the soil water potential during the first summer after planting. Air temperature was measured with a shielded thermistor placed 20 cm above ground level. Soil water potential was measured with a fiberglass-reinforced resistance block at 15 cm below the surface. The block measured water potentials between –0.05 MPa (about field capacity) and –1.50 MPa [the wilting coefficient (Brady 1974)]. Both sensors were scanned every 5 min. The data were summarized to the daily mean temperature, the minimum daily temperature scanned, and the daily mean soil water potential.

Survival was recorded in mid-June of the first growing season, after the first year in the field, and after 4 growing seasons. Total height of each surviving tree was measured to the nearest 3 cm at the end of the fourth growing season.

Results from the two species were analyzed separately. Because of the structure of the treatments, we used orthogonal contrasts to examine the main effects of lift date, storage duration, and fungicide treatment For both species, the following contrasts were used:

Lift date:
- January vs. December and February
- December vs. February

Storage duration:
- less than 1 wk vs. 3 and 6 wk
- 3 wk vs. 6 wk

Fungicide treatment:
- control vs. fungicide application
- benomyl vs. ridomil

Interactive effects of the treatments on survival and mean height were analyzed using analysis of variance (ANOVA) For hypothesis testing, differences at the 0.05 level were considered significant.

Results

Climate

Throughout the planting season, there were periods of from 1 to several consecutive days when the minimum air temperature at 20 cm was below freezing (Figure 1). Moreover, in January there were 4 successive days that the mean temperature was at or below freezing. That cold period began about a week after planting seedlings from the December lift that were stored 3 wk.

The seedlings experienced a moderate drought during the first growing season when soil water potential dropped from –0.08 MPa on June 1 to –0.40 MPa on June 19. During the rest of that summer, soil water potential at 15 cm remained near field capacity.

Survival

Four-year survival of loblolly pine among the various treatment combinations ranged from 64% to 100% (Figure 2), and averaged 90%. For longleaf pine, survival was lower,

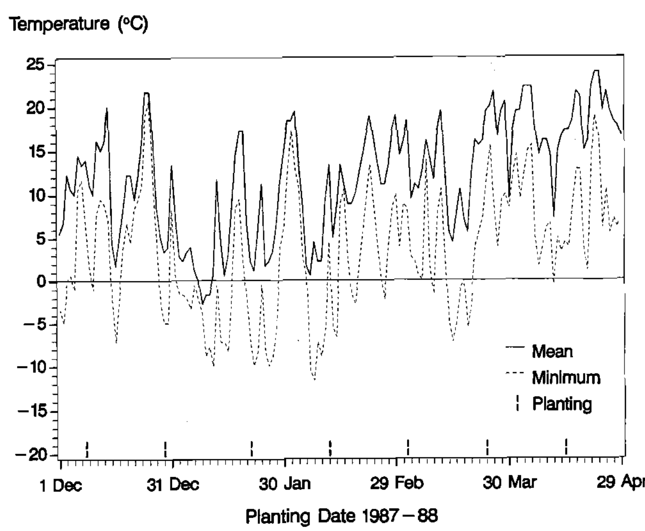

Figure 1. Mean and minimum daily temperatures 20 cm above the ground between December 1, 1987 and April 29, 1988 at the Palustris Experimental Forest in central Louisiana. Planting dates were the same for both species and are indicated by "Planting "

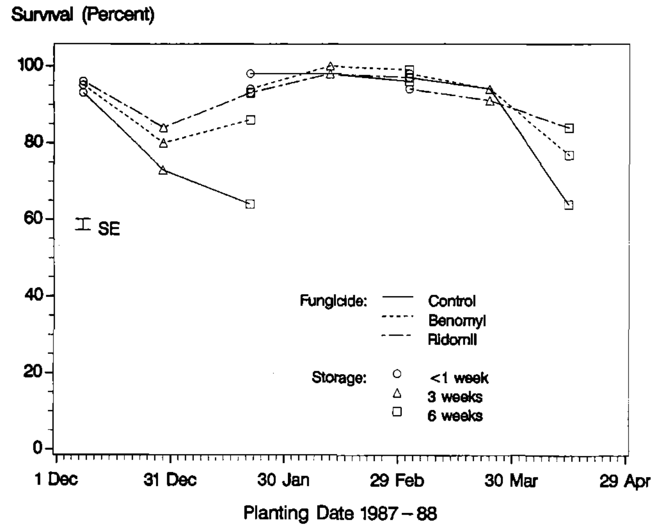

Figure 2. Effects of lift date, storage duration, and fungicide treatments on survival of loblolly pine seedlings 4 yr after planting in central Louisiana (SE = standard error).

ranging from 18% to 84% (Figure 3), and averaging 63%. The analyses showed that treatments accounted for 82% of the variation in 4 yr survival of the loblolly pine seedlings and 81% of the variation for longleaf pine. Treatments affected mortality of longleaf pine seedlings throughout the first growing season, while their effects on loblolly pine were primarily in the first 3 to 6 months after planting (Table 1). In both species, none of the mortality after the first year was attributable to treatments.

The orthogonal contrasts described several significant differences in seedling mortality that can be explained, at least in part, by the experimental treatments (Table 1). Seedlings of both species lifted in January had less mortality than seedlings lifted earlier or later. For loblolly pine, December lifting resulted in greater mortality by mid-June than did February lifting. There was no difference between those lifts for longleaf pine. After mid-June of the first growing season,

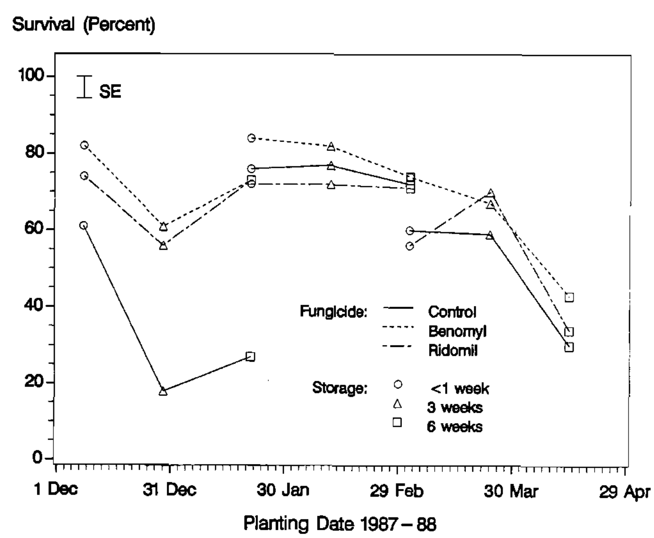

Figure 3. Effects of lift date, storage duration, and fungicide treatments on survival of longleaf pine seedlings 4 yr after planting in central Louisiana (SE = standard error).

there was no difference in mortality of loblolly pine seedlings lifted in either December or February. February-lifted longleaf pine seedlings suffered greater mortality between June and the end of the first growing season than did December-lifted seedlings.

For both species, seedlings stored for 3 or 6 wk had poorer survival than seedlings that were planted within a few days (Table 1). Furthermore, mortality was greater among seedlings stored 6 wk than among seedlings stored 3 wk.

Early mortality among untreated loblolly pine seedlings was more than twice that of seedlings treated with a fungicide (Table 1). However, there was no difference between the two fungicides for loblolly pine. An important difference between the species was the continued benefit of a fungicide throughout the first year on longleaf pine. Moreover, late in the first growing season, benomyl resulted in less longleaf pine mortality than did ridomil.

In addition to the main effects detected by the orthogonal contrasts, survival was also affected by some significant two-way interactions among the treatments. For both species, the lift date × storage duration interaction was important because seedlings lifted in January survived better after storage than those lifted in either December of February (Figures 2 and 3).

The lift date × fungicide treatment was also significant for both species. Fungicide treatment was especially beneficial for seedlings lifted in December, had essentially no effect on January-lifted stock, and provided some marginal benefit for February-lifted seedlings (Figures 2 and 3).

For loblolly pine, the interaction between storage duration and fungicide treatment was important; there was no benefit from a fungicide for seedlings that were stored for less than a week, but its value increased with increased storage duration (Figure 2). Benomyl, and in some cases ridomil, made marked improvements in survival of longleaf pine seedlings, regardless of storage duration (Figure 3). Consequently, for longleaf pine, the storage duration × fungicide treatment interaction was not significant.

Total Height

Total height of loblolly pine after 4 yr ranged from 213 cm to 249 cm for the various treatment combinations (Figure 4), with an overall mean of 231 cm. The experimental treatments explained 64% of the variation. The contrasts yielded two significant results. First, the overall mean total height of seedlings lifted in January was greater than for seedlings lifted earlier or later (Figure 4). Secondly, although fungicide-treated seedlings were not taller, on average, than untreated stock, benomyl resulted in taller trees than did ridomil (Figure 4). None of the interactions among the treatments were significant.

For longleaf pine, four-year total height among the treatment combinations ranged from 63 cm to 105 cm (Figure 5), and averaged 81 cm. The treatments accounted for 54% of the variation. Unlike loblolly pine, the mean total height for longleaf pine seedlings lifted in January was not greatest; however, seedlings lifted in December averaged taller than those lifted in February (Figure 5). Overall, treatment with either fungicide resulted in taller seedlings than the untreated

Table 1 Orthogonal contrast results for seedling mortality for three periods between planting and age 4

	Percent mortality for the period		
Species/contrast	Planting to mid-June	Mid-June to end of Year 1	End of Year 1 to end of Year 4
Loblolly Pine			
Jan. vs. Dec. + Feb.	0.8 vs. 8.6***[1]	1.5 vs. 3.1*	0.7 vs. 1.9
Dec. vs. Feb.	11.3 vs. 5.8***	2.7 vs. 3.4	1.1 vs. 2.7
No store vs. stored	2.0 vs. 7.9***	2.1 vs. 2.8	0.7 vs. 1.9
3 vs. 6 weeks storage	6.7 vs. 9.1**	1.8 vs. 3.7*	1.2 vs. 2.7
Contl. vs. fungicides	9.7 vs. 4.1***	2.7 vs. 2.5	1.3 vs. 1.6
Benomyl vs. Ridomil	4.7 vs. 3.6	2.5 vs. 2.4	1.5 vs. 1.8
Standard error[2]	1.6	1.7	1.8
Longleaf Pine			
Jan. vs. Dec. + Feb.	8.3 vs. 25.5***	8.7 vs. 12.4**	7.5 vs. 5.6
Dec. vs. Feb.	26.5 vs. 24.4	9.4 vs. 15.4***	5.8 vs. 5.4
No store vs. stored	11.4 vs. 23.9***	10.2 vs. 11.6	7.4 vs. 5.6
3 vs. 6 weeks storage	21.3 vs. 26.6*	10.3 vs. 13.0*	6.1 vs. 5.2
Contl. vs. fungicides	26.8 vs. 16.2***	13.4 vs. 10.1**	6.6 vs. 6.1
Benomyl vs. Ridomil	15.3 vs. 17.2	8.1 vs. 12.0**	5.6 vs. 6.6
Standard error[2]	4.8	2.7	2.6

1 *** = $P < 0.001$, ** = $P < 0.01$, * = $P < 0.05$
2 Degrees of freedom for error = 78 for all contrasts.

control (Figure 5). However, there was no difference in total height between the fungicides. As with loblolly pine, none of the interactions among treatments were significant.

Discussion

The success of artificial regeneration is determined by both survival and growth after outplanting. With regards to seedling survival, results of this study were similar to much of the previous research on the effects of lift date and storage duration. Survival of longleaf pine seedlings is typically lower than other southern pines, especially if the seedlings are stored (Wakeley 1954).

Of the three lift dates used in this study, mid-January was, as expected, the best for both species. An unexpected result was the rather severe early season mortality among the December-lifted loblolly pine stock, which was twice that of February-lifted seedlings. There was no such early difference between the December and February lifts of longleaf pine

February-lifted longleaf pine seedlings suffered greater mortality than December-lifted stock late in the first growing season. In longleaf pine, we have found that new root growth initiates more slowly than for the other southern pines (Brissette and Barnett, unpublished). Consequently, longleaf pine seedlings planted in late winter or early spring likely have poorer root-soil contact and exploit a smaller volume of

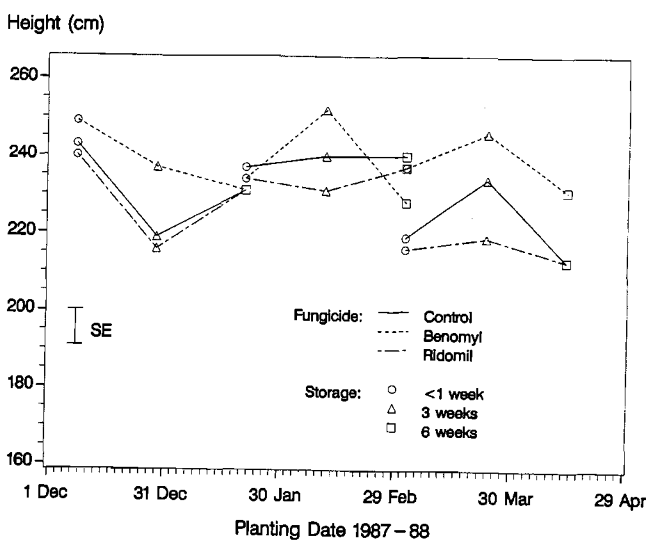

Figure 4. Effects of lift date, storage duration, and fungicide treatments on total height of loblolly pine seedlings 4 yr after planting in central Louisiana (SE = standard error).

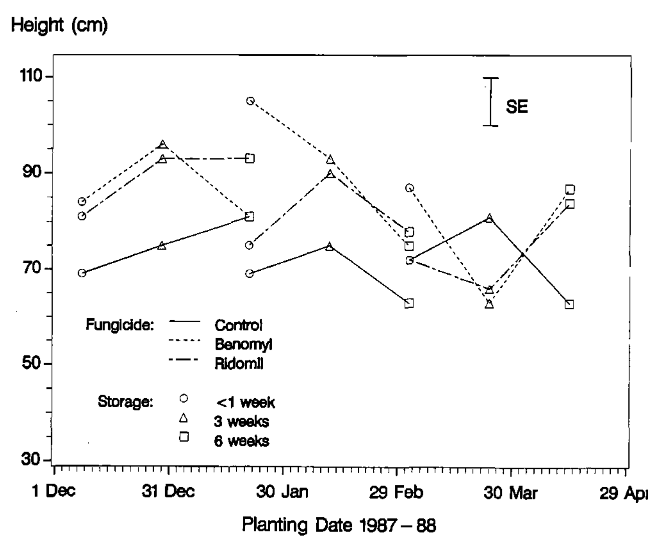

Figure 5. Effects of lift date, storage duration, and fungicide treatments on total height of longleaf pine seedlings 4 yr after planting in central Louisiana (SE = standard error).

soil than seedlings planted earlier. As a result, longleaf pine is probably more susceptible than loblolly pine to a drought such as the drought that occurred in June during the first year of this study.

In general, the pattern of mortality for the storage treatments followed the anticipated trend—increased mortality with longer storage—in both pine species. However, among the December-lifted seedlings, average survival of both species was better after 6 wk storage than after 3 wk. The 4 day period of freezing weather that followed planting of the 3 wk storage treatments, but not the 6 wk treatments, may account for that anomaly. Wakeley (1954) cites evidence from several locations that freezing of the ground within 10 days after planting can seriously reduce initial survival. Seedlings which suffer cold damage in a nursery exhibit reduced root growth potential compared to undamaged stock (Carlson 1984, Lantz 1984). Furthermore, as the results of our study also demonstrate, cold damage tends to be more severe among longleaf pine seedlings than among loblolly pine seedlings (Lantz 1984, Rowan 1984).

Contrary to the results of Stumpff and South (1991), fungicides did improve survival of loblolly pine seedings. However, the beneficial effects of treating seedlings with fungicides in this study were greater for longleaf pine than for loblolly pine. In addition to its effects on storage fungi, at 5% ai, benomyl provides systemic protection from brown-spot disease (*Mycosphaerella dearnessii* Barr) for at least 1 yr in the field (Kais and Barnett 1984, Cordell et al. 1984, Kais et al 1986a and 1986b). Brown-spot disease is frequently observed on longleaf pine trees at the Johnson Tract, although it seldom causes enough mortality to be a serious concern. Thus, whereas the rate of benomyl in this study was only 1.25%, it may have provided enough protection to explain the difference in survival between the fungicides, considering the low hazard planting site.

Longleaf pines treated with benomyl or ridomil were significantly taller than the untreated control trees. Application of either fungicide clearly resulted in taller trees after 4 yr in the field. Increased initial growth of longleaf pine seedlings treated with benomyl has been reported previously (Kais et al. 1981, Kais and Barnett, 1984). The increased height may have resulted because the treated seedlings remained in the grass stage for a shorter period of time. Height measurements taken in years 1 through 3 would have been required to test that hypothesis in this study, however.

The results of this and previous studies have shown that applying a fungicide before seedlings are stored can improve field performance. Work by other researchers has shown that not to be the case for every nursery, lift date, or planting site. The degree of fungal root infection and the composition of fungi on the roots are probably affected by a number of nursery specific factors, such as soil texture, water holding capacity, and management practices. More research is needed to fully explain the apparent interactive effects of nursery, lift date, and planting site.

In this study, two fungicides with different modes of action and ranges of fungi controlled, increased survival for loblolly and longleaf pine, when compared to untreated seedlings. Furthermore, both fungicides resulted in trees taller than the controls in longleaf pine 4 yr after planting. These results indicate that controlling the composition of fungal populations on seedling root systems in cold storage is a viable means of improving field performance.

Literature Cited

Barnett, J.P., J.C. Brissette, A.G. Kais, and J.P. Jones. 1988. Improving field performance of southern pine seedlings by treating with fungicides before storage. South. J. Appl. For. 12(4):281–285.

Brady, N.C. 1974. The nature and properties of soils. Ed. 8. MacMillan, New York. 639 p.

Brissette, J.C., J.P. Barnett, and C.L. Gramling. 1988. Root growth potential of southern pine seedlings grown at the W.W. Ashe Nursery. P. 173–183 *in* Proc. South. For. Nursery Assoc., South Carolina For. Comm., Columbia, SC.

Carlson, W.C. Cold damage to loblolly pine seedlings. 1984. P. 1–12 *in* Proc. South. Nursery Conf., USDA For. Serv. South. Reg., Atlanta, GA.

Cordell, C.E., A.G. Kais, J.P. Barnett, and C.E. Affeltranger. 1984. Effects of benomyl root storage treatments on longleaf pine seedling survival and brown-spot disease incidence. P. 84–88 *in* Proc. South. Nursery Conf., USDA For. Serv. South. Reg., Atlanta, GA.

Garber, M.P., and J.G. Mexal. 1980. Lift and store practices: Their impact on successful establishment of southern pine plantations. N.Z. J. For. Sci. 10:72-82.

Hallgren, S.W. 1992. The impact of lift and store practices on field performance of shortleaf pine seedlings. P.46–57 *in* Proc. Shortleaf Pine Regeneration Workshop. USDA For. Serv. Gen. Tech. Rep. SO-90.

Jones, J.P., D.J. Pantone, J.P. Barnett, and J.C. Brissette. 1992. The relationships between fungal population development and root damage of cold-stored longleaf pine seedlings. Louisiana State Univ. Agric. Center Bull. No. 832, 23 p.

Kais, A.G., and J.P. Barnett. 1984. Longleaf pine growth following storage and benomyl root-dip treatment. Tree Plant. Notes 35(1):30–33.

Kais, A.G., C.E. Cordell, and C.E. Affeltranger. 1986a. Benomyl root treatment controls brown-spot disease on longleaf pine in the Southern United States. For. Sci. 32:506–511.

Kais, A.G., C.E. Cordell, and C.E. Affeltranger. 1986b. Nursery application of benomyl fungicide for field control of brown-spot needle blight (*Scirrhia acicola* [Dearn.] Siggers) on longleaf pine (*Pinus palustris* Mill.). Tree Plant. Notes 37(1):5.

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.

Lantz, C.W. Freeze damage to southern pine seedlings in the nursery. 1984. P. 20–29 *in* Proc. South. Nursery Conf. USDA For. Serv. South. Reg., Atlanta, GA.

May, J.T. 1985. Lifting and field packing. Chap. 8 *in* Southern Pine Nursery Handb. USDA For. Serv., South. Reg., Atlanta, GA.

Ritchie, G.A., and Y. Tanaka. 1990. Root growth potential and the target seedling. P. 37–51 *in* Proc. Target Seedling Symp., Combined Meet. of the Western Forest Nursery Assoc. USDA For. Serv. Gen. Tech. Rep. RM-200.

Rowan, S.J. Impact of Christmas 1983 freeze on growth and survival of slash, loblolly and longleaf pine seedlings from Alabama and Georgia nurseries. 1984. P. 30-38 *in* Proc. South. Nursery Conf., USDA For. Serv. South. Reg., Atlanta, GA.

Stumpff, N.J., and D.B. South. 1991. Benomyl root dips adversely affect first-year performance of stored loblolly pine seedlings. South. J. Appl. For. 15(3):133–137.

Wakeley, P.C. 1954. Planting the southern pines. USDA For. Serv. Agric. Monogr. No. 18. 233 p.