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Contents

Hydraulic stake driver, developed by the Missoula Technology and Development Center, in use at the Bend Nursery, Bend, OR (Photo by Ben Lowman, USDA Forest Service, Missoula, MT).

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Dry Site Survival of Bareroot and Container Seedlings of Southern Pines From Different Genetic Sources Given Root Dip and Ectomycorrhizal Treatments

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*Survival rates of loblolly pine (*Pinus taeda *L.) seedlings from two seed sources and shortleaf pine (*P. echinata *Mill.) seedlings from one source were compared for the first 2 years after outplanting on drought-prone sites. Several combinations of stock type and preplanting treatments were examined: bareroot seedlings with no pretreatment, bareroot seedlings treated with Terra-Sorb® root dip, container seedlings, and container seedlings inoculated with ectomycorrhizae. Survival rates were not significantly different for seed sources. However, after two growing seasons, bareroot seedlings survived better than container seedlings and container seedlings with ectomycorrhizae on the most severe sites. On a more moderate site, container seedlings showed the highest survival, and treated bareroot seedlings showed higher survival rates than untreated bareroot seedlings.*
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The western limit of the natural range of loblolly pine (*Pinus taeda* L.) is limited by a number of ecological factors (*12*). As this edge is approached, conventional reforestation techniques (for example, planting bareroot 1+0 seedlings) commonly fail. In Texas, this problem has become more critical as interest in reforestation of marginal agricultural lands has increased and accelerated urbanization has continued to decrease existing commercial forest acreage (*2*).

The objective of this study was to evaluate the influence of genetic sources, planting stock, and root treatments relative to pine seedling survival after outplanting. These evaluations were conducted over a 2-year period under site conditions common to the region and typical of sites being reforested.

The comparison of genetic material was made among two sources of loblolly pine seed and one source of shortleaf pine (*Pinus echinata* Mill.) seed. The planting stocks and root treatments were 1) bareroot seedlings; 2) bareroot seedlings with roots dipped in Terra-Sorb®, a hygroscopic starch, before planting; 3) container-grown seedlings; and 4) ectomycorrhiza-infected container-grown seedlings. The field sites were two recent clearcuts and an old pasture.

Materials and Methods

Genetic materials, preplanting growth regimes, and treatments. Seed sources were 1) loblolly pine selected for superior growth and form, 2) loblolly pine selected for drought resistance (*30*), and 3) shortleaf pine selected for superior growth and form (table 1).

All bareroot seedlings were produced by the Texas Forest Service using standard nursery techniques at their Indian Mound Nursery near Alto, TX. Seedlings were lifted while dormant, less than 1 month before planting. When graded according to the Wakeley guidelines (*31*), all planted bareroot seedlings were grades one or two. Mycorrhizal infection was not assessed.

Container seedlings were produced in temperature-controlled and supplementally lit greenhouse space on the Texas A&M University campus, College Station, TX. Seedlings were grown in Styrofoam® planter flats with individual cells that were about 13 cm deep and 3 cm in diameter. The growing medium was a

1:1 mixture of peat and vermiculite. Fertilizer, water, and light regimes were generally manipulated for rapid growth, except for the ectomycorrhizal seedlings, which were fertilized at about half the nutrient level of the other seedlings. This lower application rate was used because high levels of nitrogen and phosphorus have been shown to inhibit ectomycorrhizal development (*25, 28*). All container seedlings were placed in a shadehouse 3 weeks before outplanting to harden seedlings (*27*).

Mycorrhizal seedlings were inoculated with *Pisolithus tinctorius* (Pers.) Coker & Couch provided by the Institute for Mycorrhizal Research and Development (IMRD), Southeastern Forest Experiment Station, USDA Forest Service, Athens, GA. Inoculation and fertilization followed the institute's guidelines. Before outplanting, a subsample of 25 inoculated and 25 non-inoculated seedlings from each seed source were sent to the IMRD for assessment of ectomycorrhizal infection. The *Pisolithus tinctorius* (Pt) indices (*17*) for inoculated superior loblolly pine, drought-hardy loblolly pine, and shortleaf pine were 74, 83, and 69, respectively. A Pt index of at least 50 is believed necessary to significantly increase survival and growth of southern pine seedlings planted on reforestation sites (*17*). On non-inoculated container seedlings, infection by Pt was absent, but an average of 10% of the root tips were infected by other ectomycorrhizal species (primarily *Thelephora terrestris* (Ehrh.) Fr.).

Table 1—*Genetic sources used in study*

Genetic source	Description
Superior loblolly pine	Collected as bulk lot from first-generation seed orchard representing the continuous range of loblolly pine in East Texas
Drought–hardy loblolly pine	Collected as bulk lot from first-generation seed orchard representing western fringe of continuous range and material selected from "Lost Pines" (*30*) region in Texas
Shortleaf pine	Collected as bulk lot from first-generation seed orchard representing natural range of shortleaf pine in Texas

For container seedlings, mean seedling shoot and root mass were 665 and 250 mg, respectively. These seedlings fell within the acceptable size criteria for container stock (*4*). We observed that the non-inoculated seedlings, probably because they received more fertilizer, were slightly taller and had better nutritional appearance than inoculated seedlings.

Bareroot seedlings were planted with and without a root dip treatment. In the root dip treatment, a slurry of water and Terra-Sorb, a gelatinized, starch-hydrolyzed polyacrylonitrile graft copolymer, was prepared in accordance with the manufacturer's instructions. Root systems receiving the treatment were dipped immediately before planting. To ensure equal care, roots of non-treated seedlings were dipped in water immediately before planting.

Study sites. The study was conducted on three sites (table 2) located near the western edge of the two species' natural range in northeast Texas (fig. 1). One study site, a clearcut, was in Henderson County near Athens (AthCC). The other sites were located in Bowie County near New Boston. One New Boston site was a clearcut (NBCC) and the other an old-field pasture (NBOP). Soil moisture and organic matter characteristics are listed in table 3. Although soil nutritional status was evaluated for each site, that work is not reported here because all sites were nutritionally adequate and there were no major differences among sites.

On each site a standard U.S. Weather Service rain gauge was maintained during the first 9 months of the study. After that, weather information was obtained from the nearest U.S. Weather Service Station.

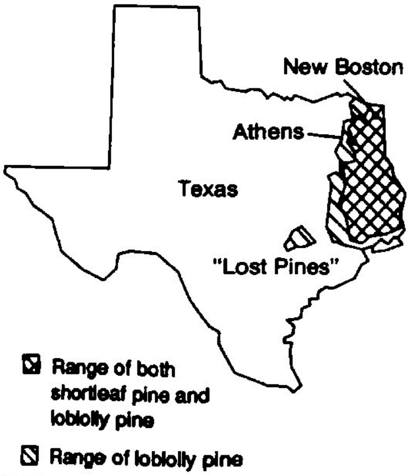

Figure 1—*Location of study sites in relation to natural ranges of loblolly and shortleaf pines.*

Experimental design. On each site, three complete replications were established. Each replication consisted of 12 numerically square plots, each containing all combinations of the four preplanting treatments and three genetic sources. Individual plots consisted of 49 trees from one combination of treatment and genetic source. Combinations were randomly assigned to plots within replications. Seedlings were planted on a 1.8 by 3.0 m spacing, with at least two border rows planted around each replication.

Planting, measurement, and analysis. All seedlings were hand planted in late February 1983 by Texas Forest Service planting crews using dibble bars. So that the influence of planters could be minimized, plots were planted one at a time, by at least three planters each. The recommendations of Owston and Stein (*22*) were followed as closely as possible in the care and planting of seedlings.

All seedlings were evaluated for survival about 2, 6, 9, 14, and 21 months after planting. For statistical analysis, the arcsine of the square root of average plot survival was used to transform data.

Soil sampling and analysis. To aid in interpretation of results, soil water retention characteristics and organic matter contents were characterized. For each plot, the first and second 15 cm of soil were sampled. Within each plot a minimum of four randomly selected points were sampled and composited for laboratory analysis.

Soil organic matter was determined by the Walkley and Black technique S (*21*), and available water-holding capacity was determined by the ceramic pressure plate extraction procedure using disturbed soil samples (*24*). Available water was assumed to be that water held between soil water potentials of −0.01 and −1.5 MPa (1 megaPascal = 10 bars).

Results

Sites were similar in temperature and total precipitation (fig. 2). However, there were

Table 2—*Description of study sites, treatments, and soils*

Site	Site description	Soil classification	Soil texture*
New Boston clearcut (NBCC)	Loblolly pine plantation, harvested December 1981, drum chopped, burned November 1982	Blevins series, fine silty, siliceous, thermic Typic Paleudult	Loam to sandy loam
New Boston old pasture (NBOP)	Dominated by *Andropogon* spp., burned December 1982	Rosalie series, loamy siliceous, thermic Arenic Paleudult	Sandy loam to loamy sand
Athens clearcut (AthCC)	Slash pine (*Pinus elliottii* Englem.) plantation, harvested spring 1982, hardwood cut or girdled, burned November 1982	Pickton series, loamy siliceous, thermic Grossarenic Paleudalf	Sand to sandy loam

*Texture of 0 to 30 cm soil depth.

marked differences among sites in the distribution of precipitation during the study. In the first 2 months, the NBCC and NBOP sites received 216 and 222 mm of precipitation, respectively, whereas the AthCC site received 99 mm. In contrast, the AthCC site, during the middle and late summer months (June–September 1983), received 25 to 100 mm more precipitation than the New Boston area sites, which had only a trace of precipitation during August 1983.

Contributing to the influence of precipitation, soils of the study sites were distinctly different from each other physically. Among sites, differences in available soil moisture-holding capacity were significant for both soil depths. For 0 to 15 and 15 to 30 cm soil depths, the NBCC site was 44 and 33% greater than that of the NBOP site and 185 and 197% greater than that of the AthCC (table 3). These differences primarily reflected differences in soil texture (table 2) but also appeared related to soil organic matter content (table 3). Organic matter content was significantly greater in the NBCC site than in the other sites, perhaps reflecting the finer soil texture and drum chopping of this site (table 2).

Seedling survival. An ANOVA table indicating statistical differences for the final (21 month) survival evaluations is presented in table 4. Over the study period there were no statistically significant differences in survival among genetic sources. Twenty-one months after planting, mean survival of genetic sources varied from 71 to 80% on the NBOP site, 70 to 73% on the NBCC site, and 52 to 58% on the AthCC site. Large pretreatment differences among the three sites were observed, leading to further analyses being performed on an individual site basis.

Preplanting treatments significantly influenced seedling survival, with the observed effects varying among sites. On the NBOP site (fig. 3), the site with highest overall survival, the container and Terra-Sorb–dipped bareroot (trsb–bareroot) seedlings showed significantly higher survival than bareroot seedlings. Also, container seedlings had significantly higher survival than ectomycorrhizal container seedlings (myco–container).

In contrast, on the NBCC site, the bareroot and trsb–bareroot seedlings had significantly higher survival than either the container or myco–container seedlings, and survival of the latter seedlings was significantly lower than in all other treatments. As shown in figure 3, the AthCC site exhibited a survival pattern similar to that of the NBCC site, but overall survival was markedly lower. After 21 months the myco–container seedlings again accounted for the lowest survival (39%) and the only significant difference between treatments.

As expected, mortality was generally greatest during the first growing season. However, while survival continued to decline in

Table 3—*Soil properties related to moisture retention on the study sites at two soil depths (0–15 cm and 15–30 cm)*

	Available soil moisture holding capacity (% of mass)		Soil organic matter (% of mass)	
Site	0–15 cm	15–30 cm	0–15 cm	15–30 cm
New Boston clearcut (NBCC)	18.2 a	19.5 a	1.52 a	0.66 a
New Boston old pasture (NBOP)	12.6 b	14.6 b	0.88 b	0.42 b
Athens clearcut (AthCC)	6.4 c	4.9 c	0.72 b	0.39 b

Numbers in the same column followed by the same letter do not differ significantly at the 0.05 level.

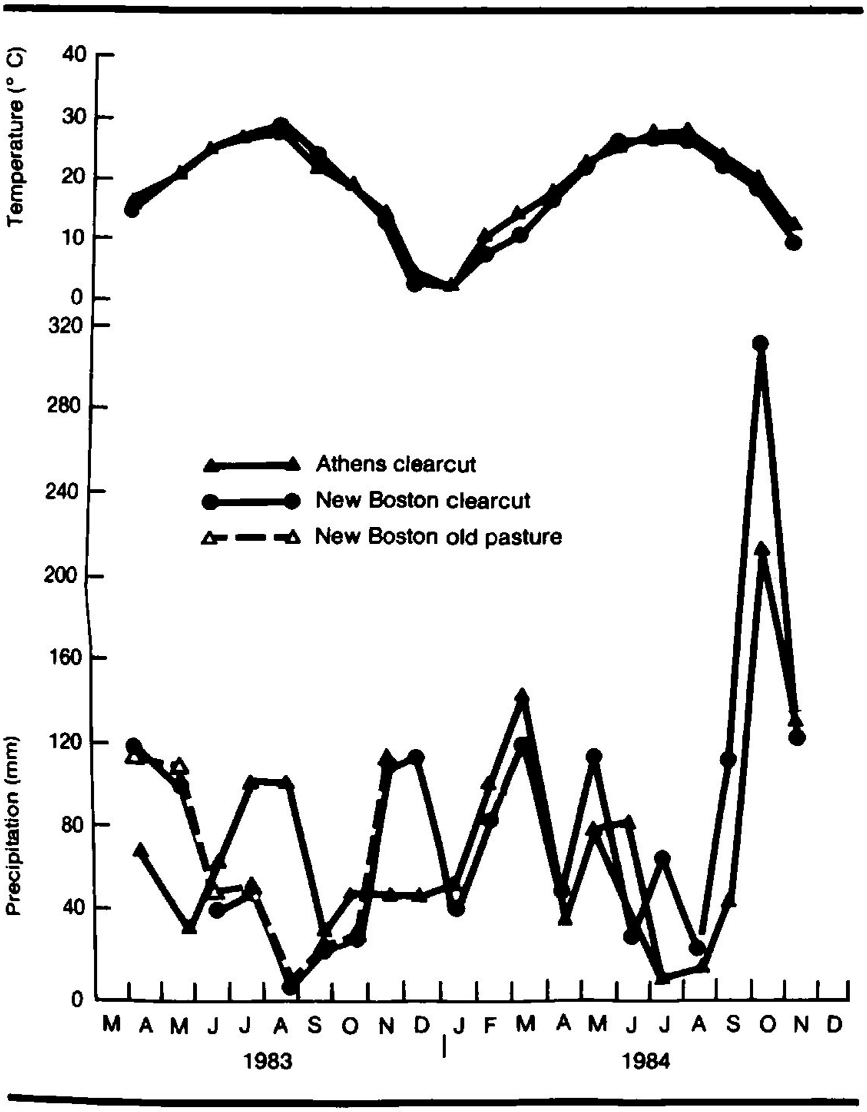

Figure 2—*Precipitation and temperature on study sites, New Boston old pasture, New Boston clearcut, Athens clearcut. Precipitation data after December 6, 1983, and all temperature data are from United States Weather Service Stations at New Boston and Athens, TX.*

the AthCC and NBOP sites over the first winter (December–April), the NBCC had little seedling loss during this period. Similarly, while all sites exhibited lower seedling mortality during the second growing season (May–November), the NBCC site had minimal additional seedling loss (fig. 3). The container and myco-container seedlings had very similar survival rates on the AthCC and NBCC sites in December 1983, but on the AthCC site, survival rates were dramatically lower 1 year later.

Discussion

Lack of significant differences in survival among seed sources was unexpected but perhaps reasonable. Shortleaf pine was chosen for its recognized ability to survive on xeric sites (*6, 11, 31, 32*). The drought-resistant loblolly pine seed source was composed of families that had been selected on the basis of seedling survival under severe drought, and similarly, the "superior" loblolly pine source, taken from the East Texas region, may have been adapted to more xeric conditions than families from more mesic portions of the species' range. However, it should be recognized that variability and lack of control of competing vegetation within sites may have contributed to statistical imprecision.

Among sites, differences in survival appeared related to soil, site history or preparation, and climatic conditions. After 21 months, seedlings on the AthCC site had the lowest overall survival. This site, with the coarsest soil texture and lowest available water-holding capacity (table 3), received only 100 mm of precipitation during the initial establishment period (2.5 months), a period of heavy mortality for all seedling treatments. Moreover, by May 1983, annual weeds were over 1 m tall and dense enough to inhibit movement by the crew. On the AthCC site this level of competition, coupled with the limited soil moisture retention capacity, appeared to be a dominant cause of sustained declines in survival throughout the study.

Similarly, the generally higher seedling survival on the NBCC site appeared related to its higher available soil moisture retention capacity (table 3) and higher rainfall in the initial establishment period (fig. 2). Declines in survival during the first growing season appeared due to intense competition from broad-leafed annuals, which were nearly 1 m tall in May and over 1.8 m tall in October 1983. Seedlings that survived this period exhibited little additional mortality, suggesting good seedling establishment after initial water deficits declined.

Table 4—*Results of analysis of variance for survival after 21 months; percentages were transformed by the arcsine–square root method*

Source	df	Sum of squares	Mean squares	F value	Probability F*
Site (St)	2	3,626.04	1,813.02	32.51	.0001
Treatment (T)	3	2,772.94	790.98	14.18	.0001
Source (So)	2	15.17	7.58	0.14	.8731
St × T	6	2,097.56	349.59	6.27	.0001
St × So	4	391.09	97.77	1.75	.1478
T × So	6	693.08	115.51	2.07	.0672
St × T × So	12	1,763.28	146.93	2.63	.0056
Error	72	4,015.41	55.77		

*Indicates probability of a higher value.

Overall seedling survival was highest on the NBOP site. Again survival appeared related to soil and site conditions. Soil moisture retention capacity (table 3) was adequate; seedlings were planted in an undisturbed soil; and the site received relatively high rainfall during the initial establishment period (2.5 months) (fig. 2). These conditions favored good early establishment. Moreover, the pasture's grass cover, normally considered a potentially severe hindrance to pine establishment (*6, 13, 26*), was not a continuous sod and its moisture-conserving mulch layer had been only partially consumed by the control burn. Thus, level of competition for soil moisture and growing space appeared lower on this site.

On the AthCC and NBCC sites, lower survival of the container and myco–container seedlings was in contrast to their higher survival on the NBOP site (fig. 3). Numerous articles have indicated that container seedlings survive better than bareroot seedlings on severe sites (*6*). Likewise, high levels of mycorrhizal infection have enhanced seedling survival (*15, 16*). However, it has also been shown that there are numerous exceptions (*23*), and both seedling morphology and site preparation may strongly influence this relative survival ranking.

The lower survival of container stock may reflect a variety of factors. In considering loblolly pine bareroot seedlings, Barnett *et al.* (*7*) have concluded that, although larger seedlings are better able to survive in areas with heavy competition and better soil moisture conditions, smaller seedlings with lower shoot–root ratios are better suited for more xeric sites. Somewhat in contrast, larger

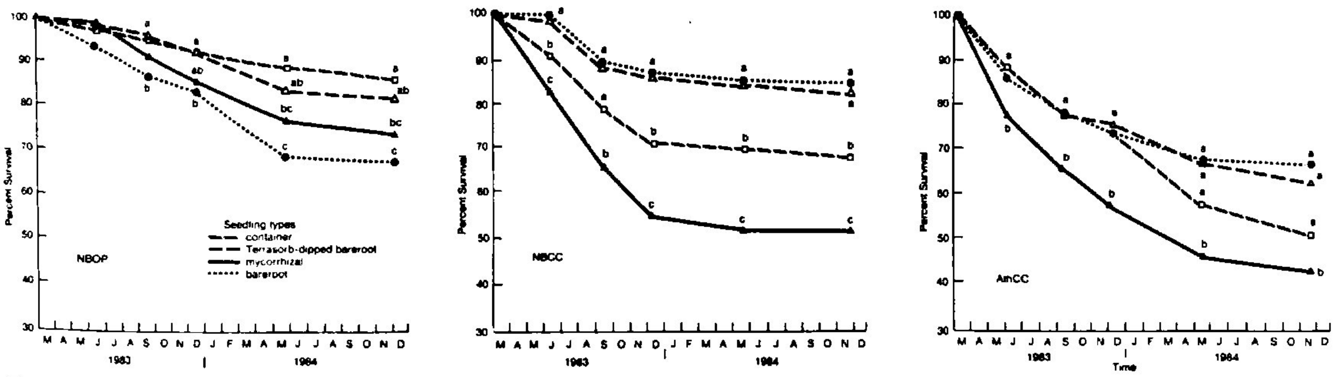

Figure 3—*Survival of pine seedlings, all species combined, on the New Boston old pasture, New Boston clearcut, and Athens clearcut, which received the following preplanting treatments: Terra-Sorb®-dipped–bareroot, bareroot, container, and mycorrhizal-container seedlings. For individual sites and times, treatments followed by a different letter differed significantly at the 0.05 level according to Duncan's multiple range test.*

container seedlings generally survive and perform better than smaller individuals (*1, 3, 5, 9*), but on the most severe sites, container stock size is less critical for survival than for seedling growth. Apparently on severe sites the intact root system of container seedlings results in good survival over a greater range in stock sizes (*7*). Considering the impact of mycorrhizae, Barnett (*4*) found larger non-inoculated container seedlings, which had received higher fertility in the greenhouse, performed better after outplanting than mycorrhizal seedlings produced at lower fertility.

The bareroot seedlings in this study, graded according to Wakeley's (*31*) criteria, were of good to excellent quality. In contrast, seedling size was not optimal for container seedlings. Although both inoculated and non-inoculated seedlings met minimum acceptable size criteria (*5*), their mean shoot mass (665 mg) was at the mid-range of shoot masses (228 to 1,249 mg) found associated with acceptable field success (*4*).

Coating of root systems with a hygroscopic substance is often done to reduce desiccation of seedlings during handling and shipment (*8, 18*). It has been suggested as a preplanting dip to reduce planting shock and mortality caused especially by short-term droughts during or immediately following planting (*14, 19, 20*). However, its effectiveness is uncertain and appears to decline with severity and duration of drought stress. Magnussen (*14*) found that coating the roots of seedlings planted on a site exposed to a brief 2-week drought improved survival by 24%. However, Tung *et al.* (*29*) and Dunsworth (*10*) working on more severe sites failed to show a significant long-term influence on survival. On the more moderate NBOP site, the early decline of control bareroot seedling relative to the trsb–bareroot seedlings and the container seedlings suggests the occurrence of a relatively short-term or more moderate post-planting drought against which the Terra-Sorb and other root treatments were effective and from which the seedlings derived long-term benefit in terms of establishment. The failure of this treatment to significantly enhance survival on the other, more severe sites is consistent with results previously discussed.

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