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Two Year Survival and Growth of Loblolly Pine Seedlings from Two Texas Seed Sources on Lignite Minesoils

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PINE SEEDLINGS FROM TWO TEXAS SEED

SOURCES ON LIGNITE MINESOILS

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TWO-YEAR SURVIVAL AND GROWTH OF LOBLOLLY PINE SEEDLINGS FROM TWO TEXAS SEED SOURCES ON LIGNITE MINESOILS

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INTRODUCTION

Lignite, as an alternative source of fuel, is the link between the oil and gas and the nuclear era for power generation in Texas (White 1978). Although only two mines were operating in the Pineywoods of East Texas in 1984, the utility industry projects increased development in lignite operation by the turn of the century. As the pace of lignite surface mining accelerates, so too the enormity of the reclamation effort increases. Applied research directed toward solving specific reclamation problems is one vital component coupling sustained energy growth with sound environmental management.

Surface Coal Mining Regulations (Railroad Commission of Texas 1981), as guided by national policy (U.S. Department of Interior 1977), require surface-mined areas to be restored to the original land use or an approved alternative. With 72 percent of the pineywoods in potential commercial forests (U.S.D.A Soil Conservation Service 1979), reforestation must be considered as a vital activity of the future.

Reclamation programs aimed at establishing southern pine plantations have had limited success. One reason consistently found for poor survival is moisture stress, particularly during the first few years of seedling establishment. The purpose of this study was to determine what advantages, if any, drought-hardy loblolly pine seedlings (Lost Pines seed source) may have over regular loblolly pine seedlings (East Texas seed source) as part of the reclamation effort.

OBJECTIVES

The objectives of this study were:

1) To compare survival and growth of loblolly pine seedlings for two years, planted in minesoils in the field and in the greenhouse, in the following manner:

a) Lost Pines versus East Texas seed sources; and

b) Treated with and without *Pisolithus tinctorius* basidiospores immediately after planting.

2) To compare the effects of seed source and *Pisolithus tinctorius* inoculation on nutrient concentrations in the foliage of the seedlings at the end of the second growing season.

3) To compare ectomycorrhizal development of inoculated and non-inoculated seedlings after the first growing season.

LITERATURE REVIEW

Loblolly pine (*Pinus taeda* L.) is the most important commercial tree species in East Texas, with thousands of acres being planted annually. Loblolly pine has also been recommended for mine spoils reclamation in the southeastern states including Texas (Vogel 1981). Clemente (1980) recognized the following economic advantages of loblolly pine plantation management on disturbed sites:

1) Minimal site clearing;
2) Minimal competing vegetation;
3) Well-maintained, accessible road networks; and
4) Possibility of using machine planting (except on easy-to-compact soils).

Although plantations have not reached economic maturity on reclaimed areas, markets are well established for sawlog and plywood products. If site factors preclude sawlog-length rotations, markets are present for fuel chips and pulpwood as well (Stayton 1980).

Three studies have demonstrated that loblolly pine can survive and grow on minesoils in East Texas. Bryson (1973) had better survival and first-year growth of loblolly pine than shortleaf pine on Texas Utilities' mine at Fairfield, Texas. Bilan (1980) compared foliar analyses, survival, and height growth of 2- to 10-year old loblolly pine plantations growing on ICI-Darco (Harrison County, Texas) minesoils with natural stands of the same species and age growing on adjacent, undisturbed sites. In situ minesoils were found to be at least as conducive to the production of loblolly pine as adjacent soils. MacBeth (1980) also concluded these ICI-Darco minesoils provide a favorable environment for establishment and growth of loblolly pine seedlings.

Analyses of minesoils at Freestone (Angel 1973, Hons et al. 1978), Harrison (MacBeth 1980), and Panola (Bryson 1980) Counties indicate that although nitrogen and phosphorus may be growth limiting, other essential plant nutrients are available in adequate amounts. Mine spoils have higher surface temperatures, greater surface air movement, and lower relative humidity (Jenkins 1980). These microclimatic conditions combine to create extreme moisture tensions on needle surfaces. Inability of roots to absorb enough moisture from the soil, largely due to the strong forces at which moisture is held in the tiny compacted particles, results in severe moisture stresses of pine seedlings. Bilan (1980) and Bryson (1980) have concluded that most seedling mortality on reclaimed areas can be attributed to moisture stress. Bryson (1973) and Jenkins (1980) suggest moisture stress in seedlings also occurs during the winter on warm days following freezing nights.

Loblolly pine seedlings from Lost Pines area are more drought resistant than ones from more eastern seed sources in Texas (van Buijtenen et al. 1976). Lost Pines comprise disjunct natural stands of loblolly pine in Bastrop, Fayette, and Caldwell counties located about 100 miles west of the contiguous range of this species. Annual rainfall in Lost Pines area is 25 to 30 percent lower than in the Pineywoods area, and July and August, the period most critical for seedling establishment, receive the lowest rate of annual precipitation. Evidently, through natural selection, Lost Pines have developed several morphological and anatomical modifications that tend to conserve moisture during drought. Zobel and Goddard (1955) first reported better survival of Lost Pines following outplanting on sites in East Texas during droughty years. Growth, form, and stem quality equalled or exceeded that of East Texas seed sources (Goddard and Brown 1959). Van Buijtenen (1966) found striking differences in survival of several progenies of Lost Pines and encouraged better identification of drought-resistant ones.

Morphological and anatomical differences between Lost Pines and East Texas seed sources have been demonstrated. Knauf and Bilan (1974) noted thicker protective layers, i.e., cuticle and cutinized epidermis, and fewer stomates per unit of surface area in secondary needles of Lost Pine seedlings. These same characteristics were observed in the cotyledons and primary needles (Knauf and Bilan 1977). Lost Pines seedlings were found to have a lower percentage of open stomates at inceptive moisture stress, allowing for more drastic reduction in transpiration (Bilan et al. 1977).

Bilan et al. (1978) characterized differences in root development of 1-year old seedlings. Lost Pines seedlings grew longer and more intensively branched roots than East Texas seedlings. Primary laterals also grew at smaller angles to the main root, allowing the longer laterals deeper penetration into the soil and better access to moisture supplies. Davies (1973) found that Lost Pines seedlings maintained higher needle-moisture content under stress, permitting quicker recovery when stress is relieved and, hence, faster return to normal physiological functions, e.g., root elongation, absorption of minerals and water, and resumption of growth activities. Colburn (1977) found no significant differences in total seasonal height growth between the two provenances, although the Lost Pines were found to grow more during periods of relatively high temperatures (moisture stress).

Mycorrhizal associations have been shown to be beneficial to survival and initial height growth of outplanted loblolly pine seedlings. Mycorrhiza is a term applied to a compound organ consisting of a plant root and fungal mycelium (Bryce 1961). Ectomycorrhizae are the type of mycorrhizae commonly found in the family Pinaceae, and are characterized by swollen and branched short roots. The fungus is confined to the root cortex where it forms an intercellular net of hyphae among the cortical cells, referred to as Hartig's net. Presence of Hartig's net is used to ascertain whether or not the short root is ectomycorrhizal (Anderson and Cordell 1979). The epidermis and root hairs are replaced by a mantle of mycelium that completely covers the root. The color of ectomycorrhizae, determined by the color of the hyphae, may be brown, black, white, red, yellow, or blends of these colors. Hyphal extensions, called rhizomorphs, link the fungal mantles to fruiting bodies (mushrooms or puffballs) on the ground's surface. Mycorrhizal associations have been shown to be important for nutrient cycling and water absorption, feeder root longevity, and tolerance to drought, high soil temperatures, soil toxins (both organic and inorganic), and pH extremes (Marx 1980).

Marks and Kozlowski (1973), Marx and Krupa (1978), and Malloch et al. (1980) have reviewed ectomycorrhizae. Marx (1975, 1976b, 1977, 1980) summarized research on the "tree tailoring" with specific forms of ectomycorrhizae for difficult-to-reforest sites. One symbiont, Pisolithus tinctorius (Pers.) Coker and Couch, is a particularly promising candidate.

Schramm (1966) characterized the relationship between P. tinctorius (Pt) and the best growing pine seedlings on anthracite wastes in Pennsylvania. Others have shown this fungus tolerant of high soil temperatures (Marx et al. 1970, Marx and Bryan 1971), and low pH (2.4) (Marx 1977). Because of its unique ability to survive and grow in especially harsh environments, inoculation of pine seedlings with Pt in the nursery for use in field planting has been conducted.

Two types of inoculum form abundant Pt mycorrhizae in the nursery: vegetative mycelium and basidiospores (Marx 1976a, Marx et al. 1976, Marx and Artman 1978, Marx et al. 1979, Cordell and Marx 1980). While the vegetative mycelium produces ectomycorrhizae quickly, it is difficult to produce, requiring a germ-free growth phase in a fermentor. Basidiospores, on the other hand, can be collected by the user from pine forests, stored for years under refrigeration, and are easy to apply with a appropriate carrier (vermiculite or hydromulch). Basidiospores also survive much longer in the soil when conditions are not conducive to infection during inoculation. Optimal soil pH for germination was found to be 5.5 and optimal soil temperature for mycorrhizal formation was 34^{o}C (Lamb and Richards 1974).

Increased survival and height growth occurred when loblolly pines were inoculated in the nursery and planted on both natural and disturbed reforestation sites (Marx et al. 1977, Berry and Marx 1978, Marx and Artman 1979, Cordell and Marx 1980, and Berry 1982).

Treating pine seedlings with inoculum immediately after planting in minesoils may also result in increased height growth. Tainter and Walstead (1977) determined that a 45 percent rate of colonization of nonmycorrhizal loblolly pine seedlings by ectomycorrhizae occurs naturally during the first growing season following outplanting on natural soils. Medve et al. (1977) introduced mycorrhizal forming amendments during outplanting of red pine (Pinus resinosa Ait.), white pine (P. strobus L.), and black locust (Robinia pseudoacacia L.) on bituminous spoils. No treatment increased survival, but white pine did show a significant height increase during six growing seasons when inoculated with macerated roots containing ectomycorrhizae (probably Pt). Pt is able to colonize seedlings outplanted with other species of ectomycorrhizae (infected naturally in the nursery) because of its ability to persist and grow in harsh environments in contrast to ectomycorrhizae developed in the nursery: these species quickly succumb to environmental extremes. Moisture stresses, inherent to minesoils, may also contribute to Pt growth because some fungi respond better at higher moisture stresses than others (Mexal and Reid 1973). Pt is a poor competitor with soil microorganisms, and high soil fertility decreases susceptibility of loblolly pine roots to Pt infection (Marx et al. 1977). Hence, minesoils may provide a sterile medium, devoid of antagonists and fertile conditions in which inoculation can take place.

MATERIALS AND METHODS

The Experimental Seedlings

Nursery-grown, 1-0 loblolly pine seedlings from Lost Pine (LP) and East Texas (ET) seed sources were obtained from the Texas Forest Service Indian Mound Nursery, Alto, Texas, during February 1983. Seedlings were promptly graded into two groups: culls and plantable. Culls included seedlings which were deformed or had root-collar diameters less than 3 mm. Plantable seedlings consisted of the remainder. After grading, plantable seedlings were "heeled in" on the Stephen F. Austin State University campus until outplanted.

The Basidiospores

Pisolithus tinctorius spores where obtained from the International Forest Seed Nursery, Birmingham, Alabama. These Pt Pellets, as named by the company, consisted of the basidiospores attached to medium-grade vermiculite with a water-soluble sticker. The pellets were shipped in an opaque, plastic container packed in a carton. After delivery, they were stored at 5^{o}C without light in a refrigerator until used.

The Field Experiment

Design. An experimental field area, measuring 96 m X 104 m (1.0 ha) was established on fresh graded spoil at Texas Utilities Martin

Lake Surface Lignite Mine in Panola County, Texas, in March 1983 (Figure 1). The area was subdivided into 16 blocks of 24 m X 26 m, each block to consist of 12 rows of 26 seedlings.

After "ripping" rows using a 45 cm vertical blade attached to a tractor and applying a straw mulch, seedlings were planted one meter apart within rows using standard hand-planting techniques with a dibble bar (Stoddard 1978). Rows were offset 45 cm from the "rip" and planted two meters apart in the following manner:

1) Row 1: Isolation.
2) Rows 2-5: Two rows planted with ET and two rows with LP seed sources. Assignment of seed sources to rows was at random.
3) Rows 6,7: Isolation.
4) Rows 8-11: Same as rows 2-5 except treated with Pt Pellets. Treatment consisted of spreading ¼ g of pellets in 15 cm radius around each seedling. Pellets were applied after planting and "scratched in" the top 5 cm of soil using a hand-held cultivator. These treatments were referred to as seedlings with Pt.
5) Row 12: Isolation.

The half block which received the Pt treatment was randomly determined in the first block and was alternated in subsequent blocks to prevent adjacent portions of different blocks from receiving the same treatment. The first and last seedlings of each row were left untreated as isolation seedlings. An equal number of ET and LP seedlings were used for isolation rows.

Tip Moth Control Procedures. During 1983 increasing damage to terminals and laterals caused by tip moths (*Rhyacionia* spp.) was

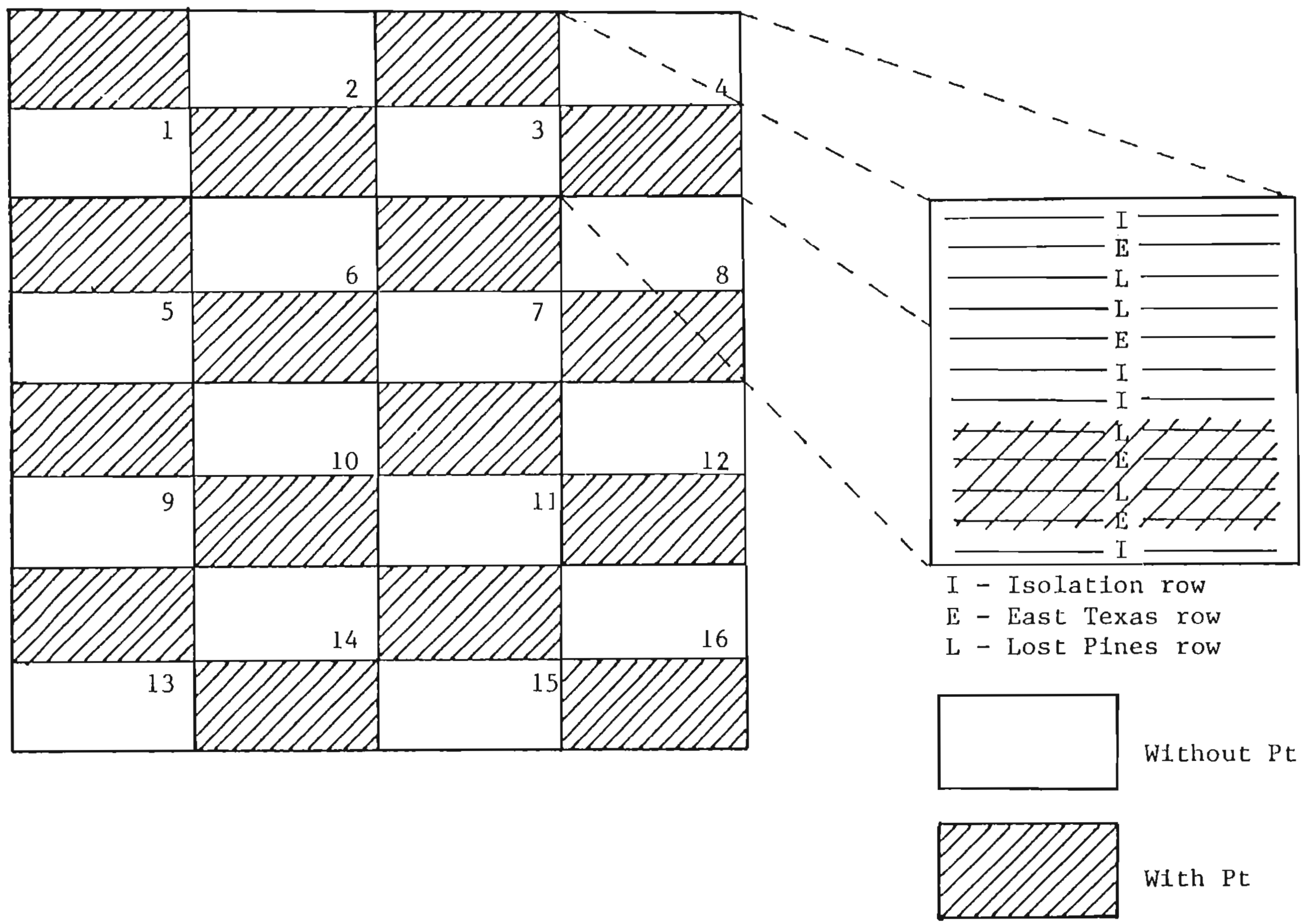

Figure 1. Layout of experimental field area at Martin Lake lignite surface mine for 1983.

observed. To eliminate this variable from 1984 results, insecticide was applied. Orthene[R] (75% acephate, 25% inert ingredients), which has been shown effective for tip moth control in research plots in East Texas[1], was used in order to reduce possible interaction between the Pt treatment and the insecticide as reported by Debarr and Marx (1984). Because acephate is absorbed through needle surfaces instead of through the roots, as was carbofuran in Debarr and Marx's study, interaction was hoped to be reduced to a minimum.

Adjacent blocks of the original sixteen were combined to form eight new blocks (Figure 2). One half of each of the blocks was treated with acephate. After randomly determining the half block to be treated in the first block, treatment was alternated in remaining blocks to prevent adjacent portions of different blocks from being treated.

A mixture made of 1 tablespoon wettable acephate powder and 3.8 liters distilled water was sprayed from a 15.2 liter hand-pump sprayer on the foliage of each treated seedling until runoff was observed. Sprayings were conducted each week for four weeks at the start of the growing season (March 15, 1984) and then reduced to two per month until October.

<u>Collection and Analyses of Data</u>. Before planting, a composite sample of needles from 25 seedlings of each seed source was taken for foliar analyses. Standard chemical analyses for macro- and micronutrients were performed by A&L Laboratories, Memphis, Tennessee (Appendix B). A composite soil sample was collected from each block

[1]Dr. James V. Robinson, Extension Entomologist, personal communication, Texas Agricultural Extension Service, Overton, Texas.

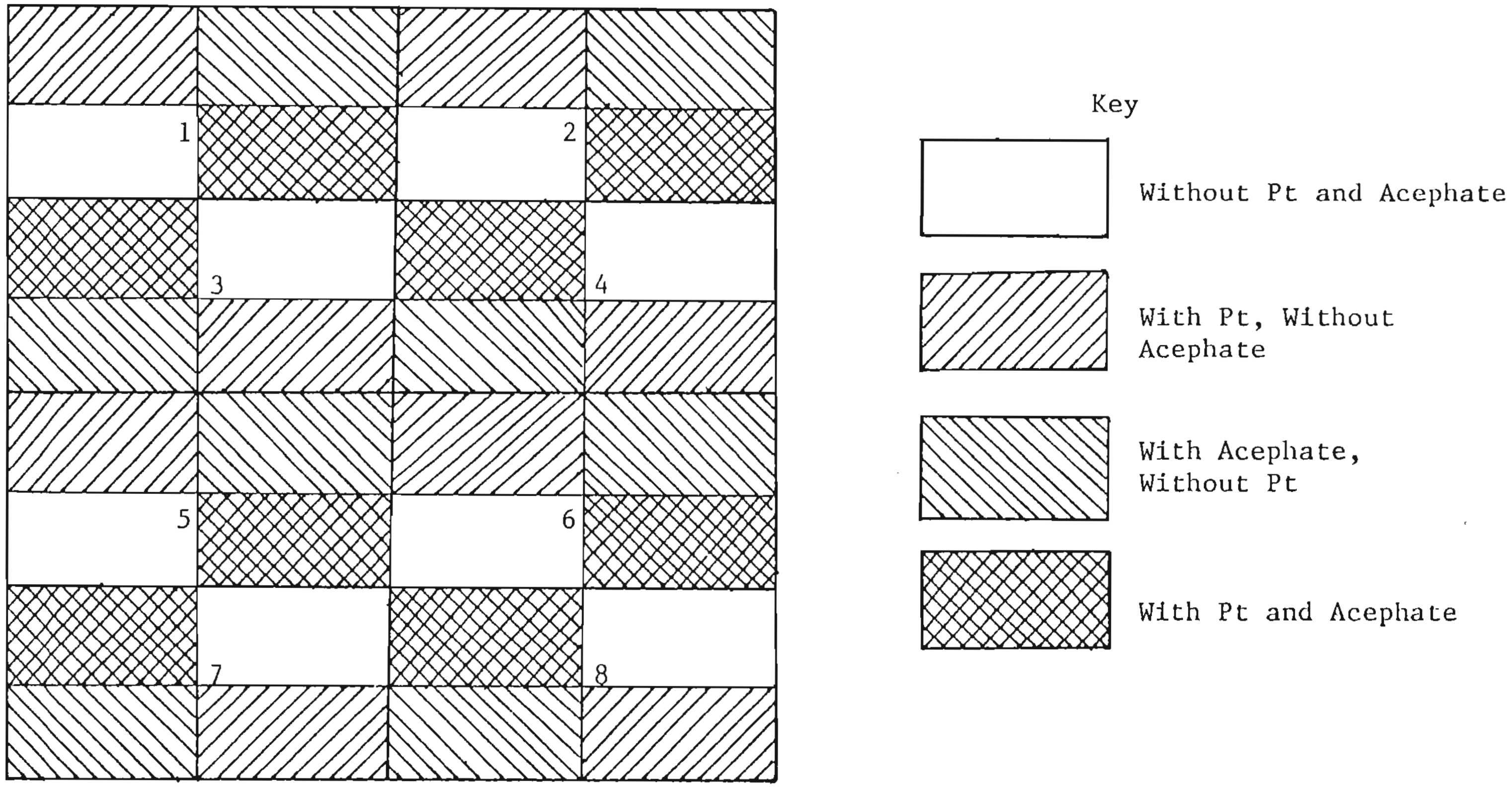

Figure 2. Layout of experimental field area at Martin Lake lignite surface mine for 1984.

by taking two 20 cm deep auger cores from each of eight treatment rows. Standard chemical and physical properties of the soil samples were also analyzed by A&L Laboratories (Appendix B).

Following planting, root-collar diameters and total heights were measured of seedlings number 6, 12, and 18 in each row. Monthly mortality was recorded during the growing seasons 1983 and 1984. In late October of each year root-collar diameters, total height, and final survival counts were recorded. In November 1984 a composite needle sample of each treatment within each replication was collected for chemical analyses by A&L Laboratories. These samples represented needles produced on the terminal leader during the first flush of height growth during the 1984 growing season. Each composite sample included foliage from ten randomly selected seedlings, five each from two rows of the same treatment in each replication. Foliage samples were oven dried ($70^{\circ}C$ for 24 hours) prior to shipment for chemical analyses.

Analysis of variance in a split-plot design with 16 replications was used to assess differences in parameters measured during 1983 (Hicks 1982). The experimental design consisted of two main-plot treatments (seedlings with Pt versus seedlings without Pt) and two split-plot treatments (LP versus ET seed sources). The application of acephate in 1984 resulted in a split-split-plot design with eight replications. This design consisted of two main-plot treatments (acephate-treated seedlings versus those untreated), two split-plot treatments (seedlings with Pt versus those without), and two split-split-plot treatments (LP versus ET seed sources). Expected mean square calculations (Hicks 1982) were used to determine appropriate

F-tests for both designs (Appendix A, Tables 1 and 2).

The Greenhouse Experiment

Design. The growing medium consisted of mine-spoil soil collected from the upper 20 cm layer from each of 16 blocks in the field experiment. This soil was thoroughly mixed and screened (4 squares per cm^2) and then it was used to fill 120 clay pots (20 cm). In early April 1983 two seedlings (one of ET and one of LP seed sources) were planted in each pot using the dibble-bar technique as in the field experiment.

Half of the pots were treated with Pt identically as in the field experiment. Three benches were used in one compartment of the greenhouse, each containing 40 pots with pots treated with Pt alternated between untreated pots. Each of the four rows of pots on each bench was rotated monthly to compensate for possible spatial variation of the environmental conditions in the greenhouse. Pots were watered and misted regularly with tap water to maintain approximate field capacity. In May 1984 distilled water was substituted for tap water to reduce mineral accumulations apparent by foliage color. Insecticide (50% malathion liquid) was applied as required to control feeding insects.

Collection and Analyses of Data. Before planting 25 seedlings from each seed source were selected for dry weight (70^{o}C for 24 hours) and root/shoot ratio determination. Five soil samples of the composite medium were collected. Root-collar diameter and total height of seedlings were recorded after planting. Survival was monitored throughout 1983 and 1984. At the end of each growing season, root-collar diameter and total height were measured.

In late September 1984, all pots were dismantled for seedling dry weight (70°C for 24 hours) and root/shoot ratio determination. Composite foliar samples were collected by dividing pots into 20 groups of five pots each (20 pots were eliminated from the study due to one non-surviving seedling, fusiform rust (Cronartium quercuum f. sp. fusiforme) infection, or to balance the statistical design). Ten groups were treated with Pt and ten were not. Samples were collected by separating two seedlings in a pot by seed source and combining foliage from five seedlings of the same seed source. As in the field experiment, foliage samples were collected from the first height growth flush produced during the 1984 growing season. Forty composite samples were taken, 10 of each Pt treatment and seed source combination. Standard foliar analyses were performed by A&L Laboratories (Appendix B).

Analysis of variance in a 2^2 factorial, fixed model design was used to assess differences in the measured parameters.

Ectomycorrhizal Development of Field Seedlings

In February 1984 one seedling per treatment per block was selected randomly for excavation. Seedlings were removed by digging a 91.5 cm long, 60.0 cm wide, and 30.5 cm deep excavation hole (length was measured parallel to the slit made by the planting bar) and carefully extracting the root system. Seedlings were labelled and roots were submerged in distilled water for transport to the laboratory. There, roots were gently washed and submerged in 1½-liter Mason jars filled with distilled water.

The root system of each seedling was examined for mycorrhizal development (Marx and Bryan 1975, Anderson and Cordell 1979). Only fine roots contained on first order laterals originating on the main root within 15 cm of the root collar were examined. Each fine root was classified as ectomycorrhizal or not based on the presence or absence of the fungal mantle. Counts were divided into yellow (the usual color of Pt) and all-other-colors categories.

Volume displacement of the root system of each seedling was determined using a 500-ml, wide-mouth graduated cylinder filled with 350 ml of water and by submerging the root system to the root collar. The difference between the new reading and 350 ml was used to calculate volume displacement. After each measurement the cylinder was refilled as necessary to the 350-ml mark.

Seedlings were severed at the root collar and oven dried for 24 hours at 70°C. Dry weight of shoots and roots was determined and root/shoot ratios were calculated.

Analysis of variance in a split-plot design was performed on the measured parameters.

RESULTS AND DISCUSSION

The Field Experiment

Precipitation. During critical seedling establishment periods in 1983 and 1984, precipitation at the Martin Lake experiment area was similar to drought periods experienced during tests of drought-hardy strains of loblolly pine seedlings in 1953 and 1954 (Table 1). In those tests 1953 was considered a mild drought, whereas 1954 was very severe. Using those criteria as a guide, the drought during both years of this study could be classified as moderate, with 1984 more severe than 1983. Heavy precipitation during late winter in 1983, while the spoil was fresh and loose prior to grading, may have mitigated the summer drought to follow because the minesoil was completely saturated.

Soil Analyses. To ascertain nutrient deficiencies, toxicities, or an unfavorable growth environment, soil analyses were conducted at the beginning of the field experiment (Table 2). Although nitrogen was low and higher concentrations of potassium, magnesium, calcium, sodium, sulfur, and iron were found than normally present in unmined East Texas forest land (Bilan 1980), no apparent deficiencies or toxicities were noted. Soil reaction averaged 5.7; 5.0 to 5.5 is considered the optimum range for loblolly pine growth. Over time soil reaction would be expected to become more acid due to oxidation of exposed pyrite in the surface layers (Bryson 1980, Kee 1984). Large percentages of silt-sized

Table 1. Monthly and annual precipitation for critical seedling establishment periods at Martin Lake field experiment area compared to precipitation data averaged across all sites in drought-hardy strains of loblolly pine tests during 1953 and 1954.

Month	Drought-hardy Tests[1]		Martin Lake[2]	
	1953	1954	1983	1984
	cm			
June	5.29	1.00	9.50	2.67
July	5.26	2.13	2.64	3.40
August	6.85	2.78	4.57	2.69
September	5.62	3.93	3.38	6.12
Annual	94.30	53.53	100.53	99.16

[1]From Zobel and Goddard (1955)

[2]From TUMCO Technical Support Section, Martin Lake, unpublished data

Table 2. Soil nutrient concentrations, soil reaction, and soil physical properties at the start of the field experiment.[1]

Nutrient	Concentration Mean ± SE	Nutrient	Concentration Mean ± SE
	-----ppm-----		-----ppm-----
Nitrogen	417.7 ± 26.2	Sulfur	781.3 ± 127.8
Phosphorus	61.4 ± 3.0	Zinc	7.8 ± 0.2
Potassium	94.8 ± 2.6	Manganese	38.9 ± 2.1
Magnesium	568.8 ± 12.0	Iron	196.6 ± 6.5
Calcium	1434.4 ± 32.2	Copper	2.2 ± 0.1
Sodium	162.9 ± 11.6	Boron	3.0 ± 0.3

	Mean ± SE
Soil Reaction:	5.7 ± 0.2

Texture	Mean ± SE
	-Percent-
Sand	30.1 ± 1.1
Silt	43.0 ± 0.9
Clay	26.7 ± 0.3
Average Classification:	loam

[1]Each mean represents average of 16 composite soil samples.

particles in the soil were indicative of susceptibility to compaction. Growth and morphology of roots would be adversely affected in this environment.

Survival. Overall survival during both years of the experiment was excellent (Table 3). Analyses of variance for survival in 1983 and 1984 are presented in Appendix A (Tables 3 and 4).

No differences in survival were found in 1983 with LP averaging 83.5 percent compared with 84.3 percent for ET. Survival of seedlings without Pt averaged 84.4 percent, while survival of seedlings with Pt averaged 83.5 percent. The moderate drought experienced in 1983 had little impact on survival. Heavy late winter rains and the mulch applied after planting might have contributed to low mortality.

In 1984 survival of ET seedlings was 80.4 percent and of LP seedlings was 75.3 percent, the difference being significant at the 95% level. Two weeks of extreme cold during December 1983 and early January 1984 was responsible for most of this difference. Temperatures reached well below zero (Celsius) quickly and remained below freezing for two weeks. Almost three times as many LP seedlings were lost within two months after the freeze as ET seedlings. Although a genetic difference in cold hardiness could have been responsible, these results are more likely indicative of the vigor of the two seed sources immediately prior to the freeze. All seedlings succumbing to the freeze were marginal in appearance and no apparently healthy seedlings of either seed source were lost.

During 1984 seedlings without Pt had greater survival (at the 90%

Table 3. Survival of loblolly pine seedlings for 1983 and 1984 in the field experiment at Martin Lake.[1]

Treatment	Survival 1983 Mean SE	Survival 1984 Mean SE
	---------------percent---------------	
Seed Source		
LP	83.5 ± 1.3 NS	75.3 ± 1.4**
ET	84.3 ± 1.5	80.4 ± 1.7
Pt Treatment		
w/o	84.4 ± 1.6 NS	79.2 ± 1.6+
with	83.5 ± 1.2	76.4 ± 1.5
Acephate Treatment		
w/o	-	77.4 ± 1.6 NS
with	-	78.3 ± 1.6

[1]Each mean is the average of 64 rows of seedlings and represents that treatment effect to the exclusion of other treatments in the study.

NS - Not statistically significant
+ - Significant at the 90% level of probability
** - Significant at the 99% level of probability

level) than those with Pt. Fungal competition for a limited pool of carbohydrates with severely stressed seedlings could account for this difference. No difference in survival was noted between acephate treatments.

No interactions between treatments were observed, but highly significant replication effects were present (Appendix A, Tables 3 and 4), pointing to micro-environmental differences among the replications. MacBeth (1980) reported similar replication effects.

Other authors have reported similar survival percentages for loblolly pine seedlings on Texas minesoils. Bryson (1973) reported 72 percent survival for loblolly pine growing in Freestone County minesoil. Bilan (1980) reported survival rates between 42 and 86 percent at the ICI-Darco Mine in Harrison County. MacBeth (1980) reported LP survival at 80.2 percent during the first growing season as compared with 77.1 percent for ET seedlings, also at Darco. Due to the design, no statistical comparisons could be made between the seed sources. Kee (1984) found 65 and 32 percent overall survival of loblolly pine seedlings for each of the first two years, respectively, across different cover crop and fertilization regimes at Martin Lake. He also reported 77 and 33 percent during the first two years in a separate nitrogen study.

Studies comparing Lost Pines and East Texas seed sources of loblolly pine have generally shown better survival rates by Lost Pine seedlings, especially during droughty seasons (van Buijtenen et al. 1976). Zobel and Goddard (1955) reported 59 percent combined survival for Lost Pines plantings in 1953 and 1954, while more easterly Texas seed sources averaged 51 percent. The absence of similar differences in survival between the seed sources in this study can be partially explained by root growth difficulties caused by the fine-textured minesoil. Van Buijtenen et al. (1979) consider root morphology the second most important drought-avoiding mechanism in the Lost Pines seed source. Deeper root systems and wider-ranging laterals are apparently of little advantage in minesoils, especially ones high in silt and low in sand content. The high levels of survival found in this study may indicate that soil moisture may not have been as critical as in the deep sandy soils studied by Zobel and Goddard (1955).

Height Growth. Heights of the two seed sources at the start of the experiment were found to be significantly different (Table 4). A Student's t-test for initial heights by treatment is presented in Appendix A (Table 5). LP seedlings had larger initial heights averaging 28.1 cm as compared to 25.0 cm for ET seedlings. Because height or diameter growth in subsequent years may have been correlated with initial height, Pearson correlation coefficients (r) and coefficients of determination (r^2) were calculated with initial height as the independent variable and growth parameters as dependent variables (Appendix A, Table 6). No strong correlations were found and adjustments to height or diameter growth based on initial height differences (covariance analysis) were not warranted.

Relatively poor height growth marked the 1983 growing season, while improving substantially during 1984 (Table 4). Analyses of variance for height growth in 1983 and 1984 are presented in Appendix A (Tables 7 and 8). Low height growth in 1983 can be partially attributed

Table 4. Initial height and height growth for 1983 and 1984 of loblolly pine seedlings in the field experiment at Martin Lake.[1]

Treatment	Initial Height	Height Growth 1983	Height Growth 1984
	Mean SE	Mean SE	Mean SE
	----------cm----------		
Seed Source			
LP	28.1 ± 0.5**	7.5 ± 0.3**	20.2 ± 0.9*
ET	25.0 ± 0.4	9.7 ± 0.5	22.7 ± 1.2
Pt Treatment			
w/o	27.1 ± 0.5 NS	8.8 ± 0.4 NS	21.6 ± 0.9 NS
with	26.0 ± 0.5	8.4 ± 0.5	21.3 ± 1.2
Acephate Treatment			
w/o	26.3 ± 0.5 NS	-	16.4 ± 0.7**
with	26.8 ± 0.5	-	26.5 ± 1.0

[1]Each mean is the average of 64 rows of seedlings and represents that treatment effect to the exclusion of other treatments in the study.

NS - Not statistically significant
 * - Significant at the 95% level of probability
** - Significant at the 99% level of probability

to late planting in March, the result of heavy rains in February which prevented grading and contouring of the minesoil. Because the minesoil was wetter than normal, soil compaction was more severe than would otherwise be expected. Resumption of root growth following planting was probably delayed as a result.

ET seedlings outgrew LP during both 1983 and 1984, 9.7 cm to 7.5 cm and 22.7 cm to 20.2 cm, respectively. Van Buijtenen et al. (1976) reported variability in growth characteristics between East Texas and Lost Pine families, although no significant relation to drought hardiness was found. Height growth differences in 1983 may have been the result of different environmental conditions in the nursery in 1982. More LP seedlings were top pruned in the nursery, which also may account for part of the difference.

Seedlings treated with acephate during 1984 grew 62 percent taller than those untreated, treated seedlings growing 26.5 cm and untreated 16.4 cm. Very little data is available for tip moth control methods during the first few years of loblolly pine plantation management, but Stephen (1983) reported that an average of 2.5 ft^3 (0.07 m^3) more wood was produced over 20 years where tip moths were controlled than where control was lacking. Significant to successful reclamation is the deformation of young trees caused by tip moths, which may prevent seedlings from obtaining suitable appearance and live crown ratios to meet pine plantation establishment criteria.

No difference in height growth between seedlings treated with and without Pt were observed in 1983 or 1984.

One main treatment interaction between acephate treatment and seed source was found at the 90% level (Appendix A, Table 8). Duncan's multiple range test (Nie et al. 1975) performed on those treatment combinations revealed ET seedlings treated with acephate had significantly more height growth (28.4 cm) than LP seedlings treated similarly (24.5 cm) in 1984. There was no difference between seed sources not treated with acephate (16.9 cm ET to 15.9 cm LP), although both treated seed sources had significantly more growth than those untreated.

Significant replication effects were found in both years (Appendix A, Tables 7 and 8) indicating, as in the survival data, microenvironmental differences between replications.

Bilan (1980) reported an average height growth of 23 cm per year for 2-year old loblolly pine seedlings on minesoils at ICI-Darco. The application of ammonium nitrates for the purpose of grass establishment probably increased growth rates of pines in his study. MacBeth (1980) reported first year height growth for Lost Pines of 11.0 cm as compared to 11.1 cm for East Texas seedlings across all treatments, also at Darco. Kee (1984) reported first and second year loblolly pine seedling height growth averaging 15 cm and 23 cm, respectively, in his phosphorus study and 11.9 cm and 19.1 cm in his nitrogen study at Martin Lake.

Zobel and Goddard (1955) reported almost identical growth rates for the two seed sources, with no loss in volume, for the first two years following outplanting. Goddard and Brown (1959) found Lost Pines had growth as good or better than East Texas and Louisiana seed sources. Three reasons may explain LP seedlings' inability to perform as well or better than ET sources in this study. First, improper drought-hardy progeny identification by the Texas Forest Service may have resulted in seedlings not truly drought avoiding (van Buijtenen 1966). Second, and more likely, restrictive rooting depth due to soil compaction may have prevented deeper and wider-ranging root systems for Lost Pines. Third, and probably most important, apparent summer drought indicated by low rainfall may not have produced as high soil moisture stresses as similar rainfall deficits on more sandy soils.

Although the research summary by Marx (1980) on the reforestation of surface mines indicated increased height growth of loblolly pine seedlings infected with *P. tinctorius*, other studies have shown no height growth differences (Marx et al. 1977, Powers and Rowan 1983). On more fertile sites other ectomycorrhizae may be better adapted than *P. tinctorius*.

Root-collar Diameter Growth. Root-collar diameters of the two seed sources at the start of the experiment were found to be significantly different (Table 5). A Student's t-test for initial root-collar diameters by treatment is presented in Appendix A (Table 9). ET seedlings had larger initial root-collar diameters, averaging 5.7 mm to 5.2 mm for LP seedlings. Calculated r and r^2 coefficients between initial root-collar diameters and subsequent growth parameters revealed little correlation and covariance analysis was not required (Appendix A, Table 10).

As height growth, root-collar diameter growth was poor in 1983, while improving substantially in 1984. Late planting probably adversely impacted the diameter growth in the same way as height growth. Analyses of variance for root-collar diameter growth are presented in Appendix A

Table 5. Initial root-collar diameter and root-collar diameter growth for 1983 and 1984 of loblolly pine seedlings in the field experiment at Martin Lake.[1]

Treatment	Initial Root-collar Diameter Mean SE	Root-collar Diameter Growth 1983 Mean SE	1984 Mean SE
	----------------------------------mm----------------------------------		
Seed Source			
LP	5.2 ± 0.1**	2.2 ± 0.2 NS	6.4 ± 0.3*
ET	5.7 ± 0.1	2.3 ± 0.2	7.4 ± 0.3
Pt Treatment			
w/o	5.6 ± 0.1 NS	2.2 ± 0.2 NS	7.0 ± 0.3 NS
with	5.3 ± 0.1	2.3 ± 0.2	6.8 ± 0.3
Acephate Treatment			
w/o	5.4 ± 0.1	-	6.1 ± 0.3*
with	5.4 ± 0.1	-	7.6 ± 0.3

[1]Each mean is the average of 64 rows of seedlings and represents that treatment effect to the exclusion of other treatments in the study.

NS - Not statistically different
* - Significant at the 95% level of probability
** - Significant at the 99% level of probability

(Tables 11 and 12).

In 1983 no difference in root-collar diameter growth between seed sources or Pt treatments was observed (Table 5). ET seedlings outgrew LP in 1984, 7.4 mm to 6.4 mm, but percent increase in terms of the initial root-collar diameter was about the same (130 percent ET to 123 percent LP). Acephate-treated seedlings outgrew untreated seedlings, 7.6 mm to 6.1 mm. No statistical difference was found between Pt treatments, although seedlings with Pt averaged lower diameter growth (6.8 mm) than those untreated (7.0 mm).

No significant interaction was found between main treatments, but replication effects continued to be highly significant (Appendix A, Tables 11 and 12).

Bilan (1980) reported loblolly pine diameters, measured one foot above the root collar at 5 and 10 years, averaging 3.4 cm and 10.5 cm, respectively, at Darco. Kee (1984) had no report of first season loblolly pine seedling diameter growth, but during the second growing season root-collar diameters increased 10.6 mm across all treatments in his phosphorus study at Martin Lake.

Though not reported specifically as root-collar diameter measurements, Zobel and Goddard (1955) and Goddard and Brown (1959) found that Lost Pines seedlings performed as well or better than East Texas seedlings.

Similarly to height growth, Marx et al. (1977) found no significant differences in root-collar diameter growth on more fertile sites in North Carolina and Florida.

Greater root-collar diameter growth by acephate-treated seedlings, when combined with height growth increases, supports greater biomass production by pine seedlings controlled for tip moths as reported by Stephen (1983).

Foliar Analyses. LP foliage contained higher concentrations of P, K, Mg, S, Fe, Al, and B, and lower concentrations of N, Na, Mn, and Zn than ET foliage at the start of all experiments (Table 6). Ca and Cu were at the same concentrations in both seed sources. Environmental conditions in the nursery are usually favorable with no nutrient or moisture deficiencies.

After two years of growth in the minesoil, dramatic increases in foliar concentrations of Mg (from 850 ppm to 2242 ppm), S (from 950 ppm to 2122 ppm), B (from 17.5 ppm to 160.4 ppm), and Cu (from 2.0 ppm to 4.7 ppm) occurred when averaged across all treatments (Table 6 versus Table 7). N increased less dramatically (from 11750 ppm to 12538 ppm). Decreased foliar concentrations were found in P (from 1350 ppm to 1067 ppm), K (from 11000 ppm to 9453 ppm), Ca (from 5000 ppm to 2359 ppm), Na (from 400 ppm to 325 ppm), Fe (from 227 ppm to 167 ppm), Al (from 750 ppm to 237 ppm), Mn (from 630 ppm to 461 ppm), and Zn (from 74.5 ppm to 36.6 ppm).

Of the foliar nutrient concentrations which increased, only Mg and B were present at levels greater than the medium ranges (800 ppm to 1800 ppm for Mg and 10 ppm to 100 ppm for B) for *Pinus* spp. reported by Leaf (1973). The Mg foliar concentrations found here probably were not

Table 6. Nutrient concentrations in loblolly pine foliage at the beginning of all experiments.[1]

Nutrient	Lost Pines	East Texas
	---ppm---	
Nitrogen	11200	12300
Phosphorus	1500	1200
Potassium	11200	10800
Magnesium	900	800
Calcium	5000	5000
Sodium	300	500
Sulfur	1100	800
Iron	275	179
Aluminum	780	720
Manganese	522	738
Boron	20	15
Copper	2	2
Zinc	68	81

[1]Each value represents one composite sample of 25 seedlings.

Table 7. Nutrient concentrations in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment.[1]

Treatment	Nitrogen Mean ± SE	Phosphorus Mean ± SE	Potassium Mean ± SE	Magnesium Mean ± SE
	ppm			
Seed Source				
LP	12350.0 ± 230.0 NS	1075.0 ± 19.6 NS	9700.0 ± 119.2**	2215.6 ± 54.3 NS
ET	12725.0 ± 208.1	1059.4 ± 22.0	9206.2 ± 122.4	2268.8 ± 52.4
Pt Treatment				
w/o	12362.5 ± 243.8 NS	1071.9 ± 19.2 NS	9434.4 ± 138.4 NS	2250.0 ± 61.9 NS
with	12712.5 ± 192.5	1062.5 ± 22.3	9471.9 ± 118.0	2234.4 ± 43.7
Acephate Treatment				
w/o	12671.9 ± 257.7 NS	1056.2 ± 21.0 NS	9059.4 ± 105.5**	2250.0 ± 54.1 NS
with	12403.1 ± 175.8	1078.1 ± 20.4	9846.9 ± 109.5	2234.4 ± 53.0

[1]Each mean is the average of 32 composite samples and represents that treatment to the exclusion of other treatments in the study.

NS - Not statistically significant

** - Significant at the 99% level of probability

Table 7. Continued.

Treatment	Calcium Mean ± SE	Sodium Mean ± SE	Sulfur Mean ± SE	Iron Mean ± SE
	ppm			
Seed Source				
LP	2362.5 ± 76.6 NS	350.0 ± 26.9**	2143.8 ± 73.1 NS	115.0 ± 3.9 NS
ET	2356.2 ± 87.2	300.0 ± 26.9	2100.0 ± 70.3	118.2 ± 4.9
Pt Treatment				
w/o	2400.0 ± 71.8 NS	321.9 ± 24.1 NS	2131.2 ± 61.6 NS	110.8 ± 3.4*
with	2318.8 ± 90.5	328.1 ± 30.2	2112.5 ± 80.7	122.3 ± 5.1
Acephate Treatment				
w/o	2271.9 ± 87.2 NS	325.0 ± 25.0 NS	2025.0 ± 58.0 NS	115.0 ± 3.9 NS
with	2446.9 ± 73.2	325.0 ± 29.4	2218.8 ± 80.0	118.2 ± 4.9

NS - Not statistically significant
* - Significant at the 95% level of probability
** - Significant at the 99% level of probability

Table 7. Continued.

Treatment	Aluminum Mean SE	Manganese Mean SE	Boron Mean SE	Copper Mean SE
	------------	------------ppm------------	------------	------------
Seed Source				
LP	227.5 ± 16.0*	447.9 ± 34.4*	151.2 ± 14.7 NS	4.62 ± 0.19 NS
ET	246.2 ± 20.4	474.9 ± 34.9	169.6 ± 13.2	4.72 ± 0.30
Pt Treatment				
w/o	233.1 ± 18.4 NS	468.0 ± 34.8 NS	148.8 ± 13.2 NS	4.62 ± 0.19 NS
with	240.6 ± 18.4	454.8 ± 34.7	172.0 ± 14.6	4.72 ± 0.30
Acephate Treatment				
w/o	227.2 ± 19.1 NS	438.0 ± 39.3	115.7 ± 10.0*	4.50 ± 0.13 NS
with	246.6 ± 17.5	484.8 ± 28.8	205.1 ± 12.9	4.84 ± 0.33

NS - Not statistically significant
* - Significant at the 95% level of probability

Table 7. Continued.

Treatment	Zinc Mean SE
	----ppm---
Seed Source	
LP	38.2 ± 1.1**
ET	35.1 ± 1.0
Pt Treatment	
w/o	37.5 ± 1.0 NS
with	35.8 ± 1.1
Acephate Treatment	
w/o	36.3 ± 1.2 NS
with	37.0 ± 1.0

NS - Not statistically significant
** - Significant at the 99% level of probability

toxic, especially since Ca foliar concentrations were larger (greater Ca levels help offset potential salinity problems caused by excess Mg alone). Boron was present, though, in foliar concentrations more than 1½ times (160.4 ppm) the reported high end of the medium range for pines. Stone and Baird (1956) reported boron toxicity in P. strobus ranging from 83 ppm to 152 ppm and in P. resinosa ranging from 73 ppm to 105 ppm. Some seedlings in this experiment exhibited excess B characteristics, i.e., brown needle tips with darker bands marking successive boundaries between dead and live tissue. Because beneficial and injurious effects of B in plants may overlap, it is impossible to place much reliance on symptoms in the early stages of B toxicity (Gauch 1972). Nonetheless, this is apparently the first report of a potential nutrient toxicity in loblolly pine seedlings growing in East Texas lignite minesoils. Moderate liming has proved beneficial in correcting B excesses in agricultural crops (Gauch 1972).

The small increase in foliar N (about 800 ppm) was probably the result of an accidental light application of 12-12-12 fertilizer (336 kg/ha) during June 1984 by Texas Utilities personnel. All of the foliar concentrations of the other nutrients at the end of the experiment remained in the medium ranges reported by Leaf (1973).

Differences in foliar nutrient concentrations between the two seed sources found before the experiment began did not remain consistent after two years of growth in the minesoils (Table 6 versus Table 7). K remained in higher foliar concentrations in LP seedlings (9700 ppm LP to 9206 ppm ET, significant at the 99% level) as in the start of the experiment (11200 ppm LP to 10800 ppm ET). Na and Zn, originally present in LP seedlings in lower concentrations (Na-300 ppm LP, 500 ppm ET; Zn-68 ppm LP, 82 ppm ET), were present in greater amounts in LP seedlings after two years (Na-350 ppm LP, 300 ppm ET, significant at the 99% level; Zn-38.2 ppm LP, 35.1 ppm ET, significant at the 99% level). Al was originally present in greater concentrations in LP seedlings (780 ppm LP to 720 ppm ET), but after two years was less than ET (227 ppm LP to 246 ppm ET, significant at the 95% level). Mn remained in larger concentrations in ET (475 ppm ET to 448 ppm LP, significant at the 95% level) as in the beginning of the experiment (738 ppm ET to 522 ppm LP). These differences present after two years of growth in the minesoil probably reflect different genetic responses by the two seed sources. Other nutrient differences between the seed sources at the start of the experiment were not present after two years in the field and probably reflect different environmental influences in the nursery.

Potassium has been reported to act as an osmotic agent in the opening and closing of stomata (Kramer and Kozlowski 1979). Higher concentrations of K in the LP foliage may have produced better stomatal control, which was reported by Bilan et al. (1977). Sodium has been reported to be as effective as K for light-stimulated opening of stomata, although conflicting data have been published (Gauch 1972). Greater Na concentration in LP foliage may have affected stomatal control similarly as K. These nutrient differences were not reflected in better survival or growth of LP seedlings, though. Excess Zn may cause Fe deficiency (Gauch 1972), but the 3.1 ppm greater concentration in LP foliage was not large enough to have that effect here. Manganese is essential for synthesis of chorophyll, which directly affects photosynthesis. Higher Mn concentrations in ET foliage may have positively affected carbohydrate production reflected in better ET growth. Aluminum has not been found to be an essential element; higher Al concentrations in ET foliage were probably incidential to better growth exhibited by those seedlings.

Only Fe concentrations were found to be significantly different between seedlings with and without Pt. Seedlings without Pt contained 110.8 ppm compared to 122.3 ppm for seedlings with Pt. Walker et al. (1982) reported higher Fe concentrations in 2-year old loblolly pine seedlings infected with P. tinctorius planted on a Tennessee coal spoil, in addition to significant differences of NO_3, Ca, S, and Mo. No differences were found in other macro- and micro-nutrients. They concluded none of the differences, including Fe, appeared to reflect responses to ectomycorrhizal treatments. Berry and Marx (1976) reported no difference in uptake of B, Cu, Fe, Mo, Mn, and Zn from sewage sludge applied to nursery beds containing loblolly pine seedlings infected with naturally occurring symbionts or P. tinctorius.

Acephate-treated seedlings showed significantly higher levels of K and B. Boron has been implicated in the translocation of sugars (Gauch 1972). Higher concentrations of B in acephate-treated seedlings, although possibly toxic, may have been used in translocation of the larger amount of sugars required for the large increases in height (62 percent) and diameter (24 percent) growth. Potassium is used in enzyme activity and deficiencies hinder translocation of carbohydrates and nitrogen metabolism (Kramer and Kozlowski 1979). Higher concentrations of K may have had a growth effect similar to B in the acephate-treated seedlings.

Analyses of variance of nutrient concentrations in needles on the terminal leader developed during the first flush of height growth in 1984 are presented in Appendix A (Tables 13-25).

The Greenhouse Experiment

Environment. Temperatures in the greenhouse ranged from 24 to 32°C during the summers, with relative humidity ranging from 30 to 100 percent. During the winters temperatures ranged from 14 to 31°C, with relative humidity ranging from 25 to 100 percent. Because of regular watering, soil moisture was assumed to be approximately at field capacity for the duration of the experiment.

Soil Analyses. Similarly to the field experiment, soil analyses were conducted at the beginning of the greenhouse experiment to determine nutrient deficiencies or potential toxities (Table 8). Values for all nutrients, soil reaction, and soil physical properties were almost identical for both experiments (Table 2 versus Table 8). Therefore, representative potting medium from the minesoil in the field was obtained for the greenhouse experiment. (NOTE: Total nitrogen was determined only for the field samples; the same concentration for nitrogen appears in both tables.)

Survival. Thirteen LP seedlings and one ET seedling died during the greenhouse experiment, all prior to July 8, 1983. These losses were attributed to transplanting shock and are not reported as survival

Table 8. Soil nutrient concentrations, soil reaction, and soil physical properties at the start of the greenhouse.[1]

Nutrient	Concentration Mean ± SE	Nutrient	Concentration Mean ± SE
	-----ppm-----		-----ppm-----
Nitrogen	417.7 ± 26.2[2]	Sulfur	826.8 ± 129.7
Phosphorus	61.6 ± 1.3	Zinc	8.1 ± 0.2
Potassium	100.2 ± 4.1	Manganese	36.0 ± 1.4
Magnesium	559.4 ± 17.6	Iron	186.0 ± 4.1
Calcium	1360.0 ± 43.0	Copper	2.2 ± 0.1
Sodium	146.0 ± 3.9	Boron	3.0 ± 0.1

	Mean ± SE
Soil Reaction:	5.6 ± 0.1

Texture	Mean ± SE
	-Percent-
Sand	31.6 ± 1.3
Silt	41.2 ± 0.5
Clay	27.2 ± 0.8
Average Classification:	loam

[1]Each mean represents average of 5 composite soil samples

[2]From field experiment soil samples

differences between the two seed sources. Heavy rainfall in the field delayed grading of the spoil and readying of the greenhouse experiment. Seedlings were planted after buds had broken while still "heeled in", which contributed to transplant shock.

Height Growth. As in the field experiment, LP seedlings were taller than ET seedlings (33.1 cm to 26.5 cm) at the start of the greenhouse experiment. A Student's t-test for initial heights by treatment is presented in Appendix A (Table 26). Calculated r and r^2 coefficients between initial heights and subsequent growth parameters revealed no strong correlations and covariance analysis was not required (Appendix A, Table 27).

Seedlings grown under near optimum moisture conditions in the greenhouse produced more height growth in 1983 than those grown in the field (Table 9 versus Table 4). ET seedlings, with 13.1 cm growth, grew 3.4 cm taller, while LP seedlings, with 8.4 cm growth, grew only 0.9 cm taller in the greenhouse. The summer drought in 1983 apparently had more effect on ET seedlings. In other words, LP seedlings did not grow appreciably more under more favorable conditions in the greenhouse than in the field.

Height growth declined in 1984 in the greenhouse for both seed sources. Differences were still highly significant between the seed sources with ET height growth at 8.5 cm and LP at 5.8 cm. Nutrient stress contributed to overall height growth decline. Limited rooting volume in the pots prevented additional nutrients from being picked up. Nutrient losses from leaching during the regular watering schedule also contributed to nutrient stress.

Table 9. Initial height and height growth for 1983 and 1984 of loblolly pine seedlings in the greenhouse experiment.[1]

Treatment	Initial Height	Height Growth 1983	Height Growth 1984
	Mean SE	Mean SE	Mean SE
	cm		
Seed Source			
LP	33.1 ± 0.3**	8.4 ± 0.4**	5.8 ± 0.3**
ET	26.5 ± 0.4	13.1 ± 0.5	8.5 ± 0.4
Pt Treatment			
w/o	30.0 ± 0.4 NS	10.5 ± 0.4 NS	7.0 ± 0.4 NS
with	29.5 ± 0.5	10.9 ± 0.5	7.3 ± 0.4

[1]Each mean is the average of 100 seedlings and represents that treatment effect to the exclusion of the other treatment in the study.

NS - Not statistically different
** - Significant at the 99% level of probability

The 1983 increase in height growth of seedlings in the greenhouse over seedlings in the field was also demonstrated in seedlings treated with and without Pt. Seedlings without Pt grew 10.5 cm in the greenhouse compared to 8.8 cm in the field. Seedlings with Pt grew 10.9 cm versus 8.4 cm in the field. Height growth in 1984 in the field increased dramatically, but declined in the greenhouse. No significant differences in height growth were found between seedlings with and without Pt in either year in the greenhouse.

Analyses of variance of height growth in the greenhouse in 1983 and 1984 are presented in Appendix A (Tables 28 and 29).

Root-collar Diameter Growth. As in the field experiment, ET seedlings were found to have larger root-collar diameters than LP seedlings at the start of the greenhouse experiment (Table 10). A Student's t-test for initial root-collar diameters by treatment is presented in Appendix A (Table 30). Calculated r and r^2 coefficients between initial root-collar diameters and subsequent growth parameters revealed little correlation and covariance analysis was not required (Appendix A, Table 31).

Contrary to height growth, seedlings put on less root-collar diameter growth in 1983 in the greenhouse than in the field (Table 10 versus Table 5). Increased height growth in the greenhouse was probably at the expense of diameter growth.

East Texas seedlings had significantly greater diameter growth in 1983 than LP seedlings, although the 0.13 mm difference probably has little practical importance (Table 10). Similarly, seedlings with Pt grew 1.10 mm in diameter compared to 0.92 mm for seedlings without Pt,

Table 10. Initial root-collar diameter and root-collar diameter growth for 1983 and 1984 of loblolly pine seedlings in the greenhouse experiment.[1]

Treatment	Initial Root-collar Diameter Mean SE	Root-collar Diameter Growth 1983 Mean SE	Root-collar Diameter Growth 1984 Mean SE
	----------mm----------		
Seed Source			
LP	6.2 ± 1.0**	0.94 ± 0.50+	0.47 ± 0.04 NS
ET	6.6 ± 1.0	1.07 ± 0.60	0.48 ± 0.04
Pt Treatment			
w/o	6.5 ± 1.0 NS	0.92 ± 0.55*	0.48 ± 0.05 NS
with	6.3 ± 1.0	1.10 ± 0.56	0.46 ± 0.04

[1] Each mean is the average of 100 seedlings and represents that treatment effect to the exclusion of the other treatment in the study.

NS - Not statistically significant
\+ - Significant at the 90% level of probability
* - Significant at the 95% level of probability
** - Significant at the 99% level of probability

but this also has little practical importance, particularly in view of no observed differences in 1984. Growth was reduced one-half from 1983 to 1984 due to nutrient deficiencies for the same reasons explained in height growth results.

Analyses of variance for root-collar diameter growth in 1983 and 1984 in the greenhouse are presented in Appendix A (Tables 32 and 33).

Biomass. ET seedlings increased significantly in root weight during two years in the greenhouse, averaging 6.8 g dry weight compared to 5.8 g for LP (Table 11). A corresponding highly significant increase in shoot weight was recorded, with ET seedlings averaging 11.8 g to 10.5 g for LP. The ratio of roots-to-shoots was not significantly different, although ET seedlings had the larger mean percentage.

Seedlings with Pt had highly significant lower root weight, but no difference in shoot weight than seedlings without Pt. This root weight difference caused Pt seedlings to have highly significant lower root/shoot ratio, 0.55 for seedlings with Pt to 0.64 for those without Pt. Kramer and Kozlowski (1979) state that trees with extensive, much-branched root systems survive droughts better than those with shallow or sparsely branched root systems. The apparent carbohydrate drain by the fungus from root systems of seedlings with Pt is probably responsible for reduced root biomass production. Once the fungus fully establishes itself, a net increase in root/shoot ratio would be expected, especially under more favorable nutrient conditions.

Analyses of variance for root and shoot weights and root/shoot ratios are presented in Appendix A (Tables 34 to 36).

Table 11. Root and shoot weights, and root/shoot ratios of loblolly pine seedlings at the end of the greenhouse experiment.[1]

Treatment	Root Weight Mean SE	Shoot Weight Mean SE	Root/Shoot Ratio Mean SE
	------------------g------------------		
Seed Source			
LP	5.8 ± 0.2**	10.5 ± 0.4*	0.58 ± 0.02 NS
ET	6.8 ± 0.2	11.8 ± 0.4	0.61 ± 0.02
Pt Treatment			
w/o	6.9 ± 0.2**	11.3 ± 0.4 NS	0.64 ± 0.02**
with	5.8 ± 0.2	11.0 ± 0.4	0.55 ± 0.02

[1]Each mean is the average of 100 seedlings and represents that treatment effect to the exclusion of the other treatment in the study.

NS - Not statistically significant
 * - Significant at the 95% level of probability
** - Significant at the 99% level of probability

Foliar Analyses. Nutrient concentrations in needles on the terminal leader developed during the first flush of height growth in 1984 are presented on Table 12. Analyses of variance are presented in Appendix A (Tables 37 to 49).

The most striking differences between foliar nutrient concentrations in the greenhouse experiment compared to the field experiment were between N, B, and Zn. Foliar N concentrations in the greenhouse (5683 ppm) were 46 percent of those in the field (12538 ppm). Leaf (1973) reports foliar nitrogen levels less than 10000 ppm to 11000 ppm as deficient. Lack of nitrogen-fixing bacteria and organisms in the almost sterile minesoil conditions in the greenhouse and leaching losses were largely responsible for these low levels. With nitrogen limiting growth, especially in 1984, the numerous interactions between other nutrients became more complex and interpretations difficult.

Boron foliar concentrations fell from 160.4 ppm in the field to 31.8 ppm in the greenhouse, well within the medium range of 10 ppm to 100 ppm reported by Leaf (1973). Leaching losses from the regular watering schedule were probably responsible for this reduction.

Zinc concentrations were found to average 138.0 ppm across all treatments in the greenhouse compared to 36.6 ppm in the field, with the medium range from 10 ppm to 125 ppm (Leaf 1973). Some seedlings displayed short, curled, yellowish-green needles and terminal leader dieback characteristic of Zn toxicity. Reduced growth of seedlings in the greenhouse allowed Zn to accumulate to excess concentrations. Whereas B perhaps was toxic in the field, Zn apparently was toxic in the greenhouse. Liming of acid soil to near neutrality has overcome Zn

Table 12. Nutrient concentrations in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.[1]

Treatment	Seed Source				Pt Treatment			
	LP		ET		w/o		with	
Nutrient	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	ppm							
Nitrogen	5675.0 ±	106.0	5690.0 ±	111.0 NS	5675.0 ±	98.0	5690.0 ±	118.0 NS
Phosphorus	1155.0 ±	38.0	1080.0 ±	27.7 NS	1100.0 ±	33.2	1135.0 ±	35.0 NS
Potassium	10710.0 ±	162.2	10605.0 ±	179.0 NS	10625.0 ±	142.0	10690.0 ±	196.0 NS
Magnesium	1725.0 ±	36.9	1605.0 ±	38.0*	1670.0 ±	27.2	1660.0 ±	49.4 NS
Calcium	1720.0 ±	79.7	1555.0 ±	51.4+	1565.0 ±	38.6	1710.0 ±	87.6 NS
Sodium	1225.0 ±	45.2	1170.0 ±	30.9 NS	1240.0 ±	32.0	1155.0 ±	43.2 NS
Sulfur	825.0 ±	28.0	805.0 ±	18.5 NS	780.0 ±	20.0	850.0 ±	24.6*
Iron	99.4 ±	2.9	87.8 ±	2.5**	92.2 ±	2.5	95.0 ±	3.4 NS
Aluminum	70.5 ±	3.6	77.5 ±	3.7+	62.5 ±	3.4	85.5 ±	1.5**
Manganese	294.1 ±	15.5	309.7 ±	17.0 NS	305.7 ±	16.1	298.1 ±	16.6 NS
Boron	32.4 ±	0.4	31.2 ±	0.5+	32.2 ±	0.4	31.4 ±	0.5 NS
Copper	9.2 ±	0.4	8.3 ±	0.3+	9.2 ±	0.4	8.4 ±	0.3+
Zinc	147.0 ±	14.0	128.6 ±	13.2 NS	138.2 ±	13.8	138.3 ±	13.7 NS

[1]Each mean is the average of 20 composite foliar samples and represents that treatment effect to the exclusion of the other treatment in the study.

NS - Not statistically different

* - Significant at the 95% level of probability

\+ - Significant at the 90% level of probability

** - Significant at the 99% level of probability

excess in soils (Gauch 1972), although application of nitrogen fertilizer is indicated here since nitrogen was apparently the limiting nutrient. Had nitrogen been present in adequate amounts, reduced biomass production would not have occurred and the Zn toxicity probably not resulted. The field experiment foliar zinc concentrations would seem to confirm this conclusion.

Lost Pines seedlings had significantly higher concentrations of Mg, Ca, Fe, B, and Cu than ET seedlings in the greenhouse, although in the field there were no differences between seed sources in these nutrient levels. Other nutrient levels which were different in the field (K, Na, Zn, and Mn) were not significantly different in the greenhouse. Greater biomass production by ET seedlings probably diluted concentrations of the nutrients reported in higher concentrations in LP. Aluminum concentrations in LP seedlings in the greenhouse were significantly lower than in ET seedlings as in the field. Higher Al levels are thought to be incidential to greater growth rather than a treatment response.

Seedlings with Pt had greater concentrations of S and Al, and smaller concentrations of Cu than seedlings without Pt. Because there was no difference in shoot biomass between these treatments, the reasons for these nutrient differences were unclear. Other researchers have reported conflicting results in host-mycorrhizae foliar nutrient concentration experiments (Mitchell et al. 1984).

Ectomycorrhizal Development of Field Seedlings

Percent Ectomycorrhizae. Lost Pine seedlings with Pt had the greatest percent of yellow and total ectomycorrhizal fine roots (Table 13). Percent of yellow ectomycorrhizae for LP with Pt (33.5 percent) was significantly greater than LP or ET seedlings without Pt (13.3 and 19.2 percent), but was not significantly greater than ET seedlings with Pt (23.1 percent). Ruehle (1980) reported minimum *Pisolithus* colonization rates of 50 to 60 percent of fine roots in order to obtain improved survival and rapid seedling growth following outplanting. The lack of difference in survival and growth of seedlings with Pt in the field experiment would be expected, based on *Pisolithus* infection percentages found here. Differences in growth may result in the future, though, as the *Pisolithus* colonizes a larger percentage of fine roots on treated seedlings. Only LP without Pt had significantly lower percentage total ectomycorrhizal roots. Symbionts on ET seedlings, either occurring naturally or brought in from the nursery, seemed as able to persist in the minesoil environment as *Pisolithus*.

Analyses of variance for percentage yellow and total ectomycorrhizae are presented in Appendix A (Tables 50 and 51).

Biomass. Although seedlings with Pt had greater average volume displacement, root weight, and shoot weight, these differences were not significant (Table 14). Perhaps these larger averages portend increasing differences which may become statistically significant as increasing infection by *Pisolithus* occurs. Only root/shoot ratio was significantly different (at the 90% level) between LP and ET seedlings, with ET

Table 13. Percent yellow and total ectomycorrhizae infecting fine roots on loblolly pine seedlings excavated from the field experiment at Martin Lake during February 1984.[1]

Treatment	Ectomycorrhizae Yellow Mean SE	Ectomycorrhizae Total Mean SE
	---percent---	
Lost Pines		
w/o Pt	13.3 ± 3.5 a	45.9 ± 5.2 a
with Pt	33.5 ± 4.4 b	69.6 ± 3.2 b
East Texas		
w/o Pt	19.2 ± 5.0 a	61.4 ± 5.5 b
with Pt	23.1 ± 4.3 ab	60.6 ± 5.8 b

[1]Significant P X S interaction in the ANOVA table required Duncan's multiple range test to be performed on all treatment combinations for correct statistical interpretation. Each mean is the average of 16 seedlings. Means within a column followed by the same letter are not significantly different at p=0.05.

Table 14. Volume displacement, root weight, shoot weight, and root/shoot ratio for loblolly pine seedlings excavated from the field experiment at Martin Lake during February 1984.[1]

Treatment	Volume Displacement Mean ± SE	Root Weight Mean ± SE	Shoot Weight Mean ± SE	Root/Shoot Ratio Mean ± SE
	-----ml------	---------g---------	---------g---------	
Seed Source				
LP	36.8 ± 5.6 NS	7.8 ± 1.2 NS	13.6 ± 1.7 NS	0.53 ± 0.03+
ET	38.7 ± 5.6	8.7 ± 1.4	14.0 ± 2.0	0.61 ± 0.03
Pt Treatment				
w/o	34.8 ± 5.3 NS	7.4 ± 1.2 NS	11.7 ± 1.4 NS	0.59 ± 0.04 NS
with	40.7 ± 5.8	9.1 ± 1.4	16.0 ± 2.2	0.54 ± 0.02

[1] Each mean is the averaged of 32 seedlings and represents that treatment effect to the exclusion of the other treatment in the study.

NS - Not statistically significant
\+ - Significant at the 90% level of probability

seedlings having the larger ratio (0.61 to 0.53 for LP).

Analyses of variance for volume displacement, root weight, shoot weight, and root/shoot ratio are presented in Appendix A (Tables 52 to 55).

SUMMARY AND CONCLUSIONS

The results of this study help substantiate the growing body of evidence that loblolly pine seedlings are well suited for use in reclamation programs for East Texas lignite minesoils. Particularly encouraging were the high rates of survival after two growing seasons with minimal site preparation and routine management. Use of the straw mulch provided benefits of reducing soil moisture losses and soil temperatures. More intensive reclamation procedures, especially during the first year of pine plantation management, are probably not warranted.

Loblolly pine seedlings from the East Texas seed source had better survival, height, and root-collar diameter growth for two years following planting in the field than Lost Pines seedlings. Lost Pines seedlings accumulated higher concentrations of K, Na, and Zn in the second year foliage, while East Texas seedlings had higher levels of Mn and Al. These foliar nutrient differences may reflect genetic variation in nutrient uptake, although the growth dissimilarities between the seed sources were probably not the result of these differences. Although the East Texas seed source seemed more adapted to the minesoils studied at Martin Lake, the high fine particle content and high soil compaction must be taken into account. On minesoils higher in sand content, and inherently less prone to compaction, morphological and anatomical characteristics of Lost Pines seedlings may provide reclamation advantages not detected in this study.

High survival percentages and acceptable growth performances by seedlings not treated with Pisolithus tinctorius basidiospores means that naturally occurring symbionts or those brought in from the nursery provided ectomycorrhizal benefits sufficient for these minesoils. Improved survival or growth was not found for seedlings treated with Pt.

Treatment of seedlings with insecticide (acephate) during the second growing season for tip moth control provided height and diameter growth increases, which improved the overall appearance of the seedlings. Tip moth control measures may be warranted in reclamation programs to insure pine plantations are able to meet release-from-bond requirements in appearance and live-crown ratios.

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APPENDIX A: STATISTICAL TESTS

Table 1. Split-plot analysis of variance linear model and expected mean square (EMS) calculations showing appropriate F-tests for significant difference testing of 1983 measured parameters in the field experiment.[1]

MODEL: $Y_{ijkm} = \mu + R_i + P_j + RP_{ij} + S_k + RS_{ik} + PS_{jk} + RPS_{ijk} + \varepsilon_{m(ijk)}$

(Whole Plot: $R_i + P_j + RP_{ij}$; Split Plot: $S_k + RS_{ik} + PS_{jk} + RPS_{ijk} + \varepsilon_{m(ijk)}$)

where: μ = Overall mean

R_i = Replication effect, i=1-16

P_j = Pt treatment effect, j=1,2

S_k = Seed source effect, k=1,2

ε_m = Random error, m=1,2

EXPECTED MEAN SQUARE CALCULATIONS

No. of levels			16	2	2	2	
Fixed or Random Factor			R	F	F	R	
	Source	DF	i	j	k	m	EMS[2]
Whole Plot	R_i	15	1	2	2	2	$\varepsilon^2 + 8\sigma^2_R$
	P_j	1	16	0	2	2	$\varepsilon^2 + 4\sigma^2_{RP} + 64\phi_P$
	RP_{ij}	15	1	0	2	2	$\varepsilon^2 + 4\sigma^2_{RP}$
Split Plot	S_k	1	16	2	0	2	$\varepsilon^2 + 4\sigma^2_{RS} + 64\phi_S$
	RS_{ik}	15	1	2	0	2	$\varepsilon^2 + 4\sigma^2_{RS}$
	PS_{jk}	1	16	0	0	2	$\varepsilon^2 + 2\sigma^2_{RPS} + 32\phi_{PS}$
	RPS_{ijk}	15	1	0	0	2	$\varepsilon^2 + 2\sigma^2_{RPS}$
	$\varepsilon_{m(ijk)}$	64	1	1	1	1	ε^2
Total		127					

(Continued)

Table 1. Continued.

[1]From Hicks (1982).

[2]EMS calculations show main factors and their interaction effects are tested against the mean square of the term immediately below them in the table. Replication effects are tested against the error mean square.

Table 2. Split-split-plot analysis of variance linear model and expected mean square (EMS) calculations showing appropriate F-tests for significant difference testing of 1984 measured parameters in the field experiment.[1]

MODEL: $Y_{ijkmq} = \mu + R_i + A_j + RA_{ij} + P_k + RP_{ik} + AP_{jk} + RAP_{ijk} +$

└─Whole Plot─┘ └───Split Plot───┘

$S_m + RS_{im} + AS_{jm} + RAS_{ijm} + PS_{km} + RPS_{ikm} + APS_{jkm} +$

└──────Split Split Plot──────

$RAPS_{ijkm} + \varepsilon_{q(ijkm)}$

────────┘

where: = Overall mean

R_i = Replication effect, i=1,8

A_j = Acephate treatment effect, j=1,2

P_k = Pt treatment effect, k=1,2

S_m = Seed source effect, m=1,2

ε_q = Random error, q=1,2

EXPECTED MEAN SQUARE CALCULATIONS

No. of levels			8	2	2	2	2	
Fixed or Random Factor			R	F	F	F	R	
	Source	DF	i	j	k	m	q	EMS[2]
Whole Plot	R_i	7	1	2	2	2	2	$\varepsilon^2 + 16\sigma^2_R$
	A_j	1	8	0	2	2	2	$\varepsilon^2 + 8\sigma^2_{RA} + 64¢_A$
	RA_{ij}	7	1	0	2	2	2	$\varepsilon^2 + 8\sigma^2_{RA}$

(Continued)

Table 2. Continued.

EXPECTED MEAN SQUARE CALCULATIONS

No. of levels			8	2	2	2	2	
Fixed or Random Factor			R	F	F	F	R	
	Source	DF	i	j	k	m	q	EMS[2]
Split Plot	P_k	1	8	2	0	2	2	$\varepsilon^2 + 8\sigma^2_{RP} + 64\phi_P$
	RP_{ik}	7	1	2	0	2	2	$\varepsilon^2 + 8\sigma^2_{RP}$
	AP_{jk}	1	8	0	0	2	2	$\varepsilon^2 + 4\sigma^2_{RAP} + 32\phi_{AP}$
	RAP_{ijk}	7	1	0	0	2	2	$\varepsilon^2 + 4\sigma^2_{RAP}$
Split Split Plot	S_m	1	8	2	2	0	2	$\varepsilon^2 + 8\sigma^2_{RS} + 64\phi_S$
	RS_{im}	7	1	2	2	0	2	$\varepsilon^2 + 8\sigma^2_{RS}$
	AS_{jm}	1	8	0	2	0	2	$\varepsilon^2 + 4\sigma^2_{RAS} + 32\phi_{AS}$
	RAS_{ijm}	7	1	0	2	0	2	$\varepsilon^2 + 4\sigma^2_{RAS}$
	PS_{km}	1	8	2	0	0	2	$\varepsilon^2 + 4\sigma^2_{RPS} + 32\phi_{PS}$
	RPS_{ikm}	7	1	2	0	0	2	$\varepsilon^2 + 4\sigma^2_{RPS}$
	APS_{jkm}	1	8	0	0	0	2	$\varepsilon^2 + 2\sigma^2_{RAPS} + 16\phi_{APS}$
	$RAPS_{ijkm}$	7	1	0	0	0	2	$\varepsilon^2 + 2\sigma^2_{RAPS}$
	$\varepsilon_{q(ijkm)}$	64	1	1	1	1	1	ε^2
Total		127						

[1]From Hicks (1982).

[2]EMS calculations show main factors and their interaction effects are tested against the mean square of the term immediately below them in the table. Replication effects are tested against the error mean square. In the absence of repeat measurements which create the error, no test for replication effects is available.

Table 3. Analysis of variance for survival of loblolly pine seedlings for 1983 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	15	3827.6	255.2	2.816**
P	1	26.6	26.6	0.156 NS
RP	15	2560.2	170.7	
S	1	19.5	19.5	0.144 NS
RS	15	2029.1	135.3	
PS	1	262.6	262.6	2.553 NS
RPS	15	1543.0	102.9	
Error	64	5798.6	90.6	
Total	127	16067.2		

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 4. Analysis of variance for survival of loblolly pine seedlings for 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	3289.9	470.0	4.645**
A	1	26.6	26.6	0.071 NS
RA	7	2634.0	376.3	
P	1	262.6	262.6	4.389+
RP	7	418.8	59.8	
AP	1	395.5	395.5	1.871 NS
RAP	7	1479.5	211.4	
S	1	825.2	825.2	12.690**
RS	7	455.2	65.0	
AS	1	138.9	138.9	0.412 NS
RAS	7	2361.1	337.3	
PS	1	91.7	91.7	1.559 NS
RPS	7	411.8	58.8	
APS	1	106.3	106.3	0.900 NS
RAPS	7	826.8	118.1	
Error	64	6475.7	101.2	
Total	127	20199.6		

NS - Not statistically significant
\+ - Significant at the 90% level of probability
** - Significant at the 99% level of probability

Table 5. Student's t-test for initial heights of loblolly pine seedlings in the field experiment at Martin Lake.[1]

T-TEST

Treatment	Initial Height (cm) Mean SE	DF	Calculated t	Table[2] t
Seed Source				
LP	28.1 ± 0.5	126	4.50	±1.98**
ET	25.0 ± 0.4			
Pt Treatment				
w/o	27.1 ± 0.5	126	1.44	±1.98 NS
with	26.0 ± 0.5			
Acephate Treatment				
w/o	26.3 ± 0.5	126	-0.59	±1.98 NS
with	26.8 ± 0.5			

[1]Each mean is the average of 64 rows of seedlings and represents initial height measurements for that treatment to the exclusion of other treatments in the study.

[2]Table t values are for the 95% level of probability

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 6. Pearson correlation coefficients (r) and coefficients of determination (r^2) for initial heights of loblolly pine seedlings and subsequent growth parameters in the field experiment at Martin Lake.

CORRELATION ANALYSIS

Dependent Variables	Initial Height (Independent Variable) r	r^2
1st year height growth	-0.30	0.09
2d year height growth	0.00	0.00
1st year diameter growth	0.06	0.00
2d year diameter growth	0.08	0.01

Table 7. Analysis of variance for height growth of loblolly pine seedlings for 1983 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	15	606.6	40.4	8.666**
P	1	5.2	5.2	0.455 NS
RP	15	176.8	11.8	
S	1	153.3	153.3	14.276**
RS	15	161.1	10.7	
PS	1	0.1	0.1	0.282 NS
RPS	15	76.8	5.1	
Error	64	298.6	4.7	
Total	127	1478.5		

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 8. Analysis of variance for height growth of loblolly pine seedlings for 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	2624.0	374.7	23.258**
A	1	3244.6	3244.6	25.961**
RA	7	874.8	125.0	
P	1	3.9	3.9	0.143 NS
RP	7	189.3	27.0	
AP	1	134.7	134.7	1.696 NS
RAP	7	556.1	79.4	
S	1	195.3	195.3	5.570*
RS	7	245.4	35.0	
AS	1	67.2	67.2	3.598+
RAS	7	130.8	18.7	
PS	1	0.8	0.8	0.064 NS
RPS	7	92.4	13.2	
APS	1	3.5	3.5	0.539 NS
RAPS	7	45.2	6.5	
Error	64	1031.5	16.1	
Total	127	9439.5		

NS - Not statistically significant
\+ - Significant at the 90% level of probability
* - Significant at the 95% level of probability
** - Significant at the 99% level of probability

Table 9. Student's t-test for initial root-collar diameters of loblolly pine seedlings in the field experiment at Martin Lake.[1]

T-TEST

Treatment	Initial Root-collar Diameter (mm) Mean SE	DF	Calculated t	Table[2] t
Seed Source				
LP	5.2 ± 0.1	126	-3.12	±1.98**
ET	5.7 ± 0.1			
Pt Treatment				
w/o	5.6 ± 0.1	126	1.60	±1.98 NS
with	5.3 ± 0.1			
Acephate Treatment				
w/o	5.4 ± 0.1	126	-0.08	±1.98 NS
with	5.4 ± 0.1			

[1]Each mean is the average of 64 rows of seedlings and represents initial root-collar diameter measurements for that treatment to the exclusion of other treatments in the study.

[2]Table t values are for the 95% level of probability

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 10. Pearson correlation coefficients (r) and coefficients of determination (r^2) for initial root-collar diameters of loblolly pine seedlings and subsequent growth parameters in the field experiment at Martin Lake.

CORRELATION ANALYSIS

	Initial Root-collar Diameter (Independent Variable)	
Dependent Variables	r	r^2
1st year height growth	-0.06	0.00
2d year height growth	-0.03	0.00
1st year diameter growth	-0.28	0.08
2d year diameter growth	0.09	0.01

Table 11. Analysis of variance for root-collar diameter growth of loblolly pine seedlings for 1983 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	15	141.7	9.4	11.546**
P	1	0.3	0.3	0.118 NS
RP	15	40.8	2.7	
S	1	0.3	0.3	0.261 NS
RS	15	18.4	1.2	
PS	1	0.5	0.5	0.396 NS
RPS	15	18.9	1.3	
Error	64	52.3	0.8	
Total	127	273.2		

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 12. Analysis of variance for root-collar diameter growth of loblolly pine seedlings for 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	213.6	30.5	14.805**
A	1	80.8	80.8	6.319*
RA	7	89.4	12.8	
P	1	0.9	0.9	0.189 NS
RP	7	32.0	4.6	
AP	1	10.5	10.5	0.942 NS
RAP	7	78.0	11.1	
S	1	32.4	32.4	6.535*
RS	7	34.7	5.0	
AS	1	3.2	3.2	0.976 NS
RAS	7	22.8	3.3	
PS	1	0.0	0.0	0.010 NS
RPS	7	9.7	1.4	
APS	1	1.5	1.5	0.842 NS
RAPS	7	12.8	1.8	
Error	64	131.9	2.1	
Total	127	754.2		

NS - Not statistically significant
* - Significant at the 95% level of probability
** - Signigicant at the 99% level of probability

Table 13. Analysis of variance for nitrogen concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	28310000.0	4044285.7	
A	1	1155625.0	1155625.0	0.323 NS
RA	7	25034375.0	3576339.3	
P	1	1960000.0	1960000.0	0.698 NS
RP	7	19650000.0	2807142.8	
AP	1	1380625.0	1380625.0	6.119*
RAP	7	1579375.0	225625.0	
S	1	2250000.0	2250000.0	3.110 NS
RS	7	5065000.0	723571.4	
AS	1	140625.0	140625.0	1.340 NS
RAS	7	734375.0	104910.7	
PS	1	722500.0	722500.0	1.013 NS
RPS	7	4992500.0	713214.3	
APS	1	30625.0	30625.0	0.046 NS
RAPS	7	4684375.0	669196.4	
Error	0	(not retrievable)		
Total	63	97690000.0		

NS - Not statistically significant
 * - Significant at the 95% level of probability

Table 14. Analysis of variance for phosphorus concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	457343.8	65334.8	
A	1	7656.2	7656.2	1.229 NS
RA	7	43593.8	6227.7	
P	1	1406.2	1406.2	0.152 NS
RP	7	64843.8	9263.4	
AP	1	7656.2	7656.2	1.000 NS
RAP	7	53593.8	7656.2	
S	1	3906.2	3906.2	2.215 NS
RS	7	12343.8	1763.4	
AS	1	1406.2	1406.2	0.330 NS
RAS	7	29843.8	4263.4	
PS	1	156.2	156.2	0.042 NS
RPS	7	26093.8	3727.7	
APS	1	35156.2	35156.2	2.120 NS
RAPS	7	116093.8	16584.8	
Error	0	(not retrievable)		
Total	63	861094.0		

NS - Not statistically significant

Table 15. Analysis of variance for potassium concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	5714375.0	816339.3	
A	1	9922500.0	9922500.0	12.148**
RA	7	5717500.0	816785.7	
P	1	22500.0	22500.0	0.195 NS
RP	7	807500.0	115357.1	
AP	1	50625.0	50625.0	0.388 NS
RAP	7	914375.0	130625.0	
S	1	3900625.0	3900625.0	20.933**
RS	7	1304375.0	186339.3	
AS	1	0.0	0.0	0.000 NS
RAS	7	570000.0	81428.6	
PS	1	62500.0	62500.0	0.322 NS
RPS	7	1357500.0	193928.6	
APS	1	1890625.0	1890625.0	21.196**
RAPS	7	624375.0	89196.4	
Error	0	(not retrievable)		
Total	63	32859375.0		

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 16. Analysis of variance for magnesium concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	2042343.8	291763.4	
A	1	3906.2	3906.2	0.020 NS
RA	7	1397343.8	199620.5	
P	1	3906.2	3906.2	0.033 NS
RP	7	827343.8	118192.0	
AP	1	156.2	156.2	0.003 NS
RAP	7	326093.8	46584.8	
S	1	45156.2	45156.2	1.612 NS
RS	7	196093.8	28013.4	
AS	1	12656.2	12656.2	0.663 NS
RAS	7	133593.8	19084.8	
PS	1	1406.2	1406.2	0.029 NS
RPS	7	334843.8	47834.8	
APS	1	7656.2	7656.2	0.147 NS
RAPS	7	363593.8	51942.0	
Error	0	(not retrievable)		
Total	63	5696094.0		

NS - Not statistically significant

Table 17. Analysis of variance for calcium concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	3221875.0	460267.8	
A	1	490000.0	490000.0	1.440 NS
RA	7	2382500.0	340357.1	
P	1	105625.0	105625.0	0.460 NS
RP	7	1606875.0	229553.6	
AP	1	22500.0	22500.0	0.196 NS
RAP	7	805000.0	115000.0	
S	1	625.0	625.0	0.004 NS
RS	7	986875.0	140982.1	
AS	1	40000.0	40000.0	0.291 NS
RAS	7	962500.0	137500.0	
PS	1	75625.0	75625.0	0.526 NS
RPS	7	1006875.0	143839.3	
APS	1	160000.0	160000.0	0.753 NS
RAPS	7	1487500.0	212500.0	
Error	0	(not retrievable)		
Total	63	13354375.0		

NS - Not statistically significant

Table 18. Analysis of variance for sodium concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	880000.0	125714.3	
A	1	0.0	0.0	0.000 NS
RA	7	165000.0	23571.4	
P	1	625.0	625.0	0.042 NS
RP	7	104375.0	14910.7	
AP	1	50625.0	50625.0	3.566 NS
RAP	7	99375.0	14196.4	
S	1	40000.0	40000.0	18.667**
RS	7	15000.0	2142.8	
AS	1	10000.0	10000.0	1.750 NS
RAS	7	40000.0	5714.3	
PS	1	5625.0	5625.0	0.724 NS
RPS	7	54375.0	7767.8	
APS	1	5625.0	5625.0	4.200+
RAPS	7	9375.0	1339.3	
Error	0	(not retrievable)		
Total	63	1470000.0		

NS - Not statistically significant
\+ - Significant at the 90% level of probability
** - Significant at the 99% level of probability

Table 19. Analysis of variance for sulfur concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	2411875.0	344553.6	
A	1	600625.0	600625.0	1.680 NS
RA	7	2501875.0	357410.7	
P	1	5625.0	5625.0	0.068 NS
RP	7	576875.0	82410.7	
AP	1	5625.0	5625.0	0.072 NS
RAP	7	546875.0	78125.0	
S	1	30625.0	30625.0	0.253 NS
RS	7	846875.0	120982.1	
AS	1	140625.0	140625.0	1.706 NS
RAS	7	576875.0	82410.7	
PS	1	15625.0	15625.0	0.123 NS
RPS	7	891875.0	127410.7	
APS	1	525625.0	525625.0	6.667*
RAPS	7	551875.0	78839.3	
Error	0	(not retrievable)		
Total	63	10228175.0		

NS - Not statistically significant
* - Significant at the 95% level of probability

Table 20. Analysis of variance for iron concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	11732.5	1676.1	
A	1	8.3	8.3	0.004 NS
RA	7	13090.1	1870.0	
P	1	2104.5	2104.5	6.833*
RP	7	2155.8	308.0	
AP	1	594.1	594.1	1.080 NS
RAP	7	3851.7	550.2	
S	1	165.8	165.8	0.680 NS
RS	7	1706.1	243.7	
AS	1	87.9	87.9	0.574 NS
RAS	7	1071.5	153.1	
PS	1	102.5	102.5	0.565 NS
RPS	7	1269.8	181.4	
APS	1	13.1	13.1	0.068 NS
RAPS	7	1343.7	192.0	
Error	0	(not retrievable)		
Total	63	39297.0		

NS - Not statistically significant
* - Significant at the 95% level of probability

Table 21. Analysis of variance for aluminum concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	150325.0	21475.0	
A	1	6006.2	6006.2	0.126 NS
RA	7	333393.8	47627.7	
P	1	900.0	900.0	0.078 NS
RP	7	81100.0	11585.7	
AP	1	18906.2	18906.2	3.702+
RAP	7	35743.8	5106.2	
S	1	5625.0	5625.0	11.667*
RS	7	3375.0	482.1	
AS	1	3306.2	3306.2	1.636 NS
RAS	7	14143.8	2020.5	
PS	1	25.0	25.0	0.015 NS
RPS	7	11625.0	1660.7	
APS	1	506.2	506.2	0.572 NS
RAPS	7	6193.8	884.8	
Error	0	(not retrievable)		
Total	63	671175.0		

NS - Not statistically significant
\+ - Significant at the 90% level of probability
* - Significant at the 95% level of probability

Table 22. Analysis of variance for manganese concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	45.955	6.565	
A	1	42.581	42.581	2.957 NS
RA	7	100.813	14.402	
P	1	0.124	0.214	0.064 NS
RP	7	23.370	3.338	
AP	1	6.423	6.423	3.360 NS
RAP	7	13.382	1.912	
S	1	5.116	5.116	5.429+
RS	7	6.596	0.942	
AS	1	1.121	1.121	4.086+
RAS	7	1.920	0.274	
PS	1	0.136	0.136	0.238 NS
RPS	7	4.001	0.572	
APS	1	0.007	0.007	0.010 NS
RAPS	7	4.782	0.683	
Error	0	(not retrievable)		
Total	63	253.417		

NS - Not statistically significant
\+ - Significant at the 90% level of probability

Table 23. Analysis of variance for boron concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	61249.7	8750.0	
A	1	127806.2	127806.2	9.556*
RA	7	93620.0	13374.3	
P	1	8556.2	8556.2	2.416 NS
RP	7	24784.5	3540.6	
AP	1	2678.1	2678.1	1.314 NS
RAP	7	14264.7	2037.8	
S	1	5365.6	5365.6	2.781 NS
RS	7	13504.7	1929.2	
AS	1	110.2	110.2	0.073 NS
RAS	7	10529.0	1504.1	
PS	1	1369.0	1369.0	1.344 NS
RPS	7	7130.8	1018.7	
APS	1	976.6	976.6	0.336 NS
RAPS	7	20358.2	2908.3	
Error	0	(not retrievable)		
Total	63	392303.5		

NS - Not statistically significant
* - Significant at the 95% level of probability

Table 24. Analysis of variance for copper concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	32.484	4.641	
A	1	1.891	1.891	0.552 NS
RA	7	23.984	3.426	
P	1	0.141	0.141	0.264 NS
RP	7	3.734	0.533	
AP	1	0.391	0.391	0.548 NS
RAP	7	4.984	0.712	
S	1	0.141	0.141	0.188 NS
RS	7	5.234	0.748	
AS	1	0.016	0.016	0.019 NS
RAS	7	5.859	0.837	
PS	1	3.516	3.516	0.899 NS
RPS	7	27.359	3.908	
APS	1	1.891	1.891	0.803 NS
RAPS	7	16.484	2.355	
Error	0	(not retrievable)		
Total	63	128.104		

NS - Not statistically significant

Table 25. Analysis of variance for zinc concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the field experiment at Martin Lake.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	7	932.2	133.2	
A	1	8.3	8.3	0.175 NS
RA	7	330.4	47.2	
P	1	47.3	47.3	1.172 NS
RP	7	282.4	40.3	
AP	1	31.6	31.6	1.227 NS
RAP	7	180.5	25.8	
S	1	159.4	159.4	17.103**
RS	7	65.2	9.3	
AS	1	1.3	1.3	0.107 NS
RAS	7	82.8	11.8	
PS	1	5.6	5.6	0.699 NS
RPS	7	56.5	8.1	
APS	1	23.8	23.8	1.148 NS
RAPS	7	144.8	10.7	
Error	0	(not retrievable)		
Total	63	2352.1		

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 26. Student's t-test for initial heights of loblolly pine seedlings in the greenhouse experiment.[1]

T-TEST

Treatment	Initial Height (cm) Mean SE	DF	Calculated t	Table[2] t
Seed Source				
LP	33.1 ± 0.3	198	13.88	±1.97**
ET	26.5 ± 0.4			
Pt Treatment				
w/o	30.0 ± 0.4	198	0.81	±1.97 NS
with	29.5 ± 0.5			

[1]Each mean is the average of 100 seedlings and represents initial height measurements for that treatment to the exclusion of the other treatment in the study.

[2]Table t values are for the 95% level of probability

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 27. Pearson correlation coefficients (r) and coefficients of determination (r^2) for initial heights of loblolly pine seedlings and subsequent growth parameters in the greenhouse experiment.

CORRELATION ANALYSIS

Dependent Variables	Initial Height (Independent Variable) r	r^2
1st year height growth	-0.49	0.24
2d year height growth	-0.30	0.09
1st year diameter growth	-0.05	0.00
2d year diameter growth	-0.07	0.00

Table 28. Analysis of variance for height growth of loblolly pine seedlings in 1983 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	1120.0	1120.0	65.0**
P	1	9.6	9.6	0.6 NS
SP	1	53.8	53.8	3.1 NS
Error	196	3379.1	17.2	
Total	199	4562.5		

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 29. Analysis of variance for height growth of loblolly pine seedlings in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	356.7	356.7	24.3**
P	1	5.3	5.3	0.4 NS
SP	1	2.3	2.3	0.2 NS
Error	196	2877.6	14.7	
Total	197	3242.0		

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 30. Student's t-test for initial root-collar diameters of loblolly pine seedlings in the greenhouse experiment.[1]

T-TEST

Treatment	Initial Root-collar Diameter (mm) Mean SE	DF	Calculated t	Table[2] t
Seed Source				
LP	6.2 ± 1.0	198	-3.16	±1.97**
ET	6.6 ± 1.0			
Pt Treatment				
w/o	6.5 ± 1.0	198	1.64	±1.97 NS
with	6.3 ± 1.0			

[1]Each mean is the average of 100 seedlings and represents initial diameter measurements for that treatment to the exclusion of the other treatment in the study.

[2]Table t values are for the 95% level of probability.

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 31. Pearson correlation coefficients (r) and coefficients of determination (r^2) for initial root-collar diameters of loblolly pine seedlings and subsequent growth parameters in the greenhouse experiment.

CORRELATION ANALYSIS

	Initial Root-collar Diameter (Independent Variable)	
Dependent Variables	r	r^2
1st year height growth	0.36	0.13
2d year height growth	0.15	0.02
1st year diameter growth	-0.01	0.00
2d year diameter growth	0.11	0.01

Table 32. Analysis of variance for root-collar diameter growth of loblolly pine seedlings in 1983 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	0.871	0.871	2.940+
P	1	1.620	1.620	5.468*
SP	1	1.345	1.345	4.539*
Error	196	57.071	0.296	
Total	199	61.907		

+ - Significant at the 90% level of probability
* - Significant at the 95% level of probability

Table 33. Analysis of variance for root-collar diameter growth of loblolly pine seedlings in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	0.003	0.003	0.017 NS
P	1	0.029	0.029	0.149 NS
SP	1	0.336	0.336	1.736 NS
Error	196	37.966	0.194	
Total	199	38.334		

Table 34. Analysis of variance for root weight of loblolly pine seedlings at the end of the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	51.3	51.3	9.875**
P	1	64.0	64.0	12.310**
SP	1	3.9	3.9	0.388 NS
Error	196	1018.4	5.2	
Total	199	1137.6		

NS - Not statistically significant
** - Significant at the 99% level of probability

Table 35. Analysis of variance for shoot weight of loblolly pine seedlings at the end of the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	81.0	81.0	4.883*
P	1	4.2	4.2	0.252 NS
SP	1	4.1	4.1	0.248 NS
Error	196	3252.2	16.6	
Total	199	3341.5		

Table 36. Analysis of variance for root/shoot ratio of loblolly pine seedlings at the end of the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	5.1	5.1	1.418 NS
P	1	41.4	41.4	11.508**
SP	1	0.0	0.0	0.000 NS
Error	196	704.8	3.6	
Total	199	751.3		

NS - Not statistically significant
 * - Significant at the 95% level of probability
** - Significant at the 99% level of probability

Table 37. Analysis of variance for nitrogen concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	2250.0	2250.0	0.009 NS
P	1	2250.0	2250.0	0.009 NS
SP	1	250.0	250.0	0.001 NS
Error	36	8952999.9	248694.4	
Total	39	8957750.0		

Table 38. Analysis of variance for phosphorus concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	56250.0	56250.0	2.461 NS
P	1	12250.0	12250.0	0.536 NS
SP	1	6250.0	6250.0	0.273 NS
Error	36	823000.0	24916.7	
Total	39	897750.0		

NS - Not statistically significant

Table 39. Analysis of variance for potassium concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	110250.0	110250.0	0.184 NS
P	1	42250.0	42250.0	0.071 NS
SP	1	600250.0	600250.0	1.004 NS
Error	36	21524998.0	579916.6	
Total	39	22277748.0		

Table 40. Analysis of variance for magnesium concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	144000.0	144000.0	4.863*
P	1	1000.0	1000.0	0.034 NS
SP	1	0.0	0.0	0.000 NS
Error	36	1066000.2	29611.1	
Total	39	1211000.2		

NS - Not statistically significant
* - Significant at the 95% level of probability

Table 41. Analysis of variance for calcium concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	272250.0	272250.0	3.052+
P	1	210250.0	210250.0	2.357 NS
SP	1	250.0	250.0	0.003 NS
Error	36	3211000.2	89194.4	
Total	39	3693750.2		

Table 42. Analysis of variance for sodium concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	30250.0	30250.0	1.050 NS
P	1	72250.0	72250.0	2.508 NS
SP	1	30250.0	30250.0	1.050 NS
Error	36	1037000.1	28805.6	
Total	39	1169750.1		

NS - Not statistically significant
\+ - Significant at the 90% level of probability

Table 43. Analysis of variance for sulfur concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	4000.0	4000.0	0.381 NS
P	1	49000.0	49000.0	4.667*
SP	1	0.0	0.0	0.000 NS
Error	36	378000.0	10500.0	
Total	39	431000.0		

Table 44. Analysis of variance for iron concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	1345.6	1345.6	9.189**
P	1	78.4	78.4	0.535 NS
SP	1	152.1	152.1	1.039
Error	36	5271.8	146.4	
Total	39	6847.9		

NS - Not statistically significant
* - Significant at the 95% level of probability
** - Significant at the 99% level of probability

Table 45. Analysis of variance for aluminum concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	490.0	490.0	3.722+
P	1	5290.0	5290.0	40.177**
SP	1	40.0	40.0	0.304 NS
Error	36	4740.0	131.7	
Total	39	10560.0		

Table 46. Analysis of variance for manganese concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	2433.6	2433.6	0.439 NS
P	1	577.6	577.6	0.104 NS
SP	1	1000.0	1000.0	0.180 NS
Error	36	199624.4	5545.1	
Total	39	203635.6		

NS - Not statistically significant
+ - Significant at the 90% level of probability
** - Significant at the 99% level of probability

Table 47. Analysis of variance for boron concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	15.625	15.625	3.253+
P	1	7.225	7.225	1.504 NS
SP	1	0.025	0.025	0.005 NS
Error	36	172.900	4.803	
Total	39	195.775		

Table 48. Analysis of variance for copper concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	9.025	9.025	3.774+
P	1	7.225	7.225	3.021+
SP	1	0.625	0.625	0.261 NS
Error	36	86.100	2.392	
Total	39	102.975		

NS - Not statistically significant
\+ - Significant at the 90% level of probability

Table 49. Analysis of variance for zinc concentration in needles produced on the terminal leader of loblolly pine seedlings during the first flush of height growth in 1984 in the greenhouse experiment.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
S	1	3724.9	3724.9	0.954 NS
P	1	0.1	0.1	0.000 NS
SP	1	12.1	12.1	0.003 NS
Error	36	140492.4	3902.6	
Total	39	144229.5		

NS - Not statistically significant

Table 50. Analysis of variance for percent yellow ectomycorrhizae infecting fine roots on loblolly pine seedlings excavated from the field experiment at Martin Lake during February 1984.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	15	7220.6	481.4	
P	1	2331.6	2331.6	9.474**
RP	15	3691.5	246.1	
S	1	79.5	79.5	0.263 NS
RS	15	4526.7	301.8	
PS	1	1056.7	1056.7	6.003*
RPS	15	2640.5	176.0	
Error	0	(not retrievable)		
Total	63	21547.1		

NS - Not statistically significant
* - Significant at the 95% level of probability
** - Signigicant at the 99% level of probability

Table 51. Analysis of variance for percent total ectomycorrhizae infecting fine roots on loblolly pine seedlings excavated from the field experiment at Martin Lake during February 1984.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	15	10643.1	709.5	
P	1	2093.2	2093.2	6.872*
RP	15	4569.3	304.6	
S	1	170.5	170.5	0.653 NS
RS	15	3915.8	261.0	
PS	1	2427.8	2427.8	7.464*
RPS	15	4878.6	325.2	
Error	0	(not retrievable)		
Total	63	28698.3		

NS - Not statistically significant
* - Significant at the 95% level of probability

Table 52. Analysis of variance for volume displacement of roots of loblolly pine seedlings excavated from the field experiment at Martin Lake during February 1984.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	15	29985.2	1999.0	
P	1	558.1	558.1	0.570 NS
RP	15	14696.6	979.8	
S	1	58.1	58.1	0.097 NS
RS	15	9091.6	601.3	
PS	1	147.0	147.0	0.287 NS
RPS	15	7689.7	512.6	
Error	0	(not retrievable)		
Total	63	52226.3		

NS - Not statistically significant

Table 53. Analysis of variance for root weight of loblolly pine seedlings excavated from the field experiment at Martin Lake during February 1984.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	15	1545.0	103.0	
P	1	43.4	43.4	0.799 NS
RP	15	814.8	54.3	
S	1	12.2	12.2	0.333 NS
RS	15	546.3	36.4	
PS	1	0.1	0.1	0.002 NS
RPS	15	419.9	28.0	
Error	0	(not retrievable)		
Total	63	3381.7		

NS - Not statistically significant

Table 54. Analysis of variance for shoot weight of loblolly pine seedlings excavated from the field experiment at Martin Lake during February 1984.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	15	2901.8	193.4	
P	1	294.1	294.1	1.990 NS
RP	15	2217.3	147.8	
S	1	2.2	2.2	0.034 NS
RS	15	947.9	63.2	
PS	1	5.9	5.9	0.101 NS
RPS	15	871.5	58.1	
Error	0	(not retrievable)		
Total	63	7240.7		

NS - Not statistically significant

Table 55. Analysis of variance for root/shoot ratio of loblolly pine seedlings excavated from the field experiment at Martin Lake during February 1984.

ANALYSIS OF VARIANCE

Source	DF	Sum of Squares	Mean Square	F-ratio
R	15	71.6	4.8	
P	1	3.8	3.8	1.195 NS
RP	15	47.5	3.2	
S	1	9.6	9.6	3.978+
RS	15	36.1	2.4	
PS	1	4.2	4.2	2.158 NS
RPS	15	29.5	2.0	
Error	0	(not retrievable)		
Total	63	202.3		

NS - Not statistically significant
\+ - Significant at the 90% level of probability

APPENDIX B: A&L LABORATORIES SOIL AND FOLIAR ANALYSES METHODS

Soil Methods

Nutrient	Description	References
Total N	Kjeldahl method: digest soil with H_2SO_4 - salicylic acid, distill into standard acid and titrate (includes NO_3-N in total value).	Black 1965
P	Extract P with dilute NH_4F-HCl, filter, and determine colormetrically.	Black 1965
K, Ca, Mg, Na	Extract 1 part soil with 5 parts 1M ammonium acetate (pH 7.0) by shaking for 10 minutes, filter. Determine metals by AA.	Black 1965
S (SO_4-S)	Extract soil with 0.5M ammonium acetate (acidified), filter, react filtrate with barium chloride and measure $BaSO_4$ turbidimetrically.	Black 1965
Zn, Mn, Fe, Cu	Extract soil with 0.1N HCl. Determine metals by AA	Black 1965
B	Extract soil with boiling water. Determine B in extract colormetrically with either Curcumin or Azomethine H.	Black 1965
Al	Extract soil with 1N KCl and determine Al by AA.	Black 1965
pH	Mix 1 part soil with 1 part H_2O and measure pH with glass electrode.	Black 1965
Texture	Hydrometer method.	Black 1965

Plant Methods

N	Kjeldahl digestion with H_2SO_4-K_2SO_4-Hq catalyst, distillation into standard acid and titrate	Horwitz 1980
P	Dry ashed at 500^{o}C and dissolved in 1:1 HCl. P in extracted ash determined colormetrically.	Horwitz 1980

Plant Methods (Continued)

Nutrient	Description	References
K, Ca, Mg, Na, Zn, Mn, Cu, B, Fe, Al	Dry ashed at 500°C and dissolved in 1:1 HCl. Metals in extracted ash determined by AA	Horwitz 1980
S	Sample burned in oxygen atmosphere in induction furnace and liberated SO_2 titrated with standard Iodine solution.	Leco manual

Method References:

Black, C. A. (ed). 1965. Methods of Soil Analysis. American Society of Agronomy, Madison, Wisconson.

Horwitz, W. (ed). 1980. Official Methods of Analysis of the Association of Official Analytical Chemists. Association of Official Analytical Chemists, Washington, D.C. 13th Edition.

Leco Corporation. No date. St. Joseph, Minnesota.

TWO-YEAR SURVIVAL AND GROWTH OF LOBLOLLY

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by

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Presented to the Faculty of the Graduate School of

Stephen F. Austin State University

In Partial Fulfillment

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ABSTRACT

Loblolly pine seedlings from Lost Pines (drought-hardy) and East Texas (regular) seed sources were planted in lignite minesoils in Panola County, Texas. Heights, root-collar diameters, and survival were monitored for two years. Treatments included application of *Pisolithus tinctorius* basidiospores immediately after planting and use of acephate for tip moth control during the second growing season. Standard foliar analyses were conducted at the end of the second growing season.

East Texas seedlings grew more in height and root-collar diameter, and had higher survival percentages than Lost Pines. No growth response from treatment with *P. tinctorius* was observed. Treatment with acephate resulted in 62 percent more height growth and 24 percent more diameter growth. Variations in growth or survival were not reflected in foliar nutrient content.

VITA

Gerald Allen Wood, the son of Charles A. Wood, Jr., and Sara M. Wood, was born in Atlanta, Georgia, on March 9, 1951. He graduated from Scotch Plains-Fanwood High School, Scotch Plains, New Jersey, in June 1969. He attended the University of Maine at Orono from September 1969 to June 1973.

On January 31, 1974, he enlisted in the United States Army. After training assignments at Fort Dix, New Jersey, and Fort Polk, Louisiana, he attended Basic Airborne School at Fort Benning, Georgia, and graduated in July 1974. He served six and one-half years assigned to ACofS, G3, 82d Airborne Division, Fort Bragg, North Carolina, as an operations sergeant. During his tenure he received the Meritorious Service Medal, the Army Commendation Medal, Senior Parachutist Award, and Distinguished Trooper Award. He was honorably discharged as a staff sergeant (E-6) on December 9, 1980.

While on active duty he received a Bachelor of Arts degree from Shaw University, Raleigh, North Carolina, majoring in public administration. In January 1981, he entered Stephen F. Austin State University and began graduate studies in forestry in August. He was awarded a full environmental sciences research fellowship from Texas Utilities Generating Company in December 1982.

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This thesis was typed by its author and follows the style of Forest Science.