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Pine Seedling Survival and Growth Related to Moisture Retention of Eight Texas Forest Soils

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RELATED TO MOISTURE RETENTION

OF EIGHT TEXAS FOREST SOILS

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PINE SEEDLING SURVIVAL AND GROWTH RELATED TO MOISTURE RETENTION OF EIGHT TEXAS FOREST SOILS

by

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INTRODUCTION

Loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pines reach their westernmost distribution in East Texas. Mature specimens of these pines occur sporadically among the oaks in the Texas post oak belt (oak-hickory type) west of the pine region. Concentrations of pines occurring west of the pine region can be found in Bastrop and Fayette counties (sometimes called the "lost pine" area). The existence of those stands indicates environmental conditions are occasionally favorable for the natural establishment of pine in the oak-hickory type (Bilan and Stransky, 1966). Drought effects generally are more pronounced in the oak-hickory type than in the pine type, due to less rainfall. Seed source availability, soil characteristics, hardwood competition, and water table variability are very likely some of the interrelated factors responsible for the occurrences of scattered pine.

Difficulties of natural regeneration may be overcome by planting 1-year-old seedlings. Before any planting projects are initiated, however, it is important to obtain information on the effect of the soils of East Texas on pine seedling behavior. Plantings in the field subject seedlings to variations in the weather, the results depending on the climatic pattern of the post-planting growing season. Greenhouse tests, on the other hand, help eliminate variations due to weather and restrict the results to soil influences on seedling growth and development.

Growing some seedlings under favorable moisture conditions permits observation of the effect of those particular soils on the growth and water use, while subjecting other seedlings to soil moisture stress after an initial growth period results in observations of the duration of moisture stress endured by the seedlings and the rate of moisture depletion in those soils.

The purpose of this study is to relate loblolly pine seedling growth and survival to moisture retention characteristics of various soil types. Seed was obtained from two sources. Seedling growth and mortality during a drought period were of special concern.

LITERATURE REVIEW

Though precipitation in East Texas is adequate (normally 40 to 50 inches annually, decreasing towards the west) for maintaining forest trees, droughts are so common that pine seedlings, whether natural or planted, usually suffer heavy mortality in their first year (Stransky, 1961). Similarities in the soils of the oak-hickory type and those of the pine region of East Texas were noted by Bray (1904) who recommends establishment of pine plantations in the oak-hickory type. However, the mortality risks for pine plantations there are greater than in the pine region.

Tests by Zobel and Goddard (1955) show that loblolly pine seed obtained from Bastrop County and Fayette County, Texas, will grow trees more drought resistant than those from seed of the pine region of East Texas. Comparisons of survival differences of seedlings from seed sources further east show more striking results. In a study where loblolly pine seedlings were grown in Robertson County, Texas, percent survival from various seed sources was as follows: Bastrop County (Texas), 74; Fayette County (Texas), 66; western edge of the southern pine region (Texas), 54; Louisiana, 51; North Carolina, 17;

Florida, 7 (Zobel and Goddard, 1955).

Goddard and Brown (1959) found significant differences in height growth and diameter at breast height (dbh) 5 years after planting loblolly pine seedlings from different seed sources. They found little indication of interaction between site and seed source in growth rate results. The average 5-year height growth on four test sites among pines from alleged drought resistant seed sources (from Bastrop County and Fayette County) was 6 percent higher than the growth of pines from seed sources in the East Texas pine region. Further, diameter growth was 7 percent higher among the trees from the Bastrop County and Fayette County seed sources.

Youngberg (1959) found that site preparation before planting was important in the Willamette Valley foothills of Oregon. On cleared sites, 83 percent of 2-0 Douglas-fir (Pseudotsuga menziesii /Mirb./ Franco) seedlings survived their first year in the field; on uncleared planting sites only 24 percent of the seedlings survived. This study was based on earlier studies where soil moisture was found to be the most critical factor affecting survival of Douglas-fir seedlings (Youngberg, 1955). Shoulders (1957) found that sod removal enhanced survival of longleaf (Pinus palustris Mill.), slash (P. elliottii Engelm.), and loblolly pines in dry years. The rapid rate of soil moisture depletion by grass can result in poor seedling survival (Lane and McComb, 1948).

Hoover, et al. (1953) found that water was withdrawn from the soil most rapidly from the zone where it was most readily available in an 11-year-old loblolly pine plantation near Union, South Carolina. This was true in spite of depth and despite the greater concentration of roots in the surface layers of the soil.

Gaiser (1952) believes that capillary moisture losses from the soil proper under forested conditions are small. Soil moisture losses observed closely approximate the amount of water extracted for transpiration. In years of average precipitation (40 inches) in hardwood forest areas of southeastern Ohio, approximately 25 inches of rain might be used in transpiration while the remaining 15 inches will be accounted for by deep-seepage, runoff, and soil evaporation (Gaiser, 1952). The amount of moisture loss attributed to transpiration here may be inaccurate due to the fact that interception losses were ignored. However, it is undoubtedly true that greater moisture loss from soil through evaporation will occur in open areas (as in new plantations) than in forested areas. Transpiration of newly planted seedlings may be less severe with an overhead forest canopy than without it, possibly because of microclimatic and vapor pressure gradient differences. The merit of underplanting pine in the drier post oak belt of East Texas with subsequent removal of the overstory hardwoods should be clear. There have been reports of success with pine underplantings in the Texas post oak region.[1]

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[1]John Stransky. Personal communication. Southern For. Exp. Sta., Forest Service, U. S. Dep. Agr.

Tests in East Texas also indicate it is unwise to start pine plantations without some sort of site preparation to conserve soil moisture and enhance seedling survival (Stransky, 1961). Planting in furrows or using other means of eliminating weed competition greatly improved survival (Stransky, 1960; Stransky and Duke, 1964; Stransky and Wilson, 1966). Fall-planted pines had better root development and survival than those planted in late winter or spring in Nacogdoches, Texas (Bilan, 1961). Loblolly pine is usually planted between December and March. In the northern part of the range, February may be the most suitable month for planting (Ursic, et al., 1967). Comparisons of loblolly pine and shortleaf pine seedling growth and survival in three soils from the Texas post oak belt (oak-hickory type) and one soil from the pine region showed some, though not pronounced, species response and soil effect differences (Bilan and Stransky, 1966). Based on the experience of previous tests, the investigation reported here compared seedling survival and growth on major forest soils of both the pine and oak-hickory regions of East Texas.

MATERIALS AND METHODS

This greenhouse experiment consisted of two parts. In the first, pine seedling growth in the various soils was measured during favorable soil moisture conditions. In the second part, the effects of soil moisture stress upon the seedlings were observed.

Forty loblolly pine seedlings (1-0) were planted in each of eight test soils. Six of the soils were obtained from the East Texas pine region in Nacogdoches County (Eustis, Troup, Ruston, Sacul, Shubuta, and Swift series). Two others were taken from the oak-hickory belt in Anderson County (Eustis and Troup series, hereafter referred to as Eustis-A and Troup-A; those samples from Nacogdoches County will be referred to as Eustis-N and Troup-N). Surface samples (15-cm) were obtained to approximate the root zone of newly planted seedlings. Analyses included determinations of texture (by hydrometer) and organic matter content (by ignition) as shown in Table 1 (Wilde, Voigt, and Iyer, 1964). Table 2 shows the reaction and nutrient character of the eight soils. Soil moisture constants at various tensions (1/3, 1/2, 3/4, 1, 5, 10, and 15 atmospheres) were determined by pressure membrane apparatus (Figure 1).

Table 1. Texture and organic matter content of 15-cm surface soil samples.

Soil type	Soil-texture class	Sand (%)	Silt (%)	Clay (%)	Organic matter (%)
Ruston	Sandy clay	47	12	41	2
Swift	Sandy loam	55	36	9	2
Sacul	Sandy loam	61	29	10	2
Shubuta	Sandy loam	62	27	11	6
Eustis-A*	Loamy sand	76	19	5	1
Troup	Loamy sand	83	9	8	2
Troup-A	Sand	90	5	5	2
Eustis	Loamy sand	82	11	7	1

*Soil types marked -A are from Anderson County; the others are from Nacogdoches County.

Table 2. Chemical analyses of the eight test soils.

Soil	pH	Total nitrogen (per cent)	Available phosphorus (ppm)	Available potassium (ppm)	Exchangeable calcium (ppm)	Exchangeable magnesium (ppm)
Ruston	5.9	0.10	0.04	3	18	8
Swift	4.7	0.10	0.03	3	6	3
Sacul	4.8	0.10	0.04	2	5	3
Shubuta	6.4	0.30	0.07	14	32	21
Eustis-A*	6.3	0.05	0.04	5	23	6
Troup	6.2	0.10	0.10	3	65	5
Troup-A	6.2	0.10	0.30	6	25	5
Eustis	6.2	0.05	0.10	4	10	5

*Soil types marked -A are from Anderson County; the others are from Nacogdoches County.

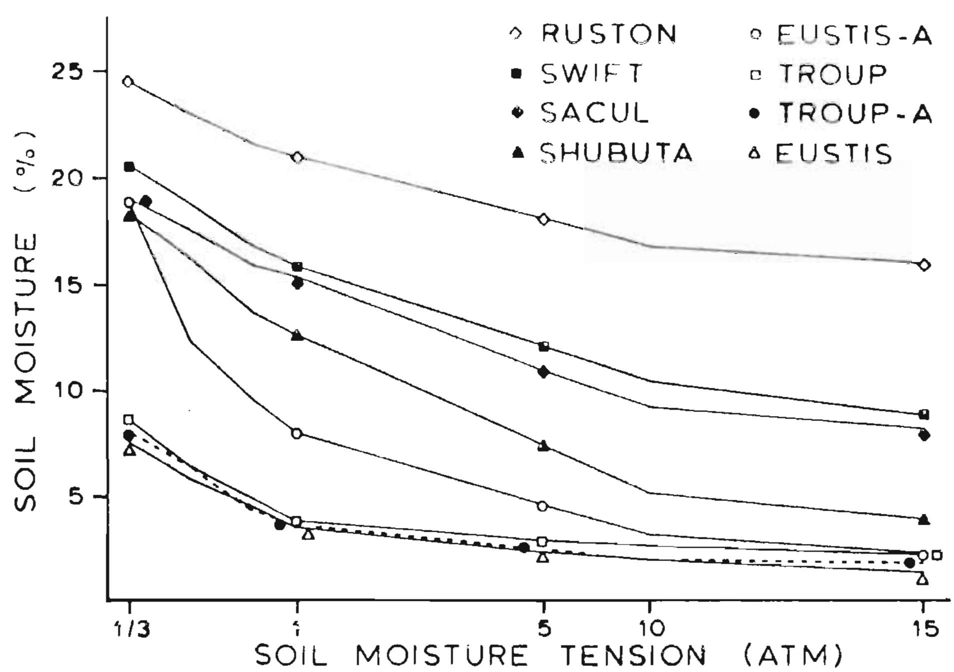

Figure 1. Moisture retention values of the six test soils from Nacogdoches County and the two test soils from Anderson County (-A).

The seedlings were obtained from two seed sources, Bastrop and Montgomery counties, Texas. (Montgomery County is in the western edge of the southern pine region.) Before seasonal height growth had started, the seedlings were planted singly in 3.8-liter (1-gallon) metal containers coated with a rust inhibitor. The containers had no drainage holes. The seedlings were arranged in a randomized-block design with 10 blocks of 32 seedlings each and 4 replications of each soil. Within each block there were 16 seedlings from each seed source, and the seed sources were equally represented in the 8 soils.

Initial seedling heights were recorded after planting (before second-growing-season growth), and growth was recorded during the beginning of the second growing season (approximately March 1, 1967 to May 17, 1967). During this first period, soil moisture contents were maintained within 20 percent of field capacity (assumed at 1/3 atm) by weight (Broadfoot and Burke, 1958). It was hoped that soil moisture levels favorable to plant development would be maintained. Evapotranspiration was determined from the total amount of water used in watering for each period after all soils were initially watered to 20 percent above approximated field capacity. Measurement of evapotranspiration commenced after all seedlings had started height growth. At the end of the first study phase (May 17) all seedlings were again rewatered to 20 percent above field capacity and measured for total height growth.

The second phase of the study was initiated on the last day of the first phase. During this second period, May 17 to June 22, 1967, one-half of the seedlings were watered as usual while water was withheld from the other seedlings. The seedlings subjected to soil moisture stress were randomly located within each block, and there was an equal representation of the different soils and seed sources under the two watering regimes. Evapotranspiration and stem height growth measurements continued until June 22. Observations of the unwatered seedlings continued until the last one died (July 15, 1967). The number of days after May 17, 1967 (date of dry-down initiation) required for these seedlings to die was recorded. Seedling death was determined by using 65 percent needle moisture content (oven-dry weight) as the indicator of the lethal point (Stransky, 1963).

RESULTS AND DISCUSSION

Seedling survival, growth, and evapotranspiration generally showed a positive relationship to the moisture retention characteristics of the eight soils. The moisture retention curves appear to group according to the clay content of the sampled soils (Figure 1 and Table 1), except for the Eustis-A soil. That soil contained 84 percent sand in the fine and very fine class, whereas Eustis-N contained only 39 percent sand in the fine and very fine class. The high content of fine and very fine sand and silt in the Eustis-A may account for the high moisture retention at 1/3-atm tension.

While performance of seedlings in this study appears to be roughly related to the content of sand or clay in the soils, soil moisture retention curves more accurately estimate seedling-soil moisture relationships (Table 1, Table 3, and Figure 1). For example, Eustis and Troup soils from both Nacogdoches and Anderson counties can be grouped on the basis of textural analyses. However, the moisture retention curve of the Eustis-A soil is noticeably different from those of the Eustis-N and both Troup soils. Seedlings in Eustis-A had a significantly higher rate of water consumption during both

Table 3. Average stem height growth and evapotranspiration for 1-year-old loblolly pine seedlings with normal watering and under soil moisture stress. Average number of days until plant death is entered for seedlings having water withheld.

	First period		Second period				
	Normally watered		Normally watered		Water withheld		
Soil Type	Height growth (cm)	E.T.* (kg)	Height growth (cm)	E.T. (kg)	Height growth (cm)	E.T. (kg)	Days until death
Ruston	11	1.70	3	1.98	1	0.86	42
Swift	13	1.94	4	2.14	1	0.70	38
Sacul	12	1.78	2	1.94	1	0.65	37
Shubuta	12	1.84	3	2.08	1	0.72	37
Eustis-A[†]	13	1.97	2	2.09	1	0.66	35
Troup	10	1.20	1	1.00	0	0.23	32
Troup-A	10	1.11	0	0.89	0	0.27	31
Eustis	11	1.13	0	0.87	0	0.25	30
<u>D</u>[‡]	3	0.30	1	0.21	1	0.21	4

*Evapotranspiration. [†]Soil types marked -A are from Anderson County; the others are from Nacogdoches County. [‡]Differences greater than or equal to <u>D</u> are significant at the 5 percent level.

Table 4. Analysis of variance of evapotranspiration (kg) during beginning of second growing season to May 17, 1967.

Source	Degrees of freedom	Sum of squares	Mean square	F
Total	319	108.53		
Blocks	9	10.84		
Seed source (SS)	1	1.65	1.65	8.68**
Soil type (ST)	7	38.48	5.50	28.95**
SS X ST	7	0.97	0.14	—
Error	295	56.59	0.19	

**Significant at the 1 per cent probability level.

Table 5. Analysis of variance of evapotranspiration (kg) during a period of the second growing season (May 17 to June 22, 1967).

Source	Degrees of freedom	Sum of squares	Mean square	F
Total	319	165.66		
Blocks	9	1.12		
Seed source (SS)	1	0.08	0.08	1.60
Watering regime (WR)	1	92.45	92.45	1,849.00**
Soil type (ST)	7	47.22	6.75	135.00**
SS X WR	1	0.09	0.09	1.80
SS X ST	7	0.11	0.02	—
ST X WR	7	9.35	1.34	26.80**
ST X WR X SS	7	0.14	0.02	—
Error	279	15.10	0.05	

experimental periods and under moisture stress (Tables 3, 4, and 5). During the second experimental period, significantly more height growth was observed in Eustis-A than in Eustis-N. Eustis-A also yielded a significantly longer survival period under moisture stress than did the Eustis-N.

Seedling Survival

Seedlings in soils with low moisture retention survived for significantly shorter periods than those in soils with high moisture retention (Table 3 and Table 6). Thus, the survival period under soil moisture stress is an important indicator

Table 6. Analysis of variance of seedling survival in number of days after last watering on May 17, 1967 until plant death.

Source	Degrees of freedom	Sum of squares	Mean square	F
Total	159	7,048.40		
Blocks	9	741.90		
Seed source (SS)	1	36.10	36.10	1.30
Soil type (ST)	7	2,318.50	331.21	11.90**
ST X SS	7	194.40	27.77	——
Error	135	3,757.50	27.83	

of planting site quality. Though field-planted seedlings may do well in years with adequate rainfall in all soils considered, in years of prolonged growing-season drought, seedling survival during the first year in the field will probably be lower in soils with low moisture retention curves.

Stem Height Growth

There was some indication that under favorable watering conditions seedlings grew more in height in sandy loam soils than in those soils with greater sand content (Tables 3, 7, and 8). Likewise, water consumption was greater in these soils than in soils with greater sand content.

As in similar experiments, height growth was retarded during soil moisture stress, though the majority of the seedlings had completed their first height growth flush when the moisture stress began. The second growth flush began for most of the seedlings during the second part of the experiment. Stransky and Wilson (1964) found that growth was inhibited by soil moisture tensions nearing 2 atm, growth stopped at 3.5 atm, and wilting occurred near 5 atm. The low-retention Eustis-N, Troup-N, and Troup-A soils showed no seedling height growth under moisture stress.

It should be pointed out that there was little height growth during moisture stress, averaging up to only 1 cm for all but three test soils. However, appreciable growth did occur on five soils; the range was from 1 to 5 cm.

Seed Source

Table 9 shows the analysis of variance of initial height of the experimental seedlings. As the first phase of the experiment had not begun when these data were obtained, it is apparent the randomized-block design distributed the

Table 7. Analysis of variance of height growth (cm) during beginning of second growing season to May 17, 1967.

Source	Degrees of freedom	Sum of squares	Mean square	F
Total	319	5,310.05		
Blocks	9	525.02		
Seed source (SS)	1	1.13	1.13	—
Soil type (ST)	7	312.23	44.60	2.99**
SS X ST	7	64.34	9.19	—
Error	295	4,407.33	14.94	

Table 8. Analysis of variance of height growth (cm) during a period of the second growing season (May 17 to June 22, 1967).

Source	Degrees of freedom	Sum of squares	Mean square	F
Total	319	1,137.99		
Blocks	9	47.30		
Seed source (SS)	1	18.05	18.05	9.30**
Watering regime (WR)	1	130.05	130.05	67.04**
Soil type (ST)	7	274.94	39.28	20.25**
SS X WR	1	0.01	0.01	—
SS X ST	7	32.80	4.69	2.42*
ST X WR	7	62.50	8.93	4.60**
ST X WR X SS	7	30.84	4.41	2.27*
Error	279	541.50	1.94	

*Significant at the 5 per cent probability level.

Table 9. Analysis of variance of initial height (cm) of 1-0 loblolly pine seedlings before their second growing season (approximately February 15, 1967).

Source	Degrees of freedom	Sum of squares	Mean square	F
Total	319	13,125.95		
Blocks	9	118.95		
Seed source (SS)	1	4,515.01	4,515.01	156.12**
Watering regime (WR)	1	8.45	8.45	——
Soil type (ST)	7	178.90	25.56	——
SS X WR	1	1.02	1.02	——
SS X ST	7	163.44	23.35	——
ST X WR	7	21.40	3.06	——
ST X WR X SS	7	49.53	7.08	——
Error	279	8,069.25	28.92	

seedlings evenly. Seedlings from the Bastrop County seed source had significantly taller initial heights than those from Montgomery County. Height growth of the seedlings from the Bastrop County seed source during the second period of the experiment was significantly greater than the height growth of the seedlings from the Montgomery County seed source (Table 8); however, there was no significant difference between the growth of the seedlings from each seed source during the first period of the experiment (Table 7).

Because initial height may have influenced the growth during the experiment, adjustment for differences in initial height between the seed sources was made by an analysis of covariance. Table 10 shows that the above conclusions about the significance of the growth of the two seed sources are reversed after covariance adjustment. Tables 11 and 12 show the analysis of covariance of initial height and height growth

Table 10. Average initial height and height growth of 1-0 loblolly pine seedlings from two Texas seed sources.

Measurement	Seed source: Bastrop Co. post oak region (cm)	Seed source: Montgomery Co. pine region (cm)	Significant difference (percent probability)
Initial height (first period)	26 (26.37)	19 (18.86)	1
Growth (first period)	12 (11.52)	12 (11.64)	not sign.
Adjusted growth (first period)	11 (10.77)	12 (12.40)	1
Initial height (second period)	38 (37.89)	30 (30.49)	1
Growth (second period)	2 (1.54)	1 (1.07)	1
Adjusted growth (second period)	1 (1.36)	1 (1.25)	not sign.

for each period of the experiment.

No significant differences in survival under soil moisture stress were noted between the seedlings from each seed source (Table 6). The Bastrop County seedlings survived for an average of 36 days, while the Montgomery County seedlings survived for an average of 35 days. There were no indications of significant differences in evapotranspiration from each seed source during the second period of the study (Table 5); Bastrop and Montgomery

Table 11. Covariance analysis of height growth (Y, in cm) and initial height (X, in cm) of 1-0 loblolly pine seedlings and significance level after adjustment for differences in initial height (first period of experiment).

Source	df	Ey^2	Exy	Ex^2	Adjusted df	Adjusted SS	Adjusted MS	Adjusted F
Total	319	5,310.05	1,715.69	13,125.95				
Blocks	9	525.02	55.31	118.95				
Seed source (SS)	1	1.13	-71.37	4,515.01				
Error	309	4,783.90	1,731.75	8,491.99	308	4,430.75	14.39	9.89**
SS + error	310	4,785.03	1,660.38	13,007.00	309	4,573.08		
Difference (SS + error - error)					1	142.33	142.33	

Table 12. Covariance analysis of height growth (Y, in cm) and initial height (X, in cm) of 1-0 loblolly pine seedlings and significance level after adjustment for differences in initial height (second period of experiment).

Source	df	Ey^2	Exy	Ex^2	Adjusted df	Adjusted SS	Adjusted MS	Adjusted F
Total	319	1,137.99	1,202.32	21,867.37				
Blocks	9	47.30	118.23	754.59				
Seed source (SS)	1	18.05	280.96	4,373.40				
Error	309	1,072.64	803.13	16,739.38	308	1,034.11	3.36	—
SS + error	310	1,090.69	1,084.09	21,112.78	309	1,035.02		
Difference (SS + error - error)					1	0.91	0.91	

county seedlings each used an average of 0.55 kilograms of water during the moisture stress period. However, during the first part of the experiment when all the seedlings were kept in favorable soil moisture conditions, significantly more evapotranspiration from the Bastrop County seedlings was observed (Table 4); the Bastrop County seedlings used an average of 1.65 kilograms of water and the Montgomery County seedlings used 1.51 kilograms of water.

Soil Moisture Retention

Regression analyses of survival, height growth, and evapotranspiration during soil moisture stress on moisture percentages of all the test soils at 1/3-atm tension yielded positive correlation coefficients of 0.96**, 0.96**, and 0.99**, respectively; at 15 atm correlation coefficients were 0.90**, 0.61, and 0.75*, respectively (One and two asterisks indicate significance at the 5 percent and 1 percent levels, respectively.). This indicates that soil moisture present at 1/3-atm tension may provide a more accurate indicator of seedling survival and development than the moisture present at 15 atm in sandy soils. Figure 2 shows the relationship of correlation coefficients for survival, height growth, and evapotranspiration during soil moisture stress and the soil moisture present in the eight test soils at various tensions (1/3, 1/2, 3/4, 1, 5, 10 and 15 atmospheres). In order to obtain the r-value, the last three columns in Table 3 were plotted as separate regressions on soil moisture retention

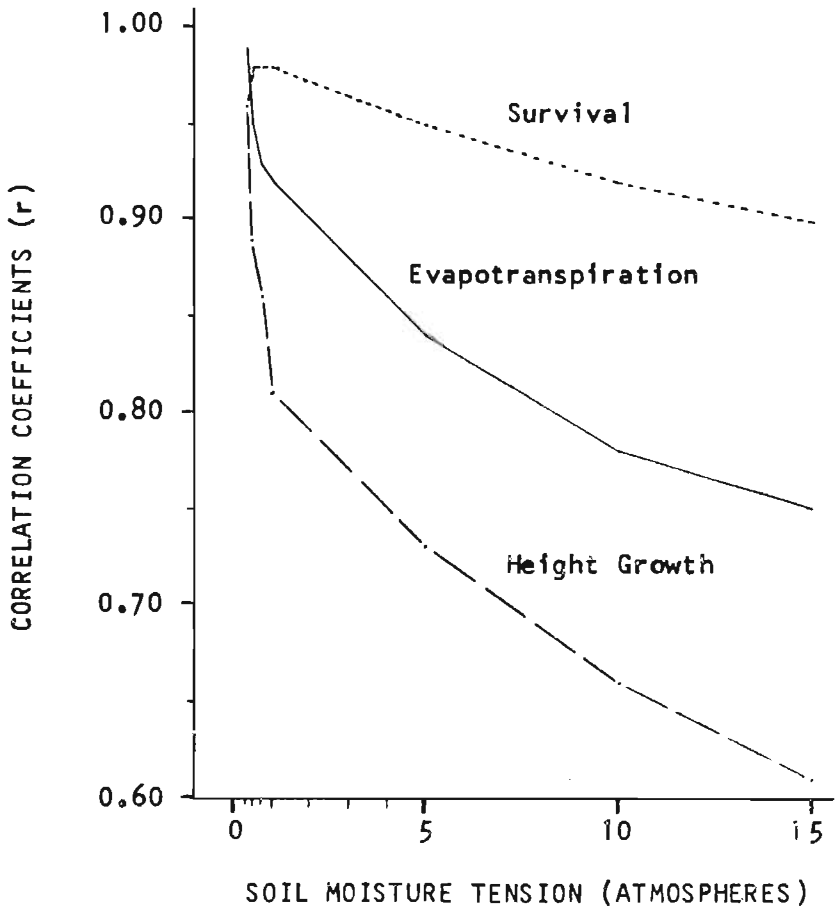

Figure 2. Relation of correlation coefficients (r) to various soil moisture tension levels, where r is the correlation coefficient for survival, height growth, and evapotranspiration of 1-0 loblolly pine seedlings on soil moisture content of eight test soils.

(percent) of each test soil at the various tension levels. There are 21 regressions (3 types of measurement, survival, growth, and evapotranspiration, and 7 soil moisture tension levels) represented in Figure 2.

CONCLUSIONS

This survival and growth study, though short in duration, indicated that there is a positive relationship between soil moisture retention characteristics and loblolly pine seedling response in sandy soils. Soil moisture retention constants nearer to field capacity tensions may give better indications of survival and development in droughty areas than moisture constants nearer to wilting point tensions. Although this study showed little indication of seedling survival differences between seedlings from the lost pine area (Bastrop County) and the pine region (Montgomery County), other tests (Zobel and Goddard, 1955) indicate that Bastrop County seed sources yield superior loblolly pine seed for East Texas plantations.

Costly reforestation failures can be avoided in this or other areas of recurrent growing-season droughts through careful selection of sites and planting dates. Although many soils of the East Texas pine type and the oak-hickory region are suitable for pine establishment, the moisture retention characteristics of those soils should be investigated to determine potential survival and development of seedlings and the extent of site preparation required prior to planting.

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OF EIGHT TEXAS FOREST SOILS

An Abstract of a Thesis

APPROVED:

(Supervising Professor)

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STEPHEN F. AUSTIN STATE COLLEGE

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PINE SEEDLING SURVIVAL AND GROWTH
RELATED TO MOISTURE RETENTION
OF EIGHT TEXAS FOREST SOILS

by

RAYMOND CURTIS ENEIM, A. A., B. S.

AN ABSTRACT OF A THESIS

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PINE SEEDLING SURVIVAL AND GROWTH
RELATED TO MOISTURE RETENTION
OF EIGHT TEXAS FOREST SOILS

ABSTRACT

Greenhouse studies showed that loblolly pine (*Pinus taeda* L.) seedling survival under severe drought and height growth under favorable and unfavorable moisture conditions were related to moisture retention values of eight East Texas soil types. Soil moisture retention constants nearer to field capacity tensions may give better indications of survival and development in droughty areas than moisture constants nearer to wilting point tensions. Likewise, water consumption (evapotranspiration) during favorable moisture conditions and during moisture stress was related to soil moisture retention characteristics. Costly reforestation failures can be avoided by examining the soil moisture retention characteristics of prospective planting sites to determine mortality risks and required site preparation in this or other areas that are characterized by recurrent growing-season droughts.

VITA

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APPENDIX

The following appendix tables are tabulations of the data obtained in this experiment (Tables I through VI). They show seedling growth, initial heights, evapotranspiration, and survival by seed source, watering regime, and soil type. Because of limited space, the soil types are abbreviated by not including the textural class of each test soil with the series name. The reader is referred to Table 1 of the text where the soil-texture classes are presented.

Table I. Height growth of 1-0 loblolly pine seedlings during the beginning of their second growing season to May 17, 1967.

			Block number									
SS[1]	WR[2]	Soil type	1 (cm)	2 (cm)	3 (cm)	4 (cm)	5 (cm)	6 (cm)	7 (cm)	8 (cm)	9 (cm)	10 (cm)
B[3]	F[4]	Eustis	15	12	8	3	14	7	14	9	15	12
B	F	Troup	16	9	12	10	10	13	14	10	12	10
B	F	Ruston	20	6	11	15	7	4	10	17	12	5
B	F	Sacul	10	6	17	13	13	13	15	19	8	12
B	F	Shubuta	17	10	18	6	13	15	8	19	10	6
B	F	Swift	11	6	12	20	13	15	6	15	12	17
B	F	Eustis-A[5]	16	12	7	13	5	16	10	21	20	18
B	F	Troup-A	10	16	11	8	9	12	6	7	11	7
B	F	Eustis	15	9	16	10	12	14	13	17	9	12
B	F	Troup	7	9	14	10	12	6	10	10	8	7
B	F	Ruston	21	4	10	16	10	16	17	15	4	7
B	F	Sacul	16	12	13	6	17	18	13	12	11	2
B	F	Shubuta	15	11	4	13	11	14	13	12	11	6
B	F	Swift	16	8	7	17	13	10	11	13	12	12
B	F	Eustis-A	13	10	6	13	13	17	11	11	7	12
B	F	Troup-A	7	10	13	16	6	11	12	9	8	7
M[6]	F	Eustis	20	14	11	8	11	12	8	12	2	8
M	F	Troup	13	10	10	11	15	11	13	5	6	15
M	F	Ruston	18	7	5	13	6	10	6	12	13	8
M	F	Sacul	12	12	11	11	16	6	11	7	11	10
M	F	Shubuta	18	12	11	16	16	13	15	9	14	13
M	F	Swift	18	19	12	10	17	12	19	10	7	6
M	F	Eustis-A	22	14	17	18	17	20	9	9	9	19
M	F	Troup-A	16	9	4	11	15	2	20	10	9	17
M	F	Eustis	13	12	12	12	10	11	13	7	8	9
M	F	Troup	15	10	7	14	11	11	8	6	7	9
M	F	Ruston	16	10	11	11	9	11	3	11	14	9
M	F	Sacul	17	14	11	12	13	9	16	5	14	20
M	F	Shubuta	17	7	14	15	6	9	7	11	15	13
M	F	Swift	17	12	15	19	11	18	14	7	16	6
M	F	Eustis-A	12	8	15	22	14	11	4	6	7	16
M	F	Troup-A	9	9	10	6	10	12	12	8	13	14

[1]Seed source.
[2]Watering regime.
[3]Bastrop County.
[4]Favorable.
[5]Soil types marked -A are from Anderson County; the others are from Nacogdoches County.
[6]Montgomery County.

Table II. Height growth of 1-0 loblolly pine seedlings during a period of their second growing season (May 17 to June 22, 1967).

			Block number									
SS	WR	Soil type	1 (cm)	2 (cm)	3 (cm)	4 (cm)	5 (cm)	6 (cm)	7 (cm)	8 (cm)	9 (cm)	10 (cm)
B	F	Eustis	0	0	0	1	0	0	0	0	0	0
B	F	Troup	2	0	1	1	0	0	1	3	0	0
B	F	Ruston	11	0	6	4	2	0	0	4	4	0
B	F	Sacul	2	1	0	0	5	3	0	0	1	0
B	F	Shubuta	9	9	2	3	4	6	1	4	5	0
B	F	Swift	5	5	3	2	6	7	5	8	5	3
B	F	Eustis-A	2	3	3	1	3	3	4	0	2	3
B	F	Troup-A	2	1	0	0	2	1	0	0	0	0
B	D[1]	Eustis	1	0	0	0	0	0	0	0	0	0
B	D	Troup	0	0	0	0	0	0	0	0	0	0
B	D	Ruston	0	0	0	3	0	5	1	0	0	0
B	D	Sacul	3	0	3	2	1	2	3	0	3	0
B	D	Shubuta	2	1	0	1	4	2	1	1	2	0
B	D	Swift	3	1	2	1	3	1	3	5	2	2
B	D	Eustis-A	0	0	3	1	1	0	0	2	2	0
B	D	Troup-A	0	0	0	0	0	0	0	0	0	0
M	F	Eustis	1	0	0	0	0	0	2	0	1	1
M	F	Troup	0	2	0	0	3	0	0	0	0	0
M	F	Ruston	5	0	0	2	3	3	3	0	4	0
M	F	Sacul	3	6	5	2	2	1	0	2	2	4
M	F	Shubuta	3	3	0	0	2	5	0	0	0	5
M	F	Swift	5	2	4	5	6	1	6	6	2	3
M	F	Eustis-A	5	1	0	1	3	0	5	2	2	0
M	F	Troup-A	0	1	1	0	0	1	0	0	0	0
M	D	Eustis	0	0	0	0	0	0	0	0	0	0
M	D	Troup	0	0	0	0	0	0	0	0	0	0
M	D	Ruston	4	2	0	2	1	3	0	0	0	0
M	D	Sacul	2	0	2	0	1	0	0	2	0	0
M	D	Shubuta	0	1	0	2	0	1	1	1	0	0
M	D	Swift	0	1	0	2	0	1	1	0	0	0
M	D	Eustis-A	1	0	0	1	0	0	2	0	0	0
M	D	Troup-A	0	0	0	0	0	0	0	0	0	0

[1]Dry-down (soil moisture stress).

Table III. Initial height of 1-0 loblolly pine seedlings before second growing season (February 15, 1967).

			Block number									
			1	2	3	4	5	6	7	8	9	10
SS	WR[1]	Soil type	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
B	F	Eustis	15	28	25	17	24	20	34	34	20	26
B	F	Troup	17	32	20	26	21	31	28	27	32	36
B	F	Ruston	43	19	45	32	15	27	21	28	34	18
B	F	Sacul	26	23	30	29	35	22	26	21	18	33
B	F	Shubuta	31	35	23	25	27	27	19	28	28	20
B	F	Swift	15	20	27	25	30	31	17	36	26	31
B	F	Eustis-A	30	29	24	22	20	29	29	28	29	32
B	F	Troup-A	24	32	25	24	27	22	37	28	23	25
B	D	Eustis	23	16	24	24	37	22	31	33	25	15
B	D	Troup	23	23	24	32	25	25	22	34	18	40
B	D	Ruston	30	20	32	31	20	24	27	33	30	20
B	D	Sacul	27	32	21	20	28	33	23	24	33	18
B	D	Shubuta	17	23	27	31	32	27	30	30	24	24
B	D	Swift	30	20	26	30	21	27	23	19	29	18
B	D	Eustis-A	27	28	26	30	30	29	27	19	27	27
B	D	Troup-A	25	24	29	29	39	27	29	26	23	30
M	F	Eustis	18	29	22	21	28	19	22	13	10	18
M	F	Troup	19	23	20	18	24	17	20	9	15	23
M	F	Ruston	24	21	19	13	13	19	13	17	13	25
M	F	Sacul	16	17	26	11	18	20	17	9	22	23
M	F	Shubuta	18	12	26	19	18	27	16	19	17	26
M	F	Swift	17	16	14	11	21	18	23	18	18	16
M	F	Eustis-A	23	29	13	20	24	17	14	25	20	17
M	F	Troup-A	26	19	17	31	23	18	15	18	21	22
M	D	Eustis	25	22	12	30	13	18	18	19	16	21
M	D	Troup	18	15	17	20	15	20	21	17	14	17
M	D	Ruston	18	21	10	20	16	21	10	15	24	17
M	D	Sacul	19	16	23	23	18	12	19	22	17	13
M	D	Shubuta	17	21	26	16	15	23	11	25	24	27
M	D	Swift	18	18	25	21	22	19	16	13	14	16
M	D	Eustis-A	23	21	25	23	19	13	14	10	10	27
M	D	Troup-A	22	16	13	29	20	17	16	18	22	24

[1]Proposed watering regime.

Table IV. Soil-seedling water loss or evapotranspiration during beginning of second growing season to May 17, 1967.

			Block number									
			1	2	3	4	5	6	7	8	9	10
SS	WR	Soil type	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
B	F	Eustis	1.28	1.34	0.85	0.76	1.29	1.03	1.22	1.29	1.03	1.08
B	F	Troup	1.36	1.44	1.08	1.24	1.15	1.24	1.14	1.30	1.44	1.20
B	F	Ruston	3.01	0.91	2.60	3.15	1.10	1.04	0.87	2.32	1.63	0.61
B	F	Sacul	1.89	1.58	2.50	2.06	2.10	1.63	1.95	1.60	1.23	1.99
B	F	Shubuta	2.38	2.17	2.87	1.31	2.24	2.25	1.57	1.88	1.40	0.79
B	F	Swift	2.18	1.19	2.24	2.38	2.02	2.27	1.20	2.26	2.53	2.07
B	F	Eustis-A	2.51	2.99	1.58	1.61	1.42	2.30	1.76	2.28	2.62	2.48
B	F	Troup-A	1.04	1.40	0.98	0.90	1.37	0.89	1.23	1.04	0.76	1.17
B	F	Eustis	1.12	1.00	1.23	1.13	1.24	1.33	1.24	1.46	0.87	1.05
B	F	Troup	1.16	1.35	1.34	1.39	1.22	1.11	0.97	1.24	0.83	1.35
B	F	Ruston	3.79	1.10	1.42	2.70	1.26	2.37	2.05	3.24	0.89	0.61
B	F	Sacul	2.20	2.78	1.77	1.48	2.57	2.52	1.38	2.15	1.37	0.76
B	F	Shubuta	2.24	1.75	1.53	2.14	2.45	2.05	2.53	2.17	1.27	1.03
B	F	Swift	2.46	1.89	1.57	2.51	2.04	1.74	1.28	1.41	2.00	1.79
B	F	Eustis-A	2.82	2.22	1.38	2.71	2.71	2.46	1.60	1.35	1.87	2.10
B	F	Troup-A	1.32	0.86	1.67	1.28	1.51	1.46	1.35	1.05	0.92	0.95
M	F	Eustis	1.24	1.51	1.25	1.09	1.26	1.10	1.00	1.09	0.56	0.95
M	F	Troup	1.16	1.41	1.12	1.27	1.59	0.99	1.29	0.94	0.90	1.26
M	F	Ruston	2.74	1.26	1.04	1.30	1.27	1.55	1.21	1.46	1.32	0.92
M	F	Sacul	1.28	1.71	2.23	1.37	1.99	1.49	1.14	1.00	1.44	2.14
M	F	Shubuta	1.98	1.77	1.94	1.66	2.03	2.07	1.43	1.34	1.37	2.32
M	F	Swift	1.91	2.38	1.50	1.44	2.35	1.38	1.98	1.90	1.40	1.14
M	F	Eustis-A	2.79	2.36	1.58	1.84	2.71	1.51	1.06	1.46	1.40	1.60
M	F	Troup-A	1.05	0.86	0.75	1.44	1.27	1.10	1.04	0.84	0.99	1.20
M	F	Eustis	1.38	1.90	0.95	1.10	0.97	0.98	1.30	0.98	0.71	1.02
M	F	Troup	1.31	1.15	1.02	1.34	1.07	1.35	1.22	1.15	0.79	1.12
M	F	Ruston	2.30	2.08	1.47	1.80	1.90	1.83	0.97	1.37	1.92	1.42
M	F	Sacul	2.30	2.38	1.84	2.06	1.78	1.28	1.30	1.97	1.26	1.81
M	F	Shubuta	2.08	1.30	2.66	2.05	1.27	1.86	1.00	1.95	1.45	1.86
M	F	Swift	2.63	2.24	2.90	2.61	2.29	2.59	1.58	0.99	2.12	1.03
M	F	Eustis-A	2.37	1.85	2.46	2.18	2.09	1.31	1.17	0.90	0.81	2.43
M	F	Troup-A	1.14	0.87	1.16	1.11	1.15	0.75	1.04	1.02	1.32	1.17

Table V. Soil-seedling water loss or evapotranspiration during a period of the second growing season (May 17 to June 22, 1967).

			Block number									
			1	2	3	4	5	6	7	8	9	10
SS	WR	Soil type	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
B	F	Eustis	0.96	0.89	0.83	0.79	0.91	0.77	0.87	0.83	0.78	0.79
B	F	Troup	1.27	1.12	1.03	0.93	0.85	0.89	0.88	1.02	1.18	0.99
B	F	Ruston	3.12	1.57	2.67	3.03	1.41	1.40	1.21	2.75	2.67	1.09
B	F	Sacul	1.95	1.75	2.26	2.12	2.12	1.94	2.02	1.91	1.75	2.11
B	F	Shubuta	2.58	2.73	2.58	1.81	2.27	2.22	1.90	2.18	1.81	1.07
B	F	Swift	2.36	1.51	2.37	2.47	2.27	2.51	1.53	2.18	2.40	2.23
B	F	Eustis-A	2.28	2.57	1.94	1.76	1.66	2.20	1.87	2.28	2.37	2.21
B	F	Troup-A	0.83	1.04	0.80	0.77	1.02	0.94	0.96	0.84	0.86	0.95
B	D	Eustis	0.22	0.25	0.26	0.22	0.25	0.26	0.26	0.25	0.22	0.27
B	D	Troup	0.30	0.31	0.28	0.27	0.30	0.28	0.28	0.27	0.26	0.28
B	D	Ruston	0.92	0.73	0.90	0.91	0.84	0.92	0.90	0.93	0.75	0.75
B	D	Sacul	0.66	0.67	0.64	0.64	0.66	0.67	0.65	0.67	0.64	0.55
B	D	Shubuta	0.73	0.73	0.70	0.72	0.76	0.72	0.73	0.73	0.74	0.69
B	D	Swift	0.71	0.71	0.71	0.71	0.69	0.70	0.68	0.74	0.69	0.69
B	D	Eustis-A	0.67	0.66	0.65	0.67	0.67	0.66	0.66	0.64	0.65	0.67
B	D	Troup-A	0.30	0.26	0.29	0.26	0.30	0.29	0.29	0.26	0.24	0.27
M	F	Eustis	0.96	1.07	0.94	0.85	0.92	0.90	0.83	0.85	0.85	0.78
M	F	Troup	0.95	1.03	0.95	1.15	1.27	0.77	1.01	0.84	0.80	1.08
M	F	Ruston	3.14	2.07	1.52	1.66	1.60	1.91	1.55	1.66	1.91	1.59
M	F	Sacul	1.69	2.14	2.23	1.79	2.20	1.88	1.50	1.34	1.98	2.14
M	F	Shubuta	2.36	1.96	1.80	1.97	1.99	2.39	1.94	1.70	1.84	2.44
M	F	Swift	2.31	2.46	2.05	1.87	2.52	1.67	2.06	2.35	2.02	1.75
M	F	Eustis-A	2.48	2.32	2.15	2.05	2.34	1.76	1.60	2.06	1.92	2.04
M	F	Troup-A	0.87	0.83	0.74	0.98	0.96	0.86	0.95	0.82	0.84	0.97
M	D	Eustis	0.25	0.26	0.23	0.25	0.27	0.25	0.26	0.26	0.25	0.26
M	D	Troup	0.29	0.29	0.30	0.29	0.25	0.28	0.28	0.28	0.27	0.28
M	D	Ruston	0.92	0.91	0.79	0.86	0.84	0.89	0.82	0.88	0.90	0.92
M	D	Sacul	0.67	0.67	0.64	0.66	0.68	0.68	0.68	0.61	0.61	0.66
M	D	Shubuta	0.71	0.71	0.73	0.73	0.70	0.72	0.70	0.73	0.70	0.72
M	D	Swift	0.71	0.72	0.71	0.70	0.70	0.73	0.69	0.67	0.68	0.66
M	D	Eustis-A	0.65	0.65	0.65	0.66	0.64	0.63	0.68	0.66	0.67	0.64
M	D	Troup-A	0.27	0.25	0.28	0.26	0.26	0.24	0.28	0.26	0.26	0.27

Table VI. Seedling survival in number of days after last watering on May 17, 1967 until plant death.

			Block number									
SS	WR	Soil type	1	2	3	4	5	6	7	8	9	10
B	D	Eustis	29	30	33	33	30	28	29	29	32	24
B	D	Troup	42	26	31	31	33	31	34	29	38	29
B	D	Ruston	33	39	40	33	48	32	36	33	51	55
B	D	Sacul	31	33	40	41	30	35	39	38	33	54
B	D	Shubuta	33	37	47	40	32	32	33	33	46	52
B	D	Swift	35	34	43	33	35	41	49	49	39	39
B	D	Eustis-A	31	37	45	31	31	32	42	36	35	39
B	D	Troup-A	30	37	29	33	26	32	28	31	33	35
M	D	Eustis	22	29	33	31	25	32	29	31	32	33
M	D	Troup	26	29	39	31	31	26	31	32	34	32
M	D	Ruston	40	35	41	52	35	36	55	59	45	41
M	D	Sacul	33	30	39	34	39	35	45	41	32	35
M	D	Shubuta	32	33	31	37	39	33	35	33	39	38
M	D	Swift	34	35	32	34	31	28	43	41	32	54
M	D	Eustis-A	34	33	29	32	30	34	41	39	41	24
M	D	Troup-A	32	33	34	30	30	35	32	32	29	26