ROOT REGENERATION IN OUT-PLANTED LOBLOLLY PINE (*Pinus taeda* L.) SEEDLINGS[1/]

M. Victor Bilan and Edwin R. Ferguson[2/]

Abstract.--1-0 loblolly pine seedlings were lifted from a nursery and planted in an open field in two-week intervals from December until March. Samples of planted seedlings were excavated in bi-weekly intervals from December 15 till June 14 to study root growth. Some roots grew through the entire winter but a number of growing tips seemed to be controlled by the low temperature. In all plantings percentage of growing root tips and the amount of growth increased with every two-week period after planting. Root regeneration began on laterals close to the root collar and proceeded downward, the main root being usually the last one to resume elongation.

INTRODUCTION

This study was initiated in 1959, during the period of intensified interest in survival of out-planted southern pine seedlings and in the final establishment of the stands. Review of then available literature (Ferguson and Stephenson, 1955) concluded that some attempts have been made to rationalize the results in view of weather conditions and/or morphological development of the planting stock, but hardly any information was available on root regeneration of the newly transplanted seedlings.

This study deals with the regeneration and development of the root systems of 1-0 loblolly pine seedlings out-planted periodically in the field from early December until late March.

OBJECTIVES

The objectives of this study were to provide at least partial answers to the following questions:

1. Do seedlings planted on different dates regenerate and develop their roots in a similar pattern in respect to the time after planting?
2. Does the weather (air and soil temperature, precipitation) affect root regeneration, and if so in what manner?
3. Do the morphological characteristics of the planting stock affect the subsequent regeneration of the roots?
4. How do the root systems of the seedlings out-planted on the different dates of a planting season compare with each other when excavated on a certain day?

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2/ The authors are, respectively, Professor of Forestry, Stephan F. Austin State University and Research Forester (now retired), U.S. Forest Service, Southern Experiment Station, Nacogdoches Research Center, Nacogdoches, Texas 75962.

METHODS AND PROCEDURE

The experimental area was located in an open field of the Austin Experimental Forest in east Texas. The prevailing soil was Cahaba fine sandy loam, an average site for loblolly pine. Since the area was covered with a rank growth of weeds and bermudagrass, it was burned before the establishment of the experiment. Five blocks, each measuring 18 x 25 m, were staked out and then 1.8-m spaced furrows, running parallel to the long sides of the blocks, were plowed with a tractor-drawn fire plow.

Experimental material consisted of 1-0 loblolly pines grown in the Austin Experimental Nursery. Seedlings were lifted, graded, root-pruned to 18 cm, and then bar-planted, using 1.8 m spacing. The planting was done in two-week intervals commencing on December 1, 1959, and ending on March 22, 1960. The first planting consisted of two rows of 14 seedlings in each of the five blocks, while all subsequent plantings consisted of a single row of 14 seedlings to each block. Selection of the rows for individual plantings was made at random. During each planting a sample of five randomly selected seedlings was taken to the laboratory for determination of green and dry weight.

Immediately after each planting the height of each seedling was recorded and the shoot classified according to the following characteristics (Figure 1):

J = Juvenile. No terminal bud, single flush of height growth, most needles juvenile.
W = Winter bud. Distinctive terminal winter bud, secondary needles abundant, especially close to tip.
WS = Winter bud stalked. Elongated terminal bud consisting of a long needleless spur (candle).
JS = Juvenile stalked. New spur of height growth, covered with juvenile needles and no distinctive terminal bud.

On December 15, one randomly selected seedling from the December 1 planting was excavated in each of the blocks. This procedure was followed at bi-weekly intervals until June 14, 1960. Sample seedlings of all other plantings were excavated in bi-weekly intervals through the 12th week after planting, and on June 14, 1960.

The excavated seedlings were tagged, placed in a bucket filled with water, and transported to the laboratory. After the seedlings had been thoroughly washed, the following information was recorded:

1. Type of the terminal bud (only during the dormant season).
2. Height of the shoot and new growth after the commencement of height growth.
3. Number and length of the lateral branches, excluding the new growth.
4. Color of the needles.
5. Presence and abundance of mycorrhizae.
6. Length of the main root plus the new growth.
7. Presence or absence of new growth on individual lateral roots of the first order.
8. Amount of the new growth on the individual laterals of the first order.

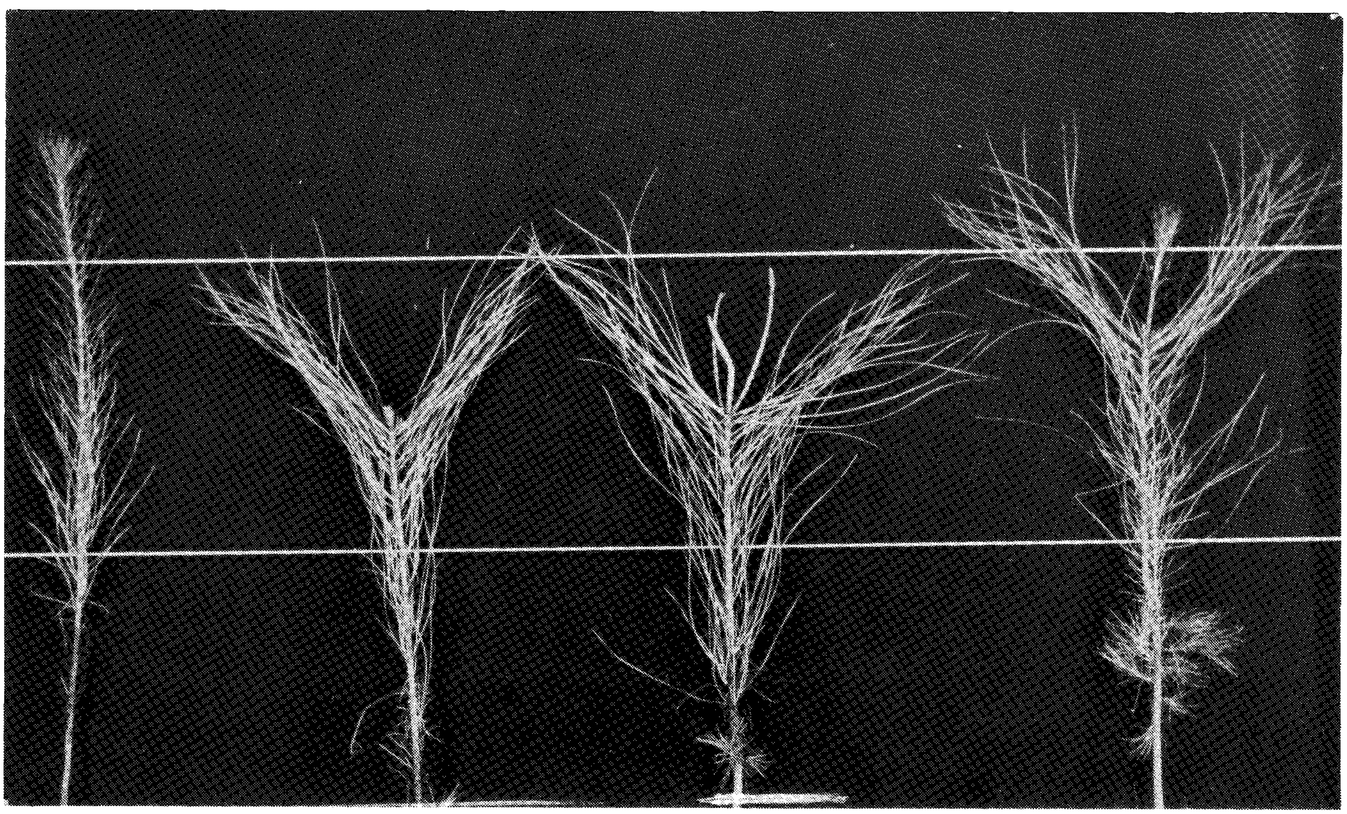

Figure 1.--Types of shoot development: Left to right, Juvenile, Winter Bud, Winter Bud Stalked, and Juvenile Stalked.

After the seedlings were examined, they were photographed, and individually placed between layers of newspaper, dried, and stored for later reference.

Climatic data for the entire period of study were available from the nearby weather station maintained by the Nacogdoches Research Center. Gravimetric methods were used to determine soil moisture from periodically collected soil samples. An attempt was made to record daily maximum and minimum soil temperatures but the collection of these data had to be terminated due to malfunction of the instruments.

The study was designed as a split-plot, randomized block with five blocks, nine plantings, and six excavations. Comparisons of the effect of date of planting on root regeneration during the twelve weeks following each planting were considered as a major effect. Data obtained from the excavation on June 14 were analyzed according to the method of randomized blocks, with five blocks and nine plantings as individual treatments.

RESULTS

Morphology of the Planting Stock

The experimental seedlings were average 1-0 planting stock as used by the Nacogdoches Research Center. Average height of seedlings per planting date ranged from 21.8 cm to 24.9 cm with an overall average of 23.1 cm (Table 1). Sixty-eight percent of seedlings had well developed terminal winter buds (W), with only an average of four percent in the juvenile stage (J).

Moisture constituted about two-thirds of the fresh weight of the planting stock and this proportion held equally for the shoots as for the roots. Dry weight of shoots and roots seemed to increase from December to March, and the shoot-root ratio showed gradual decline.

Number of Growing Roots

The tally included all laterals originating from the main root and at least 1.3 cm long. The extreme numbers of lateral roots on individuals seedlings were 7 and 27, but the most frequent numbers were between 13 and 18. The average number of lateral roots per seedling found in individual excavations ranged between 11.2 and 21.0 with an overall average of 15.5. There seemed to be no correlation between average number of first order lateral roots and either date of planting or number of weeks the sample seedlings had been out-planted.

The examination of the laterals proceeded from the root collar downward, and if there was at least one white tip, the lateral was tallied as growing. Average percentages of growing laterals by plantings and excavations are presented in Table 2. Statistical analysis revealed highly significant differences among planting dates, excavations, and planting date-excavation interactions. Duncan's multiple range test did not reveal any clear-cut pattern of correlation between the chronologic order of

Table 1.--Average parameters of seedlings by planting

Planting date	Seedlings planted	Height[1/]	Oven-dry weight			Shoot/root
			Shoot	Roots	Ent. plant	
-	number	cm	gram	gram	gram	ratio
Dec. 1	140	22.4	13.1	2.1	15.2	6.3
Dec. 15	70	24.9	13.2	2.3	15.5	5.7
Dec. 29	70	24.1	20.2	3.5	23.7	5.8
Jan. 12	70	24.9	20.7	3.7	24.4	5.7
Jan. 26	70	23.6	16.2	3.6	19.8	4.5
Feb. 9	70	22.4	21.0	5.2	26.2	4.0
Feb. 23	70	21.8	18.1	4.1	22.2	4.4
March 8	70	21.1	13.6	3.2	16.8	4.2
March 22	70	22.9	22.2	4.9	27.1	4.6
All Plantings	700	23.1	17.6	3.6	27.2	5.0

1/ Height data are based on all planted seedlings.
2/ Oven-dry weight data are based on five seedlings randomly selected during each planting.

planting and the average percentage of growing roots during the 12-week period after planting (Table 3A). Considering all plantings together, the average percentage of growing roots increased significantly with every two-week period after planting (Table 3B). As indicated by the highly significant planting date-excavation interaction, the percentage of growing roots in successive excavations did not follow the same pattern in all plantings; it was therefore decided to present the data graphically and to interpret then in terms of changing environmental conditions such as daily minimum and maximum temperature, soil moisture and precipitation.

For the graphical presentation, a first order lateral root was classified as growing only when the new growth was on its end or within 1.3 cm from the end. Such growth is termed as growing root tip. Average percentages of growing root tips per seedling during individual excavations are presented graphically in Figure 2, while the maximum and minimum temperature, distribution of precipitation and soil moisture conditions during the period of experimentation are presented in Figure 3. By studying these two figures, it can be concluded that the low temperature and soil moisture affected root growth of planted seedlings.

Freezing temperatures occurred frequently from the beginning of the study on December 1 until about March 18 with the season's low of 17°F on January 22 and February 26. The freezing spells alternated with warmer periods during which the maximum air temperature frequently reached 70°F. From December until the middle of March soil moisture was at or near field capacity (14%) but it fell to seven percent between April 5 and 19 and was only four percent during the second half of May. Until the last freeze of the season in mid-March the percentage of growing tips and side roots in all plantings seemed to be controlled by the low temperatures and the lines demoting the percentage of roots with new growth followed the general

Table 2.--Average percentage of growing first order lateral roots by plantings and excavations.

Excavation date	Planting date								
	Dec. 1	Dec. 15	Dec. 29	Jan. 12	Jan. 26	Feb. 9	Feb. 23	Mar. 8	Mar. 22
	- - - - - - - - - - Percent of growing lateral roots - - - - - - - - - -								
Dec. 15	53								
Dec. 29	72	61							
Jan. 12	76	31	51						
Jan. 26	81	57	61	41					
Feb. 9	76	49	55	45	28				
Feb. 23	82	69	64	74	74	55			
Mar. 8	94	58	83	66	72	54	59		
Mar. 22	83		69	71	79	63	52	37	
Apr. 5	87			83	81	71	74	45	40
Apr. 19	96				88	84	87	69	62
May 3	100					92	82	64	69
May 17	98						84	73	78
May 31	96							87	68
Jun. 14	94	84	84	90	97	95	80	73	66

Table 3.--Statistical comparisons of means representing percentages of growing lateral roots per seedling by planting dates (A) and by excavations (B).

A

All six excavations combined	Planting date								
		December		January		February		March	
	1	15	29	12	26	9	23	8	22
	- - - - - - - - - Percent - - - - - - - - -								
Growing roots	73.3^{a} [1/]	54.2^{c}	63.8$_{b}$	63.3^{b}	70.3^{ab}	69.8^{ab}	73.0^{a}	62.5^{bc}	63.8^{b}

B

All planting dates combined	Excavation					
	Weeks after planting					
	2	4	6	8	10	12
	- - - - - - - - - - Percent - - - - - - - - - -					
Growing roots	47.2^{e}	55.1^{d}	67.7^{c}	71.0^{bc}	76.3^{ab}	78.8^{a}

[1/] Means sharing the same letter are not significantly different at the 0.5 level.

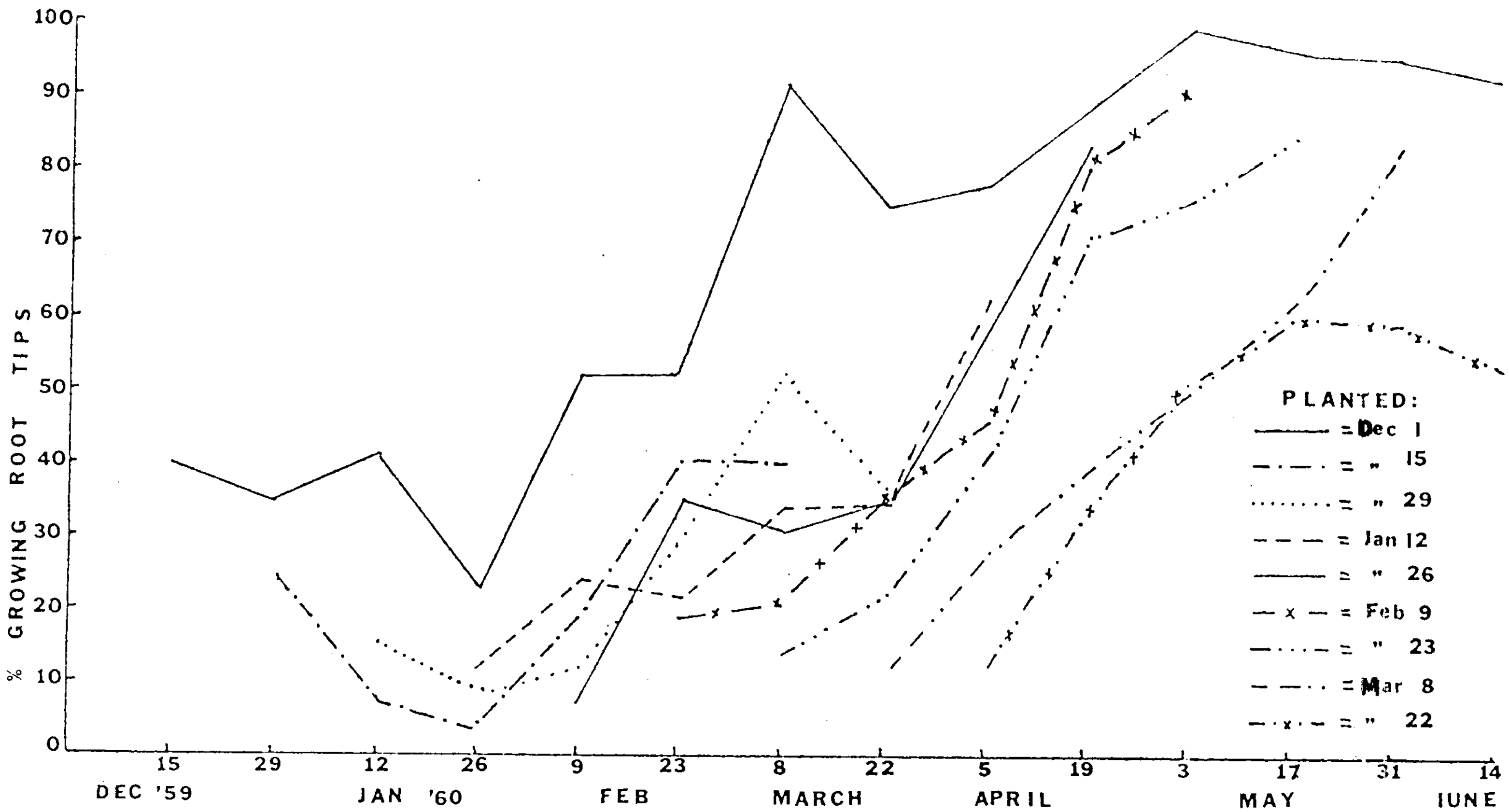

FIGURE 2. AVERAGE PERCENTAGE OF GROWING ROOT TIPS BY PLANTINGS AND EXCAVATIONS.

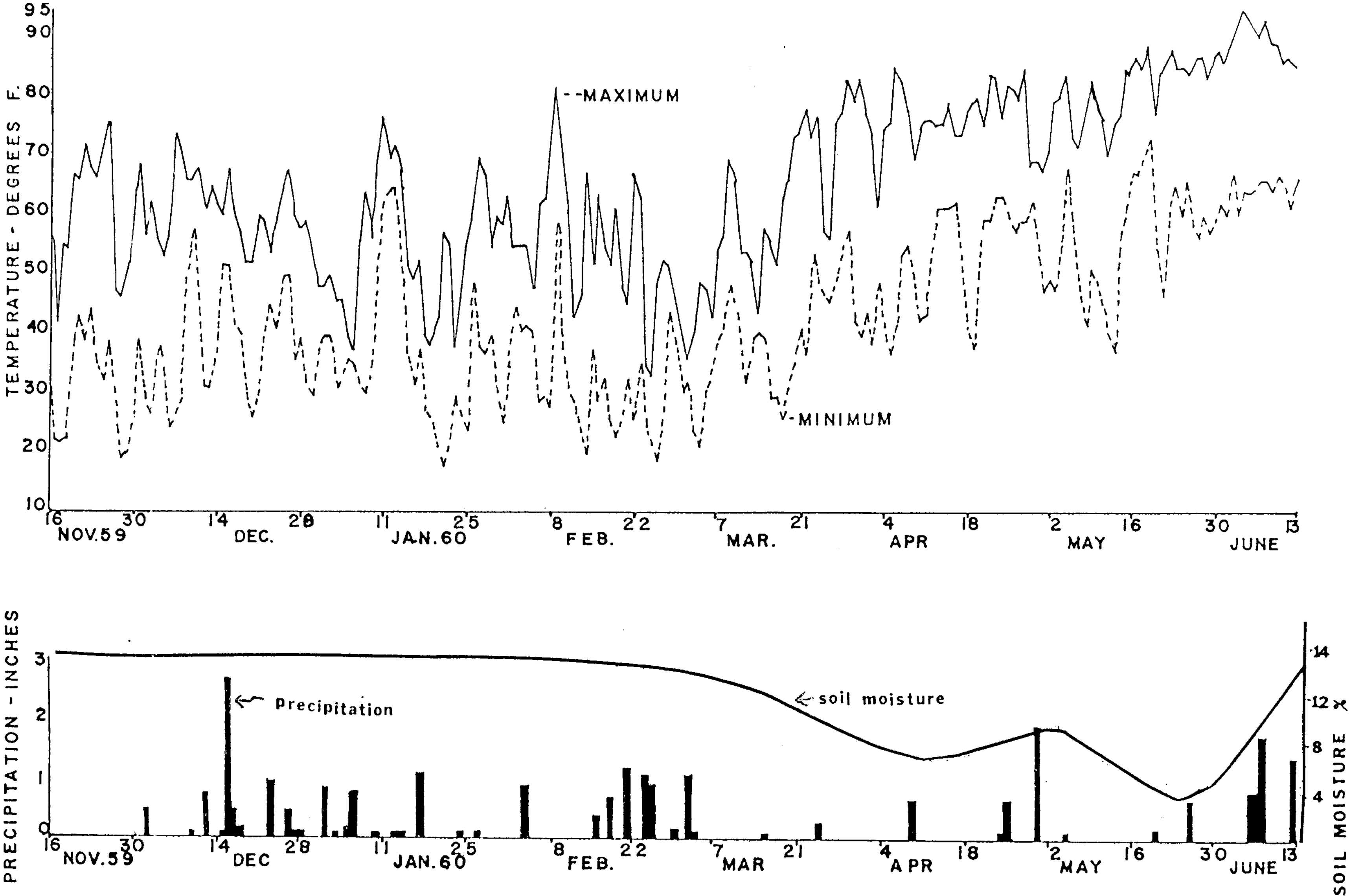

FIGURE 3. DAILY MAXIMUM AND MINIMUM AIR TEMPERATURE, SOIL MOISTURE AND PRECIPITATION DURING DECEMBER 1, 1959 THROUGH JUNE 14, 1960.

pattern of minimum daily temperatures. The lowest percentage of the growing roots was found during the severe cold spell in latter January.

After the mid-March freeze, low temperature ceased to be a limiting factor, and root growth seemed to be governed by the available soil moisture. Regardless of the time of planting and of the environmental conditions, at least ten percent of the lateral roots per seedling had white tips during the first excavation. By the middle of June the lowest percentage of growing root tips was found in seedlings planted in March.

Amount of New Root Growth

The earliest root growth consisted of tiny white tips on the fine dichotomous branches, subsequently developing into the conspicuous mycorrhizae, while the growth of long laterals commenced several weeks later. The time interval between planting and actual measurable elongation of the laterals decreased gradually from ten weeks in the first planting to four weeks in the final planting. Measurable amounts of root growth did not appear on the initial plantings for 10 weeks, with subsequent plantings this interval was gradually reduced to four weeks for the final planting of March 22 (Table 4). The new elongating roots appeared first close to the main tips of laterals and later back towards the stem. After several weeks the amount of new growth on the tips was about the same as on laterals further away from the tips. The total amount of new root growth per seedling, excluding the main root, is summarized in Table 4. Generally, the amount of root growth increased with the lapse of the time since planting, and by June, seedlings planted on December 1 had about three times more new root growth than did the seedlings planted in March.

The appearance of the elongating roots began on laterals close to the root collar and proceeded downward. The main root was usually the last one to resume the elongation. Measurable growth of main roots on seedlings planted on December 1 was noticed on April 5, while the main roots of seedlings planted on March 22 was first observed on May 17 (Table 5). By June 14 average growth of main root per seedling was 20 cm and 6 cm for the December 1 planting and for the March 8 planting, respectively.

By June 14, the average amount of total new root growth per seedling in the March plantings was significantly smaller than in the plantings December 1 through February 9.

Classification of seedling by bud development was not correlated with regeneration of root system.

Shoot Growth

Regardless of planting time, measurable stem elongation in all seedlings was noticed for the first time of April 5 (Table 6), and at that time the amount of new height growth per seedling in all plantings was about 3 cm. This certainly illustrates that some internal mechanism, possibly influenced by environmental factors, triggers height initiation and that root systems, per se, have little to do with initiation of height. There were strong indications that the seedlings planted early grew at a higher rate than seedlings planted after mid-February. Measurement of all unexcavated seedlings on May 3 revealed that the greatest height growth was

Table 4.--Average amount of new growth on all lateral roots per seedling.

Excavation date	Planting date								
	Dec. 1	Dec. 15	Dec. 29	Jan. 12	Jan. 26	Feb. 9	Feb. 23	Mar. 8	Mar. 22
	-cm-								
Dec. 15	-								
Dec. 29	-	-	-						
Jan. 12	-	-	-						
Jan. 26	-	-	-	-					
Feb. 9	2.8	-	-	-	-				
Feb. 23	3.3	1.8	4.1	-	-	-			
Mar. 8	40.6	8.1	3.1	0.8	-	-	-		
Mar. 22	27.2		1.3	3.8	1.3	0.5	1.0	-	
Apr. 5	37.9			4.3	2.0	3.8	1.3	1.3	-
Apr. 19	67.6				34.8	43.2	14.2	5.3	3.8
May 3	219.2					150.6	63.3	22.4	14.5
May 17	168.2						109.0	78.7	69.6
May 31	196.1							128.3	98.6
Jun. 14	309.9	222.8	304.8	220.2	224.3	290.1	191.8	97.8	103.9

Table 5.--Average growth of main root per seedling. Length of the first new root originating from the 2.5 cm long end section of the main root was considered as a growth of the main root.

Excavation date	Planting date								
	Dec. 1	Dec. 15	Dec. 29	Jan. 12	Jan. 26	Feb. 9	Feb. 23	Mar. 8	Mar. 22
	-cm-								
Dec. 15	-								
Dec. 29	-	-							
Jan. 12	-	-	-						
Jan. 26	-	-	-	-					
Feb. 9	-	-	-	-	-				
Feb. 23	-	-	-	-	-	-			
Mar. 8	-	-	-	-	-	-	-		
Mar. 22	-	-	-	-	-	-	-	-	
Apr. 5	0.3			-	-	-	-	-	-
Apr. 19	2.3					-	-	-	-
May 3	7.9					2.0	0.3	-	-
May 17	10.4						6.6	5.6	2.8
May 31	17.3							4.3	1.0
Jun. 14	20.1	16.0	19.1	5.1	11.4	13.7	9.4	6.1	0.0

Table 6.--Average height growth per seedling by plantings and excavations.

Excavation date	Planting date								
	Dec. 1	Dec. 15	Dec. 29	Jan. 12	Jan. 26	Feb. 9	Feb. 23	Mar. 8	Mar. 22
	- - - - - - - -	- - - -	- - - -	- - - -	-cm-	- - - -	- - - -	- - - -	- - - - - - - -
Dec. 15	-								
Dec. 29	-	-							
Jan. 12	-	-	-						
Jan. 26	-	-	-	-					
Feb. 9	-	-	-	-	-				
Feb. 23	-	-	-	-	-	-			
Mar. 8	-	-	-	-	-	-	-		
Mar. 22	-	-	-	-	-	-	-	-	
Apr. 5	3.3			2.5	2.0	3.3	3.1	3.1	3.3
Apr. 19	8.4				6.9	7.4	5.6	3.6	6.4
May 3	14.2					11.4	9.1	5.3	6.9
May 17	9.7						10.4	8.9	7.9
May 31	11.2							7.6	9.1
Jun. 14	14.4	8.4	11.9	7.9	9.7	10.9	11.2	6.6	8.1

Table 7.--New height growth per seedlings by plantings based on tally of all unexcavated seedlings measured on May 3.

Excavation date	Planting date								
	Dec. 1	Dec. 15	Dec. 29	Jan. 12	Jan. 26	Feb. 9	Feb. 23	Mar. 8	Mar. 22
	- - - - - - - -	- - - -	- - - -	- - - -	-cm-	- - - -	- - - -	- - - -	- - - - - - - -
May 3	10.7 1/	9.7	9.4	8.4	7.9	8.9	7.9	5.6	7.9

1/ Each average is based on 30 to 60 seedlings.

attained by the seedling of the first three plantings (Table 7). Regardless of time of planting the survival of the seedlings by June 14 was almost 100 percent.

DISCUSSION

Root systems of bare-root planted seedlings are usually drastically reduced by lifting and pruning, and the ability of a seedling to rapidly regenerate an extensive root system is one of the initial factors determining the survival. Wakeley (1954) expressed an opinion that the ability of planted southern pines to overcome drought seems to depend upon formation of considerable new root tissue promptly after planting. Speedy root regeneration is of a particular importance in eastern Texas where the erratic rainfall results in frequent droughts, especially during the growing season.

Preliminary studies by the senior author (Bilan, 1961) revealed that in newly outplanted loblolly pine seedlings some roots grew through the entire winter and it was anticipated that early planting would enable seedlings to develop an extensive root system before the occurrence of spring droughts. Results of the present experiment confirmed the expectations: by the middle of June, seedlings planted on December 1 made three times as much growth as did the seedlings planted in March.

The control of root growth in transplanted seedlings by the low temperature in the winter and by deficient soil moisture in the spring is in line with the correlations existing in undisturbed seedlings as found by Turner (1936), Reed (1939), Bilan (1967) and Bilan (1974). All investigators reported that in undisturbed young southern pines the periods of slowest root growth during the winter coincided with periods of lowest temperatures, while periods of slowest root growth in the summer coincided with periods of lowest soil moisture.

Expansion of a root system in a transplanted seedling is accomplished by elongation of the roots present at planting and by initiation and subsequent elongation of new roots. In the present study the first roots resuming growth after planting were fine dichotomously branching rootlets which developed gradually into a mat of mycorrhizae. Until the appearance of new straight-elongating laterals several weeks after planting the seedlings probably had to depend on the moisture and nutrients supplied mostly by the dichotomous rootlets. The above relationship indicates the importance of a fibrous root system in the planting stock of loblolly pine.

Stone and Schubert (1959) reported that the ability of ponderosa pine seedlings to initiate roots changed with the season even when seedlings were grown at a constant temperature and with abundant soil moisture. It is questionable if the decrease in number of weeks between planting and appearance of the new elongating laterals from ten weeks in December to four weeks in March was caused by the inherent characteristics of the seedlings or by the changing environment.

An interesting feature observed in the present study was the sequence of root regeneration from the upper laterals downward. Such behavior could have been a result of better growing conditions close to the soil surface, or by the differential regeneration ability of individual laterals caused by their relative position within a root system.

The lack of correlation between the bud development and the regeneration of the roots seems to indicate that the shoot development plays a lesser role in root regeneration than in the subsequent rate of height growth. The above conclusion is supported by Grigsby (1961) who reported that six morphological types of 1-0 loblolly pine seedlings did not differ from each other on the basis of survival.

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