1964

Effects of Soil Moisture on the Height Growth of Slash Pine (Pinus Elliottii, Engelm.).

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CURLIN, James William, 1932-
EFFECTS OF SOIL MOISTURE ON THE HEIGHT GROWTH OF SLASH PINE (Pinus elliottii Engelm.).

Louisiana State University, Ph.D.,1964
Agriculture, forestry and wildlife

EFFECTS OF SOIL MOISTURE ON THE HEIGHT GROWTH OF SLASH PINE (*Pinus elliottii* Engelm.)

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Agronomy Department

by
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B.S., Arkansas Agricultural and Mechanical College, 1954
M.F., Louisiana State University, 1959
August 1964

ACKNOWLEDGMENTS

The Author extends sincere thanks to Drs. William H. Patrick, Jr. and Paul Y. Burns, who as major professor and Director of the School of Forestry and Wildlife Management, respectively, supervised the organization and writing of this study.

Deeply appreciated is the financial support of the project made available by the Louisiana Agricultural Experiment Station and the services provided me by the Tennessee Valley Authority in processing the data. Equally appreciated are the suggestions of my colleagues in TVA Division of Forestry Development, as well as the cooperation extended me by the forest industries of Louisiana in collecting the data.

Special thanks go to Professor Willard M. Snyder of Georgia Polytechnic Institute for his help in the statistical aspects of the study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A study was devised to investigate the effect of soil moisture on height growth of slash pine (*Pinus elliottii* Engelm.) in Louisiana. The objectives were to identify the critical seasonal periods which influence annual height growth, and to construct prediction equations which quantify the relationship, and establish the trend of the soil moisture regime through the year.

Five slash pine plantations ranging in age from 11 to 18 years were chosen for study. The plantations were distributed throughout Louisiana on soils of both the Gulf Coastal Plain and Flatwoods physiographic regions. Five to eight one-tenth acre plots were located in each plantation; a total of 33 plots were taken. Past annual height growth of five trees in each plot was estimated by the length of internodes for a six-year period (1954 to 1959). Soil pits were dug at each plot and available soil moisture-holding capacity was determined by standard laboratory methods.

The plantations from which the data were taken showed remarkably uniform growth over the period of study. This supports the observations of other researchers who have found little racial variation in slash pine, and have noted that it is a homogenous species which seems to grow uniformly well unless planted in unsuitable climates or on distinctly unsuitable sites.

A computer program was written based on Thornthwaite's water-balance equation. Climatological data from a weather station near each study

plantation were used to compute daily evapotranspiration and available soil moisture. The daily soil moisture figures were then combined into 36 10-day periods beginning January 1 and covered the period 1953 to 1959.

Correlation analyses showed extremely high correlation between 10-day soil moisture periods, thus precluding the use of multiple regression analysis in evaluating the effects of individual soil moisture periods on height growth. Instead, multivariate analysis was used to identify the principal components so that the effect of intercorrelation among the independent soil moisture variables was reduced. It was found that soil moisture in the year preceding growth accounted for 10 to 63 percent of the variation in height growth at the five plantations, while soil moisture of the growth year accounted for 10 to 45 percent of the variation. No single 10-day period was outstanding in its contribution toward height growth. Inverse relationships occasionally appeared, particularly in the winter periods preceding growth and late in the growing season.

Based on the preliminary analysis of the 36 10-day periods, the periods were grouped into longer intervals ranging from 20 to 160 days. The combined analysis of soil moisture of the new grouped periods in the year preceding growth with that of the growth year accounted for 26 to 76 percent of the total variation in height growth. Analyses of the five plantations showed little agreement as to which soil moisture periods are universally most important. No single grouped period seemed outstanding in determining growth, but collectively the soil moisture during these periods accounted for a large proportion of the variation in total height growth.

Results of this study tend to support the hypothesis that the height

growth of multinodal slash pine is determined by a combination of the previous year's growth conditions and the conditions of the growth year, the first flush of growth in the spring being morphologically determined by the bud laid down in the previous year, while subsequent growth flushes are influenced by weather conditions prevailing in the growth year.

INTRODUCTION

Since man experienced his first impulse to explore the wonders of nature, scientists have been seeking the precise relationship of plants and their environment. Aristotle, 350 years before the birth of Christ, developed a philosophy of plant growth which theorized the existence of a "botanical soul" that regulates the physiological activities of plants. This vitalism dominated plant science until the early nineteenth century when the discovery of osmosis provided a physical explanation for many phenomena. Thus vitalism was replaced by a mechanistic concept that assumes all plant processes can be explained by chemical and physical principles.

Although plant growth depends on chemical and physical processes to maintain cell enlargement and division, it is often difficult to identify the factors that regulate growth because of the complex interrelationships among environmental factors and plants. There are those who feel as Cain (1944) or Mason and Stout (1954) that it is incorrect, if not impossible, to isolate the effect of a single environmental factor on plant growth. In spite of the difficulties encountered in the investigation of the relationship of environment to plant growth, it seems that one or more factors can often be regarded as more important than others. Of course the environmental relationships are not as simple as the basic law of the minimum proposed by Liebig (1843), Blackman (1905), and Mitscherlich (1909). The most realistic view is perhaps that of Billings (1952), who considers that limiting factors

operate within an individual environmental complex.

Tree growth is the result of the interaction of numerous physiological processes. Environmental factors can affect plant growth only by changing these internal functions. The rate of physiological activity has been shown to be closely related to the internal water balance of the tree. Severe drought creates internal water deficits that reduce vegetative growth, photosynthesis, and cell enlargement. Because of this, soil moisture often becomes a limiting factor, particularly in the southern United States where summer droughts frequently occur. Numerous studies have shown a close correspondence between the moisture regime and radial growth of many tree species. Where rainfall is limited, the width of the annual rings gives an insight to the climatic conditions of the past. In areas of abundant rainfall, diameter growth seems to be less sensitive to changes in moisture supply.

The effect of environmental factors on height growth of forest trees has been studied less extensively than has radial growth, yet the ratio of height to age is universally accepted as the standard measure of site productivity. A large proportion of the existing work has been done with northern conifers or deciduous species whose growth patterns and native climatic habitat make translation of the results to other species and climates impossible.

Most studies of the moisture-growth interaction have attempted to correlate raw precipitation data with growth measurements. Where strong associations exist the investigator is successful. However, if the relationship between growth and moisture supply is more subtle, as it apparently is in the case of height growth, then precipitation rates and intensities are meaningful only as determinants of the availability

of soil moisture. In referring to available soil moisture, confusion arises from the existence of two contradictory concepts of moisture availability to plants.

The first is Veihmeyer and Hendrickson's theory (1950, 1952) that plants can obtain water with equal ease between field capacity and permanent wilting point and that rate of growth is not diminished over the entire range of availability until the soil approaches the wilting point.

The second theory is that growth rate progressively diminishes as soil moisture falls below field capacity and ceases at the permanent wilting point. This concept is often called the "more water, more growth" idea and arises from numerous experiments which have suggested that plant growth is related to the tension with which water is held by the soil.

In a discussion of the relationship between soil moisture and growth, it must be remembered that growth is not controlled directly by soil moisture content or stress, but by the water balance of the tree. The internal water balance is regulated not only by the moisture supply, but by the relative rates of absorption and transpiration; hence it is also affected by atmospheric moisture conditions, wind movement, radiation, temperature, and a myriad of secondary factors.

Because of the lack of knowledge concerning the relations that exist between climatic factors and the height growth of southern pines, a study was devised to investigate the effect of soil moisture on the height growth of slash pine (*Pinus elliottii* Engelm.). The primary objectives of this study were: to identify the seasonal periods in which soil moisture critically influences annual height growth, to construct

prediction equations with which to quantify the relationship, and to establish the trend of the soil moisture regime through the year.

REVIEW OF LITERATURE

Over the years a considerable amount of literature has accumulated assessing the influence of the more important environmental factors on tree growth. The seasonal growth pattern of forest trees greatly influences the reaction of the tree to environmental stimuli. Coniferous species native to northern latitudes seem to make the majority of their annual height growth in a relatively short period of time early in the season. Kramer (1943) has shown that northern species, planted as far south as North Carolina, attain their annual height increment over a period of 6 to 8 weeks from onset of growth, while southern species in adjacent plots continue to grow for several months. In Missouri, Johnston (1941) observed that stem elongation of oak species extended over a very short period at the beginning of the growth season. Height growth of white pine in New England accelerated rapidly to late May, and completely ceased by late June (Kienholz, 1941). The entire growth period lasted only 60 days, and 90 percent of the growth occurred in a 30-day period beginning shortly after the onset of stem elongation. Kienholz (1934) compared his growth curves for white pine (Pinus strobus L.) with those of Stevens (1931), and detected only slight variations in the beginning and ending of leader elongation. The time of most rapid elongation occurred about June 10 in both cases. Work of Baldwin (1931) in the northeastern United States; Marie-Victorin (1927), and Walters and Soos (1963) in Canada; Illick (1919), and Brown (1915) in the northern United States corroborate these findings. Since northern

conifers produce a single whorl of branches annually, growth is almost continuous from its onset to time of cessation, as shown by Friesner (1942). On the other hand, southern conifers experience recurrent flushes of shoot growth over a longer span of time, producing several whorls of branches and internodes. Kramer (1957a) showed that loblolly pine seedlings grown in an air-conditioned greenhouse with adequate water and minerals exhibited the same tendency for shoots to elongate for a few weeks, cease growth for a time, then resume elongation just as the same species does under field conditions. This may occur three, four, or more times during the season. Eggler (1961) observed that the annual growth of both leaders and branches of longleaf pine (*Pinus palustris* Mill.), shortleaf pine (*Pinus echinata* Mill.), loblolly pine (*Pinus taeda* L.), and slash pine in Louisiana was the result of the elongation of several, rather than a single terminal bud. In most instances the buds elongated consecutively, not intermittently or recurrently. As soon as one terminal bud ceased elongation, the next one began, and there was no rest period between growth phases. Eggler's findings are contrary to most observations of the growth pattern of southern pines. Tepper (1963) noted that the growth of shortleaf pine and pitch pine (*Pinus rigida* Mill.) in New Jersey did not support Eggler's (1961) observations. The initial leader growth of both shortleaf and pitch pine was in the internodes of the winter bud. The rate of elongation of the winter bud gradually increased to a maximum late in May. After that date elongation decreased, until by late June all the pre-formed internodes from the winter bud were fully extended. Leader elongation from then on was a result of the formation and elongation of summer buds.

Langdon (1963) reported that the height growth of South Florida

slash pine (*Pinus elliottii* var. *densa* Little and Dorman), the only sub-tropical pine growing naturally in the United States, occurs intermittently throughout the year. The greatest proportion of annual height growth (55 percent) occurred in the period from March to May. The amount of height growth was about the same between June and November (22 percent), and in the winter season, December to February (23 percent).

The cause of temporary dormancy or growth flushes in southern species is not fully understood. Samish (1954) termed cessation of growth caused by unfavorable environmental conditions "quiescence" and dormancy caused by internal factors "rest". This study is primarily concerned with quiescence, but internal factors that influence rest tend to confound the results.

Causation of rest dormancy has been attributed to both exhaustion of vital growth substances within the plant and accumulation of growth inhibitors within the plant. A fact often overlooked is that trees of the same species, size, and age grown under identical environmental conditions exhibit different patterns of growth flushes (Kramer and Kozlowski, 1960). This is not apparent when growth data are represented as averages of a number of trees. Single tree data show extreme deviation between trees in the number and period of growth flushes. Temporary dormancy in one tree was often accompanied by accelerated growth of another tree exposed to the same environment.

There is considerable range in optimum temperature for growth of tree species. Physiological temperature was found by Reed (1939) to be more important in determining root and shoot growth in loblolly and shortleaf pine in North Carolina than was soil moisture. Reed (1939) also observed that almost twice as much leader growth of shortleaf and

loblolly pine occurred at night as during the day. Kramer (1957a, 1957b) later found that loblolly pine seedlings obtained best height growth with the greatest difference between day and night temperatures. Optimum growing conditions existed with a range of 12 to 13 degrees spread between day and night temperature. Even a small difference in temperature produced a measurable difference in amount of shoot growth. This "thermoperiodic" effect on herbaceous plants was observed earlier by Went (1948, 1953).

Light intensity directly affects photosynthesis, cell enlargement, height growth, and many other growth functions. Intensity of light varies daily and seasonally, and is modified by latitude. Clouds, dust, fog, and smoke tend to reduce light intensity and create variation which is reflected in tree growth. Kozlowski (1949) demonstrated the effect of reduced light intensity on height growth of loblolly pine seedlings. Height growth was reduced 17 percent by exposure to one-third the light intensity provided to the check trees. More important, stem weight was reduced 64 percent by the same light treatment.

Kozlowski (1958) summarized the present knowledge of the relationship of water to tree growth. Many investigators have reported positive correlation between radial growth of many forest species and rainfall of the current growth season (Tryon et al., 1957; Dils and Day, 1952; Tryon and Myers, 1952; Miller, 1950; Lyon, 1943; Friesner and Friesner, 1941; Goldthwaite and Lyon, 1937; Kleine et al., 1936; Shreve, 1924; and Robbins, 1921). Occasionally a study has been reported that showed no correlation between rainfall and diameter growth (Burns, 1929) or suggested an effect of excessive or deficient rainfall in the year preceding growth (Goldthwaite and Lyon, 1937; Diller, 1935; and Bogue, 1905).

Investigators that have related radial growth to soil moisture have found high correlations between growth and soil moisture conditions in the current year (Griffith, 1960; Husch, 1959; Boggess, 1956; and McClurkin, 1958).

Strong relationships between soil moisture or rainfall and radial growth of the southern pines have been found. Lodewick (1930) observed a definite relationship between width of annual rings of longleaf pine and the precipitation from March 16 to October 15 in western Florida. Coile (1936) showed that radial growth of loblolly pine in southwestern Louisiana was influenced by fluctuations of rainfall during January to May of the same year. Byram and Doolittle (1950) found that current rainfall had only a slight effect on the spring radial growth rate of shortleaf pine, but had a definitely positive effect on the summer growth rate. They concluded that temperature, sunshine, and certain inherent characteristics of the tree are limiting factors relative to growth in the spring, but as the growing season progresses, rainfall gradually becomes the most important factor affecting growth. Boggess (1956) reported that when available soil moisture approached the wilting point, radial growth of shortleaf pine ceased, but if soil moisture was recharged during the summer, growth would resume. McClurkin (1958) corroborated Boggess' findings and stated that even if moisture conditions remained uniform throughout the growth year, daily growth rate would vary because of the normal episodic growth pattern. Zahner (1962) grew loblolly pine seedlings in southern Arkansas under two moisture regimes---wet and dry. He found that gross radial growth was more than double for trees grown under low moisture stress as compared to trees grown under high moisture stress. Harms (1962) observed that radial growth of slash

pine increased linearly with increased soil moisture on coastal plain soils in Georgia. Significant correlations were also found between maximum air temperature, evaporation, and elapsed days from January 1.

Relatively few studies have been conducted to determine the effect of moisture supply on height growth of forest trees, in contrast to the large number dealing with radial growth. Motley (1949) found a strong correlation between the height growth of eastern white pine and red pine (Pinus resinosa Ait.) with the precipitation of May through November of the previous year in Indiana. This period corresponds to the time in which carbohydrates are being manufactured and stored by the tree. Motley suggested that since white pine and red pine make over 90 percent of their stem elongation during the period from mid-April to mid-June, it is reasonable to suppose that the plant must draw heavily upon the reserve food supply stored in the previous photosynthetic period. This corroborates the findings of Kirkwood (1914) with Ponderosa pine (Pinus ponderosa Laws.) and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco.) and Perry (1921) in the western United States; Tolsky (1913) in Russia; Schubert (1931), Burger (1926), Ciesler (1907), and Hesselman (1904) in Europe.

Tryon et al. (1957) found a weak positive correlation between height growth of yellow poplar (Liriodendron tulipifera L.) and the amount of precipitation of the current year. Bell (1957) found good agreement between the annual fluctuations in mean height increment of Douglas-fir and the total rainfall in April, May, and June of the current year. Similar fluctuations were found in Sitka spruce (Picea sitchensis (Bong.) Carr.) but with a marked lag of one year. Cook (1941a, 1941b) found that exceptional rainfall deficiencies in the current season retarded

the leader growth of several conifers in New York State. Johnston (1941) concluded that since oaks in the Missouri Ozarks complete their stem elongation early in the growth season before soil moisture deficiencies occur, their growth is dependent upon the previous year's conditions. Shortleaf pine in the same area continued to grow throughout the summer and was therefore dependent on the current year's moisture. Pearson (1918) and Korstian (1921) found that since height growth of western species often occurs during periods of lowest precipitation, they rely heavily on precipitation stored in the soil from the previous winter, and unless the soil moisture is supplemented by rains in April and May, the growth in that year is apt to be less. If winter precipitation is supplemented by two or more inches of precipitation in this period, height growth is stimulated. Husch (1959) observed that differences in annual leader elongation of eastern white pine can be attributed principally to differences in available moisture of the current growth year in New Hampshire. Cessation of growth in late summer was apparently controlled by an interaction of photoperiod and soil moisture. Leader elongation continued longer in years of ample soil moisture. Soil moisture changes were most important in the latter half of the growing season.

Reed (1939), studying the root and shoot growth of loblolly pine and shortleaf pine in North Carolina, found little association with precipitation or soil moisture, but found that physiological temperature was quite important in determining both root and shoot development. McClurkin (1953) showed that the amount of January to June precipitation was important in regulating the height growth of longleaf pine in Louisiana, Texas, and Mississippi. Griffith (1960) observed that site

indices of Douglas-fir seemed to be well correlated with the average available soil moisture of the site in British Columbia. Smith (1960) was unable to detect any consistent association between early height growth of slash pine and the available soil moisture of the site on which it is planted in southern Mississippi. Bethune (1960) found that the average monthly frequency of precipitation during summer, spring, autumn, and winter contributed significantly to the delineation of the natural range of slash pine in the South.

Jackson (1962) investigated the contribution of 36 independent climatic and edaphic factors to height growth of slash pine. Sample plantations were selected in the southeastern and south central United States and also from Australia and New Zealand, where slash pine has been introduced as an exotic. Jackson measured mean annual height growth of a 5-tree subsample in each plantation and recorded several soil characteristics found under these trees. Analysis of these data indicated that there is an apparent beneficial effect of increasing annual rainfall on height increment. However, growing-season rainfall (March through August) had a negative effect. Jackson concluded that if annual precipitation is 50 inches, an increase in the growing-season rainfall generally results in decreased height increment. This effect diminishes as depth to the least permeable horizon increases, particularly as trees become older. In attempting to rationalize this apparent conflict between the beneficial effects of increasing annual precipitation and the adverse effects of increasing growing-season rainfall, Jackson attached considerable importance to the amount of available moisture stored through the maximum effective depth of soil prior to the season of active growth. He hypothesized that this would be available as soon

as growth started in the spring, and that rainfall during this period of most active height growth (i.e. March through May) would result in depressive effects due to reduced soil aeration, rather than produce additional growth as a further moisture-response. These effects would obviously be much greater on shallow soils and in areas of high growing-season rainfall.

It is obvious from the foregoing literature review that a great deal is known of the interaction of tree growth and soil moisture for many species and locations, but little is yet known for the southern pines. This area of research presents an infinitely complex, but extremely challenging frontier of knowledge.

METHODS AND PROCEDURES

Location and Description of Study Areas

The assistance of the Louisiana forest industries was solicited in locating five slash pine plantations in which to carry out this study. The plantations were selected from those ten to twenty years old and within a radius of ten miles of a weather station with records covering the period of study (1953 to 1959). Ten-to twenty-year-old plantations were chosen so that at least six years of past annual height growth could be measured above breast height (4.5 feet), the approximate point at which the slow period of juvenile growth ceases (Wakeley and Marrero, 1958). Stocking was relatively homogeneous at each location, but basal area ranged from 40 to 120 square feet per acre for different plantations. Total heights ranged from approximately 30 feet for an 11-year-old stand to 40 feet for the oldest planting, 18 years old. The five areas chosen (Figure 1) were widely distributed throughout the slash pine plantation region of the state. They covered varied climatic situations and occurred on soils of both the Gulf Coastal Plain and Flatwoods regions.

Three of the plantations were described earlier by Foil (1960). Table 1 describes the location and characteristics of the plantations chosen for study.

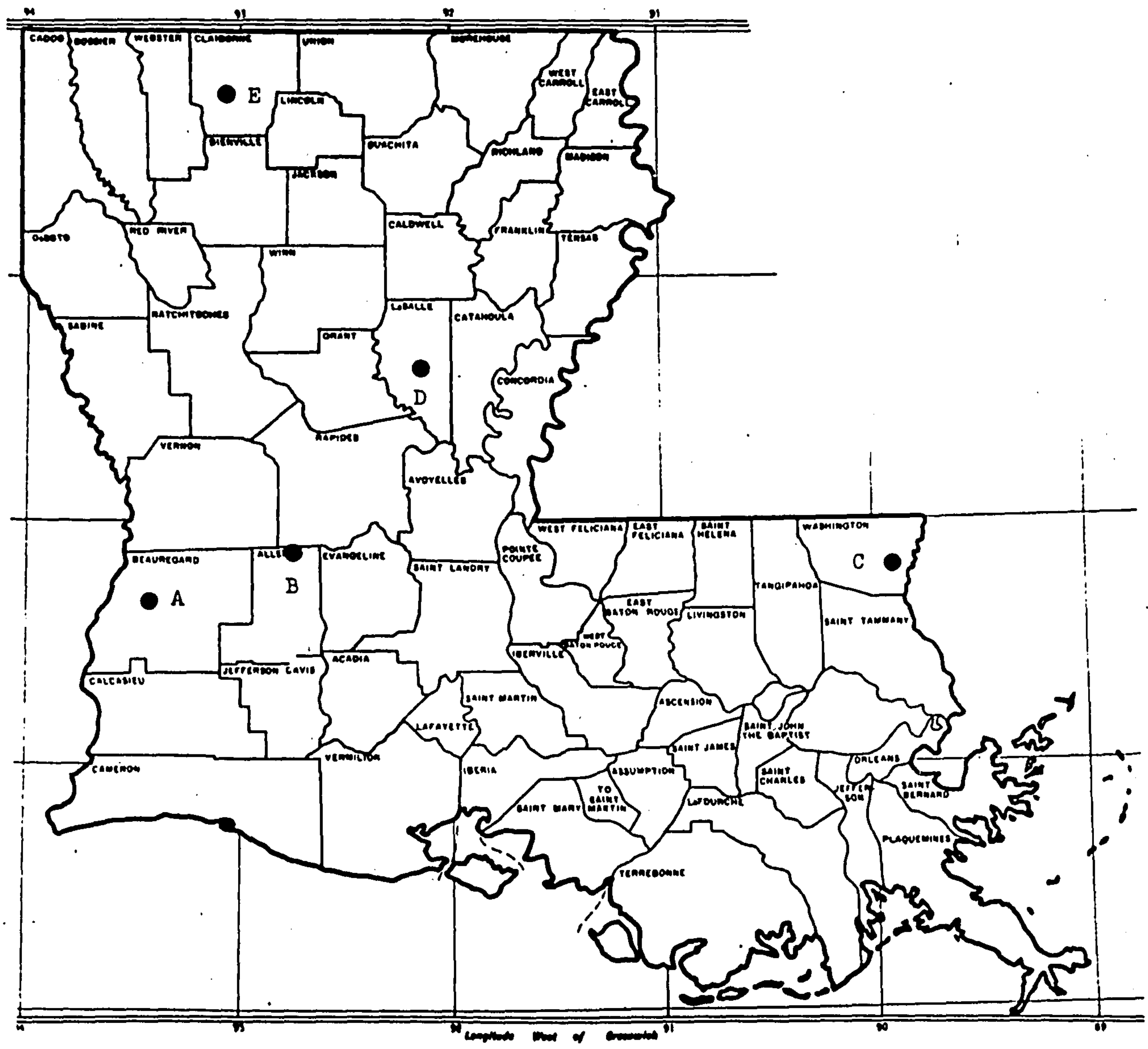


Figure 1. Map of Louisiana showing location of plantations studied

Table 1. Location and characteristics of the plantations chosen for study

Plantation	Parish	Nearest weather station	Plot numbers	Total age at measurement
				Years
A	Beauregard	Singer	1 to 6	11
B	Allen	Elizabeth	7 to 14	18
C	Washington	Bogalusa	15 to 19	11
D	LaSalle	Belah	20 to 26	12
E	Claiborne	Homer	27 to 33	11

Plantation A: Located five miles northwest of Singer, Louisiana, latitude 30°39'N, longitude 93°25'W. It was planted in the winter of 1949 by the Rice Land and Logging Company. The trees had completed 11 years of growth from seed when measured for this study in March 1959.

Topography of the area is predominantly flat with scattered areas of gently rolling hills. Soils are of the Caddo-Beauregard-Bowie catena, with a small amount of Ruston soil on the hilltops. Occasional poorly-drained areas of the Plummer series are encountered. Most of the soils are very fine sandy loams or silt loams.

Climate of the area is mild, characterized by long warm summers and short moist winters. Mean annual precipitation is between 55 and 60 inches and temperature averages 67°F. Rainfall is well distributed throughout the year. Stand characteristics of the plots taken in Plantation A are shown below.

Plot	Average DBH (Inches)	Basal area per acre (Sq.ft.)	Average total height (Feet)	Mean annual height growth (Feet)	Site index based on age 25 (Bennett *et al.*, 1959) (Feet)
1	5.6	110	39.8	3.62	75
2	6.9	90	37.0	3.36	70
3	4.7	40	26.3	2.39	50
4	6.1	70	30.8	2.80	58
5	6.3	80	33.9	3.08	65
6	5.5	50	33.2	3.02	64

Plantation B: Located four miles north of Elizabeth, Louisiana, latitude 30°52'N, longitude 92°48'W. Planted in 1942 by the Industrial Lumber Company, this plantation was 18 years old at time of measurement in 1959. The area is typical coastal flatwoods, typified by imperfect drainage. Little change in elevation is encountered over the entire area of the plantation. Soils include Caddo, Beauregard, and Plummer very fine sandy loams to silt loams. The climate of this area is similar to that of Plantation A. Stand characteristics of the plots taken in Plantation B are shown below.

Plot	Average DBH (Inches)	Basal area per acre (Sq.ft.)	Average total height (Feet)	Mean annual height growth (Feet)	Site index based on age 25 (Bennett *et al.*, 1959) (Feet)
7	7.5	110	42.1	2.34	52
8	6.6	100	41.7	2.32	49
9	7.0	80	36.5	2.03	44
10	7.1	80	42.2	2.34	52
11	7.0	90	41.1	2.28	48
12	7.4	70	43.3	2.41	54
13	6.6	70	41.0	2.28	50
14	6.3	70	39.4	2.19	47

Plantation C: Located in the "Florida Parishes" in the southeastern part of the state, 5 miles southwest of Bogalusa, Louisiana, latitude 30°47'N, longitude 89°52'W. This plantation, owned by Crown Zellerbach Corporation, was 11 years old at time of sampling. Topography of the study area is flat to gently rolling and soils of the Ruston, Kalmia,

and Myatt series predominate. Soil textures range from fine sandy loam to silt loam.

Climate of the area is characterized by long warm summers and short cool winters. Mean annual temperature is 67°F., and average annual precipitation is 66 inches. The summer months receive the greatest rainfall and October is the only excessively dry month. Stand characteristics of the plots taken in Plantation C are shown below.

Plot	Average DBH (Inches)	Basal area per acre (Sq.ft.)	Average total height (Feet)	Mean annual height growth (Feet)	Site index based on age 25 (Bennett et al., 1959) (Feet)
15	6.4	100	38.5	3.50	74
16	6.0	110	36.4	3.31	69
17	7.1	110	39.5	3.59	75
18	5.1	90	28.6	2.60	55
19	6.8	100	36.7	3.34	70

Plantation D: Located four miles south of Jena, Louisiana, latitude 31°38'N, longitude 92°11'W. The plantation, owned by the Bodcaw Company, was 12 years old at time of sampling. The study area lies on Gulf Coastal Plain uplands. Orangeburg soils predominate, but Ruston and Susquehanna series occur intermittently. Soil textures range from fine sandy loams to silty clay loams.

Average annual rainfall for the area is 58 inches. Precipitation is greatest during the spring and early summer. Mean annual temperature is 66°F. Stand characteristics of the plots taken in Plantation D are shown below.

Plot	Average DBH (Inches)	Basal area per acre (Sq.ft.)	Average total height (Feet)	Mean annual height growth (Feet)	Site index based on age 25 (Bennett *et al.*, 1959) (Feet)
20	6.1	110	30.4	2.53	53
21	6.5	80	32.0	2.67	55
22	6.6	90	34.0	2.83	58
23	5.5	110	30.6	2.55	53
24	6.6	80	27.7	2.31	47
25	7.2	120	34.1	2.84	58
26	6.4	100	33.2	2.76	57

Plantation E: Located on the North Louisiana Hill Farm Experiment Station, 2 miles southwest of Homer, Louisiana, latitude 32°45'N, longitude 93°04'W. This plantation was established for experimental purposes and was 11 years old at time of sampling. The stand is located on rolling Coastal Plain material made up predominantly of Ruston, Kirvin, and Shubuta soils. Soil textures are primarily silt loams.

Average annual rainfall is about 49 inches. Precipitation is greatest in winter and spring. Mean annual temperature is 66°F. Stand characteristics of the plots taken in Plantation E are shown below.

Plot	Average DBH (Inches)	Basal area per acre (Sq.ft.)	Average total height (Feet)	Mean annual height growth (Feet)	Site index based on age 25 (Bennett *et al.*, 1959) (Feet)
27	5.6	80	29.6	2.69	57
28	5.2	60	28.2	2.56	54
29	6.0	90	30.4	2.76	57
30	5.0	90	28.0	2.54	54
31	5.3	110	29.8	2.71	57
32	5.5	100	28.4	2.58	54
33	5.5	90	30.3	2.76	57

Climatographs for the areas in which sample plantations are located are shown in Figure 2. The climatographs are based on long-term means of temperature and precipitation for the United States Weather Bureau's climatic divisions in which the plantations are located. Mean temperature and precipitation for these divisions are derived from data covering

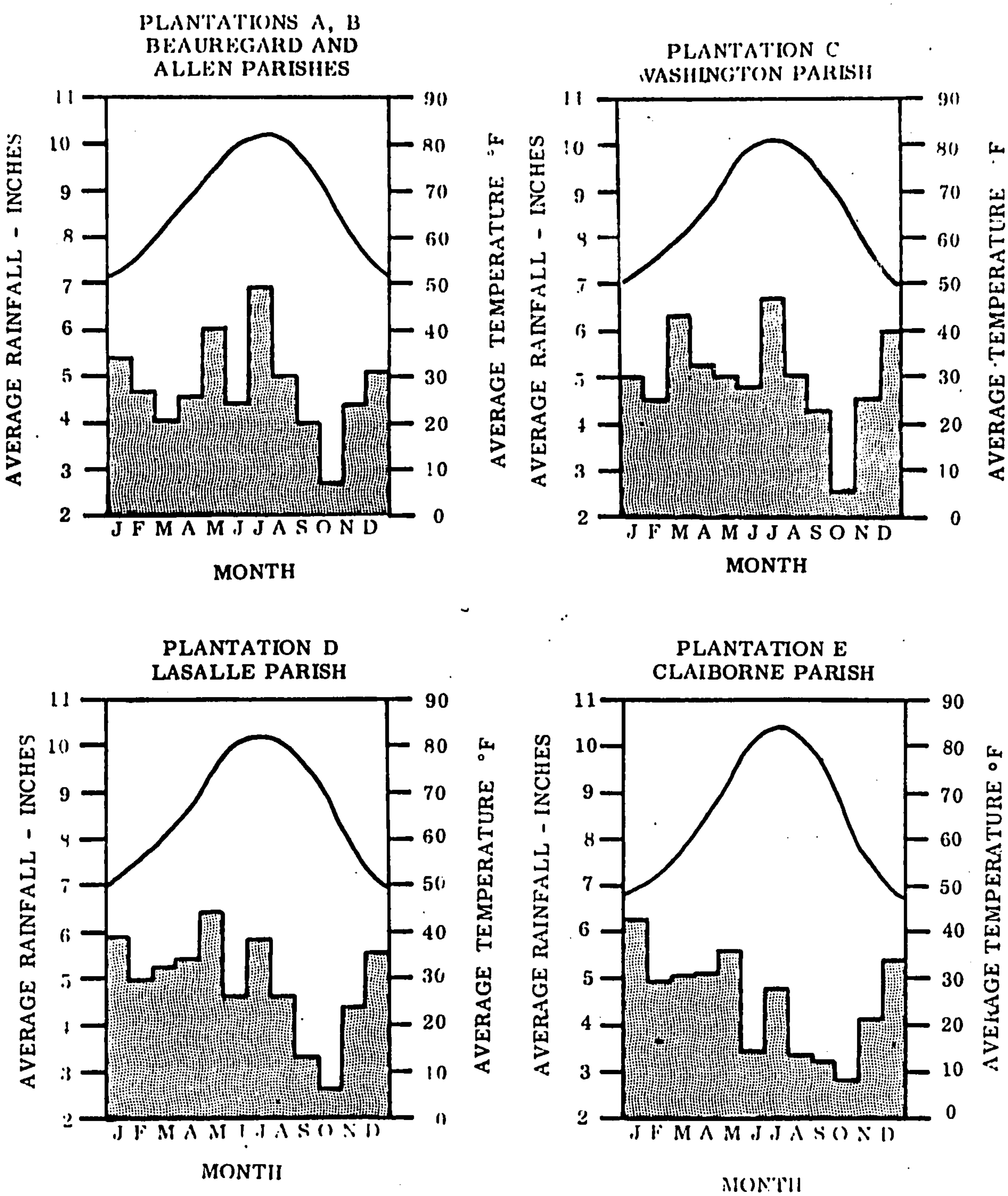


Figure 2. Climatographs for the five areas where the study plantations are located

1931 to 1955. Plantations A and B are in the west-central division. Plantation C is in the east-central division; Plantation D is in the central division; and Plantation E is located in the north-central division. Monthly precipitation and mean monthly temperatures for each plantation are shown in Appendix A.

Field Procedures

Sample Plots and Tree Measurements

The field data were collected in the winter of 1958-1959. Within each plantation, from 5 to 8 sites were located to maximize the height differential among the samples. A one-tenth acre sample plot was randomly located on each site. A total of five measurement trees were mechanically selected on each plot. The dominant or codominant tree closest to the plot center was the first sample tree. Four additional trees were then selected in the cardinal directions from the central tree at the edge of the radius for a tenth-acre plot (37.24 feet).

Past annual height growth of each tree was determined by measuring length of the internodes as described earlier by Curlin and Box (1961). By modifying the technique of Wakeley and Marrero (1958), Curlin and Box were able to reconstruct 8 to 10 years of past annual height growth from 15-year-old slash and longleaf pine trees with an average error of $\pm$ 0.28 feet.

An extendable aluminum measuring pole with a maximum extended length of 45 feet was used for the measurements. A 50-foot metallic cloth tape graduated in feet and tenths of feet was attached to the end of the pole with the zero end at the top. Measurement was done by a two-man crew: one man holding the pole against the tree, the other acting as tallyman. The tallyman stood back at a distance that enabled

him to identify each successive internode. The poleman then raised the pole until the tip was even with the terminal bud of the tree and read the tape at a reference point marked on the body of the pole. On instruction from the tallyman, the pole was lowered until the tip of the pole was even with the primary whorl of branches which represented the end of the previous year's growth. The tape was again read at the reference point. The difference between the two readings represented the growth which occurred in the year the internode was formed. This procedure was repeated on each tree for six successive years' growth, i.e. 1954 through 1959.

Data were recorded in the field on IBM Port-a-punch cards for future processing. In addition to height data, stand age estimated by increment borings, basal area per acre measured by angle gauge at the plot center, and original tree spacing were recorded for each plot.

Soil Samples

Soil pits were dug at the center of each plot. Undisturbed soil samples were taken in duplicate at successive 6-inch intervals until an impermeable layer was struck or until a depth of 42 inches was reached. A soil auger was then used to bore an additional 18 inches to detect an impermeable layer, if present at that depth. A soil sampler similar to the one described by Uhland and O'Neal (1951) was used for extracting the cores, which were retained in brass tubes holding approximately 200 cc. of soil. Samples were carefully sealed and preserved for laboratory analysis.

Laboratory Analyses

Wilting Point and Field Capacity

In the laboratory one undisturbed core from each 6-inch soil layer

was subdivided into four soil "pats" approximately 1/4-inch thick. Care was taken not to disturb the soil excessively. Each soil "pat" was placed in a 1.5-inch retaining ring for subsequent tension analysis to determine the upper and lower soil moisture constants.

Paired samples thus contained in rings were placed in a pressure plate extractor and pressure membrane extractor for the determination of field capacity and wilting point, respectively. The tension apparatus used was described by Richards (1949). After being placed in the extractors, the samples were flooded with distilled water and allowed to soak until saturated. Excess water was then siphoned off, the extractors sealed and pressure applied.

Field capacity was approximated by exposing the duplicate samples in the plate extractor to 1/3 atmosphere (4.9 p.s.i.) of pressure. Time was allowed for moisture equilibrium to be reached in the saturated atmosphere of the sealed unit. This usually required from 24 to 48 hours. After that time the samples were removed from the extractor, placed in moisture tins, weighed to the nearest milligram and dried in an oven at a temperature of 105°C. for 48 hours. The samples were then allowed to cool in a dessicator, and oven-dry weight of soil was determined.

Wilting point was estimated in a manner similar to that used for field capacity. Duplicate samples were placed under 15 atmospheres (220.5 p.s.i.) of pressure in the membrane extractor. After the samples reached moisture equilibrium they were handled in the identical manner as those for field capacity.

Field capacity and wilting point were both expressed as a percentage of moisture on an oven-dry basis.

Bulk Density

Mass per unit volume of field density soil was determined from the second undisturbed soil core. The samples were oven dried at 105°C. for 72 hours, placed in a dessicator until cool and weighed to the nearest one-tenth gram.

Bulk density was computed as grams of oven-dry soil per cubic centimeter.

Particle-Size Distribution

Soil from the bulk density sample was later ground, passed through a 2 mm. sieve and subsampled for particle-size distribution analysis. The hydrometer method of Bouyoucos (1936) was used to determine the percentages of sand, silt, and clay in each sample.

Soil Moisture-Storage Capacity

Availability of soil moisture for use by plants is classically described in terms of soil moisture tension. This tension or negative pressure is dependent on surface forces and osmotic forces caused by solutes in the soil solution. Soil moisture tension and osmotic forces work collectively to prevent soil moisture from entering the roots. In nonsaline, unfertilized soils of the humid region, osmotic forces are generally small enough to be considered negligible. Surface forces, therefore, are major determinants of soil moisture-storage capacity. Since surface forces are largely functions of surface area, soil moisture-storage capacity is greatly dependent on soil texture.

Field moisture capacity is the amount of water remaining in a well-drained soil when the gravitational flow into unsaturated soil has, for all practicality, stopped. Permanent wilting point or percentage is the amount of water retained in the soil in which plants wilt and fail

to recover. By definition then, the upper level of moisture availability is field capacity and the lower level is the wilting point. Soil moisture-holding capacity is the water contained between these two points.

Soil moisture-storage capacity is generally expressed in linear units (inches of water per inch of soil) rather than in volume units. The total soil moisture-storage capacity was calculated for each plot in the following manner:

$$\text{Water depth (inches)} = \sum_{i=1}^{N} \frac{(FC-WP)(BD)(D)}{100}$$

Where:

FC = Field capacity, percent oven-dry weight

WP = Wilting point, percent oven-dry weight

BD = Bulk density of soil, grams per cubic centimeter

D = Depth of soil layer in inches

N = Number of soil layers sampled

Estimation of Available Soil Moisture

The Concept of Water Balance

Soil moisture is one of the most variable factors affecting plant growth. It is a cyclic phenomenon which is dependent on many direct and indirect factors. Simply stated, soil moisture is a balance between water delivered to the soil as precipitation and water removed from the solum by transpiration, evaporation, and gravitational flow.

Soil moisture data are expensive, difficult, and time-consuming to collect even with the best instruments. Data covering a period of time as long as the duration of this study are seldom available in even the best controlled field experiments. In this study, indirect, empirical

means were sought for making point estimates of past available soil moisture for the five study plantations covering the period 1953 to 1959. Since this study depended on the ability to estimate past soil moisture from measurable soil factors and climatological variables, it is necessary to briefly review the basis for such estimates.

The soil mantle acts as storage reservoir for soil water, retaining it until lost to evaporation, transpiration, or gravitational force. Thornthwaite (1948) and others have cited the analogy between soil moisture storage and a bank account. For this reason terms such as water balance, water budget, and moisture deficit have come into practical usage. A balance sheet of water losses (by evaporation, transpiration, run-off, and drainage) and accretions (by precipitation) gives a measure of the changes occurring in the moisture content of the soil. Several investigators have developed methods to estimate available soil moisture by calculating the water loss from meteorological records (Thornthwaite, 1948; Penman, 1948; Blaney and Criddle, 1950).

Penman (1948, 1949, 1956), by considering the energy balance and influence of wind and vapor pressure difference on the transfer of water vapor to the atmosphere, derived an equation which enables evaporation from a water surface to be calculated from mean air temperature, mean air vapor pressure, mean wind force, and mean duration of sunshine. The conversion of water loss from a free water surface to a vegetative surface was accomplished by using empirical reduction factors.

The complexity of Penman's approach is manifest in the number of factors and constants required for his solution. It is interesting to note that only 391 weather stations in the United States, including only three in Louisiana, record data for solution of the Penman formula.

Nevertheless, Penman's equation has been used to advantage in predicting agricultural drought in North Carolina, Alabama, and elsewhere (Van Bavel and Verlinden, 1956; Ward et al., 1959).

Thornthwaite pictured water loss from the soil as an integrated function of evaporation and transpiration. After detailed study, he concluded that air temperature, being closely correlated with solar radiation, was an adequate measure of the atmospheric demands for moisture when corrected for day length. The concept of potential evapotranspiration advanced by Thornthwaite (1948) indicated he believed, as did Richards and Wadleigh (1953), that moisture becomes progressively less available to the plant as soil moisture drops below field capacity. Ideally, potential evapotranspiration is the amount of water loss from a land mass completely covered with vegetation, if adequate soil moisture is present to supply the need.

Thornthwaite and Hare (1955) outline the major factors influencing potential evapotranspiration as being:

1. Solar radiation
2. Capacity of the air to remove vapor
3. Nature of the vegetation
4. Available soil moisture in the root zone

From these factors potential evapotranspiration (PE) may be expressed theoretically as:

$$PE = Ct^a$$

Where:

PE = Monthly potential evapotranspiration, cm.

t = Mean monthly temperature, degrees C.

C = Proportionality constant

a = A constant, small in cold climates, large in warm climates

Derivation of the constants and rearrangement of Thornthwaite's basic equation finally gives:

$$PE = 1.6\ (10t/I)^{a}$$

Where:

PE = Potential evapotranspiration per month

t = Mean monthly temperature

$$I = \text{Heat index} = \sum_{i=1}^{12} (t/5)^{1.514}$$

$$a = 0.49239 + 1792 \times 10^{-5}\ I - 771 \times 10^{-7} I^{2} + 675 \times 10^{-9} I^{3}$$

This formula is based on a standard 30-day month.

Mather (1950) concluded that the type of vegetation was not an important factor in potential evapotranspiration if the root zone was fully occupied. It was found in Canada that Thornthwaite's formula showed errors of as much as 40 percent on a daily basis, but were satisfactory when averaged over a weekly period or longer (Sanderson, 1948). Zahner (1956) stated that potential evapotranspiration can be underestimated by this method in the south-central United States, but it is sufficiently precise to use it in measuring the intensity of summer drought. Studies in Missouri indicated that Thornthwaite's formula gave estimates of evapotranspiration as good or better than those computed from Penman's more complex equation (Decker, 1961). Both methods gave acceptable results for the climate of that area.

Calculation of Available Soil Moisture

Climatological data were available on punched cards for all but one of the five weather stations used as a basis for the study. Weather data for the one station not on punched cards were key-punched from

climatological records published by the Weather Bureau (U.S. Department of Commerce, 1953-1959). The punched cards were part of the permanent weather records kept by the Weather Bureau, but were transferred to the Louisiana State University Agricultural Economics Department after being converted to magnetic tape at the Asheville, North Carolina records center. The punched cards contained daily records of precipitation and temperature taken at each of the 5 weather stations during the course of the study. These data cards formed the nucleus of all subsequent computations. The heat index (I) for each year, at each plantation, was computed from mean monthly temperatures using the tables of Thornthwaite and Mather (1957).

Collaborating with the staff of the computer center, a data processing program was written for the IBM 650 digital computer. The program incorporated the tables and used the formulae outlined by Thornthwaite and Mather (1957) in their manual "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance". Briefly the program did this: given daily precipitation, daily mean temperature, heat index (I), and soil moisture-storage capacity of the soil, the program computed and punched daily values of (1) potential evapotranspiration, (2) available soil moisture, (3) actual change in soil moisture, (4) soil moisture deficit or surplus, (5) gravitational water remaining in the soil, and (6) total amount of water remaining in the soil, including both available and gravitational. Program description and operating instructions are included in Appendix B. At about the same time this work was being done, Zahner (1961), at the University of Michigan, adapted Thornthwaite's methods to an IBM 709 data processing system.

Daily values obtained as output from the IBM 650 object program

were later processed and averaged into 10-day values by a secondary data assembly program. The 10-day periods began January 1 of each year and extended through 7 years (1953-1959). Organized in this manner, the final data gave 36 consecutive periods for each year, each period representing a 10-day average. One additional period at the end of the year contained the remaining five or six days as the case might be. The 10-day system has advantages over the weekly period in that averages of soil-moisture values are easier to compute, and it lends itself well to subsequent summarization into idealized 30-day months.

RESULTS AND ANALYSIS

Height Growth Data

A summary of mean annual height growth from the measurement plots is shown in Table 2. Detailed individual tree data are listed in Appendix C. From inspection of the data, it is obvious that differences in height growth do exist between years, but the range in magnitude of these differences is surprisingly small. This difference could reflect variance caused by environmental factors, age of tree, or a combination of both. Variation between plots during the same year, in some instances, appears large enough to have been caused by differences in site quality. To verify these impressions the data were analyzed by nested or hierarchel analysis of variance (Snedecor, 1956; Anderson and Bancroft, 1952).

The mathematical model used in the analysis was:

$$Y_{ijk} = \mu + \rho_i + T_{ij} + \epsilon_{ijk}$$

Where:

Y_{ijk} = Height growth on the ith plot of the jth tree

μ = General mean

ρ_i = Effect of the ith plot

T_{ij} = Effect of the jth tree in the ith plot

ϵ_{ijk} = Effect of the kth year in the jth tree of the ith plot

Table 2. Mean annual height growth of slash pine trees on 33 selected plots in Louisiana, 1954-1959

(In feet)

Plot	1954	1955	1956	1957	1958	1959	Average
			Plantation A, Beauregard Parish				
1	4.42	3.86	4.32	3.80	4.50	4.20	4.19
2	4.96	4.30	4.62	3.76	4.24	4.70	4.44
3	3.50	3.24	3.58	2.78	4.34	4.10	3.60
4	4.64	4.14	3.78	3.54	4.20	4.26	4.10
5	4.68	4.54	4.34	4.22	4.18	4.52	4.42
6	4.72	4.10	4.08	3.96	4.36	4.64	4.32
Average	4.50	4.04	4.13	3.68	4.31	4.41	
			Plantation B, Allen Parish				
7	4.16	4.08	3.38	3.12	2.72	3.46	3.49
8	4.10	3.62	3.82	3.10	3.08	3.56	3.55
9	3.48	3.30	3.64	3.22	2.94	3.38	3.33
10	4.24	3.68	3.82	3.18	2.98	3.70	3.61
11	2.98	2.90	3.70	2.48	3.08	3.14	3.05
12	3.56	3.50	3.74	3.30	3.46	3.92	3.59
13	4.24	4.26	4.08	3.80	3.78	4.40	4.10
14	2.70	3.36	3.60	3.98	4.02	4.16	3.64
Average	3.68	3.59	3.72	3.27	3.26	3.72	
			Plantation C, Washington Parish				
15	4.06	3.60	4.42	3.64	4.14	3.78	3.95
16	3.98	3.28	4.48	4.00	4.04	3.84	3.94
17	4.20	3.50	4.36	3.78	3.94	3.44	3.88
18	2.58	2.46	3.78	3.86	3.68	4.08	3.41
19	4.26	3.32	4.28	3.90	3.80	3.96	3.93
Average	3.82	3.23	4.26	3.84	3.92	3.82	
			Plantation D, LaSalle Parish				
20	3.26	4.14	3.76	3.32	3.18	4.06	3.63
21	3.52	3.64	4.34	4.02	4.04	4.18	3.96
22	4.38	3.78	4.58	3.48	4.50	4.02	4.13
23	3.54	3.36	4.22	3.72	3.82	3.54	3.71
24	2.98	2.54	3.72	3.72	4.10	4.06	3.53
25	4.34	3.82	4.22	3.90	3.80	3.80	3.99
26	4.16	3.52	4.32	3.80	3.64	3.64	3.86
Average	3.74	3.55	4.17	3.71	3.87	3.90	
			Plantation E, Claiborne Parish				
27	3.22	3.78	4.28	4.28	4.28	3.90	3.96
28	2.50	3.28	4.08	4.46	4.54	4.42	3.89
29	3.62	3.78	3.92	4.68	4.76	4.22	4.17
30	2.62	3.26	4.22	4.46	4.46	3.86	3.82
31	3.54	3.38	4.32	4.22	4.38	3.82	3.95
32	2.96	4.10	3.84	4.26	4.10	3.76	3.84
33	3.06	3.78	4.04	4.44	4.52	3.82	3.95
Average	3.08	3.63	4.10	4.40	4.44	3.98	

Source of Variation	Degrees of Freedom	Expected Mean Square
Plots	p-1	$\sigma_y^2 + 6\sigma_t^2 + 30\sigma_p^2$
Trees-in-plots	p(t-1)	$\sigma_y^2 + 6\sigma_t^2$
Years-in-trees	pt(y-1)	σ_y^2
Total	pty-1	

p, t, and y are number of plots, trees within each plot, and years within each tree, respectively.

Results of the analyses of variance are outlined in Table 3.

Small to moderate differences between height growth of plots in each plantation were reflected in the analysis, with the exception of the plots located in Claiborne Parish in northern Louisiana. Uniform response in height growth of the five trees making up the sample in each plot was manifest in low variance ratios of the "trees-in-plots" component of the analysis.

Years-in-trees variation was used as the estimator for error in the between-trees (trees-in-plots) comparison of the analysis. Average annual height growth and associated standard errors for each plantation is shown in Figure 3. Annual height growth follows the same general trend for all plantations, except Plantation E.

The Claiborne Parish location (Plantation E) appears to be an anomaly among the plantations selected for study. Characteristic trend lines for Plantations A through D oscillate about the mean. The trend line for Plantation E is well-defined, parabolic, and does not show the same pattern of erratic annual variation as do the rest.

Table 3. Results of nested analysis of variance for annual height growth data

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Level of significance
Plantation A, Beauregard Parish					
Plots	5	14.6	2.93	8.68	< 0.001P
Trees-in-plots	24	8.1	0.34	1.06	NS
Years-in-trees	150	47.8	0.32		
Total	179				
Plantation B, Allen Parish					
Plots	7	15.8	2.26	9.16	< 0.001P
Trees-in-plots	32	7.9	0.25	< 1	NS
Years-in-trees	200	75.6	0.38		
Total	239				
Plantation C, Washington Parish					
Plots	4	6.3	1.58	2.94	< 0.05P
Trees-in-plots	20	10.8	0.54	1.60	< 0.10P
Years-in-trees	125	42.2	0.34		
Total	149				
Plantation D, LaSalle Parish					
Plots	6	12.2	2.03	4.64	< 0.01P
Trees-in-plots	28	12.2	0.44	1.38	0.10P
Years-in-trees	175	55.6	0.32		
Total	209				
Plantation E, Claiborne Parish					
Plots	6	2.4	0.40	1.33	NS
Trees-in-plots	28	8.4	0.30	< 1	NS
Years-in-trees	175	89.7	0.51		
Total	209				

NS denotes probability greater than 0.20P

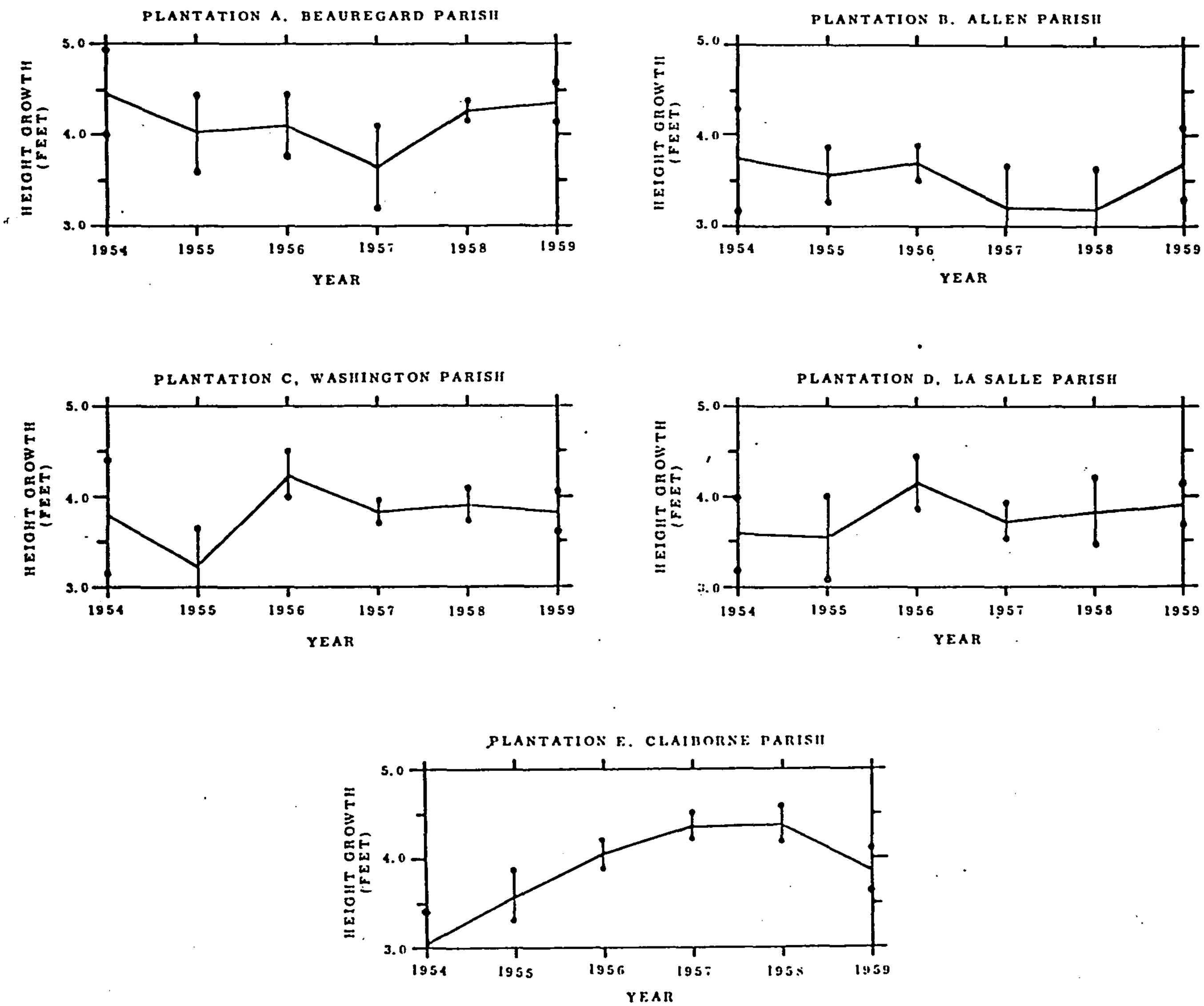


Figure 3. Average annual height growth and standard error of the mean for the five slash pine plantations, 1954-1959

Soil Moisture Data

Laboratory Analyses

Physical properties and soil moisture characteristics of the soils are shown in Appendix A; a summary of these properties is presented in Table 4.

It was found that the dependency of soil moisture constants on the texture of the soil studied is so strong that they can be estimated with fair precision from particle-size distribution alone (Curlin, 1960), thus verifying the results of Hill (1959). Polynomial and simple linear functions of the particle-size distribution analysis were fitted to the field capacity, wilting point, and available soil moisture data. The resulting prediction equations and correlation coefficients are shown below:

Field capacity	$Y = 32.936 - 0.333X_1$	$r = -0.870$
Wilting point	$Y = 1.216 + 0.295X_3 + 0.003X_3^2$	$r = +0.890$
Available soil moisture storage capacity	$Y = 0.290 + 0.289X_2$	$r = +0.761$

Where:

Y = Percent moisture by weight

X_1 = Percent sand

X_2 = Percent silt

X_3 = Percent clay

Correlation coefficients were all statistically significant at the 0.001 level of probability. These results were later corroborated by Barrett (1961) on similar soils in Louisiana. Bulk density, organic matter content, and the type of clay mineral in dominance also play an important role in determining the soil moisture constants and probably account for a large portion of the remainder of the unexplained variation.

Table 4. Gross characteristics of the soil profile at the 33 study plots.

Plot	Surface soil texture	Depth of root zone	Average soil moisture storage capacity/foot of depth	Total soil moisture storage capacity
		Inches	Inches	Inches
		Plantation A, Beauregard Parish		
1	sandy loam	60	2.018	10.09
2	sandy loam	60	1.866	9.33
3	loam	12	3.620	3.62
4	sandy loam	60	2.326	11.63
5	loam	60	2.178	10.89
6	silt loam	60	2.568	12.84
		Plantation B, Allen Parish		
7	silt loam	60	2.706	13.53
8	silt loam	60	2.960	14.80
9	silt loam	12	2.480	2.48
10	silt loam	60	2.818	14.09
11	silt loam	60	2.874	14.37
12	silt loam	60	2.806	14.03
13	sandy loam	60	1.684	8.42
		Plantation C, Washington Parish		
14	loam	60	1.942	9.71
15	sandy loam	60	1.592	7.96
16	loam	60	1.394	6.97
17	sandy loam	60	1.892	9.46
18	sandy loam	60	2.114	10.57
19	loam	60	1.950	9.75
		Plantation D, LaSalle Parish		
20	sandy loam	60	1.778	8.89
21	sandy loam	60	1.072	5.36
22	sandy loam	60	1.260	6.30
23	loamy sand	60	0.998	4.99
24	loam	18	2.500	3.75
25	loamy sand	60	1.032	5.16
26	sandy loam	60	0.758	3.79
		Plantation E, Claiborne Parish		
27	sandy loam	60	0.864	4.32
28	sandy loam	60	0.398	1.99
29	loamy sand	60	0.488	2.44
30	sandy loam	60	0.462	2.31
31	sandy loam	60	0.486	2.43
32	sandy loam	60	0.198	0.99
33	loam	60	1.212	6.06

To arrive at total available soil moisture-storage capacity, depth of the effective root zone must be taken into account. The effective root zone is that depth of soil in which plants are able to extract moisture. Obvious difficulties in working with plants as large as trees have discouraged direct studies of rooting patterns and maximum rooting depths of most species. No work in the literature establishes the maximum depth of penetration of slash pine roots, nor does it define the soil density which limits root growth.

Lack of information in defining the effective root zone is perhaps the weakest factor in this study. Meredith and Patrick (1961) artificially compacted samples of three Louisiana soils and studied the root penetration of sudan grass. Results showed that little penetration occurred above bulk density 1.60 in clay loams and 1.65 to 1.70 in sandy loams. Depth to which a root will grow and the maximum density of the material it can penetrate, is inherent in the plant. One cannot expect then to translate response of sudan grass to slash pine, but such studies do give indications of the limiting range of soil density. Florristall (1954) concluded that tree roots cannot penetrate bulk densities greater than 1.6 to 1.8. Critical density depends, however, on species involved, soil texture, and the moisture conditions of the soil. A study of the rooting characteristics of western white pine (Leaphart, 1958) indicated that a hardpan with bulk density of 1.6 or greater prohibited root penetration. Under the same conditions, lodgepole pine, Douglas-fir, and western hemlock roots were found growing in or beneath the same pan. Griffith (1960) reported that Douglas-fir roots readily penetrated sandy loam soils of bulk density 1.50. Armson and Williams (1960) presented evidence that root development

of red pine was severely reduced when the bulk density of sand was increased from 1.02 to 1.45.

It is evident that bulk density interacts with soil texture in restricting root growth, and that it is impossible to establish a limiting bulk density for all species and soil textures. In the absence of concrete information, bulk density of the soil was not considered limiting as long as the sampling tool was able to extract a core sample. Silt loam and loam soils generally sampled easily up to bulk density 1.7. Clayey soils became difficult to sample at 1.6. On plots 3, 9, and 24, the presence of an impermeable pan restricted soil sampling. The soils on these plots were loams and silt loams with bulk densities ranging from 1.51 to 1.57.

Most investigations of the depth of effective root zone have been indirect studies of the soil moisture regime through the growing season. Metz and Douglass (1959) observed moisture depletion to a depth of 66 inches under a young loblolly pine plantation. Zahner (1958) also reported water use by loblolly and shortleaf pine at depths of more than four feet. In New Jersey, moisture in a sandy soil was removed from depths of more than 10 feet under a pole-size stand of shortleaf pine (Lull and Axley, 1958).

Ample evidence exists that most southern pine species can utilize soil moisture from the upper five feet of the soil profile. A 60-inch depth was used as the maximum effective root zone in this study and available moisture data were computed on this basis, except for plots 3, 9, and 24, where a restrictive layer was present.

Soil moisture-storage capacities above five inches were rounded to the nearest even-numbered inch for use by the computer program. Those

below five were rounded to the nearest inch to conform with Thornthwaite and Mather's tables (1957).

Available Soil Moisture

Computed available soil-moisture values for the plot with the smallest and the plot with the largest storage capacity at each plantation for the period 1953 to 1959 are shown in Figure 4. These lines show the range in available soil moisture encountered at each plantation. Soil moisture cycles at all plantations are quite similar. In most cases, rapid depletion of soil moisture began between periods 10 and 14 (April 1 to May 10), proceeded erratically to the period of lowest soil moisture, which usually occurred during the 24th and 27th periods (August 18 to September 19), and finally the soil became fully recharged by the end of the calendar year.

Plantations in Claiborne, LaSalle, and Allen Parishes suffered their driest year in 1954. Beauregard Parish showed lowest soil moisture in 1956 and Washington Parish in 1957. At all locations, except Plantation D, LaSalle Parish, the wettest year was 1959. The wettest year at Plantation D was 1958.

Analysis of Height Growth

Age Trend

According to Baker (1950), the height growth pattern of forest trees occurs in three distinct stages: (1) that associated with juvenile development, (2) an intermediate stage, and (3) a period of deceleration.

Characteristics of juvenile growth vary with shade tolerance of the species and its environment. During this period slash pine, which is intolerant, exhibits rapid leader elongation soon after establishment of the tree. The juvenile portion of the growth curve is described by

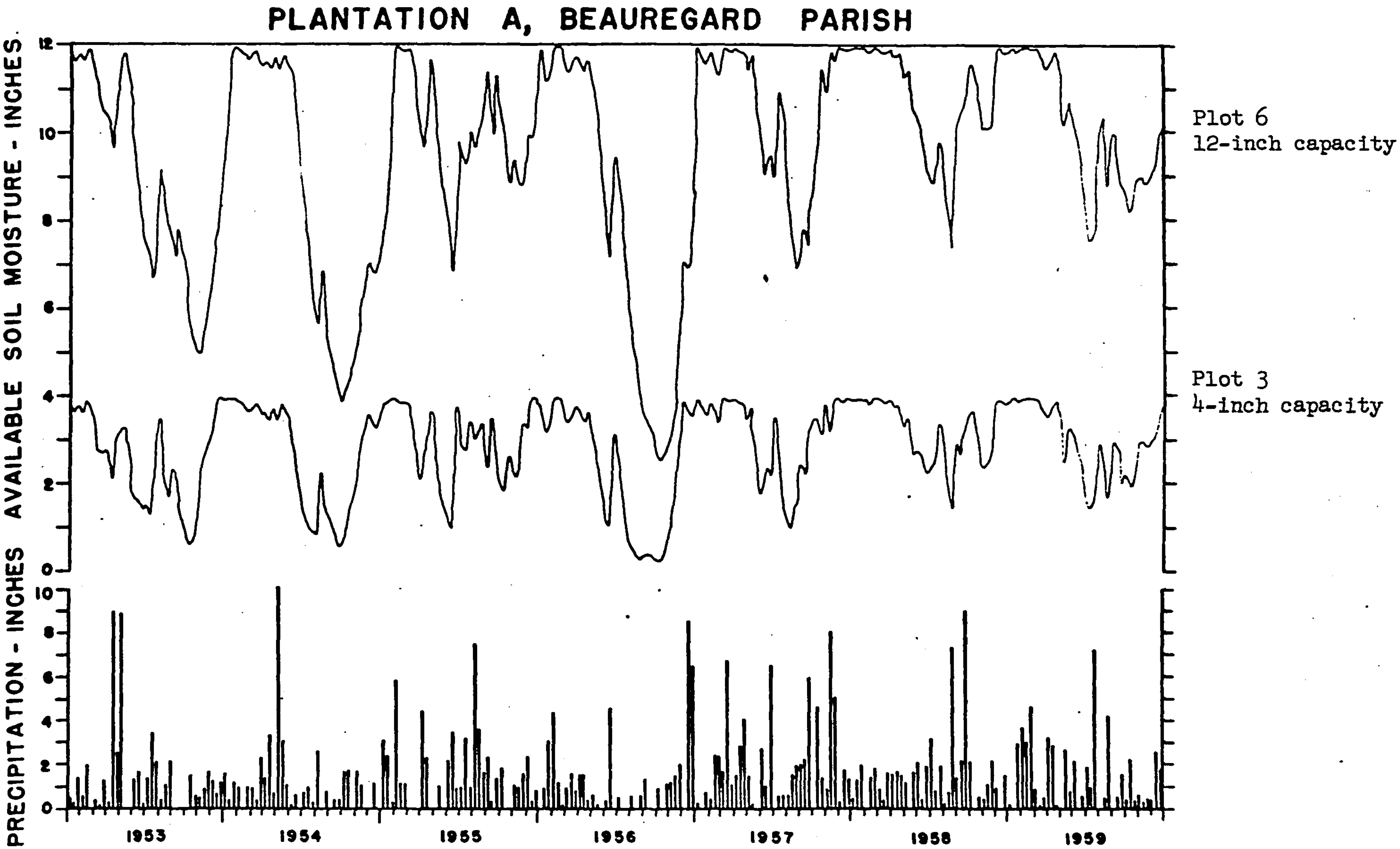


Figure 4. Precipitation and available soil moisture for plots with the largest and smallest available soil moisture-holding capacity at the five plantations for the years 1953 to 1959

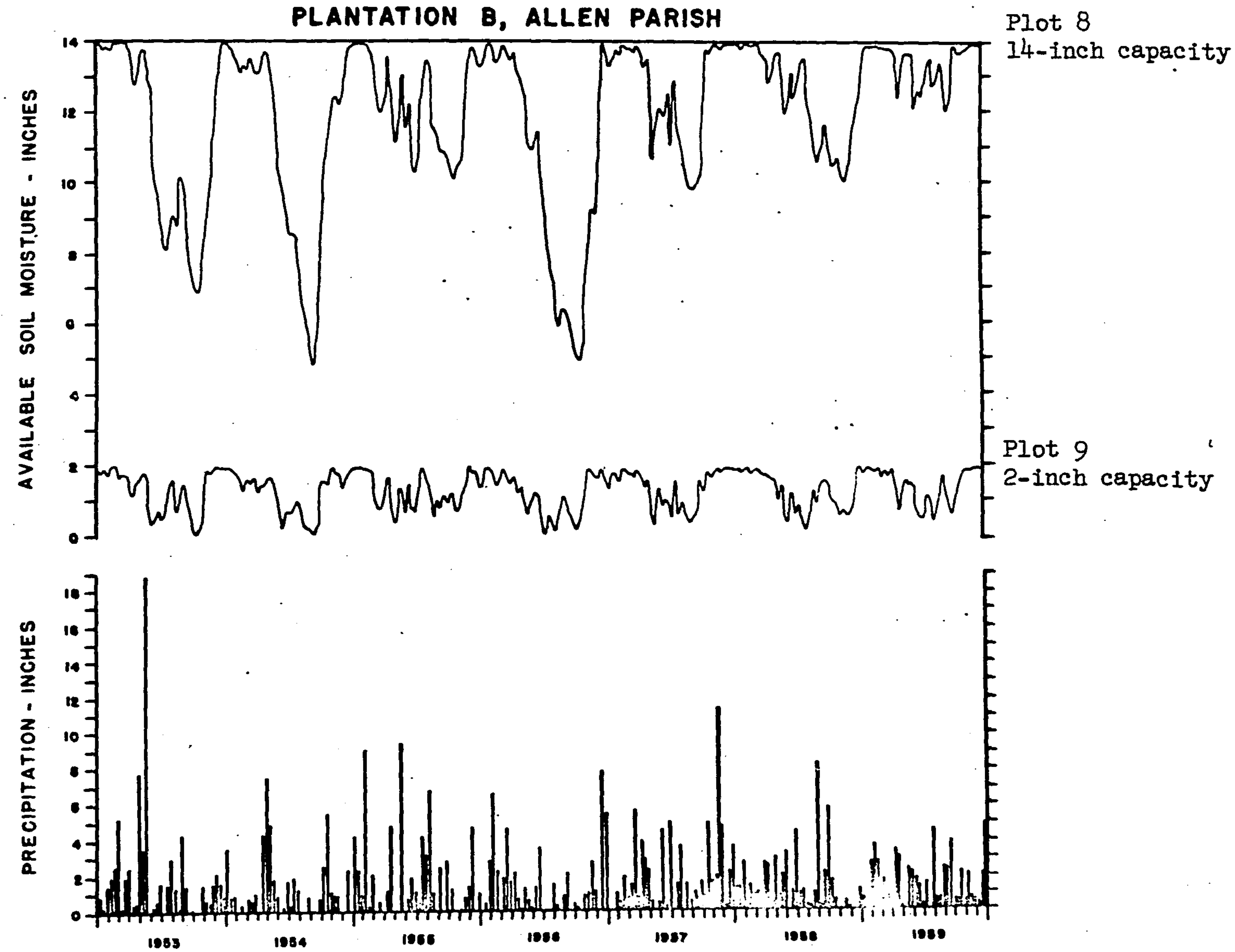


Figure 4. (Continued) Precipitation and available soil moisture for plots with the largest and smallest available soil moisture-holding capacity at the five plantations for the years 1953 to 1959

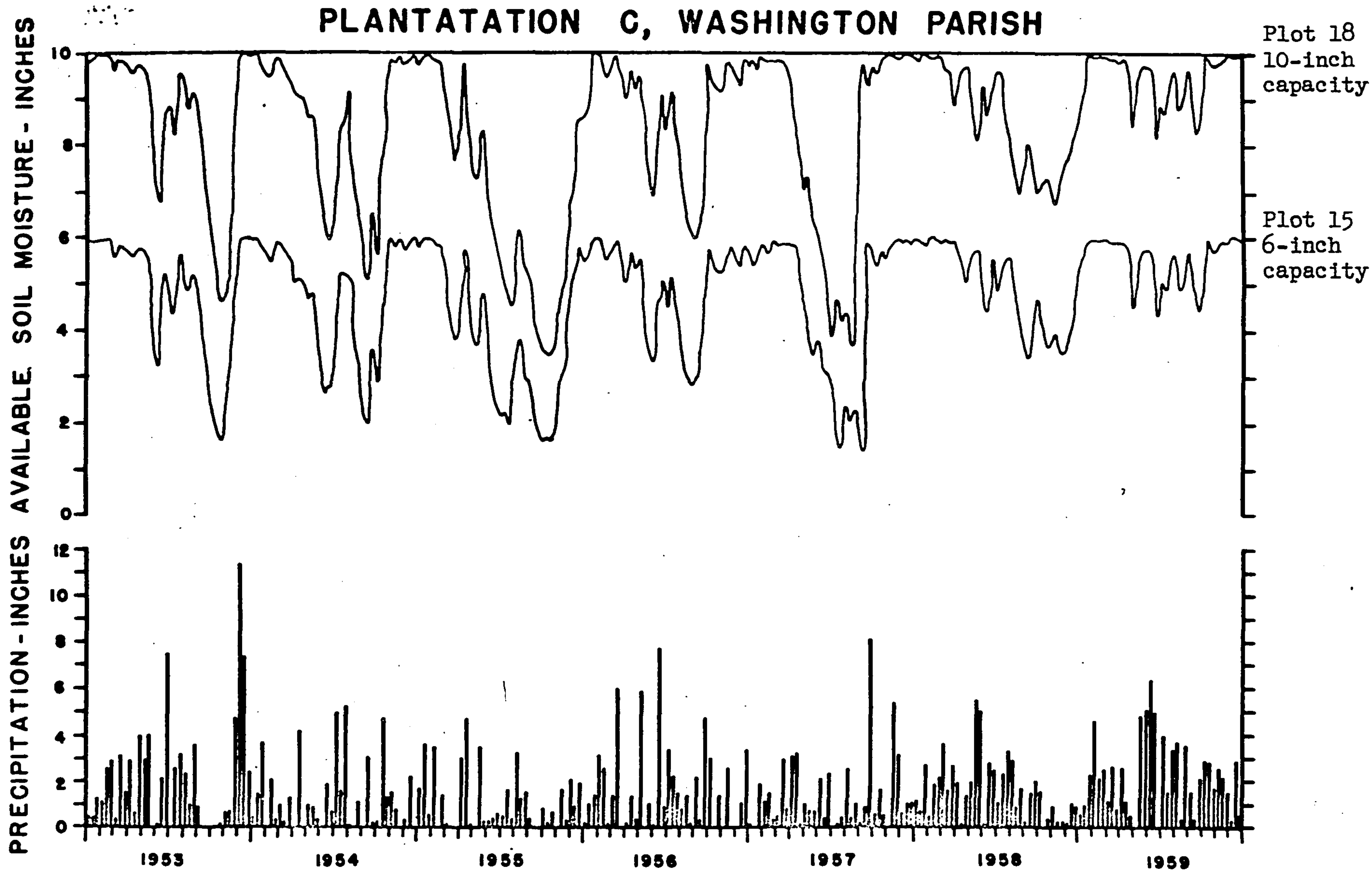


Figure 4. (Continued) Precipitation and available soil moisture for plots with the largest and smallest available soil moisture-holding capacity at the five plantations for the years 1953 to 1959

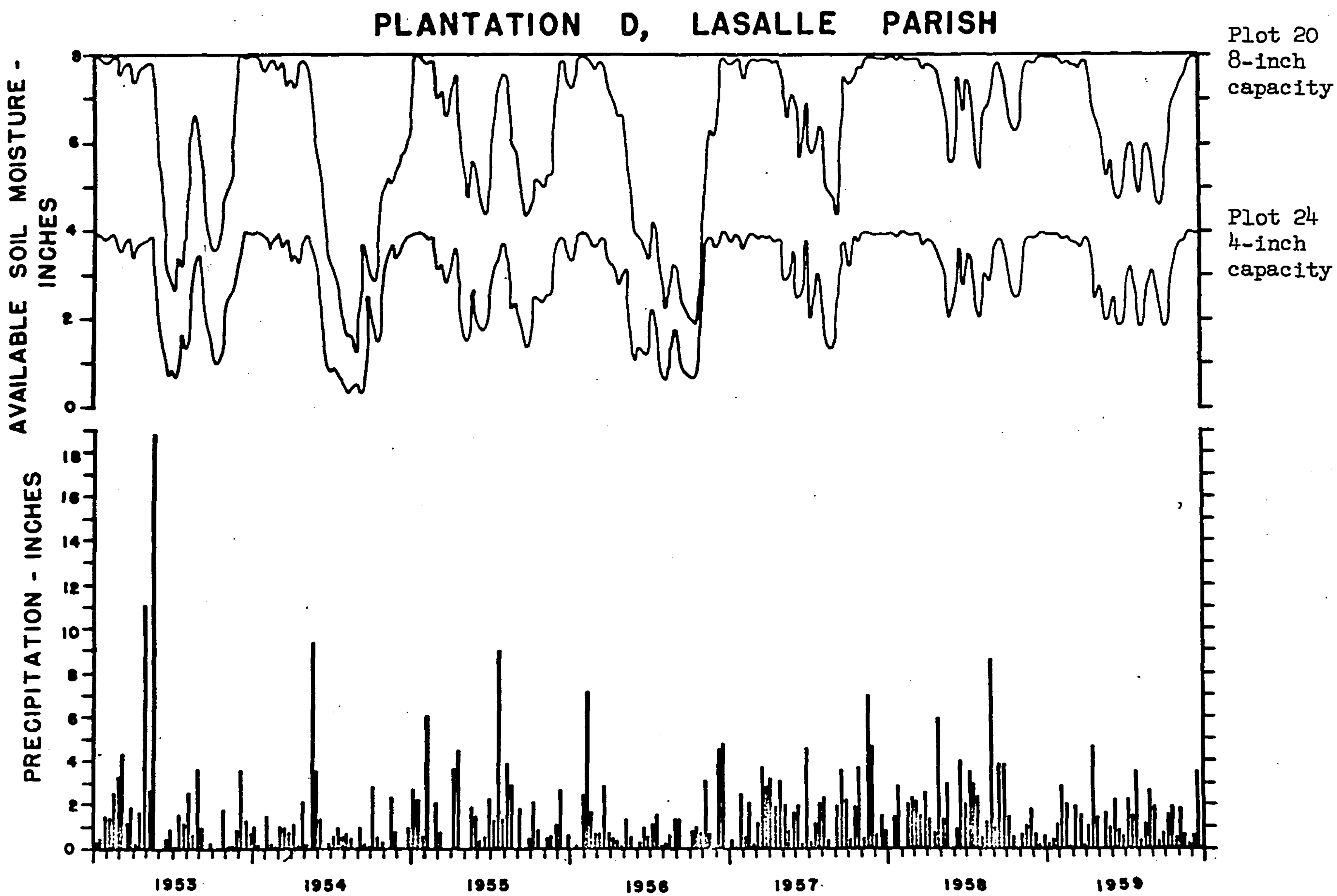


Figure 4. (Continued) Precipitation and available soil moisture for plots with the largest and smallest available soil moisture-holding capacity at the five plantations for the years 1953 to 1959

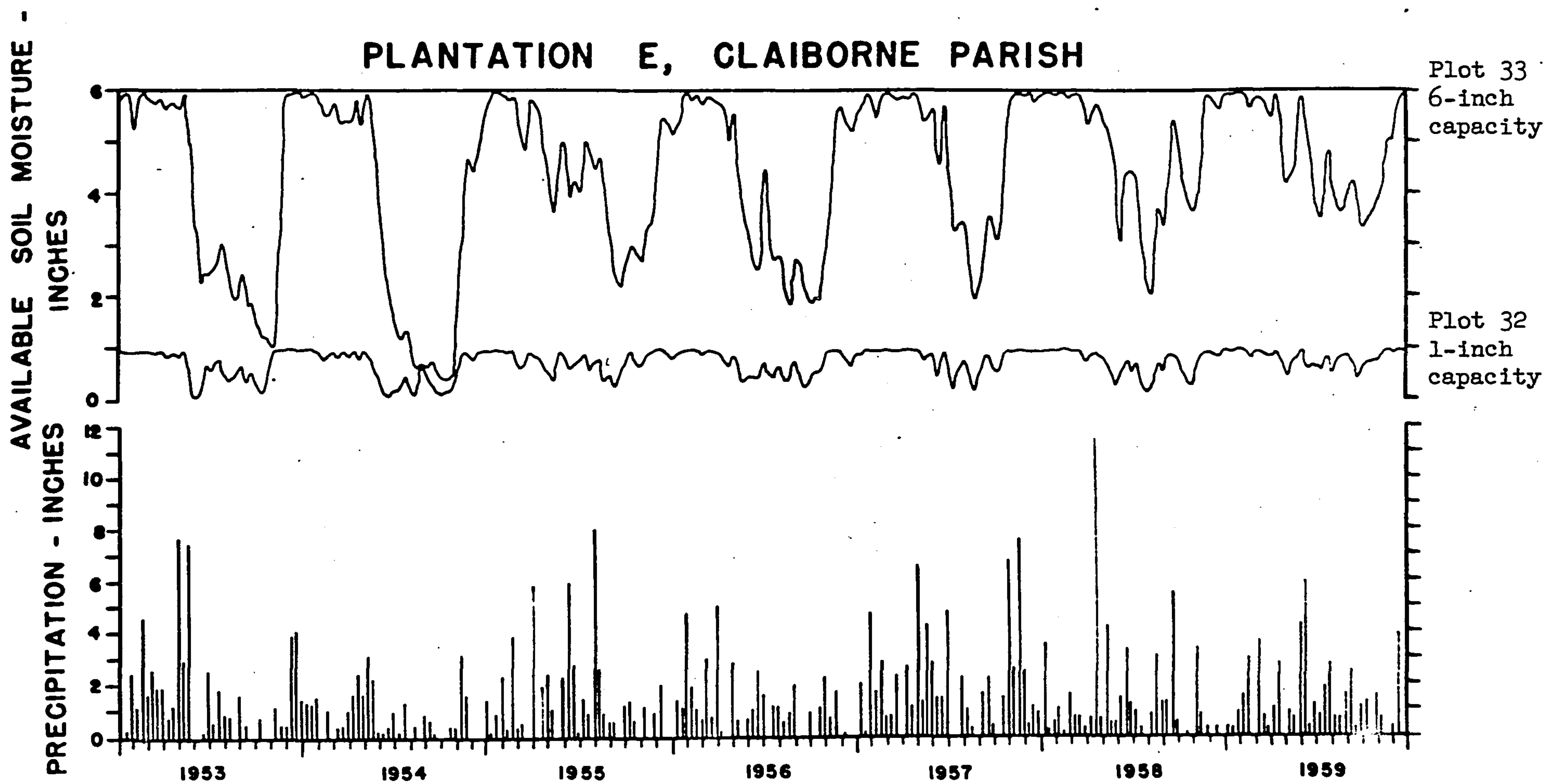


Figure 4. (Continued) Precipitation and available soil moisture for plots with the largest and smallest available soil moisture-holding capacity at the five plantations for the years 1953 to 1959

the compound interest function and is exponential in form (Baker, 1950).

The period of acceleration in the juvenile stage passes into the intermediate stage in which growth is approximately constant year to year, and is at a maximum; thus the equation describing this period of growth is linear in form. Annual height growth is maximum during the intermediate phase of development. Length of this period of sustained, rapid growth is difficult to determine because no distinct transition to the next stage is apparent.

The period of deceleration marks maturing of the tree. During this stage, the growth curve assumes a form described by Weber's formula (Büsgen and Münch, 1929). In its simplest form it is identical to the formula of the law of the minimum (Mitscherlich, 1909).

Composited, characteristic equations for the three stages of growth; juvenile, intermediate, and deceleration stage, form the integrated sigmoid function often associated with biological phenomenon.

If one mathematically differentiates the height-age curve described above, a picture of annual height growth in relation to age is obtained. Czarnowski (1961) stated, "During its first years the tree grows slowly in height, but growth increases every year up to a certain maximal value; afterwards, growth diminishes rather suddenly for a few years and then fades constantly and gently". The age at culmination of annual height growth occurs at a relatively young age, later on poor sites than on good sites. Czarnowski showed that the height growth of loblolly pine culminated at the age of 5 or 6 years on the best sites and up to 11 years on the poorer sites; however, he did not present data for slash pine.

Bennett (1963) observed that slash pine planted on an average

old-field site (site index 65, 25-year basis) in south-central Georgia, grew only 0.50 to 0.75 feet the first year, 2.0 feet the second year, and about 3.0 feet the third and fourth years. During the fifth, sixth, and seventh years, 4.0 feet or more height growth was added, while growth declined to about 3.5 feet during the eighth and ninth years. Over a 10-year period (age 10 to 20), height growth declined approximately 50 percent. There are indications that this decline in growth can be expected to continue until little effective height growth is realized after age 35 (Bennett, 1960). Bennett's data seems to support Czarnowski's theory (Czarnowski, 1960) of the age-height growth relationship.

While it is recognized that the age of the tree and stage of growth have profound effects on height increment, it was not possible to adjust the height data of this study for these differences in age because of the narrow range of age classes sampled in each plantation, and the confounding effect of environment (Figure 3).

The effect of the age factor was reduced by analyzing the effects of soil moisture on height growth separately at each location, thereby restricting the age range to 6 years. This also minimized the influence of secondary factors not pertinent to this study by restricting them to the range encountered at a single location and eliminating the confounding effect inherent in a pooled analysis.

Seasonal Course of Height Growth

The pattern of seasonal height growth of slash pine is similar to that of loblolly pine (Williston, 1951). Bennett (1956) reported that approximately 55 to 60 percent of the height growth of slash pine growing in southern Georgia was completed by April 30, and 68 to 77 percent was

completed by May 31 in 1953 and 1954. Only 10 to 20 percent of the growth occurred after June 30.

Smith (1960) observed that in 1953 to 1955 height growth of slash pine in southern Mississippi began between March 1 and March 15. Growth was 55 percent completed by May 1, 90 percent by July 1, and 95 percent completed by August 1.

Records of 2-, 3-, and 4-year-old slash pine in Georgia showed that 25 percent of the height growth was completed by the end of March, 52 percent by the end of April, 85 percent in June, and by mid-August, 95 percent of all height growth had occurred (Bennett, 1963). No measurements were made after October 31 and it was assumed that height growth was completed by that time. Only about one percent of the total growth occurred in October.

It has been noted that South Florida slash pine grows throughout the year (Langdon, 1963). The greatest proportion of the annual height growth (55 percent) occurred in the period from March through May. The amount of height growth was about the same in the summer-fall season (June to November, 22 percent), and in the winter season (December to February, 23 percent).

It is probable that height growth was completed by November at all of the plantations sampled in this study. However, the analysis of the soil moisture was extended through the end of the growth year to insure that the total growth period was included.

Height Growth - Soil Moisture Interaction

Analytical Approach

Regression analysis is particularly well adapted to interpretation of experimental results from biological studies. Multiple regression

analysis is, however, severely limited by restrictions and assumptions which must be satisfied for valid analysis. In the derivation of the simultaneous normal equations used in the least squares solution it is assumed that the independent variables are fixed variates, drawn from a normal population and are measured without error. In actuality the residual errors are inherited by the dependent variable because it is predicted from other variables. To illustrate the problem take the case of a simple linear two-variable relationship---there are two possible solutions for the experimental data of X and Y. First is a regression of Y on X with residual errors associated with Y:

$$Y = \alpha + \beta X$$

Second is the regression of X on Y with errors associated with X:

$$X = \alpha + \beta Y$$

An equation can be developed which predicts Y from X with a minimum mean square error. Similarly by interchanging X and Y, an equation can be evaluated which predicts X from Y, also with minimum mean square error. Seldom with biological data will the resulting regression coefficients of the two mathematical solutions be identical, because the residual errors are associated with different regression components, and these components are not measured without error as specified in the basic assumptions of regression analysis.

A second premise, probably the most important, is the assumption that the so-called independent variables are not intercorrelated with each other. The consequences of intercorrelations were discussed by Anderson and Bancroft (1952); they concluded that it was invalid to make significance tests of contributions of individual factors if intercorrelation was high and that the prediction equation could only be treated as a whole. Case examples of the seriousness of the problem

are manifest in work of Koelzer and Ford (1956) and Sharp *et al*. (1960). Both implied that high correlation between independent variables may result in an apparent lack of consistency such as sign reversal and unreasonable magnitude of regression coefficients. In this event the coefficients of the various terms are not estimates of the independent contributions of those terms, because the terms themselves are not independent.

In biological studies we are more often interested in the causative factors of an occurrence, rather than the prediction of the magnitude of the occurrence. What is needed in this case is a solution in which the coefficients are weighting factors for each term. The structure of the equation is more important than the accuracy of the predicted value.

A sophisticated statistical technique was developed by Wishart (1928) which partially overcomes the disadvantages of regression analysis in evaluating the interdependence of a set of variates---it is called *multivariate analysis*. More specifically, the branch of multivariate analysis used for exploring the association of variables is *component analysis*.

Multivariate analysis has had little use in practical problems, mainly because of the complexity of the mathematics involved. Kendall (1957) cites several examples where this approach has been used successfully in education, agriculture, sociology, medicine, physics, and the behavioral sciences.

The multivariate approach is based on recognition of the correlations among the independent variates. It also provides for distributing the error among all variates, rather than associating it completely with the dependent term. A component analysis is performed on the correlation

matrix of the independent variables, and this identifies all the truly independent (orthogonal) variates that are present. This is accomplished, in the terminology of matrix algebra, by finding the corresponding roots and vectors of the characteristic equation of the matrix of correlation coefficients. The resulting roots and vectors define new and mutually independent variates. Kendall (1957) and Snyder (1962) have shown how this technique may be used to evaluate equations of relationship to the original measured variates. The magnitude of the coefficients of the variates in these equations are then actual estimates of the independent contributions of the individual variables.

The first step in multivariate analysis is the conversion from the normal distribution of the original variates to the standard normal distribution with mean zero and unit variance, i.e. with $\mu = 0$ and $\sigma^2 = 1$. According to Ostle (1960), any normal distribution may be transformed to the standard normal by means of the equation:

$$Z = \frac{Y - \mu}{\sigma}$$

Where Y is the variable that is normally distributed with mean μ and variance σ^2, then Z is normally distributed with mean zero and variance one. The correlation matrix is calculated from these standardized data. By computing the determinant of the correlation matrix, the so-called characteristic equation is derived. This equation is the source of the characteristic roots and vectors commonly called eigenvalues and eigenvectors. Eigenvectors can then be used to compute the component of each of the original variates that are present in the newly computed orthogonal variate. In effect, the number of variables is reduced by discarding the linear combinations which have small

variances so that those with large variances may be identified for further study. Variables with low variance contribute little in explaining the reaction of the dependent factor.

The final equation produced by multivariate analysis, after conversion back to the original variates, is quite similar to the equation arrived at by regression analysis if high correlation does not exist among the independent variates. The added feature of reducing the effect of intercorrelation by use of multivariate analysis is gained at the cost of a decrease in the multiple correlation coefficient (R). Regression analysis gives the best least squares fit to the experimental data; multivariate analysis sacrifices the precision of fit for suppression of the adverse effects of intercorrelation.

Analysis of the 36 Soil Moisture Periods

Correlation analysis of the independent variables did indeed reveal high positive intercorrelation (Table 5). Intuitively one would expect this high degree of association, since soil moisture of one 10-day period profoundly affects the soil moisture of the following period. The wider the spread of time between periods, the lower the correlation.

The data were separated by plantation, and linear multivariate analyses were performed on the soil moisture data for the year prior to growth and the growth year. Analysis was carried out on an IBM 704 data processing system using Share 704 program "TVFPCPE Principal Components Prediction Equation 1168". This program uses the same linear model as most multiple linear regressions:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \ldots \beta_k X_k$$

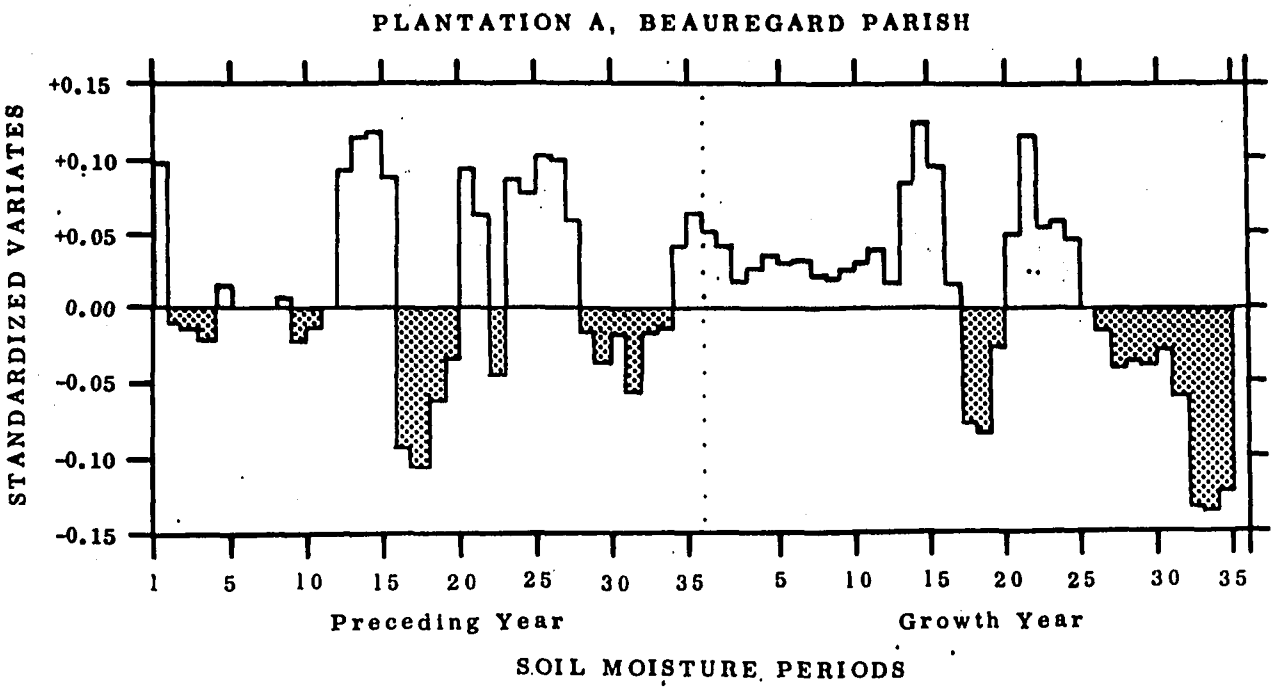
Where Y is annual height growth and $X_1 \ldots X_k$ are average soil moisture levels for the 36 soil moisture periods.

Results of these analyses are summarized in Figure 5. The relative

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	.942	.934	.928	.928	.939	.964	.965	.965	.955	.878	.964	.978	.965	.947	.951	.848	.806
2		1	.996	.993	.991	.997	.989	.963	.944	.971	.959	.989	.939	.915	.902	.895	.959	.838
3			1	.999	.995	.997	.989	.968	.949	.975	.963	.989	.930	.896	.875	.869	.971	.904
4				1	.996	.992	.987	.967	.948	.973	.966	.987	.921	.885	.863	.854	.976	.901
5					1	.990	.979	.955	.935	.960	.948	.979	.919	.893	.878	.853	.969	.870
6						1	.990	.964	.944	.973	.957	.989	.941	.909	.889	.890	.959	.909
7							1	.990	.980	.993	.964	.999	.963	.924	.904	.918	.942	.902
8								1	.997	.996	.959	.989	.957	.904	.881	.911	.920	.894
9									1	.991	.946	.979	.956	.899	.878	.916	.895	.877
10										1	.975	.991	.947	.891	.871	.910	.937	.919
11											1	.963	.867	.804	.793	.838	.969	.935
12												1	.964	.928	.907	.917	.940	.895
13													1	.983	.961	.966	.825	.807
14														1	.987	.955	.775	.712
15															1	.965	.760	.666
16																1	.763	.756
17																	1	.912
18																		1

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	.773	.649	.652	.579	.464	.545	.431	.463	.468	.477	.463	.488	.563	.570	.663	.613	.673	.778
2	.866	.798	.786	.744	.684	.673	.600	.586	.464	.528	.556	.554	.618	.658	719	.724	.802	.854
3	.878	.796	.778	.722	.672	.656	.587	.576	.533	.515	.541	.542	.603	.652	.721	.727	.812	.884
4	.871	.786	.761	.704	.657	.633	.565	.551	.507	.489	.518	519	.578	.632	.707	.712	.739	.884
5	.848	.786	.782	.735	.671	.649	.590	.566	.512	.478	.502	.492	.556	.605	.686	.701	.735	.881
6	.891	.814	.804	.749	.699	.694	.621	.616	.578	.561	.584	.586	647	689	.744	.753	.832	.878
7	.869	.765	.736	.660	.599	.630	.533	.547	.533	.535	.550	.566	.628	.662	742	.718	.789	.856
8	.849	.722	.671	.558	.497	.568	.452	.488	.495	.513	.518	.545	.603	.632	.742	691	.754	.848
9	.828	.695	.637	.511	.443	.540	.413	.459	.481	.506	.505	.536	594	.615	.737	.671	.728	.828
10	.880	.768	.709	.593	.545	.613	.501	.533	.539	.556	.570	.591	.645	.676	.775	.732	.786	.858
11	.895	.822	.731	.619	.610	.640	.547	.556	.548	.557	.600	.607	.645	.695	.785	.762	.798	.854
12	.859	.751	.723	.657	.594	.615	.519	.530	.513	.516	.532	.550	.614	.648	.726	702	.775	.847
13	.777	.644	.661	.615	.507	.570	.454	.489	.492	.505	.491	.524	.603	.606	.670	626	.705	.760
14	.686	.574	.629	.652	.514	.532	.432	.439	421	.420	.407	.432	.525	.522	.564	.534	627	.674
15	.646	.587	.643	.669	.513	.560	.458	.456	.440	.427	.416	.423	.515	.500	.556	524	602	.629
16	.736	.658	661	607	.491	.621	.485	.531	.561	.584	.570	.595	.668	.643	.702	.638	.671	.655
17	.886	.838	.782	.699	.691	.655	.607	.579	.526	.498	.547	.531	.572	.643	.724	.746	.814	.891
18	.985	.864	.772	.608	.662	.704	.621	.670	.675	.704	.737	.764	.785	.840	.877	.871	.897	.902
19	1	.919	.853	.682	.735	.796	.728	.775	.774	.789	.815	.825	.845	.894	.916	931	.953	.915
20		1	.956	.796	.832	.929	.894	.901	.875	.837	.873	.821	.829	.866	.898	953	.950	.845
21			1	.911	.900	.961	.956	.938	.876	.803	.821	.755	.784	.811	.811	.902	.938	.818
22				1	.959	.854	.893	.806	.686	.588	.629	.559	.614	.648	.567	.702	.775	.643
23					1	.863	.915	.837	.720	.638	.701	.640	.670	.725	.611	.761	.809	.649
24						1	.974	.985	.955	.896	.908	.844	.859	.861	.838	.915	.903	.703
25							1	.973	.904	.816	.839	.756	.768	.788	.736	.858	.865	.663
26								1	.974	.917	.919	.859	.864	.866	.831	.916	.900	.687
27									1	.979	.967	.927	.923	.905	.891	.829	879	652
28										1	.987	.976	.970	.946	.926	.929	.856	.622
29											1	.985	.975	.967	.930	.946	869	.627
30												1	.992	.982	.935	.928	.848	.616
31													1	.988	.639	.932	.868	644
32														1	.948	.958	908	.707
33															1	.972	925	.804
34																1	.974	.833
35																	1	.916
36																		1

Table 5. Typical correlation matrix of the 36 soil moisture periods



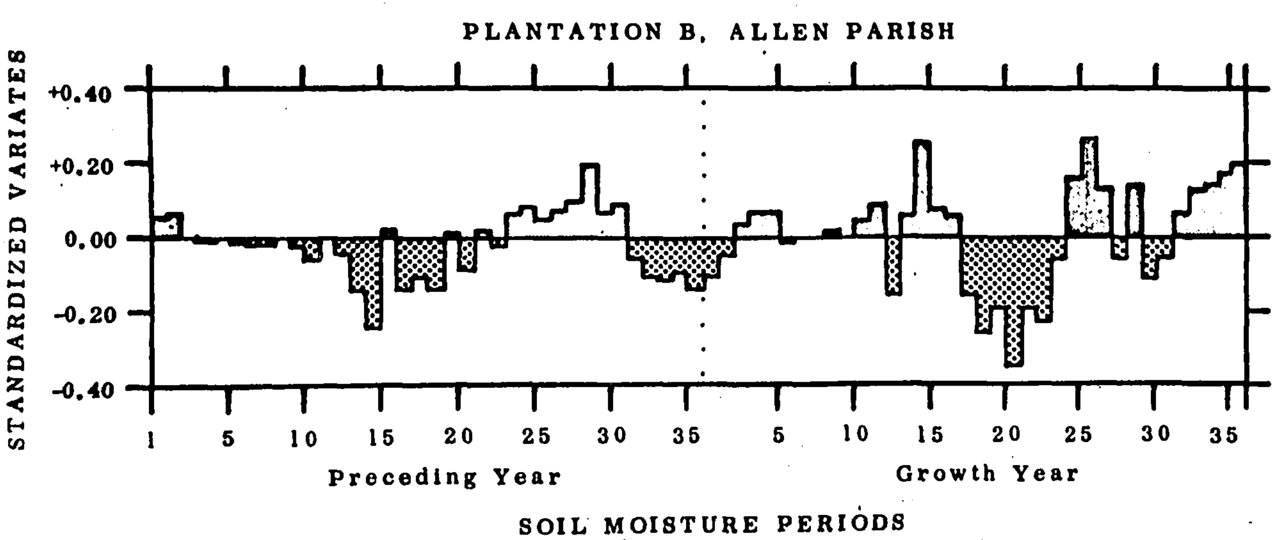
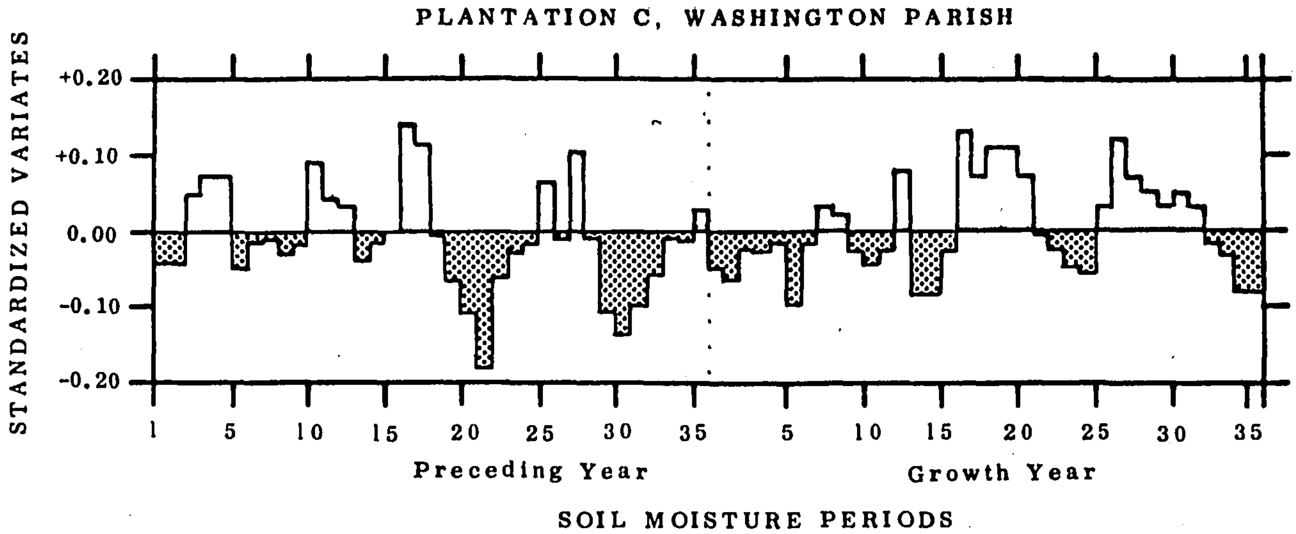


Figure 5. Standardized variates of the principal components prediction equation for 10-day soil moisture periods (Period 1 begins January 1)



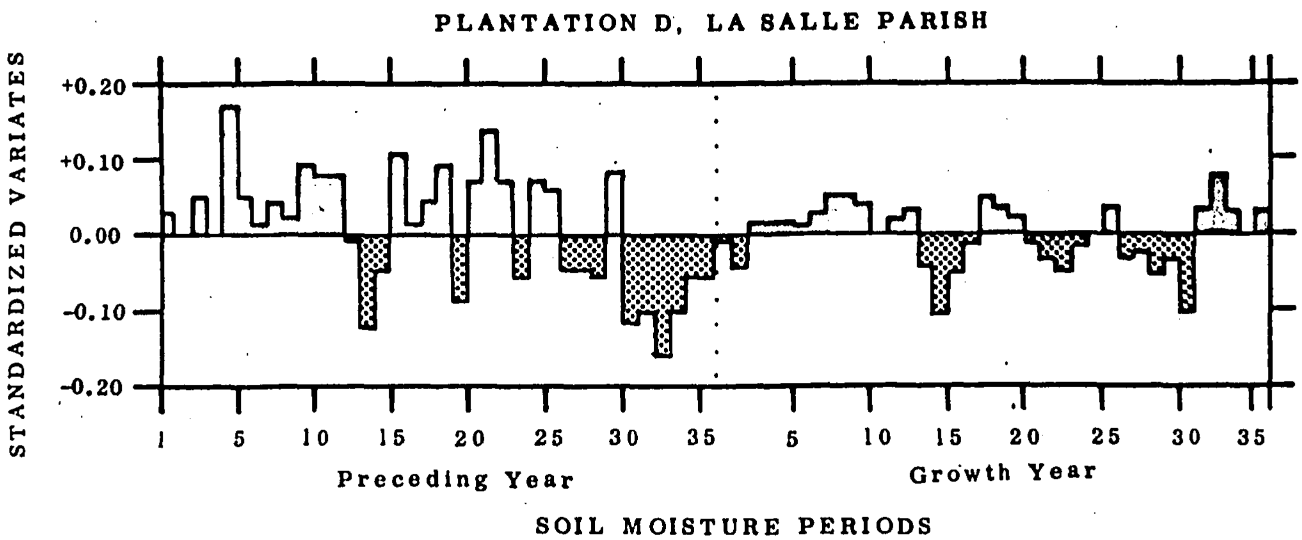


Figure 5. (Continued) Standardized variates of the principal components prediction equation for 10-day soil moisture periods (Period 1 begins January 1)

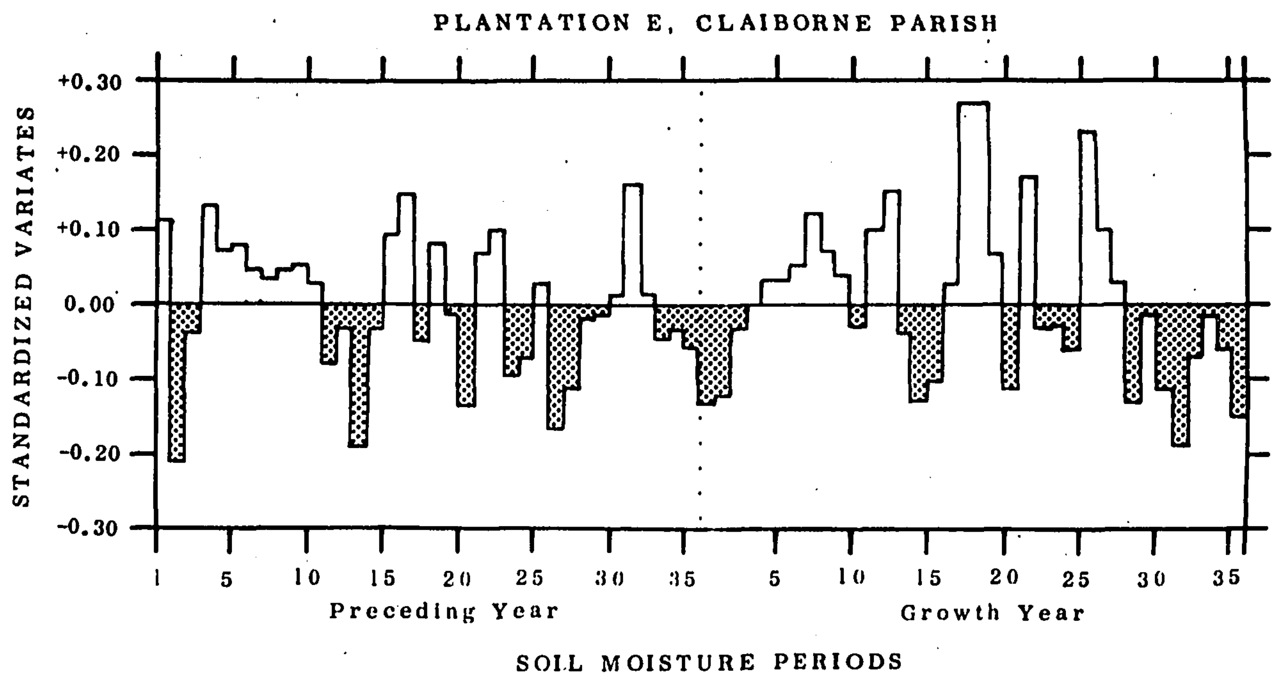


Figure 5. (Continued) Standardized variates of the principal components prediction equation for 10-day soil moisture periods (Period 1 begins January 1)

contribution of each 10-day soil moisture period toward annual height growth is reflected in the magnitude and sign of the standardized variates.

A most striking feature is the oscillation shown by the variates around the zero or "no-association" ordinate. Negative trends were found to occur as frequently and with equal magnitude as positive trends, implying a possible inverse relationship of height growth with soil moisture (or an unmeasured factor associated with soil moisture). These negative trends were predominant in the winter months immediately preceding growth and in the summer periods. Data from the year preceding growth exhibited nearly the same characteristics as data from the growth year. In many cases the calculated variates between successive years were so similar that one might suspect a one-to-one correspondence between the two. It appears that at any single location the soil moisture trends are so similar that when averaged over a period of several years, it is impossible to separate the effects of soil moisture from adjacent years on tree growth.

The variation in annual height growth explained by the combined effect of the 36, 10-day periods is shown in Table 6. Included in Table 6 are tests of significance for the multivariate solution of the principal components prediction equations based on the variance ratio (F) of the mean square of the equation to the residual mean square (error).

Multivariate equations for two of the five study plantations (C and D) showed no significant association between soil moisture and height growth for either the year preceding growth or the growth year. About 25 percent of the variation in height growth was accounted for by soil moisture in Plantation C, while only 10 percent was accounted for in

Table 6. Coefficients of multiple determination for multivariate analyses at the five study locations

Plantation and parish	Year preceding growth R^2	Year preceding growth Level of significance	Growth year R^2	Growth year Level of significance
A, Beauregard	0.184	NS	0.213	0.10P
B, Allen	0.325	0.01P	0.211	0.05P
C, Washington	0.247	NS	0.256	NS
D, LaSalle	0.100	NS	0.097	NS
E, Claiborne	0.629	0.001P	0.452	0.001P

NS denotes probability greater than 0.20P

Plantation D.

Soil moisture in the growth year explained 21 percent of the variation in Plantation A. Probability that this was a real association and not a chance occurrence was between 10 and 20 percent. Effects of the year prior to growth accounted for 18 percent of the variation, but had a computed variance ratio of less than unity.

In both Plantations B and E, significant associations were found between height growth and soil moisture in the year preceding growth and the growth year. At Plantation B in Allen Parish, 32 and 21 percent of the variation was accounted for by soil moisture in the year before growth and the year of growth, respectively.

Analysis of Grouped Soil Moisture Periods

Multivariate techniques, while overcoming many of the disadvantages inherent in multiple regression analysis, have the disadvantage of requiring extremely sophisticated mathematics for interpretation. Evaluation of the individual contribution of each independent variate is infinitely more complex than testing the partial regression coefficients for significance in a normal regression analysis. Computer programs are not yet available for computing the standard errors of the standardized variates or their corresponding F or t distributions.

It was impossible, therefore, to judge the effect of each 10-day soil moisture period for statistical significance, nor would it be desirable, since it is doubtful that the isolated moisture conditions in any single period would have serious effects on the total height growth for the entire year. For this reason, soil moisture periods were grouped together on the basis of their combined trends as indicated by plotting the standardized variates in Figure 5. Contiguous periods having variates

with the same algebraic sign were grouped and an average soil moisture level for the new grouped period was calculated. Grouped periods for each of the five study locations are shown in Table 7.

The grouped data were analyzed by multivariate analysis using the average height growth of the five measurement trees on each plot as the dependent variate.

Standardized variates for the resulting component prediction equation are shown in Table 8. In the second analysis, sign reversal occurred in several standardized variates for the grouped periods. However, sign reversals were restricted to groups of 10-day soil moisture periods which had small standardized variates in the initial analysis. Again, the similarity between standardized variates for corresponding periods in the year prior to growth and the growth year was striking.

By grouping 10-day periods and merging the previous year's data with that of the growth year before performing the multivariate analysis, coefficients of multiple determination were increased at four out of the five study areas (Table 9). A decrease in the coefficient of determination occurred when data from the preceding year was combined with that of the growth year for Plantation E.

To verify results of the multivariate analysis, the data were also analyzed by multiple regression techniques. Regression analyses were done on the IBM 1620 computer using the IBM 6.0.003 multiple regression program. Comparison of the coefficients of determination for the multivariate analysis and the regression analysis verifies that multiple regression analysis provides a better prediction equation than does the multivariate solution (Table 9).

An interesting contrast of results of the two analytical methods is

Table 7. Grouping of 10-day soil moisture periods for analysis

Group	Periods	Inclusive dates	Sign of standardized variates preliminary analysis
		Plantation A, Beauregard Parish	
		Year Preceding Growth	
1	1 to 12	January 1 to April 30	negative
2	13 to 16	May 1 to June 9	positive
3	17 to 20	June 10 to July 19	negative
4	21 to 28	July 20 to October 7	positive
5	29 to 36	October 8 to December 26	negative
		Growth Year	
6	1 to 12	January 1 to April 30	positive
7	13 to 16	May 1 to June 9	positive
8	17 to 23	June 10 to August 18	negative
9	24 to 25	August 19 to September 7	positive
10	26 to 36	September 8 to December 26	negative
		Plantation B, Allen Parish	
		Year Preceding Growth	
1	1 to 12	January 1 to April 30	negative
2	13 to 16	May 1 to June 9	positive
3	17 to 23	June 10 to August 18	negative
4	24 to 32	August 19 to November 16	positive
5	33 to 36	November 17 to December 26	negative
		Growth Year	
6	1 to 13	January 1 to April 30	negative
7	14 to 17	May 1 to June 19	positive
8	18 to 24	June 20 to August 28	negative
9	25 to 29	August 29 to October 17	positive
10	30 to 32	October 18 to November 16	negative
11	33 to 36	November 17 to December 26	positive
		Plantation C, Washington Parish	
		Year Preceding Growth	
1	1 to 5	January 1 to February 19	positive
2	6 to 10	February 20 to April 10	negative
3	11 to 18	April 11 to June 29	positive
4	19 to 24	June 30 to August 28	negative
5	25 to 28	August 29 to October 7	positive
6	29 to 36	October 8 to December 26	negative

Table 7. (Continued) Grouping of 10-day soil moisture periods for analysis

Group	Periods	Inclusive dates	Sign of standardized variates preliminary analysis
		Growth Year	
7	1 to 16	January 1 to June 9	negative
8	17 to 22	June 10 to August 8	positive
9	23 to 26	August 9 to September 17	negative
10	27 to 33	September 18 to November 26	positive
11	34 to 36	November 27 to December 26	negative
		Plantation D, LaSalle Parish	
		Year Preceding Growth	
1	1 to 12	January 1 to March 30	positive
2	13 to 15	April 1 to May 30	negative
3	16 to 26	May 31 to September 17	positive
4	27 to 36	September 18 to December 26	negative
		Growth Year	
5	1 to 13	January 1 to May 10	positive
6	14 to 16	May 11 to June 19	negative
7	17 to 22	June 20 to August 8	positive
8	23 to 36	August 9 to December 26	negative
		Plantation E, Claiborne Parish	
		Year Preceding Growth	
1	1 to 13	January 1 to May 10	positive
2	14 to 15	May 11 to May 30	negative
3	16 to 19	May 31 to July 9	positive
4	20 to 21	July 10 to July 29	negative
5	22 to 23	July 30 to August 18	positive
6	24 to 30	August 19 to October 27	negative
7	31 to 36	October 28 to December 26	positive
		Growth Year	
8	1 to 14	January 1 to May 20	positive
9	15 to 17	May 21 to June 19	negative
10	18 to 23	June 20 to August 18	positive
11	24 to 25	August 19 to September 7	negative
12	26 to 28	September 8 to October 7	positive
13	29 to 36	October 8 to December 26	negative

Table 8. Standardized variates of principal components prediction equation for grouped soil moisture periods

Group	Inclusive dates	Standardized variates
	Plantation A, Beauregard Parish	
	Year Preceding Growth	
1	January 1 to April 30	-0.038
2	May 1 to June 9	.600
3	June 10 to July 19	- .315
4	July 20 to October 7	.338
5	October 8 to December 26	.072
	Growth Year	
6	January 1 to April 30	-0.022
7	May 1 to June 9	.401
8	June 10 to August 18	- .118
9	August 19 to September 7	.151
10	September 8 to December 26	- .373
	Plantation B, Allen Parish	
	Year Preceding Growth	
1	January 1 to April 30	0.025
2	May 1 to June 9	.895
3	June 10 to August 18	- .917
4	August 19 to November 16	.916
5	November 17 to December 26	- .422
	Growth Year	
6	January 1 to April 30	-0.359
7	May 1 to June 19	.282
8	June 20 to August 28	-1.180
9	August 29 to October 17	.480
10	October 18 to November 16	- .424
11	November 17 to December 26	.539
	Plantation C, Washington Parish	
	Year Preceding Growth	
1	January 1 to February 19	-0.144
2	February 20 to April 10	- .174
3	April 11 to June 29	- .064
4	June 30 to August 28	- .378
5	August 29 to October 7	.032
6	October 8 to December 26	- .138

Table 8. (Continued) Standardized variates of principal components prediction equation for grouped soil moisture periods

Group	Inclusive dates	Standardized variates
	Growth Year	
7	January 1 to June 9	-0.012
8	June 10 to August 8	.193
9	August 9 to September 17	- .052
10	September 18 to November 26	.550
11	November 27 to December 26	.071
	Plantation D, LaSalle Parish	
	Year Preceding Growth	
1	January 1 to March 30	0.214
2	April 1 to May 30	- .310
3	May 31 to September 17	.399
4	September 18 to December 26	- .193
	Growth Year	
5	January 1 to May 10	0.350
6	May 11 to June 19	- .364
7	June 20 to August 8	- .199
8	August 9 to December 26	.036
	Plantation E, Claiborne Parish	
	Year Preceding Growth	
1	January 1 to May 10	-0.353
2	May 11 to May 30	- .036
3	May 31 to July 9	.838
4	July 10 to July 29	- .576
5	July 30 to August 18	.464
6	August 19 to October 27	- .210
7	October 28 to December 26	- .265
	Growth Year	
8	January 1 to May 20	-0.249
9	May 21 to June 19	.133
10	June 20 to August 18	.344
11	August 19 to September 7	- .226
12	September 8 to October 7	.766
13	October 8 to December 26	- .352

Table 9. Coefficients of multiple determination (R^2) associated with multivariate analysis and multiple regression analysis of grouped soil moisture periods

Plantation and parish	Multivariate analysis		Multiple regression analysis	
	R^2	Level of significance	R^2	Level of significance
A, Beauregard	0.616	0.001*P*	0.660	0.001*P*
B, Allen	0.323	0.120*P*	0.412	0.031*P*
C, Washington	0.467	0.157*P*	0.512	0.152*P*
D, LaSalle	0.222	0.250*P*	0.261	0.232*P*
E, Claiborne	0.506	0.026*P*	0.759	0.001*P*

shown in Table 10. Standardized variates, after transformation back to their original dimensions and units, should have approximately the same magnitude and sign as their partial regression coefficient counterparts if intercorrelation is absent. It is noteworthy that these parameters differ greatly in this study and that algebraic signs of the regression coefficients are often the reverse of the variates.

Results from the grouped analysis may be summarized as follows:

Plantation A, Beauregard Parish --- Association between soil moisture and height growth was strong at this location, accounting for approximately two-thirds of the variation present. Odds are better than 1,000 to 1 that a real association between growth and soil moisture exists and that it was not just a random occurrence. No particular soil moisture period seemed to stand out from the others as being influential in determining annual height increment. Soil moisture in May (May 1 to June 9) did, however, have a **stronger** positive influence in both the year preceding growth and the growth year. Both exhibited about the same strength of association. It seemed futile to attempt to separate the effects of these two periods. Negative effects, though slight, were observed for the late winter months, January through April; and mid-summer, June through August.

Plantation B, Allen Parish --- The combined effect of soil moisture was responsible for about one-third of the variation in annual height growth. There was a probability of 88 percent that a real association exists. The period of June 10 to August 18 of the year preceding growth had a relatively strong inverse effect on growth while August 19 to November 16 had an equally strong positive influence. The same June to August period of the growth year showed similar trends.

Table 10. Partial regression coefficients and comparable transformed variates from analysis of grouped soil moisture periods

Group	Inclusive dates	Variates in original units	Partial regression coefficients
	Plantation A, Beauregard Parish		
	Year Preceding Growth		
1	January 1 to April 30	-0.0069	-1.6298
2	May 1 to June 9	.1065	.1725
3	June 10 to July 19	- .0642	.4372
4	July 20 to October 7	.0575	.0927
5	October 8 to December 26	.0128	- .2737
	Growth Year		
6	January 1 to April 30	-0.0039	0.8802
7	May 1 to June 9	.0720	.1374
8	June 10 to August 18	- .0241	.4972
9	August 19 to September 7	.0228	.1589
10	September 8 to December 26	- .0629	- .2375
Intercept Term (b_o)		3.3970	4.5554
	Plantation B, Allen Parish		
	Year Preceding Growth		
1	January 1 to April 30	0.0027	0.3671
2	May 1 to June 9	.0978	.0719
3	June 10 to August 18	- .1073	- .1238
4	August 19 to November 16	.1226	.3146
5	November 17 to December 26	- .0501	.0765
	Growth Year		
6	January 1 to April 30	-0.0383	-0.2349
7	May 1 to June 19	.0308	- .6028
8	June 20 to August 28	- .1325	- .1042
9	August 29 to October 17	.0569	.0837
10	October 18 to November 16	- .0474	.0430
11	November 17 to December 26	.0610	.1960
Intercept Term (b_o)		3.6178	3.0906
	Plantation C, Washington Parish		
	Year Preceding Growth		
1	January 1 to February 19	-0.0414	-0.1795
2	February 20 to April 10	- .0485	.7867
3	April 11 to June 29	- .0182	- .2064
4	June 30 to August 28	- .0848	.7877
5	August 29 to October 7	.0093	- .4377
6	October 8 to December 26	- .0316	.2016

Table 10. (Continued) Partial regression coefficients and comparable transformed variates from analysis of grouped soil moisture periods

Group	Inclusive Dates	Variates in original units	Partial regression coefficients
		Growth Year	
7	January 1 to June 9	-0.0033	0.2908
8	June 10 to August 8	.0436	.3040
9	August 9 to September 17	- .0123	- .1144
10	September 18 to November 26	.1146	.6815
11	November 27 to December 26	.0182	- .2752
Intercept Term (b_o)		4.2725	3.3952
		Plantation D, LaSalle Parish	
		Year Preceding Growth	
1	January 1 to March 30	0.0696	-0.5533
2	April 1 to May 30	- .0886	.1040
3	May 31 to September 17	.1255	.2094
4	September 18 to December 26	- .0661	- .1652
		Growth Year	
5	January 1 to May 10	0.1149	0.5889
6	May 11 to June 19	- .1100	- .0996
7	June 20 to August 8	- .0603	- .0200
8	August 9 to December 26	.0121	- .0641
Intercept Term (b_o)		3.7253	3.9634
		Plantation E, Claiborne Parish	
		Year Preceding Growth	
1	January 1 to May 10	-0.1249	-0.6869
2	May 11 to May 30	- .0120	.1227
3	May 31 to July 9	.3738	.1594
4	July 10 to July 29	- .2924	-1.1270
5	July 30 to August 18	.2686	.7743
6	August 19 to October 27	- .1320	.2455
7	October 28 to December 26	- .1108	- .9690
		Growth Year	
8	January 1 to May 20	-0.0873	0.8238
9	May 21 to June 19	.0514	- .1585
10	June 20 to August 18	.1682	.1062
11	August 19 to September 7	- .1300	.0809
12	September 8 to October 7	.3460	.1606
13	October 8 to December 26	- .1569	.7992
Intercept Term (b_o)		4.2080	3.8818

Plantation C, Washington Parish --- Half of the variation in height growth was accounted for by the combined effects of soil moisture, and the chances are 84 out of 100 that there is a real association between growth and soil moisture. At this location practically the entire year preceding growth showed a weak negative relationship. The period June 30 to August 28 showed the strongest negative trend. In the growth year, the greatest positive effect was shown for the period September 18 to November 26

Plantation D, LaSalle Parish --- Probability that a real association exists between soil moisture and height growth at this location is 75 percent; however, only 22 percent of the variation in height growth was accounted for by the soil moisture variables. The period of June through September (May 31 to September 17) of the year preceding growth had a moderately strong direct effect on height growth. Early part of the growth year (January 1 to May 10) also influenced height growth in a positive manner while moisture conditions in May and June (May 11 to June 19) had an equally strong negative effect.

Plantation E, Claiborne Parish --- Over 50 percent of the variation in height growth was accounted for by the soil moisture variables at this location. These results were statistically significant at the 2.5 percent level of probability. Particularly strong positive effects were noted for June (May 31 to July 9) of the year preceding growth but this was followed by an inverse effect in July (July 10 to July 29). August of the preceding year, (July 30 to August 18) also showed a positive relationship with growth. Strong effects of soil moisture in the growth year were not evident until June through August (June 20 to August 18). During this period soil moisture affected tree growth in a positive manner. A rather strong direct association was indicated for the September to October period (September 8 to October 7) of the growth year.

DISCUSSION

Other environmental factors most assuredly affect tree growth as much, if not more, than the single factor, soil moisture, explored in this experiment. Unfortunately the researcher must restrict his or her attention to one or two variables because of the complexity of the interactions involved. Only under the most elaborately controlled conditions can one expect to derive experimental data of sufficient precision to describe these relationships adequately. It should be recognized that in this study the variables used as a basis for deducing the effect of soil moisture on height growth were continuous and random rather than being discretely selected as they would be in a controlled experiment; and therefore, are subject to all of the weaknesses inherent in the random sampling approach.

Importance of the seasonal growth patterns of tree species in relationship with environmental factors was mentioned in the literature review. The multi-nodal characteristics of southern pines make them react much differently to external stimuli than their northern cousins. For instance, many researchers have observed that eastern white pine, a northern species, puts on about 90 percent of its annual leader growth in 30 days and that the total growth period spans only twice that long. Intuitively one might expect that rainfall, temperature, and other environmental factors occurring after this early cessation of growth will have little effect on the height growth of that year. Southern pines, on the other hand, have been shown to continue leader elongation well into

the fall. These species most assuredly are influenced by the entire spectrum of weather in the growing season. Because of this it is expected that the relationship between climatic factors and height growth is more complex in the southern pines than in northern conifers.

Temperature is an important factor in tree growth because of its influence on physiological processes like photosynthesis, respiration, enzymatic activity, and transpiration. Many of these processes react according to Van't Hoff's principle. Their activity is directly proportional to temperature, but when a critically high threshold temperature is reached, activity declines sharply. Because of the moderating effect of precipitation on temperature and temperature's corollary effect on transpiration and water use, the two factors are correlated and have a profound combined effect on plant growth.

Light affects tree growth through its quality, intensity, duration, and periodicity. Quality of light, or wavelength, varies little under natural conditions and is probably of no physiological importance as a growth factor in this study.

Photoperiod, or seasonal differences in length of daylight, are important when comparing growth data from widely scattered points. Within this study, however, the range in daylength from the most northern location to the extreme southern was only 10.2 to 10.1 hours for the shortest day of the year and 14.2 to 14.0 hours for the longest day (Thornthwaite and Mather, 1957).

Most light factors were probably uniform at all study locations. One might expect variation in light intensity caused by cloud cover, so an apparent interaction exists between incidence of rainfall and amount and intensity of radiation reaching the ground.

External factors are not the only forces influencing plant growth. When we discuss the effect of soil moisture during a certain period on the height growth of trees; we are referring to an average effect which is dependent on the reaction of a group of single trees, each responding differently to external stimuli according to its state of growth or dormancy. This is one of the major uncontrollable factors contributing to the inherent error of a study of this type.

From data of this study there is evidence that trees at the five plantations did not respond uniformly to changes in soil moisture. Little agreement was noted for soil moisture effects between any given period of time from study area to study area.

The population from which the height growth measurements were taken was quite uniform at all locations. Mean annual growth for the six-year period of study ranged from 4.17 feet at Plantation A, Beauregard Parish to 3.55 feet at Plantation B, Allen Parish. Standard error of the mean was close to 0.07 feet at all locations and standard deviations were grouped between $\pm$ 0.42 and $\pm$ 0.54 feet. This means that 99 percent of the annual height growth at these locations was within a range of less than three feet; 1.4 feet on each side of the mean. Other investigators have reported similar results where slash pine showed remarkable uniformity in growth. An early study of growth and survival of planted slash pine in Louisiana revealed little variation in height of seedlings planted at different topographic positions (Hayes and Wakeley, 1926). Four-year-old slash pine seedlings grown on flat areas, and seedlings grown on slopes both averaged about 35.5 inches. Standard error of the mean was 0.07-inch for the seedlings on the flat, and 0.06-inch for those planted on the slope.

Sherry (1947) found that the average heights for a 9-year-old slash pine provenance test in Africa were between 35.5 and 38.1 feet. The plantations were located between latitudes 25°S and 31°S, and at elevations between 150 feet and 3,000 feet above sea level. Planting stock of Liberty County, Florida differed only 1.4 feet in height between the four areas, while trees from Osceola National Forest in Florida varied most in height---5.3 feet. Sherry noted that slash pine showed less variation in height growth than did loblolly pine. The average height difference for the slash pine from the six provenances grown at the four locations was 3.7 feet; for loblolly pine the average was 9.8 feet.

Dorman (1952) stated that slash pine showed rather uniform growth in tests made with seed from different provenances. He observed that the range of slash pine is more limited than the other major southern pines; this perhaps accounts for the uniform growth of the provenance tests.

A seed source growth study in Georgia and Florida revealed little variation of height growth of slash pine within an individual climatic zone (Squillace and Kraus, 1959). Mean total height of 4-year-old trees from five seed sources averaged 2.2 to 3.9 feet between climatic zones; however, the coefficients of variation for these means only ranged from 3.5 percent to 7.5 percent. Wakeley (1961) also observed that slash pine seed source tests showed less racial variation in height growth during the first five years than the other three species of southern pines.

Slash pine is normally regarded as a homogenous species that grows uniformly well unless planted on distinctly unsuitable sites or in adverse climates. The results of this study and the studies mentioned

above seem to support this theory.

When variation in sample data is as small as it was in this study, it is unlikely that strong associations will show up in statistical analysis. Simply stated, there must be variation to be able to account for variation.

An interesting feature of the soil moisture data for the period of study was that in 1959 soil moisture was relatively high at all locations and moisture stress remained low throughout the growth year. Plantations B, D, and E showed highest soil moisture stress in 1954; while Plantation C had its driest year in 1955, and Plantation A in 1956.

This study spanned a period of time in which there was a wide range in total annual rainfall at all of the plantations (Appendix D). Annual rainfall ranged between ± 22 percent based on the 6-year means at Plantations A, B, and D. Plantation C ranged between ± 33 percent, and Plantation E ± 42 percent. From the standpoint of studying effects of soil moisture on tree growth, the situation was favorable. Climatic contrast was great during the study period, yet even this contrast failed to show a well-defined difference in height growth.

The inverse relationships between soil moisture and height growth during certain periods are, at first-glance, aesthetically offensive and intuitively anomalous. It is easily understood how slight variations in soil moisture could have little or no effect on tree growth (zero standardized variate), but to rationalize a strong negative association one must look closer at environmental interactions.

Incidences of inverse relationships between rainfall and growth have been reported by others. Glock and Agerter (1962) observed as much as 46 percent occurrence of growth reversals between rainfall and diameter

growth in western species. Inspection of Reed's (1939) data showed tendency toward inverse trends between periodic height growth of loblolly and shortleaf pine, and periodic rainfall. Statistical analysis of the data revealed a positive relationship between growth and a measure of temperature, but no significant association with rainfall. Jackson (1962) found a beneficial effect of increasing annual rainfall on height increment of slash pine; however, the effect of growing-season rainfall (March through August) had a negative effect. His analysis indicated that if annual precipitation is 50 inches, an increase in the growing-season rainfall generally results in decreased height increment. The results of this study tend to support Jackson's findings since 6-year average rainfall was in excess of 50 inches at every plantation, and negative effects appear frequently during the growing season, periods 7 through 24 (Figure 5).

Inverse growth relationships can be caused by creation of limiting factors associated with rainfall occurrence. Fraser (1958) observed that wet summers are usually associated with lower temperatures and less sunshine. Burger (1926) stated that heavy precipitation generally results in a temperature reduction. Cursory examination of the precipitation and temperature records of the study plantations tend to support Burger's observation (Appendix D); however, small fluctuations in precipitation seem to have little effect on temperature.

Rainfall, along with cloud cover, has a tendency to modify day temperatures so that differences between day and night temperatures are minimized. Kramer's work showed that by reducing day-night temperature differential even a small amount, shoot growth of loblolly pines was reduced. In addition, reduction in day temperature reduces the

physiological temperature index Reed found so important in determining shoot growth of both shortleaf and loblolly pine. It may well be that the negative growth relationships observed in this study are related to soil moisture only indirectly as precipitation affects temperature. Such concomitant effects are difficult to separate from the influence of moisture.

Attempting to explain the occurrence of diameter growth reversals in western species, Glock and Agerter (1962) implied that rainfall or soil moisture could act as a limiting factor when deficient or in excess. Optimal range of soil moisture is dependent on both water tolerance of the species and soil moisture characteristics of the site. In attempting to rationalize the apparent conflict between the beneficial effects of increasing annual precipitation and the adverse effects of increasing growing-season rainfall on height growth of slash pine, Jackson (1962) attached considerable importance to the amount of available moisture stored in the soil prior to the season of active growth. This would be available as soon as growth started in the spring, and he postulated that additional rainfall during this period of most active height growth (i.e. March through May) would result in depressive effects due to reduced soil aeration, rather than produce additional growth as a moisture-response. Adverse effects of excess soil moisture on growth of woody plants are well documented in the literature. Drainage can be a growth factor on Flatwoods soils similar to some sampled in Plantations A and B of this study. Under conditions of poor internal drainge one might expect poor aeration and carbon dioxide accumulation to reduce root and shoot growth and interfere with plant nutrition, if the soil remains saturated for extended periods of time. It is difficult, however,

to imagine well-drained Coastal Plain soils such as those encountered in Plantation E of ever remaining saturated long enough to reduce growth.

While there is little doubt that moisture is an important factor of height growth of slash pine in Louisiana, no clearcut relationships between soil moisture variation within a given period and variation in annual height increment were detected with the analytical approach used.

Possible reasons for this apparent lack of association are several. First, it is doubtful that any single short-term period is very influential in determining growth, rather it is a combined effect of many of these periods within the growth year and probably the year preceding growth. Second, empirical techniques used in reconstructing the soil moisture regimes were subject to large experimental errors. Among these errors were: subjective appraisal of effective rooting depth, variation in actual rainfall and temperature between the weather stations and study areas, and the recognized inherent errors in Thornthwaite's water balance concept. Third, the analytical approach used is capable of identifying strong growth associations, but subtle effects or those caused by factor interactions often go undetected. Neither regression nor multivariate analyses were able to separate the effects of a soil moisture period of the year prior to growth from the effects of the same period in the growth year. Finally, other environmental factors affecting height growth interact with rainfall and soil moisture to confound the growth process. Precisely controlled growth studies are needed to evaluate the interactions between the environmental factors before the clear meaning of empirical studies based on random field sampling, as this study was, is fully understood.

SUMMARY AND CONCLUSIONS

This study of the effect of soil moisture on height growth of slash pine was conducted at five plantations in Allen, Beauregard, Claiborne, LaSalle, and Washington Parishes of Louisiana. Plots were located in plantations which ranged in age from 11 to 18 years.

Soils represented were of the Coastal Plain and Flatwoods physiographic regions of the State. Soil moisture-holding capacities varied greatly within, and between, plantations sampled, and each location received different amounts of precipitation.

A method was devised to reconstruct past annual height increment from the length of internodes of slash pine. A computer program was written to re-establish the soil moisture regimes using Thornthwaite's water balance technique and climatological data from weather stations adjacent to the study areas.

Height growth data were collected for a six-year period: 1954 through 1959. Daily soil-moisture levels were computed for the period, 1953 through 1959. Daily soil-moisture values were summarized into 36 ten-day periods for each year. Correlation analysis indicated a low degree of association between annual height growth and any single ten-day moisture level, but more importantly, it revealed extremely high intercorrelation among the soil-moisture levels of the ten-day periods. This high intercorrelation precluded the use of multiple regression to evaluate the contribution of soil moisture to annual height growth. Multivariate analysis was employed for this purpose since it adjusts

for intercorrelation and distributes the error among the independent variates as well as the dependent variates.

A preliminary analysis of the effects of the ten-day soil moisture periods of the preceding year and the growth year was used as a basis for grouping soil moisture periods. Analyses of the grouped data were then made.

Analysis of the data revealed the following:

1. Variation in annual height growth between plots at the same plantation and between plantations was small. Growth was so consistent that 99 percent of the annual height growth at all five plantations was within a range of less than 1-1/2 feet on each side of the mean.

2. Soil moisture curves showed similar trends at all locations. Soil moisture-holding capacities in the upper 5 feet ranged from 1 to 14 inches. The driest years were 1954 and 1956, while 1958 and 1959 were the wettest at all plantations. Annual rainfall ranged between ± 22 percent and ± 42 percent based on the 6-year mean rainfall at each of the five study plantations.

3. Height growth was dependent on soil moisture at three of the five plantations. Soil moisture of the 36 ten-day periods of the year preceding growth explained from 10 to 63 percent of the variation in height growth, while soil moisture of the growth year explained from 10 to 45 percent. Combined analysis of the grouped soil moisture periods in both the year preceding growth and the growth year explained more variation by accounting for 26 to 76 percent of the difference in annual height growth.

4. Pronounced effects of individual periods of soil moisture were not readily apparent, and little agreement was noted as to which periods of soil moisture are most critical. Inverse relationships between some soil moisture periods and height growth were detected. The negative effects were predominant in the winter preceding growth and during the growing season. These effects were probably caused by concomitant factors associated with rainfall occurrence, such as reduced soil aeration, reduction in radiation due to cloud cover, decrease in total temperature, or reduction in differential between day and night temperature.
5. Moisture regimes between adjacent years were so similar during the period of study that it was impossible to separate the effects of the year preceding growth from those of the growth year.

Results of this study tend to support the hypothesis that height growth of slash pine, and indeed the growth of all southern pines, is determined by a combination of the previous year's growing conditions and the conditions of the growth year. The first flush of growth in the spring is morphologically determined in the bud laid down in the previous year. The magnitude of this initial flush depends, to a large extent, on the pre-formed bud tissue and stored food which are influenced by the soil moisture and environmental conditions prevailing during the previous year (Kozlowski, 1958). Subsequent growth flushes, which along with the initial flush constitutes total annual increment, depend on conditions during the growth year.

Zahner's (1962) work with loblolly pine also embraces this theory. Under controlled moisture conditions the initial growth flush, which made up about one-third to one-half of the annual height growth, was greatly

dependent on the moisture conditions of the previous year. Trees supplied ample moisture during the growth season continued to produce three more growth flushes in the year, while those grown under high soil-moisture stress produced but one flush in addition to the initial spring flush. Total height increment was about half as much for the dry treatments as for the wet.

The results of this study further point out the homogeneity of slash pine growth, and support the observations of other researchers who have found it to show little racial variation when planted in a single climatic zone.

Additional studies conducted under controlled conditions in the greenhouse and growth chamber are needed before we can fully understand the relationship between soil moisture and other interacting environmental factors that determine the height growth of trees. If such data were now available, field studies such as this would be more meaningful.

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APPENDIX A

Physical Properties and Moisture Constants of Soils by Plots and Soil Layers

Plot	Soil layer	Composition Sand	Silt	Clay	Bulk density	Field capacity	Wilting point	Available water holding capacity
	Inches	Per-cent	Per-cent	Per-cent	Gm/cc	Percent	Percent	Inches
				Plantation A, Beauregard Parish				
1	0-6	56.8	35.6	7.6	1.31	13.07	3.55	0.74
	6-12	56.0	36.4	7.6	1.44	13.42	2.78	0.92
	12-18	52.6	33.4	14.0	1.50	15.11	6.97	0.73
	18-24	48.8	31.4	19.8	1.46	18.85	6.43	1.09
	24-30	48.2	32.4	19.4	1.44	19.34	6.57	0.95
	30-36	48.0	32.5	19.5	1.45	19.49	7.58	1.04
	36-42	48.4	32.3	19.3	1.43	19.37	7.91	0.98
	42-60	47.3	33.0	19.7	1.47	19.35	5.58	3.64
							Total	10.09
2	0-6	56.0	37.4	6.6	1.15	16.06	2.93	0.90
	6-12	53.0	34.4	7.6	1.38	12.79	2.41	0.86
	12-18	52.2	34.8	12.0	1.48	13.04	3.04	0.89
	18-24	52.0	33.4	14.6	1.48	16.24	5.49	0.95
	24-30	52.1	33.1	14.8	1.47	16.30	5.30	0.97
	30-36	51.9	33.2	14.9	1.48	16.26	5.45	0.96
	36-42	52.0	33.0	15.0	1.50	16.32	5.42	0.98
	42-60	51.7	33.0	15.3	1.52	16.29	5.99	2.82
							Total	9.33
3	0-6	43.8	37.4	18.8	1.50	24.68	7.06	1.06
	6-12	43.6	33.4	23.0	1.57	22.11	5.85	2.56
							Total	3.62
4	0-6	48.8	44.4	6.8	1.20	17.46	3.13	1.03
	6-12	47.8	43.4	8.8	1.53	13.73	2.82	1.00
	12-18	45.8	42.8	11.4	1.49	15.78	4.20	1.04
	18-24	40.8	42.6	16.6	1.50	20.15	6.56	1.22
	24-30	40.5	42.7	16.8	1.52	20.45	7.47	1.18
	30-36	40.7	42.6	16.7	1.51	20.30	7.04	1.20
	36-42	40.6	42.9	16.5	1.53	20.29	7.39	1.18
	42-60	40.8	42.3	16.9	1.52	20.39	6.58	3.78
							Total	11.63

Plot	Soil layer	Composition Sand	Silt	Clay	Bulk density	Field capacity	Wilting point	Available water holding capacity
	Inches	Per-cent	Per-cent	Per-cent	Gm/cc	Percent	Percent	Inches
5	0-6	48.8	41.4	9.8	1.33	18.67	3.69	1.19
	6-12	47.8	40.6	11.6	1.44	17.51	4.03	1.17
	12-18	42.0	38.4	19.6	1.38	20.10	8.16	0.99
	18-24	39.6	42.1	19.3	1.40	19.80	6.43	1.12
	24-30	39.3	41.2	19.5	1.41	19.89	5.91	1.18
	30-36	39.8	40.3	19.6	1.39	20.00	6.43	1.13
	36-42	40.1	40.2	19.7	1.41	19.78	6.78	1.10
	42-60	41.5	39.3	19.2	1.40	19.82	7.89	3.01
							Total	10.89
6	0-6	34.8	52.4	12.8	1.19	25.41	7.13	1.30
	6-12	33.8	47.4	18.8	1.36	19.30	6.42	1.05
	12-18	35.6	45.0	19.4	1.42	21.05	6.93	1.20
	18-24	35.8	42.6	21.6	1.47	21.82	6.81	1.32
	24-30	36.0	41.9	22.1	1.45	21.51	6.56	1.30
	30-36	35.9	42.8	21.3	1.48	21.93	6.85	1.34
	36-42	34.1	43.6	22.3	1.49	21.85	7.20	1.31
	42-60	33.5	43.3	23.2	1.50	22.01	7.12	4.02
							Total	12.84
Plantation B, Allen Parish								
7	0-6	30.2	52.8	17.0	1.34	26.34	7.60	1.50
	6-12	30.2	40.4	29.4	1.49	21.67	6.60	1.35
	12-18	25.2	48.8	26.0	1.52	21.96	8.34	1.24
	18-24	24.2	46.8	29.0	1.51	24.38	10.08	1.30
	24-30	23.9	47.3	29.0	1.50	24.51	9.05	1.39
	30-36	23.6	49.1	27.3	1.52	24.73	9.75	1.37
	36-42	23.3	48.5	28.2	1.54	24.91	10.50	1.33
	42-60	23.7	47.7	28.6	1.53	24.69	9.96	4.05
							Total	13.53
8	0-6	29.2	60.4	10.4	1.38	28.78	6.50	1.85
	6-12	29.2	46.8	19.0	1.52	20.22	6.68	1.23
	12-18	26.8	54.6	18.6	1.57	21.24	7.28	1.31
	18-24	26.2	55.9	17.9	1.55	23.21	7.81	1.48
	24-30	25.9	57.1	17.0	1.54	23.65	7.69	1.47
	30-36	26.5	56.3	17.2	1.56	23.72	7.48	1.52
	36-42	26.8	55.9	17.3	1.56	23.77	7.20	1.50
	42-60	25.7	56.8	17.5	1.58	22.95	7.33	4.44
							Total	14.80

Plot	Soil layer	Composition Sand	Silt	Clay	Bulk density	Field capacity	Wilting point	Available water holding capacity
	Inches	Per-cent	Per-cent	Per-cent	Gm/cc	Percent	Percent	Inches
9	0-6	30.2	57.8	12.0	1.47	21.50	7.21	1.26
	6-12	29.8	53.8	16.4	1.52	22.93	8.93	1.22
							Total	2.48
10	0-6	29.8	60.2	10.0	1.44	20.58	3.60	1.48
	6-12	24.8	58.4	16.8	1.52	21.80	6.62	1.39
	12-18	23.2	59.4	17.4	1.56	21.80	8.12	1.28
	18-24	22.8	58.9	18.3	1.55	22.31	7.74	1.35
	24-30	22.0	58.9	19.1	1.54	22.49	7.68	1.37
	30-36	22.5	56.4	21.1	1.53	23.00	7.84	1.39
	36-42	21.3	54.4	24.3	1.57	25.87	10.47	1.45
	42-60	20.1	54.3	25.6	1.58	24.76	9.36	4.38
							Total	14.09
11	0-6	27.6	62.0	10.4	1.11	25.80	9.70	1.07
	6-12	24.8	57.4	17.8	1.50	23.26	7.23	1.44
	12-18	26.0	49.4	24.6	1.47	24.18	7.38	1.48
	18-24	25.3	48.6	26.1	1.49	24.83	8.16	1.49
	24-30	26.4	45.3	28.3	1.51	25.32	9.15	1.46
	30-36	26.2	44.7	29.1	1.50	24.98	9.01	1.44
	36-42	26.0	43.8	30.2	1.52	25.01	8.90	1.47
	42-60	25.9	44.3	29.8	1.55	24.86	8.67	4.52
							Total	14.37
12	0-6	25.6	63.4	11.0	1.20	32.86	10.64	1.60
	6-12	22.8	56.4	20.8	1.43	24.30	8.20	1.38
	12-18	22.3	55.2	22.5	1.46	23.21	7.65	1.36
	18-24	23.9	54.4	21.7	1.51	22.13	6.52	1.41
	24-30	25.0	54.7	20.3	1.53	21.96	6.65	1.40
	30-36	25.4	52.6	22.0	1.55	23.69	8.92	1.37
	36-42	26.2	48.8	25.0	1.54	24.01	9.01	1.39
	42-60	25.9	47.7	26.4	1.57	25.23	10.65	4.12
							Total	14.03
13	0-6	71.8	21.0	7.2	1.39	11.50	2.61	0.74
	6-12	74.8	18.0	7.2	1.46	9.66	1.30	0.74
	12-18	73.6	19.4	7.0	1.61	10.14	1.62	0.83
	18-24	58.2	15.4	26.4	1.59	16.95	9.96	0.86
	24-30	57.8	14.9	27.3	1.60	18.21	8.95	0.89
	30-36	55.4	15.5	29.1	1.62	17.91	8.96	0.87
	36-42	54.7	16.4	28.9	1.65	18.31	9.69	0.85
	42-60	52.3	16.5	31.2	1.67	21.24	12.46	2.64
							Total	8.42

Plot	Soil layer	Composition Sand	Silt	Clay	Bulk density	Field capacity	Wilting point	Available water holding capacity
	Inches	Per-cent	Per-cent	Per-cent	Gm/cc	Percent	Percent	Inches
				Plantation C, Washington Parish				
14	0-6	44.2	46.4	9.4	1.43	18.15	4.01	1.22
	6-12	41.6	43.0	15.4	1.50	16.63	4.52	1.09
	12-18	39.8	40.4	19.8	1.59	18.81	7.97	1.04
	18-24	47.0	30.4	22.6	1.63	19.47	10.16	0.91
	24-30	49.2	30.0	20.8	1.65	20.75	10.91	0.97
	30-36	51.7	28.7	19.6	1.68	22.13	12.06	1.01
	36-42	53.4	28.3	18.3	1.66	21.93	12.05	0.98
	42-60	56.1	26.1	17.8	1.64	22.31	13.87	2.49
							Total	9.71
15	0-6	55.0	33.2	11.8	1.41	18.58	7.24	0.96
	6-12	56.0	24.0	20.0	1.52	15.22	8.22	0.64
	12-18	52.0	28.2	19.8	1.54	19.62	11.15	0.78
	18-24	41.0	36.0	23.0	1.61	17.14	10.29	0.66
	24-30	38.9	36.9	24.2	1.63	16.34	9.31	0.69
	30-36	37.3	37.0	25.7	1.66	18.21	10.55	0.76
	36-42	34.1	37.6	28.3	1.65	17.91	9.19	0.86
	42-60	33.9	36.9	29.2	1.67	18.10	9.40	2.61
							Total	7.96
16	0-6	44.4	38.0	17.6	1.39	18.72	8.65	0.84
	6-12	43.6	34.0	22.4	1.65	19.92	11.01	0.88
	12-18	45.6	35.0	19.4	1.71	18.62	10.84	0.80
	18-24	50.0	32.4	17.6	1.70	15.12	8.95	0.63
	24-30	52.4	31.3	16.3	1.72	14.98	9.07	0.61
	30-36	54.6	28.7	16.7	1.69	15.23	8.92	0.64
	36-42	57.3	27.3	15.4	1.71	14.78	9.03	0.59
	42-60	59.5	25.7	14.8	1.74	14.56	8.33	1.95
							Total	6.94
17	0-6	54.6	32.6	12.8	1.45	22.60	10.82	1.03
	6-12	35.4	37.6	27.0	1.66	18.64	11.18	0.74
	12-18	37.6	37.0	25.4	1.68	20.44	11.68	0.68
	18-24	45.6	36.0	18.4	1.70	19.74	9.75	1.02
	24-30	48.9	29.9	21.2	1.69	20.31	10.58	0.99
	30-36	51.3	30.8	17.9	1.72	21.24	12.32	0.92
	36-42	52.7	24.9	22.4	1.71	19.94	10.49	0.97
	42-60	55.4	19.9	24.7	1.74	18.73	9.45	2.91
							Total	9.46

Plot	Soil layer	Composition Sand	Silt	Clay	Bulk density	Field capacity	Wilting point	Available waterholding capacity
	Inches	Percent	Percent	Percent	Gm/cc	Percent	Percent	Inches
18	0-6	53.2	37.0	9.8	1.38	19.33	5.36	1.16
	6-12	58.4	29.6	12.0	1.58	15.40	6.31	0.86
	12-18	48.8	32.8	18.4	1.61	15.52	6.72	0.85
	18-24	49.6	36.0	14.4	1.66	17.43	8.86	0.86
	24-30	49.6	32.0	18.4	1.70	17.60	6.38	1.14
	30-36	47.3	32.6	20.1	1.69	18.23	8.68	0.97
	36-42	46.9	30.4	22.7	1.71	18.41	8.38	1.03
	42-60	44.3	31.2	24.5	1.73	19.71	7.83	3.70
							Total	10.57
19	0-6	50.6	31.0	18.4	1.48	17.86	8.74	0.87
	6-12	43.4	38.6	18.6	1.65	17.32	6.66	1.06
	12-18	41.6	38.0	20.4	1.64	18.42	9.06	0.92
	18-24	43.4	35.8	20.8	1.67	18.58	8.74	0.99
	24-30	42.7	34.4	22.9	1.69	19.75	9.66	1.02
	30-36	43.0	33.9	23.1	1.71	18.91	9.46	0.97
	36-42	42.3	33.1	24.6	1.73	20.21	10.22	1.04
	42-60	41.5	32.8	25.7	1.73	19.98	10.83	2.85
							Total	9.75
				Plantation D, LaSalle Parish				
20	0-6	52.0	39.2	8.8	1.39	16.69	4.71	1.00
	6-12	39.0	42.8	18.2	1.48	19.97	6.26	1.22
	12-18	30.0	37.8	32.2	1.54	21.95	13.89	0.73
	18-24	27.3	38.0	34.7	1.59	21.35	12.27	0.86
	24-30	39.4	35.3	35.3	1.63	22.16	13.77	0.82
	30-36	26.5	35.8	37.7	1.66	24.21	15.57	0.86
	36-42	25.7	34.7	39.6	1.65	24.82	16.43	0.83
	42-60	23.9	34.6	41.5	1.67	25.01	17.12	2.37
							Total	8.89
21	0-6	75.6	18.2	6.2	1.49	10.51	2.93	0.70
	6-12	75.2	17.6	7.2	1.57	8.29	1.91	0.60
	12-18	76.0	17.2	6.8	1.58	8.24	1.95	0.60
	18-24	75.6	16.6	7.8	1.51	7.84	2.40	0.49
	24-30	74.0	17.2	8.8	1.50	9.34	3.54	0.52
	30-36	68.4	18.4	13.2	1.59	10.75	5.82	0.47
	36-42	65.3	19.2	15.5	1.61	11.21	4.66	0.63
	42-60	63.9	20.3	15.8	1.63	12.46	7.84	1.35
							Total	5.36

Plot	Soil layer	Composition Sand	Silt	Clay	Bulk density	Field capacity	Wilting point	Available water holding capacity
	Inches	Per-cent	Per-cent	Per-cent	Gm/cc	Percent	Percent	Inches
22	0-6	64.0	26.8	9.2	1.39	15.25	4.25	0.92
	6-12	66.2	24.2	9.6	1.41	11.90	2.77	0.77
	12-18	73.0	18.2	8.8	1.45	9.09	2.49	0.57
	18-24	73.2	18.2	8.6	1.49	8.85	2.25	0.59
	24-30	73.8	17.9	8.3	1.51	7.96	1.55	0.58
	30-36	74.0	17.6	8.4	1.50	8.01	1.37	0.60
	36-42	74.8	17.1	8.1	1.48	8.23	1.91	0.56
	42-60	75.1	16.0	7.9	1.50	8.11	1.78	1.71
							Total	6.30
23	0-6	79.0	15.8	5.2	1.28	7.23	3.45	0.29
	6-12	77.6	13.2	9.2	1.55	8.00	2.62	0.50
	12-18	55.6	16.2	28.2	1.47	14.79	9.40	0.48
	18-24	54.9	16.4	29.7	1.49	14.91	9.28	0.50
	24-30	53.7	15.8	30.5	1.50	15.01	9.56	0.49
	30-36	51.9	14.5	32.6	1.50	14.97	9.74	0.47
	36-42	50.3	16.3	33.4	1.52	15.31	9.57	0.52
	42-60	49.9	17.1	33.0	1.54	15.61	9.35	1.74
							Total	4.99
24	0-6	43.2	45.2	11.6	1.37	18.92	4.88	1.16
	6-12	32.4	50.4	17.2	1.50	20.94	6.47	1.30
	12-18	31.3	49.3	19.4	1.51	22.65	8.35	1.29
							Total	3.75
25	0-6	82.0	12.8	5.2	1.39	7.99	3.04	0.41
	6-12	81.0	12.6	6.4	1.33	7.63	2.34	0.42
	12-18	80.0	13.6	6.4	1.36	7.10	1.27	0.48
	18-24	76.6	16.6	6.8	1.38	7.66	1.30	0.53
	24-30	73.6	18.0	8.4	1.57	11.01	3.72	0.69
	30-36	71.3	19.0	9.7	1.59	12.17	4.72	0.71
	36-42	70.2	19.8	10.0	1.60	11.93	4.89	0.68
	42-60	68.3	18.2	13.5	1.62	13.23	8.98	1.24
							Total	5.16
26	0-6	65.6	27.6	6.8	1.34	14.53	3.08	0.92
	6-12	53.6	28.8	17.6	1.44	19.60	11.51	0.70
	12-18	41.0	22.2	36.8	1.46	21.36	18.65	0.24
	18-24	38.3	19.6	42.1	1.49	23.21	20.12	0.28
	24-30	37.2	19.4	43.4	1.50	23.98	21.09	0.26
	30-36	35.7	19.4	44.9	1.52	25.01	21.94	0.28
	36-42	36.1	18.9	45.0	1.53	25.34	22.02	0.30
	42-60	34.9	18.7	46.4	1.55	25.93	23.01	0.81
							Total	3.79

Plot	Soil layer	Composition Sand	Silt	Clay	Bulk density	Field capacity	Wilting point	Available water holding capacity
	Inches	Percent	Percent	Percent	Gm/cc	Percent	Percent	Inches
				Plantation E, Claiborne Parish				
27	0-6	67.6	27.6	4.8	1.34	8.86	2.93	0.48
	6-12	60.6	32.6	6.8	1.46	11.84	2.29	0.84
	12-18	53.0	28.2	18.8	1.47	15.31	4.29	0.97
	18-24	31.6	21.2	47.2	1.38	22.43	19.18	0.27
	24-30	29.7	22.0	48.3	1.40	23.50	20.48	0.25
	30-36	28.9	21.4	49.7	1.43	24.21	20.99	0.28
	36-42	26.8	21.9	51.3	1.45	25.33	21.78	0.31
	42-60	24.3	23.7	52.0	1.51	27.24	23.86	0.92
							Total	4.32
28	0-6	75.0	20.0	5.0	1.39	4.87	2.14	0.23
	6-12	69.2	20.2	10.6	1.37	6.23	2.89	0.28
	12-18	71.0	22.6	6.4	1.36	7.51	3.84	0.30
	18-24	55.4	17.4	27.2	1.44	14.02	12.32	0.15
	24-30	53.2	17.5	29.3	1.46	15.01	13.11	0.17
	30-36	51.5	16.8	31.7	1.50	17.34	15.23	0.19
	36-42	49.8	17.2	33.0	1.52	18.12	16.33	0.16
	42-60	47.3	17.6	35.1	1.54	18.70	16.86	0.51
							Total	1.99
29	0-6	77.2	18.2	4.6	1.28	4.08	3.39	0.05
	6-12	66.0	27.8	6.2	1.51	5.03	2.90	0.19
	12-18	69.2	25.6	5.2	1.43	4.67	2.90	0.15
	18-24	66.4	24.4	9.2	1.48	6.69	4.62	0.18
	24-30	64.0	22.8	13.2	1.46	9.37	6.26	0.27
	30-36	62.7	22.3	15.0	1.49	10.24	7.05	0.28
	36-42	58.9	23.6	17.5	1.52	12.39	8.88	0.32
	42-60	56.1	23.6	20.3	1.54	13.71	10.14	1.00
							Total	2.44
30	0-6	56.4	36.4	7.2	1.24	8.13	5.89	0.17
	6-12	62.0	30.2	7.8	1.21	6.52	3.78	0.20
	12-18	56.0	30.6	13.4	1.47	9.54	4.80	0.42
	18-24	45.4	29.4	25.2	1.52	15.80	13.56	0.20
	24-30	43.2	30.0	26.8	1.53	16.21	14.27	0.18
	30-36	41.9	29.9	28.2	1.51	16.00	13.91	0.19
	36-42	39.8	30.1	30.1	1.54	18.31	15.70	0.24
	42-60	37.3	30.2	32.5	1.55	19.20	16.64	0.71
							Total	2.31

Plot	Soil layer	Composition Sand	Silt	Clay	Bulk density	Field capacity	Wilting point	Available water holding capacity
	Inches	Percent	Percent	Percent	Gm/cc	Percent	Percent	Inches
31	0-6	51.0	43.8	5.2	1.35	6.03	4.36	0.14
	6-12	45.0	49.8	6.2	1.44	6.39	4.42	0.17
	12-18	29.2	36.6	34.2	1.40	20.59	17.75	0.24
	18-24	28.3	35.9	35.8	1.41	21.36	18.68	0.23
	24-30	26.7	36.3	37.0	1.45	23.24	20.37	0.25
	30-36	24.5	36.6	38.9	1.48	23.98	21.06	0.26
	36-42	24.0	36.7	39.3	1.49	24.21	21.17	0.27
	42-60	23.1	36.4	40.5	1.52	25.01	21.83	0.87
							Total	2.43
32	0-6	69.0	25.8	5.2	1.27	10.32	6.79	0.27
	6-12	70.0	20.8	9.2	1.47	5.93	4.77	0.10
	12-18	50.0	8.8	41.2	1.47	24.17	23.42	0.07
	18-24	45.2	10.1	44.7	1.52	25.31	24.21	0.10
	24-30	46.1	10.0	43.9	1.50	25.73	24.69	0.09
	30-36	47.3	9.7	43.0	1.50	24.93	24.15	0.07
	36-42	46.9	9.0	44.1	1.49	25.11	24.40	0.06
	42-60	47.5	8.6	43.9	1.51	25.23	24.38	0.23
							Total	0.99
33	0-6	49.2	43.6	7.2	1.25	13.41	4.79	0.65
	6-12	52.3	41.5	7.2	1.46	14.86	4.86	0.89
	12-18	21.0	23.8	55.2	1.24	31.97	24.87	0.53
	18-24	18.7	24.9	56.4	1.22	33.01	25.55	0.55
	24-30	19.3	23.8	56.9	1.25	34.30	27.06	0.54
	30-36	18.4	24.3	57.3	1.31	34.93	27.77	0.56
	36-42	17.9	24.0	58.1	1.33	35.03	27.69	0.59
	42-60	17.5	24.6	57.9	1.36	35.95	28.81	1.75
							Total	6.06

APPENDIX B

Description and Operating Instructions for Louisiana State University School of Forestry and Wildlife Management's Soil Moisture-Balance Program

Purpose

Given the daily precipitation, daily mean temperature, I value (heat index) and soil moisture-storage capacity of the soil, this routine will compute and punch out the daily values of (1) Thornthwaite's potential evapotranspiration, (2) actual evapotranspiration, (3) available soil moisture level in inches, (4) soil moisture deficits and surpluses, (5) amount of gravitational water remaining in the soil and, (6) total amount of water remaining in the soil, both available and gravitational. The routine punches one for one and total number of output cards equal the total number of input cards.

Input Deck Format

The program is self-loading and self-restoring and is loaded 5 instructions per card. This program consists of two decks:

Deck 1. Computation program and tables of unadjusted daily potential evapotranspiration values

Deck 2. Tables of adjustment factors based on daily duration of sunlight at a given latitude

Data

Word 1. 0000000CXX

Where C is the location or weather station number and XX is the last two digits in the year, i.e. 19XX

Word 2. XXXX000000

Where XXXX is the month number and day of month, i.e. April 16 = 0416

Word 3. XXX0000000

Where XX.X is mean temperature for that day in degrees and tenths Fahrenheit

Word 4. 000000XXXX

Where XX.XX is precipitation in inches and hundreths

Words 5-8. Irrelevant

There is one data card for each daily observation

<u>Parameter Card</u>

Word 1. 0000XXXXXX

Where X.XXXXX is:

Storage Capacity of Soil (Inches)	X.XXXXX
1	0.00000
2	0.30103
3	0.47712
4	0.60206
5	0.69897
6	0.77815
8	0.90309
10	1.00000
12	1.07918
14	1.14613
16	1.20412

Word 2. 00000XXXXX

Where .XXXXX is:

Storage Capacity of Soil (Inches)	.XXXXX
1	.21054
2	.23320
3	.15010
4	.11197
5	.08851
6	.07447
8	.05445
10	.04340
12	.03623
14	.03110
16	.02717

Word 3. 00000000XX

Where .XX is runoff factor or amount of the total gravitational water which is retained to runoff the following day. Medium textured soils with little slope have an approximate factor of .90.

Word 4. 000XXXXXXX

Where XX.XXXXX is the amount of available water in soil at start of computations. If computations are started at first of the year this value may be assumed to be maximum soil moisture-storage capacity.

Word 5. 000000XXXX

Where XX.XX is the amount of total water available and gravitational at the start of computations. If starting at beginning of year this value may be assumed to be the maximum soil moisture-storage capacity.

Word 6. 000XXXXXXX

Where XX.XXXXX is the soil moisture-storage capacity of the soil in question.

Words 7 and 8. Zeros

All values are entered as fixed-point.

<u>Preparation of Data for Machine</u>

1. Program deck - 1
2. Program deck - 2 (appropriate deck - 2 must be inserted depending on latitude)
3. Parameter card
4. Data card

<u>Console Procedures</u>

1. Insert 80 - 80 board
2. Set console 70 1952 9999
3. Overflow - sense
4. Error - sense
5. Programmed stop-run

When program decks are being loaded the 519 will stop upon

completion of deck 1. The operator must then restart by pressing computer-reset and program-start to continue loading deck 2.

Output

Answers are in fixed point.

Word 1. MMXX000CYY

Where MM is the number of the month, XX is the day of the month, C is the location or station code number and YY is the last two digits of the year.

Word 2. 000000XXXX

Where XX.XX is the precipitation of that day in inches.

Word 3. 0000000XXX

Where X.XX is the potential evapotranspiration in inches for that day.

Word 4. 000XXXXXXX

Where XX.XXXXX is the available soil moisture stored in the soil at the end of that day.

Word 5. 000XXXXXXX

Where XX.XXXXX is the actual change in the stored available moisture in inches.

Word 6. 0000000XXX

Where X.XX is the soil moisture deficit or surplus depending on sign. Plus is surplus, minus is deficit.

Word 7. 000000XXXX

Where XX.XX is the gravitational water retained in the soil for subsequent future loss.

Word 8. 000000XXXX

Where XX.XX is the total water retained in the soil both as gravitational and available.

Availability

A program deck of this program is available at the Louisiana State University Computer Center and may be obtained by writing Louisiana State University School of Forestry and Wildlife Management, Baton Rouge 3, Louisiana.

APPENDIX C

Annual Height Growth of Measurement Trees, 1954 to 1959

(In feet)

Plot number	Tree number	1959	1958	1957	1956	1955	1954
		Plantation A, Beauregard Parish					
1	1	3.4	4.0	3.6	4.1	4.2	4.5
	2	3.9	5.1	3.6	4.5	4.0	3.8
	3	4.1	5.1	4.5	4.6	4.0	4.9
	4	3.9	3.9	3.8	3.8	3.4	4.5
	5	5.7	4.4	3.5	4.6	3.7	4.4
2	1	4.7	4.5	3.8	4.2	4.8	5.0
	2	4.1	4.5	3.3	4.9	4.1	4.9
	3	5.0	4.2	3.5	4.4	4.4	4.8
	4	4.9	4.3	4.0	4.8	4.2	5.2
	5	4.8	3.7	4.2	4.8	4.0	4.9
3	1	4.3	5.0	2.2	3.7	3.4	3.5
	2	4.4	4.2	2.1	3.2	2.8	1.8
	3	4.3	4.2	3.9	3.6	3.5	3.9
	4	3.5	3.9	2.7	3.3	3.4	3.5
	5	4.0	4.4	3.0	4.1	3.1	4.8
4	1	3.6	4.4	3.5	3.7	4.3	5.0
	2	4.4	5.5	2.8	4.2	3.4	5.4
	3	4.4	3.9	3.7	3.1	4.4	3.5
	4	4.1	4.0	3.9	4.0	4.1	5.1
	5	4.8	3.2	3.8	3.9	4.5	4.2
5	1	4.9	4.1	4.6	4.4	4.6	4.3
	2	4.1	4.1	4.8	4.1	4.4	5.0
	3	4.5	4.5	4.2	4.5	4.4	5.1
	4	4.5	4.7	3.4	4.7	4.9	4.5
	5	4.6	3.5	4.1	4.0	4.4	4.5
6	1	5.0	4.3	4.9	4.2	3.9	5.0
	2	5.0	4.6	3.5	3.8	4.7	5.3
	3	4.0	4.2	3.8	3.7	3.6	3.7
	4	4.5	4.1	3.8	4.4	4.2	4.8
	5	4.7	4.6	3.8	4.3	4.1	4.8

Plot number	Tree number	1959	1958	1957	1956	1955	1954
Plantation B, Allen Parish							
7	1	4.1	2.7	2.3	2.9	4.8	4.4
	2	3.2	2.9	3.1	3.1	3.7	3.7
	3	2.7	2.6	3.8	4.1	3.9	4.4
	4	4.0	2.2	3.6	3.5	4.3	3.9
	5	3.3	3.2	2.8	3.3	3.7	4.4
8	1	3.7	3.4	3.7	3.9	3.1	4.7
	2	3.6	2.5	3.2	3.9	3.0	4.1
	3	3.6	3.0	2.7	4.2	5.9	3.4
	4	3.1	3.5	2.9	3.7	2.9	4.2
	5	3.8	3.0	3.0	3.4	3.2	4.1
9	1	3.4	3.2	2.3	3.5	3.5	3.6
	2	3.4	3.8	3.7	3.9	3.5	3.4
	3	3.8	2.4	3.4	4.3	3.7	3.7
	4	3.4	2.7	3.1	2.5	3.4	3.8
	5	2.9	2.6	3.6	4.0	2.4	2.9
10	1	3.8	3.5	3.7	4.4	4.8	4.0
	2	3.9	2.4	3.2	3.6	3.2	4.8
	3	4.1	2.8	3.2	3.8	3.8	4.5
	4	3.7	2.4	2.8	3.9	3.0	4.1
	5	3.0	3.8	3.0	3.4	3.6	3.8
11	1	3.7	3.3	2.3	4.2	2.9	3.6
	2	2.7	3.2	2.4	3.6	2.9	3.3
	3	3.3	2.8	3.0	3.5	2.8	3.1
	4	3.1	3.3	2.7	3.5	2.5	4.9
	5	2.9	2.8	2.0	3.7	3.4	2.8
12	1	3.8	4.4	3.4	3.3	3.7	3.6
	2	4.1	4.1	3.9	3.6	3.9	3.0
	3	3.6	2.9	3.0	3.7	3.1	3.7
	4	3.7	3.0	3.2	4.1	3.5	4.5
	5	4.4	2.9	3.0	4.0	3.3	3.0
13	1	4.8	3.4	4.4	4.1	4.8	3.9
	2	4.1	4.0	3.2	4.0	3.8	4.2
	3	4.7	3.6	4.0	4.4	4.3	4.4
	4	3.8	4.1	3.8	4.4	4.0	4.7
	5	4.6	3.8	3.6	3.5	4.4	4.0
14	1	4.9	4.0	3.6	3.9	3.3	2.5
	2	3.4	4.2	4.3	4.1	3.5	3.0
	3	3.8	4.2	3.8	3.3	3.6	2.5
	4	4.7	4.2	4.9	2.8	3.4	3.1
	5	4.0	3.5	3.3	3.9	3.0	2.4

Plot number	Tree number	1959	1958	1957	1956	1955	1954
		Plantation C, Washington Parish					
15	1	3.5	3.6	3.5	4.7	3.8	3.8
	2	4.7	4.7	3.8	3.7	3.6	4.2
	3	3.7	4.8	4.1	4.8	3.9	4.1
	4	3.2	4.0	2.9	4.3	3.5	3.8
	5	3.8	3.6	3.9	4.6	3.2	4.4
16	1	3.8	4.0	4.2	4.2	3.0	3.2
	2	3.3	4.5	3.6	5.4	3.9	4.2
	3	3.5	4.1	3.7	4.3	2.8	4.3
	4	4.1	3.3	4.3	3.8	3.5	4.1
	5	4.5	4.3	4.2	4.7	3.2	4.1
17	1	3.0	4.2	3.8	5.1	3.8	4.1
	2	3.3	3.7	3.9	4.3	3.1	3.6
	3	3.3	3.5	3.6	3.8	3.0	4.0
	4	4.0	4.4	4.1	4.3	3.9	4.6
	5	3.6	3.9	3.5	4.3	3.7	4.7
18	1	3.7	3.6	3.3	4.4	1.9	2.2
	2	4.4	4.5	4.3	3.3	2.9	2.9
	3	3.8	3.0	3.9	3.2	1.8	2.2
	4	4.6	4.3	4.6	4.4	2.9	2.9
	5	3.9	3.0	3.2	3.6	2.8	2.7
19	1	3.8	3.6	4.1	3.9	4.2	4.0
	2	3.3	3.6	4.2	4.0	3.0	3.9
	3	4.3	3.2	3.4	4.5	2.7	4.1
	4	3.9	3.9	3.9	4.4	3.3	3.6
	5	4.5	4.7	3.9	4.6	3.4	5.7

Plot number	Tree number	1959	1958	1957	1956	1955	1954
			Plantation D, LaSalle Parish				
20	1	4.2	2.3	3.6	2.8	4.0	3.7
	2	4.6	2.8	3.0	3.1	3.6	3.3
	3	4.3	4.3	4.0	5.1	4.6	3.4
	4	3.7	2.7	2.4	3.8	4.6	2.6
	5	3.5	3.8	3.6	4.0	3.9	3.3
21	1	4.4	4.3	3.7	4.9	3.5	3.8
	2	4.5	3.2	4.1	4.0	3.2	2.7
	3	4.0	4.5	4.4	4.6	3.9	3.9
	4	3.6	3.8	4.1	3.9	4.2	3.6
	5	4.4	4.4	3.8	4.3	3.4	3.6
22	1	4.9	4.9	4.7	4.3	3.8	4.6
	2	4.0	4.1	2.5	4.4	4.2	4.2
	3	3.7	4.3	3.0	4.2	3.8	4.8
	4	3.5	4.6	3.4	5.9	3.8	4.3
	5	4.0	4.6	3.8	4.1	3.3	4.0
23	1	3.2	3.7	3.5	3.7	3.8	3.5
	2	3.6	4.0	3.7	4.3	3.1	3.2
	3	3.0	3.3	3.1	4.5	3.4	3.7
	4	3.6	4.7	3.9	4.8	3.3	4.0
	5	4.3	3.4	4.4	3.8	3.2	3.3
24	1	4.0	4.3	3.1	3.9	2.3	2.1
	2	4.1	4.5	3.5	3.9	2.3	1.5
	3	4.4	3.8	4.3	4.3	2.7	1.8
	4	4.0	3.9	3.6	4.0	2.5	2.4
	5	3.8	4.0	4.1	2.5	2.9	2.1
25	1	3.0	3.8	3.2	4.3	3.2	4.6
	2	4.0	4.4	3.1	4.2	3.4	4.5
	3	5.8	4.0	4.6	3.4	5.0	3.6
	4	3.1	3.3	4.9	5.5	3.6	4.6
	5	3.1	3.5	3.7	3.7	3.9	4.4
26	1	3.5	4.9	3.8	4.0	3.5	4.4
	2	3.1	2.7	3.1	4.1	3.3	3.9
	3	3.6	3.9	4.1	4.7	3.3	4.2
	4	3.9	3.7	4.0	4.8	3.6	4.0
	5	4.1	3.0	4.0	4.0	3.9	4.3

Plot number	Tree number	1959	1958	1957	1956	1955	1954
		Plantation E, Claiborne Parish					
27	1	3.7	4.1	4.0	4.2	4.3	4.3
	2	3.6	4.1	4.3	3.8	3.8	2.8
	3	4.1	4.3	4.4	4.4	4.3	3.2
	4	3.7	4.5	4.4	4.3	3.1	2.8
	5	4.4	4.4	4.3	4.7	3.4	3.0
28	1	4.3	4.3	4.1	3.8	3.5	2.9
	2	4.7	4.8	4.8	3.6	2.4	1.8
	3	3.7	4.6	4.7	4.5	3.9	2.9
	4	4.4	4.7	4.3	4.5	3.5	2.9
	5	5.0	4.3	4.4	4.0	3.1	2.0
29	1	5.5	3.7	4.7	4.0	3.3	3.6
	2	4.5	5.2	5.8	3.7	5.4	4.8
	3	3.7	4.3	4.3	4.5	3.4	2.6
	4	3.7	4.8	4.4	3.4	3.6	4.4
	5	3.7	5.8	4.2	4.0	3.2	2.7
30	1	3.5	4.1	3.7	4.0	3.1	2.7
	2	4.9	5.2	4.6	4.6	2.8	2.2
	3	3.4	4.1	4.4	3.7	3.2	3.3
	4	4.0	4.6	4.3	4.0	3.3	2.1
	5	3.5	4.3	5.3	4.8	3.9	2.8
31	1	4.0	4.7	4.5	4.3	3.8	3.5
	2	4.3	4.6	4.1	4.6	2.9	3.7
	3	3.6	4.4	4.7	4.3	3.7	3.3
	4	4.0	3.5	3.6	4.0	3.6	3.3
	5	3.2	4.7	4.2	4.4	2.9	3.9
32	1	3.2	4.3	4.2	4.1	4.1	2.9
	2	3.3	4.2	3.9	4.0	3.9	3.5
	3	4.0	3.8	4.0	4.0	4.3	2.7
	4	4.2	4.3	4.6	3.6	4.1	2.9
	5	4.1	3.9	4.6	3.5	4.1	2.8
33	1	3.8	4.1	4.5	4.5	4.0	3.1
	2	4.1	4.6	3.9	4.2	4.0	3.4
	3	4.3	4.1	4.5	3.2	4.2	3.5
	4	3.1	5.1	5.0	3.9	3.8	2.6
	5	3.8	4.7	4.3	4.4	2.9	2.7

APPENDIX D

Monthly Precipitation and Mean Monthly Temperatures at the Five Study Plantations, 1953 Through 1959

Plantation A, Beauregard Parish

Precipitation
(In inches)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1953	1.70	6.40	2.30	10.83	20.10	7.02	5.79	2.59	0.56	2.00	2.29	10.52	72.10
1954	4.32	5.06	6.20	5.30	14.35	0.88	4.45	0.87	1.15	3.33	1.72	1.60	49.23
1955	5.97	8.22	0.21	6.76	13.59	6.58	5.08	14.01	2.65	1.99	3.58	2.59	71.23
1956	4.81	4.95	3.33	3.23	1.27	5.11	0.22	1.57	0.82	2.38	4.28	15.11	47.08
1957	1.20	3.27	9.53	8.40	1.71	10.46	1.17	4.15	10.00	6.07	14.41	4.84	75.21
1958	3.64	3.43	2.95	4.82	3.07	4.48	5.88	8.30	12.71	2.73	4.34	1.91	58.26
1959	3.87	10.88	1.58	6.29	3.80	2.85	10.00	4.76	2.10	3.22	1.05	4.97	55.37
Mean	3.64	6.03	3.73	6.52	8.27	5.34	4.66	5.18	4.29	3.10	4.52	5.93	61.21

Temperature
(In degrees Fahrenheit)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1953	56.1	53.6	66.8	66.0	75.4	82.3	81.3	80.7	76.9	68.8	56.6	49.7	67.8
1954	53.7	59.3	59.6	72.0	71.0	81.6	83.7	84.4	80.2	71.1	57.8	55.2	69.1
1955	52.6	55.7	64.3	70.4	76.4	76.9	80.5	81.5	80.4	68.4	58.2	54.0	68.2
1956	50.5	58.3	62.1	67.5	76.7	78.7	83.4	82.4	78.1	70.9	57.7	57.4	68.6
1957	53.7	60.7	58.4	68.4	75.4	80.2	83.5	82.4	74.9	65.6	60.0	54.9	68.2
1958	49.5	48.8	58.2	68.5	76.0	82.1	83.1	82.4	78.6	68.2	59.7	54.2	66.8
1959	46.6	51.9	56.7	64.4	75.5	80.1	81.3	81.5	78.2	69.7	54.0	51.5	65.9
Mean	51.8	55.5	60.9	68.2	75.2	80.3	82.4	82.2	78.2	69.0	57.7	53.8	67.8

Plantation B, Allen Parish

Precipitation
(In inches)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1953	2.53	9.82	4.61	8.65	22.37	2.64	4.92	5.20	1.50	1.47	2.90	6.03	72.64
1954	3.16	0.34	3.37	5.65	14.20	1.97	4.43	0.82	2.95	7.02	2.10	2.82	48.83
1955	7.66	11.43	0.53	6.05	9.49	3.68	8.00	8.80	4.23	1.43	2.17	5.64	69.11
1956	3.72	8.53	8.26	3.06	3.61	3.47	1.55	2.72	1.06	1.47	4.64	13.22	55.31
1957	1.40	3.05	7.97	9.02	1.16	9.77	5.12	2.11	4.18	6.83	18.25	6.35	75.21
1958	5.33	3.63	4.65	5.56	6.12	5.48	2.42	9.60	8.55	2.20	2.86	1.77	58.17
1959	4.25	7.69	2.97	6.64	5.54	3.51	6.02	4.26	6.91	4.72	2.16	7.08	61.75
Mean	4.01	6.36	4.62	6.38	8.93	4.36	4.64	4.79	4.20	3.59	5.01	6.13	63.00

Temperature
(In degrees Fahrenheit)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1953	54.2	54.2	66.1	66.7	76.2	83.6	82.0	81.6	78.5	70.4	56.9	49.4	68.3
1954	53.7	59.3	59.6	72.0	71.0	81.6	83.7	84.4	80.2	71.1	57.8	55.2	69.1
1955	51.5	53.1	63.5	70.5	77.2	78.1	81.3	81.6	80.2	67.6	55.4	53.0	67.7
1956	49.1	56.9	59.1	65.4	75.9	78.3	83.7	82.0	76.3	71.9	57.6	58.2	67.9
1957	53.0	60.5	56.1	67.4	76.0	69.8	83.6	82.2	73.7	66.0	59.1	50.9	67.3
1958	44.9	46.7	53.6	65.7	75.1	81.6	82.7	80.9	79.0	67.1	59.6	47.7	65.3
1959	47.2	52.6	57.3	64.6	75.0	79.3	80.5	81.3	77.5	69.2	53.8	51.4	65.8
Mean	50.5	54.8	59.3	67.5	75.2	78.9	82.5	82.0	77.9	69.0	57.2	52.3	67.3

Plantation C, Washington Parish

Precipitation
(In inches)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1953	2.48	6.64	5.17	7.59	6.95	9.67	5.97	6.64	0.71	0.05	6.36	21.52	79.75
1954	2.17	2.50	2.57	4.38	2.31	2.59	11.85	1.36	3.32	6.36	2.53	4.73	46.67
1955	5.92	4.88	0.22	7.78	3.84	1.37	3.36	5.49	1.09	1.70	3.30	2.96	41.91
1956	2.63	7.11	7.10	1.98	6.96	8.80	7.45	2.37	6.68	4.58	2.60	4.46	62.72
1957	2.16	3.06	4.30	6.48	2.53	4.82	1.30	3.43	9.13	2.77	9.22	3.74	52.94
1958	4.64	4.57	7.86	4.24	11.93	5.48	7.97	4.25	3.79	1.37	0.96	1.96	59.02
1959	4.32	7.80	4.50	4.21	11.14	10.13	9.70	7.15	3.55	9.54	3.99	3.91	79.94
Mean	3.47	5.22	4.53	5.24	6.52	6.12	6.80	4.38	4.04	3.77	4.14	6.18	60.42

Temperature
(In degrees Fahrenheit)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1953	54.2	53.3	63.9	65.9	76.8	83.7	81.2	80.9	76.8	68.7	56.3	49.2	67.6
1954	52.2	56.9	57.4	71.4	70.2	81.3	82.6	83.5	79.7	68.8	55.4	50.2	67.5
1955	50.3	54.4	63.6	68.4	77.0	77.3	81.7	81.4	79.3	66.6	56.9	52.8	67.5
1956	47.7	58.4	57.8	65.1	76.5	78.3	82.3	81.3	75.4	68.6	58.1	61.4	67.6
1957	58.9	63.6	60.6	69.9	76.6	81.4	83.7	81.0	76.0	64.0	60.9	54.2	69.3
1958	46.8	47.9	57.6	68.9	74.9	81.4	82.5	81.4	79.1	66.8	60.5	48.2	66.4
1959	46.5	53.2	55.9	64.6	75.8	79.5	81.0	81.4	77.7	70.4	54.9	51.5	66.0
Mean	50.9	55.4	59.5	67.7	75.4	80.4	82.1	81.6	77.7	67.7	57.6	52.5	67.4

Plantation D, LaSalle Parish

Precipitation
(In inches)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1953	2.51	7.48	7.53	13.11	21.57	1.60	3.05	7.55	0.67	1.95	1.50	7.09	75.61
1954	3.10	1.25	2.93	2.71	14.40	0.88	2.71	1.28	3.70	2.18	1.49	1.83	38.46
1955	5.88	8.21	0.94	8.32	3.38	3.49	12.16	6.46	1.98	3.38	1.94	3.52	59.66
1956	2.68	9.53	4.43	1.16	2.38	2.70	2.86	3.52	0.39	2.64	4.14	9.30	45.73
1957	3.18	2.86	7.99	8.38	4.49	6.67	5.70	0.56	7.99	5.80	12.46	3.51	69.59
1958	4.76	4.41	6.26	8.02	4.40	6.90	8.55	10.25	8.74	2.02	3.92	1.41	69.64
1959	1.84	4.87	3.59	7.13	4.70	3.45	7.22	4.66	2.20	5.44	1.02	6.74	52.86
Mean	3.42	5.52	4.81	6.98	7.90	3.67	6.04	4.90	3.67	3.34	3.78	4.77	58.79

Temperature
(In degrees Fahrenheit)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1953	52.2	51.6	63.7	66.4	74.3	83.3	81.2	79.2	76.0	67.3	53.1	45.6	66.0
1954	48.7	54.8	55.2	67.6	66.1	80.4	84.3	83.5	80.0	68.6	55.5	51.1	66.3
1955	48.3	50.8	62.2	69.4	75.2	76.6	81.3	80.5	78.5	65.7	55.4	50.6	66.2
1956	46.1	54.6	58.0	65.4	76.9	78.5	82.6	82.3	76.8	69.5	55.3	55.8	66.8
1957	50.5	58.7	57.4	67.2	73.9	79.6	82.2	81.0	76.0	64.0	60.9	54.2	69.3
1958	44.1	43.5	52.3	65.9	74.2	80.1	82.1	80.4	78.3	67.2	58.5	46.2	64.4
1959	45.2	51.6	56.2	64.7	74.9	78.7	80.9	81.2	76.9	68.4	52.9	50.0	65.1
Mean	47.9	52.2	57.9	66.7	73.6	79.6	82.1	81.2	77.5	67.2	55.9	50.5	66.3

Plantation E, Claiborne Parish

Precipitation
(In inches)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1953	4.59	6.23	6.45	9.74	10.49	2.70	3.24	2.97	0.72	1.14	5.01	6.06	59.34
1954	4.12	1.00	1.68	5.66	5.51	0.86	1.64	0.80	0.55	0.92	4.39	3.48	30.61
1955	3.36	4.53	5.96	5.32	8.29	4.76	9.08	3.78	1.91	1.35	1.82	2.05	52.21
1956	2.62	7.78	4.36	6.28	2.83	4.57	1.90	2.66	1.73	2.52	4.33	2.92	44.50
1957	7.53	4.75	3.07	10.55	8.90	7.52	2.92	0.82	4.38	8.39	12.87	3.10	74.80
1958	3.74	2.38	3.10	11.73	6.28	5.09	5.24	4.04	9.88	0.45	4.23	0.79	56.95
1959	1.56	4.68	4.59	4.30	6.05	7.37	5.66	3.17	3.65	1.87	2.24	5.12	50.26
Mean	3.93	4.48	4.17	7.65	6.91	4.70	4.24	2.61	3.26	2.38	4.98	3.36	52.67

Temperature
(In degrees Fahrenheit)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1953	52.8	49.8	62.0	62.1	73.0	83.7	80.7	80.2	77.2	68.9	55.0	45.8	65.9
1954	49.7	56.5	56.2	68.7	67.2	81.0	85.3	85.4	79.3	68.4	55.5	50.9	67.0
1955	46.9	48.9	60.1	67.3	73.8	74.8	80.6	79.6	77.6	66.1	54.6	46.3	64.7
1956	45.9	53.6	55.9	63.4	74.4	77.8	81.9	82.2	75.4	68.3	55.8	55.0	65.7
1957	46.5	55.8	53.4	62.7	71.3	77.4	81.3	80.4	72.9	61.2	54.3	51.7	64.1
1958	43.2	42.6	51.4	63.9	72.6	79.7	81.8	80.7	76.0	63.9	57.1	44.1	63.1
1959	44.3	50.9	55.6	63.4	74.6	77.1	79.5	79.5	75.4	65.3	50.9	48.9	63.8
Mean	47.0	51.2	56.4	64.5	72.4	78.8	81.6	81.1	76.3	66.0	54.7	49.0	64.9

VITA

James W. Curlin was born in Pine Bluff, Arkansas, October 4, 1932. Shortly after his birth his parents moved to St. Louis, Missouri. There he attended primary school and graduated from suburban Kirkwood High School, Kirkwood, Missouri in 1950. Mr. Curlin enrolled the same year at Arkansas Agricultural and Mechanical College, College Heights, Arkansas and majored in forestry. He received his Bachelor of Science degree in 1954. Shortly thereafter he entered the U.S. Army, served in Korea, and was released from active duty in 1956.

Mr. Curlin worked for Kirby Lumber Corporation, and International Paper Company as a management forester in Texas and Louisiana before enrolling in the graduate program of the School of Forestry and Wildlife Management at Louisiana State University. He earned his Master of Forestry degree in 1959 and continued graduate work toward a doctorate in the L. S. U. Agronomy Department.

Since 1960, Curlin has been employed by the Division of Forestry Development of the Tennessee Valley Authority, Norris, Tennessee. He is responsible for the Division's program in forest fertilization research.

Mr. Curlin is married to the former Patricia Ann Stevens and is the father of two children, Kimberly, 7 years old and James, 8 months old. Curlin is presently a candidate for the degree of Doctor of Philosophy.

EXAMINATION AND THESIS REPORT

Candidate: James William Curlin

Major Field: Agronomy

Title of Thesis: Effects of Soil Moisture on the Height Growth of Slash Pine (Pinus elliottii Engelm.)

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

July 16, 1964