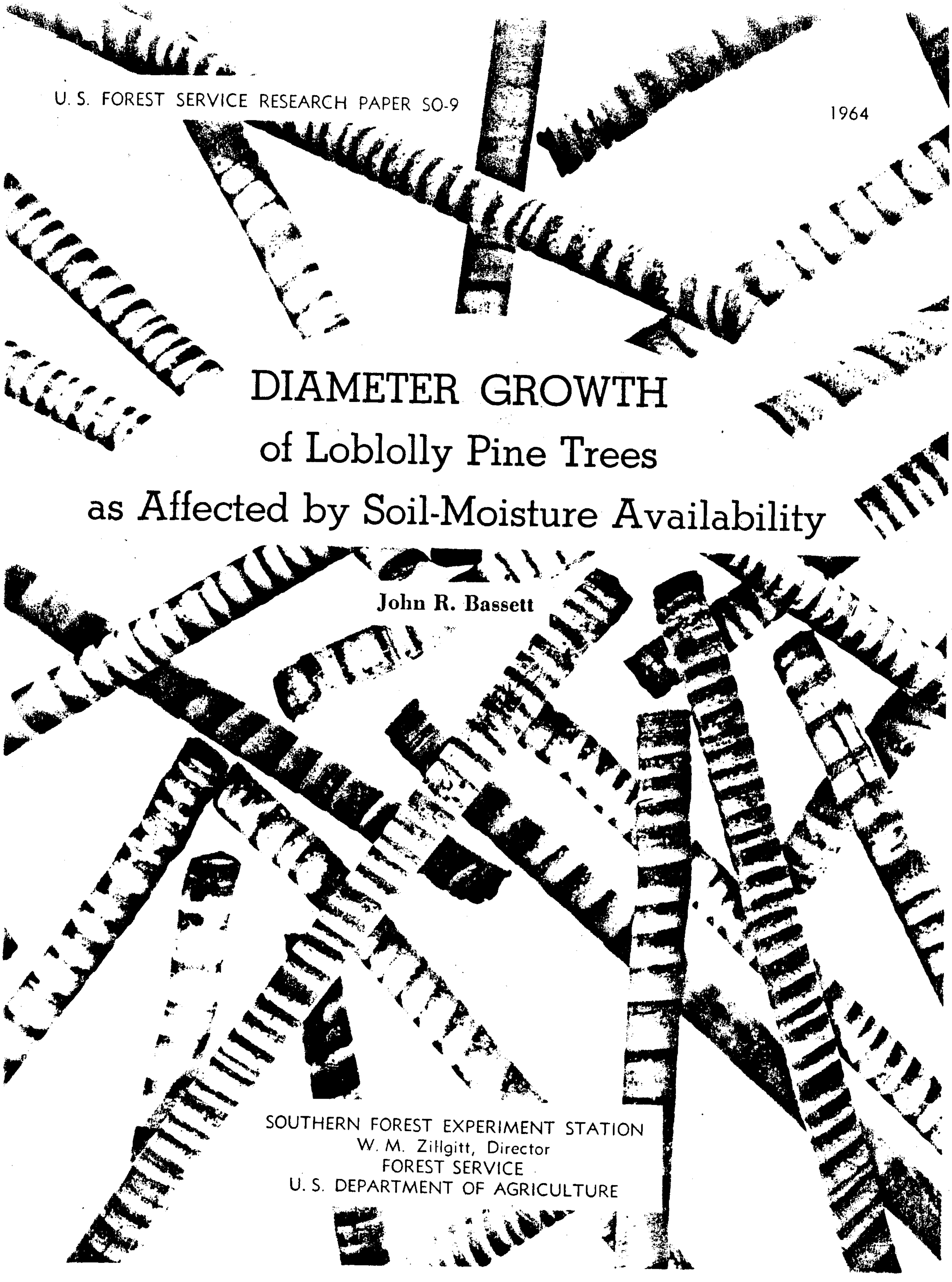

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DIAMETER GROWTH of Loblolly Pine Trees as Affected by Soil-Moisture Availability

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In a 30-year-old even-aged stand of loblolly pine on a site 90 loessial soil in southeast Arkansas during four growing seasons, most trees on plots thinned to 125 square feet of basal area per acre increased in basal area continuously when, under the crown canopy, available water in the surface foot remained above 65 percent. Measurable diameter growth ceased when available water under crowns was less than 40 percent and daily potential evapotranspiration exceeded 0.24 inch of water. Trees on plots thinned to 55 square feet of basal area per acre grew continuously.

In the Midsouth soil-moisture supply often limits diameter increment during the growing season *(20, 28)*.[1] Some investigators have demonstrated this fact indirectly by relating increment to periodic precipitation *(2, 3, 6, 10, 17, 26)*. Others have related bole growth directly to soil-water content *(1, 4, 7, 8, 9, 12, 18)*.

The forester determines, by thinning, which trees in a stand comprise growing stock and, presumably, influences the rates at which they absorb water. However, he faces the question of how growth rates differ by stocking level and site. The answer will enable him to carry the lowest level needed to grow wood of the desired properties on a given site in the shortest time.

[1] Italic numbers in parentheses refer to Literature Cited, p. 6.

This paper reports results of a study designed to learn at what level of soil-water deficiency diameter increment is appreciably reduced in loblolly pine *(Pinus taeda* L.) trees growing on loessial soils in southeast Arkansas.

STUDY AREA

The study area is 14 miles east of Crossett, Ark., in an even-aged stand of southern pines, chiefly loblolly, 30 years old in 1960. Soils consist primarily of site 90 Calloway and Grenada silt loams, Gray-Brown Podzolic types derived from loess. A fragipan at a depth of 18 to 25 inches impedes roots and contributes to the formation of a perched water table which normally appears in January and remains until May. The upper 4 feet stores about 13 inches of water available to roots (table 1).

Normal rainfall during the growing season (March through October) is about 33 inches. Total growing-season rainfall in 1960 was 4 inches below normal, primarily because of a July drought. In 1961 it was 5 inches above normal and unusually well distributed. In 1962, March-October rainfall was 7 inches below normal, and most of the deficit occurred during spring. In 1963 it was 3 inches below normal, but the preceding 4 months were so dry that soil was not recharged.

From Thornthwaite's method *(23)* and field observations, Zahner *(28)* estimated that nor-

TABLE 1.—*Soil physical properties*

Soil		Contents of—			Bulk density	Water		
Horizon	Depth	Sand	Silt	Clay		At 0.06-atm. tension	At 15-atm. tension	Available to roots [1]
	Inches	*- - - Percent - - -*			*G./c.c.*	*- - - - - Inches - - - - -*		
A	0-7	14	72	14	1.38	2.8	0.6	2.2
B	7-22	13	68	19	1.48	5.5	1.4	4.1
Fragipan	22-48	12	66	22	1.60	9.2	2.5	6.7
Total						17.5	4.5	13.0

[1] Water held between 0.06 and 15-atm. tension.

mal daily potential evapotranspiration (PE) at Crossett is about 0.07 inch of water in early April, rises to 0.27 inch in mid-July, and returns to 0.07 inch by late October.

METHODS

Treatments.—In December 1949, as part of another study, many 0.1-acre plots were established. All plots were subsequently thinned from below to prescribed levels of basal area in January of 1950, 1955, and 1960. Three plots were selected from each of three levels: 55, 80, and 125 square feet per acre, hereafter referred to as T-55, T-80, and T-125 plots. Adjacent plots are 130 to 400 feet apart. Table 2 summarizes stand data before and after thinning.

Measurements.—Diameter increment, rainfall, and soil moisture were measured during the growing seasons of 1960-63. Moisture data were not collected regularly in 1962. Diameter increments of all trees were measured to the nearest 0.01 inch, weekly in 1960 and 1963 and biweekly in 1961 and 1962, with aluminum-band dendrometers *(11, 16)*. Precipitation was collected on a T-55 plot in one standard rain gage.

During 1960 moisture was measured by 6-inch layers to a depth of 48 inches. Thereafter moisture sampling was restricted to the 0-6 and 6-12 inch layers because so many roots are concentrated in the surface foot that most summer rainfall is absorbed before penetrating below it.

Each time moisture was measured at a plot the 0-6 and 6-12 inch layers were sampled gravimetrically at four random points under the crown canopy. Supplemental moisture samples were collected in openings. During 1960 moisture was measured weekly from April to July 13, then biweekly through October. As the soil remained relatively wet throughout 1961, sampling was deferred until July 9 after the initial measurement in April, then scheduled six times until October 12. During 1963 moisture was measured on March 6 and May 13, then weekly from June 10 to September 2. Moisture contents between measurements were estimated. Accretion was based on the amount of precipitation and storage space available at the time of the storm. Depletion rates were based on measured depletion between rainfalls.

Undisturbed soil cores and bulk soil samples were collected from the 0-6 and 6-12 inch layers at four points on each plot. They were saturated and subjected to pressures *(15, 22)* of 0.06 to 15 atmospheres (atm.) to relate the amount of available water and its tension to water content in the surface foot (fig. 1).

TABLE 2.—*Stand data per acre, January 1960*

Treatment	Before thinning			After thinning		
	Trees	D.b.h.	Basal area	Trees	D.b.h.	Basal area
	Number	*Inches*	*Sq. ft.*	*Number*	*Inches*	*Sq. ft.*
T-55	167	10.1	89.6	83	11.2	56.5
T-80	307	8.5	116.9	150	9.9	79.7
T-125	380	8.6	153.8	260	9.5	126.5

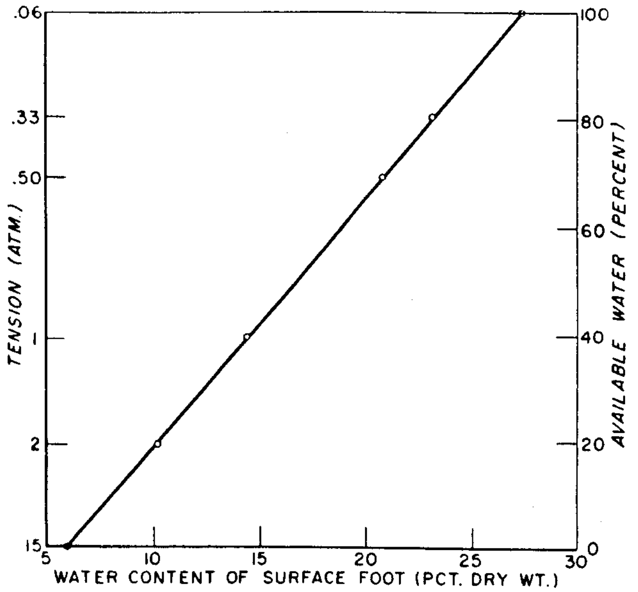

FIGURE 1.—*Relation of amount of available water and its tension to water content in surface foot of soil.*

RESULTS

Growth on T-125, T-80, and T-55 plots totaled 20.6, 19.7, and 18.3 square feet of basal area per acre (table 3). The 83 trees per acre on the T-55 plots increased 89 percent as much in basal area as the 260 trees per acre on the T-125 plots. Figure 2 illustrates mean annual basal-area growth of equal-size trees by treatment. For example, each 11-inch tree on T-55 plots increased 0.049 square foot whereas its counterparts on T-80 and T-125 plots grew 0.039 and 0.029 square foot. The key to these growth differences is the relation of diameter increment to availability of soil moisture.

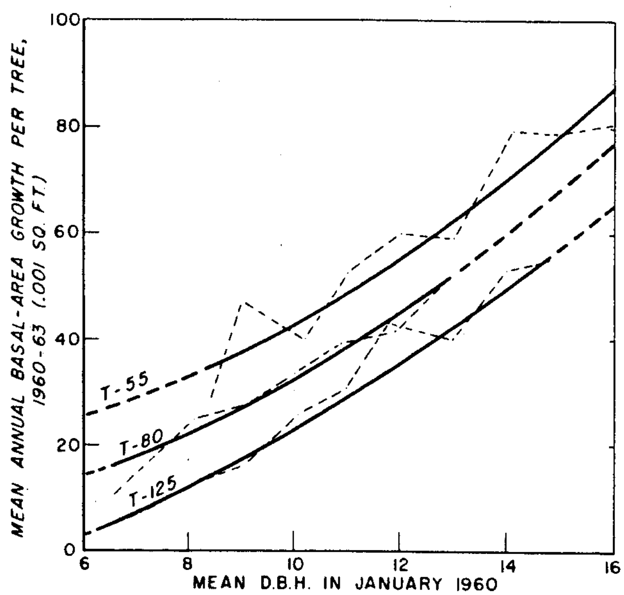

FIGURE 2.—*Mean annual basal-area growth by 1-inch diameter classes.*

TABLE 3.—*Basal-area growth per acre, 1960-63*

Year	Treatments T-55	T-80	T-125
	- - - - - - *Sq. ft.*	- - - - - -	
1960	4.2	4.6	5.2
1961	5.3	5.7	6.1
1962	5.3	5.7	5.8
1963	3.5	3.7	3.5
Total	18.3	19.7	20.6

T-125 plots are used to illustrate this relation because, at their level of stocking, little if any available water (AW) in the root zone escaped absorption, even during the first year following thinning. Moreover, in some site 90 stands this stocking level produces near-maximum cubic-foot growth *(21, p. 7)*.

In 1960 (fig. 3), from early April to May 24, basal-area growth was rapid because AW remained near 100 percent and transpiration demands were relatively low (normal PE reaches 0.17 inch of water per day by May 24). By June 24, when normal PE is 0.22 inch, AW under crowns had dropped to 47 percent; growth continued between May 24 and June 24, but at one-third the rate during the previous 30 days. On July 8, when normal PE is 0.26 inch, AW again was 47 percent, but most trees had stopped measurable increment. Rapid growth followed the heavy rains of early August. Growth rates diminished during September and were negligible after October 7.

During 1961 AW under crowns remained above 60 percent throughout the growing season except for a few days in July (fig. 4). Diameter increment was relatively uniform through September 15 and continued until November 18.

Diameter increment in 1963 began early and accelerated through April (fig. 4). In contrast to 1961, soil-moisture deficits limited growth during the summer and early fall of 1963. On June 14 AW under crowns was 10 percent, yet most trees continued to enlarge, although at diminished rates. From late June through July PE normally exceeds 0.25 inch, and measurable increment ceased when AW

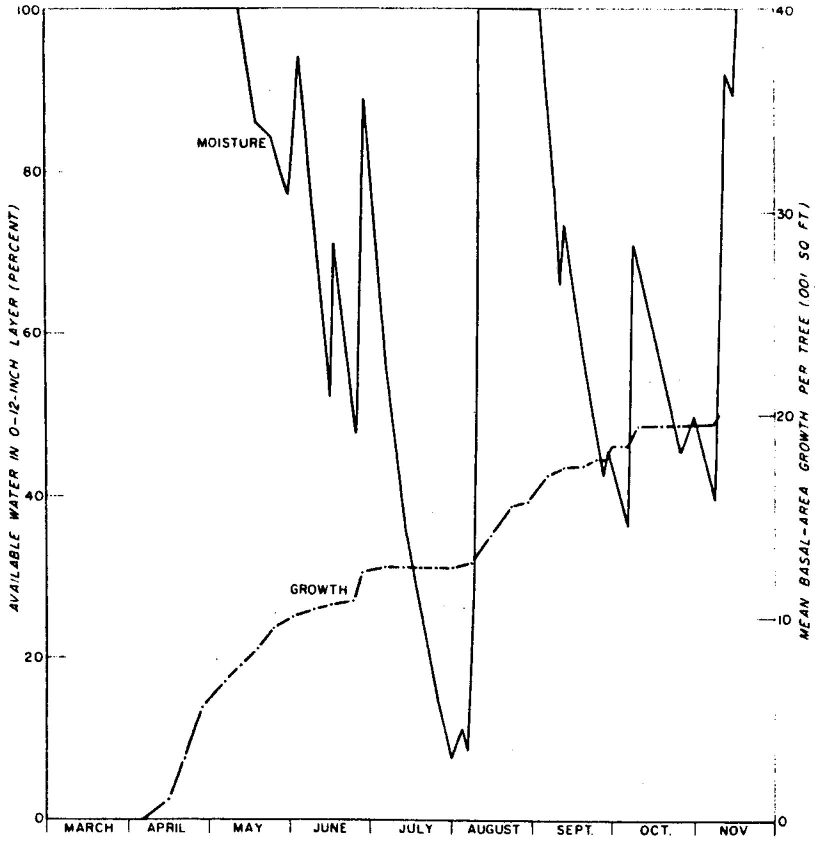

FIGURE 3.—
Growth on T-125 plots related to available water, 1960.

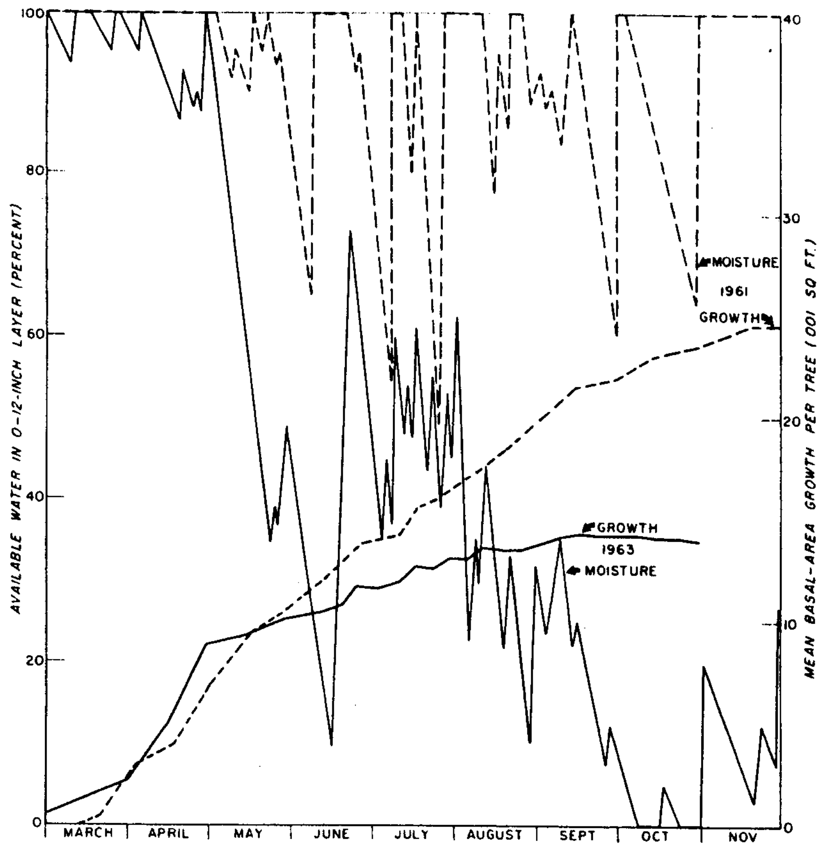

FIGURE 4.—
Growth on T-125 plots related to available water, 1961 and 1963.

dropped below about 40 percent. The remainder of the growing season after August 12 was very dry, and growth was negligible.

In contrast, T-55 trees enlarged continuously throughout each summer, including four periods (80 days) during which AW under crowns was between 15 and 45 percent. During October 1963 AW was less than 15 percent on T-55 plots, and most trees ceased measurable growth. In autumn cambial activity is often limited by other factors, e.g., temperature *(6)* and photoperiod *(5)*.

Growth rates and AW contents on T-80 plots were intermediate, but were closer to those on the T-125 than on the T-55 plots.

DISCUSSION

Conductivity of soil water is very slow when tension exceeds 0.33 atm. *(19)*. Theoretically, an increase in tension to more than 1 or 2 atm. should diminish diameter growth *(14)*. Of course, the physiological processes of trees do not depend directly upon soil-moisture supply but rather on the balance between transpired and absorbed water that results from interactions of the tree with soil-moisture stress and atmospheric conditions *(13, 24)*.

Throughout March and April AW is at or near 100 percent and transpirational demands are relatively low. Hence tree water stress is low, and cambial activity is correspondingly high.

Transpiration demands increase rapidly in May and June. During June trees partially fulfill these demands by extracting water from lower depths *(27)*. Hence on June 14, 1963, trees were enlarging even though the surface foot contained only 10 percent AW (fig. 4). By June 30 stored water normally is largely depleted, and subsequent diameter growth depends upon precipitation.

During July and August cambial activity often is indirectly curtailed because roots cannot absorb water as fast as it is transpired. This occurred in July 1960 and August 1963 when AW was less than about 40 percent—equivalent to 1 atm. tension (fig. 1). Tension in soil pores immediately adjacent to root hairs certainly exceeded 1 atm. when measurable growth stopped, but this mean value may serve as an index of the moisture stresses in all pores of the surface foot regardless of their distance from root hairs.

In contrast, T-55 trees grew continuously throughout each summer even though, under the crown canopy, mean moisture tension in the surface foot at times exceeded 1 atm. Why?

All treatments prescribed thinning from below, so most trees cut from T-125 plots were either suppressed or intermediate trees which, by inference, had relatively small root systems. Their removal did not create large voids overhead or in the root zone. Trees thinned from T-55 plots, on the other hand, had larger crowns and presumably more extensive rooting: Crown and root competition were appreciably reduced where these trees were removed. Supplemental sampling in 1960 and 1962 showed that soil on T-55 plots was significantly (0.05 level) wetter near the center of the openings than under crowns. On T-125 plots, where openings were small and root competition was high, such reservoirs of available water did not exist. T-55 trees presumably were tapping low-tension water in openings when mean tension under crowns exceeded 1 atm. Consequently, water stress in T-55 trees probably never reached the high level experienced by T-125 trees. A few dominant and codominant T-80 trees grew continuously because their roots found low-tension water in the medium-size openings.

What do these results imply? Some foresters believe that, in managed stands of loblolly pine on site 90, 80 to 95 square feet of basal area per acre approximates the minimum level of stocking that will produce pulpwood and sawtimber without wasting growing space *(25, p. 297)*. When available water content is high, as it usually is in spring, root-free areas are, in a sense, waste space. But later, when soil-moisture supply limits diameter growth on heavily stocked stands, so-called waste space in more lightly stocked stands serves as a reservoir of available water that enables trees to continue growth. Little space is being wasted on T-55 plots, because their 4-year basal-area growth has nearly equaled that of T-125 plots.

A second implication is that soil-moisture measurements may be used to estimate current annual volume growth in well-stocked stands. For example, soils at Crossett normally store enough water over winter to enable trees to keep pace with transpirational demands through May. Enough stored water is available in June so that even without precipitation diameter growth continues slowly, although June rains stimulate growth. From July on, summer growth depends wholly upon rainfall, most of which is absorbed before it penetrates below the surface foot. Perhaps growth for a given year might be estimated from the expression:

$$G = a - bx$$

in which G = current annual volume growth
a = potential annual volume growth, based on growth during a wet year such as 1961
b = a constant
x = a soil-moisture index

Diameter growth in the well-stocked stands was appreciably reduced during summer when AW in the surface foot of soil was less than 40 percent. The value x, then, could be the number of days from June 1 to September 30 on which AW is less than 40 percent—an index of that portion of the growing season "lost" because of excessive tree water stress.

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