

STAND MANIPULATION: EFFECTS ON SOIL MOISTURE
AND TREE GROWTH IN SOUTHERN PINE AND PINE-HARDWOOD STANDS

O. Gordon Langdon and Kenneth B. Trousdell^{1/}

Abstract.--A literature review shows that water yields and soil moisture are affected by the amount and kind of vegetation present and that cuttings which reduce stand density increase soil moisture through increased throughfall and decreased water use resulting in more available water for the residual stand. Seasonal rainfall patterns differ within the South; droughts during the growing season are more frequent in the Midsouth than in the South Atlantic Region. Field studies have demonstrated adverse effects of soil moisture deficits on tree growth. Results of a study on a poorly drained site in the South Atlantic Coastal Plain showed that reducing stand density raised water table levels and that water table depths during the growing season are highly correlated with functions of stand basal area, precipitation, evaporation, and their interactions. Management strategies are discussed for reducing effects of moisture stress on moisture-deficient sites and of high water tables on wet, poorly drained sites.

Additional keywords: Water yields, stand density, moisture-deficient sites, poorly drained sites, rainfall patterns, cutting, water table levels, management strategies, loblolly pine, shortleaf pine, white pine, white oak, aspen.

INTRODUCTION

Our topic is centered around the question: Can one manipulate pine and pine-hardwood stands to change soil moisture relations in a way that improves tree growth?

Since one purpose of this symposium is to collate past and current work on the relationships between soil moisture and site productivity, we review pertinent literature on stand manipulation on both moisture-deficient and poorly drained sites. We also present the results of a recently completed study on how cutting stands on a poorly drained site in North Carolina affect water table levels.

^{1/} Principal Silviculturist and Silviculturist (Retired), Southeastern Forest Experiment Station, U. S. Department of Agriculture Forest Service, Charleston, S.C.

REVIEW OF THE LITERATURE

Effects of forest cutting on water yield

In reviewing the hydrology literature on effects of forest cutting on water yield, it becomes evident that the amount and kind of vegetation greatly influence runoff. When a mature forest is cut, water yields increase 5 to 16 inches per year depending on climate, soils, topography and other factors. Yields then decrease each year as the trees grow into sapling and larger sizes. In general, the increases are greater when normal streamflow is lowest, but streamflow is affected to some extent at all levels (Hart 1966; Hewlett 1958; Hewlett and Hibbert 1961; Hibbert 1966; Hibbert 1969; Hoover 1944; Kovner 1956; Lull and Sopper 1965; McMinn and Hewlett 1975; Reinhart and Lull 1965; Swank and Helvey 1970; Ursic and Thames 1960; Wooldridge 1968). Changing species from hardwood to white pine (*Pinus strobus* L.) decreased annual water yields after 10 years by 3.7 inches per year and after 15 years by nearly 8 inches over those expected from a hardwood forest (Swank and Miner 1968; Swank and Douglass 1974). But changing a hardwood stand to grass vegetation increased water yields by 5 inches annually (Hibbert 1969).

Part of these effects on water yields are attributed to species differences in transpiration rates and root distribution (Douglass 1966), but interception of rainfall also plays an important role and accounts for losses ranging from 10 to 35 percent (Swank 1968; Swank and others 1972). Other studies have shown that throughfall can be changed by manipulating stand density (Rogerson 1968). In fact, in a study with loblolly pine (*P. taeda* L.) in northern Mississippi where rainfall averages 52 inches, Rogerson (1968) found that each 20-square-foot decrease in basal area increased the rainfall reaching the ground by 1 inch per year.

Effect of cutting on soil moisture

Since cutting stands and changing species strongly influence water yields, we could deduce that these activities also affect soil moisture. Indeed, this conclusion is confirmed by studies in such widely separated areas as Arkansas, Lower Michigan, Ohio, South Carolina, and Australia (Moyle and Zahner 1954; Zahner and Donnelly 1967; Rogerson 1976; Marston 1962; Douglass 1960; Butcher 1976).

The intensity of thinning is positively correlated with the increase in available soil moisture (Zahner and Whitmore 1960). These effects, however, are not static; the roots of the unthinned trees quickly move into the space formerly occupied by trees that were removed. In fact, the effects of thinning on soil moisture decrease after 1 year (Douglass 1960) and disappear within a few years.

Effects of soil moisture on tree growth

Water deficits and water excesses affect tree growth by modifying various internal physiological processes (Kozlowski 1968; Kramer 1962). Several field studies have demonstrated the adverse effects of soil moisture deficits on growth of shortleaf pine (*P. echinata* Mill.) and white oak (*Quercus alba* L.) in Illinois, shortleaf in north Mississippi, loblolly in Arkansas, and loblolly in the Piedmont of South Carolina (Boggess 1956; McClurkin 1958; Stransky and Wilson 1964; Zahner and Whitmore 1960; Hoover and others 1953). In contrast, a 2-year study of soil-water relations with loblolly pine on a poorly drained site in the South Carolina Coastal Plain revealed no soil moisture deficits and no growth responses (Klawitter 1966).

Differences in rainfall patterns in the South

Long-term rainfall averages for many weather stations in the South vary between 45 and 55 inches per year; a few such as Coweeta, N.C., have averages of more than 70 inches. If this rainfall were ideally distributed through the year, then we probably would seldom be concerned about inadequate soil moisture. But distribution is often poor. Long-term rainfall in the South, reveal seasonal distributional patterns (fig. 1). The Midsouth (Arkansas, Louisiana, Texas, and Mississippi) tend to have more rain

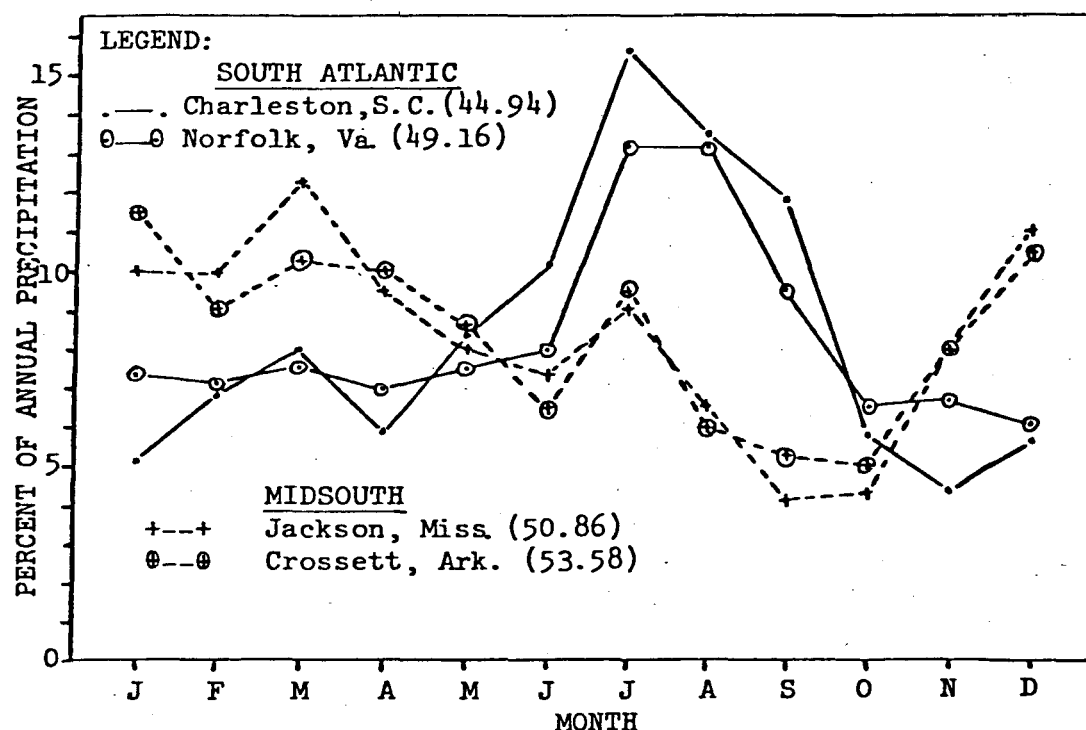


Figure 1.--Monthly distribution of rainfall for selected stations in Midsouth and South Atlantic Coastal Regions based on 30 years average rainfall (Officials of the National Oceanic and Atmospheric Administration 1974.)

in the dormant season than does the South Atlantic Region. Conversely, the South Atlantic Region has more rain in the growing season. Thus droughts during the growing season are more frequent in the Midsouth (Klawitter 1966).

Correlation of rainfall with tree growth

Lack of available soil moisture often reduces or interrupts tree-diameter growth during the growing season. In an Arkansas study using 21 years of growth data, Bassett (1964) found that annual basal area and cubic-volume growth were highly correlated ($r^2=.97$) with indices of "growth days" and "no-growth days" which he calculated using rainfall and estimated potential evaporation.

Using only the rainfall and growth data that Bassett presented, we found (fig 2) that departures of the April-October rainfall from long-term means were also highly correlated with annual basal area and cubic-volume growth ($r^2=0.84$ and 0.93). A comparison of growth for the extreme

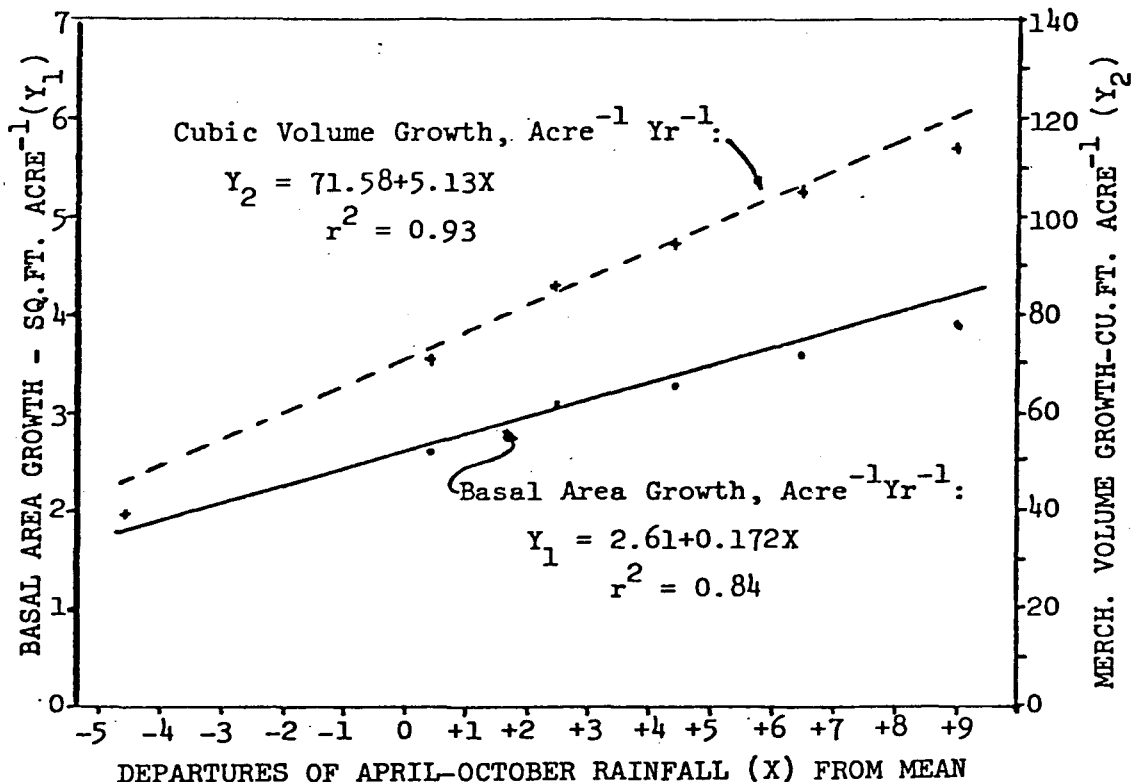


Figure 2.--Correlation of rainfall with tree growth, Crossett Experimental Forest, Arkansas (after Bassett 1964)

rainfall departures (-4.6 vs. + 9.0 inches) shows a difference of nearly 74 cubic feet of annual growth. These data indicate that moisture deficits during the growing season can cause large growth losses.

Effect of cutting on water table levels on poorly drained sites

As Stone (1973) has pointed out, there are only a few documented accounts in the United States of water tables being affected by forest cutting. One of the first reports of such effects was by Wilde and co-workers (1953) in Wisconsin. They observed that clearcutting an aspen (*Populus tremuloides* Michx.) stand converted a reasonably well-drained podsolized soil into a semi-swamp. Trousdell and Hoover (1955) reported the effects of selective cutting and clearcutting loblolly pine-hardwood stands on ground-water tables on a poorly drained site in North Carolina. They concluded that clearcutting appreciably affected water table levels on poorly drained soils and provided some evidence that partial cutting also affected water table levels. Because of the implications and interest in these early results, we reactivated the study in 1960 and carried the measurements through 1973. These results are reported in the following section.

STUDY OF EFFECTS OF CUTTING ON WATER TABLE LEVELS ON A POORLY DRAINED SITE ^{2/}

Methods

Briefly, this study compares water levels beneath two stands treated in various ways over a long period. In the 24 years (1950 through 1973) over which data were collected, the effects of six sets of stands treatments on water table levels were observed:

<u>Period</u>	<u>Stand Number</u>	<u>Treatment</u>
1950-52	1	Old-growth loblolly pine-hardwood stand, selectively cut in 1949
	2	Old-growth loblolly pine-hardwood stand, uncut

^{2/} Study area is located on lands owned by Union-Camp Corporation, Franklin Division, Franklin, Virginia, in Hertford County, North Carolina. The cooperation of the Union-Camp Corporation in this long-term study is gratefully acknowledged. Authors also wish to acknowledge the work of Joseph T. Stewart who carried out the field measurements.

1952-53	1	Old-growth stand, selectively cut in 1949
	2	Clearcut in August, 1952 and regenerated to loblolly by 1953
1960-64	1	Old-growth stand, selectively cut in 1949
	2	Sapling-sized loblolly pine stand, age 7 to 12 years
1965-69	1	Old-growth stand, selectively cut in 1949
	2	Pole-sized loblolly pine stand, 12 to 17 years
1970-72	1	Old-growth stand thinned to same basal area (115 square feet) as pole-sized stand in winter 1969-70.
	2	Pole-sized loblolly pine stand, 17 to 20 years
1973	1	Clearcut in winter 1972-73 and regenerated to loblolly pine in 1973
	2	Pole-sized loblolly pine stand, 20 to 21 years

Two 1/5-acre plots were established within each stand with a water well about 12 feet deep centered in each. The water table level in each well was measured weekly beginning each year on, or about May 1 and ending in mid-November. In our analysis, we grouped the weekly measurements into seven 4-week periods and computed average water table depths for each period by year. We tested the data for treatment differences, and related water table depth to stand basal area, precipitation, and pan evaporation and their interactions by regression analyses.

Results

Average water table depths, 1950-52.--In 1950, stand 1 was an old-growth stand that has been selectively cut in 1949 to 123 square feet of basal area. Stand 2 was an old-growth, uncut stand with 194 square

feet of basal area. From 1950 through period 3, 1952, water table levels were about 2 feet deeper in the uncut than in the selectively cut stand (fig. 3). These water table differences were significant at the 0.01 level.

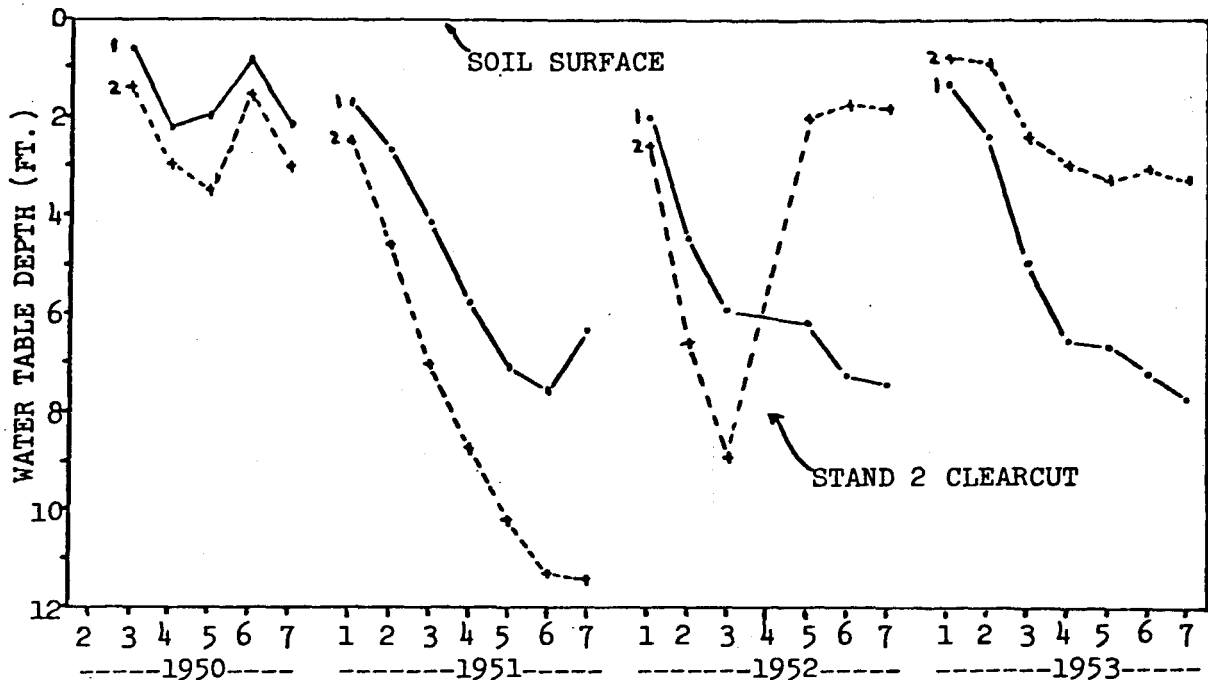


Figure 3.--Average water table depths by stand treatment and period for years 1950 through 1953. Stand 1 was old-growth timber, selectively cut in 1949 to 123 square feet of basal area. Stand 2, an old-growth uncut stand, was clearcut in period 4, 1952 and naturally regenerated by period 1, 1953. Each point plotted is an average of 10 observations.

Average water table depths, 1952-53.--Stand 2 was clearcut in August 1952, and natural regeneration was established by the spring 1953. This cutting reversed the relationship between water table levels in the two stands (fig. 3). The average water table level from period 5, 1952 through 1953, for stand 1--the old-growth, selectively cut stand--was 3.5 feet deeper than stand 2--the recently clearcut stand. Again, water table level differences were highly significant.

Average water table depths, 1960-64.--The water well measurements were discontinued in 1953, but resumed in 1960 to determine how water table levels in sapling and pole stands compared with those in old-growth stands. In 1960 the young stand was 7 years old and had 24 square feet of basal area, and the old-growth stand had 144 square feet. Over the 5 years the difference in water table depths in the two stands was 2.28 feet, with the young stand having a water table averaging 3.73 feet deep and the old-growth

stand 6.01 feet (fig. 4). Figure 4 illustrates another point. In 1960, high rainfall throughout the spring and summer resulted in shallow water tables in both stands. In years with high rainfall, differences in water depths attributable to stand treatment would not usually be very great. Although in this case, differences were significant for periods 3 through 7.

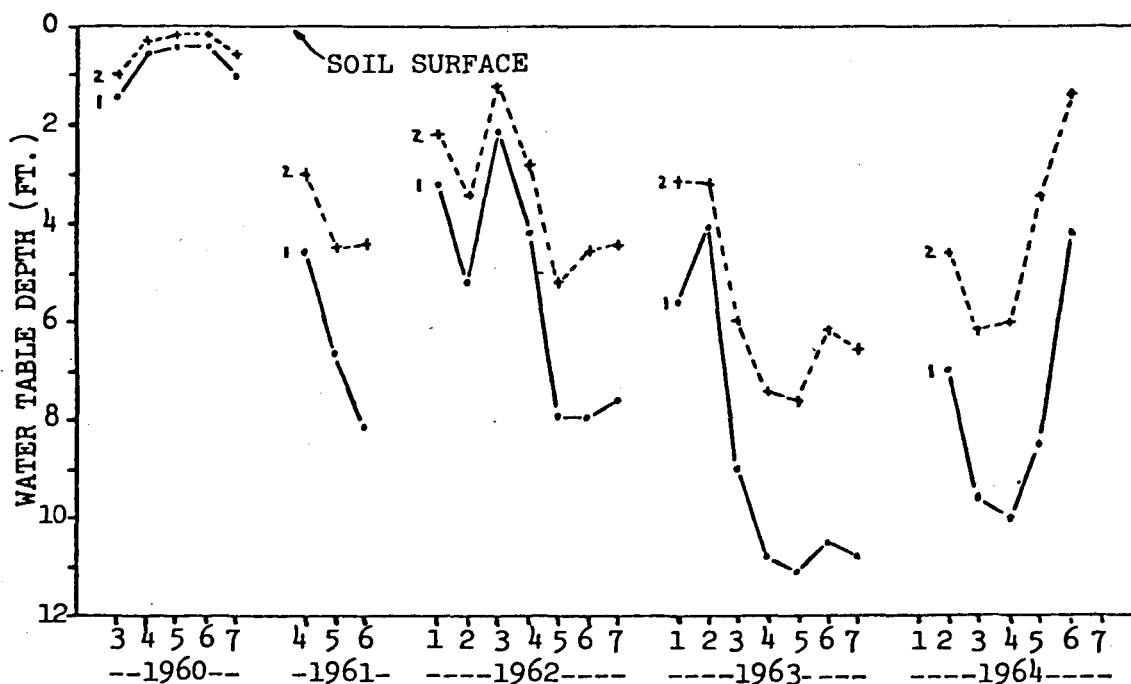


Figure 4.--Average water table depths by stand treatment and period for years 1960 through 1964. Stand 1 was old-growth timber that in 1960 had 144 square feet of basal area. Stand 2 was 7 years old in 1960 with 24 square feet of basal area. Each point plotted is an average of 10 observations.

Average water table depths, 1965-69.--During this period, basal area increased from 56 square feet at age 12 to 112 square feet at age 17 in the young stand, and from 157 to 176 square feet in the old stand. Through this 5-year period, the difference in the average water tables was 1.92 feet, only slightly less than 2.28 feet difference of the previous 5 years (fig. 5).

Average water table depths, 1969-72.--Although by 1969 the water table depths in the two stands appeared to be gradually equalizing, we decided in winter 1969-70 to hasten the process by thinning the old-growth stand back to the same basal area as the young stand, 115 square feet. As a result of thinning, the water table was 2.29 feet higher in the old-growth than in the young stand in 1970 (fig. 6). Apparently, the space occupied

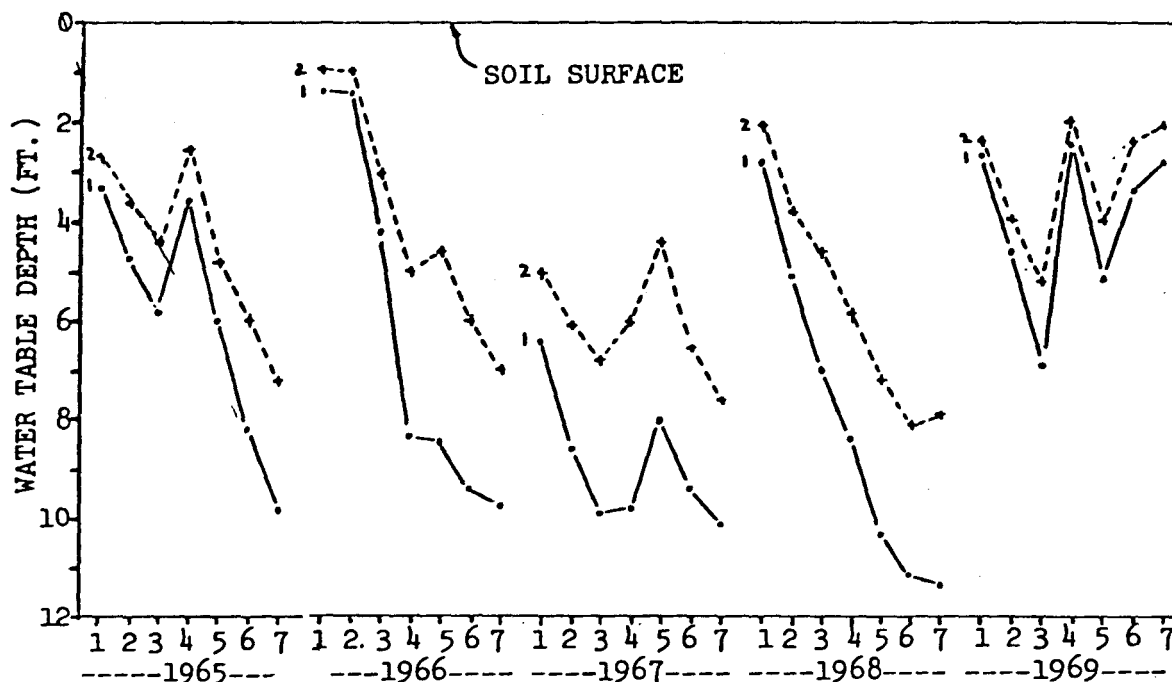


Figure 5.--Average water table depths by stand treatment and period for years 1965 through 1969. Stand 1 was old-growth timber that in 1965 had 157 square feet of basal area. Stand 2 was 12 years old in 1965 with 56 square feet of basal area. Each point plotted is an average of 10 observations.

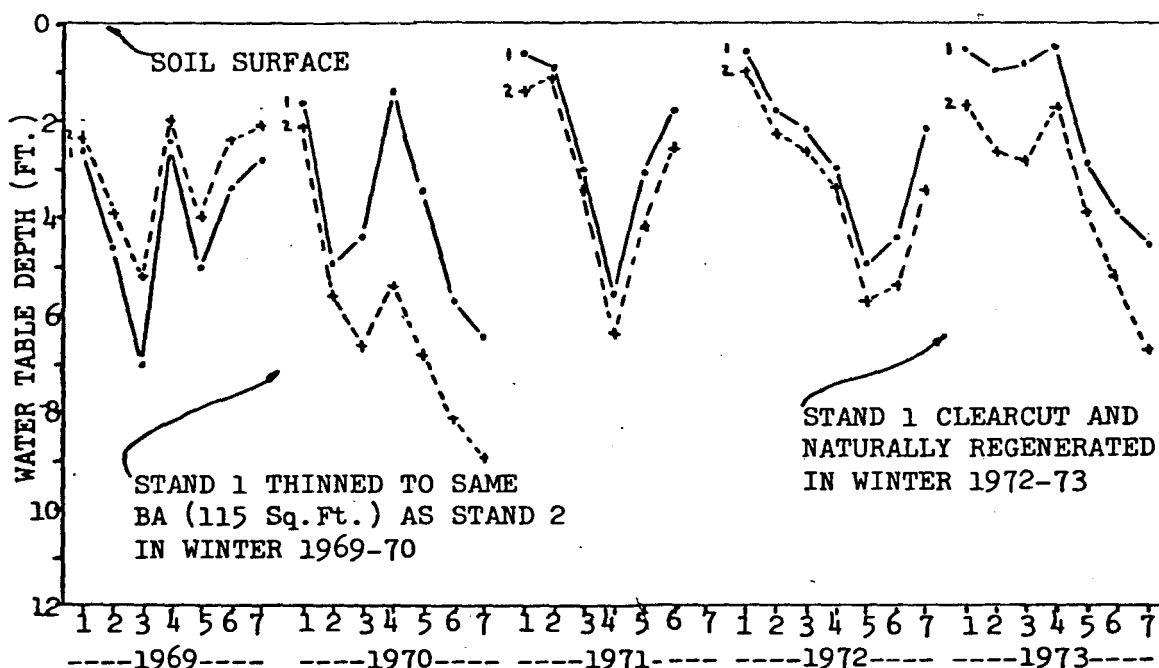


Figure 6.--Average water table depths by stand treatment and period for years 1969 through 1973. Stand 1 was thinned in the winter of 1969-70 to same basal area (115 square feet) as stand 2 at age 17. In the winter of 1972-73 stand 1 was clearcut and naturally regenerated. Each point plotted is an average of 10 observations.

by the root systems of the large trees which were removed was not fully occupied during 1970, resulting in less water use and higher water table levels. But by 1971 and 1972 the roots had reoccupied the space and water table level differences were only 0.67 feet. Part of this difference could be accounted for by the young stand growing faster than old one. In 3 years the young stand grew 21 while the old stand grew only 7 square feet of basal area.

Average water table depths, 1973.--In order to complete the cycle of cutting, the old-growth stand was clearcut in the winter of 1972-73 and naturally regenerated. This cutting increased the water table level differences in 1973 to an average of 1.44 feet, which was highly significant (fig. 6).

Factors affecting water table levels.--Regression analyses of the data collected in the 18 years that the study was active showed that water table depths (Y) between May 1 and November 15 were related to functions of cumulative precipitation (P) and cumulative pan evaporation (E) from February 1, stand basal area (BA), and their interaction:

$$Y = 0.3408 - 0.1790(P-E) - 0.0024(BA)(P-E) + 0.0000038(BA)^2(P-E)$$

$$n = 456$$

$$R^2 = 0.645$$

Water table depths increase as the rainfall deficit increases; conversely, as the cumulative rainfall and evaporation differences decrease, water table depths decrease (fig. 7). Stand basal area interacts with cumulative rainfall and evaporation to influence water table depths. As rainfall deficit increases, the effect of stand basal area on water table depths increases.

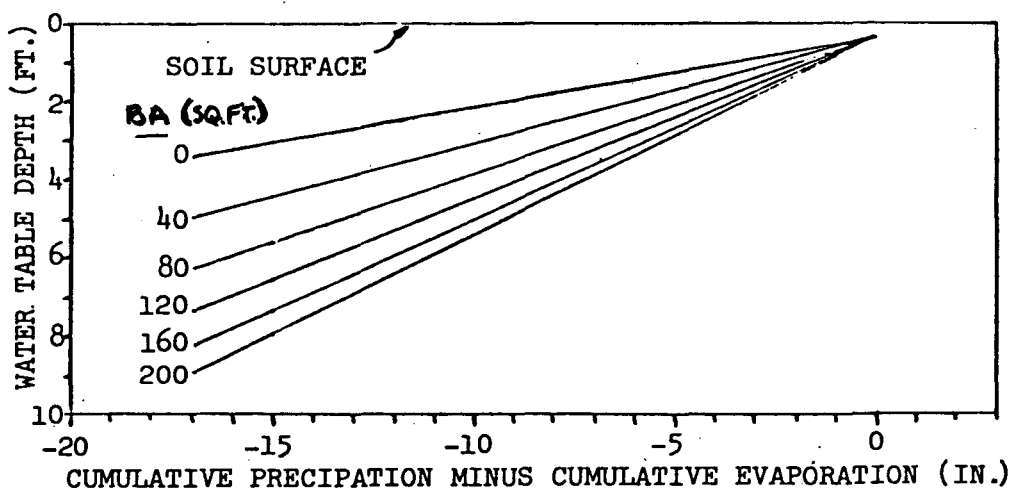


Figure 7.--Effect of cumulative precipitation and evaporation from February 1 and stand basal area on water table depths on a poorly drained loblolly pine site, Bigwoods Experimental Forest, N.C.

Factors affecting periodic change in water table depths.--Periodic changes in water table depths (Y) were related to precipitation (PP) and evaporation (PE) during the 4-week period and to the interaction of these variables with stand basal area (BA):

$$Y = -0.3099 - 0.1771 (PP)^2 + 0.0129(PP)^3 + 0.4621(PE) - 0.0000062(BA)^2(PP) + 0.0000083(BA)^2(PE)$$

$$n = 456$$

$$R^2 = 0.612$$

As precipitation during a 4-week period increases, water table depths change from falling (+change) to rising (-change). This reversal depends also on how heavily stocked the stand is and on what the evaporation rate is (fig. 8). Water table depths drop (+change) more in 4 weeks at higher stand basal areas than at lower ones, and rise (-change) more at lower stand basal areas than at higher ones.

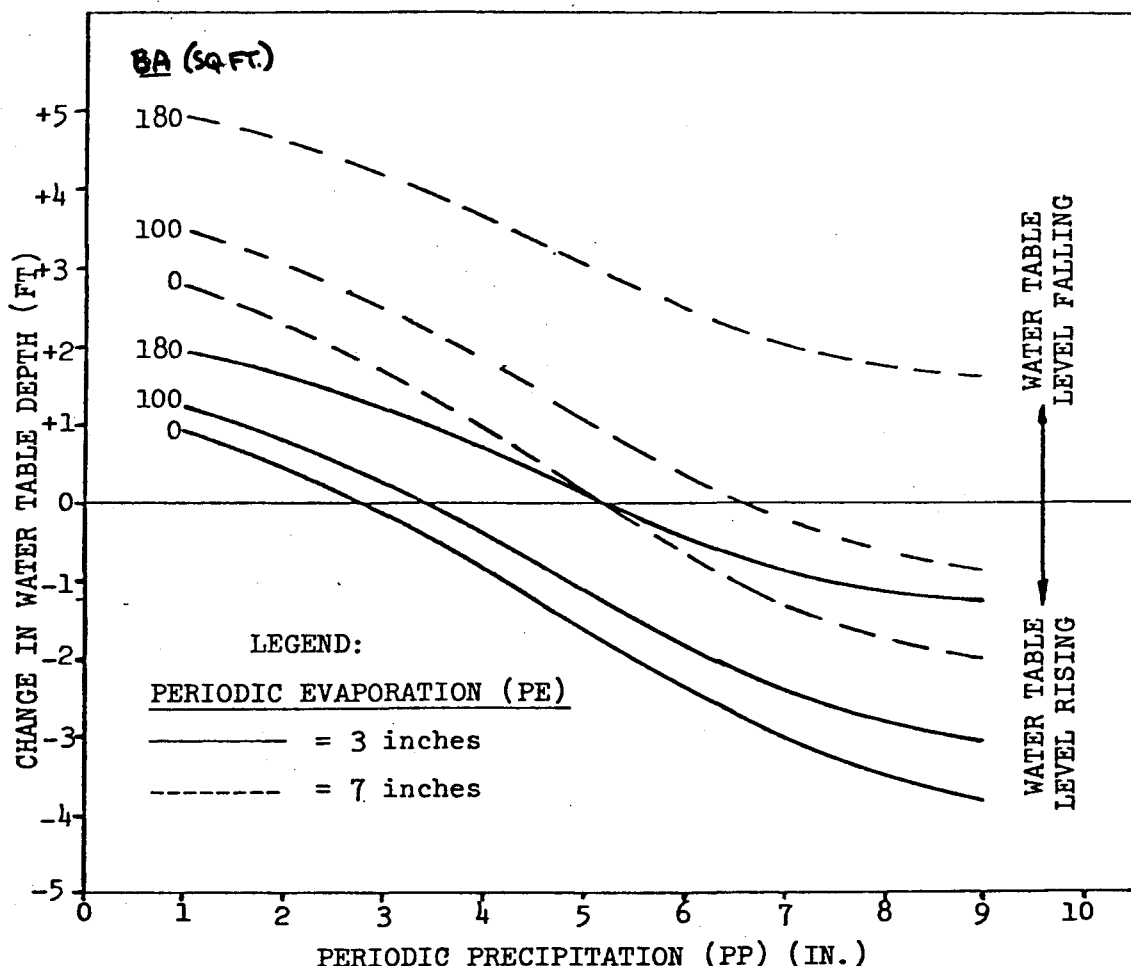


Figure 8.--Effect of periodic precipitation, evaporation, and stand basal area on periodic change in water table depths on a poorly drained loblolly pine site, Bigwoods Experimental Forest, N.C.

DISCUSSION OF SOME MANAGEMENT STRATEGIES FOR MANIPULATING STANDS

Manipulating stands on moisture-deficient sites

Our review of the literature has shown that water yields and soil moisture are affected by the amount and kind of vegetation present. In various parts of the South and especially in the Midsouth, rainfall is often deficient in certain years, and significant growth losses occur in these years. Cuttings which reduce stand density increase soil moisture by increasing throughfall and decreasing water use. The result is more available water for use by the residual stand.

Now the key question is: Can growth be increased by stand manipulation on moisture-deficient sites? Although there is no conclusive evidence in the literature, on a theoretical basis it appears that it can be. For example, growth might be increased by thinning a stand to a point where the need for water equaled the available soil moisture most of the time. Thinning would reduce the period when a moisture deficiency would occur. On the other hand, from rainfall records we know that even where rainfall-deficient years are fairly frequent, there are years in which rainfall is adequate.

Regional growth and yield studies show that cubic volume growth is positively correlated with stocking levels--i.e., the higher the stocking level the greater the growth. Thus, if we try to regulate our stand density to maximize growth in the rainfall-deficient years, we may lack enough stocking to maximize growth when rainfall is adequate. However, if the landowner's objective is to maximize sawtimber growth, rather than cubic volume growth, then carrying lower densities with frequent thinnings may be the best strategy to pursue. Studies both in Arkansas (Burton 1976) and in North Carolina (Langdon and Trousdell 1975) have shown large increases in sawtimber growth after thinning. This treatment would also tend to minimize moisture deficiencies.

Manipulating stands on poorly drained sites

On poorly drained sites, especially in the South Atlantic Coastal Plain, water deficiencies during the growing season are not common. Thus, in our opinion, thinning to increase soil moisture availability is not necessary there. Evidence is accumulating that on drier sites there is a moisture-nutrient interaction that is related to stand density (Butcher 1976). If this is also the case on wet sites where soil moisture levels appear to control nutrient availability, then carrying higher densities with higher fertility levels offers a possible strategy for improving growth (McKee 1976; Langdon and Hatchell 1977). More research is needed to test this hypothesis.

Manipulating stands on poorly drained sites at time of harvest to control water table levels does offer opportunities for improving establishment and seedling growth (Trousdel and Hoover 1955). As our study has clearly shown, when a mature stand is harvested, water levels rise. And if the rainfall pattern causes the water table to remain above or near the soil surface for long periods during the growing season, seed germination and seedling survival will be reduced and seedling growth will be slowed (Miller 1966). As Terry and Hughes (1975) and Campbell (1976) have pointed out, industrial owners in the Atlantic Coastal Plain have resorted to draining and bedding wet sites to improve seedling growth. But for the nonindustrial owner who lack funds to invest in drainage, bedding, or other site preparation treatments, an alternative might be to use modification of the shelterwood system with appropriate site and seedbed preparation. This strategy would establish advance natural regeneration on the site prior to the final harvest of the mature stand, and thus circumvent, in part at least, the effects of high water table levels when the seedlings are most vulnerable.

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