EFFECTS OF INTENSIVE CULTURAL MANAGEMENT ON GROWTH AND CERTAIN WOOD PROPERTIES OF YOUNG LOBLOLLY PINE

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ABSTRACT

A study was undertaken to determine the effects of cultural treatment on wood quality. Increment core samples of eight-year-old loblolly pine trees from four treatment plots were obtained. In comparison with the control, trees that had undergone the most intensive cultural treatment (plowed before planting, irrigated, fertilized, mowed, tip-moth and brush controlled) averaged greater diameter growth and longer tracheid length. There were no differences between treatment plots for tree moisture, specific gravity, and extractives content. Tree diameter was found to be positively correlated with tracheid length of the outer sapwood, and specific gravity was negatively correlated with total extractives content.

In recent years there have been many studies on the response of forest trees to various kinds of silvicultural treatment designed to provide favorable growth conditions. A review of the literature indicates that most researchers were concerned mainly with volume yield, and only a few have studied the effects of irrigation (Howe 1968) and fertilization (Larson 1968; Klem 1968) on wood quality. No studies, however, have been made to determine the effects on the properties of wood of maximum growth through intensive cultural forest management. Therefore, this study was initiated on the variation of tree diameter, specific gravity, tracheid length, tree moisture, and extractives content within loblolly pine trees that have undergone different types of cultural treatments.

MATERIALS AND METHODS

The trees used in this study came from a seven-year-old loblolly pine (*Pinus taeda* L.) plantation, established in 1963 for the purpose of determining the maximum growth potential of the species when factors affecting growth were maintained at the optimum (Box and Linnartz 1967). The stand is on the Lee Memorial Forest in southeast Louisiana on a local stream terrace. The soil is classified as Kalmia fine sandy loam, moderately well drained. The Site Index is 110, which is considered high for loblolly pine. The trees were 1-0 seedlings from seed of several high-quality, fast-growing loblolly pine in Livingston Parish, Louisiana.

The sampling area consisted of four nonreplicated plots. Because of physical and economic restrictions, it was not feasible to replicate in this preliminary study. Each of the study plots was about three-fourths of an acre in size and contained 299 trees. The plots received the following treatments:

Plot A: Plowed before planting, irrigated, fertilized, mowed, tip-moth and brush controlled.

Plot B: Plowed before planting, fertilized, mowed, tip-moth and brush controlled.

Plot C: Fertilized, tip-moth and brush controlled.

Plot D: Control, no treatment.

Fertilization of Plots A, B and C was done early in 1963 with slowly soluble ferrous ammonium phosphate (7-35-0) at the rate of 8 oz per seedling; and in 1967 with ammonium nitrate and treble superphosphate, each at the rate of 0.5 lb per tree. Also,

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these three plots received Thimet, a systemic insecticide, each year for three years to control tip moth. Mowing of Plots A and B was done three times yearly to control weeds and grass competition.

Plot A was irrigated with a water sprinkling system each time the available moisture dropped to 40% of field capacity. The moisture was determined weekly with an electrical resistance meter and with gypsum soil-moisture blocks located 6, 12, and 24 inches deep at five locations in Plot A.

Twenty trees were selected at random from each of the four plots. A 10-mm increment core sample was removed from each tree at the breast height position (4.5 ft above ground level). Immediately after extraction from the tree, each core sample was wrapped in commercial Saran Wrap and placed in an insulated box filled with dry ice, to prevent moisture loss during transportation.

Every core sample was divided into two parts, consisting of outer sapwood section and inner sapwood (including the pith) section. From each section, which measured approximately 1.5 inches in length, the following wood properties were determined: tree moisture content (oven-dry weight basis), degree of saturation (ratio of water content to maximum water content), unextracted specific gravity (green volume basis), and extractives content (unextracted oven-dry weight basis). Specific gravity was determined by two methods, the maximum moisture content technique (Smith 1954) and mercury displacement, using an Amsler volumeter. The removal of extractives was done in a Soxhlet extractor, using consecutive extractions of boiling distilled water for 24 hr, 95% ethanol for 24 hr, and 2:1 benzene-ethanol solution for 24 hr.

For tracheid length measurements, two ⅛-inch earlywood disks were obtained from the outer sapwood section, one from each end (bark and center areas, respectively); and one ⅛-inch earlywood disk from the end near the pith of the inner sapwood section. These disks were cut into matchstick-size slivers and macerated, refluxing with equal parts of glacial acetic acid and hydrogen peroxide (Franklin 1946). The lengths of 25 tracheids per sample, randomly chosen from temporary slide mounts, were measured with a fiberscope calibrated to 65× magnification.

The variance of the results obtained from 20 trees from each plot was analyzed for significant differences among plots to assess the effects of the treatments, according to the schemes shown in Table 2.

It should be emphasized that the detection of significant differences among the data from different plots did not lead to reasonable certainty that these differences were due to the differences in treatments applied to the plots. Replication would have reduced the probability of confounding variation in site from plot to plot coinciding with treatment variations. In addition, the differences between treatments were not well defined. For instance, the treatment of Plot A differed in no respect from that of Plot B for at least one year, and in other years the effect treatment difference may have been minimal. Also, fertilizing after planting was added at the same step (between Plots B and C) so as to preclude conclusions as to which, if either, produce plot differences.

DISCUSSION OF RESULTS

The averages of diameter growth and the various wood properties for 20 trees from each plot are given in Table 1. The summary of analyses of variance for tree diameter, tree moisture, specific gravity, and extractives content is shown in Table 2. Results of the correlation analysis are presented in Table 3. In the following discussion, each of the wood properties is dealt with separately.

Diameter growth

Although there were significant differences among diameters of the trees on the different plots, there was no significant difference between the diameters of Plots A and B. Most of the difference among the means resided between the control Plot (Plot D) and the average of all other plots. The average diameter of Plot A and B was

TABLE 1. *Summary of average values of tree characteristics for various plots and wood-sections*

Plot and wood-section	Tree diameter	Tracheid length	Moisture content	Degree of saturation	Unextracted sp. gravity (max. MC)	Unextracted sp. gravity (hg displ.)	Extractives content water-sol.	Extractives content total
	(inch)	(mm)	(%)	(%)	(green volume)		(%)	(%)
PLOT "A"								
Bark[1]		2.78						
) Outer Sap			127.8	69.9	0.410	0.410	1.75	3.63
Center		2.31						
) Inner Sap			161.1	74.0	0.352	0.357	2.40	4.71
Pith		1.61						
Average	6.48	2.24	144.5	72.0	0.381	0.383	2.08	4.17
PLOT "B"								
Bark		2.56						
) Outer Sap			128.3	67.7	0.404	0.399	2.44	3.43
Center		2.11						
) Inner Sap			155.6	72.1	0.366	0.360	2.90	4.42
Pith		1.64						
Average	6.47	2.12	142.0	69.9	0.385	0.379	2.67	3.92
PLOT "C"								
Bark		2.49						
) Outer Sap			135.5	69.8	0.384	0.388	2.52	4.63
Center		2.19						
) Inner Sap			149.9	69.4	0.355	0.358	2.81	5.41
Pith		1.77						
Average	5.85	2.17	142.7	69.6	0.369	0.373	2.66	5.02
PLOT "D"								
Bark		2.39						
) Outer Sap			125.1	67.4	0.401	0.401	2.78	4.39
Center		2.04						
) Inner Sap			144.1	68.5	0.363	0.367	3.09	5.24
Pith		1.62						
Average	5.07	2.01	134.6	69.9	0.382	0.384	2.94	4.82

[1] The word "bark" in this case refers to section of wood (xylem) adjacent to the bark.

6.5 inches, which is 1.4 inch larger than that of the control plot. It appears, therefore, that the effect upon diameter growth of the irrigation applied in this study was negligible. In actual fact, irrigation was applied from as few as no times per year to eleven times in a year. Also, in the years that irrigation was applied more frequently, there is no certainty that nonirrigated plots reached a point where a truly critical soil moisture condition existed for any prolonged period of time. Zahner (1962) and Zahner, Lotan, and Baughman (1964) reported that irrigation had a significant effect upon diameter growth, when soil moisture supplies become critical. It would appear that such a situation did not, in fact, occur in these study plots, at least with respect to diameter growth.

The effect of applying fertilizer, tip-moth control, and brush control can be seen in that Plot C had 15% greater average diameter than Plot D. The addition of plowing before planting and mowing to reduce grass and herb competition results in a further increase of 12% in diameter. The effect of applying fertilizer alone cannot, because of the experimental design, be separated from the effect of plowing before planting. However, the significant increase in diameter growth obtained by the combination of plowing and fertilizing is consistent with the trend reported by others for fertilizer application alone (Erickson and Lambert 1958; Williams and Hamilton 1961; Gentle, Bamber, and Humphreys 1968).

Tracheid length

Highly significant differences were found in the earlywood tracheid length among plots. By orthogonal comparisons, the differences were found to be mainly between Plot C and Plot D, and between Plot A and Plots B, C, and D; hence these differences are attributed largely to both irrigation and fertilizer treatments. Plowing and mowing apparently had little effect on tracheid length, since there was no significant dif-

TABLE 2. *Summary of results of analyses of variance, showing F-ratios and levels of significance by individual wood properties*

Independent variable	D.F.	Tracheid length	D.F.	Tree diameter	Moisture content	Degree of saturation	Specific gravity[1]	Extractives content: water-sol.	Extractives content: total
Total	239		159						
Plot (A, B, C and D)	3	8.75**	3	27.45**	1.37NS	1.56NS	<1.0 NS	2.31NS	2.56NS
D vs. C	1	9.60**	1	18.32**	—	—	—	—	—
D + C vs. B	1	1.0 NS	1	42.37**	—	—	—	—	—
D + C + B vs. A	1	15.82**	1	21.82**	—	—	—	—	—
Error "A" (Trees/Plot)	76		76						
Position (outer sap and inner sap)	2	469.10**	1	—	74.52**	3.57NS	66.00**	33.91**	36.19**
Interaction (Position × Plot)	6	6.14**	3	—	2.39NS	<1.0 NS	<1.0 NS	1.27NS	<1.0 NS
Error "B" (Trees/Plot × Position)	152		76						

[1] Maximum-moisture method.
** Significant at 1% level of probability.
NS — Not significant.

ference between Plot B and Plots C and D. The evidence concerning the effect of fertilization appears to be contradictory. Both Underwood (1963) and Bhagwat (1967) indicated a significant increase in tracheid length with increasing rate of nitrogen and/or potassium application. Wardrop (1951) and Posey (1964), however, found the opposite response and showed a drastic shortening of tracheid length following fertilization; while Zobel et al. (1961) and Klem (1968) did not find any significant difference between treatments or between treatments and control. To the authors' knowledge, the effect of irrigation on tracheid length has not been reported elsewhere; but the reported increase in latewood percentage following irrigation (Howe 1968) and the longer latewood tracheid as compared to earlywood tracheids in conifers (Bisset and Dadswell 1950) should contribute to an increase in the proportion of long tracheids.

The correlation analysis revealed that diameter growth is positively correlated with tracheid length ($r = 0.41$) in the outer sapwood only. Negative correlation coefficients have been reported for loblolly pine (Zobel, Thorbjornsen, and Henson 1960) and Virginia pine (Thor 1964) and positive correlation coefficients for western hemlock (Wellwood 1960) and young eastern white pine (Thor 1965); but Stairs et al. (1966) did not find any significant difference in tracheid length between fast-grown and slow-grown Norway spruce. Kennedy (1957) has explained that, of the two factors causing variations in fiber length, the length of the initiating cell in the cambium is more important in coniferous trees than the elongation of the young daughter cells after differentiation. If this relationship holds true, the tracheid length might be shorter in a fast-growing tree since more cambial initials have divided anticlinally. An analysis of covariance for outermost tracheid with tree diameter, however, showed that when diameter was held constant, there remained differences in tracheid length among the four treatments.

Additionally, it was found that Plots B,

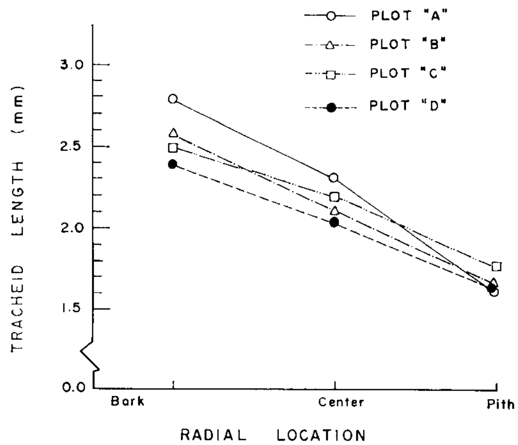

FIG. 1. Average tracheid length at different radial locations for various treatment plots.

C, and D had the same tracheid length after adjustment to a common mean diameter, and that only Plot A differed in its adjusted mean tracheid length. Thus, it appears that the increase in tracheid length was not necessarily caused by growth per se; but rather it was the effect of cultural treatment, and, more specifically, of the additional effect of irrigation, which itself had no effect on diameter growth.

As expected, the difference in tracheid length between the outer sapwood and the inner sapwood was highly significant. The tracheids are expected to be shorter near the pith end and, as a result of an increase in size of the fusiform initials in the cambium with age, continue to increase in length to a certain peak (Anderson 1951). As shown in Figure 1, the average tracheid length increased with age for all the four treatments plots, and is shortest near the pith, intermediate in the center, and longest near the bark. No correlation, however, was found between tracheid length and specific gravity.

Specific gravity

The variation in specific gravity among plots was not significant; likewise there was no correlation between specific gravity and diameter growth. There is much controversy among the relationship between radial growth and specific gravity, but the general consensus is that the relationship is not very close (Larson 1957; Thor 1964, 1965; Zobel et al. 1960), primarily because about half of the variation in specific gravity is attributed to variation in the percentage of latewood. Published results on factors affecting specific gravity are not only numerous but they are also confusing and contradictory. Fertilization has been reported by several authors (Erickson and Lambert 1958; Zobel et al. 1961; Williams and Hamilton 1961) to cause a drastic reduction in specific gravity; but others (Underwood 1963; Bhagwat 1967; Gentle et al. 1968) either found no difference or they found an increase in specific gravity. The effect of irrigation is also unresolved, since a number of investigators (Paul and Marts 1954; Howe 1968) have reported an increase in latewood formation and thus an increase in specific gravity; Zahner et al. (1964), on the other hand, obtained the same proportion of latewood between red pine trees under irrigation and artificial drought. The failure to find any significant differences in specific gravity among plots in this study has done nothing to clarify the situation, other than to indicate that for loblolly pine grown to eight years, the cultural treatments did not appear to influence specific gravity.

A comparison between the maximum-moisture and the mercury-displacement methods of determining specific gravity (Table 1) for intermediate size (10 mm) increment core samples by a simple "t" test showed no significant difference. This finding confirms the observations of Smith (1954, 1955) that little error occurred as a result of determining specific gravity by the maximum moisture method. However, Smith (1955) noted a consistent but significantly lower specific gravity value with the maximum-moisture method compared with the water-displacement method when using a value of 1.53 for the specific gravity of wood substance. The results obtained from this study show that the assumption of a constant of 1.53 for wood substance specific gravity is justified in the calculation for specific gravity by the maximum-moisture method, and the mercury displacement technique can be used for specific gravity determination of green core samples for growth-quality studies without unacceptable error.

Extractive content

There was no significant difference in the amount of extractives among trees of different plots. Erickson and Lambert (1958), working with Douglas-fir, however, have shown that the total extractives (hot water, benzene-alcohol, and ether solubles) before and after fertilization were significantly different in plots that were initially fertilized, and fertilized and thinned. They also reported that the most significant changes were in the benzene-alcohol extraction, but these changes could be due to position in the sapwood. To the authors' knowledge, no other results on the effect of fertilization or other silvicultural treatment on extractives have been reported.

The difference in extractives content between the outer sapwood and the inner sapwood was highly significant. According to Posey and Robinson (1969), the concentration of extractives in juvenile wood of shortleaf pine begins at approximately tree age 15. The results obtained in this study show that a concentration gradient already exists at an earlier age, at least for loblolly pine; and at age 8 and long before the formation of heartwood, the amount of extractives in some trees is already as high as 6.5% of the oven-dry weight of wood.

Extractives content was found to be negatively correlated with the unextracted specific gravity in the outer sapwood ($r = -0.29$) as well as in the inner sapwood ($r = -0.39$). This phenomenon is unexpected, since specific gravity before extraction has been considered to be a fairly good estimate of specific gravity after extraction, by virtue of the fact that there is a definite and positive correlation between extractives and specific gravity. Stonecypher and Zobel (1966), however, stated that the extraction of resinous materials from young juvenile trees has little effect on specific gravity.

TABLE 3. *Correlation between tree characteristics*

Dependent variable	vs. Independent variable	Correlation coefficient[1]
	OUTER SAPWOOD	
Tree Diameter	Moisture content	N.S.
	Degree of saturation	N.S.
	Specific gravity[2]	N.S.
	Total extractives content	N.S.
	Tracheid length	0.41**
Moisture Content	Degree of saturation	0.55**
	Specific gravity	–0.65**
	Total extractives content	N.S.
	Tracheid length	N.S.
Specific Gravity	Degree of saturation	N.S.
	Total extractives content	–0.29*
	Tracheid length	N.S.
	INNER SAPWOOD	
Tree Diameter	Moisture content	N.S.
	Degree of saturation	N.S.
	Specific gravity	N.S.
	Total extractives content	N.S.
	Tracheid length	N.S.
Moisture Content	Degree of saturation	0.64**
	Specific gravity	–0.75**
	Total extractives content	N.S.
	Tracheid length	N.S.
Specific Gravity	Degree of saturation	N.S.
	Total extractives content	–0.39**
	Tracheid length	N.S.

[1] Based on 80 number of trees pooled.
[2] Based on maximum-moisture method, unextracted.
* Significant at 5% level of probability.
** Significant at 1% level of probability.
N.S. Not significant

Even though extractives content was not correlated with diameter growth in this study, Thor (1964, 1965) reported a positive correlation. Moreover, according to Stairs et al. (1966), the content of alcohol-benzene extractives was approximately twice as great in the slow-grown trees as in the fast-grown trees, while the reverse was observed for the hot water extractives.

Tree moisture

The amount of water in wood can be expressed either as "moisture content" or as "percent saturation." The former is based on the dry weight of wood and therefore is dependent on specific gravity; the latter, however, is related to the actual amount of free water that fills the cell cavities and therefore should be less dependent on specific gravity. The results of correlation analyses in Table 3 confirmed these relationships. In addition, it is interesting to note from Table 2 that between outer sapwood and inner sapwood, the difference in moisture content is significant, but the difference in degree of saturation is not. The interpretation of this phenomenon is that the actual water contents in the two sapwood sections were approximately the same, but the moisture contents (expressed in terms of the dry weight) were not as a result of differences in specific gravity between the two sections.

The most intensively managed plot (Plot A) had the highest moisture content and percent saturation. However, there was no significant difference in either moisture content or percent saturation between plots. Evidence of a slight increase in tree moisture following fertilization treatment has been reported by Broerman (1968).

SUMMARY AND CONCLUSIONS

The effects of cultural management on certain properties of wood were investigated for a seven-year old plantation-grown loblolly pine stand in southeast Louisiana. Four plots of varying degrees of cultural treatments were compared.

The trees that underwent the most intensive treatment (plowed before planting, irrigated, fertilized, mowed, tip-moth and brush controlled) had the highest diameter growth and the longest tracheid length, whereas those that did not undergo any post-treatment had the smallest diameter growth and the shortest tracheid length. Tree diameter was positively correlated with tracheid length for the outer portion of the sapwood.

There were no significant differences in specific gravity, tree moisture content, and extractives content among the four treatments; and this suggests that when fast growth rate is the result of cultural treatment, these properties are independent of growth rate.

There were gradients in the distribution of wood properties in the lateral direction. The inner sapwood had shorter tracheid length, higher moisture content, lower specific gravity, and higher extractives content than the outer sapwood. The water content, expressed in terms of degree of saturation, was approximately the same in these two sapwood sections.

There was no statistical difference between the specific gravity values obtained by the maximum-moisture method and those obtained from the mercury-displacement method.

This study shows the possibility of maintaining the inherent wood characteristics of a tree under maximum growth conditions. Even though the information presented here indicates some variation in the response of trees to cultural treatment, it should be considered in light of variations in wood properties due both to genetic difference and to differing growth conditions. In other words, individual trees can be expected to react differently to treatment. The main advantage of intensive cultural treatment indicated in this study is the improvement of growth rate, which is not accompanied by any deleterious effect on the studied wood properties. The efficacy of irrigation under the conditions of this study appears in doubt, except possibly in increasing the tracheid length.

This study was made on young trees and the long-term effect is still unknown. Also, this study was necessarily limited to a small forest area, and it did not include replicated plots. In view of the confounding effect of age of trees and environmental differences within large natural stands, the use of a small area is considered desirable and, if the location has relatively uniform environment and the trees are of the same age, justifiable. Further studies, however, should include replications on different locations and sites, as well as sampling of both juvenile and mature wood sections.[2] Also, other wood properties affecting pulp quality should be evaluated.

[2] Further studies on the present plots cannot be contemplated, since two of the four plots in this study were completely destroyed by hurricane Camille a few weeks after sampling.

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