EFFECT OF CULTURAL TREATMENT AND WOOD-TYPE ON SOME PHYSICAL PROPERTIES OF LONGLEAF AND SLASH PINE WOOD

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ABSTRACT

Wood was studied from relatively mature longleaf and slash pine trees that had been growing under experimental treatments including cultivation, two levels of thinning, and four levels of fertilization in various combinations. From discs taken at five heights and separated into three wood-types, green moisture content, radial shrinkage, tangential shrinkage, volumetric shrinkage, latewood percentage, number of rings per inch, and specific gravity were determined. In longleaf pine, there were indications of treatment effect on latewood percentage and the number of rings per inch, with the more intensive treatments generally leading to fewer rings and higher amounts of latewood. In slash pine, a similar trend was found with these two variables. The species exhibited an almost identical trend in the interrelationships among properties. Green moisture content was negatively correlated with specific gravity and moisture content of the innerwood and middlewood increased with height. Shrinkage was found to be negatively correlated with height and positively correlated with specific gravity, except in the innerwood. Latewood percentage accounted for much of the variation in specific gravity in all wood-types. In the outerwood only, there was a positive but weak correlation of number of rings with specific gravity.

Keywords: Longleaf pine, slash pine, fertilization, thinning, moisture content, shrinkage, latewood percentage, rings per inch, specific gravity, tree height, wood-type.

INTRODUCTION

Certain non-mechanical physical properties of wood such as specific gravity and shrinkage are generally recognized to be important in wood quality because they are closely associated with other wood properties that affect the manufacture and utilization of solid wood. However, these properties can vary a great deal within a single tree and among trees within a species. Variability of specific gravity in trees of the southern pines has been studied extensively (Koch 1972). Yao (1969) studied within-tree shrinkage variation in loblolly pine. Beckwith and Reines (1978) reported that aerial fertilization of planted 23-year-old loblolly pines resulted in increased volume and weight. Specific gravity of fertilized trees did not decrease after fertilization as did that of the control trees during the same time period. The effect of cultural treatments, such as fertilization, thinning, and cultivation, on physical properties is still not well understood, particularly on trees beyond the early growth stages, and there is no work in the literature dealing with cultural effects on shrinkage and other hygroscopic properties in the southern pines.

Therefore, research was undertaken to study the variations in certain physical properties of two southern pine species, with particular emphasis on shrinkage variation due to differences in wood-types and as a result of cultural treatments.

MATERIALS AND METHODS

Thirty-six longleaf pine (*Pinus palustris* Mill.) and an equal number of slash pine (*Pinus elliottii* Engelm.) trees growing on the Kitsatchie National Forest in central Louisiana were felled. The longleaf pine trees (averaging 63 years old—site index of 80) came from a natural stand, whereas the slash pine trees (averaging 40 years old—site index of 95) came from planted stands. The stands had been under experimental treatment for 18 years in a Southern Forest Experiment Station study designed to test the effects of thinning, cultivation, and fertilization on seed and cone production and growth. In each stand, 0.1-acre square plots with ½-chain isolation strips were allocated to one of ten treatments as described by Shoulders (1968). The following treatments were sampled for wood properties:

Treatment A: light thinning (residual basal area of 90 sq ft/ac)
Treatment B: heavy thinning (residual basal area of 50 sq ft/ac)
Treatment C: heavy thinning with cultivation (annual disking)
Treatment D: heavy thinning, cultivation, and fertilization with low NPK (250 lb/ac/year 15-25-10 fertilizer)
Treatment E: heavy thinning, cultivation, and fertilization with medium NPK (500 lb/ac/year 15-25-10 fertilizer)
Treatment F: heavy thinning, cultivation, and fertilization with high NPK (1,000 lb/ac/year 15-25-10 fertilizer)

Fertilization and cultivation treatments were applied annually for 7 years, beginning in May 1958. For each treatment, three plots were selected, and from each plot two trees were felled to give a total of six trees per treatment. Thus, for each species, a total of 36 trees were felled. At the time of felling, the slash pine sample trees averaged 15.7 inches DBH with a mean total height of 87 ft, and the longleaf sample trees averaged 18.4 inches DBH with a mean total height of 85 ft.

From each tree, disks approximately 2 inches in thickness were removed at breast height (4.5 feet) and at ¼, ⅓, ½, and ¾ of the total tree height. At the time of felling, the disks were marked to identify the north face of each tree and were carefully wrapped in plastic to prevent loss of moisture. The disks were divided into quadrants and the east and west quadrants used in this study to provide two samples per wood-type for a given tree height. From each quadrant, three sample blocks measuring 1 inch in cross-section and ½-inch in thickness were prepared and labelled "outerwood" (next to bark section), "middlewood" (middle section), and "innerwood" (1-inch from the pith) to represent the three wood-types. The outerwood samples reflected the continuing effects of annual fertilization and disking that were discontinued in 1965. Depending on tree size, according to ring counts, some innerwood samples from the topmost disk contained some wood

TABLE 1. *Average values of selected wood properties for longleaf pine and slash pine.*

Measured property	Longleaf pine	Slash pine
	Outerwood	
Number of samples	311	326
Green Moisture Content (GMC), %	116.6 (33.8)[1]	115.0 (29.6)
Radial Shrinkage (SR), %	4.7 (1.0)	5.2 (1.2)
Tangential Shrinkage (ST), %	6.3 (1.0)	6.2 (1.2)
Latewood Percentage (LW)	28.2 (8.6)	31.3 (8.1)
Number of Rings (NR), per inch	9.1 (2.1)	6.9 (1.9)
Sp. Gravity, green volume (SG)	0.46 (0.05)	0.46 (0.3)
TR Ratio	1.4 (0.3)	1.2 (0.3)
	Middlewood	
Number of Samples	257	243
Green Moisture Content (GMC), %	122.0 (28.0)	122.1 (25.0)
Radial Shrinkage (SR), %	4.9 (1.3)	5.2 (1.1)
Tangential Shrinkage (ST), %	6.6 (1.1)	6.0 (1.1)
Latewood Percentage (LW)	32.1 (9.3)	33.6 (8.0)
Number of Rings (NR), per inch	7.8 (1.6)	6.1 (1.4)
Sp. Gravity, green volume (SG)	0.47 (0.05)	0.46 (0.05)
TR Ratio	1.4 (0.5)	1.2 (0.2)
	Innerwood	
Number of Samples	293	289
Green Moisture Content (GMC), %	55.2 (35.0)	76.5 (41.6)
Radial Shrinkage (SR), %	3.8 (1.0)	3.7 (1.0)
Tangential Shrinkage (ST), %	5.7 (1.1)	5.1 (1.1)
Latewood Percentage (LW)	34.1 (10.4)	31.8 (10.5)
Number of Rings (NR), per inch	5.5 (1.3)	4.6 (1.3)
Sp. Gravity, green volume (SG)	0.52 (0.09)	0.47 (0.07)
TR Ratio	1.6 (0.5)	1.5 (0.5)

[1] Number in parenthesis refers to standard deviation.

that was formed after cultural treatments were initiated. Other innerwood samples contained only wood formed before 1958. No middlewood samples were prepared from the topmost disk. Also, data from some samples were excluded from analysis if damage occurred during laboratory handling. Thus, there were unequal numbers of samples for each wood-type and species.

Wood properties determined for each sample block include green moisture content (GMC), total (green to oven-dry) radial (SR) and tangential shrinkage (ST), specific gravity (SG), number of rings per inch (NR), and latewood percentage (LW). Shrinkage values in a given structural direction were calculated from the ratio of the change in dimension from swollen size to the oven-dry dimension and were expressed as a percentage. The measurements of the linear dimensions of shrinkage samples were made to the nearest 0.001 inch with a dial gauge. Volumetric shrinkage (SV) was estimated simply from the summation of the radial and tangential shrinkages, which has been shown to give a reliable and close approximation of the true volumetric shrinkage (Choong 1969a). Specific gravity of each sample was determined by the maximum moisture content method (Smith 1954). The number of rings per inch and width of the latewood were measured with a ruler. The percentage latewood was determined from the ratio of total latewood width to total width of whole rings within the sample.

TABLE 2. *Summary of analysis of variance for various properties for longleaf pine and slash pine.*

Source	DF	GMC	SR	ST	SV	LW	NR	SG
Species (Sp)	1	NS	NS	NS	NS	NS	**	**
Treatment (Trt)	5	NS	*	*	*	*	**	**
Sp × Trt	5	NS	NS	NS	NS	**	NS	**
Height	4	**	**	**	**	**	**	**
Wood-type	2	**	**	**	**	**	**	**
Quadrant	1	NS	**	**	**	NS	NS	NS

NS Not significant.
* Significant at 5% level of probability.
** Significant at 1% level of probability.

RESULTS AND DISCUSSION

The results of this study are summarized in Table 1 in terms of all the measured properties for both longleaf pine and slash pine and with regard to the three wood-types. Comparison of the average values of the properties indicated little difference between the two species. However, between either the outerwood or the middlewood and the innerwood, there were differences in some properties. In the innerwood, the transverse (radial and tangential) shrinkages were lower, the specific gravity was slightly higher, the number of rings was less, and the green moisture content was much lower than in the other wood-types.

Effect of cultural treatment

The analysis of variance (Table 2) indicates that latewood percentage, number of rings, and shrinkages in the transverse directions were affected by treatments in both species. There was a species effect for number of rings and specific gravity, and a species × treatment interaction for latewood percentage and specific gravity. Height in the tree also had an effect, as did wood-type, on all the variables.

Duncan's Multiple Range Test (Table 3) demonstrates that significant differences existed between treatments A and F in all the variables listed in Table 2

TABLE 3. *Duncan's multiple range test for longleaf pine and slash pine.*[1]

Variable	Treatment and mean[2]					
SR	A	E	B	D	C	F
(%)	4.8	4.8	4.7	4.6	4.3	4.2
ST	A	B	C	D	E	F
(%)	6.3	6.2	5.9	5.9	5.8	5.7
SV	A	B	E	D	C	F
(%)	11.2	10.8	10.6	10.4	10.2	9.9
LW	A	E	D	B	F	C
(%)	33.4	33.0	32.2	31.4	31.3	29.4
NR	A	C	B	D	E	F
	7.1	7.0	6.9	6.6	6.5	6.0
SG	A	D	B	C	E	F
	.49	.48	.47	.47	.47	.44

[1] Underlining connects means that do not differ significantly.
[2] Letter corresponds to treatment as listed in text.

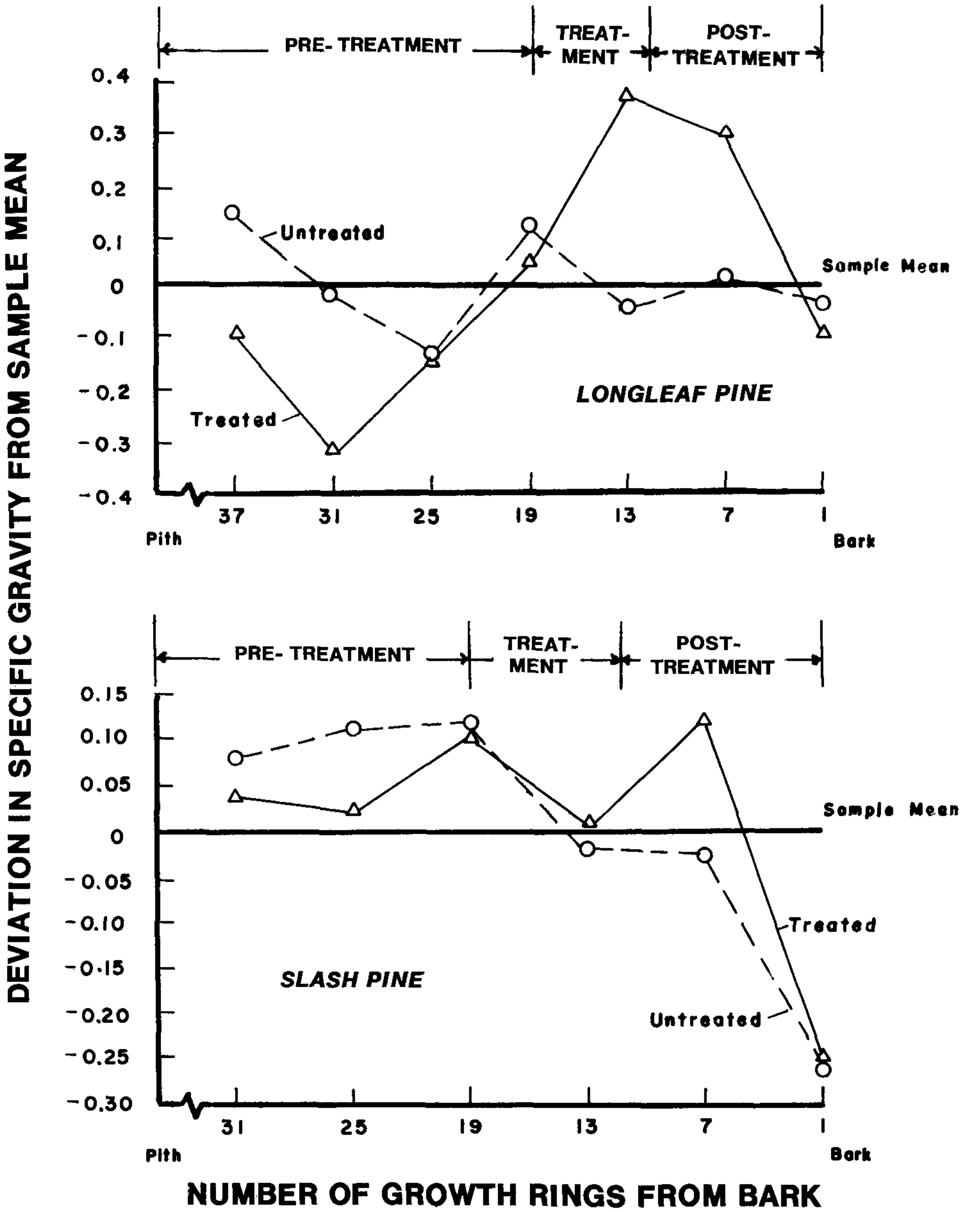

FIG. 1. Deviations in specific gravity from sample mean as related to number of growth rings from the bark in longleaf pine and slash pine.

except latewood percentage. In all cases, treatment A had the higher mean value and treatment F the lower mean value. Intermediate treatments did not fall into a regular sequence. This is expected because the distribution of samples of maturewood and juvenile wood will obscure treatment effects. Also, most of the samples taken from the innerwood were actually formed in the tree before the treatments were applied. Hence, the breakdown by wood-type was necessary.

TABLE 4. *Summary of analysis of variance for longleaf pine.*

Source	df	GMC	SR	ST	SV	LW	NR	SG
				Outerwood				
Treatment	5	**	**	**	**	**	**	**
Height	5	**	**	**	**	**	**	**
Quadrant	1	NS	NS	**	**	**	NS	NS
				Middlewood				
Treatment	5	**	**	**	**	**	NS	**
Height	5	**	**	**	**	**	**	**
Quadrant	1	NS	NS	NS	NS	**	NS	NS
				Innerwood				
Treatment	5	**	**	**	**	**	**	**
Height	5	**	**	**	**	**	**	**
Quadrant	1	NS	NS	NS	NS	**	NS	NS

NS Not significant.
* Significant at 5% level of probability.
** Significant at 1% level of probability.

Species differences for number of rings and specific gravity tend to obscure treatment differences, especially in the case of specific gravity where there was significant treatment × species interaction. Despite these factors that tended to obscure the response to cultural treatments, the trend in number of rings reflects the fact that diameter growth was increased by heavy thinning and fertilization (number of rings per inch reduced), whereas diameter growth was reduced by annual disking (Shoulders 1967).

The specific gravity of sequential samples taken along the north and south quadrants of the lowest discs was measured to determine whether the effects of treatments were short-lived. Each sample contained six complete growth rings. The specific gravity of the outermost samples (nearest the bark) representing wood formed entirely after the cessation of treatment showed no difference between treated and nontreated plots. Thus, although treatments increased specific gravity above the pretreatment level in both species, later the specific gravity of treated trees fell back to the same level as the untreated trees (Fig. 1).

The summary of the analysis of variance for longleaf pine (Table 4), which is broken down by wood-type, indicates that the height effect shows up consistently for all variables. Only latewood percentage, number of rings, and specific gravity are significantly affected by treatment. Failure to find significant treatment effects on shrinkage properties of the two species analyzed separately may be attributable to the smaller sample size in the separate analyses. Also, since specific gravity has an effect on shrinkage, treatment effects on shrinkage may be masked by the specific gravity effect. The effects of treatment and height on specific gravity were significant in each wood-type, whereas latewood percentage and number of rings are significant only in the outerwood. The latter is indicative of a real treatment effect because it is in this position of the tree that the wood was laid down subsequent to the applied treatments. The significant treatment effect on specific gravity of middlewood and innerwood before treatments were started may be due to chance variation not eliminated by randomization or it may reflect differences between treatments in the deposition of extractives and/or formation of heart-

TABLE 5. *Duncan's multiple range test for longleaf pine.*[1]

Variable	Treatment					
			Outerwood			
SV	A	B	C	D	E	F
	11.8	11.4	10.9	10.9	10.7	10.1
LW	A	D	E	B	F	C
	33.4	29.9	28.6	26.6	25.7	24.6
NR	B	C	A	E	D	F
	10.2	9.9	9.8	8.6	8.5	7.6
SG	A	D	E	C	B	F
	.51	.47	.47	.47	.46	.41
			Middlewood			
SV	A	B	E	D	F	C
	12.2	12.0	11.6	11.2	11.0	11.0
LW	A	B	D	E	F	C
	37.7	33.0	32.4	30.8	29.9	29.2
NR	C	E	F	D	B	A
	8.3	8.1	7.7	7.7	7.6	7.4
SG	A	B	D	C	E	F
	.50	.48	.48	.47	.46	.43
			Innerwood			
SV	A	B	E	F	C	D
	10.0	10.0	9.7	9.5	9.1	9.0
LW	A	B	E	D	F	C
	37.6	36.9	34.0	33.6	31.9	31.1
NR	C	B	A	E	D	F
	5.9	5.8	5.8	5.7	5.2	4.9
SG	D	A	B	E	C	F
	.54	.54	.52	.52	.51	.47

[1] Underlining connects means that do not differ significantly.

wood. Perhaps more important than the way in which the significant differences show up is the relatively regular sequence of outerwood means from the lowest to highest, as shown in the Duncan's test (Table 5). There is little consistency about the sequence within both the middlewood and innerwood. Most of the differences reside between treatment F (the most intensive treatment) at one end of the scale and treatments A and B (less intensively treated) at the other end of the scale.

The analysis of variance for slash pine (Table 6), by wood-type, indicates that treatment had an effect on latewood percentage and number of rings in the outerwood only. Since this is the zone of wood formed after the treatments were applied, it is indicative of a real treatment effect. Height affected all variables in all wood-types, except the inner number of rings. Again, this is a reflection to some extent of the amount of juvenile and mature wood at different heights. The Duncan's test (Table 7) reveals that outerwood showed no regular sequence of means between treatment A and treatment F, with the greatest difference lying between samples from most intensive to least intensive treatment.

TABLE 6. *Summary of analysis of variance for slash pine.*

Source	df	GMC	SR	ST	SV	LW	NR	SG
				Outerwood				
Treatment	5	NS	**	**	**	**	**	**
Height	5	**	**	**	**	**	**	**
Quadrant	1	NS	NS	NS	NS	**	NS	NS
				Middlewood				
Treatment	5	NS	**	**	**	**	**	**
Height	5	**	**	**	**	*	**	**
Quadrant	1	NS	NS	*	*	**	NS	NS
				Innerwood				
Treatment	5	**	**	*	**	NS	**	NS
Height	5	**	**	**	**	**	NS	**
Quadrant	1	NS	NS	NS	NS	NS	NS	NS

NS Not significant.
* Significant at 5% level of probability.
** Significant at 1% level of probability.

Interrelationships among properties

Even though the analysis of variance (Table 2) indicates no significant difference in various properties between longleaf pine and slash pine, except in number of rings and specific gravity, the correlations of several important relationships, shown in Table 8, are presented separately by wood-type for each of the two species in order to show the similarity in trend in both species.

Green moisture content.—The average green moisture contents of outerwood and middlewood are about the same for both species (Table 1). In contrast, the average green moisture contents in the innerwood for both species are much lower than in the other wood-types. This phenomenon is not surprising since Zobel et al. (1968) and Choong (1969b) reported that the moisture content of heartwood of southern pine is much lower than that of sapwood.

Green moisture content was found to be negatively correlated with specific gravity for the wholewood in both species (Fig. 2); thus, it is expected that wood with low specific gravity contains higher green moisture content than wood with high specific gravity because there is more void space for water to occupy. This relationship applies to all the three wood-types. Green moisture content is not correlated with height in the wholewood, but it is found to be correlated in the middlewood and the innerwood (Table 8). The outerwood may have a high amount of moisture that is independent of height in the tree.

Shrinkage.—Volumetric shrinkage is negatively correlated with height in the tree and positively correlated with specific gravity in the wholewood for both species. However, as shown in Table 8, these relationships apply only to the outerwood and the middlewood, and they do not apply to the innerwood. Volumetric shrinkage is also correlated with latewood percentage and number of rings.

The negative relationship between volumetric shrinkage and height in the tree, as shown in Fig. 3 for the wholewood in both species, has also been reported by Yao (1969) in loblolly pine. This relationship, however, may be simply a reflection of the common relationship of specific gravity with height (Fig. 4).

TABLE 7. *Duncan's multiple range test for slash pine.*[1]

Variable	Treatment					
			Outerwood			
SV	A	B	D	E	C	F
	11.9	11.7	11.5	11.4	11.0	10.4
LW	E	F	D	B	C	A
	34.6	33.6	31.9	30.5	29.0	28.7
NR	A	B	C	D	E	F
	7.8	7.5	7.0	6.7	6.4	6.2
SG	A	E	D	B	C	F
	.47	.47	.47	.46	.46	.44
			Middlewood			
SV	A	B	E	C	D	F
	11.8	11.5	11.3	11.2	11.1	10.3
LW	E	F	D	B	A	C
	37.2	35.5	33.5	33.5	31.6	30.9
NR	A	D	C	B	E	F
	6.6	6.5	6.4	6.2	5.7	5.3
SG	A	B	D	E	C	F
	.48	.47	.46	.46	.46	.44
			Innerwood			
SV	A	E	D	B	C	F
	9.3	9.3	8.7	8.6	8.4	8.1
LW	E	F	D	A	C	B
	34.2	33.2	31.9	31.8	31.1	28.8
NR	D	E	A	C	B	F
	5.1	4.8	4.7	4.6	4.3	4.2
SG	F	C	A	D	E	B
	.48	.47	.47	.47	.46	.46

[1] Underlining connects means that do not differ significantly.

The analysis of variance in Table 2 shows that all shrinkages varied in a significant manner with cardinal directions. The differences, however, are small. The means for volumetric shrinkage are 10.8% for the east side and 10.5% for the west side in longleaf pine, and 10.5% for the east side and 10.3% for the west side in slash pine. It is interesting to note that the east side has somewhat higher volumetric shrinkage than the west side in both species. Therefore, there appears to be an effect of cardinal direction on shrinkage properties. Compression wood could cause this effect, but the analysis of variance indicates no significant relationship between cardinal direction and specific gravity. Yao (1969) found no difference in shrinkages of loblolly pine in the east, west, and north directions, but the shrinkage in the south side was definitely lower than the others. He explained this lower shrinkage as a result of shorter tracheids in the specimens from the south side of the pith.

The relationship between volumetric shrinkage and specific gravity, as estimated by correlation analysis, indicates significant relationship (at 1% level of probability) in the wholewood for both species, but the correlation coefficients are low

TABLE 8. *Correlations of wood characteristics for various wood-types in longleaf pine and slash pine.*

Relationship	Longleaf pine Outerwood (N = 310)	Longleaf pine Middlewood (N = 256)	Longleaf pine Innerwood (N = 294)	Slash pine Outerwood (N = 325)	Slash pine Middlewood (N = 256)	Slash pine Innerwood (N = 288)
Vol. shrinkage vs.						
Tree height	−0.42[1]	−0.53	NS	−0.52	−0.47	NS
Latewood percentage	0.29	0.28	0.29	NS	NS	NS
Number of rings	0.32	0.25	NS	0.49	0.43	NS
Specific gravity	0.46	0.51	NS	0.60	0.53	NS
Moisture content vs.						
Tree height	NS	0.46	0.42	NS	0.38	0.52
Specific gravity	−0.41	−0.76	−0.48	−0.64	−0.55	−0.59
Specific gravity vs.						
Tree height	−0.20	−0.61	−0.69	−0.64	−0.55	−0.59
Latewood percentage	0.48	0.35	0.40	0.33	0.25	0.33
Number of rings	0.24	NS	NS	0.34	NS	NS

[1] Number refers to correlation coefficient that is significant at 1% level of probability.
NS Not significant.

(r = .20 for longleaf pine, and r = .25 for slash pine). This means that specific gravity accounted for only 4.0% of the variation in volumetric shrinkage in longleaf pine, and only 6.0% in slash pine. However, when the effect of wood-type is considered, we see that the innerwood is responsible for these low r-values in the wholewood because there is no relationship between volumetric shrinkage and

TABLE 9. *Linear relationship between volumetric shrinkage (S) and specific gravity (G) in longleaf pine and slash pine.*

		R^2	N
A. Based on data from individual samples			
	Longleaf pine		
Outerwood	$S = 1.68 + 20.08(G)$	0.21	310
Middlewood	$S = 1.99 + 20.16(G)$	0.26	256
Innerwood	—	NS	294
	Slash pine		
Outerwood	$S = -1.79 + 28.36(G)$	0.36	325
Middlewood	$S = 1.55 + 20.93(G)$	0.28	256
Innerwood	—	NS	288
B. Based on data from tree average			
	Longleaf pine		
Outerwood	$\bar{S} = 2.75 + 17.56(\bar{G})$	0.55	36
Middlewood	$\bar{S} = 1.35 + 21.51(\bar{G})$	0.53	36
Innerwood	—	NS	36
	Slash pine		
Outerwood	$\bar{S} = -1.75 + 28.22(\bar{G})$	0.56	36
Middlewood	$\bar{S} = 0.11 + 24.16(\bar{G})$	0.63	36
Innerwood	—	NS	36

The symbols refer to the following:
R^2 Coefficient of determination that is significant at 1% level of probability.
NS Not significant.
N Number of observation.

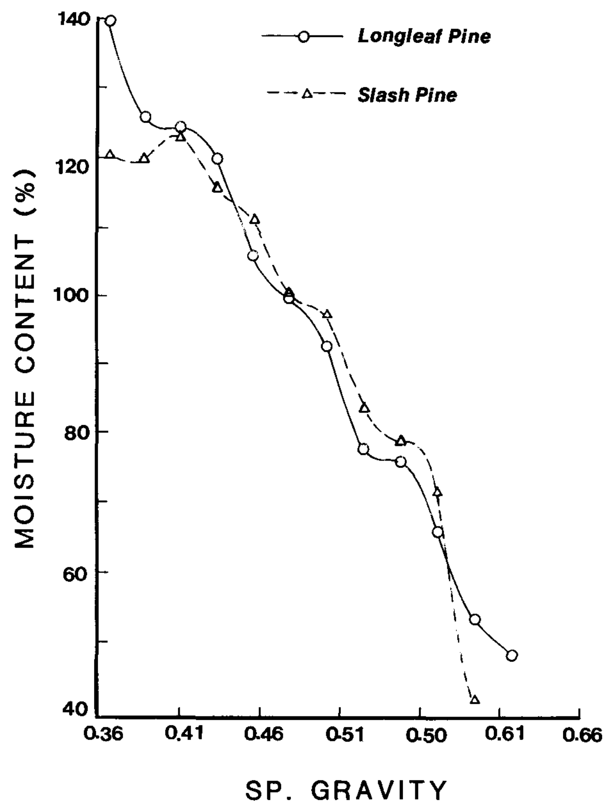

FIG. 2. Relationship between green moisture content and specific gravity (green volume basis) for the wholewood of longleaf pine and slash pine.

specific gravity in the innerwood. Without the innerwood, the *r*-values increased considerably. For longleaf pine, specific gravity now accounts for 21% and 26% of the variations in volumetric shrinkage in the outerwood and middlewood, respectively. For slash pine, the figures are 36% and 28%, respectively. Their regression equations are shown in Table 9. The variability between trees is usually much greater than the within-tree variance; therefore, when the effect of the tree factor is minimized by using the tree average (Table 9), i.e., average of all the measured samples within a tree, the R^2 values show a marked improvement from the previous results. In this case, the specific gravity accounts for over 50% of the variation in volumetric shrinkage for both outerwood and middlewood in each of the two species. On the other hand, the relationship between volumetric shrinkage and specific gravity is still not significant in the innerwood for both species.

The effect of specific gravity on volumetric shrinkage has long been recognized (Stamm and Loughborough 1942; Yao 1969) and explained by Stamm (1964) on the basis that the sorption of water in the cell wall is proportional to the amount of noncrystalline cellulose present. However, there is a greater amount of extractives in the innerwood (McMillin 1968). Moreover, Choong (1969a) reported that longleaf pine and slash pine have considerably more extractives than the other southern pine species. Extractives not only increase specific gravity but also inhibit

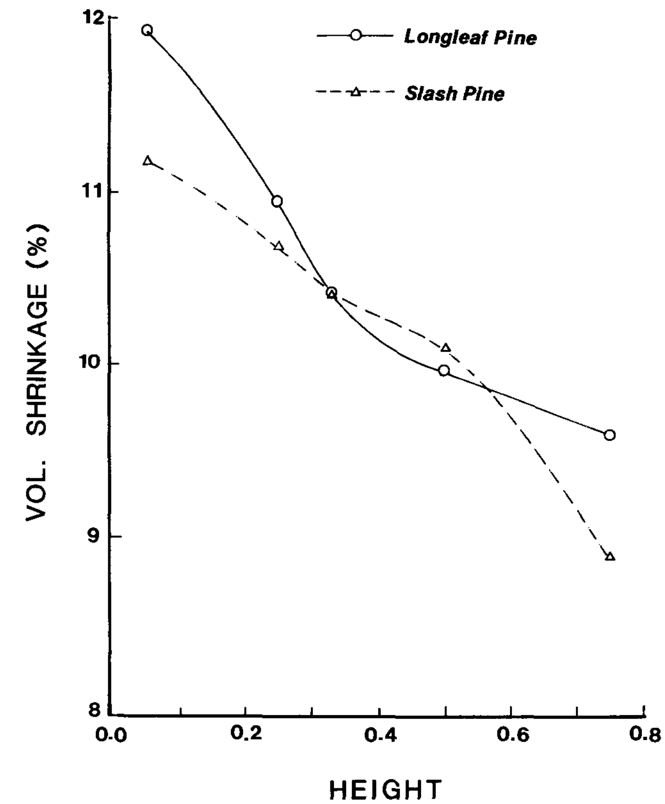

FIG. 3. Relationship between volumetric shrinkage and height (fraction of total height) for the wholewood of longleaf pine and slash pine.

normal shrinkage by bulking the amorphous region in the cell wall substance. This explains why the innerwood (heartwood) shrinks less than the sapwood (middlewood and outerwood) and why there is no apparent relationship between volumetric shrinkage and specific gravity in the innerwood.

Specific gravity.—Specific gravity was found to be negatively correlated with height in the tree. This relationship, shown in Fig. 4 for the wholewood in both species, is not surprising since others (Goggans 1962; Yao 1970) have reported the same trend. The decrease in specific gravity of wood with an increase in tree height is due partly to the influence of crown-formed wood, which consists largely of earlywood. In addition, the relationship also suggests the possibility of changes in the cell wall dimensions of wood with height. Similar relationships were found for all the wood-types in both species.

Specific gravity is also shown to be correlated with latewood percentage. This relationship is generally well known and has been reported by a number of investigators (for example, Yao 1970; Van Buijtenen et al. 1961). Southern pine's specific gravity is governed by the proportion of earlywood and latewood. Latewood has more cell-wall substance and therefore is more dense than the earlywood. It is obvious that wood with higher latewood percentage exhibits greater specific gravity than wood with lower latewood percentage. The effect of growth ring width

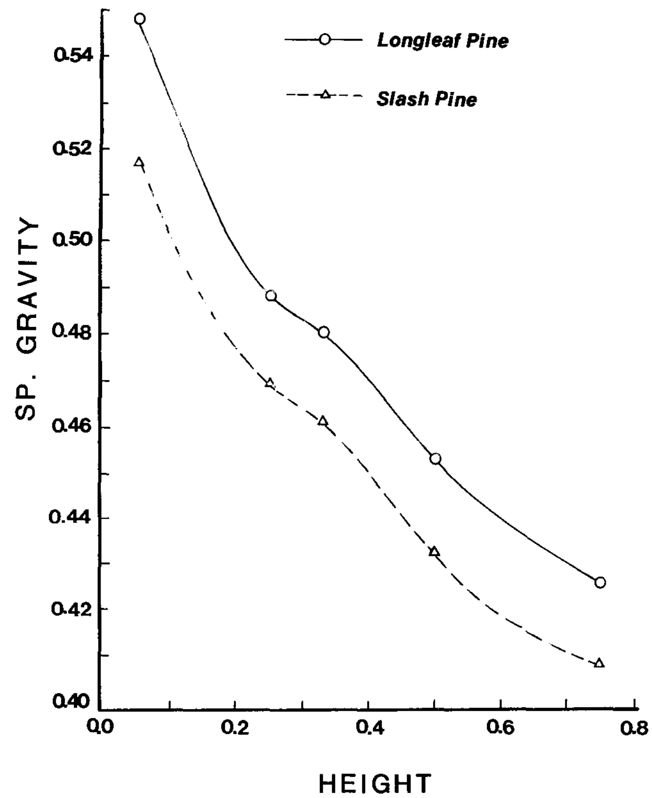

FIG. 4. Relationship between specific gravity (green volume basis) and height (fraction of total height) for the wholewood of longleaf pine and slash pine.

is more obscure because it is governed by many environmental factors. Since the sampled trees were manipulated by cultural treatments, it is not possible to make detailed analysis of the contribution of ring width on specific gravity. Nevertheless, the data show significant but weak relationship between specific gravity and number of rings.

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