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ESTIMATING TREE SPECIFIC GRAVITY FROM A SINGLE INCREMENT CORE

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Summary

A single conventional increment core, taken at breast height, can be used to estimate the average specific gravity of the merchantable portion of a southern yellow pine tree. Simple regression equations have been worked out for estimating tree specific gravity of longleaf, slash, loblolly, and shortleaf pines. This investigation was made by the Forest Products Laboratory and Southern Forest Experiment Station of the Forest Service, U. S. Department of Agriculture in cooperation with the International Paper Co.

Introduction

Forest managers have long used volume estimates of standing timber for their working plans and have predicted yields from their stands in cords, cubic feet, board feet, and similar volume units. But as forest industry advances technologically in a competitive field, the need for quality and weight criteria to stratify volume estimates becomes more and more evident. To convert inventory information from board feet or cords to statements of tons per acre, a nondestructive mensurational procedure is needed.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

For many years, the specific gravity or density (pounds per cubic foot) of wood has been used as a general index of wood quality; among other things it supplies an estimate of the strength, paintability, gluability, and some of the working properties of the wood (3).[2] It is a direct measure of the amount of wood substance and therefore an index of strength properties and pulp yields. Average yields of sulfate pulp can be readily calculated from the weight per cubic foot of pulpwood. Combined estimates of wood volume and weight can thus serve to evaluate wood quality in stands or in individual trees for forest management, silvicultural treatments, or genetical studies (4).

Some rapid methods of determining specific gravity have been devised. Among them, the use of an increment core as a sample is most applicable to standing timber (2). Paul and Baudendistel (5) found that increment core methods compared closely in accuracy with standard methods of determining specific gravity in wood specimens of limited size.

Data at the Forest Products Laboratory show consistent trends of decreasing specific gravity at successive heights in southern pines. Specific gravity for entire cross sections of trees also varies appreciably with such factors as age and growth rates in general association with spacing, soil, and moisture conditions in timber stands. It was therefore necessary to determine how increment core specific gravity at breast height correlates with that of cross sections at successive heights throughout the merchantable volume of the trees.

Field Procedure

One hundred trees each of longleaf, slash, loblolly, and shortleaf pine were sampled in five counties of Mississippi in February 1957 (fig. 1). The samples were collected in conjunction with pulpwood operations. Trees ranged in diameter from 5 to 16 inches.

After the trees were felled, pulpwood bolts were cut progressively from the stump to a minimum top diameter of 3 inches. Complete cross sections, about 1-1/2 inches thick, were cut from the tree between each pulpwood bolt, except that no sample was taken at the butt end of the first bolt (fig. 2). The bolts from which disk segments were cut averaged approximately 5.4 feet in length. To provide information on the total height of each tree, the length of the unused portion of the top was measured. Table 1 shows the ranges in stand type, age, diameter, and height represented by the samples.

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[2] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

The diameter at breast height, located 8 to 10 inches below the top end of the butt bolt, was measured with a diameter tape. An increment core was extracted at this position and the length from bark to pith was measured to the nearest 0.01 inch (fig. 3). The fact that the bolts were lying on the ground facilitated aiming the borer directly at the pith.

All the wood samples from each tree were put into separate sacks, which were tagged with the appropriate tree and species number (fig. 4). When segments were too large for the sacks, their diameter inside bark was measured and recorded before a representative segment was split from the cross section.

Laboratory Procedure

Samples were submerged in water for 24 hours to assure green volume. After the bark had been removed, the age, diameter inside bark, and green volume (water-immersion method) were determined and recorded. Samples were ovendried at 105° C. Specific gravity for each wood sample was computed on the basis of its ovendry weight and volume when green.

Merchantable volume of each tree was computed as the summation of individual volume determinations of each bolt, including its disk, taken in the pulpwood operation. The average specific gravity for each bolt was computed as the mean gravity of its terminal disks (except single disk observations for butt bolts); and the average specific gravity for each tree was weighted for proportional representation of the bolt volumes. These computations are described in the Appendix.

Results

Three relationships were studied:

1. Density correlations between the core and its adjacent wood (the nearest disk).

2. Density correlations between the core (and its adjacent wood) and the average for the merchantable volume.

3. The different specific gravity values encountered in the stem with increase in height.

The Core and Its Adjacent Disk

When the average specific gravity of the cores from the 100 trees of each species was compared with the average of their disks, t-tests indicated no significant differences between these means on either a group or a paired basis (6). As would be expected from the smaller core sample, the cores showed more variation in specific gravity than the disks. Table 2 shows the average, range, standard deviation, and coefficient of variation for each set of samples.

Scatter diagrams made it clear that, although the average core and disk values were the same for all practical purposes, the relationship was not in a 1:1 ratio at all levels of specific gravity. Regression analyses yielded significant correlation coefficients for a simple linear relationship of disk gravity to the core value.

A significant reduction in residual variation was achieved, however, by using the reciprocal of core gravity as the independent variable. Transposed, these regressions by species take the form of the curves shown in figure 5. Longleaf and slash pine regressions have highly significant correlation coefficients of -0.6 and loblolly and shortleaf pine regressions -0.7. Standard errors of estimate, measuring variation about the line of regression, were approximately 0.03 gram of dry wood fiber per cubic centimeter of green volume. Species differences shown for these values are, of course, much more likely to be due to sampling rather than to true specific variation.

The Core and the Tree

With the reciprocal of the increment core specific gravity as the independent variable, regressions to predict tree specific gravity (Y) were computed as follows:

Longleaf pine: $$Y = 0.79605 - \frac{0.146112}{X}$$

Slash pine: $$Y = 0.78116 - \frac{0.140213}{X}$$

Loblolly pine: $$Y = 0.69798 - \frac{0.116701}{X}$$

Shortleaf pine: $$Y = 0.71916 - \frac{0.12567}{X}$$

The correlation coefficients are significant at the 1 percent level in each case. Figures 6, 7, 8, and 9 illustrate the relationships, and figure 10 compares the differences between species.

Core specific gravity is thus higher than that of the whole tree. This is to be expected in the average nonjuvenile tree, since the sample is taken in the lower and typically denser part of the stem. Because of the relatively small number of observations in the lower part of the range of specific gravity, this may not be the case with young trees of small diameter. At this youthful stage, the more mature wood of typically higher density possibly had not been laid down in the tree.

Density Variation with Height in Stem

The expected inverse relationship between specific gravity and increase in height above stump was confirmed by the measurements of sample disks. Approximate regressions, transferred from straightline relationships on log-log paper, are shown in figure 11.

The apparent effect of age is illustrated by the two curves each for longleaf and loblolly pine, sample trees in these species having come from two age groups. Lowest specific gravity at all heights was observed in an old-field stand of rapidly growing loblolly pine. The sample tree data for each species are shown in table 1.

Discussion of Results

The results given are a simplification of an extremely complex relationship between the specific gravity of a single increment core and that of the merchantable volume of an average 30-year-old southern yellow pine tree. The sample size is in the ratio of perhaps 1 part per 100,000. The recommended regressions at best explain only 53 percent of the variation found in a single species (loblolly pine). Observations were sparse at the extremes of specific gravity encountered, because sampling was limited to the trees cut in a commercial pulpwood operation. Furthermore, multiple regression analyses (1) involving as many as nine independent variables -- made up of, in addition to core gravity, various simple and combined measures of age, diameter, growth rate, merchantable height, and volume -- did not increase appreciably the proportion of explained variation.

Nevertheless, within the main body of the sample observations, it is believed that reliance may be placed upon the predictive statements implied by the regressions for any appreciable number of trees from similar southern yellow pine stands.

When the adjacent disk was used instead of the single core to predict the mean for the whole tree, an encouraging reduction in unexplained variation was made:

Species	Unexplained variation $(1-r^2)$ 1/Core	Disk
Longleaf pine	0.5942	0.2274
Slash pine	0.7509	0.2193
Loblolly pine	0.4684	0.1571
Shortleaf pine	0.5338	0.2335

Thus, the problem is reduced to working out improvements in measuring the specific gravity of adjacent wood by using increment cores. Remaining variation may be attributed to differences in site or inherited distribution patterns of specific gravity in the bole as well as simple random variation. Future studies should solve this much smaller problem, and the weaknesses found in this first attempt should be resolved. A larger core sample, more cores, segmental core values weighted for proportional representation of juvenile and nonjuvenile wood are logical approaches.

It must be kept in mind, however, that the solution must meet the needs of practicing foresters, and reasonable estimates of average values with measurable errors will be more useful than expensive, highly technical procedures of greater accuracy. One rather obvious simplification, for example, is the possibility that further sampling may permit the pooling of longleaf and slash pines and loblolly and shortleaf pines for practical purposes. There is analytical evidence to support this possibility.

Conclusions

Significant relationships of specific gravity of breast-height increment cores to the tree specific gravity for four species of southern yellow pine were found.

Tree specific gravity can be estimated to a reasonable degree of accuracy for nonjuvenile southern pine trees by using appropriate regression equations. Much of the unexplained residual variation in the equations can be attributed to the variation that exists between the increment core and its adjacent wood.

Progressive decrease in specific gravity with increasing height is confirmed. Approximate illustrative regressions have been developed.

Further research is needed to (a) develop optimum mensurational procedures for nondestructive determination of specific gravity of approximately breast-height segments of tree stems; and (b) continue sampling of southern yellow pine forest stands to strengthen relationships between core sample and tree gravity for the full range of site, age, diameter, and specific gravity.

APPENDIX

Mathematical Computations

Merchantable density and merchantable weighted specific gravity for each tree were obtained in the following steps:

1. a. Volume in cubic feet for each bolt and its disk in the tree was computed by the formula: $V = dib^2 \times 0.0054542 \times \text{length in feet}$.
   b. Merchantable volume of the tree was the sum of the bolt and disk volumes.

2. The average specific gravity of each bolt was taken as the average specific gravity of the cross sections at each end except for the butt bolt of the tree for which only the specific gravity from the top end was used.

3. a. The weight of wood substance in pounds for each bolt was obtained from the formula: Weight in pounds = bolt vol in cu. ft. x bolt sp. gr. x 62.43.
   b. Merchantable weight of wood substance for the tree was the sum of the bolt weights.

4. Merchantable density in pounds per cubic foot equals the merchantable weight divided by the merchantable volume.

5. Tree specific gravity, the final figure sought, was computed by dividing the merchantable density by 62.43.

The increment core specific gravity based on ovendry weight and green volume was computed by the following formula:

$$\text{Specific gravity} = \text{O. d. wt. (gr.)} \div \frac{\text{diam.}^2 \times 0.7854 \times \text{lgth (in.)}}{0.061}$$

The diameter of each increment core was the caliber of the cutting edge of the increment borer determined to the nearest 0.001 inch.

Analysis of Variables of Core, Diameter, Age, and Height

In addition to the relatively simple relationships discussed in the body of the report, data available in the sample were subjected to further analysis. Because of the paucity of observations in many factorial cells, it was decided that the simpler relationships would best serve the objectives of this study, and that the additional analytical data be reported here for information only.

Since all variables are intercorrelated, advantage was taken of a new and powerful regression program. These were the first experimental data analyzed by using the Southern Forest Experiment Station's 704 Regression Program (6). Listed below are the nine independent variables which were selected, and all possible (511) linear combinations used to see how much of the variation of the dependent variable could be accounted for.

Variables Used in Analysis

Y - Tree specific gravity
X_1 - Product of core specific gravity and age
X_2 - Core specific gravity
X_3 - Reciprocal of age
X_4 - Age
X_5 - Reciprocal of diameter
X_6 - Diameter at breast height (inches)
X_7 - Product of X_2 and X_6
X_8 - X_6 divided by X_4 (slash, loblolly, and shortleaf pine)
X_9 - X_4 divided by X_6 (slash, loblolly and shortleaf pine)
X_{88} - Merchantable height (feet) (longleaf pine only)
X_{99} - Squared diameter breast high (inches) multiplied by merchantable height (feet) (longleaf pine only)

From table 3 it will be seen that only variable X_2 (specific gravity of the increment core) explained any appreciable amount of the variation for all four species. The higher proportion explained for loblolly pine can probably be attributed to the even-aged stands from which the sample was drawn.

With all possible combinations of the nine variables tested by the 704 Program, the tabulated combinations are simply those with the highest value of R^2 (proportion of variation explained by regression) for each level. It should be noted that the step-wise approach used in conventional analytical practice would have arrived at different "best" 3-variable and "best" 4-variable regressions in all cases except slash pine. See table 4. The only cases where the "best" regressions for two species involved the same variables were the 4-variable regressions for slash and longleaf; even here, the coefficients for X_2 and the coefficients for X_3 differed in sign between species.

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Table 1.--Data on sample trees

Species and locality	Stand type	Tree age class	Diameter breast height			Merchantable height			Total height		
			Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum
		Yr.	In.	In.	In.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
Longleaf pine											
Jackson County											
Area 1[1]	Residual	24-160	10.9	6.5	17.0	43.2	27.6	69.1	55.8	42.6	77.1
Area 2	Second growth	17-32	8.5	5.1	11.6	43.4	27.1	59.1	56.9	46.1	71.1
Slash pine											
Jackson County	Second growth	19-31	10.2	5.5	18.0	42.7	22.2	62.6	55.4	36.2	76.6
Hancock County	Second growth	17-28	6.8	4.6	11.0	31.0	15.9	58.0	42.4	18.0	69.0
Loblolly pine											
Madison County	Old field	18-28	7.8	5.2	16.1	25.0	10.8	37.9	37.4	21.8	51.9
Scott County	Second growth	36-51	9.7	5.9	16.8	43.6	21.7	61.5	57.5	29.7	75.5
Shortleaf pine											
Scott County	Second growth	30-48	8.6	4.5	16.3	39.2	16.5	72.0	51.7	27.6	81.0
Leake County	Second growth	27-48	8.7	5.0	14.1	37.8	21.5	59.3	49.7	33.6	67.3

[1] The two areas represent two sections of one township in Jackson County.

Table 2.--Averages and ranges of specific gravity and correlation data of increment core and adjacent disk samples

	Longleaf pine	Slash pine	Loblolly pine	Shortleaf pine
Specific gravity				
Increment core				
Average	0.573	0.558	0.480	0.509
Minimum	.471	.478	.382	.408
Maximum	.692	.677	.597	.641
Disk				
Average	.579	.565	.481	.509
Minimum	.498	.448	.398	.395
Maximum	.677	.651	.565	.594
Standard deviation				
Increment core	.0483	.0370	.0440	.0461
Disk	.0403	.0360	.0384	.0413
Coefficient of variation				
Increment core, percent	8.43	6.64	9.15	9.06
Disk, percent	6.96	6.38	7.99	8.10
Correlation coefficient[1]	-.6086	-.5956	-.7003	-.7196
Standard error of estimate[1]	.0321	.0291	.0276	.0288

[1] From regression of disk specific gravity on reciprocal of increment core specific gravity (1/X). All correlation coefficients significant at the 1 percent level of probability.

Table 3.--Proportion of total variation explained by each of the nine independent variables taken singly (r^2)

Independent variables	Longleaf	Slash	Loblolly	Shortleaf
X_1	0.1261	0.0054	0.3241	0.1567
X_2	.3913	.2379	.5197	.3059
X_3	.0380	.0005	.1588	.0158
X_4	.0946	.0016	.2043	.0222
X_5	.0016	.1225	.0007	.0507
X_6	.0002	.1461	.0013	.0659
X_7	.0336	.0773	.0502	.0012
X_8	....	.1291	.1385	.1433
X_9	....	.1014	.1951	.1578
X_{88}	.0111	....	....	....
X_{99}	.0015	....	....	....

Table 4.--"Best" multiple regressions for each species and proportion of total variation explained

Species	Number of independent variables							
	2		3		4		9	
	Variables	R^2	Variables	R^2	Variables	R^2	Variables	R^2
Longleaf	X_2, X_5	0.4849	X_1, X_2, X_6	0.5453	X_1, X_2, X_3, X_7	0.5690	$X_1, \ldots X_9$	0.5764
Slash	X_2, X_7	.4285	X_1, X_2, X_7	.4304	X_1, X_2, X_3, X_7	.4402	$X_1, \ldots X_9$	.4530
Loblolly	X_2, X_9	.5693	X_1, X_4, X_5	.6150	X_1, X_3, X_4, X_9	.6213	$X_1, \ldots X_9$	.6550
Shortleaf	X_2, X_8	.4978	X_2, X_3, X_6	.5291	X_2, X_3, X_4, X_9	.5481	$X_1, \ldots X_9$	.5549

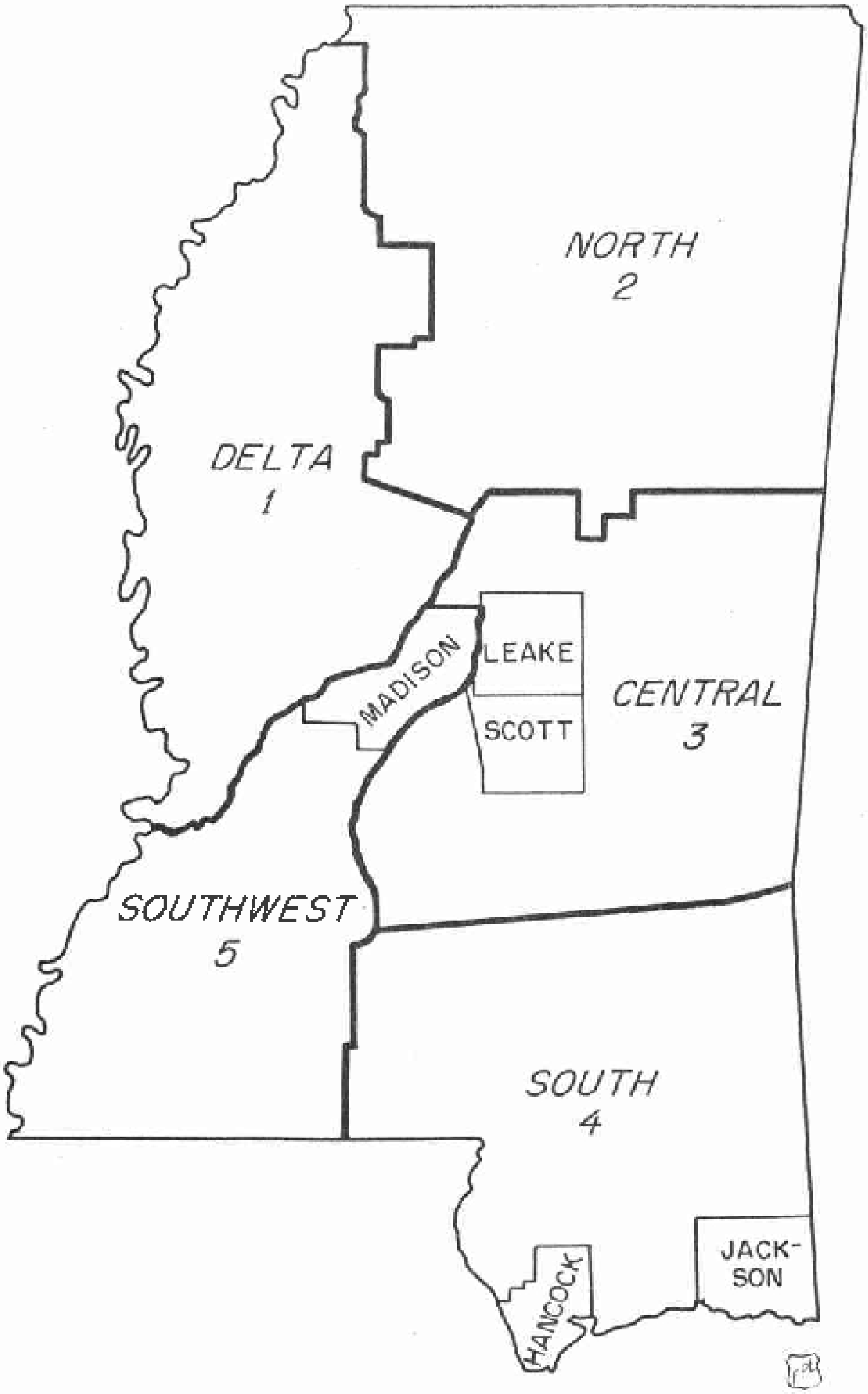

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Figure 1. --Map of Mississippi showing five Counties from which samples were taken.

Figure 2.--Southern pine tree showing cross section sample for specific gravity cut from the top end of each pulpwood stick.

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Figure 3.--Method of taking increment core at breast height for specific gravity sampling from butt bolt.

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Figure 4.--All cross section samples from one tree were put into a sack and tagged with appropriate tree and species number.

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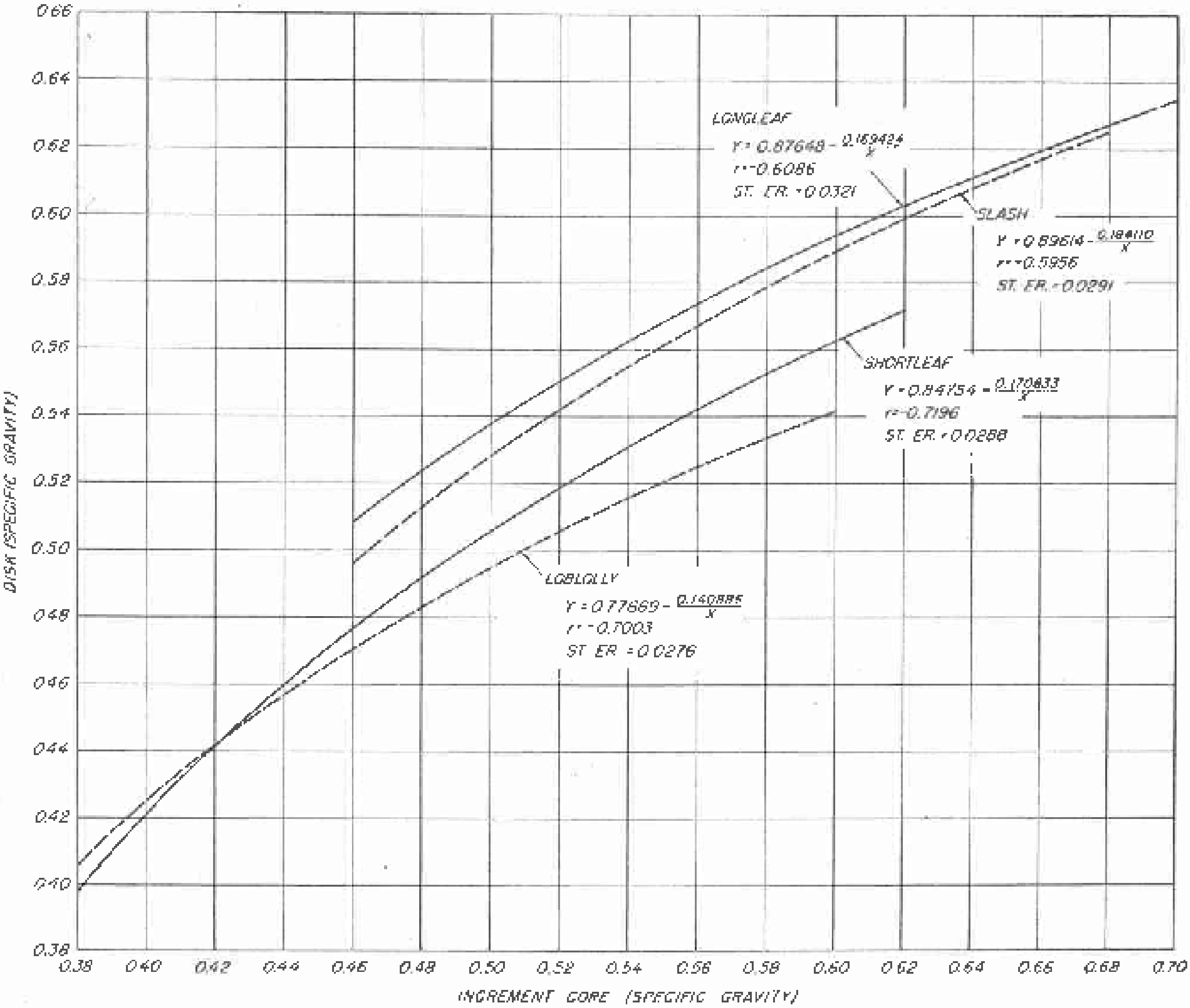

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Figure 5. --Simple regressions of disk specific gravity on reciprocal of increment core specific gravity for the four species of southern yellow pine.

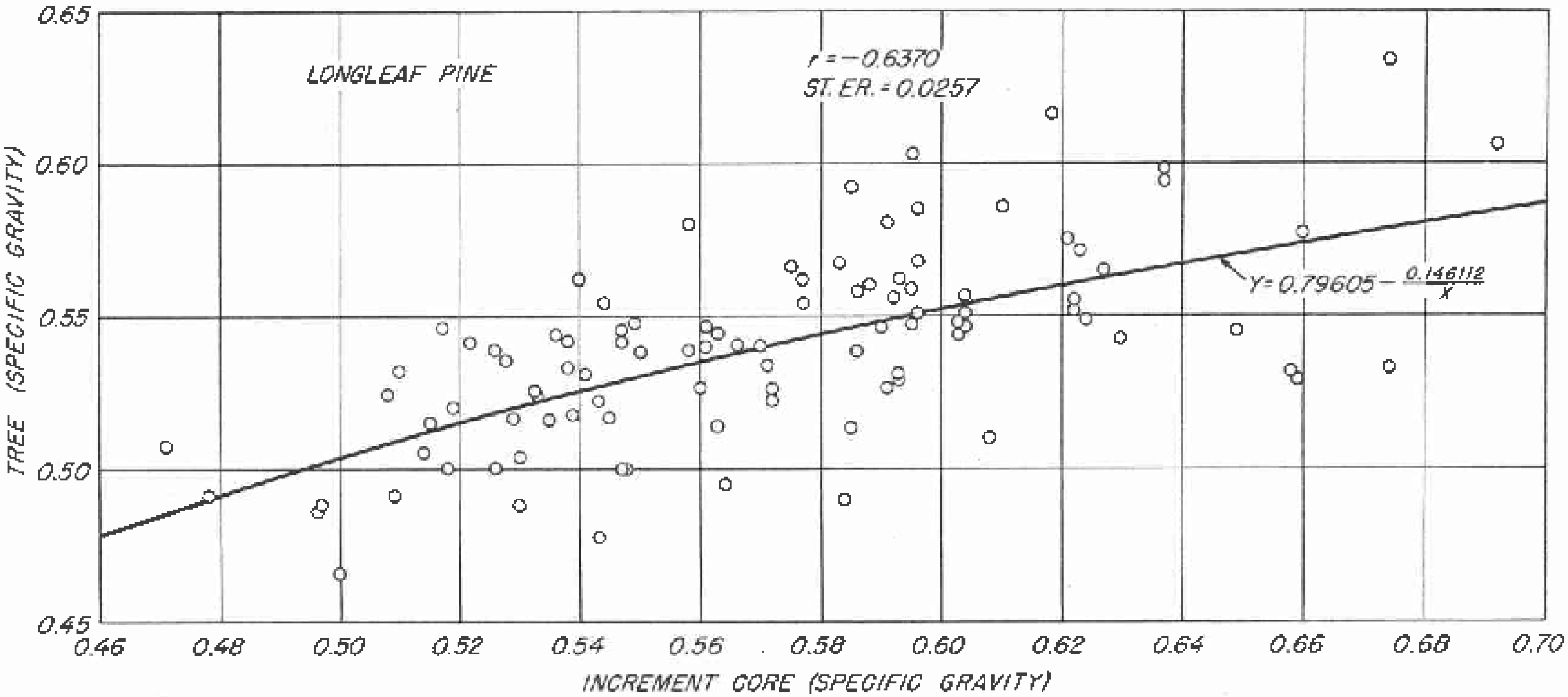

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Figure 6. --Simple regression of tree specific gravity on reciprocal of increment core specific gravity from 100 longleaf pine trees.

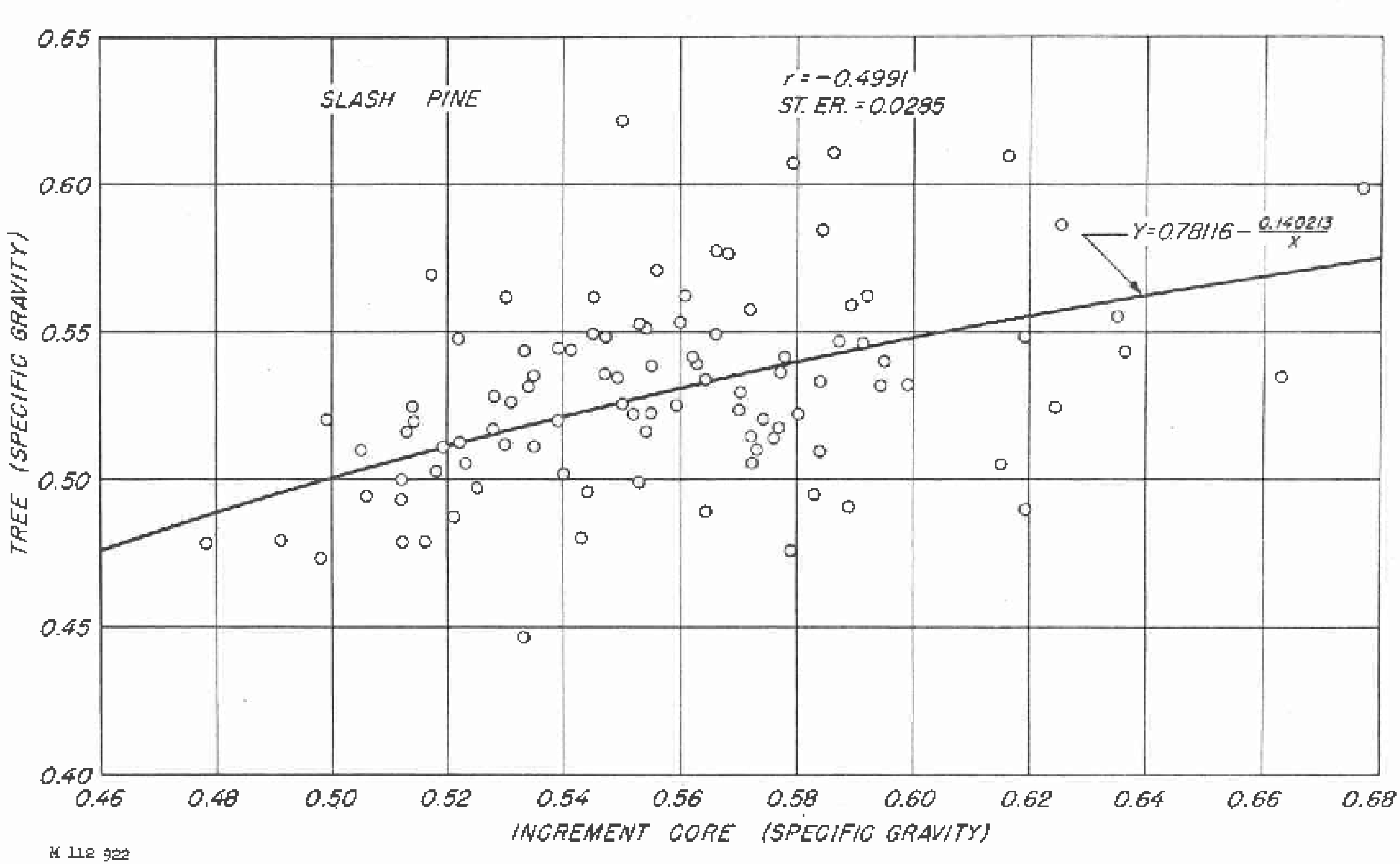

Figure 7. --Simple regression of tree specific gravity on reciprocal of increment core specific gravity from 100 slash pine trees.

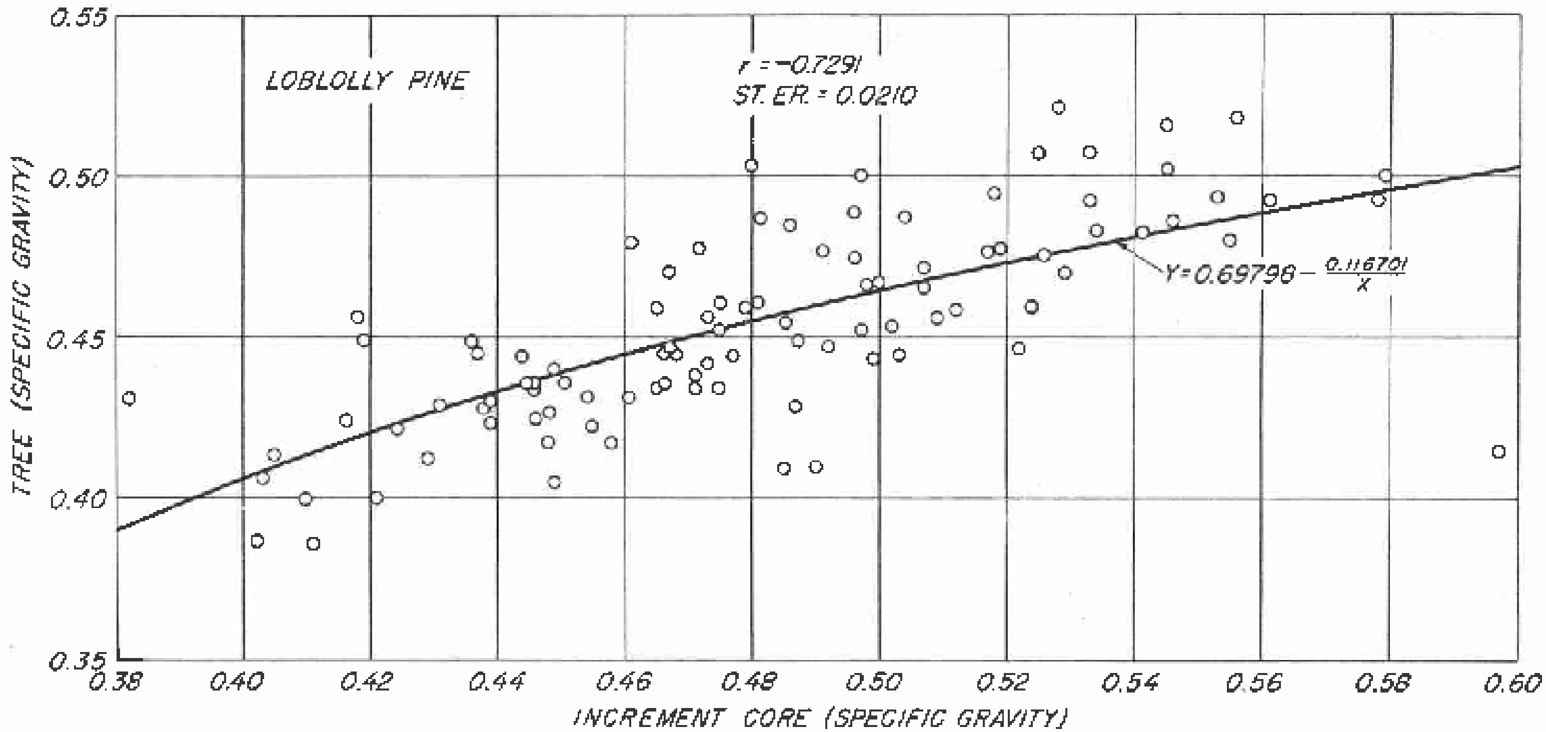

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Figure 8. --Simple regression of tree specific gravity on reciprocal of increment core specific gravity for 100 loblolly pine trees.

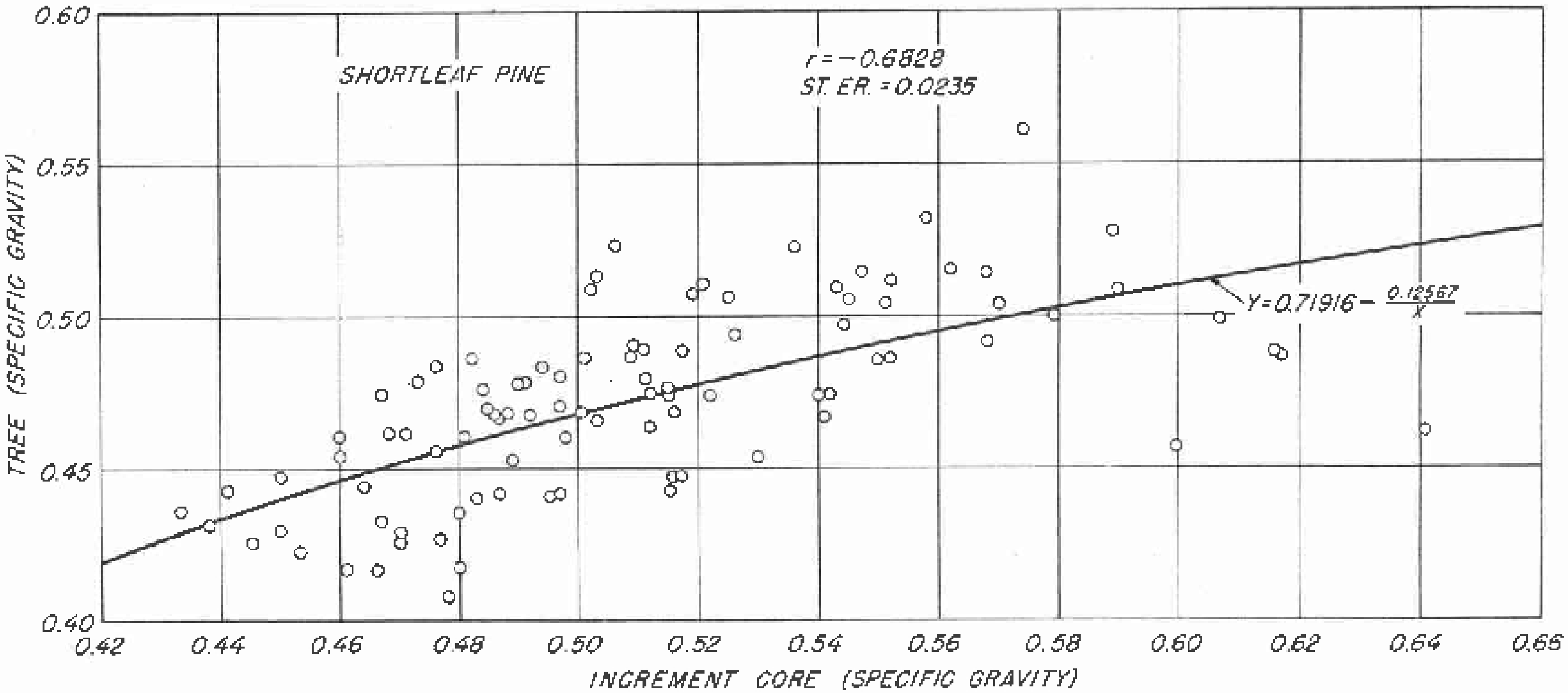

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Figure 9. --Simple regression of tree specific gravity on reciprocal of increment core specific gravity for 100 shortleaf pine trees.

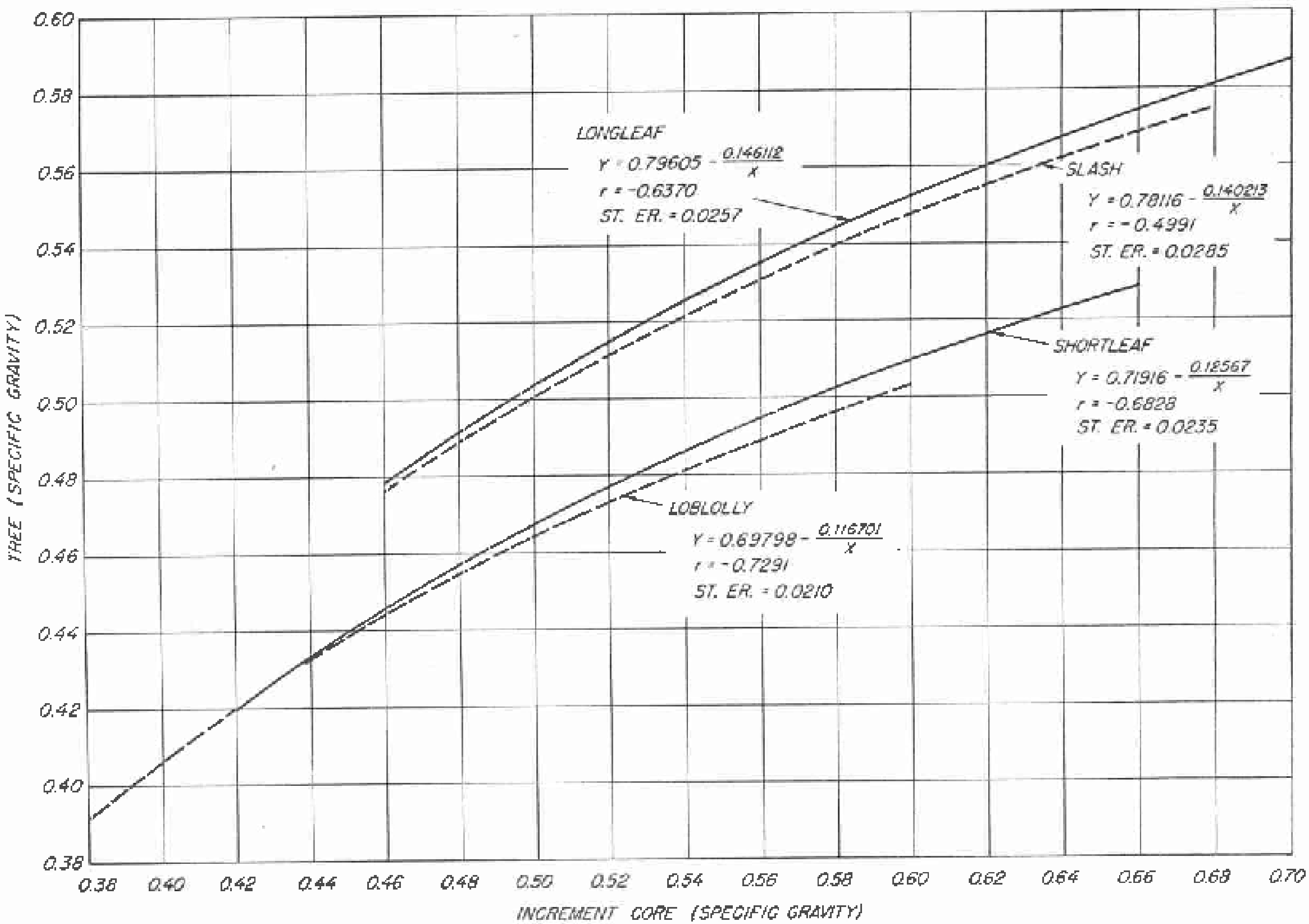

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Figure 10. --Simple regressions of tree specific gravity on reciprocal of increment core specific gravity for the four species of southern yellow pine.

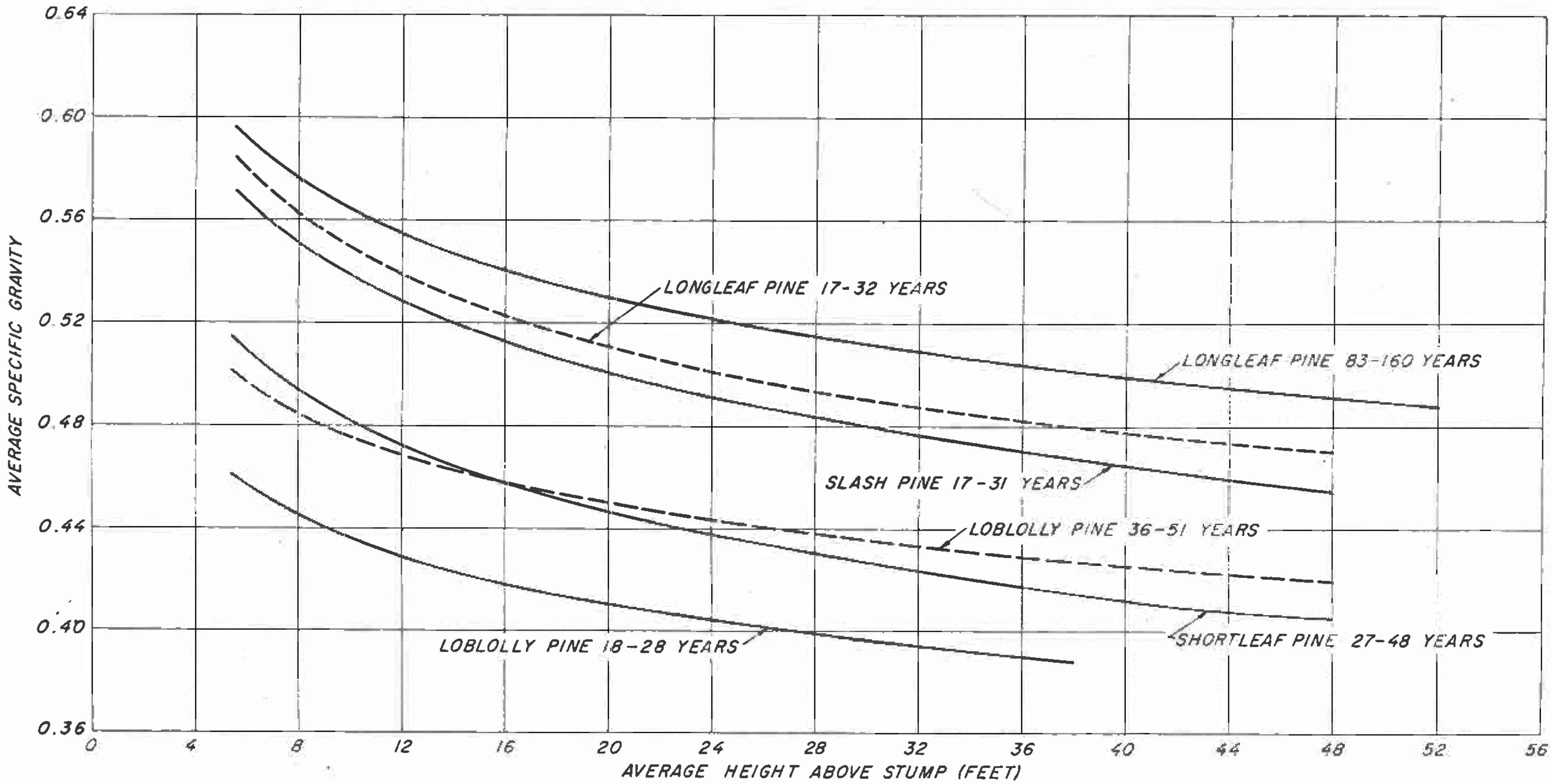

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Figure 11.--Approximate relations of average specific gravity at successive heights by age class of longleaf, slash, loblolly, and shortleaf pines.