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Regan B. Willson, Bryce E. Schlaegel, and Harvey E. Kennedy, Jr.

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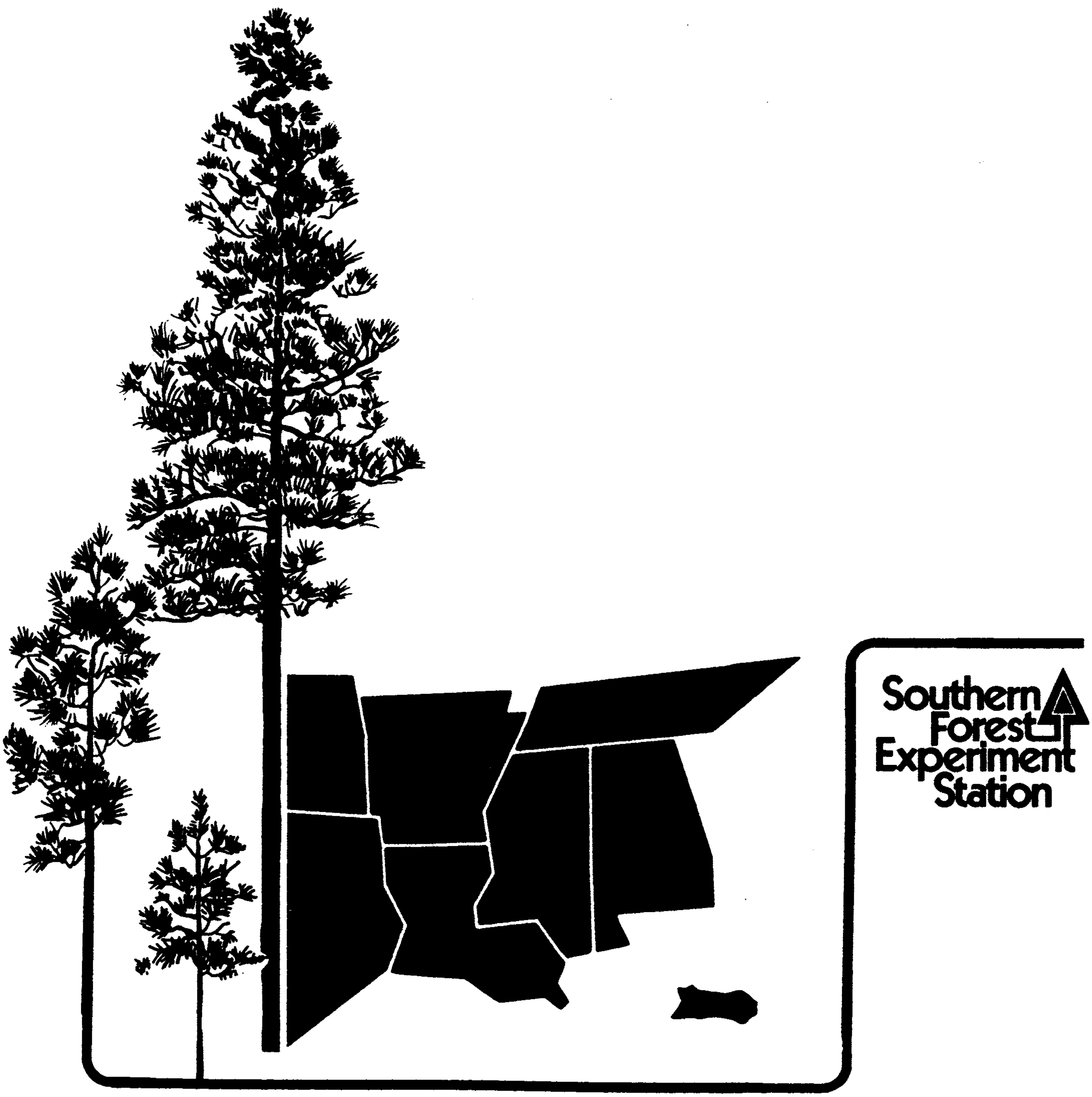

INDIVIDUAL TREE BIOMASS MODELS FOR PLANTATION GROWN AMERICAN SYCAMORE[1/]

Regan B. Willson, Bryce E. Schlaegel, and Harvey E. Kennedy, Jr.[2/]

Abstract.--Individual tree volume and green and dry weight equations are derived for American sycamore from a 5-year-old plantation in southeast Arkansas. Two trees have been destructively sampled each year from each of 20 plots. Observations from 168 trees are used to predict tree weight and volume as a function of dbh, total height, age, and initial number of trees. Separate component equations are given for bole wood, bole bark, branch wood, and branch bark. Additivity of the predicted component values is discussed. Based on fit index and the coefficient of variation, the sum of the predicted component values are good estimates of total bole, branch, and tree volume and weight.

INTRODUCTION

The short rotation concept with coppice reproduction was devised on the premise that some tree species can be grown at close spacing using short rotations and coppice regeneration. This concept has led to the question: What species-spacing combination and rotation length would maximize total fiber production?

The American sycamore (Platanus occidentalis L.), a rapid growing species that is relatively free from insect and disease attack, was the first species used to test the silage concept of Herrick and Brown (1967). This silage concept originally envisioned plantings at very close spacings, perhaps as close as 1 x 4 or 2 x 4 feet, harvested at 1- to 3-year intervals. But research has shown high rates of stump mortality at these close spacings (Kormanik et al. 1973), resulting in a natural widening of the original spacings. Early results indicated that the number of surviving sprouts per stump increases with the spacing (Kulchol 1971) and that coppice yields increase as stump diameter increases (Belanger and Saucier 1975).

These findings indicate that it might be both economically and biologically better to grow fewer large-size trees at wide spacings than many small-size trees at close spacings. The best cutting strategy might be to grow the original seedling stand for 4 or more years before harvest and then begin coppice rotations. Or, instead of harvesting at specific intervals, perhaps the best time to harvest is the year when mean annual increment (MAI) peaks.

Tree size, per acre biomass production, and thus current MAI, are directly correlated with the initial spacing and the current plantation age. This paper presents individual tree volume and weight equations for sycamore based on dbh, total height, age, and initial spacing.

METHODS

Installation and Measurements

A randomized complete block design of four blocks and five spacings was planted in late May of 1976 in a minor stream bottom in southeastern Arkansas. The spacings in feet and respective number of trees per acre were 2 x 8 (2723), 3 x 8 (1815), 4 x 8 (1361), 8 x 8 (681), and 12 x 12 (303). The spacings were chosen to span from the narrow coppice spacings to the more usual pulpwood and saw log spacings. The 8-foot distance between rows was chosen to allow tending by standard farm equipment.

Each of the 20 plots consists of 169 trees planted in a rectangular grid of 13 x 13 rows. The interior 5 x 5 rows are designated as permanent remeasurement rows with the outer 4 rows as a buffer.

Beginning in the fall of 1977, two trees from the 2nd and 3rd buffer rows representative of the plot were destructively sampled each fall for a total of five annual samples. Field measurements included diameter 6 inches above the ground, dbh, total height, crown height, total bole weight, and

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2/ Regan B. Willson is Instructor in Computer Information Systems at Delta State University, Cleveland, Mississippi. Bryce E. Schlaegel is Principal Mensurationist and Harvey E. Kennedy, Jr. is Principal Silviculturist at the Southern Hardwoods Laboratory, maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group.

total crown weight. Separate bole, limb, and leaf samples were taken and sealed in separate polyethylene bags for laboratory determination of green and dry weights and volume. One-inch thick disks were cut from the bole at a 6-inch stump and at intervals of 20, 40, 60, and 80 percent of total tree height. The branch and leaf samples consisted of selecting two representative limbs from each quarter of the crown and consolidating these into an eight-branch tree sample; leaves were detached from the branches in the field and bagged separately.

Green weights, dry weights, and volumes were determined in the laboratory as follows:

Bole analysis:

1. Weigh all five bole sections together to the nearest gram for total sample green weight.
2. Separate wood and bark with a knife and weigh each component for their respective green weights.
3. Obtain separate wood and bark volumes by water immersion.
4. Oven-dry the wood and bark at 105°C for 48 hours, then reweigh for their respective dry weights.

Sample branch analysis:

1. Obtain the green weight of the combined eight-branch sample.
2. Randomly choose at least a 200-gram branch subsample.
3. Separate wood and bark in the subsample and obtain green weights of each.
4. Obtain the subsample volumes for each component by water immersion.
5. Reweigh subsample wood and bark after drying at 105°C for 48 hours for their respective dry weights.

Leaf analysis:

1. Obtain sample green weight.
2. Dry sample at 70°C for 48 hours and reweigh.

Green weights of bole wood and bark for each tree were obtained by multiplying the proportion of each in the bole sample times the total bole green weight measured in the field. Green weights of branch wood, branch bark, and leaves were derived by adding the leaf and branch sample weights, finding the proportion of each component in the sample and applying the proportions to the total crown weight obtained in the field.

Total dry weights and volumes for each component were calculated using the consolidated sample component moisture contents and specific gravities. Moisture content and specific gravity were assumed to be uniform within each component.

Deriving the Volume and Weight Equations

Allometric models of the form $LN(Y) = LN(b_0) + b_1LN(D^2H)$ have been repeatedly used in biomass studies (Schlaegel 1981, Clark and Schroeder 1977, Clark and Taras 1976). For these models

Y = the component volume or weight variable of interest

D = tree dbh in inches or centimeters,

H = total tree height in feet or meters,

LN is a natural logarithm, and

b_0 and b_1 are coefficients estimated from the data.

However, when this model was fitted to the sycamore data across all age-spacing combinations and the residuals plotted separately over age and spacing, the residuals plots indicated that dbh and height alone were not sufficient to accurately predict either tree volume or weight for all ages and spacings.

To account for age, the data were fitted to the model

$$LN(Y) = LN(b_0) + b_1LN(D^2H) + b_2(1/A). \qquad (1)$$

The addition of the age term (1/A) proved significant by the conditional error test for addition of a new variable (Kleinbaum and Kupper 1978). A plot of the residuals over age showed no discernible pattern. However, plotting the residuals over spacing showed the model was inadequate in predicting overall spacings.

The next model examined was

$$LN(Y) = LN(b_0) + b_1LN(D^2H) + b_2(1/A) + b_3LN(N) \qquad (2)$$

where N = the planted number of trees per acre. Using the conditional error test and a plot of the residuals, the addition of the spacing term proved significant.

Although the model was a good predictor of bole and branch wood weights and volumes, it did not sufficiently predict bark weights and volumes.

Plotting the residuals over age, holding spacing constant; and, over spacing, holding age constant; indicated an interaction term between age and spacing.

With the interaction term, LN(N)/A, the model took the following form:

$$LN(Y) = LN(b_0) + b_1 LN(D^2H) + b_2(1/A) + b_3 LN(N) + b_4[LN(N)/A] \quad (3)$$

Fitting this model to the bark components showed by the conditional error test significant improvement over the previous model (2). Applying model 3 to the wood components showed no significant difference between models 2 and 3. However, the interaction term was included in the final model form for predicting all components.

RESULTS

Of the possible 200 trees from the 100 age-spacing combinations, only the 168 trees taller than 4.5 feet were used in the analysis. Characteristics of these trees are:

	Average	Range
Dbh (in)	1.4	0.2 - 4.6
Total height (ft)	14.3	4.5 - 30.5
Green bole wood (lbs)	11.29	0.20 - 88.49
Green bole bark (lbs)	1.38	0.07 - 9.13
Green branch wood (lbs)	4.67	0.02 - 49.60
Green branch bark (lbs)	1.01	0.01 - 8.42
Dry bole wood (lbs)	5.63	0.09 - 45.35
Dry bole bark (lbs)	0.65	0.02 - 4.65
Dry branch wood (lbs)	2.39	0.01 - 23.99
Dry branch bark (lbs)	0.48	0.004 - 4.01
Bole wood volume (ft^3)	0.18	0.003 - 1.36
Bole bark volume (ft^3)	0.03	0.001 - 0.17
Branch wood volume (ft^3)	0.08	0.0004 - 0.78
Branch bark volume (ft^3)	0.02	0.0002 - 0.15

Individual tree bole wood, bole bark, branch wood, and branch bark volumes and weights were fitted to the final model (3).

When logarithmic estimates are converted back to original units, they are biased downward, because the antilogarithm of the estimated means gives the geometric rather than the arithmetic mean (Cunia 1964). Converting estimates from logarithmic units back to arithmetic units produces a systematic underestimate of the dependent variable. To account for this bias a correction factor was computed using a procedure described by Baskerville (1972) and applied to each equation. Estimates of the coefficients for each component are presented in table 1 for predicting green weights in pounds, in table 2 for predicting dry weights in pounds, and in table 3 for predicting cubic-foot volume. Also included in tables 1, 2, and 3 are the component average, coefficient of determination (R^2), and the regression standard error of the estimate ($\hat{S}_{y.x}$). The coefficient of determination, which measures how much variation in the dependent variable can be accounted for by the explanatory variables of the model, ranges from 0.811 for green branch bark weight to 0.977 for green bole wood weight.

Can the predicted values from the component equations be added together to predict totals? This question often arises when working with biomass models. Kozak (1970) showed that when each component was fit to the same linear model with the same number of observations, the sum of the predicted component values was equal to the predicted total.

Although linear in appearance, allometric models are not mathematically additive. The regression coefficients from the allometric component equations cannot be added together to obtain the regression coefficients for the total equation. If not linear or additive, how well does the sum of the predicted component values fit the sum of the measured components? Criteria useful for determining the prediction accuracy include fit index, coefficient of variation, mean of the residuals, and the standard error in actual units. But to use these statistics requires a method of comparison.

Each predicted component value was converted back to arithmetic units and tested against the actual (measured) component value. The sum in actual units of the predicted component values was compared to the sum of the actual component values. The component average, fit index, coefficient of variation, mean of the residuals, and the standard error in actual units are presented in table 4. Fit index, which is similar to R^2, is used to judge goodness of fit when the dependent variable has been transformed (Farrar 1978) and is calculated in actual units from the total and residual sums of squares.

Bole wood can be estimated more precisely than any other component with fit indices ranging from 0.953 to 0.962 and an average coefficient of variation of 28 percent. Branch bark can be predicted with the least precision with fit indices ranging from 0.838 to 0.849 and an average coefficient of variation of 57 percent. But since branch bark averages only 7 percent of the total tree while bole wood averages 61 percent of the tree, these apparent inaccuracies are not as important as they first appear.

The sums of individual component predictions, when compared to the measured totals, prove to be accurate estimates of total bole, total branches, or total tree. The fit indices for total tree average 0.964; the average coefficient of variation is 27 percent.

Table 1.--Regression statistics for predicting sycamore green weight in pounds; $LN(Y) = LN(b_0) + b_1 LN(D^2H) + b_2(1/A) + b_3 LN(N) + b_4(LN(N)/A)$

Component	Average Y	$LN(b_0)$	b_1	b_2	b_3	b_4	R^2 1/	$\hat{S}_{y.x}$ 2/
Bole wood	11.29	3.15434	0.55729	-3.36436	-0.33979	0.24809	0.977	0.228
Bole bark	1.39	1.58110	0.44755	-3.42180	-0.35866	0.30269	0.967	0.222
Branch wood	4.67	3.47453	0.68005	-1.40599	-0.69415	0.24220	0.878	0.512
Branch bark	1.01	2.10107	0.56438	-1.16312	-0.63781	0.22162	0.811	0.546

1/ Coefficient of determination of the logarithmic equation.
2/ Standard error of the estimate in logarithmic units.

Table 2.--Regression statistics for predicting sycamore dry weight in pounds; $LN(Y) = LN(b_0) + b_1 LN(D^2H) + b_2(1/A) + b_3 LN(N) + b_4(LN(N)/A)$

Component	Average Y	$LN(b_0)$	b_1	b_2	b_3	b_4	R^2 1/	$\hat{S}_{y.x}$ 2/
Bole wood	5.63	2.98036	0.53368	-4.31724	-0.39063	0.35312	0.975	0.243
Bole bark	0.65	1.39662	0.44432	-4.74322	-0.41780	0.41875	0.970	0.237
Branch wood	2.39	3.39153	0.65847	-2.38055	-0.75737	0.35758	0.867	0.540
Branch bark	0.48	2.41373	0.52302	-3.14340	-0.74572	0.43921	0.812	0.560

1/ Coefficient of determination of the logarithmic equation.
2/ Standard error of the estimate in logarithmic units.

Table 3.--Regression statistics for predicting sycamore volume in cubic feet; $LN(Y) = LN(b_0) + b_1 LN(D^2H) + b_2(1/A) + b_3 LN(N) + b_4(LN(N)/A)$

Component	Average Y	$LN(b_0)$	b_1	b_2	b_3	b_4	R^2 1/	$\hat{S}_{y.x}$ 2/
Bole wood	0.18	-1.03377	0.55167	-3.33050	-0.32188	0.23225	0.975	0.238
Bole bark	0.02	-2.62140	0.45788	-3.31830	-0.32965	0.27174	0.966	0.236
Branch wood	0.08	-0.06153	0.65766	-2.18253	-0.75925	0.34295	0.867	0.532
Branch bark	0.02	-1.53846	0.53647	-1.67142	-0.63822	0.24663	0.814	0.550

1/ Coefficient of determination of the logarithmic equation.
2/ Standard error of the estimate in logarithmic units.

Table 4.--Statistics comparing predictions to measured tree components

Component	Average Y	Fit index	Coefficient of variation percent	Standard error of estimate actual units	Mean residuals
	Green weight (pounds)				
Bole wood	11.29	0.960	28	3.155	0.302
Bole bark	1.39	0.949	27	0.372	0.038
Bole wood and bark	12.68	0.960	27	3.457	0.340
Branch wood	4.67	0.917	50	2.328	-0.189
Branch bark	1.01	0.847	55	0.560	-0.057
Branch wood and bark	5.68	0.913	49	2.789	-0.247
Total tree without leaves	18.36	0.964	27	4.969	0.093
	Dry weight (pounds)				
Bole wood	5.63	0.962	27	1.516	0.105
Bole bark	0.65	0.946	29	0.187	0.013
Bole wood and bark	6.28	0.963	26	1.654	0.118
Branch wood	2.39	0.911	51	1.226	-0.132
Branch bark	0.48	0.849	56	0.269	-0.032
Branch wood and bark	2.87	0.907	51	1.460	-0.164
Total tree without leaves	9.15	0.965	27	2.468	-0.046
	Volume (cubic feet)				
Bole wood	0.18	0.953	28	0.055	0.005
Bole bark	0.03	0.943	27	0.008	0.001
Bole wood and bark	0.20	0.955	30	0.060	0.006
Branch wood	0.08	0.916	48	0.038	-0.004
Branch bark	0.02	0.838	60	0.012	-0.001
Branch wood and bark	0.10	0.910	45	0.045	-0.006
Total tree without leaves	0.30	0.962	28	0.085	0.0004

The estimates from an allometric model are biased when converted back to actual units. Even though an approximate correction was made as suggested by Baskerville (1972), a slight bias still exists. These biases are indicated by the mean residuals tabulated in table 4.

Since the sum of residuals is the Σ(Y actual - Y estimated), a positive mean residual indicates a slight underestimate for that particular component. But these average biases are small when compared to the component means. For the total tree the average green weight is underestimated by 0.5 percent, the dry weight is overestimated by 0.5 percent, and the volume is underestimated by 0.1 percent.

The average bias for individual components is slightly higher. For instance, the bias for green bole wood is 2.7 percent; bole bark, 2.7 percent; and branch bark, -5.6 percent. Thus, there appears to be no problem in predicting a total tree weight or volume by adding the predictions of the individual components.

SUMMARY

Working with 168 trees from a 5-year-old sycamore plantation in southeast Arkansas, individual tree volume and weight equations are derived as a function of dbh, total height, age, and initial number of trees. Regression equations for predicting bole wood, bole bark, branch wood, and branch bark, and associated statistics are presented. Although the equations are not mathematically additive, comparing the predicted component values to the actual component values and comparing the sum of the predicted values to the sum of the actual component values showed the estimates of totals to be as good or better than the individual components.

Although some slight bias results when converting from logarithmic units to actual units, this bias is small in relation to the component mean. Thus, total tree estimates can be accurately obtained by adding predicted values of individual components.

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