ABSTRACT.—Forty-four sample hardwood trees felled on 24 plots were separated into three above-ground components—stem, branches, and leaves—and weighed for dry matter content. Tree, stand, and site variables were tested for significant relationships with dry weight of tree parts. Weight increase of stems was a logarithmic function of both stem diameter and height, whereas for branches and leaves, only diameter was significantly related to dry weight. The fact that hardwood stems and branches have much higher weight values than pine is attributed primarily to higher wood densities of hardwoods. Larger crown/stem diameter ratios observed for hardwoods also help deter relative differences in weight of branchwood. Although not tested rigorously, comparative data on growth rates suggest that loblolly pine produces more usable dry material per unit of land area than upland hardwoods.

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Dry Weight of Several Piedmont Hardwoods

IN THE PAST, forest productivity has been measured mainly in units of board feet, cubic feet, and cords. However, from both ecological and timber utilization standpoints there is a real need for a more precise and less subjective method for assessing timber quantity. Evaluation on a weight basis offers a logical answer to this need, and, indeed, many wood-using firms are purchasing bulk products such as pulpwood and wood chips by weight rather than volume measure.

With increasing interest in weight transactions at the mill, it is apparent that forest managers will require information on weight of standing trees in order to predict growth and yield in gravimetric units. Also, comparisons of relative productivity and growth rates of different species on a volumetric basis is particularly inappropriate for cellulose products because of wide inherent differences in wood specific gravity between species. Here, too, weight evaluation provides a valid method for comparison.

Since very little information on weight relations of upland Piedmont hardwoods has been reported, data were collected to formulate tree weight tables for several species and to compare relative biomass of hardwoods and pine. Also, as more complete utilization of trees becomes common practice, knowledge of branch weight will be indispensable. Data on amounts of foliage are of importance to physiologists, forest fire specialists, and silviculturists. For these reasons, branch and foliage weights were included in the present study as well as that of stems.

Methods

Basic data for this study were collected in a number of hardwood and pine-hardwood stands of the Duke Forest near Durham, N. C. Forty-four sample trees for weight measurement were felled on 24 temporary plots after various stand data such as number of trees per acre, basal area, average height of dominant stand, and age class of stand had been obtained. Sample trees selected were codominant or dominant trees of the following species: *Quercus falcata* Michx., *Q. coccinea* Muenchh., *Q. rubra* L., *Q. alba* L., *Carya tomentosa* Nutt., *C. glabra* (Mill.) Sweet, *C. ovata* (Mill.) K. Koch. Morphological data recorded for each sample tree included: diameter at 4.5 feet, age, total length of stem, and total live crown length and width.

After felling each tree, its branches were removed and the stem was sectioned into five-foot lengths. In the laboratory various additional data were taken including fresh weight of each stem section, fresh weight of leaves and branches, and diameter inside and outside bark at the upper and lower end of each section. Two-inch cross-sections were removed from the upper end of each stem bolt, weighed, and dried to constant weight at 70°C. Fresh/dry weight ratios of these sample sections were used to calculate dry weight (70°C) of the entire stem. Branches and leaves were placed in burlap bags and dried to constant weight at 70°C in a dry-kiln. Leaves were then removed from the branches, and separate weights of these components were obtained.

From *a priori* consideration of the nature of the analysis, it was felt that certain variables such as tree height, diameter, form factor, site index, and stand density should be related to tree weight. However, preliminary graphical analysis indicated strong linear trends only for logarithmic functions of tree weight and stem diameter and height. Using the services and machine program of the Duke University Digital Computer Laboratory, mathematical expressions of weight of tree parts were obtained in terms of tree height and diameter by least squares multiple regression techniques described by Snedecor (*6*).

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Results and Discussion

Regression analyses indicated a linear relationship between the logarithm of weight and logarithm of tree height and diameter in the case of stem weight. However, logarithm of tree diameter was the only significant variable related to weight of branches and leaves. Statistical parameters including regression coefficients for each species and tree component are presented in Table 1. Weight estimates for tree parts can be calculated after substituting appropriate coefficients in an expression of the form:

$$\text{Log(WT.)} = b_o + b_1 [\text{Log(Dia.)}] + b_2 [\text{Log(HT.)}]$$

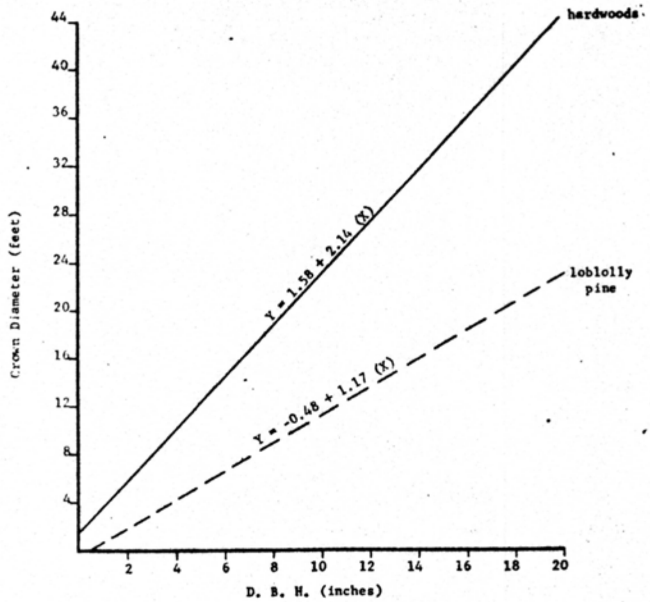
Hardwood weights shown in Tables 2 and 3 were computed in this manner.

In hopes of generating a more interesting discussion, observations on weight of above-ground components of oaks and hickories will be compared with estimates compiled by Baker for loblolly pine (*1*). The principal *a priori* assumptions used in making weight contrasts of pine and hardwoods were that valid conclusions could be derived by comparing trees of equal diameter, height, and leaf weight. The last assumption is of particular consequence in that it establishes the stocking level to be used in calculation of weight components for pine. Since weight of branches and leaves of pine varies appreciably with stand density (*1*), for purposes of comparison it seems reasonable to specify a stocking value that yields leaf weights in pine similar to hardwood leaf weight values.

Foliage.—When one considers the role of leaves as the source of food materials used in the synthesis and accretion of all plant parts, it is rather surprising that until recently foliage weight relationships have not received greater attention in studies of forest trees.

As reported for other species, leaf weight increase of oaks and hickories can be expressed as a logarithmic function of stem diameter. Although the error of estimate for single observations was rather large, none of the other tree or stand variables provided additional increases in precision. Although it seems likely—as reported by Baker (*1*) for loblolly pine—that leaf weight of hardwoods also is affected by stand density, no stocking correlations were evident in the analysis. One would expect to find increase in crown diameter,

Fig. 1.—Crown diameter-stem diameter relationship for hardwoods and loblolly pine. (Equations based on 74 hardwood trees and 395 loblolly pine trees.)



length, and weight within given stem diameter classes as stocking decreases. Apparent lack of correlation of the stocking variable used in the present study may be due to inapplicability of stocking criteria developed for oak in the Central States region (*2*) to stands sampled in this study. In addition, most hardwood stands in the Piedmont (including the ones sampled) tend to have an irregular multistoried structure due to past selective cutting. Such conditions are not conducive to clear-cut evaluation of stocking effects.

Trends of leaf weight and stem diameter for hardwood and loblolly pine are shown in Table 2. Estimates of foliage weight for loblolly pine listed in Table 2 for stands of 50 percent stocking are approximately the same as average values for hardwoods. This relationship suggested that pine stocking at 50 percent provided a reasonable basis for deriving other comparisons of weight components.

Branches.—As noted by earlier investigators for other species, total branch weight of the hardwood species studied increases with increasing stem diame-

Table 1.—Regression Data by Species

Component	Regression coefficients b_o	b_1	b_2	Error of single obs. in percent	Mult. corr. coeff.
		White oak			
Stem	−0.67	1.93 ± 0.17	0.84 ± 0.24	8.7	0.999
Branches	−0.41	2.48 ± 0.12	—	33.0	0.982
Leaves	−0.42	1.77 ± 0.10	—	27.5	0.976
		Red oak			
Stem	−0.92	1.61 ± 0.24	1.13 ± 0.33	11.5	0.999
Branches	−0.21	2.26 ± 0.16	—	48.8	0.970
Leaves	−0.53	1.86 ± 0.15	—	43.3	0.965
		Hickory			
Stem	−1.02	1.77 ± 0.17	1.14 ± 0.25	8.4	0.999
Branches	−0.50	2.68 ± 0.17	—	34.3	0.979
Leaves	−0.56	1.96 ± 0.21	—	41.7	0.945
		Species combined			
Stem	−0.88	1.73 ± 0.10	1.06 ± 0.14	10.2	0.998
Branches	−0.33	2.40 ± 0.09	—	40.0	0.974
Leaves	−0.50	1.86 ± 0.08	—	36.2	0.965

Table 2.—Oven-Dry Weight of Leaves and Branches as Related to Tree Diameter

D.b.h.	Leaf weight		Branch weight	
	Hardwood	Pine	Hardwood	Pine
Inches	*Pounds*		*Pounds*	
4	4.2	4.6	13	10
5	5.8	6.6	23	16
6	8.8	9.3	35	24
7	11.7	12.2	50	33
8	15.0	16.6	70	42
9	18.7	19.6	93	54
10	22.8	24.2	120	67
11	27.2		150	
12	32.0		185	

ter. This relation was expressed by a linear trend using logarithmic functions of branch weight and stem diameter. The data presented in Table 2 show that branch weights for the hardwood species studied are considerably higher than weights of branches for loblolly pine trees of the same size. This difference is due in part to differences in specific gravity, since investigations of specific gravity of stem wood indicated considerably higher values for hardwoods (*5, 7,*). Also it should be noted that Piedmont hardwoods often have larger crowns than loblolly pine trees of the same stem diameter. Evidence of differences in crown-stem diameter relationships is presented graphically in Figure 1. Evidently, larger crown size contributes substantially to greater hardwood branch weight, particularly for trees larger than seven inches in diameter.

Stem.—Stem weight analysis shows that dry weight of stems of red oak, white oak, and hickory increases with both height and diameter. Ovington and Madgwick (*3*) working with birch in Great Britain found a similar trend using either diameter or height as the independent variable, but found no particular advantage in using both height and diameter in a multiple regression equation. It should be noted, however, that their study did not include a range of tree heights within single diameter classes. Since in the present study a number of tree heights were observed within single diameter classes, it is evident that a height variable will contribute significantly to the estimate. This conclusion is supported by earlier findings for conifers by Baker (*1*) and Vaidya (*8*).

With height and stocking held constant at 70 feet and 50 percent respectively, stem weight values for loblolly pine were computed for various diameters.[1] Comparison of these values with the weight of hardwood stems presented in Table 3 shows that stem weight values for loblolly pine are substantially less than those of hardwood stems of comparable height and diameter. Greater weight for hardwoods is attributed primarily to differences in wood specific gravity. In a separate study conducted on the same sample trees, Turner (*7*) found that average stem specific gravity (including bark) for white oak, red oak, and hickory was 0.617. This value is considerably higher than average stem specific gravity of loblolly pine (0.424) determined by Smith (*5*). These values indicate that on the average, pine stem weight is only 68 percent of that of hardwood stems of the same size.

Table 3.—Loblolly Pine and Hardwood Stem Weights (Height Constant at 70 ft.)

D.b.h.	Weight	
	Hardwoods	Pine
	Pounds	
7	349	330
8	440	380
9	539	425
10	647	475
11	762	525
12	887	565

In view of demonstrably greater weight of substances contained in oaks and hickories than in pines of similar size, it is interesting to speculate on their relative rates of wood production. If they increase in volume at equal rates, the hardwoods obviously will out-produce pines by a significant amount. However, according to Ovington and Pearsall (*4*), there is evidence that upland hardwoods produce less dry matter per unit land area than conifers. Unfortunately, this hypothesis cannot be tested with our weight equations because conventional stand and yield table data are not available for Piedmont hardwoods. Nevertheless, our records do indicate that eight of the fastest growing sample trees from bottomland and cove sites averaged 7 inches in diameter and 57 feet in height at an age of 34 years. Estimated stem weight for such trees is 278 pounds. Plantation-grown loblolly pines on comparable sites will average about 10 inches in diameter and 74 feet in height at the same age. Since the bole of a pine of these dimensions weighs about 469 pounds, it would appear that there may be an appreciable differential in rates of dry matter production.

Even though this illustrative analysis is not particularly rigorous, it does point out the advantage of a gravimetric approach to problems involving relative rates of wood production. It also points to a need for additional mensurational and physiological research on problems of this nature.

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[1]Weights computed by an equation derived by Baker (1).