DIAMETER GROWTH

of individual hardwood trees

The effect of certain tree and environmental factors on the growth of several species

by G. R. Trimble, Jr.

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Introduction

BETWEEN 1959 and 1967 a study of d.b.h. growth rates was made on individual hardwood trees near Parsons, W. Va. From this study, we obtained information that will help foresters to predict growth. We learned that the correlation of the more easily used crown classification with d.b.h. growth is as good as or better than the correlation of vigor classes with d.b.h. growth. We discovered that when crown classes are identified, crown measurements such as width and length add practically nothing of predictive value. We established that tree d.b.h. is positively and strongly correlated with d.b.h. growth in these mixed hardwood stands. We learned that a measure of total surrounding basal area is not a good predictor of individual tree d.b.h. growth in these stands. We compiled annual d.b.h. growth by crown classes for several important species on several levels of forest site quality.

In this report, d.b.h. growth is discussed in relationship to: (1) crown and vigor classes, (2) crown measurements, (3)

initial d.b.h., (4) basal-area density, and (5) species and site quality.

The Study Area

The study locale, the Fernow Experimental Forest, which lies at an elevation between 1,800 and 3,600 feet, has an annual precipitation of 58 inches and an annual average temperature of 48° F. The average land gradient is about 35 percent. The soil mantle is 3 to 4 feet deep, medium textured, and well drained.

The trees were growing in mixed hardwood stands where average stand densities ranged, when the study was initiated, from 60 to 120 square feet of basal area in trees over 1.0 inch d.b.h. Site indexes (for oak) were: 85 (an excellent site), 63 (a fair site), and, for some white (*Quercus alba* L.) and chestnut oak (*Q. prinus* L.), 50 (a poor site). The stands, approximately 55 years old in 1959, were even-aged with a scattering of older dominant residuals. The stands on the two better-site areas had been partially cut—a combination thinning and improvement cutting—in 1954. The poor-site stands had never been cut.

Methods

Sample trees were selected mechanically: the timber cruiser designated each fifth tree he measured in the stand inventory as a sample.

The following measurements and observations were taken on these trees: (1) d.b.h. (at 4.5 feet as measured and indicated by a scribe mark); (2) total tree height, measured with a Spiegel Relaskop; (3) crown length, from the lowest live branch to the top of crown, measured with a Spiegel Relaskop; (4) crown width, measured on the ground as an average of the north-south and east-west crown projection; (5) basal area around the sample tree, measured with a Spiegel Relaskop, using 10 and 40 factors; (6) crown class; and (7) vigor class.

Measurements were repeated after four and eight growing seasons. About 1,000 trees were included in the study.

Growth Related to Crown and Vigor Classes

Two types of tree classes related to growth rate have been used by foresters to guide selective marking: crown classes and vigor classes (see definitions in appendix 1).

Tree vigor classes have been used successfully to predict d.b.h. growth rates for hardwood species *(3, 4)*. In the development of vigor classifications, emphasis has been placed on crown features such as position in the canopy, on size and relative "health," and on bark characteristics *(1, 2)*. Probably the least subjective judgment made in assigning vigor class is crown position; and the question naturally arises: Is vigor class actually better correlated with diameter growth than is crown position alone? If not, then why not rely on the simpler-to-use and better-recognized crown classifications described in almost all textbooks on silviculture, and discontinue making all the additional and highly subjective secondary observations?

This study provided the opportunity to test the two yardsticks, and the sample trees were classified by both systems. Nine sets of comparisons were made; they included six species and three site quality classes.

The rank correlation (R) shows the relative accuracy of the two systems in classifying tree d.b.h. growth rates. The rank correlation was computed for: (1) crown class and growth and (2) vigor class and growth (table 1). The system of classification with the larger value of R could be considered best.

The rank correlations showed that for five of the nine sets of data the separation into crown classes ranks the trees more accurately for growth rates than does separation into vigor classes, although differences are small. The highest R, for both crown and vigor classifications, was for site index 85 red oak, indicating excellent suitability of both as predictors of d.b.h. growth.

R for sugar maple was low, especially for crown class. The extreme shade tolerance of this species may account for this low accuracy of ranking by crown class. Crown position appears to

make less difference in growth rates with such species (although our information on this in the case of sugar maple is limited because sample trees were confined to the lower crown classes) because they can utilize lower intensities of light more efficiently. With them, we might reason that a vigor classification based mainly on the appearance of the crown—with little weight given to crown position—might be the best way to classify trees for growth-prediction purposes.

Overall, there appears to be little advantage to using either crown or vigor classes in choosing which trees to cut or leave in thinning operations in stands of middle-aged mixed hardwoods. We want to emphasize that the culls had been removed from these fairly-well-stocked to well-stocked stands. In open understocked stands or in highly defective or decadent stands, vigor class, in comparison to crown class, might show greater accuracy in ranking trees for growth prediction purposes.

An interesting trend showed up between crown class and the size of the coefficients of variation (table 2). The dominant crown class had the lowest average coefficient of variation—0.25; and the others fell in order with a rising c.v. as tree dominance class decreased. That is, the average c.v. for the codominant class was 0.28; for intermediate crown class, 0.39; and for overtopped, 0.50. This indicates that growth varied least within the dominant crown class and most within the overtopped class.

The degree of agreement between corresponding crown and vigor classes varied with species and tree classes themselves (table 3). For red, chestnut, and white oak the ratings by crown and vigor class corresponded quite well. Yellow-poplar classifications of crown class also agreed fairly well with the corresponding vigor class except for the codominant-vigor II comparison. With black cherry agreement was good for the two middle classes, and poor for the highest and lowest classes. Observers rated the vigor of the tolerant sugar maple relatively higher for its crown class than they did any of the other species. Growth for the lower crown classes of this species can be expected to be greater relative to the growth of the higher crown classes than for the less-tolerant species like yellow-poplar.

Growth Related to Crown Measurements

The effect of crown dimensions on diameter growth rates has long been recognized, and investigations have demonstrated direct relationships between radial increment and crown size. In this study we assessed the association between growth at breast height and these crown measurements: (1) crown length, (2) live crown ratio, (3) crown width, and (4) the product of crown length times crown diameter.

Correlation coefficients were computed for each species and site, ignoring crown class (table 4); and for each species and site, considering crown class. These were used to judge the degree of association between the various crown parameters and diameter growth.

When the growth data were not grouped by crown class, certain crown measurements were found to be important indicators of potential diameter growth. Nine groups of trees (species-site combinations) were tested with these results:

- Seven groups showed a significant effect of crown diameter on growth, with a maximum r^2 of 0.66.
- Eight groups showed a significant effect on growth of the product of crown length and crown width, with a maximum r^2 of 0.48.
- Five groups showed a significant[1] positive effect of crown length on d.b.h. growth, with a maximum r^2 of 0.29.
- No group showed a significant effect of crown ratio on d.b.h. growth.

When the growth data were grouped by crown class, significant relationships between growth and the other crown parameters were rarely found, indicating that these variables added but little additional information about diameter growth rates. In

[1] Significance is accepted at the 5-percent level.

only 11 out of a total of 124 sets of data were significant relationships indicated between crown measurements and d.b.h. growth. These are so few we can safely conclude that, if crown class is identified, the additional crown measurements are not very likely to be of appreciable value as growth predictors.

For practical classification of trees for growth prediction purposes in stands similar to these, identification of crown class alone, which is a simple observation, is preferable to any of the crown measurements tested; and once crown class is identified, none of these measurements would be very likely to explain additional d.b.h. growth variation.

Growth Related to Initial D.B.H.

Analyses showed that, on the average, the larger trees grew faster in diameter than the smaller trees. The reason for this is that the larger trees occupy more dominant positions in the canopy (and have more voluminous functional crowns); this is shown by the larger average d.b.h.'s for the more dominant crown classes (table 5). All of the nine species-site combinations tested showed significant positive correlations between d.b.h. growth and initial d.b.h. Red oak on site index 85 had the highest r^2—0.86; and chestnut oak on site index 50 had the lowest r^2—0.19. Because of this relationship between growth rate and d.b.h., tree diameter can be used to appraise relative tree growth rates in even-aged stands.

When analyses of the relationship between d.b.h. and d.b.h. growth were made on trees *within* crown class, only 4 out of the 21 groups of data tested showed significant correlations (table 5). This indicated that within crown classes tree d.b.h. was not a good predictor of diameter growth.

Growth Related to Basal-Area Density

Ten and 40 factors were used to measure basal-area density. The 10-factor measurements extend twice as far as the 40-factor measurements (table 6).

The data indicated a general—if not invariable—reduction in surrounding basal area with increasing tree dominance (table 7). In other words, dominant trees tended to reduce nearby competition—or to be dominant because of a lack of nearby competition. This was slightly more evident with the 40-factor measurements than with the 10-factor.

When trees were not grouped by crown classes, correlation between d.b.h. growth and surrounding basal area, taken with both 10 and 40 factors, were significant at the 5-percent level in only five out of nine species-site combinations (table 8). Moreover, even where significance was attained, correlation was weak, indicating that total surrounding basal area had little value as a predictor of d.b.h. growth rates of individual trees.

In six cases out of nine, the 40-factor (which has only half the reach of the 10-factor) was a slightly better predictor of growth, as indicated by the size of the r^2, than the 10-factor (table 8).

The next step was to study the effect of basal-area density (as expressed by the 40-factor) on growth *within* crown classes. In only 2 out of 15 groups tested were significant correlations found (table 9), indicating that within a crown class surrounding basal area is poorly correlated with d.b.h. growth.

The general weakness of total surrounding basal area as a predictor of diameter growth should not be suprising in stands like these comprising many species with different crown and diameter growth characteristics, different shade tolerances, and with a rather wide range of ages for even-aged stands. The competitive effects on a tree of surrounding stems depends on: (1) the relative sizes of the sample tree and its competitors, (2) the distance from sample tree to surrounding stems, and (3) interaction between relative tree size (sample trees vs. competitors)

and distance between stems. Use of basal area as a growth predictor could be expected to be much more appropriate in more even-aged stands composed of fewer species.

Growth by Species and Site Quality

Diameter growth data for a number of species were compiled by oak site-index class and tree-crown class (table 10). Annual d.b.h. growth was determined only for classes represented by five or more study trees. As a result, some of the cells are empty. However, coverage was sufficient to indicate clearly that growth was positively correlated with site quality and that an increase in crown dominance was accompanied by an increase in growth.

These findings confirmed the results of other studies made in the area. Moreover, the d.b.h. growth ranking, by species fell pretty much in line with the results of other studies made in similar 45- to 60-year-old stands *(5, 6)*. (We want to emphasize that these were middle-aged stands. In stands older or younger the relative d.b.h. growth rates of the species might be, and probably would be, considerably different.)

Because of the lack of data for many groups—that is, the absence or scarcity of study trees in many classifications—species growth comparisons were incomplete. However, some things stand out. Middle-aged red oak grew faster in diameter than any of its associates on site indexes 63 and 85. Yellow-poplar was a not-too-close second on the higher site. White and chestnut oak grew slowly. Sugar maple grew faster in subdominant positions on site index 85 than black cherry or yellow-poplar. This was to be expected of such a tolerant species.

Considering the great variability of d.b.h. growth rates and the low number of sample trees in some classes, too much reliance should not be placed on the accuracy of the averages; some classes were significantly different from others, many were not. The confidence limits (table 10) indicate which categories have overlapping growth rates and do not differ at the 5-percent level in d.b.h. growth rates.

Summary and Discussion

Comparison of the relationship of d.b.h. growth to crown class and vigor class showed no clearcut advantage of either as a predictor of d.b.h. growth rates. Both ranked growth in logical order. Because the standard crown classes are easier to use, we recommend them, rather than vigor classes, for use as growth predictors.

These crown variables were studied in their relationship to d.b.h. growth: crown length, crown ratio, crown diameter, and the product of crown length by crown diameter. When trees were not separated into crown classes but only into species-site groups, crown diameter and the product of crown length by crown diameter were significantly correlated with d.b.h. growth for most species-site combinations. For about half of the combinations, crown length was correlated with d.b.h. growth. Crown ratio was correlated with growth in none of the nine combinations. When trees were grouped by crown class within a species-site combination, we found little relationship of any of these crown variables to d.b.h. growth. For purposes of predicting d.b.h. growth, these variables add but little to crown class alone.

Trees of greater d.b.h. grew faster; initial d.b.h. of hardwood trees was strongly and positively correlated with subsequent 8-year d.b.h. growth for a number of species-site combinations. However, when the combinations were stratified by crown class, few groups showed significant relationships between initial d.b.h. and d.b.h. growth. This indicated that the real growth relationship was to crown class; larger diameter trees in the even-aged stands had more dominant crowns and for this reason grew faster.

Averages of total basal area taken around study trees indicated there was a general reduction of tree-dominance class with greater surrounding basal-area density. When trees were not stratified into crown classes, d.b.h. growth was significantly correlated with surrounding density in five out of nine species-site groups. However, in the five cases correlation was weak, indicating that total

surrounding basal area had little value as a predictor of d.b.h. growth rates for individual trees. Moreover, when the study trees were further stratified by crown classes within the species-site combinations, basal-area density showed little relationship to growth.

This study indicated that a strong relationship existed between d.b.h. growth and species, site quality, and crown class. Although the d.b.h. growth for combinations of these factors was highly variable, measurements of initial d.b.h., surrounding basal area, and several crown parameters added little significant growth-prediction information.

For operations involving tree-growth assessment, such as selective marking and determining rotation diameters, this study indicated that in stands like these, the best growth predictors—within a species on a given site—are crown class and relative d.b.h. Because of the heterogeneous nature of the stands—mixtures of species and tree size—undifferentiated basal-area measurements are not good predictors of growth. Crown class (which expresses the vigor of the tree's food-manufacturing process) and relative d.b.h. (which reflects the efficiency of the crown) are highly correlated, and both reflect to an extent the total competitive pressure of surrounding stand density.

In young even-aged stands composed of only a few species of similar growth characteristics, relative d.b.h. is probably the most easily assessed indicator of growth capacity; crown classes are hard to distinguish in such stands. Crown class, as an indicator of growth, becomes more usable in older stands, in stands composed of a greater variety of species, and in stands encompassing a wider age span. In other words, in uniform stands d.b.h. is the best practical indicator of growth potential; in diversified stands crown class is a better yardstick.

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Appendix I

VIGOR CLASS DEFINITIONS*

Vigor I.—A tree in this vigor class has a large, healthy, full crown in a dominant or codominant position. Half the crown or more is exposed to direct sunlight. The crown is dense, with no evidence of disease or injury. Crown quality and position is more important than total length. The bark and twigs have good color and vigorous appearance.

Vigor II.—A tree in this vigor class has a fair-sized crown in a codominant position. Less than half the crown is exposed to direct sunlight. The crown is less dense and not so perfect as that of a Vigor I tree. This class may also include a large-crowned tree that fails to meet the requirements of Vigor I because of mechanical injury or dying limbs.

Vigor III.—A tree in this vigor class has a medium to small crown usually in an intermediate position. Only the tip is exposed to direct sunlight. The crown may be open, with some dead or broken limbs, or thinly foliated. This class also includes trees with fair to large crowns in a codominant position that cannot meet the requirements for a Vigor I tree.

Vigor IV.—A tree in this class usually has a small crown in an overtopped position. This class includes all living trees that fail to meet the requirements of higher vigor classes.

CROWN CLASS DEFINITIONS

Dominant.—Trees with crowns extending above the general level of crown cover and receiving full light from above and partly from the sides; larger than the average trees in the stand, and with crowns well developed but possibly somewhat crowded on the side.

Codominant.—Trees with crowns forming the general level of the crown cover and receiving full light from above but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

Intermediate.—Trees shorter than those in the two preceding classes but with crowns extending into the crown cover formed by codominant and dominant trees; receiving a little direct light from above but none from the sides; usually with small crowns considerably crowded on the sides.

Overtopped.—Trees with crowns entirely below the general level of the crown cover, receiving no direct light either from above or the sides.

*Bark characteristics were used only very incidentally. These vary greatly by species and for some species appear to vary little or not at all with tree vigor. Moreover, they have proved applicable very inconsistently across site qualities.

Table 1.—*Rank correlations between d.b.h. growth rates and crown and vigor classes*

Species	Oak site index	Rank correlation	
		Crown class	Vigor class
	Feet	*R*[1]	*R*
Red oak (*Quercus rubra* L.)	85	0.80	0.75
Red oak	63	.67	.71
White oak	63	.50	.44
Yellow-poplar (*Liridodendron tulipifera* L.)	85	.54	.52
Sugar maple (*Acer saccharum Marsh.*)	85	.31	.49
Black cherry (*Prunus serotina* Ehrh.)	85	.53	.66
Chestnut oak	63	.58	.57
Chestnut oak	50	.46	.55
White oak	50	.65	.58

[1] All of the R's are significant at the 5-percent level.

Table 2.—*Comparison of coefficients of variation of 8-year d.b.h. growth rates by crown class and vigor class*

Species and oak site index	Dominant crown classs	Vigor class I	Codominant crown class	Vigor class II	Intermediate crown class	Vigor class III	Overtopped crown class	Vigor class IV
Red oak: site index 85:								
8-year d.b.h. growth	3.01	2.93	2.23	2.06	1.39	1.30	0.64	0.55
Coefficient of variation	.14	.14	.28	.32	.40	.53	.65	.49
Number of trees	7	11	30	27	18	23	13	7
Yellow-poplar: site index 85:								
8-year d.b.h. growth	1.68	1.64	1.39	1.21	0.95	1.00	—	—
Coefficient of variation	.26	.26	.30	.33	.35	.40	—	—
Number of trees	18	27	22	15	9	6	—	—
Black cherry: site index 85:								
8-year d.b.h. growth	1.18	1.46	1.22	1.21	0.78	0.75	0.47	0.45
Coefficient of variation	.30	.24	.32	.33	.55	.53	.46	.39
Number of trees	11	11	42	39	21	25	7	6
Sugar maple: site index 85:								
8-year d.b.h. growth	—	—	—	1.28	1.31	0.73	1.00	0.70
Coefficient of variation	—	—	—	.43	.33	.42	.55	.71
Number of trees	—	—	—	35	14	14	40	7
Red oak: site index 63:								
8-year d.b.h. growth	2.10	2.29	1.98	1.99	1.36	1.49	1.04	0.97
Coefficient of variation	.17	.19	.24	.20	.34	.28	.23	.27
Number of trees	5	7	32	23	14	21	7	7

CONTINUED

Table 2.—Continued

Species and oak site index	Dominant crown class	Vigor class I	Codominant crown class	Vigor class II	Intermediate crown class	Vigor class III	Overtopped crown class	Vigor class IV
White oak: site index 63:								
8-year d.b.h. growth	1.50	1.45	1.24	1.28	1.03	1.09	0.52	0.72
Coefficient of variation	.24	.27	.36	.29	.50	.54	.65	.72
Number of trees	5	4	14	12	8	9	4	6
Chestnut oak: site index 63:								
8-year d.b.h. growth	1.48	1.49	1.16	1.21	0.87	0.90	0.53	0.51
Coefficient of variation	.37	.36	.26	.28	.41	.40	.53	.54
Number of trees	22	15	80	75	30	45	19	16
Chestnut oak: site index 50:								
8-year d.b.h. growth	—	—	0.66	0.73	0.59	0.59	0.48	0.48
Coefficient of variation	—	—	.17	.10	.19	.19	.23	.23
Number of trees	—	—	5	3	15	15	6	6
White oak: site index 50:								
8-year d.b.h. growth	—	—	0.57	0.55	0.45	0.44	0.19	0.21
Coefficient of variation	—	—	.30	.34	.43	.45	.71	.74
Number of trees	—	—	12	10	25	25	15	15

Table 3.—*Deviation of vigor classification from crown class*

[Number of sample trees is shown in parentheses]

Species	Site index (oak)	Percentage division of trees in a crown class by vigor classes											
		Dominant crown class			Codominant crown class			Intermediate crown class			Overtopped crown class		
		Vigor I	Vigor II	Vigor III	Vigor I	Vigor II	Vigor III	Vigor II	Vigor III	Vigor IV	Vigor II	Vigor III	Vigor IV
Red oak	85	100	0	0	13	67	20	33	61	6	8	46	46
		(7)			(4)	(20)	(6)	(6)	(11)	(1)	(1)	(6)	(6)
Red oak	63	100	0	0	6	75	16	0	86	14	0	29	71
		(5)			(2)	(24)	(5)[a]		(12)	(2)		(2)	(5)
White oak	63	80	20	0	0	79	21	0	62	38	0	25	75
		(4)	(1)			(11)	(3)		(5)	(3)		(1)	(3)
Yellow-poplar	85	89	11	0	50	50	0	33	67	0	0	0	100
		(16)	(2)		(11)	(11)		(3)	(6)				(3)
Black cherry	85	55	45	0	12	74	14	10	76	14	0	57	43
		(6)	(5)		(5)	(31)	(6)	(2)	(16)	(3)		(4)	(3)
Sugar maple	85	0	0	0	67	33	0	79	14	0	60	28	12
					(2)	(1)		(11)[b]	(2)		(24)	(11)	(5)
Chestnut oak	63	64	32	4	1	84	15	3	90	7	0	26	74
		(14)	(7)	(1)	(1)	(67)	(12)	(1)	(27)	(2)		(5)	(14)
Chestnut oak	50	—	—	—	40	60	0	0	100	0	0	0	100
					(2)	(3)			(15)				(6)
White oak	50	—	—	—	17	83	0	0	96	4	0	7	93
					(2)	(10)			(24)	(1)		(1)	(14)

[a] 1 tree—3 percent in vigor class IV.
[b] 1 tree—7 percent in vigor class I.

Table 4.—*Correlation of d.b.h. growth with crown features (ignoring crown class)*

Species and site index	Number of trees	r^2 — Coefficient of variation			
		With crown length	With crown ratio	With crown diameter	With product of crown length x crown diameter
Red oak: site index 85	55	0.07*	0.04^N	0.66**	0.48**
Red oak: site index 63	58	.03^N	.05^N	.25**	.21**
White oak: site index 63	31	.06^N	.004^N	.08^N	.07^N
White oak: site index 50	52	.08*	.02^N	.27**	.23**
Chestnut oak: site index 63	130	.04*	.005^N	.14**	.08**
Chestnut oak: site index 50	26	.29**	.14^N	.06^N	.28**
Sugar maple: site index 85	57	.03^N	.01^N	.08*	.08*
Yellow-poplar: site index 85	51	.12*	.01^N	.28**	.28**
Black cherry: site index 85	81	.02^N	.001^N	.30**	.24**

* r is significant at the 5-percent level.
** r is significant at the 1-percent level.
^{N} r is not significant at the 5-percent level.

Table 5.—*Correlation between d.b.h. growth and initial d.b.h.*

Species and crown class	Site index (oak)	Stems	Average d.b.h. 1959	Range in d.b.h. of sample trees 1959	r^2 between d.b.h. growth and initial d.b.h.[1]
		No.	*Inches*	*Inches*	
Red oak	85	68	11.7	6.3-20.0	0.86**
Dominant		7	16.9	11.0-20.0	—
Codominant		30	13.7	8.6-17.9	.42**
Intermediate		18	9.5	6.3-13.6	.02^N
Overtopped		13	7.2	6.3- 9.4	.05^N
Yellow-poplar	85	53	14.1	5.8-21.7	.66**
Dominant		18	17.8	10.6-21.7	.06^N
Codominant		22	14.4	9.0-16.8	.00^N
Intermediate		9	9.3	7.6-16.7	—
Overtopped		4	6.2	5.8- 6.5	—
Sugar maple	85	57	6.9	5.0-11.9	.49**
Dominant		—	—	—	—
Codominant		3	10.3	7.7-11.9	—
Intermediate		14	8.0	5.1-16.1	.02^N
Overtopped		40	6.3	5.0-12.1	.02^N

CONTINUED

Table 5.—Continued

Species and crown class	Site index (oak)	Stems	Average d.b.h. 1959	Range in d.b.h. sample trees 1959	r^2 between d.b.h. growth and initial d.b.h.[1]
Black cherry	85	81	12.6	6.8-20.1	.43**
Dominant		11	15.6	11.7-20.1	.01^N
Codominant		42	14.0	11.0-21.8	.13*
Intermediate		21	9.9	7.7-11.3	.01^N
Overtopped		7	7.8	6.8- 9.6	—
Red oak	63	58	9.1	5.0-24.0	.51**
Dominant		5	15.3	11.2-24.0	—
Codominant		32	9.8	6.1-19.1	.08^N
Intermediate		14	6.9	5.3-10.6	.03^N
Overtopped		7	6.0	5.0- 9.2	—
White oak	63	31	10.2	5.0-18.9	.55**
Dominant		5	16.6	12.9-18.9	—
Codominant		14	10.8	7.5-16.7	.00^N
Intermediate		8	7.2	5.6-10.2	—
Overtopped		4	5.8	5.0- 6.8	—
Chestnut oak	63	151	9.6	5.1-23.5	.44**
Dominant		22	14.1	8.5-23.5	.00^N
Codominant		80	10.2	5.5-22.7	.00^N
Intermediate		30	7.3	5.2-14.2	.00^N
Overtopped		19	5.7	5.1- 7.6	.05^N
Chestnut oak	50	26	7.0	5.4-10.3	.19*
Dominant		—	—	—	—
Codominant		5	8.6	6.3-19.3	—
Intermediate		15	6.9	5.8- 8.5	.41*
Overtopped		6	5.9	5.4- 6.6	—
White oak	50	52	7.2	4.5-13.0	.42**
Dominant		—	—	—	—
Codominant		12	9.4	7.0-13.0	.03^N
Intermediate		25	7.2	5.0- 8.7	.30**
Overtopped		15	5.4	4.5- 6.2	.08^N

[1] Indicates the amount of d.b.h. growth variation accounted for by initial d.b.h. The correlation is always positive: the greater the initial d.b.h., the greater the d.b.h. growth rate.

*r is significant at the 5-percent level.

**r is significant at the 1-percent level.

^{N} r is not significant at the 5-percent level.

Table 6.—*Plot radius in feet for trees of given d.b.h.*

Tree d.b.h. (inches)	Horizontal distance that will include tree	
	40-factor	10-factor
	Feet	*Feet*
6	8.25	16.50
10	13.75	27.50
14	19.25	38.50
18	24.75	49.50
22	30.25	60.50
26	35.75	71.50

Table 7.—*Total basal area around study trees (includes trees over about 1.0 inches d.b.h.)*

Species	Crown class	Number of stems	Site index (oak)	Average basal area (1963)	
				10-factor	40-factor
Red oak	Dominant	7	85	110	109
	Codominant	30	85	123	149
	Intermediate	18	85	124	120
	Overtopped	13	85	127	151
Yellow-poplar ..	Dominant	18	85	118	118
	Codominant	22	85	130	142
	Intermediate	9	85	122	169
	Overtopped	4	85	130	120
Sugar maple ...	Dominant	4	85	—	—
	Codominant	3	85	97	80
	Intermediate	14	85	101	100
	Overtopped	40	85	128	133
Black cherry	Dominant	11	85	125	156
	Codominant	42	85	150	173
	Intermediate	21	85	153	189
	Overtopped	7	85	139	183
Red oak	Dominant	5	63	76	48
	Codominant	32	63	106	82
	Intermediate	14	63	111	103
	Overtopped	7	63	110	120
White oak	Dominant	5	63	76	56
	Codominant	14	63	103	69
	Intermediate	8	63	105	75
	Overtopped	4	63	108	100
Chestnut oak ...	Dominant	22	63	95	52
	Codominant	80	63	99	84
	Intermediate	30	63	100	100
	Overtopped	19	63	104	105
Chestnut oak ...	Dominant	0	50	—	—
	Codominant	5	50	110	104
	Intermediate	15	50	100	83
	Overtopped	6	50	90	100
White oak	Dominant	0	50	—	—
	Codominant	12	50	105	103
	Intermediate	25	50	113	114
	Overtopped	15	50	109	112

Table 8.—*Effect of initial density (10 and 40 factors) on 4-year d.b.h. growth—within a species and site class and regardless of tree crown class*

Correlation coefficients and r^2 with 4-year d.b.h. growth

Species	Site index (oak)	Number of sample trees	10-factor density		40-factor density		Difference in r^2 40-factor − 10-factor
			r	r^2	r	r^2	
Red oak	85	67	−0.15[N]	0.02	−0.19[N]	0.04	+.02
Yellow-poplar	85	51	−.32*	.10	−.36**	.13	+.03
Black cherry	85	81	−.06[N]	.004	−.09[N]	.008	+.004
Sugar maple	85	57	−.35**	.12	−.33**	.11	−.01
Red oak	63	58	−.26*	.07	−.33**	.11	+.04
White oak	63	31	−.55**	.30	−.34*	.12	−.18
Chestnut oak	63	151	−.29**	.08	−.33**	.11	+.03
Chestnut oak	50	26	−.15[N]	.02	−.18[N]	.03	+.01
White oak	50	52	+.12[N]	.02	+.12[N]	.01	−.01

* r is significant at the 5-percent level.
** r is significant at the the 1-percent level.
[N] r is not significant at the 5-percent level.

Table 9.—*Effect of initial total basal area on subsequent 4-year d.b.h. growth expressed in correlation* [1]

Species	Site index (oak)	Crown class	Number of sample trees	40-factor r with growth	basal area r^2
Red oak	85	Codominant	30	—0.37*	0.14
	85	Intermediate	18	—.01[N]	.00
Yellow-poplar	85	Dominant	18	—.36[N]	.13
	85	Codominant	22	—.28[N]	.08
Black cherry	85	Codominant	42	—.00[N]	.00
	85	Intermediate	21	—.10[N]	.01
Sugar maple	85	Overtopped	40	—.22[N]	.05
Red oak	63	Codominant	32	—.15[N]	.02
Chestnut oak	63	Dominant	22	—.39[N]	.15
	63	Codominant	80	—.13[N]	.02
	63	Intermediate	30	—.19[N]	.04
	63	Overtopped	19	+.03[N]	.00
Chestnut oak	50	Dominant	0	—	—
	50	Codominant	5	—	—
	50	Intermediate	15	—.05[N]	.003
	50	Overtopped	6	—	—
White oak	50	Dominant	0	—	—
	50	Codominant	12	—	—
	50	Intermediate	25	—.01[N]	.00
	50	Overtopped	15	+.51*	.26

[1] Analyses made for groups containing at least 15 trees.
* r is significant at the 5-percent level.
[N] r is not significant at the 5-percent level.

Table 10.—Annual d.b.h. growth of species, site quality, and crown class

Species	Dominant crown class		Codominant crown class		Intermediate crown class		Overtopped crown class	
	Annual d.b.h. growth in inches	Number of trees	Annual d.b.h. growth in inches	Number of trees	Annual d.b.h. growth in inches	Number of trees	Annual d.b.h. growth in inches	Number of trees
			SITE INDEX 50					
White oak								
Mean	—	—	0.071	12	0.056	25	0.024	15
Confidence limits	—		0.085-0.057		0.066-0.046		0.033-0.015	
Chestnut oak								
Mean	—	—	0.082	5	0.073	15	0.060	6
Confidence limits	—		0.099-0.065		0.081-0.065		0.074-0.046	
Scarlet oak								
Mean	0.093	7	0.070	32	0.058	8	—	—
Confidence limits	0.114-0.072		0.080-0.060		0.069-0.047		—	
			SITE INDEX 63					
White oak								
Mean	0.187	5	0.154	14	0.130	8	—	—
Confidence limits	0.242-0.132		0.187-0.121		0.183-0.777		—	
Chestnut oak								
Mean	0.185	22	0.145	80	0.108	30	0.066	19
Confidence limits	0.216-0.154		0.153-0.137		0.124-0.092		0.083-0.049	
Red oak								
Mean	0.262	5	0.248	32	0.170	14	0.130	7
Confidence limits	0.318-0.206		0.270-0.226		0.202-0.138		0.150-0.101	

Red maple								
Mean	—	—	0.212	8	0.131	14	0.095	12
Confidence limits	—		0.282-0.142		0.157-0.105		0.112-0.078	
			SITE INDEX 85					
Red oak								
Mean	0.377	7	0.280	30	0.174	18	0.081	13
Confidence limits	0.425-0.329		0.308-0.252		0.209-0.139		0.112-0.050	
Sugar maple								
Mean	—	—	—	—	0.163	14	0.125	40
Confidence limits	—		—		0.195-0.131		0.147-0.103	
Black cherry								
Mean	0.148	11	0.153	42	0.098	21	0.059	7
Confidence limits	0.178-0.118		0.168-0.138		0.122-0.074		0.083-0.035	
Yellow-poplar								
Mean	0.210	18	0.173	22	0.120	9	—	—
Confidence limits	0.237-0.183		0.196-0.150		0.151-0.089		—	
White ash								
Mean	—	—	0.197	13	0.125	10	—	—
Confidence limits	—		0.218-0.176		0.172-0.078		—	
Sweet birch								
Mean	—	—	—	—	0.141	15	0.110	9
Confidence limits	—	—	—		0.171-0.111		0.164-0.056	

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