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Growth and Yield of Thinned Yellow-Poplar

by

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Diameter distributions and yields for various combinations of site index, age, and density for unthinned and largely undisturbed stands of yellow-poplar (Liriodendron tulipifera L.) have been presented by McGee and Della-Bianca (1967) and Beck and Della-Bianca (1970). Their results were based on the initial measurements of a network of permanent sample plots throughout the southern Appalachians. In this paper we present equations for predicting basal-area growth and cubic-foot volume growth and yield in stands thinned to various levels of basal area. These results are based on measurements of the permanent plots taken 5 years after the initial thinnings.

METHODS

Plot Selection

Data for this study were obtained from 141 circular, $\frac{1}{4}$-acre plots established in the Appalachian Mountains of North Carolina (93 plots), Virginia (31 plots), and Georgia (17 plots). To be included in the study, the plots had to contain 75 percent or more yellow-poplar in the overstory, be free from insect and disease damage, and show no evidence of past cutting. All plots came from even-aged stands ranging in age from 17 to 76 years. Site index ranged from 74 to 138 feet. Site index at age 50 was determined with an equation (Beck 1962) that used average height and age of the five tallest yellow-poplar trees in each plot. Initial basal area varied from 44 to 208 square feet per acre.

Thinning

To obtain a range of basal area for various site-age combinations, each plot was thinned at the time of installation. Prior to thinning, each plot was assigned to a basal-area class and then thinned to the midpoint of a randomly selected lower basal-area class. For example, stands

with 91 through 110 square feet of basal area per acre would be assigned to the 100-foot class, then thinned to the 80-, 60-, or 40-square-foot basal-area class.

Low thinning (Society of American Foresters 1964) was used to reduce the stand basal area. Suppressed trees were cut first, then thinning was extended into higher crown classes as needed to obtain the desired residual density in well-spaced trees. The effect of this procedure was to reduce the range of tree diameters and concentrate the growing stock in the dominant and codominant crown classes. A $\frac{1}{2}$-chain isolation strip around each $\frac{1}{4}$-acre plot was thinned to the same residual basal area as the plot. All trees and shrubs less than 4.5 inches d.b.h. were cut to ground level to eliminate competition from stems other than residual trees (fig. 1). Species other than yellow-poplar were generally cut in thinning, except in a few plots other species were retained to avoid irregular spacing among residual yellow-poplar trees. Stand densities immediately after thinning ranged from 40 to 160 square feet of basal area per acre in trees 4.5 inches d.b.h. and over. Table 1 shows distribution of plots at the beginning of the 5-year measurement period by site index, age, and residual stand density.

Figure 1.--A 35-year-old yellow-poplar stand, site index 99, after thinning to 42 square feet of basal area per acre. All trees and shrubs less than 4.5 inches d.b.h. were cut to ground level.

Table 1.--Distribution of yellow-poplar plots by site index, age, and residual basal area after thinning

Site index (feet at 50 years)	Age class	Residual basal area (sq. ft./acre)							Total
		40	60	80	100	120	140	160	
	Years	Number of plots							
80	50	--	2	--	--	--	--	--	3
	60	--	--	--	--	--	--	--	
	70+	--	--	1	--	--	--	--	
90	20	--	--	--	--	--	--	--	16
	30	3	1	--	--	--	--	--	
	40	1	1	1	--	--	--	--	
	50	--	--	1	--	--	--	--	
	60	--	1	3	--	--	--	--	
	70+	--	--	--	1	3	--	--	
100	20	2	--	--	1	--	--	--	32
	30	2	--	1	--	--	--	--	
	40	1	--	1	1	--	--	--	
	50	--	3	3	1	1	--	--	
	60	1	2	1	1	3	--	1	
	70+	--	1	2	3	--	--	--	
110	20	--	--	--	1	--	--	--	52
	30	1	2	1	1	--	--	--	
	40	2	2	3	2	2	--	--	
	50	1	1	3	1	3	2	1	
	60	--	3	5	2	3	3	--	
	70+	--	1	2	2	1	1	--	
120	20	--	1	--	--	--	--	--	26
	30	3	1	3	2	2	--	1	
	40	1	2	1	2	--	--	--	
	50	--	--	--	1	2	--	--	
	60	--	--	--	--	1	1	1	
	70+	--	--	--	1	--	--	--	
130	20	1	--	--	--	--	--	--	10
	30	--	1	--	1	3	--	--	
	40	1	--	--	1	2	--	--	
	50	--	--	--	--	--	--	--	
	60	--	--	--	--	--	--	--	
	70+	--	--	--	--	--	--	--	
140	20	--	--	--	--	--	--	--	2
	30	--	--	--	1	--	--	--	
	40	--	--	--	--	--	--	--	
	50	--	--	--	--	--	--	--	
	60	--	--	--	--	--	--	--	
	70+	--	--	1	--	--	--	--	
Total		20	25	33	26	26	7	4	141

Volume Estimates

Volumes and basal areas were computed when the plots were thinned and again after five growing seasons. All stems, 4.5 inches d.b.h. and over, were measured by diameter tape and tallied to the nearest 0.1 inch. Total tree height was measured for the first tree and every tenth tree thereafter in each 1-inch diameter class. For each plot, a height-diameter equation of the general form log ht. = $a + b(\text{d.b.h.})^{-1}$ was fitted by least squares to the height and diameter data obtained from every tenth tree; the results were used to estimate total height for each tree in the plot. The volume in individual trees was determined from existing equations (Beck 1963, 1964). Plot volumes were computed from these data.

Analysis

The analysis was accomplished by using the system of compatible growth and yield models proposed by Clutter (1963) and later extended and refined by Sullivan and Clutter (1972). These models allow prediction of basal area and volume at some projected age when site index, initial age, and basal area are given. The projection model we used in this study is:

$$\ln Y_2 = b_0 + b_1(S^{-1}) + b_2(A_2^{-1}) + b_3(A_1/A_2)(\ln B_1) + b_4(1 - A_1/A_2) + b_5(S)(1 - A_1/A_2) \quad (1)$$

Where: Y_2 is stand volume at some projected age A_2; S is site index; B_1 is present basal area; A_1 is present age; and ln indicates the natural (Naperian) logarithm.

When $A_2 = A_1 = A$, i.e., the projection period is zero years, and $B_1 = B_2 = B$, then equation (1) reduces to the general yield model or stand volume equation:

$$\ln Y = b_0 + b_1(S^{-1}) + b_2(A^{-1}) + b_3(\ln B) \quad (2)$$

The yield projection model, equation (1), was essentially derived by substituting a basal-area projection equation for the basal-area term in a stand-volume equation, such as equation (2). Therefore, inserting $\ln Y_2$, A_2, and $\ln B_2$ into equation (2) and getting the resulting expression equal to the right side of equation (1), then solving the equality for $\ln B_2$ gives the model for projected basal area B_2 at projected age A_2:

$$\ln B_2 = (A_1/A_2)(\ln B_1) + (b_4/b_3)(1 - A_1/A_2) + (b_5/b_3)(S)(1 - A_1/A_2) \quad (3)$$

By taking the first derivative of the basal-area yield model, equation (3), with respect to age, the equation for basal-area growth is obtained:

$$dB/dA = (B)(A^{-1})[(b_4/b_3) + (b_5/b_3)(S) - (\ln B)] \quad (4)$$

Likewise, the first derivative of the cubic-foot yield model, equation (2), gives the cubic-foot growth model:

$$dY/dA = y^*[-b_2(A^{-2}) + b_3(B^{-1})(dB/dA)] \quad (5)$$

The variable y^* is total cubic-foot yield calculated with equation (2). The parameters of the basic yield model, equation (1), were estimated by the least squares method using total cubic-foot stand volume as the yield observation. In fitting the equation, data taken following thinning at plot establishment and again 5 years after thinning were combined, for a total of 282 observations. In this procedure, the data taken at establishment are viewed as observations on the yield projection function in equation (1) with projection period = zero, so $A_2 = A_1$. The data taken at remeasurement are viewed as observations on the same yield function after a 5-year projection period, i.e., $A_2 = A_1 + 5$. In fitting the least squares regression, the two sets are treated as independent observations when they are not. The consequences of this for statistical inference were not serious in the case examined by Sullivan and Clutter (1972). Readers interested in detailed justification for the procedure are referred to this paper.

RESULTS

All independent variables of the yield model were highly significant (table 2); hence, projected total cubic-foot yield per acre was estimated by:

$$\begin{aligned} \ln Y_2 = {} & 5.36437 - 101.16296(S^{-1}) - 22.00048(A_2{}^{-1}) \\ & + 0.97116(A_1/A_2)(\ln B_1) + 3.71796(1 - A_1/A_2) \\ & + 0.01619(S)(1 - A_1/A_2) \end{aligned} \quad (6)$$

Table 2.--Analysis of variance for projected total cubic-foot yield per acre of yellow-poplar

Source	d.f.	SS	MS	F
Effect of (S^{-1})	1	6.02912		2,084.16**
Added effect of $(A_2{}^{-1})$	1	29.56379		10,219.67**
Added effect of $(A_1/A_2)(\ln B_1)$	1	11.70101		4,044.83**
Added effect of $(1 - A_1/A_2)$	1	16.08572		5,560.54**
Added effect of $(S)(1 - A_1/A_2)$	1	0.04179		14.45**
Error	276	0.79842	0.00289	
Total	281	64.21985		

**Indicates significance at .01 level of probability.

Growth and yield equations derived directly from the fitted regression equation (6) are:

Total cubic-foot yield per acre when $A_2 = A_1 = A$:

$$\ln Y = 5.36437 - 101.16296(S^{-1}) - 22.00048(A^{-1}) + 0.97116(\ln B) \quad (7)$$

Projected basal-area yield per acre:

$$\ln B_2 = (A_1/A_2)(\ln B_1) + 3.82837(1 - A_1/A_2) + 0.01667(S)(1 - A_1/A_2) \quad (8)$$

Instantaneous basal-area growth per acre per year:

$$dB/dA = (B)(A^{-1})[3.82837 + 0.01667(S) - (\ln B)] \quad (9)$$

Instantaneous total cubic-foot growth per acre per year:

$$dY/dA = y^*[3.71796(A^{-1}) + 0.01619(S)(A^{-1}) - 0.97116(A^{-1})(\ln B) + 22.00048(A^{-2})] \quad (10)$$

With $y^* = Y$ computed by equation (7).

The values of the dependent variables for equations (6) through (10) were solved for each of 141 plots, and residuals were plotted against each of the independent variables. There were no discernible trends of the residuals with site index, age, or basal area. Curves of estimated values for specified combinations of site index, age, and density were logical in form and reasonable in predicted values. Comparisons of actual and estimated yellow-poplar growth and yield are summarized in table 3.

Estimates from equations (6) through (10) for selected values of the independent variables are shown in the Appendix (tables 5 through 7 and figures 8 and 9). Table 5, from equation (7), gives estimates of present yellow-poplar stand volume in total cubic feet per acre for various combinations of site index, age, and stand basal area. Figures 8 and 9 (from equations (8) and (6), respectively) show the projected development of basal area and total cubic-foot volume in yellow-poplar stands with prescribed initial basal areas. Tables 6 and 7 (from equations (9) and (10), respectively) show instantaneous basal-area growth and total cubic-foot growth per acre per year for given site-index, age, and basal-area values.

DISCUSSION

The equations presented in this paper are a first approximation to the growth and yield response surfaces for thinned yellow-poplar stands. The fit of the yield equations to the data compares favorably with that re-

Table 3.--Comparisons of observed and estimated yellow-poplar growth and yield per acre after thinning

Equation number	Data set	Average observed growth or yield	Average difference between observed and estimated	Variation explained by equation
				Percent
(7)	First period total cubic-foot measurements used as yield observations	3,778	+38.8	98.7
(7)	Second period total cubic-foot measurements used as yield observations	4,560	+14.4	99.3
(6)	Second period total cubic-foot volumes as projected from first period measurements	4,560	+54.7	98.3
(10)	Instantaneous total cubic-foot growth per year	156	+17.2	33.4
(8)	Second period basal area (sq. ft./acre) as projected from first period measurements	97	+0.8	98.5
(9)	Instantaneous basal-area growth (sq. ft./acre/year)	2.4	+0.06	47.2

ported for loblolly pine by Sullivan and Clutter (1972). The fit of the basal-area growth and cubic-foot volume growth equations is also comparable to that found for loblolly pine at the first 5-year remeasurement (Wenger et al. 1958). Experience with other tree species has shown that we can expect the precision of growth and yield predictors to improve as we accumulate additional cutting cycles and remeasurements in our permanent sample plots. Until additional data become available, however, the equations and graphs presented here are useful in estimating the effects of varying initial densities on basal-area growth, total cubic-foot growth, and total cubic-foot production.

Figures 2 and 3, from equations (9) and (10), illustrate the relationship of basal-area growth and total cubic-foot volume growth to initial basal area of thinned yellow-poplar stands over a range of site indices at a given stand age. The relatively flat curve with culmination of growth at progressively higher basal areas as site quality increases is similar to that found for loblolly pine (Nelson et al. 1961). Basal-area growth, in particular, changes but little over a wide range of residual basal areas. For example, a 40-year-old yellow-poplar stand on site index 110 produces basal area at better than 95 percent of its maximum rate for basal areas between 70 and 140 square feet per acre.

Figures 2 and 3 also point up the need to know site quality of yellow-poplar stands and to manage them accordingly. For example, on site index 90 land, maximum basal-area growth in a 40-year-old stand is

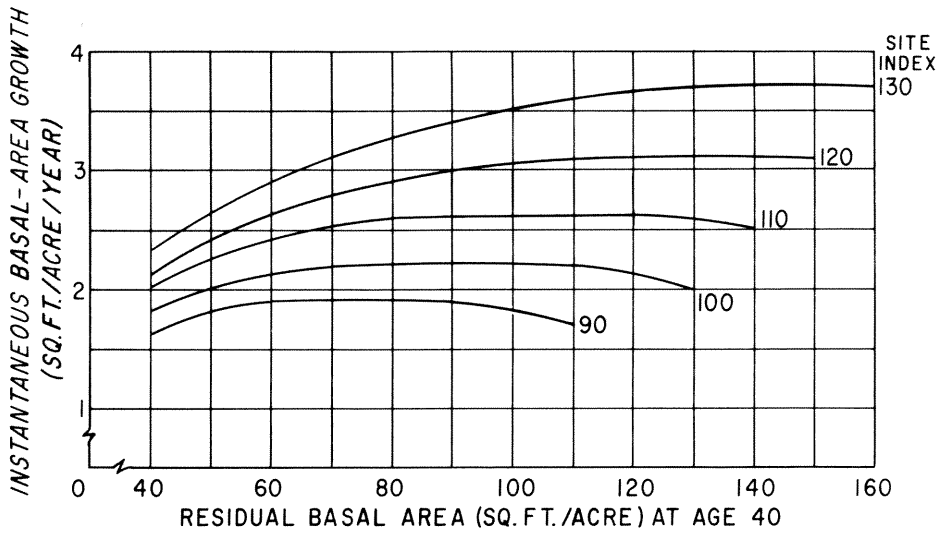

Figure 2.--Instantaneous basal-area growth in relation to site index and residual basal area at age 40.

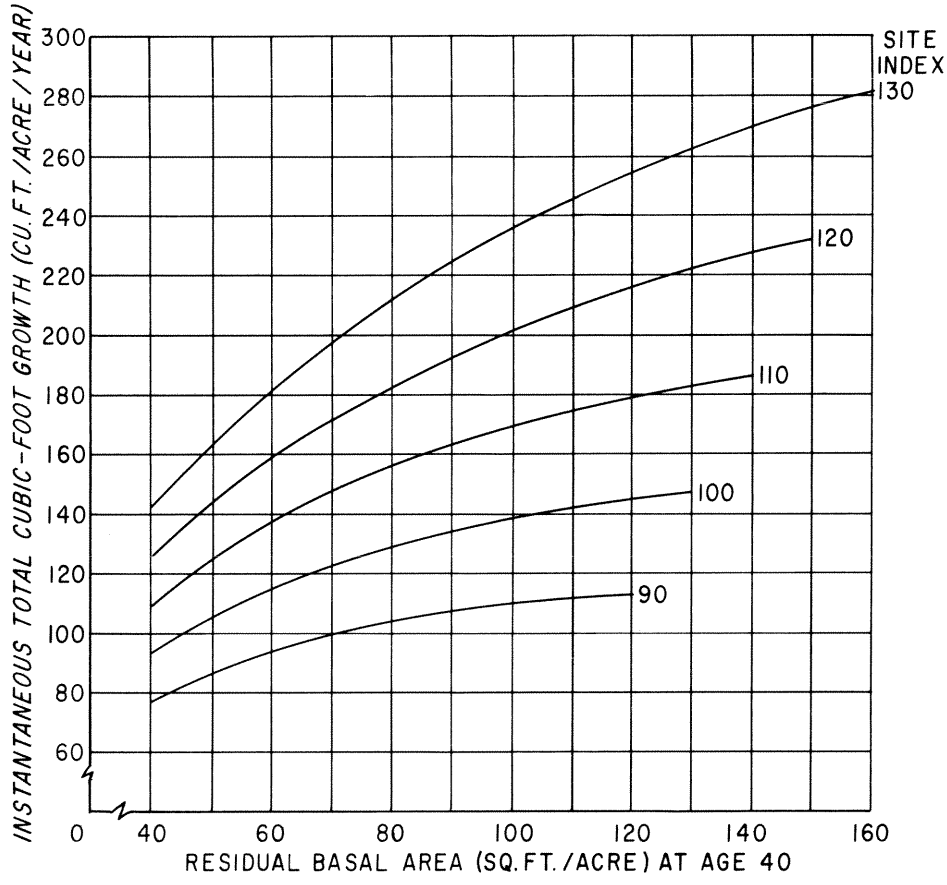

Figure 3.--Instantaneous total cubic-foot growth in relation to site index and residual basal area at age 40.

reached at approximately 80 square feet of basal area per acre. But on site index 130 in a 40-year-old stand, the rate of basal-area growth is still increasing at 160 square feet of basal area per acre, indicating that high residual densities are justifiable for our best yellow-poplar sites.

Probably the most instructive comparisons can be made by using equation (6) for projected total cubic-foot yield and equation (8) for projected basal area. By evaluating these equations with different values for the independent variables, the results by varying density, rotation age, and thinning regime can be examined. Figures 8 and 9, for example, are graphic presentations of solutions of the projecting equations for several initial densities and site-index values at age 20.

Consider, for example, a previously unthinned stand of 40-year-old yellow-poplar at site index 110 and with 150 square feet of basal area per acre. To concentrate growth on the best trees, the stand must be thinned. What thinning regime should be followed? Figures 4 through 7 illustrate basal-area and cubic-foot yield under two of many alternative schemes. Under option A (figures 4 and 5), the stand is thinned to 120 square feet of basal area per acre and carried to rotation age 70 without further thinning. Under option B (figures 6 and 7), the 40-year-old stand is thinned to 120 square feet of basal area per acre, is rethinned to the same level at age 50 and again at age 60, and liquidated at age 70.

In order to graphically project total cubic-foot yield it is necessary to first project basal area. For example, to determine production under option A, enter figure 4 at age 40 and 150 square feet of basal area. This point lies approximately on the curve of expected development for a stand that began with 80 square feet of basal area at age 20. When the stand is thinned to 120 square feet per acre it drops down to the curve for a stand with a basal area at age 20 of 50 square feet per acre and develops along this curve to age 70. In figure 5, enter at age 40 and go up to the curve for basal area 80 at age 20. Estimated total cubic-foot yield of the stand is read off the left. Dropping down to the curve for basal area 50 at age 20 gives total cubic-foot yield of the stand at age 40 after thinning. Projecting the stand along the curve for basal area 50 at age 20 gives total cubic-foot yield at age 70 under option A.

Basal-area and total cubic-foot yield under options A and B are summarized in table 4. In total cubic-foot yield there is no measurable difference between the two thinning options. On the other hand, tree-size distribution and possibly merchantable yields would differ, permitting a choice of thinning regimes based on these factors.

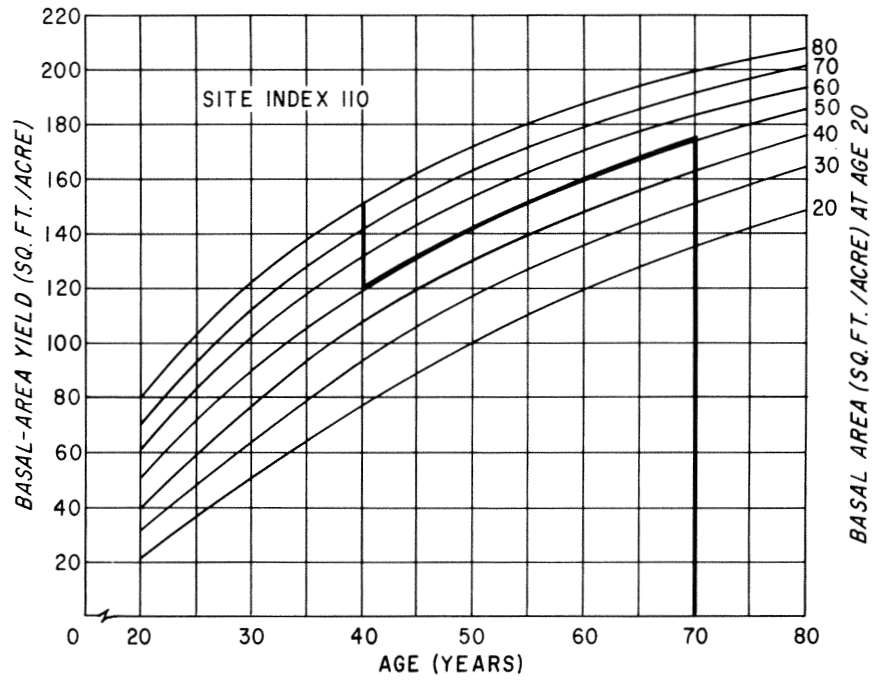

Figure 4.--Predicted basal-area yield for yellow-poplar stand of site index 110 with basal area of 150 square feet at age 40 under option A.

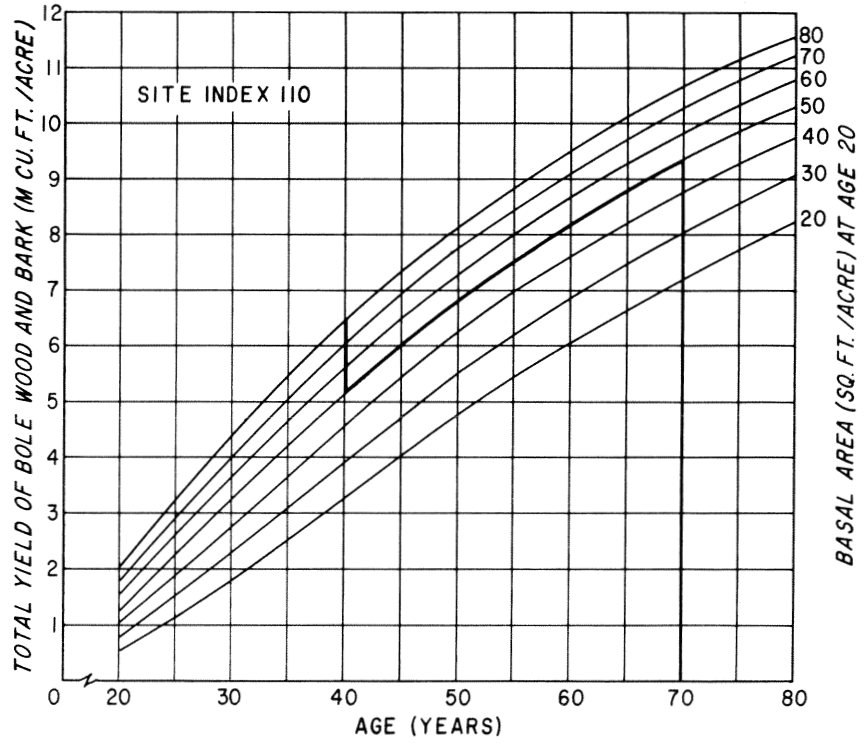

Figure 5.--Predicted total cubic-foot yield for yellow-poplar stand of site index 110 with basal area of 150 square feet at age 40 under option A.

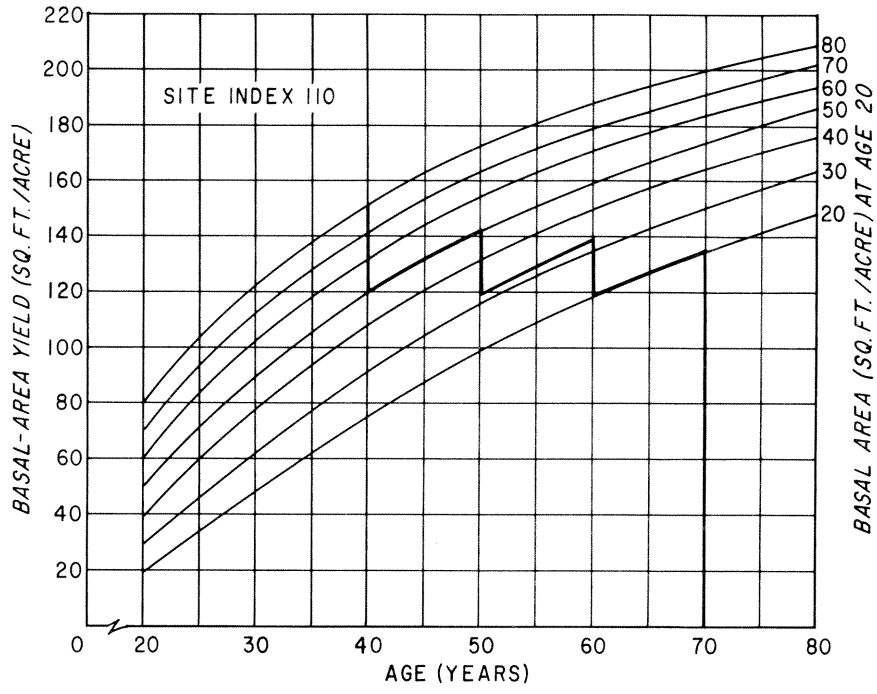

Figure 6.--Predicted basal-area yield for yellow-poplar stand of site index 110 with basal area of 150 square feet at age 40 under option B.

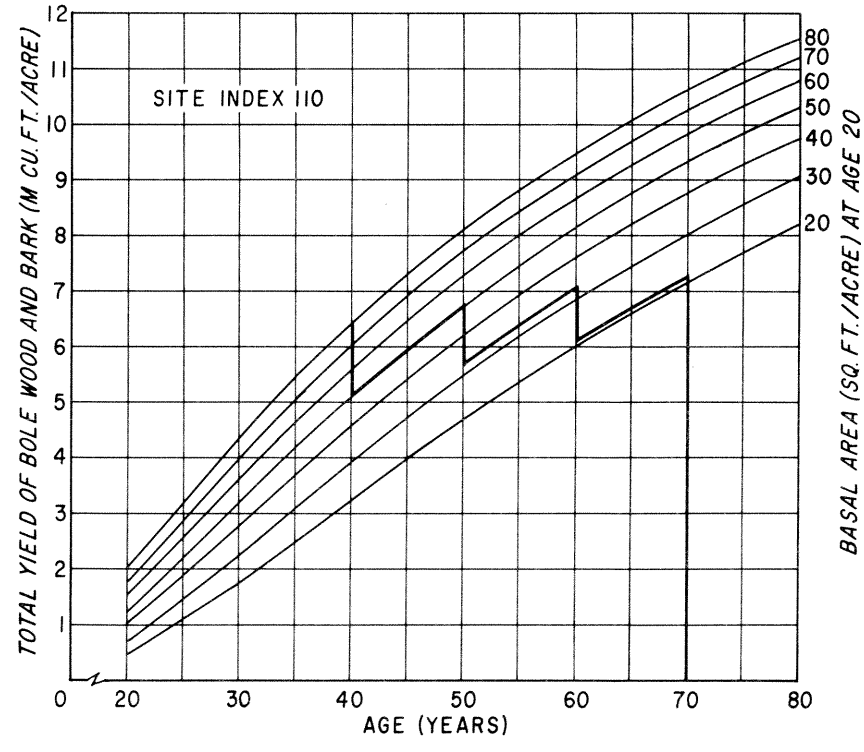

Figure 7. --Predicted total cubic-foot yield for yellow-poplar stand of site index 110 with basal area of 150 square feet at age 40 under option B.

Table 4.--Yield for a yellow-poplar stand with site index 110, age 40, with 150 square feet of basal area per acre, under two thinning options

OPTION A

Age (years)	Basal area			Total cubic-foot volume		
	Before thinning	After thinning	Amount cut	Before thinning	After thinning	Amount cut
	- - - - - Sq. ft./acre - - - - -			- - - - - Cu. ft./acre - - - - -		
40	150	120	30	6,379	5,149	1,230
70	174	0	174	9,350	0	9,350
Total			204			10,580
OPTION B						
40	150	120	30	6,379	5,149	1,230
50	143	120	23	6,795	5,734	1,061
60	139	120	19	7,108	6,170	938
70	136	0	136	7,345	0	7,345
Total			208			10,574

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APPENDIX

Table 5.--Total cubic-foot yield for thinned stands of yellow-poplar[1]

SITE INDEX 90

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cu. ft./acre												
20	831	1,032	1,232	1,431									
25	1,036	1,286	1,536	1,783	2,030								
30	1,199	1,490	1,778	2,065	2,351	2,636	2,920						
35	1,332	1,654	1,974	2,293	2,611	2,927	3,242	3,557					
40	1,441	1,789	2,136	2,481	2,824	3,166	3,508	3,848	4,187				
45	1,531	1,902	2,270	2,637	3,002	3,366	3,729	4,090	4,451				
50	1,608	1,997	2,384	2,769	3,153	3,535	3,915	4,295	4,674	5,052			
55	1,674	2,079	2,481	2,882	3,281	3,679	4,075	4,470	4,865	5,258			
60	1,731	2,149	2,566	2,980	3,393	3,804	4,213	4,622	5,030	5,436	5,842		
65	1,780	2,211	2,639	3,065	3,490	3,912	4,334	4,754	5,173	5,592	6,009		
70	1,824	2,265	2,704	3,140	3,575	4,008	4,440	4,870	5,300	5,728	6,156	6,582	
75	1,862	2,313	2,761	3,207	3,651	4,093	4,534	4,974	5,412	5,850	6,286	6,722	
80	1,897	2,356	2,812	3,266	3,718	4,169	4,618	5,066	5,512	5,958	6,403	6,846	7,289

SITE INDEX 100

20	930	1,155	1,379	1,602	1,823								
25	1,159	1,439	1,718	1,996	2,272	2,547							
30	1,342	1,667	1,990	2,311	2,631	2,950	3,267	3,584					
35	1,490	1,851	2,209	2,566	2,921	3,275	3,628	3,980	4,331				
40	1,612	2,002	2,390	2,776	3,160	3,543	3,925	4,306	4,685	5,064	5,442		
45	1,714	2,128	2,541	2,951	3,359	3,766	4,172	4,577	4,980	5,383	5,785		
50	1,799	2,235	2,668	3,099	3,528	3,955	4,381	4,806	5,230	5,653	6,074	6,496	6,916
55	1,873	2,326	2,777	3,225	3,672	4,116	4,560	5,002	5,443	5,883	6,322	6,760	7,198
60	1,936	2,405	2,871	3,334	3,796	4,256	4,715	5,172	5,628	6,083	6,537	6,990	7,442
65	1,992	2,474	2,953	3,430	3,905	4,378	4,850	5,320	5,789	6,257	6,724	7,190	7,655
70	2,040	2,534	3,025	3,514	4,000	4,485	4,968	5,450	5,930	6,410	6,888	7,366	7,842
75	2,084	2,588	3,089	3,588	4,085	4,580	5,073	5,565	6,056	6,546	7,034	7,522	8,008
80	2,122	2,636	3,146	3,655	4,160	4,665	5,167	5,668	6,168	6,667	7,164	7,661	8,156

SITE INDEX 110

20	1,020	1,266	1,512	1,756	1,999								
25	1,270	1,578	1,884	2,188	2,491	2,793	3,094	3,394					
30	1,471	1,827	2,181	2,533	2,884	3,234	3,582	3,930	4,276	4,622			
35	1,634	2,029	2,422	2,813	3,203	3,591	3,978	4,364	4,748	5,132			
40	1,767	2,195	2,620	3,043	3,465	3,884	4,303	4,720	5,136	5,552	5,966	6,379	
45	1,879	2,333	2,785	3,235	3,683	4,129	4,574	5,018	5,460	5,902	6,342	6,781	7,220
50	1,973	2,450	2,925	3,397	3,867	4,336	4,803	5,269	5,734	6,197	6,660	7,121	7,582
55	2,053	2,550	3,044	3,536	4,025	4,513	4,999	5,484	5,968	6,450	6,931	7,412	7,891
60	2,123	2,637	3,147	3,656	4,162	4,666	5,169	5,670	6,170	6,669	7,166	7,663	8,159
65	2,184	2,712	3,237	3,760	4,281	4,800	5,317	5,832	6,346	6,860	7,371	7,882	8,392
70	2,237	2,778	3,316	3,852	4,386	4,917	5,447	5,975	6,502	7,027	7,552	8,075	8,597
75	2,284	2,837	3,387	3,934	4,478	5,021	5,562	6,102	6,640	7,176	7,712	8,246	8,780
80	2,327	2,890	3,449	4,006	4,561	5,114	5,665	6,214	6,762	7,309	7,854	8,399	8,942

SITE INDEX 120

20	1,101	1,367	1,632	1,896	2,158	2,420							
25	1,372	1,704	2,034	2,362	2,689	3,015	3,340	3,664	3,987				
30	1,588	1,973	2,355	2,735	3,114	3,491	3,868	4,242	4,617	4,990	5,362		
35	1,764	2,191	2,615	3,037	3,458	3,877	4,295	4,711	5,126	5,541	5,954	6,367	6,779
40	1,908	2,370	2,829	3,286	3,740	4,194	4,646	5,096	5,546	5,994	6,441	6,888	7,333
45	2,028	2,519	3,007	3,493	3,976	4,458	4,938	5,417	5,895	6,372	6,847	7,322	7,795
50	2,130	2,645	3,158	3,668	4,176	4,682	5,186	5,689	6,190	6,691	7,190	7,688	8,186
55	2,217	2,753	3,287	3,817	4,346	4,872	5,398	5,921	6,443	6,964	7,484	8,002	8,520
60	2,292	2,847	3,398	3,947	4,493	5,038	5,580	6,122	6,661	7,200	7,737	8,273	8,808
65	2,358	2,928	3,495	4,060	4,622	5,182	5,740	6,297	6,852	7,406	7,959	8,510	9,060
70	2,415	3,000	3,581	4,159	4,735	5,309	5,881	6,451	7,020	7,587	8,153	8,718	9,282
75	2,466	3,063	3,656	4,247	4,835	5,421	6,005	6,588	7,168	7,748	8,326	8,903	9,479
80	2,512	3,120	3,724	4,326	4,924	5,521	6,116	6,709	7,301	7,891	8,480	9,068	9,654

[1]Only bole wood and bark of trees 4.5 inches d.b.h. and larger are included.

Table 5.--Total cubic-foot yield for thinned stands of yellow-poplar[1] (continued)

SITE INDEX 130

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cu. ft./acre												
20	1,175	1,459	1,741	2,023	2,303	2,582	2,860						
25	1,464	1,818	2,170	2,520	2,869	3,217	3,564	3,909	4,254	4,598			
30	1,695	2,105	2,513	2,918	3,323	3,725	4,127	4,527	4,926	5,324	5,721	6,118	6,514
35	1,882	2,337	2,790	3,241	3,690	4,137	4,582	5,027	5,470	5,912	6,353	6,794	7,233
40	2,036	2,529	3,018	3,506	3,991	4,475	4,957	5,438	5,917	6,395	6,873	7,349	7,824
45	2,164	2,688	3,208	3,727	4,243	4,757	5,269	5,780	6,290	6,798	7,306	7,812	8,317
50	2,273	2,822	3,369	3,913	4,455	4,995	5,533	6,070	6,605	7,139	7,672	8,204	8,734
55	2,365	2,938	3,507	4,073	4,637	5,199	5,759	6,318	6,875	7,430	7,985	8,538	9,090
60	2,446	3,037	3,626	4,211	4,794	5,375	5,954	6,532	7,108	7,682	8,256	8,828	9,399
65	2,516	3,124	3,729	4,332	4,931	5,529	6,125	6,719	7,311	7,902	8,492	9,080	9,668
70	2,577	3,201	3,821	4,438	5,052	5,664	6,274	6,883	7,490	8,095	8,700	9,302	9,904
75	2,632	3,268	3,902	4,532	5,159	5,784	6,407	7,029	7,649	8,267	8,884	9,499	10,114
80	2,680	3,329	3,974	4,615	5,254	5,891	6,526	7,159	7,790	8,420	9,048	9,675	10,301

[1]Only bole wood and bark of trees 4.5 inches d.b.h. and larger are included.

Table 6.--Instantaneous basal-area growth for thinned stands of yellow-poplar[1 2]

SITE INDEX 90

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Sq. ft./acre/year												
20	3.3	3.5	3.7	3.8									
25	2.6	2.8	3.0	3.0	3.0								
30	2.2	2.4	2.5	2.5	2.5	2.5	2.4						
35	1.9	2.0	2.1	2.2	2.2	2.1	2.1	2.0					
40	1.6	1.8	1.9	1.9	1.9	1.9	1.8	1.7	1.6				
45	1.5	1.6	1.6	1.7	1.7	1.7	1.6	1.5	1.4				
50	1.3	1.4	1.5	1.5	1.5	1.5	1.4	1.4	1.3	1.2			
55	1.2	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.2	1.1			
60	1.1	1.2	1.2	1.3	1.3	1.2	1.2	1.2	1.1	1.0	0.9		
65	1.0	1.1	1.1	1.2	1.2	1.1	1.1	1.1	1.0	0.9	0.8		
70	0.9	1.0	1.1	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.7	
75	0.9	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.8	0.7	0.6	
80	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.7	0.7	0.6	0.5
	SITE INDEX 100												
20	3.6	4.0	4.2	4.4	4.5								
25	2.9	3.2	3.4	3.5	3.6	3.6							
30	2.4	2.6	2.8	2.9	3.0	3.0	3.0	2.9					
35	2.1	2.3	2.4	2.5	2.5	2.6	2.5	2.5	2.4				
40	1.8	2.0	2.1	2.2	2.2	2.2	2.2	2.2	2.1	2.0	1.9		
45	1.6	1.8	1.9	1.9	2.0	2.0	2.0	1.9	1.9	1.8	1.7		
50	1.4	1.6	1.7	1.7	1.8	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.3
55	1.3	1.4	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.4	1.3	1.2
60	1.2	1.3	1.4	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.3	1.2	1.1
65	1.1	1.2	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.1	1.0
70	1.0	1.1	1.2	1.2	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.0	1.0
75	1.0	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.0	1.0	0.9
80	0.9	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	0.9	0.8

[1]Only trees 4.5 inches d.b.h. and larger are included.
[2]First derivative of equation (8), equation (9).

Table 6.--Instantaneous basal-area growth for thinned stands of yellow-poplar[1] [2] (continued)

SITE INDEX 110

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Sq. ft./acre/year												
20	3.9	4.4	4.7	4.9	5.1								
25	3.2	3.5	3.8	4.0	4.1	4.2	4.2	4.2					
30	2.6	2.9	3.1	3.3	3.4	3.5	3.5	3.5	3.5	3.4			
35	2.3	2.5	2.7	2.8	2.9	3.0	3.0	3.0	3.0	3.0			
40	2.0	2.2	2.4	2.5	2.6	2.6	2.6	2.6	2.6	2.6	2.5	2.4	
45	1.8	1.9	2.1	2.2	2.3	2.3	2.3	2.4	2.3	2.3	2.2	2.2	2.1
50	1.6	1.8	1.9	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.0	2.0	1.9
55	1.4	1.6	1.7	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.7
60	1.3	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.7	1.7	1.7	1.6	1.6
65	1.2	1.3	1.4	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.4
70	1.1	1.3	1.3	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.3
75	1.1	1.2	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3
80	1.0	1.1	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2
	SITE INDEX 120												
20	4.3	4.8	5.2	5.5	5.8	6.0							
25	3.4	3.8	4.2	4.4	4.6	4.8	4.9	5.0	5.0				
30	2.9	3.2	3.5	3.7	3.9	4.0	4.1	4.1	4.2	4.2	4.1		
35	2.4	2.7	3.0	3.2	3.3	3.4	3.5	3.5	3.6	3.6	3.5	3.5	3.4
40	2.1	2.4	2.6	2.8	2.9	3.0	3.1	3.1	3.1	3.1	3.1	3.1	3.0
45	1.9	2.1	2.3	2.5	2.6	2.7	2.7	2.8	2.8	2.8	2.8	2.7	2.7
50	1.7	1.9	2.1	2.2	2.3	2.4	2.4	2.5	2.5	2.5	2.5	2.5	2.4
55	1.6	1.7	1.9	2.0	2.1	2.2	2.2	2.3	2.3	2.3	2.3	2.2	2.2
60	1.4	1.6	1.7	1.8	1.9	2.0	2.0	2.1	2.1	2.1	2.1	2.0	2.0
65	1.3	1.5	1.6	1.7	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9
70	1.2	1.4	1.5	1.6	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.7
75	1.1	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.7	1.7	1.6	1.6
80	1.1	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5
	SITE INDEX 130												
20	4.6	5.2	5.7	6.1	6.5	6.7	7.0						
25	3.7	4.2	4.6	4.9	5.2	5.4	5.6	5.7	5.8	5.9			
30	3.1	3.5	3.8	4.1	4.3	4.5	4.6	4.7	4.8	4.9	4.9	4.9	4.9
35	2.6	3.0	3.3	3.5	3.7	3.8	4.0	4.1	4.1	4.2	4.2	4.2	4.2
40	2.3	2.6	2.9	3.1	3.2	3.4	3.5	3.6	3.6	3.7	3.7	3.7	3.7
45	2.1	2.3	2.5	2.7	2.9	3.0	3.1	3.2	3.2	3.3	3.3	3.3	3.3
50	1.8	2.1	2.3	2.4	2.6	2.7	2.8	2.8	2.9	2.9	3.0	3.0	2.9
55	1.7	1.9	2.1	2.2	2.3	2.4	2.5	2.6	2.6	2.7	2.7	2.7	2.7
60	1.5	1.7	1.9	2.0	2.2	2.2	2.3	2.4	2.4	2.4	2.5	2.5	2.5
65	1.4	1.6	1.8	1.9	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.3	2.3
70	1.3	1.5	1.6	1.7	1.8	1.9	2.0	2.0	2.1	2.1	2.1	2.1	2.1
75	1.2	1.4	1.5	1.6	1.7	1.8	1.9	1.9	1.9	2.0	2.0	2.0	2.0
80	1.2	1.3	1.4	1.5	1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8

[1] Only trees 4.5 inches d.b.h. and larger are included.
[2] First derivative of equation (8), equation (9).

Table 7.--Instantaneous total cubic-foot growth for thinned stands of yellow-poplar[1] [2]

SITE INDEX 90

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cu. ft./acre/year												
20	112	128	142	154									
25	102	116	128	138	146								
30	93	105	114	123	130	135	140						
35	84	95	103	110	116	120	123	126					
40	77	86	93	99	104	107	110	112	113				
45	71	79	85	90	94	97	99	100	100				
50	65	72	78	82	86	88	90	90	90	90			
55	61	67	72	76	79	81	82	82	82	81			
60	56	62	67	70	73	74	75	75	75	74	72		
65	53	58	62	65	68	69	69	69	69	68	66		
70	50	55	58	61	63	64	64	64	64	62	61	59	
75	47	52	55	57	59	60	60	60	59	58	56	54	
80	44	49	52	54	56	56	56	56	55	54	52	50	48

SITE INDEX 100

20	133	152	170	185	199								
25	122	139	154	167	178	188							
30	111	126	139	150	159	167	174	180					
35	102	115	126	135	143	149	155	159	163				
40	93	104	114	122	129	134	139	142	145	147	148		
45	85	96	104	112	117	122	126	128	130	131	132		
50	79	88	96	102	107	111	114	116	118	119	119	118	117
55	73	82	89	94	99	102	105	107	108	108	108	107	106
60	68	76	83	88	92	95	97	98	99	99	98	98	96
65	64	71	77	82	85	88	90	91	91	91	91	90	88
70	60	67	72	77	80	82	84	85	85	85	84	83	81
75	57	63	68	72	75	77	78	79	79	79	78	77	75
80	54	60	64	68	70	72	74	74	74	74	73	71	70

SITE INDEX 110

20	154	177	198	217	234								
25	142	163	181	197	212	224	236	246					
30	130	148	164	178	190	201	210	218	226	232			
35	119	135	149	161	171	180	188	195	200	205			
40	109	123	136	146	155	163	170	175	180	183	186	189	
45	100	114	124	134	142	148	154	159	162	165	168	169	170
50	93	105	115	123	130	136	141	145	148	150	152	153	153
55	86	97	106	114	120	125	130	133	136	137	139	139	139
60	81	91	99	106	112	116	120	123	125	126	127	128	127
65	76	85	93	99	104	108	112	114	116	117	118	118	117
70	71	80	87	93	98	101	104	106	108	109	109	109	109
75	67	75	82	87	92	95	98	100	101	102	102	102	101
80	64	71	78	82	87	90	92	94	95	96	96	95	94

[1] Only bole wood and bark of trees 4.5 inches d.b.h. and larger are included.
[2] First derivative of equation (7), equation (10).

Table 7.--Instantaneous total cubic-foot growth for thinned stands of yellow-poplar[1] [2] (continued)

SITE INDEX 120

Age (years)	Basal area (sq. ft./acre)												
	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cu. ft./acre/year												
20	174	202	227	250	270	289							
25	162	187	209	228	246	262	276	290	302				
30	149	171	190	207	222	236	248	259	268	277	285		
35	136	156	173	188	201	213	223	232	240	247	254	259	264
40	125	143	158	171	183	193	202	210	216	222	227	232	235
45	116	132	145	157	167	176	184	191	196	201	206	209	212
50	107	122	134	145	154	162	169	175	180	184	187	190	192
55	100	113	125	134	143	150	156	161	165	169	172	174	175
60	93	106	116	125	133	139	145	149	153	156	158	160	161
65	88	99	109	117	124	130	135	139	142	145	147	148	149
70	83	93	102	110	116	122	126	130	133	135	137	138	139
75	78	88	96	104	110	114	119	122	125	127	128	129	130
80	74	83	91	98	103	108	112	115	117	119	120	121	122

SITE INDEX 130

20	196	228	256	283	307	330	350						
25	183	211	237	260	281	300	318	334	349	363			
30	168	193	216	236	255	271	287	300	313	325	335	345	353
35	154	177	197	215	231	246	259	271	282	291	300	308	315
40	142	163	181	197	211	224	236	246	255	263	270	277	282
45	131	150	166	181	194	205	215	224	232	239	246	251	256
50	122	139	154	167	179	189	198	206	213	219	225	229	233
55	114	129	143	155	166	175	183	190	197	202	207	211	214
60	106	121	134	145	154	163	170	177	182	187	191	195	198
65	100	114	125	136	145	152	159	165	170	174	178	181	183
70	94	107	118	128	136	143	149	155	159	163	166	169	171
75	89	101	111	120	128	135	140	145	150	153	156	158	160
80	84	96	105	114	121	127	133	137	141	144	147	149	150

[1] Only bole wood and bark of trees 4.5 inches d.b.h. and larger are included.
[2] First derivative of equation (7), equation (10).

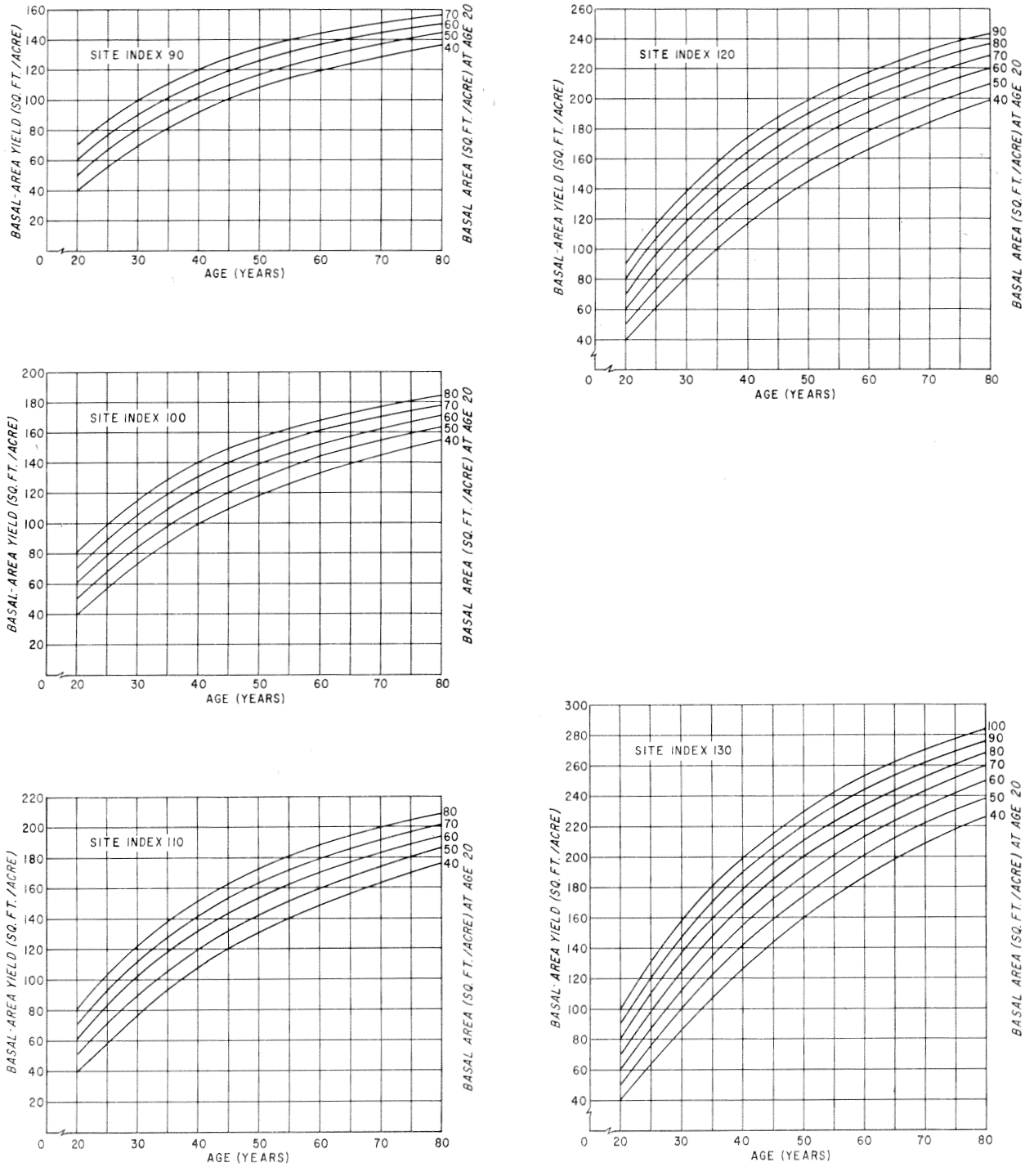

Figure 8. --Projected basal-area yield by site index, age, and basal area at age 20.

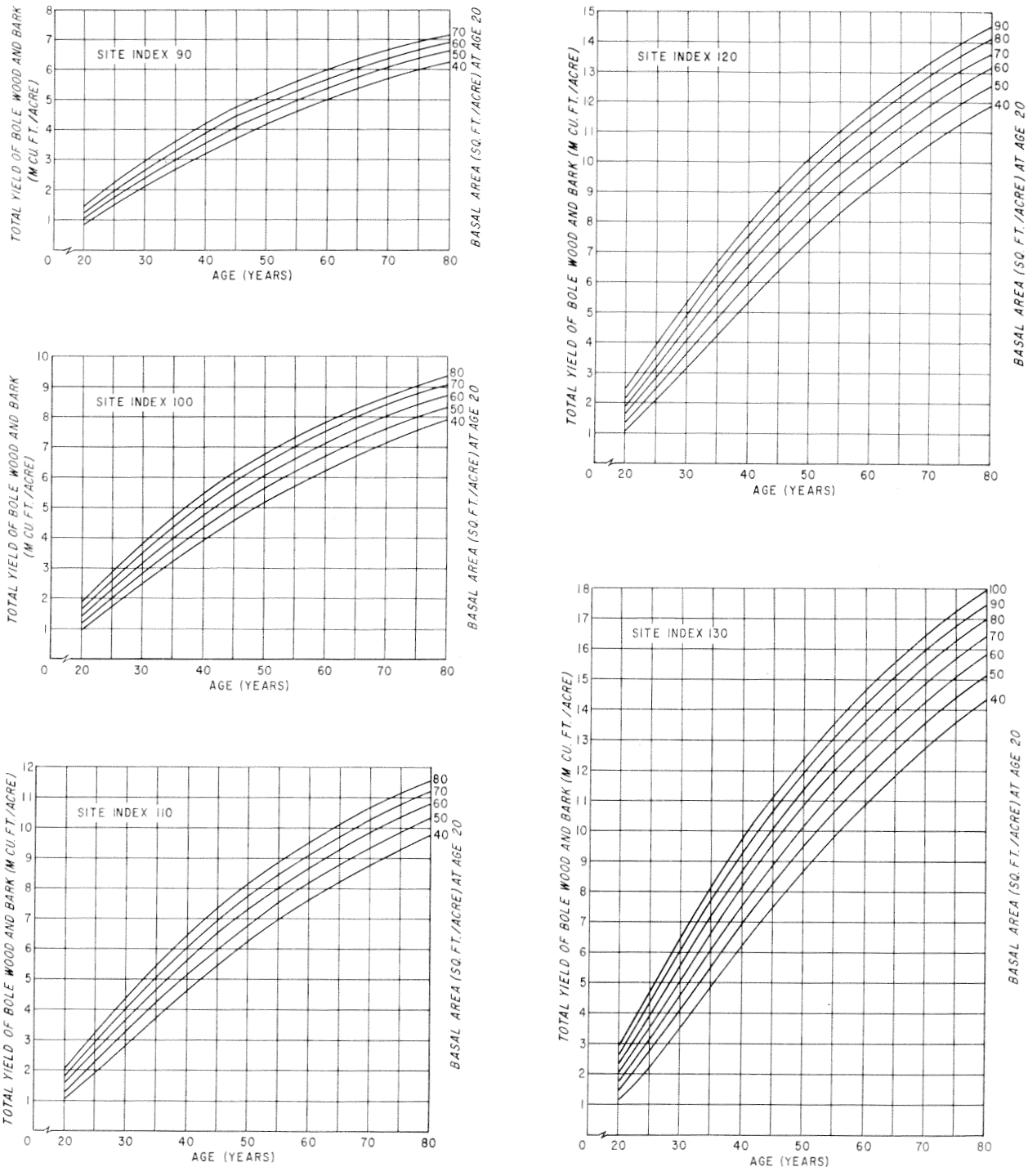

Figure 9.--Projected total cubic-foot yield by site index, age, and basal area at age 20.

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Beck, Donald E., and Della-Bianca, Lino
1972. Growth and yield of thinned yellow-poplar. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-101, 20 pp.

Basal area and cubic-foot volume development of stands of yellow-poplar (Liriodendron tulipifera L.) is described in relation to age, site index, and stand density following thinning. The growth and yield equations and tables are based on data from 141 natural yellow-poplar stands in the Appalachian Mountains of Virginia, North Carolina, and Georgia.

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