GROWTH RELATIONSHIPS FOR UPLAND HARDWOOD SAWTIMBER STANDS IN INDIANA[1]

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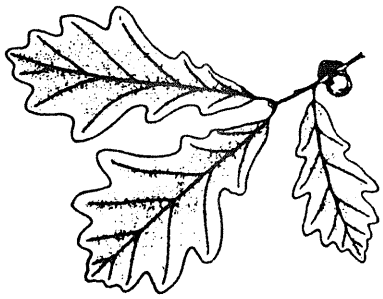

ABSTRACT.--Data from one-fifth acre continuous forest inventory plots (486 measurements) established in the 1950's on Purdue University properties located in southern and central Indiana are used to test relationships between growth rates and stocking for sawtimber size stands. The plots represent woodland conditions typically encountered in the area - mixed species stands of upland hardwoods, uneven-size structure and various levels of stocking. Relationships between stand basal area growth and Doyle board foot volume growth and stocking for sawtimber size trees (≥ 9 inches dbh) were tested using regression analysis. Significant relationships were found for basal area survivor growth, basal area ingrowth and board foot survivor growth. Net growth plus ingrowth was calculated and general trends developed for basal area and board foot volume. Maximum sawtimber size stand basal area growth was found to occur in stands of relatively low basal and high tree numbers. Board foot volume growth was maximized in stands of high basal area and tree numbers.

INTRODUCTION

Although growth and yield parameters are valuable tools in estimating growth and assessing silvicultural strategies, they are not readily available for upland hardwoods in the Central States. This is particularly true for upland hardwood sawtimber stands of mixed species that are at less than full stocking. This is unfortunate, because present day silvicultural practices for managing established upland mixed hardwoods stands have "evolved" to a point where new or "radical" departures from "normal" management procedures are difficult to evaluate. Thus, the collection, summarization, and analysis of growth data from continuous forest inventory and other permanent data plots is critical to both forestry research and forest management activities. The objective of this study is to relate stand basal area and Doyle board foot volume growth of trees greater than 9.0 inches dbh to numbers of trees and basal area per acre for sawtimber size mixed upland hardwood stands in Indiana.

The currently accepted silvicultural guide for managing upland central hardwoods (Roach and Gingrich 1968) carefully outlines the even-aged silvicultural system for upland central hardwoods. Stocking standards developed by Gingrich (1967) are emphasized. These stocking standards are presented in graphical form showing the relation of basal area, number of trees, and average tree diameter to stocking percentage. It is suggested (Gingrich 1967) that upland central hardwoods can be grown at a wide range of stand densities (between the A line - 100% stocking and B line - 58% stocking) and total growth will be about equal for stands of similar site and species composition. No quantitative data on growth or yield is presented within the guide.

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The upland central hardwood silvicultural guide has been updated (Sander 1977) for oaks in the north central states. This publication includes yield data from Gingrich (1971a) and indicates that early thinnings (age 10 - 20) followed by a 10 year thinning cycle will increase yield. Again, no growth rates for basal area, cubic or board foot volumes are given. Dale (1968 and 1972) has evaluated growth responses to thinning for young even-aged white oak stands and upland oak stands. Gingrich (1971a and 1971b) has reviewed the predicted stand development and growth responses of managed upland oak stands with relation to the upland hardwood stocking guide.

Many Central States foresters use growth estimates based on Schnur (1937). These yield, stand, and volume tables for upland oaks are still the most widely utilized for the upland central hardwoods. Growth figures commonly reported in county soil surveys and other publications (Fehrenbocker, 1978, Wray and Thomson 1980) using site index and productivity are generally derived from Schnur. Limitations of Schnur's data to predict yield, although well documented, are usually ignored. Although Schnur used the International Log Rule, the accepted log rule in Indiana and most other Central States is the Doyle Log Rule. Also, Schnur allowed more generous dimensions in logs considered as merchantable for sawtimber; for example, tree height was measured in feet to a 5 inch d.i.b. lower limit, current Indiana sawlog minimums are 8-foot logs to a 10 inch (or greater) d.i.b. limit. Finally, yield tables are estimates of growth under specified conditions. In Schnur's work plots selected for analysis had to meet the following criteria:

1. Thirty percent or more of the dominant stand composed of upland oak;
2. Fully stocked, as indicated by closed crown canopies (80 - 90% of complete closure) and the absence of very dense undergrowth;
3. Even-aged;
4. Uniformly spaced stems.

Volume (cubic feet and board feet) was calculated from these plots and then plotted over age by site index to determine "normal" stand stocking. Few woodlands have conditions that meet these criteria, yet the relationships developed in this study are applied throughout the Central States to a variety of sites and situations.

Purdue CFI Data Base

Continuous Forest Inventory (CFI) plots were established throughout Indiana between 1940 and the 1960's. Many of these plots were maintained and periodically remeasured. However, only a few summaries of the data were attempted (Beers and Hall, 1960) and the data, if not lost, was simply filed in many instances. The relocation and remeasurement of the Purdue portion of Indiana's CFI data base is nearing completion. These efforts will result in a data base of over 400 CFI plots, with more than 1200 plot and 10,000 tree measurements. Plots are located in 10 Indiana counties, on 6 Purdue Agricultural Centers and 4 Purdue University Department of Forestry and Natural Resources woodlands.

CFI data is collected from 0.2 acre circular plots. Plot data include a property number, plot number, aspect, slope, and other site factors. Tree data (for trees 9.0 inches dbh and greater) include tree number, species, dbh, sawtimber and pulpwood heights, butt log grade, tree class, soundness, and status. Sapling/pole-size trees, when measured, are summarized by species and 2-inch dbh size class (4, 6 and 8 inch classes).

All CFI data are stored on tape at the Purdue University Computer Center. We have developed software to error check, summarize, and analyze the data. Initial analysis of the data base has concentrated on the development, growth and yield of forest stands, and the response of individual trees by species and size class.

Stand growth is summarized by growth components (i.e. - survivor growth, ingrowth, mortality, and cut) for basal area and board foot volume. Further description of data collection methods and analysis is in Schroering and Fischer (1982).

STUDY SITES

CFI data from the Southern Indiana Purdue Agricultural Center (SIPAC) in Dubois County, the Feldun Purdue Agricultural Center (FELPAC) in Lawrence County, and the Finley Memorial Forest in Clay County were utilized for this study. In general each of these woodlands has had a history of partial cutting and resultant understocking. Cutting in the last 30 years within plots considered in this study has been limited to improvement or selection cuttings of low intensity. Tree ages in most plots are currently estimated to exceed 60 years. The SIPAC woodlands are further described by Schroering and Fischer (1982). Table 1 describes the properties and data base.

TABLE 1.--Site quality and data base for study sites.

Property	Soil-Site Index (Bl. Oak; age 50)	No. Plots	No. Meas.	Measurement Span
FELPAC	70-85	50	5	1950-82
		16	4	1961-82
Finley	80-95	30	5	1958-80
SIPAC	65-80	69	5	1953-80

METHODS AND MATERIALS

Plot location was based on systematic random sampling. Several plots were not located in the upland hardwood type and were removed from the sample for purposes of analyses. Of 644 plot measurements 44 were eliminated because they were not of the upland hardwood type. These were either bottomland hardwoods or pine plantations. Of the remaining 600 measurements 114 were removed because they were not from sawtimber size stands.

Criteria for deciding whether a plot was of sawtimber size or not was first based on the two stand growth phases for oak as described by Hibbs and Bentley (1984). Phase I occurs in oak stands less than age 40, and represents the stand growth stage during which trees rapidly increase in merchantable height. Phase II begins after age 40, and represents the growth phase when diameter and quality growth are most significant, and merchantable height remains rather constant (i.e. sawtimber size trees). For many plots, age data were unavailable or variable so a second selection criteria was chosen. A minimum basal area limit of 40 sq. ft. per acre for trees 9.0 inches dbh and greater was required. A level of 40 sq. ft. is the minimum C level stocking on the upland hardwood stocking guide for stands with average diameter greater than 7 inches. If a plot had less than 40 sq. ft. of basal area it was considered understocked for sawtimber, and therefore, not a sawtimber size plot.

Survivor growth, ingrowth and mortality components (Beers 1962) were analyzed for both basal area and board foot volume growth. Basal area and number of trees 9.0 inches and greater were the stand parameters utilized to formulate relationships because these are the parameters used in most stocking guides. Due to the variable plot measurement periods (3 to 14 years) mean per acre values were used instead of initial values. Growth relationships were formulated using tabular and SPSS regression analysis techniques (Kim and Kohout 1975).

RESULTS

Species composition for the pooled data consisted primarily of upland oaks, hickory and yellow-poplar. The oaks represented 32% of the sample. White oak and black oak predominated comprising 44% and 34% of the oak, respectively. Northern red oak made up the majority of the remainder. Yellow-poplar and hickory each represented 13% of the composition. American beech and sugar maple were the next most dominant species. White ash, elm, and black walnut represented smaller components.

The diameter distribution of the pooled data was very close to that of a balanced uneven-aged stand. Simple linear regression analysis of the natural log of number of trees over diameter class (2-inch dbh classes from 10 to 38 inches) yielded a q-value of 1.4 with an r^2 of .97. Mean plot dbh ranged from 10 to 30 inches with an overall mean of 16 inches.

Basal area of the plots ranged from the lower set limit of 40 to 136 sq. ft. per acre. The number of trees ranged from 20 to 100 trees per acre. Mean basal area per acre was 65 sq. ft., and mean number of trees per acre was 50. The net standing Doyle board foot volume of the measurements ranged from 70 to 14,000 board feet per acre with a mean of 2,600 board feet. This wide range is the result of low stocking, the natural variation in merchantable heights, and deductions for defect in these relatively unmanaged stands.

Initial analysis involved obtaining simple linear regression equations for the growth components by number of trees per acre and basal area per acre. Tables 2 and 3 summarize the results of the simple linear regression analysis of growth by number of trees and basal area respectively.

By comparing Tables 2 and 3 it can be seen that basal area growth was more directly related to number of trees while volume growth was more directly related to basal area. This can be attributed to the fact that both volume and basal area are a function of tree diameter.

TABLE 2.—Summary of simple linear regression of components of growth by number of trees ≥ 9.0 inches dbh per acre.

Growth Component	Regression Statistics			
	a	b	F	r^2
Basal Area				
Survivor	.231	.0209	345.872**	.43
Ingrowth	.0730	.0116	25.491**	.05
Mortality	.873	-.00629	2.284	.01
Volume[1]				
Survivor	20.332	2.232	58.456**	.11
Ingrowth	3.954	.00577	.028	.0001
Mortality	14.771	-.00637	.002	.0000

[1]Doyle Board Foot Volume
**significant at the .01 level

TABLE 3.—Summary of simple linear regression of components of growth by basal area of trees ≥ 9.0 inches dbh per acre.

Growth Component	Regression Statistics			
	a	b	F	r^2
Basal Area				
Survivor	.365	.0132	142.296**	.24
Ingrowth	1.174	-.00798	16.601**	.04
Mortality	.934	-.00546	2.398	.01
Volume[1]				
Survivor	-20.237	2.220	84.599**	.16
Ingrowth	6.844	-.0391	2.177	.004
Mortality	18.274	-.0567	.190	.0004

[1]Doyle Board Foot Volume
**significant at the .01 level

Significant relationships were obtained only or basal area survivor growth, basal area ngrowth, and volume survivor growth. Mortality ıeems to be a more random event and is not lependent on numbers of trees or basal area per ıcre at the levels represented.

Volume ingrowth did not show a significant :elationship because of the definitions of ;awtimber merchantability and ingrowth. Ingrowth ɔccurs when a tree crosses the threshold of 9.0 inches dbh, however, sawtimber merchantability ɔegins at about 11.0 inches. Therefore, volume ingrowth would probably only occur during long remeasurement periods.

The next step in the analysis involved cross tabulation of the growth components by number of trees and basal area. Tables 4 - 6 show the components of basal area growth and Tables 7 - 9 show the components of Doyle board foot volume growth. Analysis of variance was unable to be conducted due to the number of empty cells and the unequal observations in the cells; however, overall trends can be observed.

In Tables 4 and 7 it can be seen that survivor growth for both basal area and volume increase, within the range of the data, with both increasing numbers of trees and increasing basal area. The ingrowth trend was different (Tables 5 and 8). Increasing the number of trees resulted in an increase in ingrowth, but increasing basal area resulted in a decrease in ingrowth. The trends for mortality (Tables 6 and 9) were not very obvious. Mortality remained about the same at all levels.

TABLE 4.--Average basal area survivor growth per acre per year by basal area and number of trees ≥ 9.0 inches dbh per acre.

Trees per acre	Basal Area Per Acre 40	60	80	100	120
	growth				
20	0.638 (32)[1]	0.698 (27)	1.029 (4)		
40	0.849 (79)	0.941 (65)	1.170 (38)	1.471 (23)	1.567 (6)
60	1.214 (32)	1.338 (49)	1.351 (36)	1.607 (24)	1.333 (1)
80		1.779 (18)	1.941 (25)	2.052 (15)	1.903 (5)
100			2.322 (3)	1.561 (3)	2.373 (1)

[1] ( ) indicates sample size

TABLE 5.--Average basal area ingrowth per acre per year by basal area and number of trees ≥ 9.0 in. dbh per acre.

Trees per acre	Basal Area Per Acre 40	60	80	100	120
	growth				
20	0.281[1]	0.229	0.000		
40	0.846	0.519	0.288	0.193	0.133
60	1.306	0.928	0.429	0.581	0.000
80		1.059	0.818	0.619	0.107
100			0.867	1.079	1.913

[1] sample sizes given in Table 4.

TABLE 6.--Average basal area mortality per acre per year by basal area and number of trees ≥ 9.0 in. dbh per acre.

Trees per acre	Basal Area Per Acre 40	60	80	100	120
	growth				
20	0.587[1]	1.574	0.217		
40	0.471	0.597	0.571	0.416	0.039
60	0.591	0.546	0.513	0.205	0.000
80		0.591	0.255	0.385	0.000
100			1.878	0.098	0.000

[1] sample sizes given in Table 4.

TABLE 7.--Average Doyle board foot volume survivor growth per acre per year by basal area and number of trees ≥ 9.0 in. dbh per acre.

Trees per acre	Basal Area Per Acre 40	60	80	100	120
	growth				
20	65.5[1]	58.3	128.1		
40	69.4	72.8	133.0	170.0	211.8
60	100.4	121.2	160.3	249.1	87.3
80		181.9	189.5	253.8	110.1
100			233.2	165.9	269.5

[1] sample sizes given in Table 4.

TABLE 8.—Average Doyle board foot volume ingrowth per acre per year by basal area and number of trees ≥ 9.0 in. dbh per acre.

Trees per acre	Basal Area Per Acre				
	40	60	80	100	120
	growth				
20	1.5[1]	5.8	0.0		
40	5.6	6.0	3.3	0.9	0.0
60	2.1	5.7	2.9	2.2	0.0
80		5.4	4.3	4.1	0.8
100			0.0	11.6	20.5

[1] sample sizes given in Table 4.

TABLE 9.—Average Doyle board foot volume mortality per acre per year by basal area and number of trees ≥ 9.0 in. dbh per acre.

Trees per acre	Basal Area Per Acre				
	40	60	80	100	120
	growth				
20	21.9[1]	0.6	0.0		
40	8.5	27.1	7.4	17.7	1.0
60	8.2	14.6	30.0	6.9	0.0
80		8.1	6.3	15.1	0.0
100			48.8	2.7	0.0

[1] sample sizes given in Table 4.

Net growth plus ingrowth was then calculated for both basal area and Doyle board foot volume. Multiple regression analysis was used to formulate relationships between net growth plus ingrowth, and number of trees and basal area per acre. The model utilized in the analyses was of the form:

$$G = a + b_1X_1 + b_2X_2 + b_3X_1X_2$$

where,

G = growth per acre per year

a, b_1, b_2, b_3 = regression coefficients

X_1 = number of trees ≥ 9.0 inches dbh

X_2 = basal area per acre.

Net growth plus ingrowth was the growth measure chosen since this is the measure of growth a forester would observe between inventories on uncut stands. Table 10 summarizes the results of these analyses. Both relationships were significant at the .01 level.

TABLE 10.—Results of multiple regression analysis of the components of growth by number of trees and basal area per acre for trees ≥ 9.0 in. dbh.

Growth Measure	Regression Statistics					
	a	b_1	b_2	b_3	F	R^2
Basal Area	-1.76	.070	.0016	-.00041	23.2**	.13
Volume[1]	-94.65	1.99	2.19	-.00917	26.2**	.15

[1]Doyle Board Foot Volume
**significant at .01 level

Figures 1 and 2 present the relationships from Table 10 for basal area and volume growth respectively. The basal area relationship (Fig. 1) shows that the influence of increasing basal area on growth rate changes between the various density (# of trees/acre) levels. In the lowest density level (20 trees) the influence of increasing basal area was positive, but for the higher density levels (60 - 100) an increase in basal area resulted in a decrease in the stand basal area growth rate. For board foot growth (Fig. 2), however, the influence of increasing basal area was positive for all density levels.

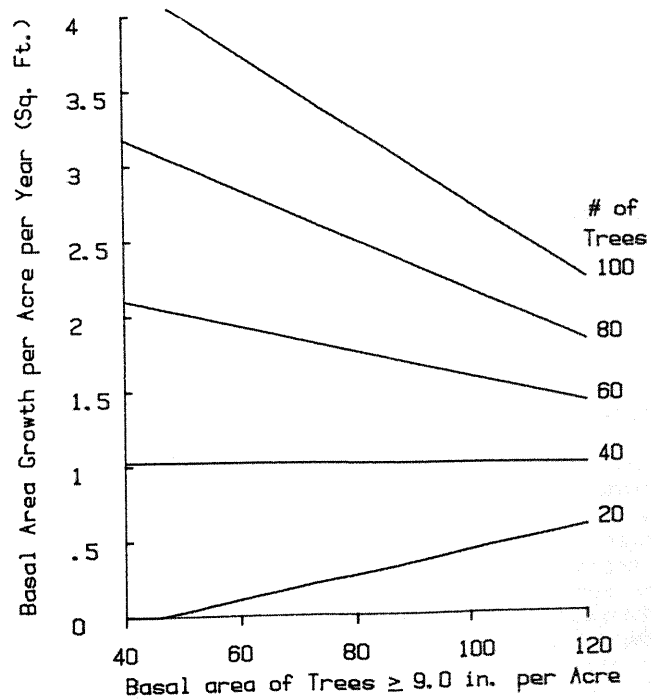

FIGURE 1.—The relationship between number of trees and basal area per acre to net basal area growth plus ingrowth per acre per year for trees ≥ 9.0 inches dbh.

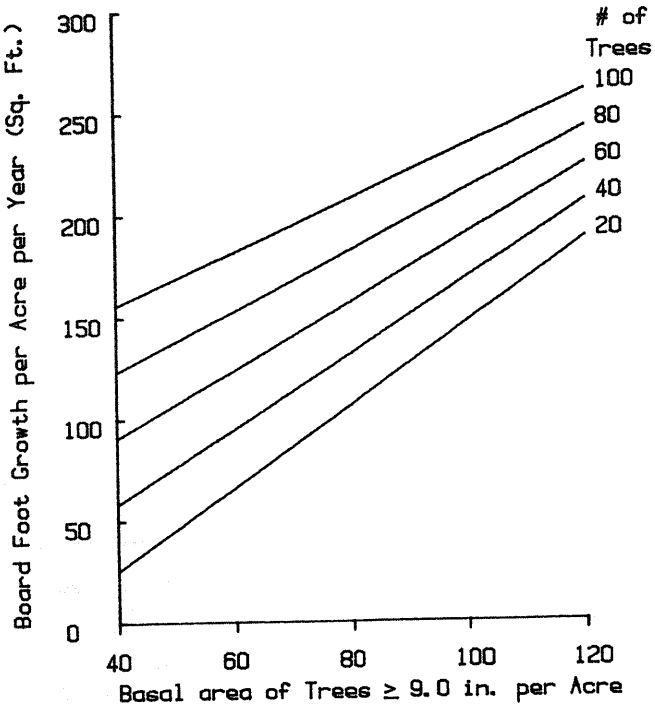

FIGURE 2.--The relationship between number of trees and basal area per acre to net Doyle board foot volume growth plus ingrowth per acre per year for trees ≥ 9.0 inches dbh.

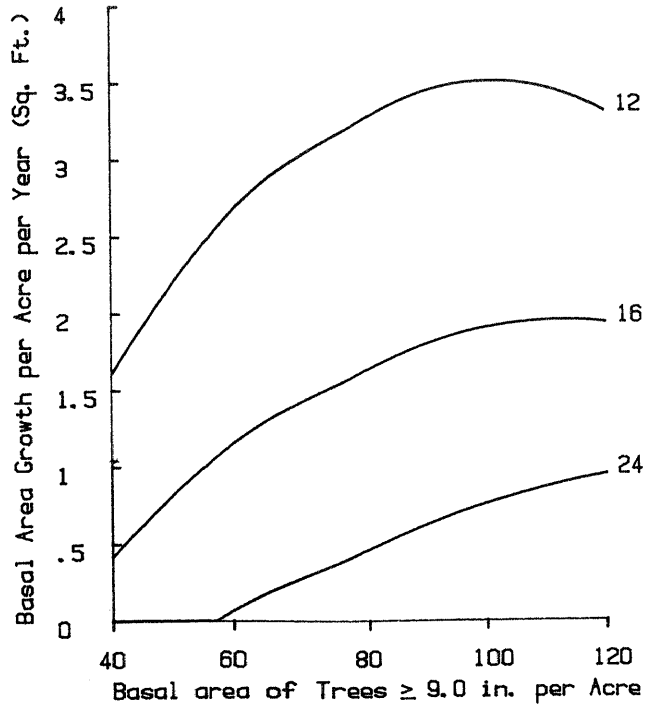

FIGURE 3.--The relationship between mean stand dbh and basal area per acre to net basal area growth plus ingrowth per acre per year for trees ≥ 9.0 inches dbh.

Figures 3 and 4 show the same growth relationships as demonstrated in Figure 1 and 2 but keeping mean stand diameter constant instead of number of trees per acre. The 12 and 24 inch dbh lines show the lower and upper mean plot dbh where there were sufficient data over the range of basal areas. The 16 inch line represents the overall mean dbh for the study. Both figures show that stands of smaller mean diameter grow faster. A peak basal area growth rate was observed for the 12 and 16 inch stands, while the 24 inch stands appear to be approaching a peak. No similar peaks were observed for board foot growth.

DISCUSSION

The results of the analyses indicate that in sawtimber size mixed upland hardwood stands, stand basal area growth increases as stocking decreases. The highest stand basal area growth occurred in sawtimber size stands with relatively low basal area and high numbers of trees per acre. These results are similar to the findings of Leak (1981) for northern hardwoods which showed that maximum basal area growth occurred between the C and B stocking lines on the northern hardwood stocking guide.

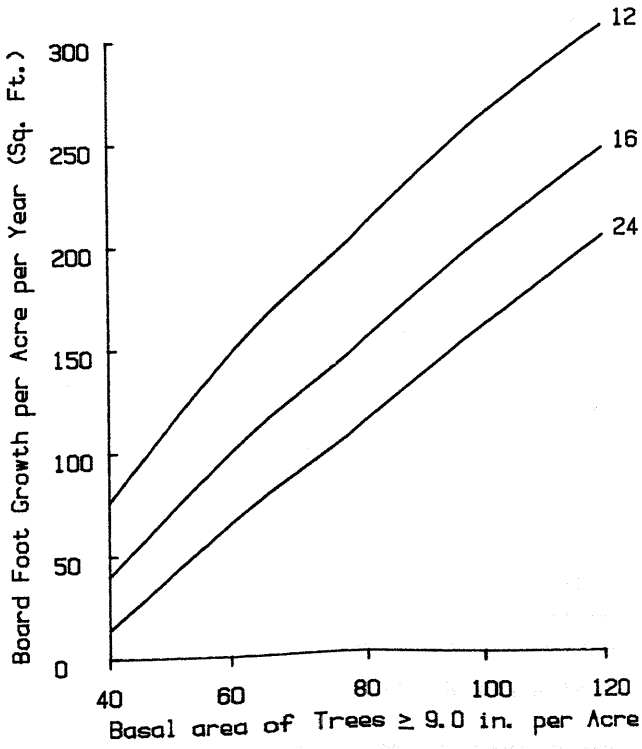

FIGURE 4.--The relationship between mean stand dbh and basal area per acre to net Doyle board foot volume growth plus ingrowth per acre per year for trees ≥ 9.0 inches dbh.

In terms of basal area, we found that sawtimber stands with large numbers of smaller trees (9 - 14 inches dbh) will have greater basal area growth than stands with small numbers of large sawtimber size trees. Gingrich (1971b) shows the same type of relationship for basal area growth vs stand age for even-aged upland oak. Young, even-aged stands (smaller diameter trees) had higher net basal area growth plus ingrowth per acre per year than older even-aged stands (larger diameter trees). We found a similar relationship between smaller and larger sawtimber size stands (Fig. 1). Gingrich further stated that net basal area growth plus ingrowth is not influenced by site quality and is a function of average tree size and stocking. Figure 3 demonstrates this relationship for our sawtimber size stand data.

Stand Doyle board foot volume growth increased both with increasing density and increasing basal area. Maximum volume growth was observed in the highest stocked stands (Fig. 2). Similar to the basal area growth sawtimber size stands with smaller trees (example 12 inches dbh) showed the highest volume growth rate (Fig. 4). This higher volume growth rate in the smaller size stands can be attributed to three factors. First these stands had the highest basal area growth rate. Secondly, the merchantable height gains are greater in the smaller trees. Once a hardwood tree reaches about 16 inches dbh the merchantable sawtimber height in most cases is "fixed" by branching or other defects thus remaining relatively constant. On the other hand merchantability in smaller trees is limited by a size restriction (10 inches dib in our data). Finally, smaller size even-aged stands have a greater number of trees crossing the merchantable threshold (11 inches dbh) and thus results in more trees producing board foot growth.

Because the results of this study are based on plot data from relatively unmanaged sawtimber size stands with little or no recent cutting, care should be exercised in applying these concepts directly to thinning response. The results suggest that basal area growth should remain constant or increase in carefully planned thinnings that reduce the basal area in densely stocked small sawtimber size stands. However, high stocking appears to maximize board foot volume growth in sawtimber size stands.

CONCLUSION

Since stand prescriptions are often made in terms of basal area it is important to understand the relationships between stand growth and density. Development of stand growth relationships based on density measures will better enable foresters to make decisions on thinnings and/or regeneration cuttings in sawtimber size mixed upland hardwood stands. Combining such knowledge with economic information and tree and stand quality changes should improve management decision-making.

LITERATURE CITED

BEERS, T. W. and O. F. HALL. 1960. Summary of forest growth and stocking on the Morgan-Monroe and Harrison State Forests. Unpublished Report. Dept. of For. and Cons., Purdue University. 43p.

BEERS, T. W. 1962. Components of forest growth. J. For. 60(4): 245-248.

DALE, M. E. 1968. Growth response from thinning young even-aged white oak stands. USDA For. Serv. Res. Pap. NE-112. 19p.

DALE, M. E. 1972. Growth and yield predictions for upland oak stands. USDA For. Serv. Res. Pap. NE-241. 21p.

FEHRENBOCKER, J. B. 1978. Soil productivity in Illinois. Univ. of IL, Urbana-Champaign, College of Agriculture, Coop. Ext. Serv. Circ. 1156, 21p.

GINGRICH, S. F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the Central States. For. Sci. 13(1): 38-53.

GINGRICH, S. F. 1971a. Management of young and intermediate stands of upland hardwoods. USDA For. Serv. Res. Pap. NE-195, 26p.

GINGRICH, S. F. 1971b. Stocking, growth and yield of oak stands. In: Proceedings of the oak symposium. Morgantown, WV. p. 65-73.

HIBBS, D. E. and W. R. BENTLEY. 1984. A growth model for red oak in New England. Can. J. For. 14: 250-254.

KIM, J. and F. J. KOHOUT. 1975. Chapter 20. Multiple regression analysis. In: SPSS - statistical package for the social sciences. 2nd ed. Nie, N. H. et. al. Eds. McGraw-Hill Book Company: New York. 320-367.

LEAK, W. B. 1981. Do stocking guides in the eastern United States relate to stand growth? J. For. 79(10): 661-664.

ROACH, B. A., and S. F. GINGRICH. 1968. Even-aged silviculture for upland central hardwoods. USDA For. Serv. Agric. Hdbk. 355, 39 p.

SANDER, I. L. 1977. Manager's handbook for oaks in the north central states. USDA For. Serv. Gen. Tech. Rep. NC-37, 35p.

SCHNUR, G. L. 1937. Yield, stand, and volume tables for even-aged upland oak forests. USDA Tech. Bull. 560, 88p.

SCHROERING, J. D., and B. C. FISCHER. 1982. Growth and yield of upland hardwoods in southern Indiana. Proceedings Fourth Central Hardwood Forest Conference. Lexington, KY. pp. 141-157.

WRAY, P. H. and G. W. THOMSON. 1980. Yield information for natural stands of Iowa hardwoods. Pm-941. Coop. Ext. Serv. Iowa State University, Ames, IA. 8 p.