VOLUME AND VALUE GROWTH OF SUGAR MAPLE
IN UPPER MICHIGAN

Submitted by LaMont G. Engle in partial fulfillment of requirements for Master of Forestry degree. May, 1949.

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School of Forestry and Conservation
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TABLE OF CONTENTS

CHARTS

INTRODUCTION AND ACKNOWLEDGMENTS

The forests of the Upper Peninsula of Michigan contain about 3,222,000 acres of the northern hardwood type, of which about one million acres are classed as sawtimber (1). This type covers 34.5 percent of the forest land in Upper Michigan; thus it plays an important part in the production of forest products from the area.

There is a need for more information about the sawtimber type so that it may be managed for maximum yields - in either volume or value. Optimum densities of stocking for greatest volume growth and greatest return on investment per acre have been determined from cuttings on the Upper Peninsula Experimental Forest. However, there is little definite information about the growth of the individual trees in the stand.

What is the optimum size to which a tree should be grown for greatest volume or value return? There should be some time in the rotation when its rate of growth decreases to a point where it is no longer worth holding through another cutting cycle. Private companies managing hardwoods under a selection system have incorporated this concept in their marking rules through the setting of flexible diameter limits. Certainly in northern hardwoods proper marking for partial cutting cannot be based on iron bound diameter limits. However, flexible limits are a useful guide and should become even more so in subsequent cycles when the stands have less cull and a good distribution of size classes.

This paper is an attempt to analyze both the volume and value growth of the individual sugar maple tree in the northern hardwood type at Dukes, Michigan.

The writer wishes to thank E. L. Demmon and F. H. Eyre of the Lake States Forest Experiment Station for permission to use Station file data in the study, and W. M. Zillgitt and W. A. Salminen for their kind help and advice which was given so generously through the entire period the writer spent at Dukes. Acknowledgment is made of the aid of John Carow of the University of Michigan under whose supervision the paper was prepared.

BACKGROUND MATERIAL

Growth and grade data for the study are taken from records of the Upper Peninsula Experimental Forest which is located at Dukes, Michigan about 20 miles southeast of Marquette, Michigan.

The Experimental Forest (2) was established in 1926 by the gift of 320 acres of second growth and 320 acres of old growth timber from the Cleveland-Cliffs Iron Company and was later enlarged through the purchase of over 4,000 acres of land by the Federal Government. The Forest is administered by the Lake States Forest Experiment Station in cooperation with the Upper Michigan National Forest.

Precipitation at the Forest averages 34 inches per year with one-third falling as snow. Mean temperature during the growing season, June 1 to September 30, is 60° F. The soil is a well drained sandy loam and could be classed as a gray-brown podzol. The site is considered good for Upper Michigan with average merchantable height between 2½ and 3 logs.

Growth and value

data used in the paper come from records maintained on experimental cuttings made on the 320 acres of old growth sawtimber acquired in 1926. These cuttings all lie in the northern hardwood type. Sugar maple is the most common species, comprising 87 percent of the net volume. Yellow birch is the only other species present in any volume on the cuttings. Elm, basswood, white spruce, and balsam also occur occasionally.

Markets are good in the vicinity of the Forest. High grade logs find markets at veneer and bowling pin mills. Local mills take logs and tie cuts. The iron mines use small low grade logs for mine timbers and the hardwood distillation plant in Marquette utilizes cull logs and limb material down to 4 inches in diameter.

W. M. Zillgitt (3) (4) analyzed the records of the experimental cuttings made at Dukes and concluded that the greatest financial rate of return per acre was obtained by cutting to a residual volume of about 3,500 bd. ft. net (44 sq. ft. of basal area) ~~net~~ per acre on a 15-year cutting cycle; while best board foot growth was obtained by cutting to a residual volume of about 6,000 bd. ft. net (64 sq. ft. of basal area) per acre. Between these two maxima lay a range of residual volumes giving both good growth and a satisfactory return on the investment.

Cuttings lying in this range of residual volumes were considered for this study. The cuttings having a residual volume of about 3.5 M contained the largest number of sample trees so the data from these were used. It was felt that the results could be applied with little error to stands with residual volumes up to 4.5 M per acre.

A description of cuttings used in the paper follows:

<u>Overmature and defective number 1 (Plot 9)</u>

Ten acres were logged in the winter of 1927-28. All overmature and defective trees were marked, regardless of size or position in the stand. The cut was 4,900 ft. b.m. net, with a residual volume of 3,540 bd. ft. net. Sixty-two percent of the gross volume was removed. A two acre plot was established after cutting.

Seventy percent selection (Plot 33)

Almost 30 acres were logged in 1930. Overmature and defective trees and trees over 17 inches d.b.h. were cut unless their removal would leave too large an opening in the stand. The cut was 3,500 bd. ft. net per acre. The residual volume was 3,200 bd. ft. net. Sixty-eight percent of the gross volume was removed. A 4-acre sample plot was established.

Growth and value data were derived from the above plots only (plots 9, 33).

Overmature and defective number 2 (Plot 41)

In 1932-33 13 acres were logged. Overmature and defective trees were cut regardless of size or spacing. The cut was 4,200 bd, ft. net, while residual volume was 5,500 bd. ft. net. Fifty-nine percent of the gross volume was removed. A one acre plot was established. Only diameter growth data were analyzed for this plot to compare with the results from the preceding cuttings.

Virgin forest reserve (Plot 1)

The reserve area of nine acres was set aside in 1927. Its net volume in 1942 was 10,130 bd. ft. per acre. A two acre plot was established. Here again only diameter growth was analyzed to compare with the results from the other cuttings.

VOLUME GROWTH

A primary factor affecting volume growth of the tree is its rate of diameter increment. It is generally accepted that diameter growth varies inversely with the density of the stand on any given site. However, little has been published on the rate of growth of northern hardwoods after partial cutting. Eyre and Neetzel (5) analyzed growth at Dukes in 1937 covering one five-year growth period. Zon and Scholz (6) in studies in Northern Wisconsin found that in the virgin stand sugar maple averaged about .5 inches diameter growth per five-year period. They found no difference in growth rate with size after partial cutting and list the following average growth for sugar maple after a heavy partial cut:

first 5 year period after cutting - .8 inches
first 10 year period after cutting - 1.6 inches
first 15 year period after cutting - 2.5 inches
first 20 year period after cutting - 3.3 inches

Growth was almost at a constant rate of .8 inches per 5 year period for 20 years after cutting.

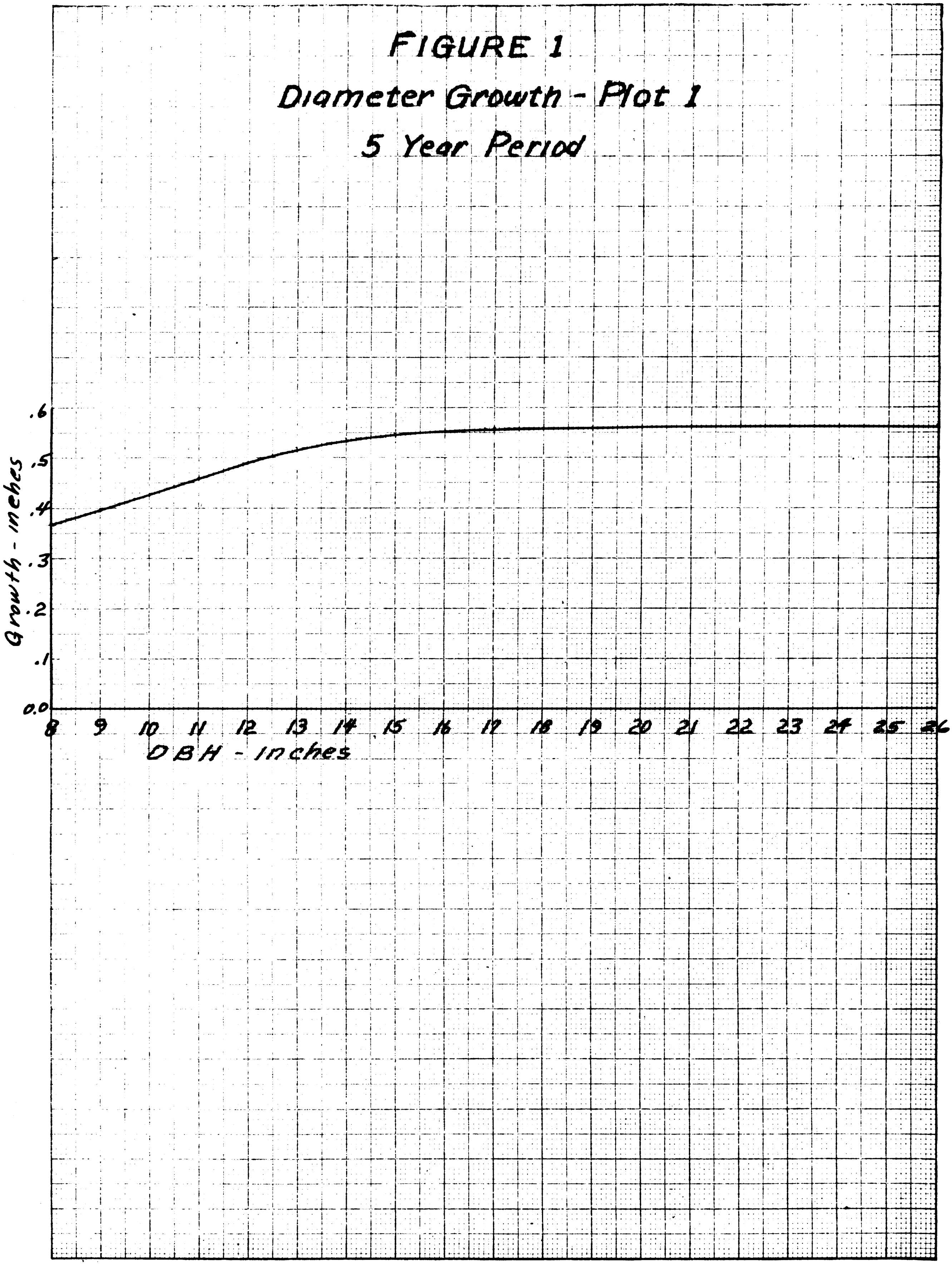
Figure 1 is a curve of diameter growth in relation to d.b.h. on the virgin forest reserve plot. On this and all other plots measurements were made at 5 year intervals, so this is the period of time used as a basis in comparing growth rates. The growth on the virgin plot is included only to provide a base for evaluating the growth on the cuttings.

Growth is shown to increase with tree size up to about 14 inches d.b.h. Above this size growth rapidly levels off.

FIGURE 1

Diameter Growth - Plot 1

5 Year Period



Diameter is generally related directly to crown class in the all age forest so the growth is probably a response to crown development.

Above 14 inches most trees have reached a codominant position in the stand so growth rapidly approaches its maximum shortly thereafter. The data are scanty above 19 inches d.b.h. but there is no reason to expect growth to increase in trees above that size. The data are not sufficient to determine if growth again falls off with greater size.

Figure 2 shows diameter growth in relation to d.b.h. on plot 41, the selection cutting where 5,500 bd. ft. remained as a residual volume after cutting. Growth is given by 5 year periods after cutting, with the abscissa in all cases being the d.b.h. at the time of cutting.

The smallest diameter classes made the greatest response after cutting, with the best growth occurring on trees 10 to 13 inches d.b.h. Even on this moderate cutting, growth had not yet decreased in the third 5 year period after cutting. After 15 years this plot has over 9,000 bd. ft. net per acre and growth can be expected to maintain itself for another 5 year period. There is shown to be a dropping off of growth in trees above 14 inches d.b.h. but the curves are based on a rather small sample so the trend cannot be relied upon to be conclusive.

Figure 3 shows curves of growth for plots 9 and 33 combined. Even though these plots were cut much more heavily than plot 41 there was poorer growth in the 15 year period following cutting. One reason for this may be that the site

FIGURE 2

Diameter Growth - Plot 41

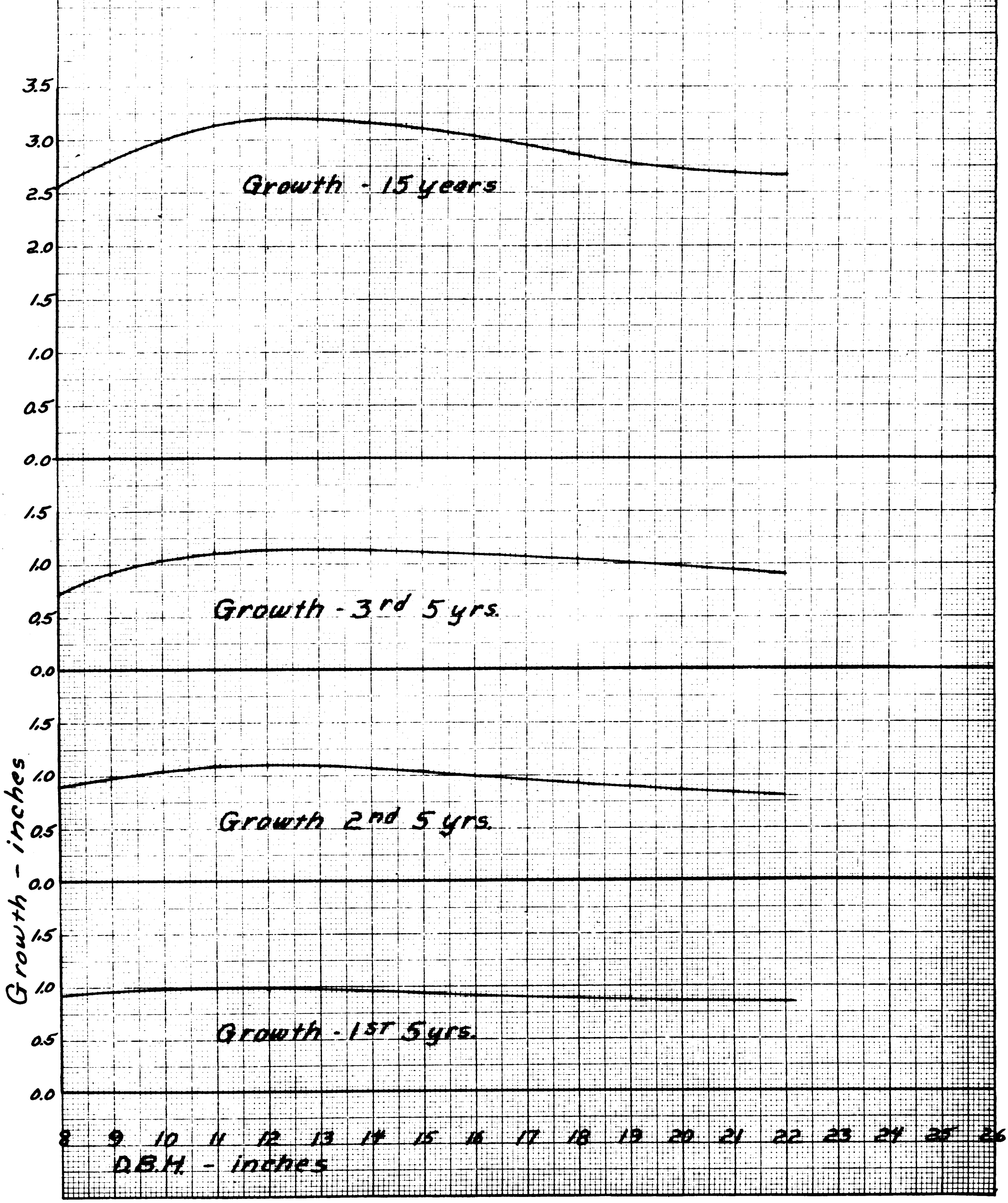
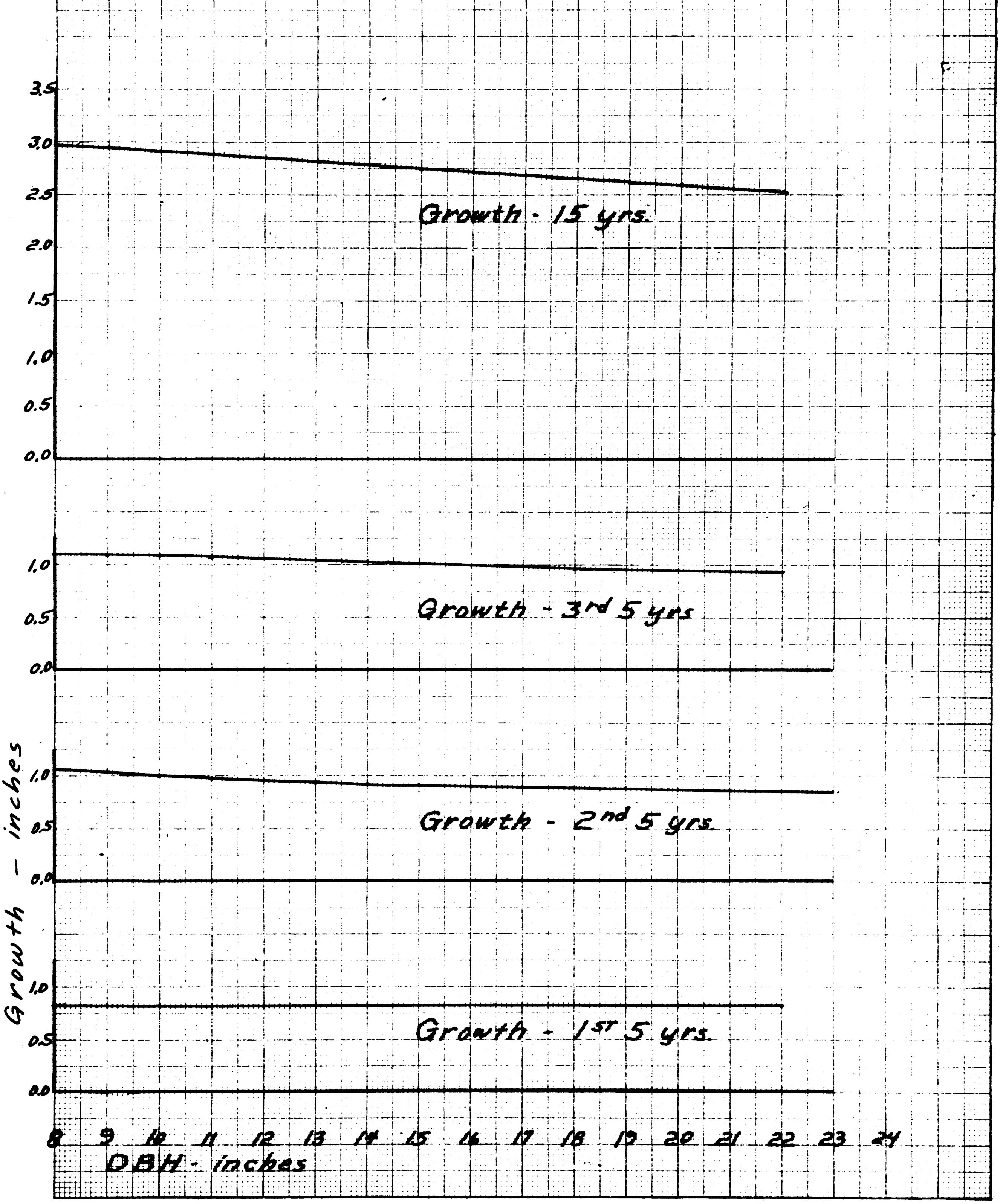


FIGURE 3

Diameter Growth - Plot 9,33



is better on plot 41; this is indicated by the greater volume that was originally on plot 41 before cutting. Another reason may be found in sampling error. Because of the small sample on plot 41 there may actually be no significant difference in the growth rates. A further contributing factor may have been the die-back of crowns on the more heavily cut plots. In these heavy cuttings most of the residual trees that were in the dominant and codominant crown positions before logging died back to some extent. This effect of logging had been noted in the Northeast by Dana (7). At present, 20 years after cutting, a few dead branches can still be seen in the tops of the crowns in some trees. According to the notes taken at the time of each measurement the crowns were generally rejuvinated by the time of the second remeasurement (10 years after cutting). A few of the trees with extreme die-back have never recovered and on some the crowns were broken off completely. Even though these few trees were still alive after 15 years they were not included in the growth averages used to make up the curves.

Growth increased through each succeeding 5 year period and it can be expected to maintain itself for another 5 years. Thus, over a 20 year cutting cycle growth should be at least as good as through a 15 year cycle.

The smaller diameter classes again made the greatest response after cutting, with best growth occurring in trees below 10 inches d.b.h. Here, as on plot 41, the rate of growth decreases for larger diameters, at least up to about 21 inches. Beyond that size there are no data.

One feature which is different on the three curves is the point of the maximum of each curve. The maximum varies in position with the intensity of cut. In the virgin stand the largest trees grow best. On lightly cut stands the medium sized trees respond best, while on the heavily cut stands the smallest trees respond best. The shock of opening the stand affects the largest trees most adversely. On plots 9 and 33 the trees over 14 inches d.b.h. increased their growth only slightly over that in the virgin stand in the first five years after cutting.

A comparison of 15 years' growth on the three areas considered is given below:

DBH	Plot 1	Plot 41	Plots 9, 33
	inches	inches	inches
10-14	1.40	3.10	2.85
15-19	1.65	2.95	2.70
20-24	1.70	2.70	2.55

From the curve for plots 9, 33 Table 1[1/] was prepared giving the diameter growth through a 15 year cycle and the estimated diameter growth for a 20 year cycle. These figures are the ones used in volume and value growth calculations.

In order to learn what growth rates could be expected in better trees in the stand the top quartile growth was found for plots 9, 33. Because of the small sample involved growth for all diameter classes was averaged. This growth was found to be 3.75 inches in 15 years; about 36 percent higher than the average.

In order to determine volume growth, a volume table was needed. An average height volume table was prepared by

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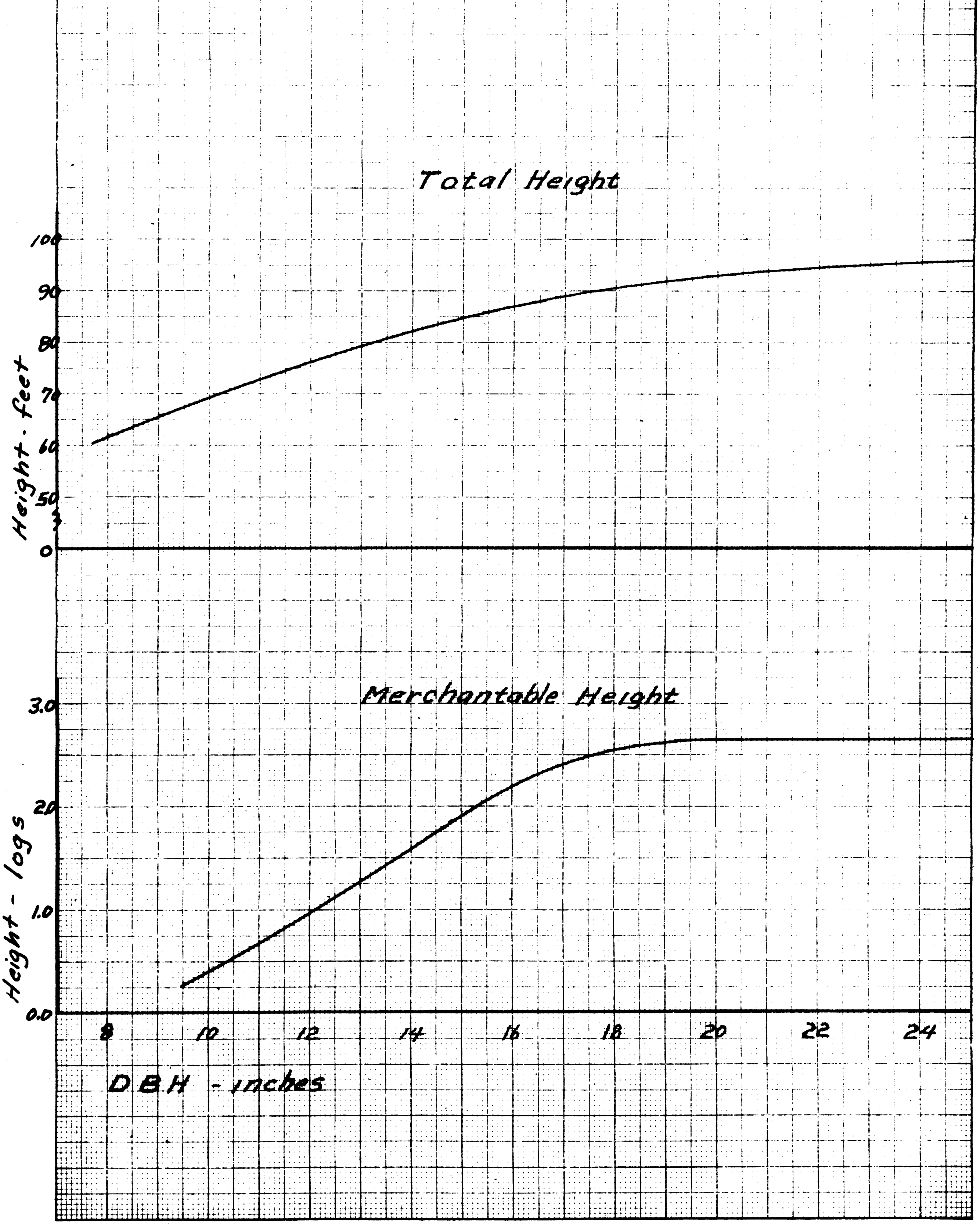
1/ All tables are found in the appendix.

curving average merchantable height (Figure 4) over d.b.h. and applying Composite Volume Table No. 1 of the Lake States Forest Experiment Station interpolated to heights determined from the curve. The resulting volumes were again curved to smooth the values and to provide values for fractional diameters. Table 2 is a tabulation of merchantable height and volume by diameter and is the local volume table used in the study.

An average height cubic foot volume table was prepared by curving total height over diameter (Figure 4) and applying Composite Table No. 4 of the Lake States Forest Experiment Station interpolated to the heights determined from the curve. The resulting volumes were again curved to smooth the values and provide values for fractional diameters. A tabulation of cubic foot volume by diameter classes is found in Table 2.

Figure 5 shows board foot and cubic foot increment over the 15 year cycle. Cubic foot increment varies directly with diameter but board foot increment rises and then levels off through several diameter classes before rising again. The explanation is found in the volume table. From 10 to 17 inches d.b.h. the difference in volume between succeeding diameter classes increases. From 17 to 21 inches the difference remains constant, after which it again increases. This effect in turn depends somewhat on the merchantable height curve used in making the volume table. Merchantable height does not increase in the form of a smooth curve, but rises steeply with diameter to about 17 inches where its rate of rise beginsto decelerate rapidly. This deceleration occurs between 17 and 19 inches

FIGURE 4



Total Height
100
90
80
70
60
50
0
Height - feet
Merchantable Height
3.0
2.0
1.0
0.0
Height - logs
8
10
12
14
16
18
20
22
24
DBH - inches

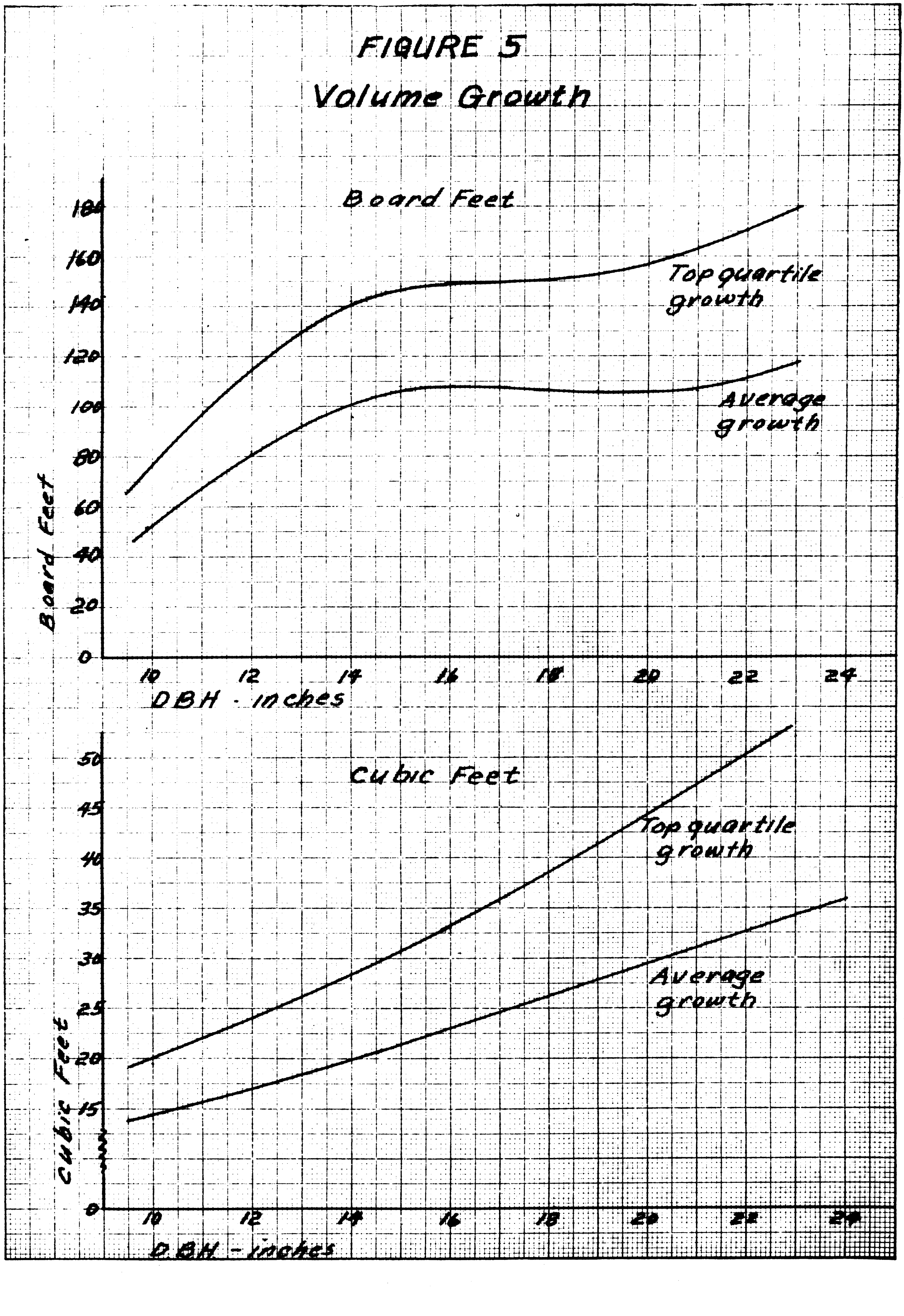


FIGURE 5
Volume Growth
Board Feet
Top quartile growth
Average growth
Board Feet
0
20
40
60
80
100
120
140
160
180
10
12
14
16
18
20
22
24
DBH - inches
Cubic Feet
Top quartile growth
Average growth
Cubic Feet
0
15
20
25
30
35
40
45
50
10
12
14
16
18
20
22
24
DBH - inches

and at 20 inches there is no further increase in height with size. With each inch of diameter increment at any given height, volume increment increases with increasing diameter of tree. Increase in height also increases volume. From 17 to 20 inches the increase in volume increment with diameter is offset by the decrease in the rate of height growth so the net result is a constant change of volume with d.b.h. Above 20 inches height is constant and has no effect on volume, so each additional inch in diameter causes a steadily increasing increment in volume.

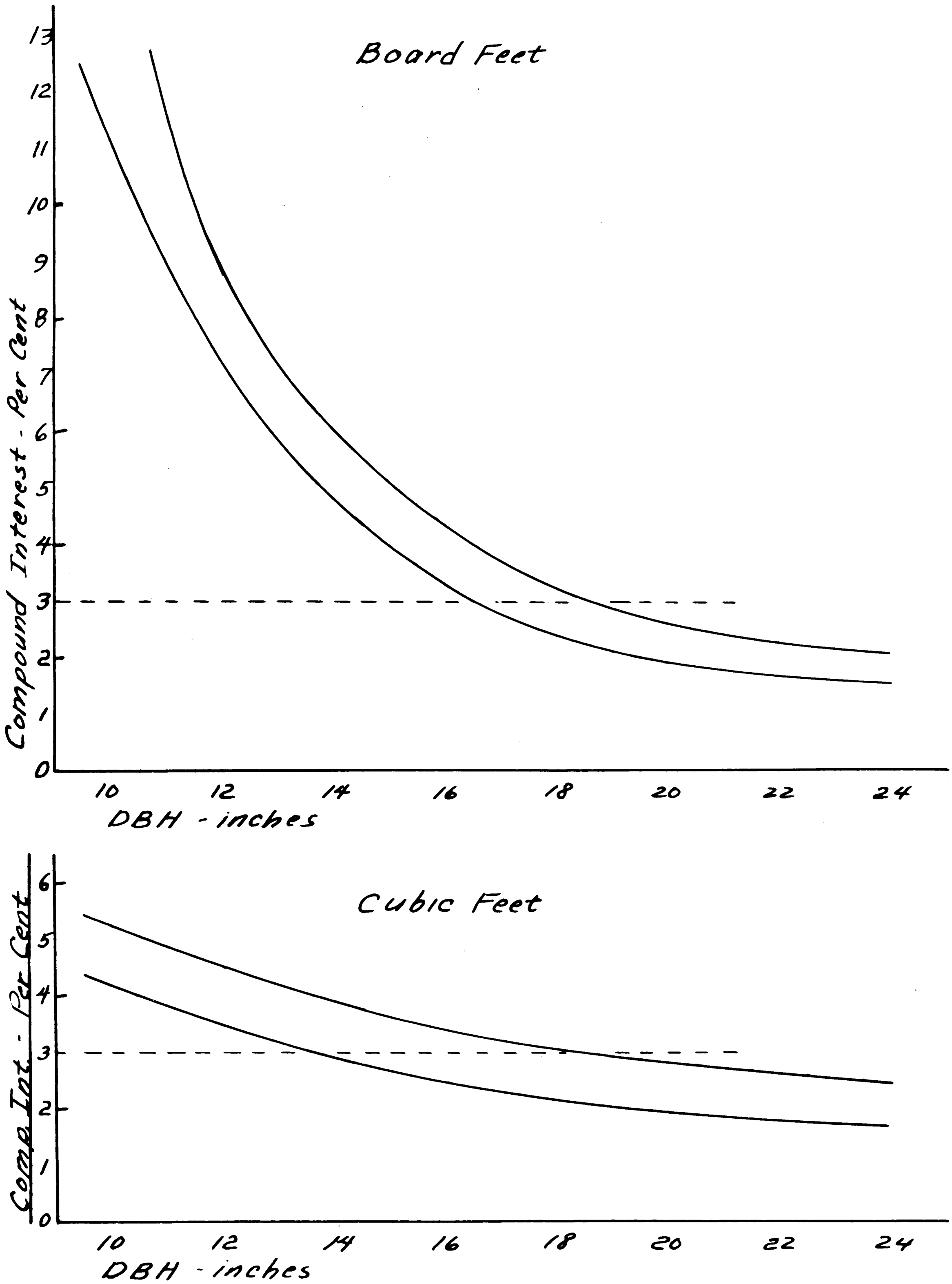
Maximum periodic growth occurs at 15 to 17 inches for trees of average growth rate. Mean growth per tree through the entire rotation would be lower and would have a more constant rate of change than periodic growth. Mean growth was not determined because it is felt that growth rates determined in this study could only be applied accurately for a short period of time. They should not be expected to remain constant through an entire rotation and would not be representative of the crop trees.

The curve of top quartile growth follows the same trend as the curve of growth of the average trees but the flattening of the curve is not as pronounced.

Figure 6 gives periodic rate of increment in terms of compound interest. The periodic rate of board foot growth constantly decreases with size and falls below 3 percent compound interest between 16 and 17 inches d.b.h. with average diameter growth. For the fast growing trees the rate falls below 3 percent at about 19 inches.

FIGURE 6

Rate of Growth



Tables 3 and 4 are tabulations of volume increase and growth percent from which Figures 5 and 6 were constructed. Table 5 is a tabulation of growth for a 20 year cycle. Interest rates for a 20 year cycle were just slightly less than for a 15 year cycle for sizes from 10 to 19 inches. From 19 inches and up they were identical.

VALUE GROWTH

Reynolds et al (8) calculated increase in residual value for southern pines and found high rates of return for smaller trees, with the rate decreasing with increasing size. They point out that the high rates are not significant for small trees because of the extremely low investment values involved. Slight decreases in the profit margin would wipe out these values. They also conclude that only trees of exceptional quality and vigor should be left to grow to a large size (over 21 inches d.b.h.).

Wahlenberg (9) in a study of longleaf pine, compared present stumpage values with expected values 10 years later discounted at 4 percent compound interest. The result showed at what size the interest rate fell below 4 percent. He found that the rate of return for sawlogs fell below this rate at about 16 inches d.b.h.

The U. S. Forest Service (10) made an economic study of individual tree growth in northern hardwoods based on 4 tree grades and 4 vigor classes.

Before any calculations could be made on value growth, proper prices and costs had to be determined. In actual practice prices and costs are continually fluctuating and current values could not be expected to remain constant for 15 years. A stand partially cut in 1934 would yield excellent returns on the investment made then. On the other hand, an investment in the residual stand in periods of high profits would yield a low return if prices dropped thereafter. A long-term business which survived a complete economic cycle would balance out in time, however.

Because of the intricacies of economic cycles and the inability to predict accurately what the future would bring it was assumed that values would be constant through a cutting cycle. The choice of values to use was set by the fact that OPA log grading rules were used in grading the trees in the study. OPA log prices for 1945 were used, and costs were built up on that basis.

A management plan was assumed so that proper costs and growth rates could be used. Growth records covered a 15 year period, and Zillgitt's studies showed 15 years as the cycle providing the best rate of return, so this period was set as the length of a cutting cycle. It was assumed the stand would be cut to a residual volume of 4.5 M ft. b.m. net with an average cull of 21 percent. Growth was taken to be 200 bd. ft. net per acre per year. The resulting volume after 15 years would then be 7.5 M ft. b.m. net of which 3 M ft. b.m. would be cut, again leaving 4.5 M ft. b.m. as a residual volume.

Cull for each tree on the plots had been calculated by Zillgitt (11). These figures were averaged by d.b.h. classes and it was found that cull did not vary with diameter. This is to be expected in a stand where the worst trees have been removed. In time, under management, cull should decrease with diameter because only the best trees would be left to grow.

Logs in all the trees on the plots had been graded by the Experiment Station staff using OPA grading rules (12). The average volume in each grade was determined for each d.b.h. class and curves drawn showing the proportion of the tree volume in each log grade by d.b.h. classes (Figure 7). Table 6 is derived from the curve. Trees below 12 inches d.b.h. have few logs better than mine timbers but above that size there is a rapid increase in the proportion of better grades up to about the 18 inch size class. Above 18 inches there is little increase in proportion of better grades.

As a further analysis of value growth the grades for a better than average were calculated. It was assumed that a tree was of such a quality that, as it grew, its log grade was limited only by the minimum diameter for that grade; and that the final condition was such that the butt log was a number 1, the second log a number 2, and the remainder a number 3 log. The tree would have no cull. OPA rules provide that a number 3 log have a minimum diameter of 8 inches, a number 2 log, 11 inches or 10 inches if a butt log, and a number 1 log, 12 inches or 11 inches if over 12 feet long.

Using a taper table developed by Gevorkiantz (13) the taper for each d.b.h. class was determined and from this the breakdown of each d.b.h. class into log grades was made. Volumes by grades were calculated and a curve of log grade proportions drawn (Figure 8, Table 7). The results show that this hypothetical tree reached its maximum grade at 16 inches d.b.h. A comparison of this curve with Figure 7 shows that there is not much lag in the size necessary to provide maximum grades in the average tree. For the average tree this is 18 inches. The comparison indicates that once a tree has reached

FIGURE 7

Proportion of Log Grades by DBH Classes

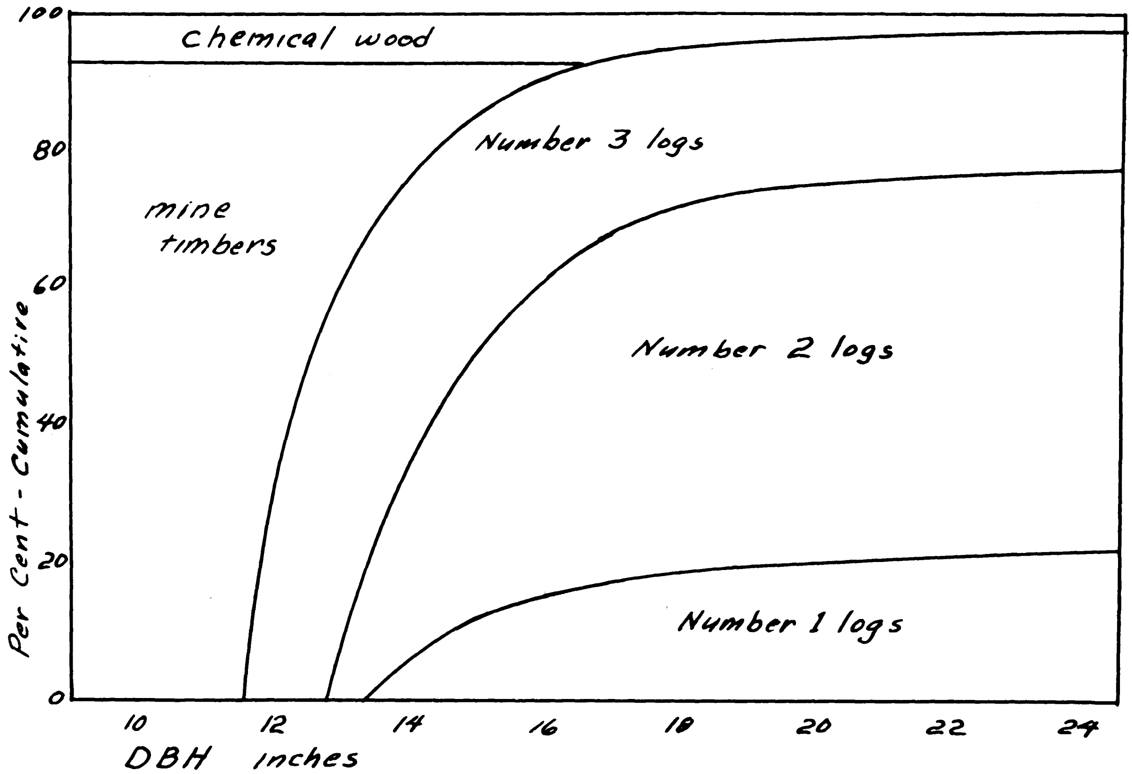
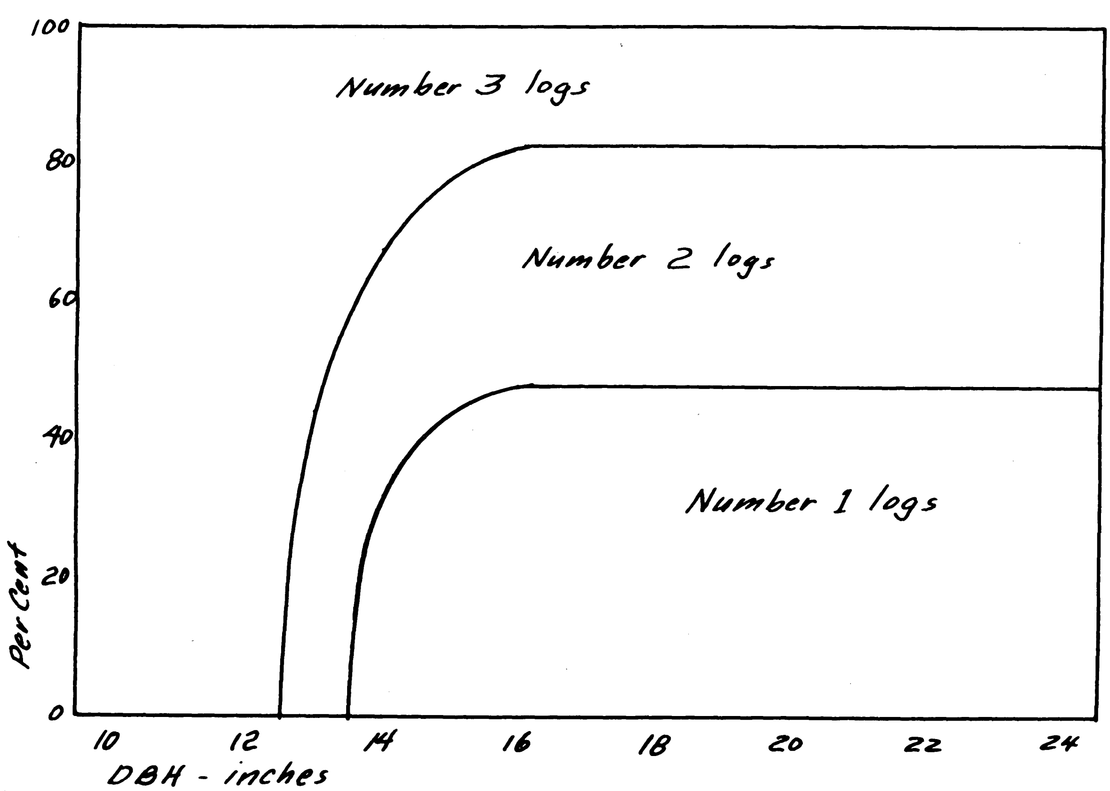


FIGURE 8

Proportion of Log Grades

by DBH Classes

High Value Trees



the minimum size necessary for maximum grade there is not much more increase in grade due to the growing over of grade defects.

From the proportions of log grade for average trees the gross volume per grade for each d.b.h. class was found (Table 8). These volumes then had to be reduced to net volumes. In the reduction it was felt that a flat 21 percent cull reduction per grade would not be equitable. The rules for Number 1 log provide for very little cull, while chemical wood is at least 50 percent cull. Accordingly the volumes in Number 1 grade were reduced 5 percent and those in chemical wood 50 percent. The remainder of the cull was distributed equally over the other grades. This averaged about 23 percent (Table 9). Net volumes are given in Table 8. The value per tree was then computed using net log volumes and gross chemical wood and mine timber volumes (Figure 9, Table 10).

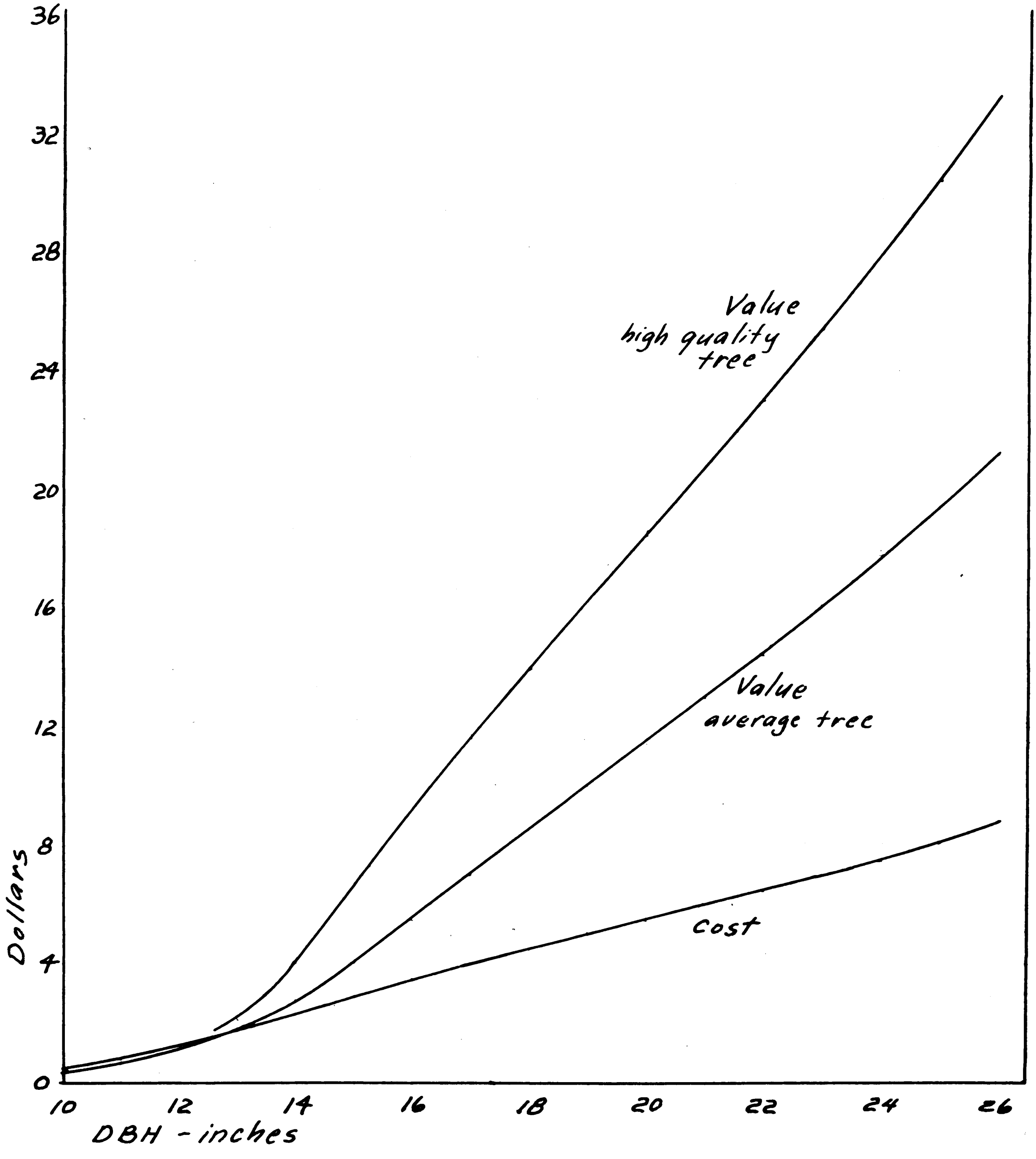
These latter products are sold on a gross basis.

The high value tree was considered to have no cull so value per tree was easily derived from the gross volume in each grade. (Figure 9, Table 11)

Time studies made in 1936 in Northern Wisconsin (13) were used in making a differential cost appraisal by diameter classes. The site was similar to that at Dukes and equipment was of the same type. Unit costs were developed and are given in Table 12. The time and cost per M of operations are given in Table 13. Fixed costs were taken to be $7.50 per acre. This value does not include new road or camp construction; but only maintenance costs, supervision, marking, and snow

FIGURE 9

Production Costs and Log Values per Tree



removal. For a cut of 3 M this would be $2.50 per M. Hauling was to the railroad siding four miles from the operations and cost was taken at $3.00 per M. Hauling cost varies only slightly with tree size and it was taken as constant in the appraisal.

From costs per M, costs per tree were computed. These were then curved in Figure 9 along with values per tree. The curves show the constantly increasing difference between cost and value beyond 13 inches d.b.h.

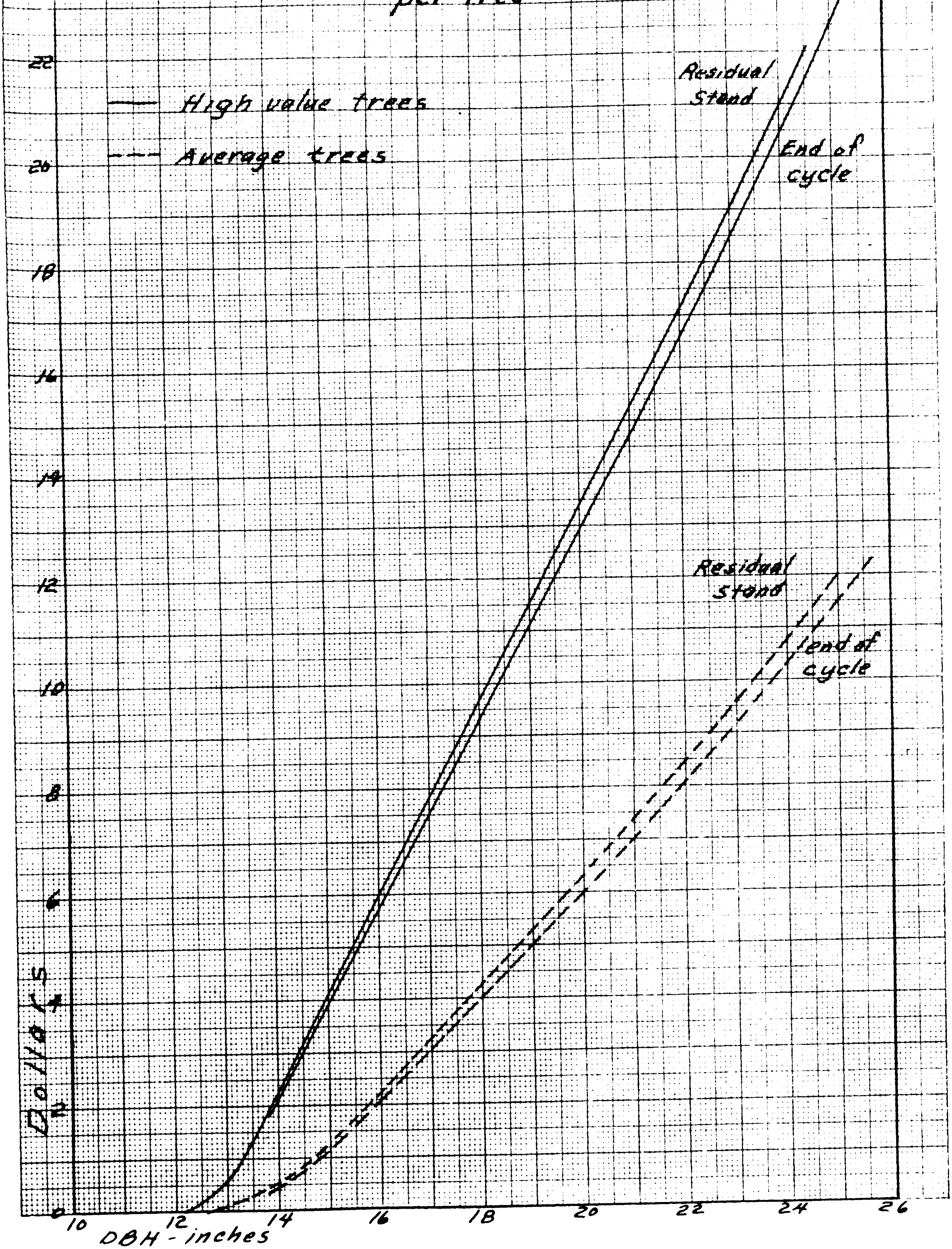
The total cost of logging the stand 15 years hence would be slightly more than logging the residual stand immediately. Variable costs would remain the same but some fixed cost items would be reduced or removed. There would be no marking cost and road and camp maintenance would be less. Therefore, two cost schedules were used in calculating residual value per tree. The schedule of costs applied to residual trees was $1.00 per M less than that applied to the stand at the end of the cycle.

Residual values by d.b.h. were computed for the average tree (Table 14) and these were curved in Figure 10 so that values for fractional diameters could be found. Residual values were computed for the high value tree (Table 15) and these were also curved in Figure 10.

Growth in residual value was found by reading residual values off the curves for the appropriate diameters at the beginning and end of the cycle. Compound interest return was computed using the formula: $1.0P^n = \frac{Cn}{Co}$. Growth in residual value and compound interest return were calculated for average

FIGURE 10

Residual Value per Tree



trees with average growth (Table 16), average trees with top quartile growth (Table 17), and high value trees with top quartile growth (Table 18).

Increase in residual value and percent return for the above three cases are compared below:

Comparison of Residual Value Growth for Three Combinations of Value and Growth[1/]

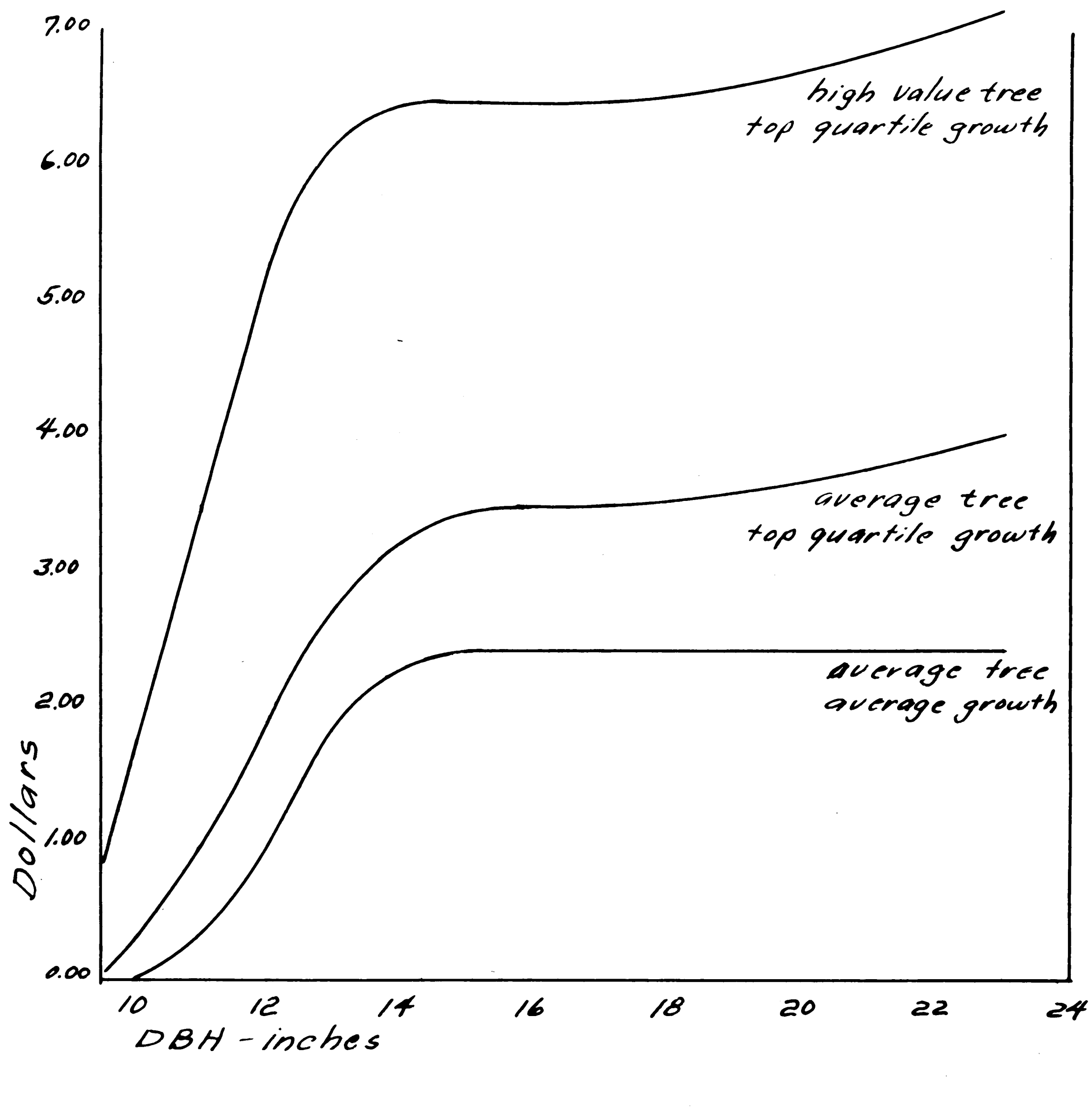
DBH	Increase in Value			Rate of Return		
	I	II	III	I	II	III
inches			dollars			
10	0	.28	1.70	-	-	-
11	.33	.95	3.50	-	-	-
12	1.02	1.88	5.29	-	-	-
13	1.84	2.71	6.55	22	25.0	19.3
14	2.38	3.28	6.60	12.8	14.8	9.5
15	2.47	3.46	6.58	7.5	9.05	6.6
16	2.44	3.49	6.52	5.0	6.5	5.05
17	2.44	3.51	6.44	3.8	5.0	4.1
18	2.38	3.54	6.48	3.0	4.1	3.5
19	2.40	3.62	6.57	2.6	3.6	3.05
20	2.42	3.69	6.71	2.3	3.15	2.8
21	2.45	3.82	6.85	2.0	2.9	2.5
22	2.46	3.83	7.04	1.8	2.5	2.4
23	2.42			1.5		

1/ I - Average tree value and average growth.
II - Average tree value and top quartile growth.
III - High quality tree and top quartile growth.

Residual value growth for the cases are curved in Figure 11. It is seen that the high quality trees made almost twice the value growth of the average trees with the same diameter growth and over 2½ times that of average trees with average diameter growth. The tremendous influence of quality on value growth shows up here. A striking feature of all the curves is the leveling off of growth at about 14 inches. Fourteen inch trees increase in value over 15 years just as much as do the 19 inch trees. This is current periodic growth, however. The mean growth continues to increase beyond 14 inches.

FIGURE 11

Residual Value Growth per Tree

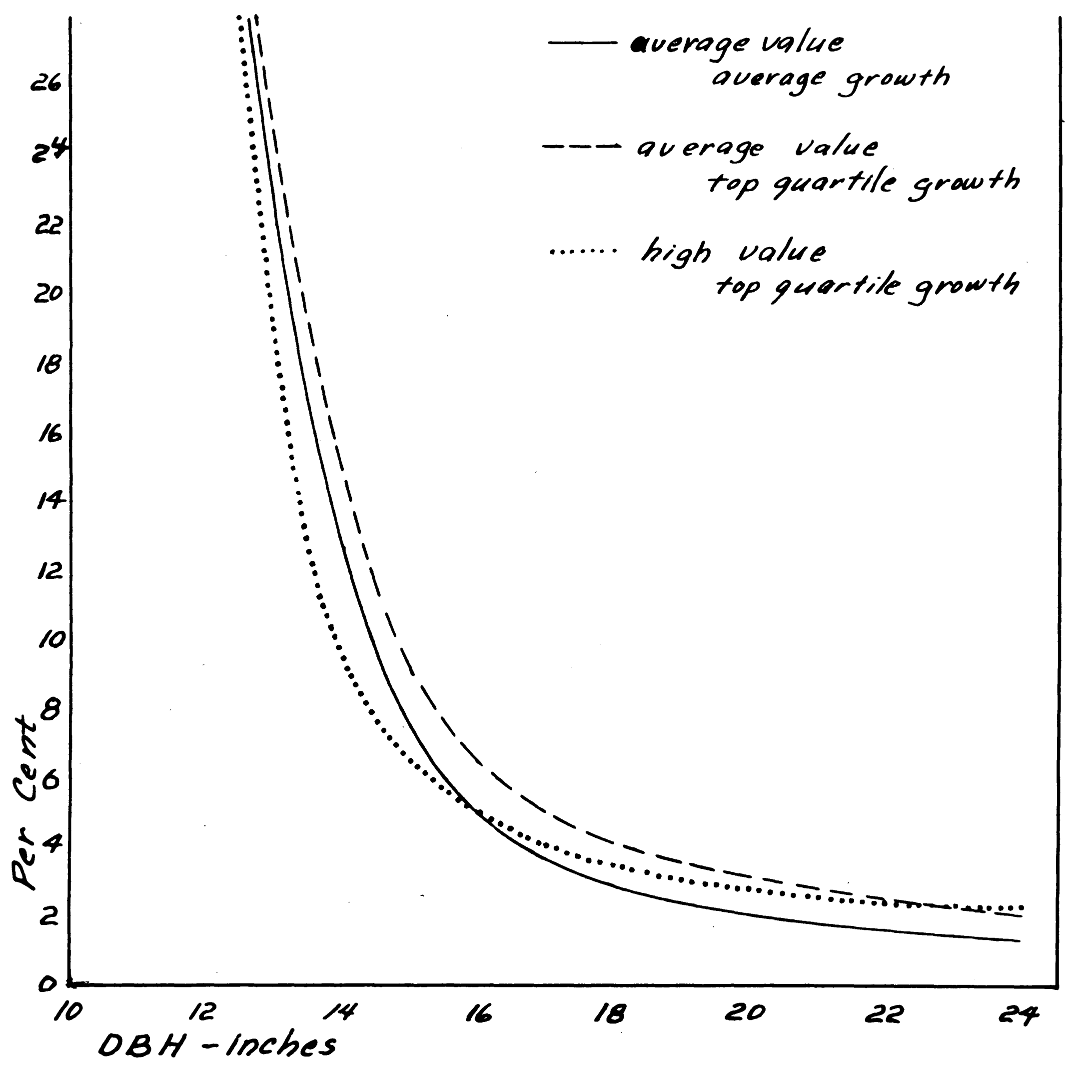


The curves of interest return are shown in Figure 12. Average trees with best growth give higher values than average trees with average growth. But the high value trees do not show better returns as one might expect. The rate of increase has nothing to do with the magnitude of the actual growth figures. No values could be computed for trees 12 inches and smaller because the residual values of the residual trees were negative. Trees above 12 inches already have such a large residual value in the high quality trees that the rate of increase is comparatively low. However, above 16 inches, where the curves level off somewhat, the high value trees maintain their rates of growth better than the others and above 23 inches they give the maximum rate of return.

Diameter growth and the increase in proportion of better log grades with size have more of an effect on rate of return than the absolute proportion of log grades in trees. That is, between two trees of similar quality the faster growing tree gives the best rate of growth. Between two trees with similar diameter growth the tree whose proportion of better log grades <u>is increasing with size</u> will give a better rate than the tree with a constant proportion of grades - even if the value of the second tree is much greater than that of the first.

FIGURE 12

Compound Interest Return on Residual Value



CONCLUSIONS

Maximum Board Foot Production

The essential results of the analysis are given in the curves of growth and rate of return (Figures 5 and 6). What can be concluded from these curves? Current periodic growth remains almost constant in trees 15" d.b.h. and up. Mean growth per tree would continue to rise above that size. The rate of rise, however, would lessen above 15 inches. If current growth remained at a constant value above 15 inches, mean growth would never reach a maximum, but would approach the curve of current growth asymptotically. In this case, trees should be grown to as large a size as possible. But above 20 inches growth data are so scant that no definite statement can be made in this regard. It can only be stated that mean growth per tree continues to increase with size beyond 20 inches d.b.h.

In the complete picture, growth per tree cannot be divorced from growth per acre, which is equal to the sum of growth on the individual trees. Mean growth per tree increases with size, but the number of trees which can be supported on one acre decreases with size, so there must be some combination of tree size and number which will give the best growth per acre. A tentative conclusion would be that a stand consisting entirely of 15 inch trees should give the best current periodic growth per acre.

The above conclusion can be checked with a yield table for northern hardwoods on a good site(14). Using the number of trees per acre by diameter from the table and the volume table developed in this paper, it was found that current growth per acre was best between 14 inches and 15 inches, with a rapid drop in growth above 15 inches. From inspection of the table, mean growth appeared to culminate at about 18 or 19 inches.

Translating these results to the all-aged stand for maximum yield per acre, a harvest of most trees over 17 to 19 inches in size would appear best. This would result in some trees being up to 22 inches in size fifteen years after the cutting. Exceptionally vigorous trees would be left well above the 17 to 19 inch size, while the poorer trees would be cut in the thinning of lower diameter classes. The number of these latter trees to cut would be determined by the total residual volume sought per acre. In shorter cycles the harvest size would be slightly higher and in longer cycles slightly lower; the objective always being to cut the most trees at that size which would give the maximum mean growth per acre.

Growth percent decreases rapidly with size to about 16 inches d.b.h. and then decreases more slowly. Rate of growth per acre is an average of the rates of all the trees, regardless of the number of trees. Therefore, the desire for high rate of return would tend to lower the size of the trees kept after cutting.

Other factors to be considered in growth are cull and mortality. Cull was found not to increase with the size of the tree in the stand studied. Ultimately, in a managed stand, it should decrease with size because the poor trees would be constantly weeded out. Cull would be no detriment in leaving the trees to grow to large harvest size.

Risk of mortality is a deterrent to leaving trees of large size in the stand. Even if risk per tree were no greater for the large than for the small tree, the loss would be much greater. It would be preferable to have the volume spread over many small trees than a few large individuals. As was pointed out previously, die-back after cutting was more severe on the larger trees. This might cause some mortality and would be another reason for not holding trees to an extremely large size. Risk of mortality, then, serves against growing trees to large size.

Maximum Value Production

There are two economic factors influencing the manager of a tract of timber: first, the rate of return on the investment, and second, the size of the return in dollars. Maximum rate of return calls for small trees while maximum dollar return is obtained from large trees. If land were limited and opportunities for other investment were poor, the maximum dollar return would be sought; while if productive land or other good investment were available, a high rate of return would be the objective.

In most cases a compromise would probably be made, with trees being cut to yield a fair rate of return and a good dollar return. In any event, the best course would be to maintain as high quality trees as possible, because for the same rate of return as a poor tree, the dollar return is much greater.

Figure 11 shows current periodic value growth per tree. Here, as with volume growth, the curve of growth levels off at 15 inches for the average grade tree. Mean value growth would not reach a definite maximum but would approach the current growth curve asymptotically and gradually flatten out at some point beyond 15 inches. The same argument regarding volume growth per acre holds here, and average trees could be cut down to 17-19 inches, thus providing trees up to 22 inches in size for the next cut. The high value trees provide such a high value growth that they could be grown to as large a size as possible. As shown in Figure 12 a good rate of return would also be made by growing trees to 17-19 inches and leaving only the exceptionally high quality trees above that size. Low value trees would be cut below that size.

Other factors also point to this size class as being the optimum for cutting. Trees 17 inches d.b.h. are generally large enough to provide maximum log grade and there is little change in grade above this size due to growing over of defects. The low value trees can probably be eliminated early in the rotation because final log grade in a tree can be judged when the tree is still relatively small. By the time trees reach 12 inches in size their boles are almost as clear as they ever would be under normal conditions. Thus, if trees are limby or defective when 12 inches, there would be very little chance of them ever having high grade logs, and they could be removed as silvicultural requirements warrant.

Merchantable height does not increase in trees above 19 inches d.b.h. so there is no reason to hold a tree beyond this size to get the maximum number of logs out of the tree.

Costs per M decrease only a little in trees over 19 inches so there is no reason to grow larger trees in order to reduce logging costs. Cutters usually like this size best as they are big enough to get high production yet are small enough to handle easily.

Farmers or small owners doing their own logging would be pressed to cut trees smaller than this size. In this way their investment would be low and a good rate of return could be obtained. Even though the residual value per tree would be decreased by cutting smaller trees, the loss in residual value would be compensated to some extent by the greater labor involved in producing one M of timber. In the case of the owner doing his own work, this would be a form of income. For this type of operation, harvest size could be lowered to 16 inches, leaving no trees above this size unless silvicultural consideration necessitated it. A ten year cycle would provide 17-18 inch trees for the harvest cut along with smaller trees from thinning.

These figures are based on the selling of logs by grades. In the case of the owner of the land using his logs in his own mill, the results would be different. Here, value per M per tree and current value growth would continue to increase with size beyond 15 inches. With lumber as the product of sale the owner would probably leave larger trees to get the best return.

Residual value is equal to stumpage plus margin and to the term "conversion return" used in stumpage appraisals. The owner of a tract of timber has other costs not included in the determination of residual values. These are taxes and investment charges on the land. These annual charges would tend to depress the harvest size of the timber because both dollar return and rate of interest return are lowered for all sized trees.

SUMMARY

A fifteen year record of growth on the Upper Peninsula Experimental Forest was used in analyzing volume increment of sugar maple in the northern hardwood type after a heavy selection cutting. Diameter growth varies with size of tree and is at a maximum for trees below 10 inches d.b.h. Average diameter growth over a 15 year period is 2.8 inches. Growth had not yet decelerated in the third 5 year period after cutting.

Maximum merchantable height is reached by the time the tree is 19 inches in size.

Current board foot increment remains almost constant in trees 15 inches d.b.h. and larger, both for trees with average diameter growth and upper quartile diameter growth. Mean annual growth continues to increase with size in trees above 15 inches d.b.h. but mean growth per acre reaches a maximum with trees 17 to 19 inches in size. Current rate of growth in terms of compound interest decreases extremely rapidly with increasing size of tree up to 16 inches d.b.h. Thereafter it decreases more slowly. Current rate of growth falls below 3 percent at 16 inches.

Value per tree in terms of log grades was determined from grade records on the Upper Peninsula Experimental Forest. The average tree reaches near maximum log value by the time it is 18 inches d.b.h.

Using a differential cost schedule, residual value or "conversion return" per tree was determined. Growth in residual value did not increase greatly for trees above 14 inches d.b.h.

Rate of return was high for the small trees and decreased rapidly with size. Current periodic rate of return was less than 3 percent for trees 19 inches and up in size.

Maximum value and volume growth per acre should be achieved by leaving trees 17 to 19 inches and smaller on good sites with a 15 year cutting cycle.

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Table 1.--Periodic Diameter Growth 1/

DBH Class	Period After Cutting: 1st 5 yrs.	2nd 5 yrs.	3rd 5 yrs.	Total 15 yrs.
Inches	Inches	Inches	Inches	Inches
10	80	1.00	1.10	2.90
11	85	.95	1.05	2.85
12	85	.95	1.05	2.85
13	80	.95	1.05	2.80
14	85	.90	1.05	2.80
15	85	.90	1.00	2.75
16	80	.90	1.00	2.70
17	80	.90	1.00	2.70
18	80	.90	.95	2.65
19	75	.90	.95	2.60
20	80	.85	.95	2.60
21	75	.85	.95	2.55
22	75	.85	.95	2.55
23	75	.85	.90	2.50

1/ Curved values.

Table 2.--Merchantable Height and Volume by Diameter Classes

DBH Class	Merch. Height	Gross Volume	Gross Volume
Inches	16' Logs	Bd. Ft. 1/	Cu. Ft. 2/
8	--	--	9.7
9	--	--	12.5
10	.45	13	17.0
11	.65	26	21.0
12	.95	46	26.0
13	1.25	70	32.0
14	1.55	98	38.0
15	1.90	132	44.5
16	2.20	171	52.0
17	2.40	210	60.0
18	2.55	250	68.0
19	2.60	290	77.5
20	2.65	330	87.5
21	2.65	370	98.5
22	2.65	411	110.0
23	2.65	453	122.0
24	2.65	497	135.0
25	2.65	544	149.0
26	2.65	593	163.0
27	2.65	645	177.0
28	2.65	697	191.0

1/ Minimum top d.i.b. 8 inches. Curved values derived from Composite Table No. 1, Lake States Forest Experiment Station, St. Paul, Minnesota.

2/ Minimum top d.i.b. 2 inches. Curved values derived from Composite Table No. 4, Lake States Forest Experiment Station, St. Paul, Minnesota.

Table 3.--Volume Growth During 15-Year Cycle Based on Average Diameter Growth

DBH begin.	DBH end	Board Feet begin.	Board Feet end	Board Feet diff.	Comp. Int.	Cubic Feet begin.	Cubic Feet end	Cubic Feet diff.	Comp. Int.
10	12.90	13	66	53	11.1	17	31	14	4.1
11	13.85	26	93	67	8.9	21	37	16	3.9
12	14.85	46	127	81	7.0	26	44	18	3.6
13	15.80	70	163	93	5.8	32	50.5	18.5	3.1
14	16.80	98	203	105	5.0	38	58	20	2.9
15	17.75	132	240	108	4.2	44.5	66	21.5	2.7
16	18.70	171	279	108	3.4	52	75	23	2.5
17	19.70	210	318	108	2.8	60	84.5	24.5	2.35
18	20.65	250	357	107	2.4	68	94.5	26.5	2.2
19	21.62	290	396	106	2.1	77.5	105	27.5	2.05
20	22.60	330	435	105	1.9	87.5	117	29.5	2.0
22	24.55	411	523	112	1.7	110	143	33	1.8
23	25.50	453	570	117	1.6	122	157	35	1.75

Table 4.--Volume Growth During 15-Year Cycle Based on Top Quartile Diameter Growth

DBH - inches begin.	DBH - inches end	Board Feet begin.	Board Feet end	Board Feet diff.	Int. Rate Comp. %	Cubic Feet begin.	Cubic Feet end	Cubic Feet diff.	Int. Rate Comp. %
10	13.75	13	90	77	14.8	17	36.5	19.5	5.2
11	14.75	26	123	97	12.0	21	43	22	4.9
12	15.75	46	161	115	8.8	26	50	24	4.5
13	16.75	70	200	130	7.3	32	58	26	4.1
14	17.75	98	240	142	6.2	38	66	28	3.8
15	18.75	132	280	148	5.15	44.5	75	30.5	3.55
16	19.75	171	320	149	4.3	52	85	33	3.3
17	20.75	210	360	150	3.7	60	95.5	35.5	3.15
18	21.75	250	401	151	3.2	68	106	38	3.0
19	22.75	290	443	153	2.9	77.5	119	41.5	2.9
20	23.75	330	487	157	2.6	87.5	132	44.5	2.8
21	24.75	370	533	163	2.45	98.5	146	47.5	2.7
22	25.75	411	582	171	2.3	110	160	50	2.6
23	26.75	453	632	179	2.2	122	174	52	2.5

Table 5.--Diameter and Volume Growth During 20-Year Cycle.

DBH - inches		Board Feet			Int. Rate	Cubic Feet			Int. Rate
begin.	end	begin.	end	diff.	Comp.%	begin.	end	diff.	Comp. %
9	12.90	0	66	66	--	12.5	31	18.5	4.6
10	13.90	13	95	82	10.5	17	37.5	20.5	4.0
11	14.85	26	127	101	8.3	21	44	23	3.8
12	15.85	46	164	118	6.6	26	50.5	24.5	3.4
13	16.80	70	203	133	5.5	32	58	26	3.0
14	17.80	98	243	145	4.65	38	66.5	28.5	2.8
15	18.75	132	280	148	3.85	44.5	75	30.5	2.6
16	19.70	171	318	147	3.2	52	84.5	32.5	2.45
17	20.70	210	358	148	2.7	60	95	35	2.3
18	21.65	250	396	146	2.3	68	105.5	37.5	2.2
19	22.60	290	435	145	2.1	77.5	117	39.5	2.1
20	23.60	330	480	150	1.9	87.5	130	42.5	2.0
21	24.55	370	524	154	1.75	98.5	143	44.5	1.9
22	25.55	411	570	159	1.7	110	157	47	1.8
23	26.50	453	620	167	1.6	122	170.5	48.5	1.7

Table 6.--Distribution of Products from Average Quality Trees

DBH Class	Logs Grade 1	Logs Grade 2	Logs Grade 3	Mine Timbers	Chemical Wood	Total
Inches			Per cent			
10	0	0	0	93.0	7.0	100
11	0	0	0	93.0	7.0	100
12	0	0	29.0	64.0	7.0	100
13	0	7.0	53.5	32.5	7.0	100
14	6.0	28.5	41.5	17.0	7.0	100
15	12.0	39.5	34.5	7.0	7.0	100
16	15.5	47.0	28.5	2.0	7.0	100
17	17.5	51.5	25.0	0	6.0	100
18	19.0	54.0	22.0	0	5.0	100
19	19.5	55.5	21.0	0	4.0	100
20	20.0	55.5	20.5	0	4.0	100
21	20.5	55.5	20.5	0	3.5	100
22	21.0	55.5	20.0	0	3.5	100
23	21.5	55.5	20.0	0	3.0	100
24	22.0	55.5	19.5	0	3.0	100
25	22.0	56.0	19.0	0	3.0	100
26	22.0	56.0	19.0	0	3.0	100

Table 7.--Distribution of Log Grades in High Value Trees

DBH Class	Grade 1	Grade 2	Grade 3	Total
Inches		Per cent		
10	0	0	100	100
11	0	0	100	100
12	0	0	100	100
13	0	44	56	100
14	32	36	32	100
15	44	35	21	100
16	48	35	17	100
17	48	35	17	100
18	48	35	17	100
19	48	35	17	100
20	48	35	17	100
21	48	35	17	100
22	48	35	17	100
23	48	35	17	100
24	48	35	17	100
25	48	35	17	100
26	48	35	17	100

Table 8.--Gross Board Foot Volume of Products in Average Quality Trees

DBH Class	Logs Grade 1	Logs Grade 2	Logs Grade 3	Mine Timbers	Chemical Wood	Total
Inches						
10	--	--	--	12	1	13
11	--	--	--	24	2	26
12	--	--	13	30	3	46
13	--	5	37	23	5	70
14	6	28	40	17	7	98
15	16	52	46	9	9	132
16	27	80	49	3	12	171
17	37	108	53	--	12	210
18	48	135	55	--	12	250
19	56	161	61	--	12	290
20	66	183	68	--	13	330
21	76	205	76	--	13	370
22	86	228	83	--	14	411
23	97	251	91	--	14	453
24	109	276	97	--	15	497
25	120	305	103	--	16	545
26	130	332	113	--	18	593

Table 8a.--Net Board Foot Volume of Products in Average Quality Trees

DBH Class	Logs Grade 1	Logs Grade 2	Logs Grade 3	Mine Timbers	Chemical Wood	Total
Inches						
10	--	--	--	9	1	10
11	--	--	--	20	1	21
12	--	--	10	24	2	36
13	--	4	30	18	3	55
14	6	22	32	13	4	77
15	15	41	36	7	5	104
16	25	63	39	2	6	135
17	35	84	41	--	6	166
18	45	104	43	--	6	198
19	53	123	47	--	6	229
20	63	139	52	--	7	261
21	72	155	58	--	7	292
22	82	173	63	--	7	325
23	92	190	69	--	7	358
24	104	208	73	--	8	393
25	114	230	78	--	8	430
26	124	250	85	--	9	468

Table 9.--Cull Deduction by Log Grade and Diameter Class

DBH Class	Cull volume in: Per tree total	Cull volume in: Chem. wood	Cull volume in: Grade 1 logs	Cull volume in: Grade 2,3 logs mine timber	Gross volume in: Grade 2,3 logs mine timber	Cull in Grade 2,3 logs mine timber	Cull volume in: Grade 2 logs	Cull volume in: Grade 3 logs	Cull volume in: Mine timbers
Inches	Bd. Ft.	Bd. Ft.	Bd. Ft.	Bd. Ft.	Bd. Ft.	Percent	Bd. Ft.	Bd. Ft.	Bd. Ft.
10	3	0	-	3	12	25	--	--	3
11	5	1	-	4	24	16.6	--	--	4
12	10	1	-	9	43	20.9	--	3	6
13	15	2	-	13	65	20.0	1	7	5
14	21	3	0	18	85	21.2	6	8	4
15	28	4	1	23	107	21.5	11	10	2
16	36	6	2	28	132	21.2	17	10	1
17	44	6	2	36	161	22.4	24	12	--
18	52	6	3	43	190	22.6	31	12	--
19	61	6	3	52	222	23.4	38	14	--
20	69	6	3	60	251	23.9	44	16	--
21	78	6	4	68	281	24.2	50	18	--
22	86	7	4	75	311	24.1	55	20	--
23	95	7	5	83	342	24.3	61	22	--
24	104	7	5	92	373	24.7	68	24	--
25	114	8	6	100	408	24.5	75	25	--
26	125	9	6	110	445	24.7	82	28	--

Table 10.--Log Value Per Tree for Average Quality Trees 1/

DBH Class	Log Grade No. 1	Log Grade No. 2	Log Grade No. 3	Mine Timbers	Chemical Wood	Total	Curved Total
Inches				Dollars			
10	--	--	--	.30	.03	.33	.33
11	--	--	--	.62	.05	.67	.68
12	--	--	.26	.78	.08	1.12	1.18
13	--	.13	.78	.60	.13	1.64	1.80
14	.50	.73	.83	.44	.18	2.68	2.69
15	1.26	1.35	.94	.24	.23	4.02	4.02
16	2.10	2.08	1.02	.08	.30	5.58	5.56
17	2.94	2.77	1.07	--	.30	7.08	7.07
18	3.78	3.43	1.12	--	.30	8.63	8.60
19	4.45	4.06	1.22	--	.30	10.03	10.08
20	5.30	4.59	1.35	--	.33	11.57	11.54
21	6.05	5.12	1.51	--	.33	13.01	13.01
22	6.89	5.71	1.64	--	.35	14.59	14.58
23	7.73	6.28	1.79	--	.35	16.15	16.16
24	8.74	6.87	1.90	--	.38	17.89	17.89
25	9.58	7.60	2.03	--	.41	19.62	19.62
26	10.42	8.26	2.21	--	.46	21.35	21.36

1/ Log Values per M FOB Car

No. 1	$84.00
No. 2	33.00
No. 3	26.00
M. Tbr.	28.30
Chem.	26.00

Table 11.--Gross Board Foot Volume by Log Grades for High Quality Trees

DBH Class	Grade 1 Logs	Grade 2 Logs	Grade 3 Logs	Total
Inches		Board Feet		
10	--	--	14	14
11	--	--	26	26
12	--	--	46	46
13	--	31	39	70
14	31	35	32	98
15	58	46	28	132
16	82	60	29	171
17	101	73.0	36	210
18	120	87.5	42.5	250
19	139	102.0	49	290
20	158	116.0	56	330
21	178	129.0	63	370
22	197	144	70	411
23	218	158.0	77	453
24	239	174	84	497
25	261	190	93	544
26	284	208.0	101	593

Table 11a.--Value by Grades for High Quality Trees

DBH	Logs			Total	Curved
Class	Grade 1	Grade 2	Grade 3		Total
Inches			Dollars		
10	--	--	.36	.36	.36
11	--	--	.68	.68	.68
12	--	--	1.20	1.20	1.20
13	--	1.02	1.01	2.03	2.20
14	2.60	1.16	.83	4.59	4.30
15	4.87	1.52	.70	7.09	6.80
16	6.89	1.98	.75	9.62	9.25
17	8.48	2.41	.94	11.83	11.65
18	10.08	2.89	1.11	14.08	13.95
19	11.68	3.36	1.27	16.31	16.25
20	13.27	3.83	1.46	18.56	18.50
21	14.95	4.26	1.64	20.85	20.80
22	16.55	4.75	1.82	23.12	23.10
23	18.31	5.21	2.00	25.52	25.50
24	20.08	5.74	2.18	28.00	28.00
25	21.92	6.27	2.42	30.61	30.60
26	23.87	6.86	2.62	33.35	33.35

Table 12.--Log Costs from Stump to F.O.B. Railroad Car

	Costs Per Hour
Felling and bucking	
Labor	$ .90
21% for Insurance, Workman's Compensation, Unemployment	.19
Supplies, depreciation, maintenance, and equipment	.16
Total	$1.25
Skidding	
Teamster	.80
21% for Insurance, Workman's Compensation, Unemployment	.17
Barn boss (overhead)	.15
Maintenance, depreciation on the investment	.42
Total for man and team	$1.54
Swamping	.42
Total	$1.96
Truck loading	
Man and team	.38
Hookers, 2 men	.49
Truck and driver	.66
Total	$1.53
Load cars	
Man and team	.38
Hookers, 2 men	.49
Top loader	.24
Jammer	.10
Total	$1.21
	Costs Per M ft. b.m.
Truck haul and unload	$3.00
Fixed cost	$2.50

Table 13.--Time and Costs per M Board Feet[1] from Stump to Railroad Car

DBH	Cutting		Skidding		Truck loading		Car loading		Fixed	Total	Value	
Class	Time	Cost	Time	Cost	Time	Cost	Time	Cost	Costs[2]	Costs	per M	Residual/M
Inches	Man/Hrs.	Dollars	Man/Hrs.	Dollars	Man/Hrs.	Dollars	Man/Hrs.	Dollars	Dollars	Dollars		
10	6.02	7.52	6.55	12.84	2.07	3.17	2.07	2.50	5.50	31.52	25.80	-5.72
11	5.58	6.97	5.94	11.65	1.93	2.95	1.93	2.34	"	29.41	25.80	-3.61
12	5.13	6.41	5.33	10.45	1.80	2.75	1.80	2.18	"	27.29	25.80	-1.49
13	4.75	5.94	4.74	9.30	1.64	2.51	1.64	1.99	"	25.24	25.80	+ .56
14	4.40	5.50	4.22	8.27	1.50	2.30	1.50	2.30	"	23.38	27.45	+4.07
15	4.08	5.10	3.76	7.37	1.37	2.09	1.37	1.66	"	21.72	30.45	8.73
16	3.88	4.85	3.36	6.58	1.25	1.91	1.25	1.51	"	20.35	32.50	12.15
17	3.68	4.60	3.03	5.94	1.16	1.77	1.16	1.39	"	19.20	33.67	14.47
18	3.53	4.41	2.77	5.43	1.06	1.62	1.06	1.28	"	18.24	34.30	16.06
19	3.43	4.29	2.57	5.04	.97	1.49	.97	1.17	"	17.49	34.70	17.21
20	3.33	4.16	2.37	4.65	.90	1.38	.90	1.09	"	16.78	34.95	18.17
21	3.29	4.11	2.23	4.37	.83	1.27	.83	1.01	"	16.26	35.20	18.94
22	3.22	4.03	2.12	4.16	.78	1.19	.78	.94	"	15.82	35.45	19.63
23	3.19	3.99	2.01	3.94	.74	1.13	.74	.90	"	15.46	35.70	20.24
24	3.17	3.96	1.87	3.66	.70	1.07	.70	.85	"	15.04	35.70	20.66
25	3.17	3.96	1.84	3.61	.68	1.04	.68	.82	"	14.93	36.00	21.07
26	3.17	3.96	1.82	3.57	.66	1.01	.66	.80	"	14.84	36.00	21.16

1/ 0.5 hour added to Phelps time study cutting time.
0.14 hour added to Phelps study skidding time.

2/ $3.00 hauling costs, $2.50 other fixed costs.

Table 14.--Residual Values for Average Quality Trees

DBH Class	End of Cycle: Curved cost/M	End of Cycle: Cost per tree	End of Cycle: Value per tree	End of Cycle: Residual per tree	Beginning of Cycle 1/: Cost per tree	Beginning of Cycle 1/: Residual per tree
Inches	Dollars					
10	31.52	.41	.33	-.08	.40	-.07
11	29.38	.76	.68	-.08	.74	-.06
12	27.28	1.25	1.18	-.07	1.21	-.03
13	25.30	1.77	1.80	+.03	1.70	+.10
14	23.40	2.29	2.68	+.39	2.20	.48
15	21.70	2.86	4.02	1.16	2.73	1.29
16	20.32	3.48	5.56	2.08	3.30	2.26
17	19.18	4.03	7.07	3.04	3.82	3.25
18	18.24	4.56	8.60	4.04	4.31	4.29
19	17.48	5.07	10.08	5.01	4.78	5.30
20	16.79	5.54	11.54	6.00	5.21	6.33
21	16.26	6.02	13.02	7.00	5.65	7.37
22	15.82	6.50	14.58	8.08	6.09	8.49
23	15.43	6.99	16.16	9.17	6.54	9.62
24	15.12	7.51	17.89	10.38	7.02	10.87
25	14.94	8.12	19.62	11.50	--	--
26	14.84	8.80	21.36	12.56	--	--

1/ $1.00 less fixed cost per M.

Table 15.--Residual Values of High Quality Trees

DBH Class	End of Cycle: Value per tree	End of Cycle: Cost per tree	End of Cycle: Residual per tree	Beginning of Cycle: Cost per tree	Beginning of Cycle: Residual per tree
Inches			Dollars		
10	.36	.41	-.05	.40	-.04
11	.68	.76	-.08	.74	-.06
12	1.20	1.25	-.05	1.21	-.01
13	2.20	1.77	+.43	1.70	+.50
14	4.30	2.29	2.01	2.20	2.10
15	6.80	2.86	3.94	2.73	4.07
16	9.25	3.48	5.77	3.30	5.95
17	11.65	4.03	7.62	3.82	7.83
18	13.95	4.56	9.39	4.31	9.64
19	16.25	5.07	11.18	4.78	11.47
20	18.50	5.54	12.96	5.21	13.29
21	20.80	6.02	14.78	5.65	15.15
22	23.10	6.50	16.60	6.09	17.01
23	25.50	6.99	18.51	6.54	18.96
24	28.00	7.51	20.49	7.02	20.98
25	30.60	8.12	22.48	--	--
26	33.35	8.80	24.55	--	--

Table 16.--Residual Value Growth for Average Quality Trees with Average Diameter Growth

DBH begin.	DBH end	Residual Value begin.	Residual Value end	Diff.	Interest Rate Compound %
Inches		Dollars			
10	12.90	-.07	0.0	--	--
11	13.85	-.06	+.33	.33	--
12	14.85	-.03	1.02	1.02	--
13	15.80	+.10	1.94	1.84	22
14	16.80	.48	2.86	2.38	12.75
15	17.75	1.29	3.76	2.47	7.5
16	18.70	2.26	4.70	2.44	5.0
17	19.70	3.25	5.69	2.44	3.8
18	20.65	4.29	6.67	2.38	3.0
19	21.62	5.30	7.70	2.40	2.55
20	22.60	6.33	8.75	2.42	2.25
21	23.55	7.37	9.82	2.45	2.0
22	24.55	8.49	10.95	2.46	1.8
23	25.50	9.62	12.04	2.42	1.5

Table 17.--Residual Value Growth for Average Quality Trees with Top Quartile Diameter Growth

DBH begin.	DBH end	Residual value begin.	Residual value end	Difference	Interest rate compound
Inches		Dollars			Percent
10	13.75	-.07	.28	.28	--
11	14.75	-.06	.95	.95	--
12	15.75	-.03	1.88	1.88	--
13	16.75	+.10	2.81	2.71	25.0
14	17.75	.48	3.76	3.28	14.8
15	18.75	1.29	4.75	3.46	9.05
16	19.75	2.26	5.75	3.49	6.5
17	20.75	3.25	6.76	3.51	5.0
18	21.75	4.29	7.83	3.54	4.1+
19	22.75	5.30	8.92	3.62	3.6
20	23.75	6.33	10.02	3.69	3.15
21	24.75	7.37	11.19	3.82	2.9
22	25.75	8.49	12.32	3.83	2.5

Table 18.--Residual Value Growth for High Quality Trees with Top Quartile Diameter Growth

DBH begin.	DBH end	Residual value begin.	Residual value end	Difference	Interest rate compound
Inches		Dollars			Percent
10	13.75	-.04	+1.70	1.70	--
11	14.75	-.06	3.50	3.50	--
12	15.75	-.01	5.29	5.29	--
13	16.75	+.50	7.05	6.55	19.3
14	17.75	2.25	8.85	6.60	9.55
15	18.75	4.07	10.65	6.58	6.6
16	19.75	5.95	12.47	6.52	5.05
17	20.75	7.83	14.27	6.44	4.1
18	21.75	9.64	16.12	6.48	3.5
19	22.75	11.47	18.04	6.57	3.05
20	23.75	13.29	20.00	6.71	2.8
21	24.75	15.15	22.00	6.85	2.5
22	25.75	17.01	24.05	7.04	2.4