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FOREWORD

MR. S. R. GEVORKIANTZ of the Lake States Forest Experiment Station has kindly reviewed this paper, and offered many helpful suggestions for improving it. Mr. Robert M. Borg assisted in collecting the field data.

INTRODUCTION

THAT some trees have very definite site preferences is a fact well known to foresters. Thus, hemlock *(Tsuga canadensis* Carr.) is ordinarily associated with sandy loam or loamy soils on cool, moist situations in the Lake States and Appalachian Mountain regions. Similarly, the mention of yellow poplar *(Liriodendron tulipifera* L.) almost always conjures up the vision of a deep, moist loam soil in the mountains or foothills of the eastern United States. At the opposite end of the scale are those species such as aspen *(Populus tremuloides)* which seemingly will grow anywhere. In the Hudson River Highland Region of New York State, red oak *(Quercus borealis* Michx.) and chestnut oak *(Quercus montana* Willd.) fall into this latter category.

So long as forest management consists only of protecting forest stands from fire and other natural enemies, the knowledge that some species are more exacting than others in their site requirements may find little practical application. However, when forestry passes from the protection stage into a production phase, such things as soil preferences, moisture requirements, response to exposure, etc., must be evaluated for each important species. Otherwise, it will not be possible to obtain the highest yields of wood.

On the Black Rock Forest, red oak and chestnut oak are found growing nearly everywhere on the 3100-acre tract including practically all cove situations (Tryon, 1930). Because of their common occurrence it becomes rather important to learn as much as possible about the site requirements of these two species. One of the first opportunities for collecting such information came more or less as a consequence of another study,—an investigation of the physical properties of the cove soils of the forest (Scholz, 1931).

METHOD OF COLLECTING AND ANALYZING FIELD DATA

Although field observations indicated that there were unmistakably some sites where red and chestnut oaks had made better-than-average growth, clear-cut differences which might be tied in directly with soil texture were not easy to see. Seemingly such factors as slope, exposure, elevation above the principal valleys, and the abundance and availability of moisture were combining to obscure the effect of soil texture upon the growth of these two oaks.

In order to obtain concrete information relative to the possible effect of soil texture upon the rate of growth of red and chestnut oaks, sample plots $\frac{1}{25}$ acre in size were taken at the location of each soil profile. The soil wells or profiles were used as plot centers. In all, 134 plots were examined.

On these plots, a complete tally was made by species and 1-inch diameter classes of all forest trees. Seedlings or sprouts less than 0.5 inch in diameter at breast height (4.5 feet above the average ground line) were tallied as reproduction. In addition, the total age at breast height, average bark thickness at the same point, and total height were determined for all red and chestnut oak 1.6 inches in diameter or larger. Diameters of sample trees were measured with a steel diameter tape; ages were determined by means of a Swedish increment borer; and heights were obtained with a Klaussner hypsometer.[2]

Site quality can be appraised quite conveniently in fully stocked, even-aged stands by the use of yield tables. When, however, it becomes necessary to compare, plot-by-plot, the rate of growth of one or two tree species occurring as a mixture in all-aged stands of variable density, the problem of correlating growth with site becomes more difficult.

Before attempting such a correlation for red and chestnut oaks, it was first necessary to develop some sort of a rejection scheme to eliminate badly suppressed and "wolf" trees, a step obligated by the failure to reject these trees in the field. Obviously, the effect of some physical factor of site, such as soil texture, might be badly obscured or lost entirely if a tree received only enough light and moisture to keep it alive. Similarly, a "wolf" tree which receives a superabundance of light and water is not likely to reflect average growth conditions for that particular plot.

All subnormal and abnormal trees were rejected upon the basis of growth deficiencies or excesses as compared to "average" red and chestnut oaks on the plot. The growth index was expressed as a ratio by the formula $\frac{HD^2}{A}$, where H is the total height of the tree in feet, D is the diameter of the tree outside bark at breast height, and A is the age at breast height. This ratio is an approxi-

[1] Associate Silviculturist, Lake States Forest Experiment Station, U. S. Department of Agriculture. Data for this paper was collected in 1930-31 while the author was a student at Harvard Forest.

[2] See Black Rock Forest Paper, Vol. 1, No. 8. "Diameter Outside Bark as an Index of Bark Thickness at Breast Height for Red and Chestnut Oak."

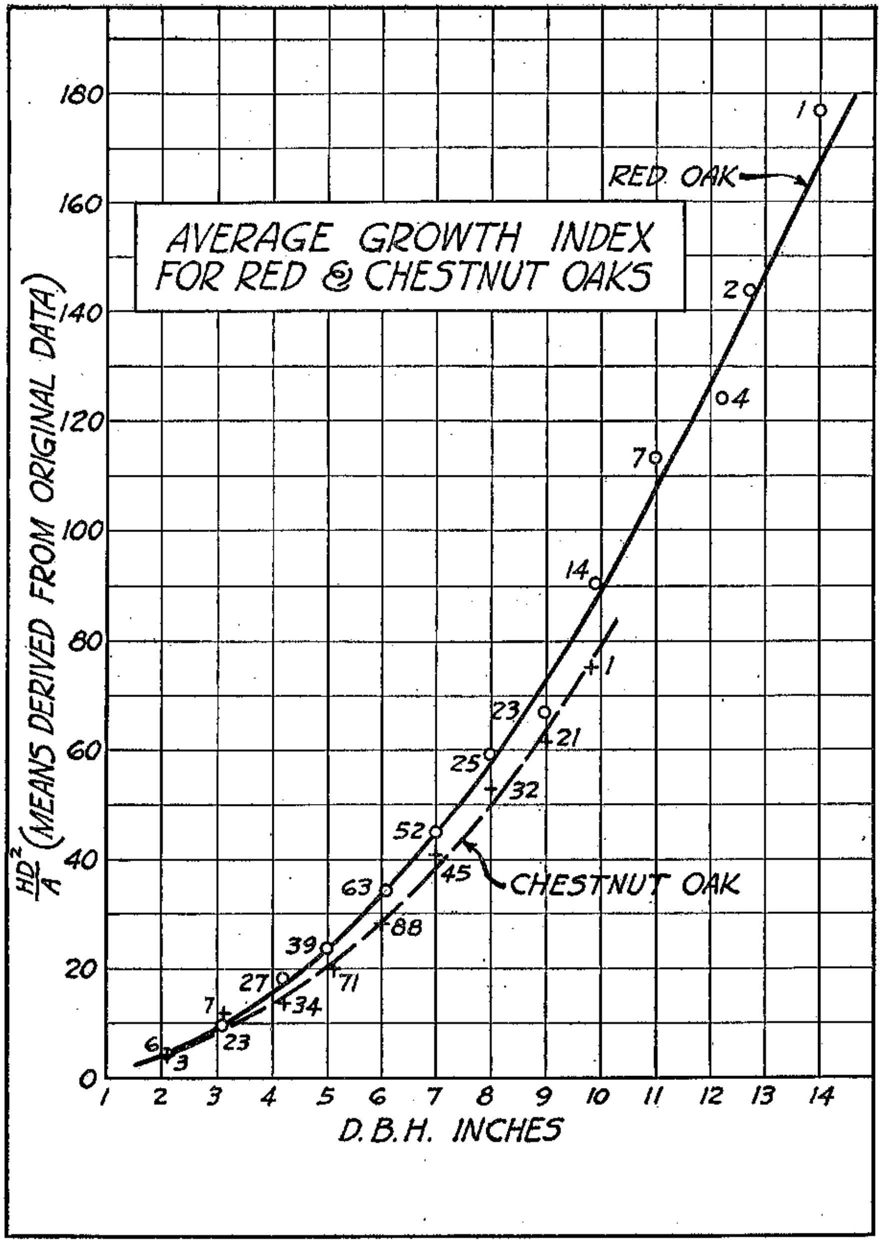

FIG. 1

mate expression of the mean annual growth. For a tree of any given d.b.h., the ratio is high if either H is high or A is low.

Such ratios were calculated for the red and chestnut oaks on 134 $\frac{1}{25}$-acre sample plots. Any tree having a growth index ratio which deviated from the average ratio for a set [3] of plots by more than one deviate (standard deviation) was rejected. By actual numbers, 116 out of a total of 402 red oak were eliminated, and 135 out of a total of 437 chestnut oak, or 29 and 31 per cent respectively.

It is recognized that this rejection plan is not foolproof. For example, it tends to eliminate large dominants which in reality are not wolf trees, and is inclined to over-rate the site for extremely young, fast-growing trees occurring in mixture with somewhat larger though much older individuals. Early suppression, followed by subsequent release and rapid growth of a tree, might also pull down the $\frac{HD^2}{A}$ ratio and make it appear the site was poorer than was actually the case. Still another source of error is the assumption, made on the basis of field observations, that the form of red and chestnut oaks is unaffected by soil texture. However, on the whole, the above scheme worked out very satisfactorily.

There was some question as to whether the density of the stand might not affect the $\frac{HD^2}{A}$ values of unrejected red and chestnut oaks. An analysis of the available data failed to show any relaship whatever between the total basal area of a plot and poorer or better-than-average growth of sample trees.

An examination of sample plot compilations brought out the fact that for a given diameter, the volume of the oaks (red and chestnut) was much greater for some trees than others. In order to obtain some mathematical expression of this variation, all sample trees were grouped and averaged by diameter classes and species. The means of $\frac{HD^2}{A}$ were then curved over d.b.h., o.b. (Figure 1), and a new (average) set of these values were read from the curves. By dividing the $\frac{HD^2}{A}$'s for individual trees by the corresponding curve $\frac{HD^2}{A}$'s, each red and chestnut oak was rated. Thus, a tree which had a growth index equal to the mean was rated at 1.0. A ratio of less than 1.0 showed that the tree had made less than average growth while a ratio of more than 1.0 indicated superiority in this respect. When traced back to individual trees, low ratios were found to be a result of height deficiencies or excessive age. Conversely, those trees which had made the most rapid height growth, or were younger than average, gave the highest ratios.

THE RELATIONSHIP OF GROWTH RATE TO SOIL TEXTURE

In nature, chance plays an important role. Thus, an exact duplication of the number of trees per acre, identical growth of sample trees, proportional occurrence of the species comprising a mixed stand, etc., is rarely met with on two forest areas even though they may be very close together. When, therefore, it becomes necessary to draw some conclusions regarding the effect of such fac-

[3] A set of plots of three (in one instance, two) 1/25-acre samples taken within an area of 0.04 to 0.58 acre.

tors as soil upon tree growth, this variability must be analyzed carefully. Failure to do so may result in erroneous deductions of cause and effect.

There are several ways in which a group of data can be analyzed to determine whether any significant relationship exists between one factor and another. One such method is known as an Analysis of Variance and it is particularly well suited for problems of a biological nature. Its application to a study of the relationship of the growth of red and chestnut oak to soil texture is herewith presented (Tables 1, 2, and 3).

In these tables, each sample tree has been assigned a place depending upon its growth index ratio and the soil type upon which it grew. Thus at a glance, the association between soil texture and growth may be observed. For example, Table 1 shows 67 trees on clay loam have a growth index ratio of 1.0 or larger and 49 trees have a ratio of 0.99 or smaller, whereas on clay the trends are strongly reversed. A similar relationship will be observed for Tables 2 and 3.

That better growth has been made on some soil texture types than on others is also brought out by these tables. The so-called X's values are nothing more than weighed, average residuals, and indicate whether sample trees have grown fastest on clay loam, heavy clay loam, or clay soils. Here again, it will be noted that both red

TABLE 1

Distribution of Red and Chestnut Oak Sample Trees by Soil Texture Types and Growth-Index Ratios.

Ratio [1] (Class Interval)	SOIL TYPE			
	Clay Loam	"Heavy" Clay Loam [2]	Clay	Total
	(Number of Trees)			
0.40—0.49 ...	..	4	...	4
0.50—0.59 ...	..	15	9	24
0.60—0.69 ...	2	21	29	52
0.70—0.79 ...	4	29	18	51
0.80—0.89 ...	12	30	19	61
0.90—0.99 ...	31	54	21	106
1.00—1.09 ...	26	62	6	94
1.10—1.19 ...	20	52	11	83
1.20—1.29 ...	16	30	4	50
1.30—1.39 ...	2	18	3	23
1.40—1.49 ...	2	8	..	10
1.50—1.59 ...	1	7	..	8
1.60—1.69 ...	..	2	..	2
1.70—1.79 ...	..	4	..	4
1.80—1.89 ...	..	1	..	1
1.90—1.99 ...	..	1	..	1
2.00—2.09 ...	..	1	..	1
2.10—2.19 ...	..	1	..	1
2.20—2.29 ...	..	1	..	1
X's ...	0.9655	0.8211	-1.0500	0.4610

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Variance [3]	Value of Z	
				Computed	Table 1%
Between soil types	347.72	2	173.9	1.67	0.7636
Within soil types	3497.65	574	6.1		
Total	3845.37	576			

[1] Ratio of actual $(\frac{HD^2}{A}a)$ to the mean $(\frac{HD^2}{A}c)$ growth index.

[2] Contains 25-30 per cent clay (material less than 0.005 millimeter in diameter). Clay loam contains 20-25 per cent of the clay fraction.

[3] The mean variance in this case is expressed in relative units. To convert to actual units of growth index multiply 173.9 and 6.1 by 0.01.

TABLE 2

Distribution of Red Oak Sample Trees by Soil Texture Types and Growth-Index Ratios.

Ratio [1] (Class Interval)	SOIL TYPE			
	Clay Loam	"Heavy" Clay Loam [2]	Clay	Total
	(Number of Trees)			
0.40—0.49 ...	..	3	..	3
0.50—0.59 ...	..	3	6	9
0.60—0.69 ...	2	8	13	23
0.70—0.79 ...	..	13	9	22
0.80—0.89 ...	6	20	9	35
0.90—0.99 ...	8	28	11	47
1.00—1.09 ...	11	35	4	50
1.10—1.19 ...	3	30	7	40
1.20—1.29 ...	7	14	2	23
1.30—1.39 ...	1	11	3	15
1.40—1.49 ...	1	3	..	4
1.50—1.59 ...	1	2	..	3
1.60—1.69 ...	..	1	..	1
1.70—1.79 ...	..	2	..	2
1.80—1.89 ...	..	..	..	..
1.90—1.99 ...	..	1	..	1
2.00—2.09 ...	..	1	..	1
2.10—2.19 ...	..	..	..	..
2.20—2.29 ...	..	1	..	1
X's ...	0.0250	-0.0454	-1.8438	-0.446

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Variance [3]	Value of Z	
				Computed	Table 1%
Between soil types	162.20	2	81.10	1.28	0.7636
Within soil types	1733.05	277	6.30		
Total	1895.25	279			

[1] Ratio of actual $(\frac{HD^2}{A}a)$ to the mean $(\frac{HD^2}{A}c)$ growth index.

[2] Contains 25-30 per cent clay (material less than 0.005 millimeter in diameter). Clay loam contains 20-25 per cent of the clay fraction.

[3] The mean variance in this case is expressed in relative units. To convert to actual units of growth index multiply 81.10 and 6.30 by 0.01.

and chestnut oaks have made the best average growth on the soils having the lowest clay content.

In order to determine whether or not the differences between these means are significant or simply variations within a single universe, the data from Tables 1, 2, and 3 have been analyzed by one of the adaptations of the so-called Z-test (Tippett, 1931).

Since the computed values for Z exceed 0.7636, the 1-per cent level, by 1.7 to 2.2 times, not only must we conclude that the growth of red and chestnut oak sample trees has been more rapid on clay loams than on either heavy clay loam or clay, but also that these differences on the average are highly significant despite the large variation observed among individual trees.

TABLE 3

Distribution of Chestnut Oak Sample Trees by Soil Texture Types and Growth-Index Ratios.

Ratio [1] (Class Interval)	SOIL TYPE			
	Clay Loam	"Heavy" Clay Loam [2]	Clay	Total
	(Number of Trees)			
0.40—0.49 ...	..	1	..	1
0.50—0.59 ...	..	12	3	15
0.60—0.69 ...	..	13	16	29
0.70—0.79 ...	4	16	9	29
0.80—0.89 ...	6	10	10	26
0.90—0.99 ...	23	26	10	59
1.00—1.09 ...	15	27	2	44
1.10—1.19 ...	17	22	4	43
1.20—1.29 ...	9	16	2	27
1.30—1.39 ...	1	7	..	8
1.40—1.49 ...	1	5	..	6
1.50—1.59 ...	..	5	..	5
1.60—1.69 ...	..	1	..	1
1.70—1.79 ...	..	2	..	2
1.80—1.89 ...	..	1	..	1
1.90—1.99 ...	..	..	..	..
2.00—2.09 ...	..	..	..	..
2.10—2.19 ...	..	1	..	1
2.20—2.29 ...	..	..	..	..
X's ...	0.9342	0.6788	–1.2857	0.372

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Variance [3]	Value of Z	
				Computed	Table 1%
Between soil types	193.64	2	96.82	1.39	0.7636
Within soil types	1770.07	294	6.0		
Total	1963.71	296			

[1] Ratio of actual ($\frac{HD^2}{A}$ a) to the mean ($\frac{HD^2}{A}$ c) growth index.

[2] Contains 25-30 per cent clay (material less than 0.005 millimeter in diameter). Clay loam contains 20-25 per cent of the clay fraction.

[3] The mean variance in this case is expressed in relative uits. To convert to actual units of growth index multiply 96.82 and 6.0 by 0.01.

DISCUSSION OF RESULTS

Although the association between the growth index ratio and soil texture is strongly significant, the correlation, as shown by the scatter of the values within a soil texture class, is not high. The prediction of growth index ratio upon the basis of soil texture therefore would not be possible.

There are several explanations for this lack of correlation. For one thing, two areas having soil of the same mechanical composition may be very much different in respect to other physical factors of site such as exposure, slope, depth of forest floor, moisture content of the profile, etc. Naturally, these things affect the rate at which the forest grows.

In the second place, the growing stock on the Black Rock Forest does not all have the same origin. Most of the trees have developed from sprouts; a far smaller number have sprung from seedlings. Because of the long duration of coppicing (Revolutionary War days down to the present), the trees originating from sprouts have, by and large, less vigor than those trees owing their origin to seedlings. This means, of course, that on a given site some red and chestnut oak are inherently more vigorous than others. The various other factors which tend to lower the correlation between the growth index ratio of sample trees and soil texture are disregarded in this paper.

It is believed that by establishing the fact that the rate of growth of red and chestnut oak is significantly different on the several soil texture types, substantial progress has been made toward sounder forest management. However, before the final answer can be furnished to the question, "What is the Ideal Red and Chestnut Oak Site?," studies must be made of the other important chemical-physical properties responsible for growth.

In carrying on these investigations, the forest stands on clay loam should be recognized as different from those stands growing on heavy clay loam, or clay.

SUMMARY

1. Red and chestnut oak on the Black Rock Forest cove areas have made more rapid growth on clay loam than on heavy clay loam or clay soils. These differences in growth were proven highly significant by statistical methods.

2. By showing that a definite and significant relationship exists between the growth index ratio of red and chestnut oak and soil texture types, the way has been cleared for more detailed and exhaustive studies of the factors of site.

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