Distribution of DIAMETER GROWTH RATES & CLEAR STEM LENGTHS *as a Basis for Selecting* SUPERIOR PHENOTYPES

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THE FIRST STEP in obtaining stock for developing seed orchards of superior genotypes is to select superior phenotypes, or plus trees. These plus trees may be chosen for their superiority in a single characteristic, or for their high ratings in a combination of characteristics.

A candidate plus tree is usually chosen tentatively for the good appearance of its features of interest. It is carefully measured for these features. After that, a number of nearby trees of the same species, age, and crown class—usually three to five if available—are measured and compared to the candidate tree. If the candidate tree rates sufficiently better than the comparison trees, then it is classed as a superior phenotype, acceptable for inclusion in the tree-selection program.

There are a number of variations to this procedure, which range from simply selecting trees that look good to methods that include weighing a large number of features desired in a tree and rating the candidate tree against the weighted measurements from several comparison trees. The cost of selecting plus trees goes up as the number of measured characteristics increases and in proportion to the number of comparison trees used. But aside from its cost, the system of using comparison trees involves another serious drawback. If there are no suitable comparison trees nearby, as is often the case, there is no yardstick for judging the candidate tree; and thus superior trees may be passed up.

If we knew how the features of interest were distributed in the tree population, we could set any level we wished as the criterion for a plus tree without the need to measure comparison trees. For example, if we were interested in high diameter growth rates, we could select trees with growth rates in the upper percentiles of the distribution for a given site index.

Other desirable characteristics could be considered in the same way; however, when we select for more than one characteristic, we must consider the joint distribution of the variables in the tree population. For instance, this paper presents the joint distribution of diameter growth and length of clear stem for northern red oak (*Quercus rubra* L.). These data could be used in an actual tree-selection program for this species.

GROWTH RATES

Not only is fast diameter growth desirable, but also there is reason to believe that increased growth in red oak can be effected through selective intraspecific breeding.[1]

The distribution of d.b.h. growth rates (i.b.) was based on 292 sample trees measured in a site study (*Trimble and Weitzman 1956*) made in even-aged, unmanaged, well-stocked stands in north-central West Virginia and western Maryland. These trees were of dominant and codominant crown classes—the classes from which plus trees are customarily selected—and were stratified by oak site-index classes (*Schnur 1937*). The trees included in the growth distribution were restricted to between 40 and 70 years of age because: (1) within this range in red oak, age probably has little effect on d.b.h. growth rates; (2) site differences are clearly expressed; and (3) the point at which the clear stem breaks up into the crown is well established (*Trimble and Weitzman 1956*).

Ten-year diameter growth rates, measured on increment-borer cores to the nearest even 1/10 inch, were chosen as criteria rather than 20-year rates or average growth over the tree's age, because it was thought that the shorter-growth period better reflected tree and stand conditions at the time of tree selection.

The distribution of diameter growth rates is given by 10-foot site-index classes: 60—a fair site (table 1); 70—a good site

[1] Schreiner, Ernst J. Forest Tree Improvement Research. Unpublished problem analysis, Northeastern Forest Experiment Station.

Table 1. — Number of trees by diameter growth rate and length of clear stem; northern red oak, site index 60

Clear stem length (feet)	10-year d.b.h. growth (i.b.), in inches										Total	
	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	Frequency	Percentile
13	—	—	—	—	—	—	1	—	—	—	1	1.8
16	—	—	—	—	—	—	—	1	—	—	1	3.6
18	—	—	—	1	—	—	—	—	—	—	1	5.4
21	—	—	—	1	1	—	—	—	—	—	2	8.9
22	—	—	—	1	—	1	—	—	1	1	4	16.1
23	—	—	1	—	—	—	—	—	—	—	1	17.9
24	—	1	—	—	1	—	1	—	—	—	3	23.2
25	1	—	—	1	—	1	—	1	—	—	4	30.4
26	—	—	1	2	—	—	—	—	—	—	3	35.7
27	1	—	—	—	—	—	—	—	1	—	2	39.3
28	—	1	—	1	1	—	—	1	1	—	5	48.2
29	—	—	—	—	—	1	—	—	—	—	1	50.0
30	—	—	—	1	—	1	2	—	1	—	5	58.9
31	—	—	—	—	1	1	—	—	—	1	3	64.3
32	1	—	2	—	—	2	—	—	—	2	7	76.8
33	—	1	1	—	—	—	—	—	—	—	2	80.4
34	—	—	—	—	—	1	—	—	—	—	1	82.1
35	1	—	—	—	—	1	—	1	—	—	3	87.5
36	—	—	1	—	—	—	—	—	—	—	1	89.3
37	—	—	—	1	—	—	—	—	—	1	2	92.4
38	1	—	—	2	—	—	—	—	—	—	3	98.2
39	—	—	—	—	—	—	1	—	—	—	1	100.0
Frequency	5	3	6	11	4	9	5	4	4	5	56 trees	
Percentile	8.9	14.3	25.0	44.6	51.8	67.9	76.8	83.9	91.1	100.0	100 percent	
Average clear stem length (feet)	31.4	28.3	30.3	28.1	26.0	33.8	21.0	26.0	26.8	30.8	—	—

(table 2); and 80—an excellent site (table 3). Essentially these three classes cover the site range in which red oak is an important component of forest stands.

Matching the 10-year diameter growth rates with the percentile provides values for the acceptance of plus trees. For example, if only trees growing in the upper 10 percent of the range are acceptable, then the following rates would qualify: site index 60—over 2.6 inches in 10 years; site index 70—over 2.8 inches; and site index 80—over 3.2 inches.

LENGTH OF CLEAR STEM

Length of clear stem, determined by the point at which the crown begins, is measured from the ground line on the uphill side to this point. As stated previously, this point is permanently established for red oak by the time trees are 40 years old. Distributions of clear-stem lengths have been computed for oak site-index classes 60, 70, and 80 (tables 1, 2, 3).

As with diameter growth rates, matching lengths of clear stem with percentiles provides values for acceptance of plus trees. If only trees with clear stem lengths in the upper third of the range are acceptable, the following lengths would qualify: site index 60—over 31 feet; site index 70—over 32 feet; and site index 80—over 40 feet.

Because the distribution of sample-tree clear lengths is not proportional by site classes,[2] it might be desirable to make an adjustment. For example, set the acceptable length for site index 60 a little lower than 31 feet and the level for site index 70 a little higher than 32 feet. The important point is not the exact level at which to set acceptability, but that these arrays, measured on definite tree classes, offer a means of estimating the relative superiority of one tree over another in terms of clear stem length.

[2] Part of the reason for this is that the sampling by site classes was skewed: for the site index 60 range the average was 61; for the 70 range it was 69; and for the 80 range it was 80. In other words, the spread between site index classes 60 and 70 was 8 feet and between 70 and 80 it was 11 feet.

Table 2. — Number of trees by diameter growth rates and length of clear stem; northern red oak, site index 70

Clear stem length (feet)	10-year d.b.h. growth (i.b.) in inches																	Total	
	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	4.2	4.4	Frequency	Percentile
13	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0.8
16	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	1.6
19	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1	2.4
20	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	3.1
21	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	3.9
22	—	1	—	1	—	—	2	2	—	—	—	—	—	1	—	—	1	8	10.2
23	—	—	1	1	1	—	1	1	—	—	—	1	—	—	—	—	—	6	15.0
24	—	—	—	2	—	2	—	—	1	—	1	—	—	—	—	—	—	6	19.7
25	—	—	—	—	—	—	—	1	—	1	1	—	—	—	1	—	—	4	22.8
26	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	2	24.4
27	—	—	—	—	1	2	1	1	1	—	1	—	—	—	—	—	—	7	29.9
28	—	—	1	—	1	—	3	1	3	1	—	1	—	—	—	—	—	11	38.6
29	—	—	—	1	—	2	—	—	1	1	1	1	—	—	—	1	—	8	44.9
30	—	—	—	2	—	1	1	—	1	—	—	—	—	—	—	—	—	5	48.8
31	—	—	1	2	1	1	—	1	—	1	—	—	—	—	—	—	—	7	54.3
32	—	—	—	—	2	—	3	3	1	—	—	—	1	—	—	—	—	10	62.2
33	2	—	—	1	1	1	1	1	—	1	—	1	—	—	—	—	—	9	69.3
34	—	—	1	1	2	2	—	1	2	—	—	—	—	—	1	—	—	10	77.2
35	—	—	—	—	—	1	1	—	1	1	1	—	—	—	—	—	—	5	81.1
36	—	—	1	1	2	1	1	—	—	—	—	—	—	—	—	—	—	6	85.8
37	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	3	88.2
38	—	—	—	1	1	—	—	1	—	—	—	—	—	—	—	—	—	3	90.6
39	—	—	—	1	—	—	1	—	—	—	1	—	—	—	—	—	—	3	92.9
40	—	—	—	—	1	—	1	—	—	—	1	—	—	—	—	—	—	3	95.3
41	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	2	96.8
42	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	97.6
43	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	98.4
44	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	99.2
46	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	100.0
Frequency	2	2	5	15	15	16	19	15	13	6	8	4	1	2	2	1	1	127 trees	
Percentile	1.6	3.1	7.1	18.9	30.7	43.3	58.3	70.1	80.3	85.0	91.3	94.5	95.3	96.8	98.4	99.2	100.0	100 percent	
Average clear stem length (feet)	33.0	33.0	30.4	29.1	32.4	31.8	30.3	28.0	31.8	30.2	29.8	28.2	32.0	31.5	29.5	29.0	22.0	—	—

Table 3. — Number of trees by diameter growth rate and length of clear stem; northern red oak, site index 80

Clear stem length (feet)	10-year d.b.h. growth (i.b.), in inches																Total	
	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	Frequency	Percentile
24	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0.9
25	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	2	2.8
26	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1	3.7
27	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	4.6
28	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	5.5
29	—	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	2	7.3
30	—	—	—	—	—	1	1	—	1	—	—	—	—	—	—	—	3	10.1
31	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	—	2	11.9
32	—	—	1	1	1	2	3	2	—	2	—	—	—	—	—	—	12	22.9
33	—	—	—	—	2	—	1	—	1	—	—	—	—	—	—	—	4	26.6
34	—	—	—	1	—	—	—	1	—	1	1	—	—	—	—	—	4	30.3
35	—	—	1	—	—	—	—	1	1	—	—	—	—	1	—	—	4	33.9
36	—	—	1	—	—	1	—	2	2	—	—	—	—	—	—	—	6	39.4
37	—	—	—	1	—	—	1	1	1	1	1	1	—	—	—	—	7	45.9
38	—	—	—	1	—	—	1	—	1	—	—	—	1	—	1	—	5	50.5
39	—	—	—	—	—	—	—	1	1	4	—	—	—	—	—	—	6	56.0
40	1	—	—	2	—	—	2	—	—	—	1	—	—	1	1	—	8	63.3
41	1	—	—	2	—	—	—	1	—	—	—	—	—	—	1	—	5	67.9
42	—	—	—	2	1	1	—	2	2	—	—	—	—	—	—	—	8	75.2
43	—	—	—	—	—	2	1	—	—	1	—	—	1	—	—	—	5	79.8
44	—	—	1	—	—	—	1	1	—	—	—	—	—	—	—	—	3	82.6
45	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	2	84.4
46	—	—	1	1	—	1	—	1	1	—	1	1	—	—	—	—	7	90.8
47	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—	2	92.7
48	—	—	—	—	—	—	1	—	—	—	—	—	1	1	—	—	3	95.4
49	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	2	97.2
52	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1	98.2
54	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	99.1
60	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	100.0
Frequency	3	1	7	13	5	11	13	14	11	12	5	3	3	4	3	1	109 trees	
Percentile	2.8	3.7	10.1	22.0	26.6	36.7	48.6	61.5	71.6	82.6	87.2	89.9	92.7	96.3	99.1	100.0	100 percent	
Average clear stem length (feet)	36.0	47.0	38.7	41.7	37.8	37.5	36.5	37.2	37.6	37.9	37.0	38.0	43.0	38.0	39.7	45.0	—	—

OTHER TREE FEATURES OF INTEREST IN A TREE SELECTION PROGRAM

We will not attempt to cover all the tree features that might be considered in a plus-tree selection program, but we will discuss some quality factors pertinent to red oak.

First, we suggest that an acceptance level for sweep or crook in the butt log be set somewhere below 15 percent. Fifteen percent is the maximum allowed for a grade-1 log (*Ostrander and others 1965*).

Second, we suggest that grade factors other than sweep and crook be recognized. Serious consideration should be given to discarding trees with an unusual number of dormant bud clusters, epicormic branches, and/or a profusion of slow-healing branch scars. The following publications should be studied before threshold levels are set for the acceptance of log-quality features: (1) A GUIDE TO HARDWOOD LOG GRADING (*Ostrander and others 1965*), (2) POTENTIAL TREE GRADE OF YOUNG RED OAKS GROWING IN EVEN-AGED STANDS (*Ward 1964*), and (3) PROVISIONAL GRADE SPECIFICATIONS FOR HARDWOOD GROWING-STOCK TREES (*Boyce and Carpenter 1968*).

DISCUSSION

Selection for one feature may be incompatible with selection for other desirable features. This is true of some species in selection for length of clear stem and diameter growth rate.

Trees with long clear stems and short crowns tend to grow slower than trees of the same size that have shorter stems and longer crowns. Holsoe (*1950*), finding this to be true of yellow-poplar (*Liriodendron tulipifera* L.), recommended growing relatively short-boled, long-crowned trees.

But the crown form of red oak is different from that of yellow-poplar. Red oak has a deliquescent form: yellow-poplar has an excurrent form.

To determine the effect of the crown ratio for red oak, correlation coefficients were calculated for the relationship between length of clear bole and d.b.h. growth. The correlation coefficients were negative, but close to zero and nonsignificant. Scatter diagrams (tables 1, 2, and 3) indicate that d.b.h. growth is independent of the length of clear bole.

However, imposing clear-length restrictions onto diameter growth limitations does reduce the number of plus trees that will be chosen. The probability that a tree is a plus tree in both diameter growth and length of clear bole is equal to the product of probabilities of each of the plus classes.

Thus, if we wanted plus trees to be in the upper 10 percent for diameter growth and the upper 30 percent for clear length, we would expect 3 out of 100 trees to qualify.

Table 4 (using data from tables 1, 2, and 3) shows the number and percentage of trees within diameter-growth classes, by clear-stem percentiles. The percentages give estimates of the probabilities of finding plus trees in the given percentiles of both characteristics. In areas of site index 60, for example, we would expect to find about two trees per hundred with a 10-year d.b.h. growth rate over 2.6 inches and a clear bole length over 36 feet.

Restrictions on other factors will further reduce the chances of finding acceptable plus trees. In designing a plus-tree selection program, keep this fact clearly in mind and be careful in determining the primary selection objective. You should set levels of acceptance for less important variables that do not too drastically curtail the chances of finding plus trees, yet the thresholds must be high enough so that trees with poor heritable characteristics are not selected.

In a red oak selection program aimed primarily at developing improved veneer and sawlog trees, growth rate is of primary importance, and upper logs are of minor economic value.

The main interest in clear length should be to select trees with above-average clear bole length for the site. To meet the objective, acceptable values of growth might be set between the 80 and 90 percentiles, and thresholds for length of clear stem might be set between the 50 and 65 percentiles. Thresholds for other features should be treated accordingly.

Success in the use of this method of selecting plus trees depends

Table 4. — Number and percent of red oak trees by clear-stem percentiles within two diameter-growth classes on three sites

Percentile (and clear stem length)	10-year d.b.h. growth (i.b.)			
	Number of trees	*Percent of total*	*Number of trees*	*Percent of total*
	SITE INDEX 60			
	Over 2.6 inches		*Over 2.4 inches*	
Upper 10 (over 36 feet)	1	1.8	1	1.8
Upper 20 (over 33 feet)	1	1.8	1	1.8
Upper 35 (over 31 feet)	3	5.4	3	5.4
Upper 50 (over 28 feet)	4	7.1	5	8.9
Upper 100 (all lengths)	5	8.9	9	16.1
	SITE INDEX 70			
	Over 2.8 inches		*Over 2.6 inches*	
Upper 10 (over 38 feet)	1	0.7	3	2.4
Upper 20 (over 35 feet)	1	.7	3	2.4
Upper 35 (over 32 feet)	3	2.4	6	4.7
Upper 50 (over 30 feet)	4	3.1	7	5.5
Upper 100 (all lengths)	11	8.7	19	15.0
	SITE INDEX 80			
	Over 3.2 inches		*Over 2.8 inches*	
Upper 10 (over 46 feet)	2	1.8	2	1.8
Upper 20 (over 43 feet)	3	2.8	5	4.6
Upper 35 (over 40 feet)	5	4.6	7	6.4
Upper 50 (over 38 feet)	7	6.4	10	9.2
Upper 100 (all lengths)	11	10.1	19	17.4

upon reasonably accurate recognition of site quality. Unfortunately, such recognition is not uniformly feasible. For oak, in many locations, site studies have been used to develop methods of determining site index that depend on measurable soil and topographic features. While this same situation exists for some other important species and locations, there are many situations for which no soil-site data are available. And in some instances, where such data are available, the measurement of the prediction variables is so time-consuming and difficult that the advantages of using the procedure described in this paper are nullified.

In areas where the species involved is a frequent component of the forest stands, enough suitable trees are usually available near the candidate tree to determine an average site index from height-over-age relationships. Also, where site quality is relatively uniform over wide areas, such as in flat regions with similar soil conditions, site-index determinations made on a group of suitable trees may be extrapolated over long distances.

The following cases, and combinations of them, represent the most difficult situations for determination of site index: (1) areas where site changes are frequent and large; (2) areas and species for which soil-site information is not available or is difficult to apply; (3) stands in which the species of interest are widely scattered; and (4) where the personnel assigned to this work are not experienced in the area, with the species, nor in site determination.

Plus-tree selection is a first step in one type of tree-improvement program. The trees selected are phenotypes. The real test of heritable traits comes when the progeny are compared. For many species, the frequency distribution of the characteristics of interest may be available or easily collected. If so, and if problems of site quality determination can be resolved, the data should be used in selecting plus trees.

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