VARIATION IN HEIGHT GROWTH AND FLUSHING OF NORTHERN RED OAK (*QUERCUS* RUBRA L.)

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Abstract.--Forty-nine five-year-old Northern red oak open-pollinated families from six geographic sources were used to derive heritability estimates for height growth and date of bud break. Response to nitrogen fertilizer was positive for total height and number of flushes. Progenies from more southerly sources leafed out earlier than those of more northerly origin.

Additional keywords: Nitrogen, maternal effects, bud break, heritability, provenance, gain.

Although Northern red oak (*Quercus rubra* L.) is a fast-growing and desirable species, slow early growth has been a problem in artificial regeneration of the species. Kriebel and Thielges (1969) reviewed the literature on genetic work with Northern red oak and concluded that little information was available. Still, no published estimates of heritabilities have been presented.

Northern red oak has been shown to respond to application of nitrogen fertilizer (Farmer et al., 1970; Foster and Farmer, 1970), except when natural soil nitrogen is high (McComb, 1949). Date of bud break of Northern red oak progenies (McGee, 1970) is related to the altitude of the mother trees. Zasada and Zahner (1970) report that date of bud break is related to stage of vessel development in Northern red oak, so the variation in date of bud break associated with genetic and environmental factors may affect wood properties such as specific gravity.

This paper is a preliminary report on an experiment established by the Tennessee Valley Authority to determine inheritance patterns for, and the effect of fertilizer on, selected growth characteristics, such as height and date of bud break, in Northern red oak.

METHODS

Acorn collections in 1966 resulted in forty-nine open-pollinated families from six forest stands, or sources (Table 1). Seedlings were grown in three replications in the nursery for one year before outplanting on Jones Island in the Clinch River near Oak Ridge, Tennessee at a latitude of 35° 54' N. and an elevation of 760 feet. The soil was a very fine sandy loam, and the ground cover Kentucky 31 Tall Fescue, which was mowed periodically.

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Table 1.--Locations of seed sources, numbers of families from each, latitude, longitude and elevation in feet.

Source	No. of Families	Latitude	Longitude	Elevation
Ohio	8	40° 45'	81° 55'	960
Western Kentucky	5	36° 49'	88° 2'	500
Norris Lake	11	36° 20'	83° 57'	1300
Norris Dam	10	36° 12'	84° 5'	1100
Cumberland Plateau	10	35° 44'	85° 22'	1200
North Alabama	5	34° 31'	86° 57'	550

Twelve-seedling family plots were established in seven blocks. Half-sib families were randomized within each source, and sources were randomized within each block. Each plot consisted of two rows of six trees each, with nine feet between rows and four feet between trees within rows.

In May, 1971, six of these blocks were regrouped into three replications, each containing two blocks. One block in each of the three replications was selected at random and treated with 220 lbs. of nitrogen per acre by the application of 0.22 lbs. of ammonium nitrate per tree in a two-foot-diameter circle.

In 1970, 1971 and 1972, the first, third and fifth seedlings in each family plot were measured. Date of bud break was determined, as well as the number of flushes during each growing season. In addition, total heights of all seedlings were measured in 1968, 1969, 1970 and 1972.

The data were analyzed using a compact family block design, as described by Panse and Sukhatme (1954). This analysis was used because of time limitations; a more complex combined analysis will be conducted to obtain better heritability estimates.

The following model was used to analyze variation among sources:

Source	d.f.	EMS
Blocks	b-1	$\sigma^2_{BS} + s\sigma^2_B$
Sources	s-1	$\sigma^2_{BS} + b\sigma^2_S$
Blocks x Sources	(b-1)(s-1)	σ^2_{BS}

The following model was used to determine within source variation:

Source	d.f.	EMS
Blocks	b-1	$\sigma_W^2 + w\sigma_{BF}^2 + wf\sigma_B^2$
Families	f-1	$\sigma_W^2 + w\sigma_{BF}^2 + wb\sigma_F^2$
Blocks x Families	(b-1)(f-1)	$\sigma_W^2 + w\sigma_{BF}^2$
Within Plot	bf(w-1)	σ_W^2

The genetic component estimated was assumed, as in Namkoong et al., (1965), to represent $\sigma_A^2 + {}_2\sigma_{AE}^2$, where σ_A^2 is the causal component due to additive inheritance and σ_{AE}^2 is that due to the interaction of additive inheritance with the environment. The estimates of heritability were computed in the following way:

$$h^2 = \frac{4\sigma_F^2}{\sigma_W^2 + \sigma_{BF}^2 + \sigma_F^2}.$$

RESULTS

Total Height

Table 2 demonstrates the outstanding superiority of the western Kentucky source with regard to total height. The Norris Dam source was equal in heigh to the western Kentucky source in the first year after outplanting. In the fifth year, the Norris Dam source was second by a wide margin to the western Kentucky source.

Table 2.--Total heights by source and year, in feet

Sources	1968	1969	1970	1972
Western Kentucky	1.68	2.43	3.31	5.22 [a]
Norris Dam	1.68	2.16	2.86	4.31
North Alabama	1.60	2.18	2.85	3.92
Ohio	1.27	1.72	2.38	3.36
Norris Lake	1.31	1.79	2.43	3.25
Cumberland Plateau	1.23	1.74	2.39	3.20

a/ The western Kentucky source is significantly different from four other sources at the 5% level.

In Figure 1, total height is plotted against latitude for each of the four years in which total height was measured. The curves are nearly horizontal with respect to latitude, indicating little relationship between Latitude and total height. The differences among the sources are accentuated as the trees grow older. In Figure 2 total height is plotted against years after outplanting. Trees from different sources appear to have different growth rates.

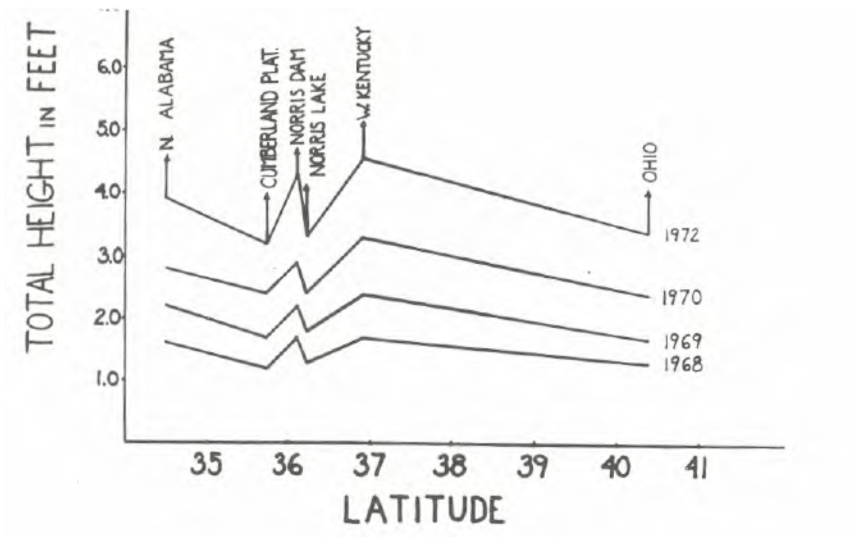

Figure 1.--Mean height of six seed sources at ages 1,2,3 and 5 as a function of latitude.

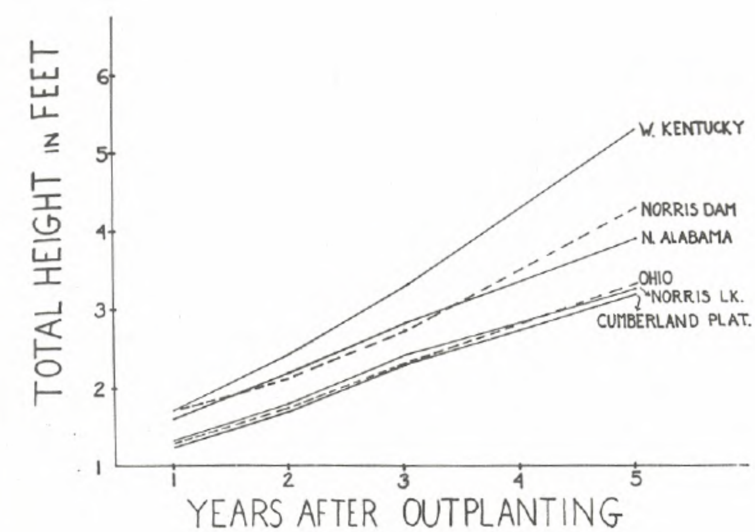

Figure 2.--Mean height of six seed sources measured following 1,2,3 and 5 growing seasons in the field.

Estimates of heritability of total height by source and year are presented in Table 3. In the first year after outplanting, two of the sources had estimates greater than unity. In the third year, two of the sources yielded estimates which were not significant at the .05 level of probability. In the fifth year, two of the sources had estimates which were negative but not significant at the .05 level. The estimates decrease in magnitude with increasing age of the trees and decrease at a decreasing rate after the first year.

Table 3.--Estimates of heritability of total height

Source	Heritability Estimates			
	1968	1969	1970	1972
Western Kentucky	.82	.40	.43	.38
Norris Dam	.29	.12	.10 n.s.[a/]	.23
North Alabama	.64	.12	.06 n.s.	.05 n.s.
Ohio	.57	.46	.39	.40
Norris Lake	1.30	.37	.23	-.03 n.s.
Cumberland Plateau	1.02	.35	.31	.25

a/ n.s. indicates the family component in the analysis of variance was not significant at the .05 level of probability.

Correlations between acorn weight and total height yielded coefficients of 0.32, 0.19, 0.16 and -0.027 for the first, second, third and fifth years respectively. The correlations were significant at the .05 level for the first three years, but not for the fifth year. Thus, the size of the correlation coefficient decreases with age.

Nitrogen Fertilizer

Effects of fertilizer on total height and number of flushes were analyzed using a compact family block design. The fertilizer effect was significant at the .05 level in increasing total height in 1972 and in increasing the number of flushes in 1971, the year of application of the fertilizer, but not in 1970 or 1972. The differences between fertilized and unfertilized trees are as follows:

	#flushes 70	#flushes 71	#flushes 72	ht 72
fertilized	1.24	2.04	1.19	4.6 ft.
unfertilized	1.31	1.31	1.43	3.7 ft.

Date of Bud Break

Date of bud break is presented, by source and year, in Table 4. The rank of the sources is the same in all three years in which measurements were taken. Three of the sources were not separated by Duncan's New Multiple Range Test.

Table 4.--Date of bud break, in days after March 31

Source	1970	1971	1972
North Alabama	22.3	25.3	21.2
Cumberland Plateau	24.9 a)	29.6	26.1
Western Kentucky	25.0 a)	29.8	26.2
Norris Dam	25.7 a)	30.9	27.4
Norris Lake	27.8	33.5	31.0
Ohio	34.2	40.8	38.3

a/ Three dates connected with line are not significantly different at the 5 percent level.

Date of bud break is plotted against latitude in Figure 3. The date of bud break is generally earlier the more southerly the seed source, the western Kentucky source being the exception to the pattern.

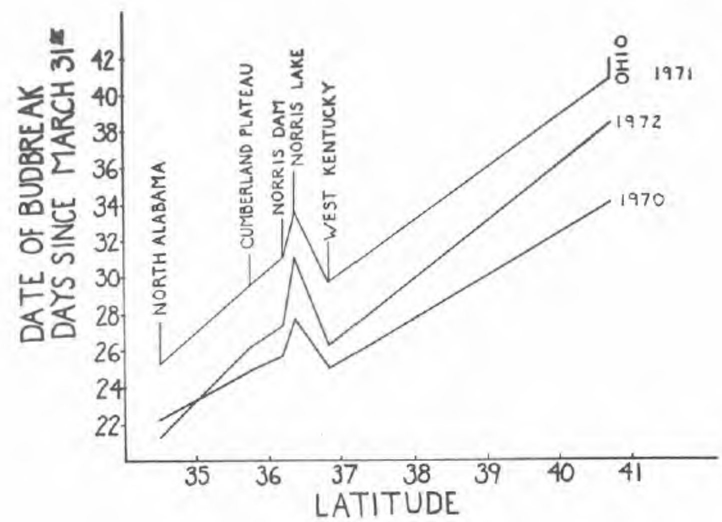

Figure 3.--Mean date of bud break of six seed sources for three years as a function of latitude.

Estimates of heritability of date of bud break (Table 5) are variable from year to year and from source to source. Five of the estimates are greater than unity, four of these being in two sources. Six estimates were derived from family components which were not significant at the .05 level of probability, including three for the Cumberland Plateau source. All three of the estimates for the Norris Lake source were equal to .36 and were derived from family components which were significant at the .05 level.

Table 5.--Estimates of heritability of date of bud break, by sources and years

Source	Heritability Estimates		
	1970	1971	1972
North Alabama	.68	1.33	1.78
Cumberland Plateau	.14 n.s.[a/]	.25 n.s.	.30 n.s.
Western Kentucky	1.01	.27 n.s.	.31 n.s.
Norris Dam	.52	1.38	1.14
Norris Lake	.36	.36	.36
Ohio	.35 n.s.	.70	.58

n.s. indicates the family component in the analysis of variance was not significant at the .05 level of probability.

DISCUSSION

Total Height

The correlations between acorn weight and total height for the first three years imply that the high estimates of heritability of total height in the first year are primarily due to maternal effects. The decrease with age in both the size of the correlation coefficient and of the heritability estimates indicates that these maternal effects decrease with age, losing their effect in the fifth year. For this reason, the fifth year heritability estimates are probably the most reliable. The differential growth rates of the various sources become more apparent with age, indicating, too, the loss of influence of acorn weight.

The difference in fifth-year heritability estimates from source to source may be due to either or both of two possible causes. One of the possibilities is that the heritabilities, in fact, differ for different populations of the same species. The second is that the estimates vary in size because they are based on small numbers of families. Nevertheless, the variation in size of the estimates indicates that the variance components for family effects from different sources are heterogeneous and that, for this reason, the use of the compact family block design was justified.

Fertilizer

A positive response in total height to fertilizer application has been demonstrated previously. The increase in number of flushes in the season in which fertilizer was applied means that most of the increase in total height due to fertilizer probably occurs during that season. Further, it means that nitrogen increases total height by increasing the number of flushes, as well, perhaps, as by increasing the average length of each flush.

Date of Bud Break

A regression using 1972 total height as the dependent variable and the date of bud break and number of flushes in the same year as independent variables was significant at the .05 level of probability. The coefficient of determination, R^2, was .13. Partial correlation coefficients for date of bud break and number of flushes were -0.32 and 0.22 respectively, both significant at the .05 level. The partial correlation coefficient for date of bud break indicates that trees which leaf out early grow taller. Thus, if one selects for late bud break in order to avoid frost injury, one may be selecting for low total height. An example of this situation may be seen in the case of the western Kentucky source, which is the tallest source, but which leafs out early relative to the latitude of its origin.

Some of the estimates of heritability of date of bud break are greater than unity. One possible explanation is that a large proportion of the progenies from some sources may be full sibs, since all the mother trees in each source are near each other. Another possibility is that the estimates represent the effects of two or more traits, which may interact. Response to daylength, for example, may be one trait, and response to temperature another. Thus, if warming-up occurs gradually in one year, the dates of bud break may be well differentiated within each source. If warming-up is delayed until late in the year and occurs suddenly, all the families of a given source may leaf out almost simultaneously.

Expected Gains

In proposing a selection scheme, it is suggested that one select for tallness in stands with high heritability estimates and discard tall families from stands with low heritability estimates. By selecting one tree from each twelve-tree plot and the twenty-five tallest of forty-nine families, with the exception of the preceding consideration, a seed orchard with an average of 49 trees per acre will remain. The expected gain in total height by this selection scheme is 20 percent at age 5.

CONCLUSIONS

Poor early height growth has been a problem in the artificial regeneration of Northern red oak. This problem may be ameliorated by the selection of families with rapid juvenile height growth. In addition, nitrogen fertilizer increases early height growth, as well as the number of flushes per season.

There was one outstanding seed source in this plantation. The western Kentucky source was the tallest after five years, as well as the fastest-growing and third in order of bud break.

Maternal effects, evidenced by correlations between acorn weight and total height, produced abnormally high estimates of heritability of height in the first year. Maternal effects decreased with increasing age for the first three years and disappeared by age five.

The sources leafed out in the same order in all three years. There was a shift in all the dates of bud break, however, from year to year. Estimates of heritability of date of bud break were high, but generally not constant. Several estimates were greater than one, possibly because of a high frequency of full sibs and or the control of one response by two or more traits. It is suggested that planting stock may be selected for late bud break to avoid frost injury in more northerly areas and for early bud break to increase height growth in more southerly areas.

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