RELATION BETWEEN HEIGHT GROWTH AND FUSIFORM RUST INFECTION IN SLASH PINE 1/

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Abstract.--Data from four open-pollinated slash pine progeny tests were analyzed to study relationships between growth rate and several measures of fusiform rust infection. Genetic correlations, estimated from half-sib variances and covariances, were variable among tests but usually negative, suggesting that selection for rapid growth will not cause a loss in rust resistance and may increase it slightly. Environmental correlations were positive at young ages, when number of cankers per tree or percent infected trees was used as a measure of infection. Practical implications of the results are discussed.
Additional keywords: *Pinus elliottii* Engelm., forest genetics, forest tree improvement.

The relationship between growth rate and fusiform rust infection in slash (*Pinus elliottii* Engelm.) and loblolly pines (*P. taeda* L.) is unclear. A number of reports (cited by Rowan and Steinbeck 1977) have shown that site factors and cultural practices (such as cultivation and fertilization) which increase growth rates also tend to increase rust incidence. On the other hand, several authors (cited by Dorman 1976, p. 193 and 257) reported little or no relationship between growth rates of families or individual trees and infection in progeny tests.

To our knowledge none of the past studies have attempted to determine the nature of the relationship from a genetic standpoint. The overall association between two traits in members of a population is called the "phenotypic correlation". It is not particularly revealing, because it is a composite of the "genetic correlation" and the "environmental correlation". The genetic correlation is a measure of the degree to which the two traits are affected by the same gene or genes. The environmental correlation is a measure of the degree to which the two traits are affected by similar differences in environmental conditions. (For more precise definitions and discussion of these terms see Falconer 1960, p. 312). Each of these correlations may be positive or negative. If the genetic and environmental correlations differ in sign, the phenotypic correlation may be 0 or close to it.

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The genetic correlation is especially important to tree breeders. If, for example, the genetic correlation between growth rate and rust infection is strongly positive, selection for rapid growth alone would result in increased infection, and simultaneous selection for superiority in these traits would be difficult. Appreciable environmental correlations also are important to the breeder because they may suggest the need for covariance adjustments when assessing breeding values of selections for each trait. In this report, we estimate the three types of correlations between growth rate and fusiform rust infection in slash pine.

METHODS

In this study we utilized data from four open-pollinated progeny test plantations (Table 1). They involved a total of 52 different families and 3 check lots. The parents of the families had been selected mainly for rapid growth and desirable tree form. All plantations contained 10-tree single-family row plots, randomly assigned within each of 10 replications. Some of the families were planted in 2 or more of the tests and all check lots were included in all tests. At 3 or 4 years of age, tree heights were measured and stem and limb galls were counted on each tree. At 10 years, heights were again measured, and presence or absence of galls was noted.

Table 1.--Details of the slash pine plantations studied. [a/]

Test number	Year established	Ages when measured (years)	Number of families [b/]
7	1967	4 and 10	16
8	1967	4 and 10	21
9	1967	3 and 10	21
10	1968	3	41

a/ All plantations were established by Scott Paper Co., in Escambia Co., AL. All families were established from open pollinated seed collected in a seed orchard at Greene Co., MS.

b/ Three check lots were also included in each test. Two were from natural stands and one was from a commercial source.

Components of variance and covariance were analyzed (Falconer 1960, p. 312; Helwig and Council 1979) to estimate genetic, environmental, and phenotypic correlations between tree height and 1) number of limb galls per tree, 2) number of stem galls per tree, 3) number of limb plus stem galls per tree and, 4) percent of trees infected in each plot. Analyses involving limb and stem galls were on an individual-tree basis, while analyses of percent infection were on a plot mean basis. Percentages of trees infected at 3 or 4 years and at 10 years included trees that had died from infection.

RESULTS

Genetic correlations between tree height and various measures of infection varied among tests but were usually negative at both young (3 or 4 years) and older (10 years) ages (Table 2). Negative correlations suggest that trees with inherently rapid growth tend to be more resistant to fusiform rust than inherently slow growers (or similarly, that resistant trees tend to grow more rapidly). The variation among tests may have been partly due to differences in the overall infection among tests. Tests 8 and 9 had the lowest overall infection percentages (Table 3) and showed the strongest negative correlations. Tests 7 and 10 had the highest infection percentages and showed weakly negative or position correlations.

Environmental correlations between tree height and 1) number of limb galls, 2) number of limb plus stem galls, and 3) percent infected trees were small but consistently positive at ages 3 or 4 (Table 2). Within families, trees on the more favorable microsites grew more rapidly and had more infection than those on poor microsites. Presumably, rapid growth resulted in more foliage and more surface area for infection. At 10 years, however, the environmental correlations for these traits became negative or zero. Apparently the higher degree of infection on trees growing rapidly at young ages eventually caused their growth to slow down. Environmental correlations between height and frequency of stem galls at the young ages were 0 or negative, probably because stem galls can reduce growth rates even at early ages.

Although phenotypic correlations are not directly interpretive, they presented in Table 2 for the sake of completeness, and because they are sometimes used in preparing selection indices.

An empirical view of some of the results clarifies relationships found and gives some idea of their magnitude. Test 8 at age 4 years showed pronounced microsite variation in both tree height and degree of infection. The block means for tree height and number of cankers per tree are shown in Figure 1. Note that trees in the west-central block had lowest average height (8.00 feet) and the least average number of cankers per tree (0.47). Blocks to the north, east, and south of this block showed increasingly greater growth and increasingly greater infection. Since all families were represented in all blocks, the pattern is essentially environmental.

Figure 2 depicts the effects of both the genetic and environmental correlations between tree height and gall frequency in test 8 at 4 years. The block means for the seven fastest growing families (selected on the basis of growth in tests other than those reported on here) are plotted along with the means for the seven slowest growing families. Note that, overall, galls per tree increased with increasing tree height, a reflection of environmental effects. But the most rapid growing families on the average had less infection for a given height than the slow growing trees. The fast growers averaged about 0.67 galls per tree, while the slow growers averaged 0.72 galls per tree. This difference is small, but after covariance adjustment to a common height for the effects of tree height, the difference increased, with the fast growers averaging 0.63 galls per tree and slow growers averaging 0.79 galls per tree.

Table 2.--Correlations between tree height and fusiform rust infection in slash pine.

Test no.	Genetic [a]	Environmental	Phenotypic
	HEIGHT VS. LIMB GALLS AT 3 OR 4 YEARS [b]		
7	-.20(.31)	0.12	0.07
8	-.81(.15)	.11	.07
9	-.66(.22)	.13	.08
10	.24(.18)	.12	.14
	HEIGHT VS. STEM GALLS AT 3 OR 4 YEARS [b]		
7	.00	.05	-.04
8	-.10(.51)	.01	.01
9	-.56(.29)	-.01	-.04
10	-.05(.20)	-.19	-.17
	HEIGHT VS. LIMB + STEM GALLS AT 3 OR 4 YEARS [b]		
7	-.24(.38)	.09	.04
8	-.70(.22)	.10	.06
9	-.68(.21)	.12	.07
10	.19(.11)	.04	.07
	HEIGHT VS. PERCENT INFECTED AT 3 OR 4 YEARS [b]		
7	-.31	.16	.06
8	-.66	.33	.28
9	-.69	.18	.08
10	.15	.17	.16
	HEIGHT VS. PERCENT INFECTED AT 10 YEARS		
7	-.42	-.11	-.17
8	-.27	.05	.00
9	-.54	-.22	-.34
10	c/	c/	c/

Type of correlation: Genetic, Environmental, Phenotypic.

a/ Standard errors of genetic correlations based on individual trees are in parentheses.
b/ At 4 years for tests 7 and 8, and at 3 years for tests 9 and 10.
c/ Test number 10 was not measured at 10 years.

Table 3.--Mean tree heights (families only) and degrees of infection by plantation and age.

Test number	Age 3 or 4 [a/] Height	Galls per tree [b/]	Infected tree [c/]	Age 10 Height	Infected trees
	Feet	Number	Percent	Feet	Percent
7	9.2	1.02	48	30	64
8	8.8	.69	35	30	48
9	5.9	.72	34	29	64
10	5.1	1.10	52	d/	d/

a/ At 4 years for tests 7 and 8 and at 3 years for tests 9 and 10.
b/ Includes both stem and limb galls.
c/ Trees with either stem or limb galls.
d/ Test number 10 was not measured at 10 years.

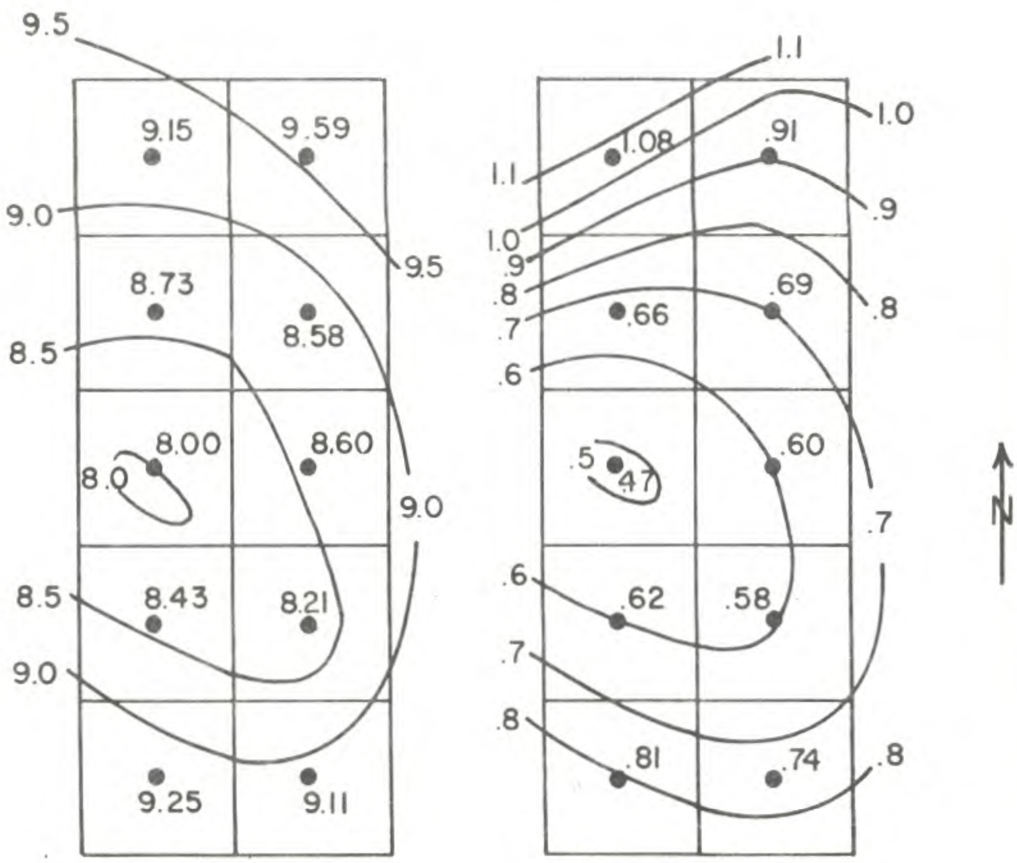

Figure 1. Correspondence between microsite variation of tree heights (in feet, left) with average number of galls per tree (right) in the 10 blocks in slash pine test 8 at 4 years. Values in centers of squares are block means.

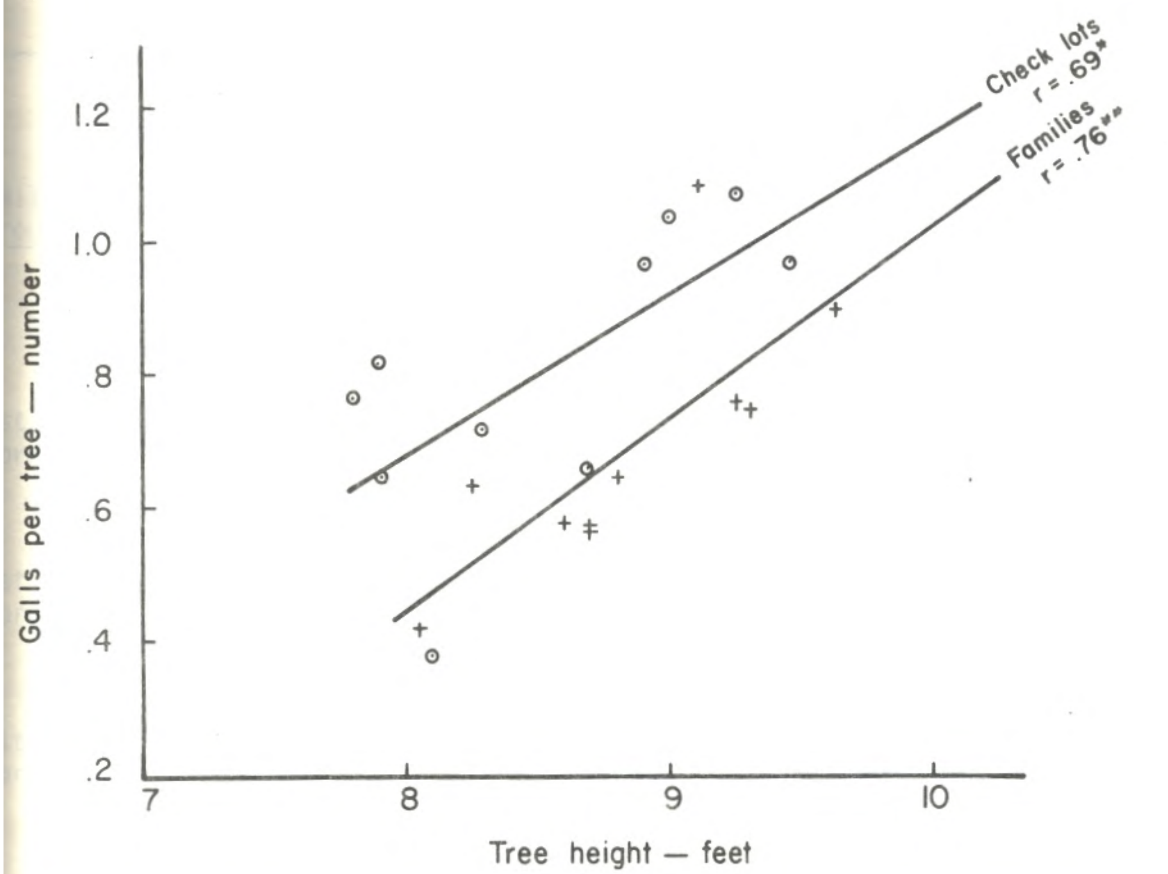

Figure 3. Replication means of number of galls per tree plotted over tree heights in slash pine test 8 at 4 years, for check lots (0) vs. families (+).

Although we used test 8 for making the above comparisons of the effects of selection, we also made computations for all tests (Table 4). Note that progeny of the faster growing parents usually had slightly lower infection percentages than those of poorest growers. Also, covariance adjustment usually increased the difference in infection between rapid and slow growers at the younger ages but not at age 10. Similar patterns were found when number of galls per tree was used as the measure of infection.

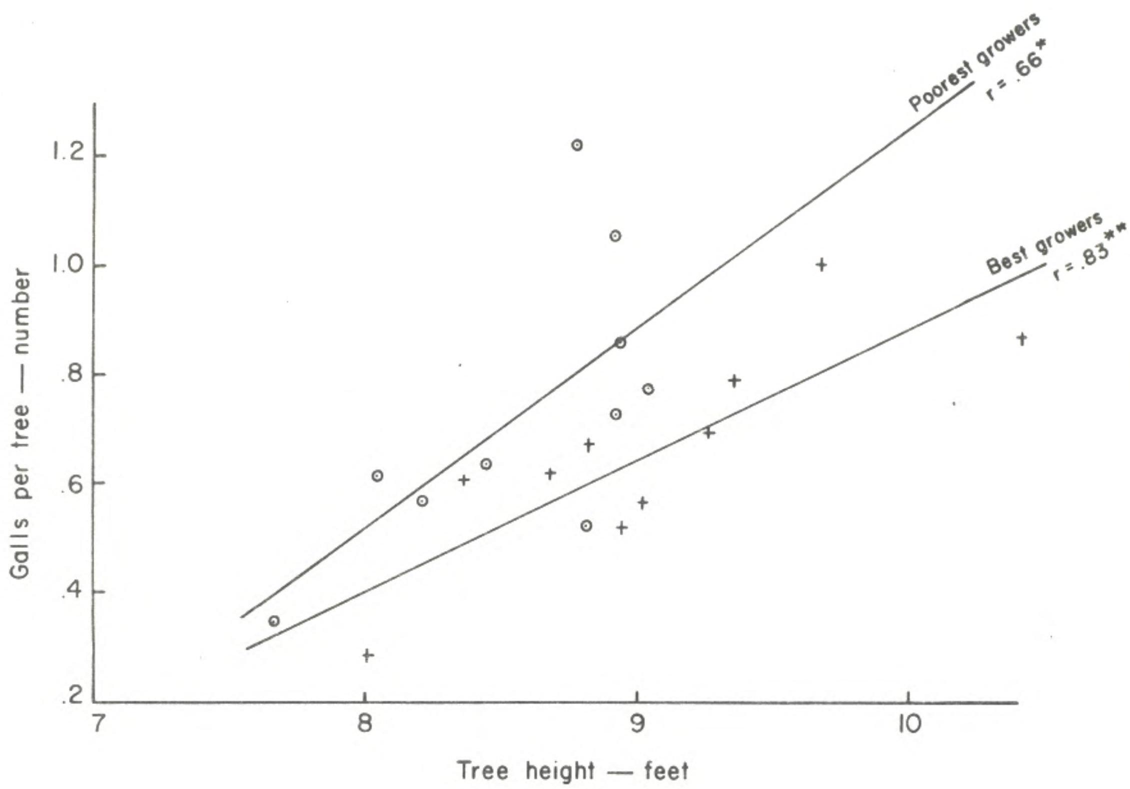

Figure 2. Replication means of number of galls per tree plotted over tree heights in slash pine test 8 at 4 years, for progeny of the poorest 1/3 parents selected for growth performance in other tests (O) vs. progeny of the best 1/3(+).

In the above analysis, the "selections" were made on the basis of performance in other tests in order to minimize the possibility of extraneous effects. That is, if we chose the trees on the basis of performance in Test 8, one could argue that in choosing the best growers we were essentially choosing those that had the least infection in this test, since infection can reduce growth rates. Actually, we made comparisons using both selection techniques and results were similar.

A similar comparison was made for check lots vs. families, again in test 8 at 4 years (Fig. 3). Since parents of the families were originally selected partly for rapid growth, they were expected to grow more rapidly than checks. Results, were essentially the same as those in Figure 2, with the check lots having more infection than families at given tree heights.

Table 4.--Effect of selection for growth rate [a/] upon degree of rust infection before and after covariance adjustment for growth.

Family group	Percent infection at: 3 or 4 years [b/]		10 years	
	Before adjust.	After adjust.	Before adjust.	After adjust.
		TEST 7		
Best 1/3	47	46	61	61
Poorest 1/3	47	48	64	66
		TEST 8		
Best 1/3	35	34	46	46
Poorest 1/3	37	37	48	49
		TEST 9		
Best 1/3	32	31	58	59
Poorest 1/3	38	38	70	66
		TEST 10		
Best 1/3	46	45	c/	c/
Poorest 1/3	59	59	c/	c/
Ave. best 1/3	40.0	39.0	55.0	55.3
Ave. poorest 1/3	45.2	45.5	60.7	60.3

a/ The best and poorest families were selected on the basis of parental evaluations made from tests other than those involved here.

b/ At 4 years for tests 7 and 8, and at 3 years for tests 9 and 10.

c/ Test 10 was not measured at 10 years.

CONCLUSIONS AND RECOMMENDATIONS

The negative genetic correlations found between growth rate and fusiform rust infection suggest that selection of trees for rapid growth will not cause a decrease in resistance and may even increase it slightly. The positive environmental correlations found at young ages mean that trees planted on sites favorable for growth are likely to incur more infection than if those same trees were planted on unfavorable sites. The latter conclusion agrees with findings by several investigators that stimulation of growth through cultural practices usually increases infection. Stimulation of growth, either through cultural means or by planting on sites favorable for growth, probably causes an increase in growing tips and foliage with an attendant increase in surface area for infection. But physiological effects may also be involved.

We recommend that tree breeders continue to select for rapid growth along with rust resistance when developing strains for planting on high rust hazard sites. We further suggest that when evaluating trees for rust resistance at young ages one should adjust for the effects of growth rate by covariance techniques. Adjustment at older ages may not be necessary.

Stimulation of growth through cultural practices in high rust hazard areas is another matter. Here the forest manager needs to weigh the costs of such practices, plus the expected increase in rust infection, against the expected gains in growth rate. From a long-term standpoint, we feel that it may be preferable to expand efforts to develop and utilize strains of trees superior in both growth and resistance.

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