RELATIONSHIP BETWEEN STABILITY INDICES AT THE TIME OF GERMINATION AND AT THE SEEDLING STAGE IN JACK PINE

D. R. Govindaraju, 1/ and B. P. Dancik 2/

Abstract.--The predictability of stability indices at different developmental stages of seedling growth was studied in forty open-pollinated families of jack pine (*Pinus banksiana* Lamb.). Two sets of studies were conducted simultaneously under greenhouse conditions. In the first, the seeds were germinated under four levels of water stresses; in the second, they were grown on four soil media. Stability indices were calculated for radicle length of germinating seeds and total seedling biomass using the Eberhart-Russell model. The correlation of stability indices from the two developmental stages under similar environmental conditions was insignificant. We conclude that the unpredictability of stability may be associated not only with genotype-environment interactions, but also with developmental and/or demographic genetic effects.

Additional keywords: Jack pine, stability indices, developmental stages.

Breeding for consistent performance of genotypes across environments is one of the primary goals in many tree improvement programs. The relative sensitivity or stability of genotypes across environments is described in terms of genotype-environment interactions (Haldane 1946, Falconer 1952, Allard and Bradshaw 1964, Zobel and Talbert 1986). Genotypes that show least sensitivity or greatest buffering to environmental changes are selected and propagated. The magnitude of sensitivity of genotypes to environmental variations is generally estimated using phenotypic stability models (Finlay and Wilkinson 1963, Eberhart and Russell 1966, Hanson 1970, Freeman 1973). These models assume that the most stable genotype will show the least variance for a given trait across environments. With this assumption, stability is measured in terms of regression (stability index or "b" value) of performance of a genotype in different environments on the respective means of all genotypes. The most stable genotype is characterized by a regression coefficient of 1, with minimum deviation from regression.

In practice, genotypes are grown under different environmental (field) conditions; the "b" values are subsequently estimated for the character of

---

1/Research Associate, Department of Forestry, University of Kentucky, Lexington, Kentucky.

2/Professor of Forest Genetics, University of Alberta, Edmonton, Alberta, Canada.

The authors thank S. Friedman and D. B. Wagner for comments, and NSERCC (F-0041) for financial support to D.R.G.

interest. Also, the stability values are generally estimated at a single developmental stage in the life history of the organism. In addition, evaluation of large number of genotypes under a wide array of environmental conditions is often a formidable task, particularly in tree breeding programs. Therefore, if a positive significant correlation between stability indices at different developmental or demographic stages or both, consistently exist, for similar set(s) of environmental conditions, then it is possible to select genotypes under laboratory (greenhouse) conditions. The objective of this study was to examine the relationship between stability indices estimated on a number of genotypes of jack pine *(Pinus banksiana* Lamb.), under similar sets of environments, at two different developmental stages. Germinating seeds were used to estimate phenotypic stability for the following reasons: a) the rate of germination is a genetically controlled trait (Whittington 1973), and thus influences the subsequent development of growth of plants (Hayes et al. 1955, Harper 1977), and b) a large number of families could be evaluated economically under extremely diverse environmental conditions in a very short time.

METHODS

The seed material used in this study consisted of 40 open-pollinated families from a single stand in Central Alberta. Two sets of experiments were carried out simultaneously using the same seed material. The experiments were laid out in a randomized block design with four replications. Experiment 1 consisted of four arbitrary levels of salt (water) stresses; they are: 1) control (deionized water), and sodium chloride, 2) -1.14, 3) -2.29, 4) -3.43 bars. Ten seeds from each family were placed in 9 X 1 cm petri dishes on Whatman No. 1 filter paper, and each petri dish was considered as a replication. Filter papers in the petridishes were moistened once every three days with 5 ml of the appropriate solution from the day of sowing. The seeds were allowed to germinate for 12 days under greenhouse conditions. Data were recorded on five randomly chosen radicles from each family and each replication. Experiment 2 was initiated with fifty seeds from each of the forty families. These were germinated separately, on a thin layer of inert sand, in a mist chamber. Ten, 10-day old seedlings were selected at random from the fifty seeds of each family, and were transplanted at the rate of one seedling per pot in each of the four media. The media included sand (medium 1; pH = 8.6), silt (medium 2; pH = 6.8), 50:50 peat-vermiculite mixture (medium 3; pH = 4.5), and peat (medium 4; pH = 3.8), placed in 2.5 X 2.5 X 5 cm seedling trays. The seedlings were grown under greenhouse conditions for 120 days. At the end of the experiment, all ten seedlings from each of the families and treatments were harvested at the root collar level, and their fresh weight immediately determined. Data on mean radicle length and biomass of each family from the each environment were used to calculte stability indices according to Eberhart and Russell (1965). The relationships between mean radicle length, biomass production and their respective phenotypic stabilities, and between the phenotypic stabilities of radicle length and biomass were calculated using Pearson correlation coefficients.

Table 1.--Mean radicle length, biomass production and phenotypic stability values of various families under two sets of environment.

	Radicle length (cm) under salt stress					Biomass (g) in soil media				
Family	Control	-1.14 bars	-2.29 bars	-3.43 bars	"b" values	Sand	Silt	Peat-verm.	Peat	"b" values
1	2.740	0.913	0.333	0.100	1.092	0.258	0.681	2.841	3.051	0.925
2	2.713	1.080	0.386	0.100	0.839	0.506	0.676	3.242	3.400	1.091
3	3.240	1.720	0.686	0.173	0.822	0.483	0.351	2.596	3.018	0.950
4	2.660	1.173	0.313	0.100	0.939	0.504	0.420	2.833	3.014	0.976
5	3.613	1.520	0.500	0.106	0.812	0.397	0.840	3.080	4.050	1.200
6	3.630	0.946	0.213	0.100	1.099	0.176	0.302	2.563	2.240	0.856
7	3.773	1.530	0.680	0.153	1.149	0.471	0.574	3.392	3.018	1.061
8	2.773	1.186	0.533	0.100	1.120	0.651	0.550	3.726	3.937	1.280
9	3.430	1.560	0.586	0.100	0.821	0.540	0.705	3.835	4.581	1.440
10	4.040	1.920	0.906	0.226	1.031	0.344	0.647	3.106	3.491	1.128
11	3.426	0.900	0.333	0.100	1.165	0.376	0.452	2.870	3.057	1.017
12	4.433	1.106	0.120	0.100	1.067	0.241	0.564	2.737	2.438	0.872
13	5.093	1.120	0.193	0.100	1.425	0.440	0.420	3.032	3.505	1.133
14	1.913	0.706	0.320	0.100	1.634	0.360	0.720	3.713	3.211	1.163
15	2.680	0.986	0.406	0.100	0.567	0.420	0.600	4.066	4.006	1.403
16	2.273	0.740	0.573	0.126	0.808	0.400	0.756	4.260	4.926	1.616
17	3.473	1.620	0.840	0.133	0.648	0.292	0.534	3.790	3.680	1.324
18	4.373	1.633	0.800	0.120	1.003	0.264	0.510	4.000	4.622	1.575
19	3.920	1.100	0.313	0.133	1.308	0.572	0.910	4.200	3.822	1.302
20	5.040	1.473	0.386	0.100	1.225	0.184	0.400	2.880	3.034	1.067
21	4.613	1.646	0.680	0.120	1.591	0.400	1.062	3.242	4.038	1.189
22	2.200	0.766	0.220	0.100	1.404	0.362	0.440	3.498	3.272	1.182

(continued)

Table 1. Continued.

	Radicle length (cm) under salt stress					Biomass (g) in soil media				
Family	Control	-1.14 bars	-2.29 bars	-3.43 bars	"b" values	Sand	Silt	Peat-verm.	Peat	"b" values
23	2.913	1.193	0.406	0.133	0.676	0.302	1.042	3.054	3.904	1.153
24	4.026	2.073	0.893	0.253	0.877	0.360	0.542	4.544	4.212	1.558
25	6.010	1.570	0.900	0.353	1.158	0.356	0.338	3.254	2.474	0.984
26	4.220	2.140	0.826	0.420	1.790	0.192	0.426	3.090	2.666	1.020
27	4.920	2.220	1.480	0.560	1.188	0.192	0.484	3.000	3.400	1.152
28	3.860	1.073	0.640	0.386	1.315	0.242	0.678	4.524	3.616	1.431
29	2.866	1.420	1.190	0.580	1.113	0.744	0.580	2.850	4.600	1.239
30	4.186	1.786	0.806	0.533	0.669	0.306	0.532	2.932	2.762	0.968
31	4.153	1.280	0.486	0.106	1.164	0.404	0.512	3.656	2.950	1.120
32	3.326	1.093	0.280	0.100	1.282	0.176	0.344	3.694	2.950	1.208
33	4.773	1.626	0.486	0.100	1.040	0.350	0.792	4.600	4.154	1.517
34	4.273	1.360	0.320	0.100	1.487	0.260	0.494	3.200	2.374	0.950
35	2.866	0.950	0.246	0.100	1.345	0.240	0.578	3.680	3.130	1.190
36	3.653	1.100	0.466	0.193	0.889	0.234	0.686	3.150	3.730	1.207
37	4.990	1.300	0.400	0.100	1.103	0.250	0.796	3.120	4.430	1.330
38	1.460	1.180	0.320	0.106	1.565	0.426	0.832	4.512	4.084	1.462
39	3.053	1.546	0.453	0.173	0.414	0.248	0.496	3.374	3.274	1.177
40	2.600	0.946	0.413	0.120	0.909	0.352	0.628	3.458	3.688	1.236
Mean	3.605	1.330	0.533	0.175	1.088	0.356	0.597	3.436	3.478	1.191
S.D.	0.983	0.385	0.287	0.136	0.307	0.020	0.281	0.090	0.105	0.198

RESULTS AND DISCUSSION

The mean radicle length In the germination experiment was higher in the (deionized water treatment), as expected, than under any of the other three stresses; and decreased with the magnitude of stress. On the other hand, in the seedling experiment, biomass production was highest on the peat-vermiculite medium, but lowest in sand medium. The phenotypic stability values for radicle length and for biomass varied from 0.856 to 1.616, and 0.414 to 1.790 respectively (table 1). An insignificant but positive association was found between radicle length and its "b" values (figure 1a, r = 0.038). On the other hand, a significant positive association was found between biomass production and its phenotypic stability (figure 1b, r = 0.937) the correlation coefficient of "b" values between radicle length and biomass production was slightly negative and insignificant (figure 2, r = -0.145).

The data presented in Table 1 indicate the following: 1) not all families that showed a high degree of stability (b.-- 1) for highly stable genotypes at germination stage show a similar response at seedling stages; 2) only two families (27, 31) which showed relatively high stability (b = 1.120 - 1.188) for radicle length also showed a similar trend for biomass production; 3) when the criterion of minimum deviation (ie. maximum stability, b = 1) was ignored, twenty percent of the families showed similar stability values (t 0.1) for radicle length and biomass production.

These results, although preliminary in nature, indicate that the average performance of a genotype across environments (or sets) and developmental stages is largely unpredictable. Although Mather (1953) suggested that average response of genotypes to environmental stresses may be genetically controlled, the relationship between stability and productivity is not universal (Hardwick 1981); individual families show either specific or general environmental sensitivities (Conolly and Jinks 1982). Accordingly, as found in this study, certain genotypes may show some degree of stability consistently across environments and also across developmental stages. However, a general relationship among stability indices across environments, across developmental and demographic stages is difficult to obtain. Recently, Huhn and Leon (1985) also reported inconsistent relationships between stability parameters and means of lines in different years on *Brassica napus*, and cautioned against making generalizations using stability parameters in plant breeding programs.

The inconsistent relationship between stability values at two developmental stages could be due to the fact that data on radicle length and biomass were obtained on different individuals of the same family raised under two sets of environments. It has been suggested that any quantitative character of a genotype when measured in different environments must be considered as different characters, because in each environment, genes associated with the expression of quantitative characters respond differently (Falconer 1954, Yamada 1962). A similar argument could be made for characters measured at different developmental and/or demographic stages. Indeed, age-specific gene action in the evolution of age-structured populations, such as forest trees, is well-known (Charlesworth 1980). Furthermore, a linear and a

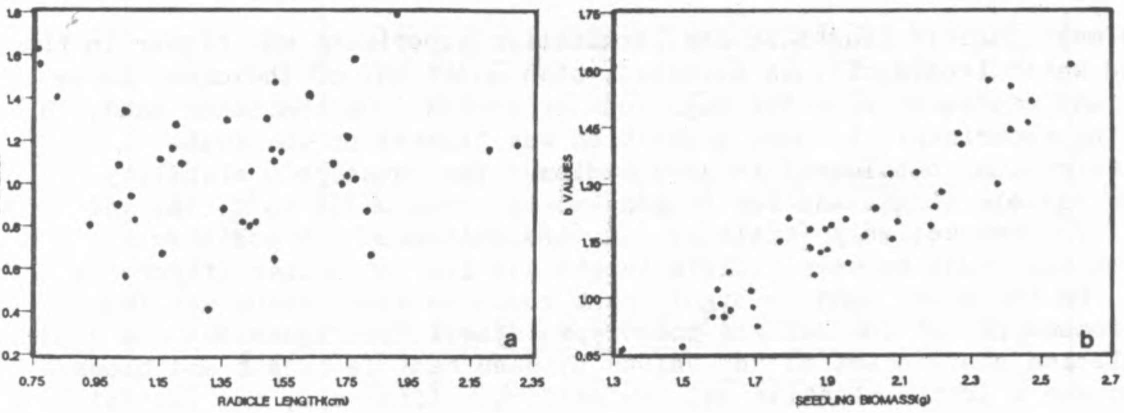

Figure 1. a. Association between mean radicle length of different families and and their 'b' values (r = 0.038; p = N.S.); b. association between mean seedling biomass of various families and their 'b' values (r = 0.937; p < 0.0001).

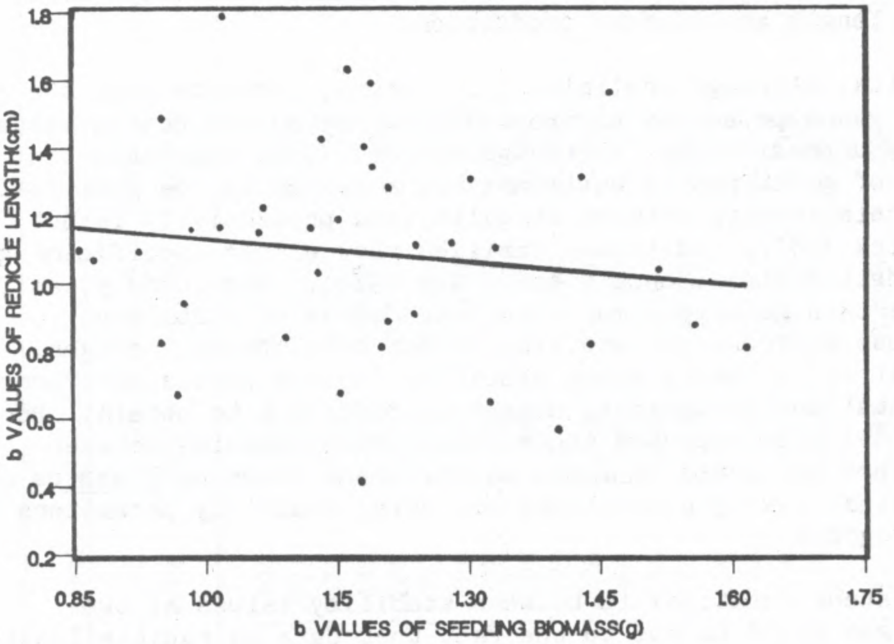

Figure 2. Association between the 'b' values of mean radicle length and mean seedling biomass (r =-0.145; p = N.S.).

tripartite relationship among phenotypic stability, heterosis and productivity has been reported for various crop plants (Adams and Shank 1959, Allard 1961, Pfahler 1966). These concepts (particularly phenotypic stability) have been considered as equivalent and commutative to the concept of homeostasis (Baker 1981). Nevertheless, reports indicate that phenotypic stability fluctuates over years and environments (Weber and Wricke 1986, Huhn and Leon 1985). Also the expression of both heterosis (Williams 1959, Griffing and Zsiros 1971, Barlow 1982, Govindaraju and Dancik 1987) and homeostasis (Orzack 1985) is strongly dependent on environmental variation. Therefore, we suggest that, although many important advances have been made in plant and forest tree breeding programs, using the concept of phenotypic stability its use as a universal predictor of stability across spatial, temporal, developmental and demographic differences based on correlated traits may be limited.

LITERATURE CITED

Adams, M. W. and D. B. Shank. 1959. The relationship of heterozygosity and homeostasis in maize hybrids. Genetics 44:777-786.

Allard, R. W. 1961. Relationship between genetic diversity and consistency of performance in different environments. Crop Sci. 1:127-133.

Allard, R. W. and A. D. Bradshaw. 1964. Implication of genotype X environment interaction in applied plant breeding. Crop Sci. 4:503-508.

Barlow, R. 1981. Experimental evidence for interaction between heterosis and environment in animals. Anim. Breed. Abst. 49:715-737.

Becker, H. C. 1981. Correlations among some statistical measures of phenotypic stability. Euphytica 30:835-840.

Charlesworth, B. 1980. Evolution in Age Structured Populations. Cambridge Univ. Press, Cambridge.

Connolly, V. and J. L. Jinks. 1975. The genetical architecture of general and specific environmental sensitivity. Heredity 35:249-259.

Eberhart, S. A. and W. A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:26-40.

Falconer, D. S. 1952. The problem of environment and selection. Amer. Nat. 86:293-298.

Finlay, K. W. and G. N. Wilkinson. 1963. The analysis of adaptation in a plant breeding program. Aust. J. Agric. Res. 14:742-754.

Freeman, G. H. 1973. Statistical methods for the analysis of genotype-environment interactions. Heredity 31:339-354.

Govindaraju, D. R. and B. P. Dancik. 1987. Allozyme heterozygosity and homeostasis in germinating seeds of jack pine. Heredity (in press).

Griffing, B. and D. E. Zsiros. 1971. Heterosis associated with genotype environment interactions. Genetics 68:443-455.

Haldane, J. B. S. 1946. The interaction of nature and nurture. Ann. Eugen. 13:197-205.

Hanson, W. D. 1970. Genotypic stability. Theor. Appl. Genet. 40:226-231.

Hardwick, R. C. 1981. The analysis of genotype X environment interactions: what does it mean if varietal stability in linearly related to varietal performance? Euphytica 30:217-221.

Hayes, H. K., Immer, F. R. and D. C. Smith. 1955. Methods of Plant Breeding. McGraw-Hill, New York.

Huhn, M. and J. Leon. 1985. Genotype X environment interactions and phenotypic stability. Z. Pflanzenzuchtg. 95:135-146.

Mather, K. 1953. Genetical control of stability. Heredity 7:297-336.

Orzack, S. H. 1985. Population dynamics in variable environments V. The genetics of homeostasis revisited. Amer. Nat. 125:550-572.

Pfahler, P. L. 1966. Heterosis and homeostasis in rye (Secale cereale L.) II. Production of varieties, intravarietal crosses and composite population under various population densities. Crop Sci. 6:401-405.

Whittington, W. J. 1973. Genetic regulation of germination. In Heydecker, W. (ed.) Seed Ecology. The Pennsylvania State University Press, University Park.

Williams, W. 1959. Heterosis and the genetics of complex characters. Nature 184:527-530.

Wricke, G. and W. E. Weber. 1986. Quantitative Genetics and Selection in Plant Breeding. Walter de Gruyter, Berlin.

Yamada, Y. 1962. Genotype by environment interaction and genetic correlation of the same trait under different environment. Jap. J. Genet. 37: 498-509.

Zobel, B. J. and J. T. Talbert. 1984. Applied Forest Tree Improvement. John Wiley and Sons, New York.