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A Comparison of Different Stability Models in Wheat*

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Summary. Eight different varieties of wheat, namely S-308, WG-377, K-227, PV-18, HD-1941, HD-1949, C-306 and C-281, were tested under twenty-four environments over two successive years. The models of Eberhart and Russell (1966), Perkins and Jinks (1968a), and Freeman and Perkins (1971) were applied to study genotype-environment interactions. The correlations between different environments were also determined and the partitioning of sum of squares due to genotype × environment interaction attributable to each variety was done as suggested by Wricke (1962). The term 'ecovalence' was used to signify this parameter. The major findings of the study were as follows:

(i) The models of Eberhart and Russell, and Perkins and Jinks, produced similar results with respect to both responsiveness (b) and stability ($\overline{S}_d^2$). The pattern of *b*-values in Freeman and Perkins' model was also similar to its pattern using these two models.

(ii) The pattern of correlations between environments (*r*) for various genotypes showed high similarity with the pattern of *b*-values obtained in various models. The varieties having high *b*-values were found to have high environmental correlations and *vice versa.*

(iii) Ecovalence and Freeman and Perkins' model were quite similar to each other for determining the stability of a genotype, but the rank correlations between ecovalence and Eberhart and Russell's model were low. It was, however, observed that the most stable varieties could be detected by using any of these models. Keeping in view the computational convenience, the use of correlation between environments (*r*) and ecovalence was suggested for predicting responsiveness and stability of genotypes, respectively.

It is commonly observed that the relative performance of different genotypes varies in different environments, i.e., there exists a genotype-environment interaction. The occurrence of genotype-environment interactions has long provided a major challenge to obtaining fuller understanding of the genetic control of variability. The study of genotype-environment interaction in its biometrical aspect is thus important not only from the genetical and evolutionary points of view, but also is very relevant to production problems of agriculture in general and to plant breeding in particular (Breese, 1969).

In the past, the principal analytical approach has been to estimate genotype-environment interaction from the pooled analysis of variance (Immer *et al.*, 1934; Salmon, 1951; Horner and Frey, 1957; Sandison and Bartlett, 1958). These estimates were then used to identify those environmental factors which interacted more strongly with the genotypes so that subsequent experiments might be modified accordingly. This technique, however, could provide information only on the existence of genotype-environment interaction and was unable to give any measurement of the interaction of individual genotypes with environment. An early attempt to obtain measurements of the stability of individual lines was made by Plaisted and Peterson (1959), but their method becomes cumbersome when a large number of genotypes are tested. Recently, interest has been centred on regression technique as an alternative method of analysing the genotype-environment interaction. One of the essential features in developing this technique was to quantify the environment on the basis of mean performance of test material. Originally suggested by Yates and Cochran (1938), it has been modified by different workers for use in breeding experiments (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Perkins and Jinks, 1968a, b; Breese, 1969; Freeman and Perkins, 1971; Hardwick and Wood, 1972). The regression of genotype on environment provides two simple measures of the genotypic changes to environments, namely, regression coefficient and deviation from regression slope.

It is almost a rule that in all field trials one has to choose the analysis of variance for testing the significance of varietal performance under the given set of conditions in which experiments are conducted. It is easy to conceive that calculation would be simpler if we had a method which was based on the information available directly from such analysis of variance for estimating the stability of the variety. The suggestion made by Wricke (1962) in this connection merits special consideration.

With these points in view, the present investigation was planned and the experiments were conducted to compare the efficiency of the different models now in

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use for the estimation of genotype-environment interaction and the stability of the varieties, and to suggest an easy alternative for the estimation of stability.

Material and Methods

The experimental material consisted of eight varieties of wheat, S-308, WG-377, K-227, PV-18, HD-1941, HD-1949, C-306 and C-281. These varieties were tested under multi-environments, created by changing agronomic treatments. Four doses of nitrogen (40, 80, 120, 160 kg N/ha), two spacings (17 cm; 22.5 cm) and three dates of sowing (29th Oct., 29th Nov. and 29th Dec.) were considered in all possible combinations. Each combination represented one environment. The same set of environmental combinations was tried in two successive years, i.e. 1971—72 and 1972—73. The experiments were laid out in a randomized block design with three replications. The observations were recorded on ten randomly selected plants from each plot for grain yield, number of ears per plant, number of grains per ear, 1000-grain weight and plant height.

The data were first subjected to the analysis of variance to test the significance of genotype × environment interaction. Various stability parameters (i.e. μ, b and $\bar{S}_d^2$) were estimated using models proposed by Eberhart and Russell (1966), Perkins and Jinks (1968a) and Freeman and Perkins (1971).

Another parameter, the correlation between different environments, was determined by the following formula:

$$r_1^{(x)} = \frac{\text{Cov }(x_1, x_2)}{\sqrt{\sigma_{x_1}^2 \times \sigma_{x_2}^2}} \qquad (1)$$

where,

$r_1^{(x)}$ is the correlation between environment 1 and 2 for character x of the i^{th} variety;
x_1 = the measurement for x in environment 1;
x_2 = the measurement for x in environment 2;
Cov (x_1, x_2) = Covariance between environment 1 and 2 for particular character x;
$\sigma_{x_1}^2$ = Variance in x for environment 1;
$\sigma_{x_2}^2$ = Variance in x for environment 2.

Ecovalence, a term used for the relative contribution by i^{th} variety to the total genotype × environment interaction (Wricke, 1962), was calculated using the following formula

$$\sum_j \left(x_{ij} - \frac{X_{i.}}{q} - \frac{X_{.j}}{p} - \frac{X_{..}}{pq}\right)^2 \qquad (2)$$

where,

X_{ij} stands for a measurement on i^{th} variety in j^{th} environment;
$X_{i.}$ = Sum of i^{th} variety over all the environments (q);
$X_{.j}$ = Sum of j^{th} environment over all the varieties (p);
q is the number of environments;
p is the number of varieties.

Results

Analysis of variance: A pooled analysis of variance is presented in Table 1. The partitioning of variance into various components revealed that a large portion of variance for all characters was attributable to varieties and environments. When tested against genotype × environment interaction component, these were found to be significant in most of the cases. The results thus satisfied the basic requirement for such studies, since they indicate that the average performance of varieties with respect to yield and other characters varied significantly in different environments and that the varieties also varied significantly so far as their average performance over all the environments was concerned.

Comparison of various stability models: In Table 2, b^E stands for regression coefficient as per model given by Eberhart and Russell (1966), β_i is the regression coefficient for Perkins and Jinks' model (1968a) and b^F represents the regression coefficient under Freeman and Perkins' model (1971). Similarly, $\bar{S}_{d(E)}^2$ and $\bar{S}_{d(F)}^2$ represent variances of deviations around the regression line under Eberhart and Russell (1966) and Freeman and Perkins model (1971), respectively.

From the data given in Table 2 on grain yield, the following observations could be made: (i) The order of ranking of various genotypes, both with respect to response (b) and stability, was the same under Eberhart and Russell (1966) as with Perkins and Jinks (1968a) model. This was expected because the latter model, being $b^E - 1$, is in no way different from the former. (ii) The genotypes which were least responsive towards environmental changes (i.e., smaller b values) were also those having the lowest environmental correlations (r) and *vice versa*. For example, K-227 had the lowest regression coefficient (0.428) and also the lowest environmental correlations (0.335), followed by HD-1941 ($b = 0.620$; $r = 0.335$). The genotypes S-308, WG-377, PV-18, HD-1949, C-308 and C-281 had higher values of regression coefficient and also exhibited higher values of environmental correlation. The rank correlation between the pattern of b and r for different varieties was 0.834. This showed that values of b were closely comparable with the values for environmental correlations. In other words, the environmental correlations were as good as regression coefficients (b) for predicting the re-

Table 1. *Analysis of variance for certain quantitative traits pooled over forty-eight environments*

Source of variation	D.F.	Grain yield	Ears per plant	Grains per ear	1000-grain weight	Height
Environments (*E*)	48	16.579**	0.245**	59.310**	64.263**	595.202**
Genotypes (*G*)	7	87.117**	0.270**	1054.174**	580.588**	6227.342**
G × *E*	329	4.288**	0.019**	15.628**	5.475**	220.986**
Pooled error	768	0.604	0.008	8.413	4.136	24.643

** significant at 1 per cent level

Table 2. *Estimates of stability parameters based on forty-eight environments using various models for grain yield in wheat*

Genotypes	$\mu + d_i$	Reg. coeff. b^E	β_i	b^F	r	Ecovalence	$\overline{S}^2_{d(E)}$	$\overline{S}^2_{d(F)}$
S-308	12.029	0.953*	−0.047*	0.445	0.518	144.298	1.437*	277.511
WG-377	13.109	0.902*	−0.098*	0.686	0.525	235.927	0.246	315.738
K-227	15.476	0.428*	−0.572*	0.316	0.335	120.388	0.227	242.314
PV-18	12.304	1.491*	0.491*	0.786	0.549	241.021	0.667	482.314
HD-1941	16.261	0.620*	−0.380*	0.186	0.367	147.837	−0.137	509.561
HD-1949	12.852	1.526*	0.526*	0.865	0.564	165.070	0.801	264.870
C-306	14.274	1.010*	0.010*	0.643	0.381	186.307	2.204*	377.239
C-281	13.426	1.067*	0.067*	0.741	0.666	170.358	0.489	327.803

Rank correlations: $r_s(b^E:\beta_i) = 1.00^{**}$

$r_s(b^E:b^F) = 0.90^{**}$

$r_s(b^E:r) = 0.83^{*}$

$r_s\{\text{ecov}:\ \overline{S}^2_{d(E)}\} = 0.35$

$r_s\{\text{ecov}:\ \overline{S}^2_{d(F)}\} = 0.54$

$r_s\{\overline{S}^2_{d(E)}:\overline{S}^2_{d(F)}\} = -0.09$

sponsiveness of the genotypes. As indicated by high rank correlations ($r_s = 0.90$), the regression coefficients of Freeman and Perkins' model (b^F) showed a similar trend to those of Eberhart and Russell (b^E). Under both these models, the most responsive variety was HD-1949, followed by PV-18 and C-281. In the rest of the cases there were shifts of one position only. For example, C-306, which occupied 4th position under the Eberhart and Russell model, was ranked 5th under the Freeman and Perkins model. (iii) There did not seem to be any correlation ($r_s = 0.35$) between the ranking pattern of varieties based on ecovalence and $\overline{S}^2_d$ of Eberhart and Russell's model. In contrast, the ecovalence seemed to be highly correlated with the $\overline{S}^2_d$ of Freeman and Perkins' model $\overline{S}^2_{d(F)}$, the rank correlation being 0.45. However, the ranking of varieties on the basis of $\overline{S}^2_d$ of Eberhart and Russell, $\overline{S}^2_{d(E)}$, was not reflected by the ranking done on the basis of Freeman and Perkins' model, $\overline{S}^2_{d(F)}$. None of the varieties occupied a common position under both models. This was also indicated by the low and non-significant rank correlation ($r_s = -0.09$).

In Table 3, the various parameters of responsiveness and stability obtained by using different statistical models for number of ears per plant are given. The behaviour of these parameters for ears per plant seemed to be very similar to those for grain yield per plant described above. The models of Eberhart and Russell (1966) and Perkins and Jinks (1968a) gave a similar picture for both response and stability. The genotypes which were least responsive towards environmental variations (i.e., smaller b values) were also those having the lowest environmental correlations, and *vice versa*. For example, K-227 had the lowest regression coefficient (0.36) and also the lowest environmental correlation (0.11), followed by HD-1941 ($b = 0.69$; $r = 0.16$), WG-377 ($b = 0.95$, $r = 0.25$) and S-308 ($b = 1.04$, $r = 0.25$). PV-18, HD-1949, C-306 and C-281 had higher values of regression coefficient (b) and also showed higher values for environmental correlation (r). The rank correlation between regression coefficient and environmental correlation was high and significant ($r_s = 0.834$). In other words, the environmental correlation was as good as regression coefficient for predicting the responsiveness of a variety. As indicated by high and

Table 3. *Estimates of stability parameters based on forty-eight environments using various models for ears per plant*

Genotypes	$\mu + d_i$	Reg. coeff. b^E	β_i	b^F	r	Ecovalence	$\overline{S}^2_{d(E)}$	$\overline{S}^2_{d(F)}$
S-308	2.980	1.041*	0.041*	0.798	0.285	0.459	−0.044*	17.268
WG-377	2.967	0.949*	−0.051*	0.340	0.249	0.463	−0.004	17.155
K-227	3.093	0.360*	−0.640*	0.107	0.107	0.361	−0.004	16.335
PV-18	2.943	1.343*	0.343*	1.015	0.318	1.722	−0.020	19.751
HD-1941	3.151	0.687*	−0.313*	0.059	1.005	0.155	−0.049*	19.751
HD-1949	3.001	1.094*	0.094*	1.194	0.390	0.708	−0.038*	17.586
C-306	3.107	1.316*	0.316*	1.472	0.437	1.164	−0.031*	18.542
C-281	3.043	1.207*	0.207*	0.657	0.504	0.486	−0.049*	18.045

Rank correlations: $r_s(b^E:\beta_i) = 1.00^{**}$

$r_s(b^E:\beta^F) = 0.810^{*}$

$r_s(b^F:r) = 0.834^{*}$

$r_s\{\text{ecov}:\ \overline{S}^2_{d(E)}\} = 0.16$

$r_s\{\text{ecov}:\ \overline{S}^2_{d(F)}\} = 0.93^{**}$

$r_e\{\overline{S}^2_{d(E)}:\overline{S}^2_{d(F)}\} = 0.48$

significant rank correlation ($r_s = 0.81$), the regression coefficients of both Freeman and Perkins' (1971) and Eberhart and Russell's models (1966) were equally efficient in predicting the responsiveness of the varieties. Under both these models, the least responsive variety was K-227, followed by HD-1941 and WG-377. In the rest of the cases, there were shifts of one or two positions.

As in the case of grain yield per plant, the rank correlation for number of ears per plant between ecovalence and $\bar{S}^2_{d(E)}$ was very low ($r_s = 0.16$). However, as indicated by high and significant rank correlation (0.93), the ecovalence seemed to be highly correlated with the $\bar{S}^2_d$ of Freeman and Perkins' model $\bar{S}^2_{d(F)}$. However, the ranking of genotypes on the basis of $\bar{S}^2_d$ of Eberhart and Russell $\bar{S}^2_{d(E)}$ was not similar to the ranking done on the basis of Freeman and Perkins' model ($r_s = 0.48$).

The stability parameters, based on various models, for number of grains per ear are given in Table 4. Here again, the ranking under the models of Eberhart and Russell (1966) and Perkins and Jinks (1968a) was the same both for response and stability. As in the case of grain yield per plant and number of ears per plant, the pattern of b values for this character also was more or less similar to that of the environmental correlations. Genotypes showing high b-values were the ones which had high environmental correlation as well. For example, WG-377, PV-18, HD-1941, C-306 and C-281 had higher values of regression coefficient and also of environmental correlation. In contrast, the regression coefficients under Freeman and Perkins' (1971) and Eberhart and Russell's (1966) models indicated low correlation (0.46). Similarly, the ecovalence was correlated neither with the $\bar{S}^2_d$ of Eberhart and Russell's model nor with Freeman and Perkins' model as indicated by low rank correlations i.e. 0.02 in both these cases. K-227 was, however, the most stable variety under both these situations. In contrast to the observations made for other characters, the rank correlation between $\bar{S}^2_{d(E)}$ and $\bar{S}^2_{d(F)}$ for grains per ear was high, though none of the parents was found to occupy a common position under both the models.

Perusal of the data in Table 5 on 1000-grain weight clearly shows that the pattern of b^E and b^F and r values was similar over all the genotypes. The rank

Table 4. *Estimates of stability parameters based on forty-eight environments using various models for grains per ear*

Genotypes	$\mu + d_i$	Reg. coeff.			r	Ecovalence	$\bar{S}^2_{d(E)}$	$\bar{S}^2_{d(F)}$
		b^E	β_i	b^F				
S-308	33.459	0.838*	−0.162	2.207	−0.121	695.251	15.502	3930.251
WG-377	42.852	1.167*	0.167*	−0.034	0.076	903.028	13.239	3547.665
K-227	48.073	0.431	−0.569	−1.023	0.001	299.673	9.931	3516.231
PV-18	44.205	1.108*	0.018*	0.508	0.399	675.362	43.001	4368.404
HD-1941	45.238	1.195*	0.195*	0.340	0.067	585.850	4.546	3764.951
HD-1949	39.622	0.685*	−0.315*	1.396	−0.025	336.198	19.783	3988.470
C-306	37.613	1.277*	0.277*	1.763	0.028	1021.766	5.049	3662.383
C-281	39.400	1.385*	0.850*	1.358	0.305	625.872	11.715	3853.221

Rank correlations:

$r_s(b^E:\beta_i) = 1.00^{**}$

$r_s(b^E:b^F) = 0.46$

$r_s(b^E:r) = 0.572$

$r_s\{\text{ecov}: \bar{S}^2_{d(E)}\} = 0.02$

$r_s\{\text{ecov}: \bar{S}^2_{d(F)}\} = 0.02$

$r_s\{\bar{S}^2_{d(E)}:\bar{S}^2_{d(F)}\} = 0.64$

Table 5. *Estimates of stability parameters based on forty-eight environments using various models for 1000-grain weight*

Genotypes	$\mu + d_i$	Reg. coeff.			r	Ecovalence	$\bar{S}^2_{d(E)}$	$\bar{S}^2_{d(F)}$
		b^E	β_i	b^F				
S-308	47.045	0.870*	−0.130*	−3.322	0.246	299.363	4.263	3243.033
WG-377	39.365	1.195*	0.195*	3.889	0.699	373.408	5.194	3767.806
K-227	47.968	0.667*	−0.333*	−3.656	0.210	96.681	0.096	2916.588
PV-18	36.265	0.913*	−0.087*	−2.100	0.538	230.044	3.764	3288.340
HD-1941	30.487	0.987*	−0.013*	−2.393	0.233	58.564	0.096	3090.232
HD-1949	39.832	0.707*	−0.293*	−0.049	0.280	157.998	1.557	3551.675
C-306	44.500	1.086*	0.086*	1.112	0.592	300.682	5.299	3039.855
C-281	41.363	1.571	0.573*	1.423	0.623	285.224	4.711	3486.377

Rank correlations:

$r_s(b^E:\beta_i) = 1.00^{*}$

$r_s(b^E:b^F) = 0.81^{*}$

$r_s(b^E:r) = 0.834^{*}$

$r_s\{\text{ecov}: \bar{S}^2_{d(E)}\} = 0.93^{**}$

$r_s\{\text{ecov}: \bar{S}^2_{d(F)}\} = 0.39$

$r_s\{\bar{S}^2_{d(E)}:\bar{S}^2_{d(F)} = 0.34$

Table 6. *Estimates of stability parameters based on forty-eight environments using various models for height*

Genotypes	$\mu + d_i$	Reg. coeff.			r	Ecovalence	$\overline{S}^2_{d(E)}$	$\overline{S}^2_{d(F)}$
		b^E	β_i	b^F				
S-308	87.784	0.717*	−0.283*	1.601	0.582	17157.074	4.737	17872.016
WG-377	86.309	0.804*	−0.196*	1.514	0.608	4756.933	4.961	17617.331
K-227	89.807	0.830*	−0.170*	2.718	0.612	7660.991	1.355	18793.664
PV-18	84.493	0.897*	−0.103*	1.936	0.424	6235.105	28.492	18548.301
HD-1941	72.218	0.575*	−0.425*	1.038	0.398	4122.780	9.987	10892.224
HD-1949	66.528	0.546*	−0.454*	1.293	0.500	3118.749	1.183	10233.248
C-306	110.415	1.775*	0.775*	5.634	0.628	5687.819	66.029*	31453.260
C-281	111.834	1.851*	0.851*	4.662	0.619	24157.076	81.704*	31358.206

Rank correlations: $r_s(b^E:\beta_i) = 1.00^*$ $\qquad r_s\{\text{ecov}: \overline{S}^2_{d(E)}\} = 0.39$

$r_s(b^E:b^F) = 0.91^{**}$ $\qquad r_s\{\text{ecov}: \overline{S}^2_{d(F)}\} = 0.70$

$r_s(b^E:r) = 0.691$ $\qquad r_s\{\overline{S}^2_{d(E)}:\overline{S}^2_{d(F)}\} = 0.64$

Table 7. *Selection of stable genotypes using $\overline{S}^2_d$ and ecovalence for various traits in wheat*

Grain yield		Ears per plant		Grains per ear		1000-grain weight		Plant height	
$\overline{S}^2_d$	Ecovalence	$\overline{S}^2_d$	Ecoval.	$\overline{S}^2_d$	Ecovalence	$\overline{S}^2_d$	Ecovalence	$\overline{S}^2_d$	Ecovalence
K-227	K-227	K-227	K-227	K-227	K-227	K-227	K-227	HD-1949	HD-1949
WG-377	WG-377	WG-377	WG-377	HD-1949	HD-1949	HD-1949	HD-1949	HD-1941	HD-1941
HD-1941	HD-1949	—	—	S-308	2C-81	HD-1941	HD-1941	S-308	C-306
C-281	S-308	—	—	HD-1941	HD-1941	PV-18	PV-18	WG-377	WG-377

correlation was very high and significant in all cases. Contrary to the position with all other characters described, the rank correlation between ecovalence and $\overline{S}^2_{d(E)}$ was very high and significant for 1000-grain weight, whereas the rank correlations between $\overline{S}^2_{d(E)}$ and $\overline{S}^2_{d(F)}$ and between ecovalence and $\overline{S}^2_{d(F)}$ were relatively low.

For plant height also, the pattern of stability parameters was in no way different from those for other characters (Table 6). The three parameters b^E, b^F, and β_i gave similar pictures. The rank correlation between b values and the environmental correlations were high (0.69). In this case also, the pattern of genotypic rankings under ecovalence did not seem to be reflected by the ranking pattern under $\overline{S}^2_{d(E)}$ as indicated by low rank correlation (0.39). On the other hand, ecovalence showed a high association with the $\overline{S}^2_{d(F)}$. HD-1949 showed high stability under both ecovalence and Freeman and Perkins' model. The correlation between ranking pattern under $\overline{S}^2_{d(E)}$ and $\overline{S}^2_{d(F)}$ was also high (0.64).

These results have clearly shown that the rank correlations between the rankings of parents based on $\overline{S}^2_{d(E)}$ and ecovalence for all the characters, except 1000-grain weight, were generally low. On the other hand, ecovalence showed high correlation with $\overline{S}^2_d$ of Freeman and Perkins' model. Table 7 shows the most stable parents with regard to different characters, taking two criteria, evocalence and $\overline{S}^2_d$ of Eberhart and Russell's model (1966), into consideration. For 1000-grain weight, the same four parents, i.e. K-227, HD-1941, HD-1949 and PV-18, were selected by both the criteria of selection. For two other characters, grains per ear and plant height, three out of four parents were common using both criteria. For ears per plant, when considering $\overline{S}^2_d$ only two lines, K-227 ad WG-377, proved to be stable; the same two lines were found to have the least contribution to the genotype × environment interaction variance under the ecovalence method also. For grain yield also, the two most stable varieties (K-227 and WG-377) were selected under both the criteria. This clearly suggests that the most stable varities may be spotted by both these methods, though the ranking of least stable varieties under ecovalence was not the same as under Eberhart and Russell's model.

Discussion

Plant Breeding is the exploitation of genetic variability which is, however, not directly measurable by itself and has to be inferred from the phenotype. This is further complicated by the fact that all genotypes need not react in a similar way to changes in the environment, that is to say, there is a genotype × environment interaction. Screening of genotypes for high stability under varying environmental conditions has thus become an essential part of the breeding programme. The three models used in the present study, i.e. Eberhart and Russell (1966), Perkins and

Jinks (1968a) and Freeman and Perkins (1971), provide various estimates of stability parameters. The two models, Perkins and Jinks' model and Eberhart and Russell's model, are associated with each other such that x_i, b_i and $\overline{S}^2_d$ of the former is equivalent to $(\mu + d_i)$, $(1 + \beta_i)$ and $\overline{S}^2_d$ of the latter, respectively. Consequently, the ranking pattern of genotypes under Perkins and Jinks' model will be similar to the pattern under Eberhart and Russell's model, and this was the case in the present investigation also. Apparently, using Eberhart and Russell's model could give no additional information compared with Perkins and Jinks' model for these parameters. Interestingly, the ranking pattern of the genotypes for their responsiveness using b-values estimated on the basis of Freeman and Perkins' model was also similar to the rankings done under the two models described above. This clearly showed that any of the three models could be used with almost equal efficiency for selecting the desirable genotypes giving higher response under favourable environments.

Another parameter which showed high association with the pattern of regression coefficients obtained under various models (b^E, β_i and b^F) was the correlation coefficient (r) measured between different environments for each genotype with regard to a specific character at a time. For all those genotypes, where the b-values were high for a particular character, the environmental correlations were also high, and *vice versa*. High and significant rank correlations were established between these two parameters for all the characters studied here. Clearly, the prediction of most responsive variety may be made by studying the environmental correlations as well. Similar observations were also made by Tehlan (1973) in wheat.

Considering that in all field trials one has to use variance analysis for testing the significance of genotypic, environmental and genotype × environmental interactions, and if at the same time the sum of product between two environments for a particular character is also constructed and fed to the computer, the estimation of the environmental correlations will not require any additional computational cost. The estimation of b-values is comparatively complicated and time consuming as well. Actually, the estimation of correlation (r) falls well in the pathway of variance analysis and hence is easier to compute than the estimation of b-values, which requires a separate pathway for computation.

For the stability parameter, the ranking of genotypes under Perkins and Jinks' model was the same as under Eberhart and Russell's model. However, the rankings under these two models were not reflected by the ranking on the basis of $\overline{S}^2_d$ estimated by Freeman and Perkins' model. The rank correlations were low for all the characters. In contrast, the ranking on the basis of ecovalence was very similar to the ranking based on $\overline{S}^2_d$ of Freeman and Perkins, model. The rank correlations for these two models were high as well as significant. As a matter of fact, the comparison between the stability models ended here because there was no basis on which to speak about the superiority or inferiority of one model over the other, as no statistical test was applied to assess the extent of precision of estimates under these models. It was, however, evident that the two models, ecovalence and the $\overline{S}^2_{d(F)}$, gave similar results, whereas Eberhart and Russell's model presented, in general, a different picture of stability of various genotypes. Further, as stated by Freeman and Perkins (1971), the stability parameters under Eberhart and Russell's model were based on a regression model which did not fulfil the fundamental statistical assumptions. Conclusively, more reliance should be placed on the stability parameters estimated on the basis of the statistical technique proposed by Freeman and Perkins (1971) in which the necessary assumptions were taken fully into account. Considering that ecovalence was highly associated with Freeman and Perkins' model and was also more convenient from a computational point of view, ecovalence should be given preference to other methods for predicting the stability in performance of a genotype.

A simple empirical basis was used for comparing ecovalence and Eberhart and Russell's model. By using these two models independently, the few most stable varieties were selected with regard to each character. Interestingly, the most stable genotypes were found to be the same under both these criteria of selection. For example, K-227 and WG-377 were found to be the most stable varieties for grain yield under both criteria. For other characters also, the most stable varieties were always the same irrespective of whether the selection criterion was ecovalence or Eberhart and Russell's model. This clearly showed that so far as the selection of a few stable genotypes was concerned, each of the two models was equally effective. The problem arose only with the ranking of less stable genotypes, whose positions differed greatly under these two models. If, therefore, a breeder's interest is only to spot the most stable genotypes, it is immaterial, so far as efficiency is concerned, which of these two techniques is followed. However, considering the simple and direct computational steps involved in the 'ecovalence', one would definitely prefer this model. Ecovalence falls well in the pathway of variance analysis and variance analysis is a must for testing the significance of genotype × environmental interaction. The estimation of ecovalence would not require much additional computational complication because when the sum of squares due to genotype × environmental interaction is constructed, it would be possible to partition this sum of squares into different parts attributable to each genotype. It is known that the sum of squares due to genotype × environment interaction is equal to:

$$\sum_i \sum_j X_{ij}^2 - \frac{1}{p} \sum_j X_{.j}^2 - \frac{1}{q} \sum_i X_{i.}^2 + \frac{1}{pq} X_{..}^2 \qquad (3)$$

whereas 'ecovalence' as given under 'Material and Method' (equation 2) may also be expressed as follows:

$$\sum_j X_{ij}^2 - \frac{2}{p} \sum_j X_{ij.} X_{.j} + \frac{1}{p^2} \sum_j X_{.j}^2 - \frac{1}{q} \left(X_{1.} - \frac{X_{..}}{p} \right)^2 . \qquad (4)$$

It is easy to show that a summation of this equation (4) over all the genotypes (i) would give;

$$\sum_i \sum_j X_{ij}^2 - \frac{2}{p} \sum_j X_{.j}^2 + \frac{1}{p} \sum_j X_{.j}^2 - \frac{1}{q} \sum_i X_i^2 + + \frac{2}{pq} X_{..}^2 - \frac{1}{pq} X_{..}^2 ,$$

which ultimately is the same as equation 3 (Wricke, 1962).

This means that both these components can be calculated simultaneously and without any additional shift in the flow of the data in the computer. Keeping computational convenience and efficiency in view, it may be concluded that the two parameters, i.e. correlation between environments and the ecovalence, may be given preference for predicting the response and the stability, respectively, without any loss of precision.

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