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A Review on Genotype Environment Interaction and its Stability Measures

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Abstract: ***Genotype× Environment Interaction (GEI) is a common phenomenon in genetics as it results in inconsistent performance between the genotype across environments. When interaction occurs, factor present in environment, as well as the genetic constitution of genotype, influences the phenotypic expression of a trait. Due to their importance in the practical world the different methodsof calculating it have been studied in present paper. The stability measures of different genotypes have also been studied.***

Keywords: ANOVA, Regression coefficient, Stability Measure, etc.

1. Introduction

The increase in population and the subsequent rise in the demand for agricultural produce are expected to be greater in regions where production is already insufficient, in particular in South Asia. The necessary increase in agricultural production represents a have challenges to local forming systems and must come mainly from increased yield per unit area, given the limited scope for extension of cultivated land worldwide. To meet this requirement various crop improvement programmes all over the world have been initiated. Under any crop improvement programme a sample of promising genotypes are performance tested each year at a number of site, representing the major growing area of the crop with a view to identify genotypes which proses the dual qualities of high-yield sustainability to adverse changes in environment condition. It is observed that a specified difference in environment may produce differential effect on genotype. This interplay of genetic and non-genetic effects causing differential relative performances of genotypes in different environments is called Genotype × Environment Interaction(GEI).

For carrying out stability analysis, one needs to have mean performance to all the genotypes in each of the environments. But it practice, due to various reasons such as insufficient seed, pour germination, missing observation, etc, it is usually not possible to test every genotype at environment thus the resulting genotype environment table becomes incomplete. Obviously, one should incorporate some adjustment in the genotypic effect due to unequal number of observations so as to compensate the loss. The modified regression methods suggested by different workers are considered to analysis such data. For finding the stability measure experimenters firstly go for the designing of experiment of multi-location trails and then analysis of the design. This is usually evidenced by a significant location year interaction in the ANOVA. Analysis of variance of multi-location trails is useful for estimating variance components related to different source of variation, including genotype and genotype × environmental interaction (GEI). In general, variance component methodology is important in multi-location trails, since largely from GEI. Therefore, knowledge of the size of this interaction is required to (a) obtain efficient estimates of the genotypic effects and (b) determine optimum resources allocations, that is, the number of plots and locations to be including in future trails. Different concept and definition of stability and its types have been described over the last five decades years.

Plaisted and Peterson (1959) estimated the variance component of genotype environment interactions for interactions for each of the possible pairs of cultivars and considered the average of the estimate for all combinations with a common cultivar to be measure of stability. According to them the cultivars which show lower value for the $\theta_i(\%)$ estimate are considered more stable. Their original measure was originally defined in term of replicated data but the formula is modified and is based on the cell mean. The mean variance component for pair-wise GEI $(\bar{\theta}_i)$

$$\bar{\theta}_i = \frac{S.S.G.E}{(m-2)(n-1)} + \sum_j^n (GE)^2 \frac{1}{2(m-1)(n-1)}$$

Where m and n are number of genotypes and environments respectably and

$$SSGE = \sum_i \sum_j (y_{ij} - \bar{y}_{i.} - \bar{y}_{.j} - \bar{y}_{..})^2 ;$$

$GE = y_{ij} - \bar{y}_{i.} - \bar{y}_{.j} + \bar{y}_{..}$ with $i = 1,2,\dots,m$ and $j = 1,2,\dots,n$; y_{ij} is the mean yield of the i^{th} genotype and in j^{th} environment; $\bar{y}_{.j}$ is the mean yield of all genotypes in the j^{th} environment and $\bar{y}_{..}$ is the mean of all genotypes in all environments. The genotype with the smallest mean variance component contributor lest to the total interaction and is considered the most stable.

Plaisted (1960) modified his work and proposed a modified measure of stability to defect the i^{th} genotype from the subset was termed as the stability index of the i^{th} genotype, mathematically it may be written as.

$$\theta_{(i)} = \frac{SSGE}{(m-2)(n-1)} - \frac{m}{(m-1)(m-2)(n-1)} \sum_j (GE)^2$$

Wricke (1962) proposed model use the contribution of each genotype to the sum of squares as a stability measure and define simple to calculated and is expressed as

$$W_i^2 = \sum_j (y_{ij} - \bar{y}_{i.} - \bar{y}_{.j} + \bar{y}_{..})^2$$

Thus, a genotype with the smallest ecovalence was to be considered as the most stable.

A perfect measure of phenotypic stability was considered by Finlay and Wilkinson (1963) with regression coefficient, $b_i = 0$, of a genotype whose yield in each environment was almost the same. The observed values were regressed onto the environment indices, defined as the difference between the marginal mean of environments and the general mean. The stability measure is given by

$$b_i = \frac{\sum_j (y_{ij} - \bar{y}_{i.})(\bar{y}_{.j} - \bar{y}_{..})}{\sum_j (\bar{y}_{.j} - \bar{y}_{..})^2}$$

Eberhant and Rusell (1966) developed Finlay and Wilkinson (1963) regression concept of stability and suggested the use of two stability parameters. They proposed that the regression of each cultivar on an environmental index and a function of the squared deviations from regression would provide more useful estimate of yield stability parameters and may be given as

$$\delta_i^2 = \frac{1}{(n-2)} \sum_j (y_{ij} - \bar{y}_{i.})^2 - \frac{b_i^2}{(n-2)} \sum_j (\bar{y}_{.j} - \bar{y}_{..})^2$$

They defined a stable genotype as the one which showed high mean yield, regression coefficient (b_i) around unity and deviation from regression near zero. Accordingly, of the mean and deviation from regression of each genotype were for testing the varietal response. Genotypes with high mean b_i >1 with non-significant δ_i^2 are considered as below average in stability such genotypes tend to respond favourably to better environments but give poor yield in unfavorable environment. Hence, they are suitable for favorable environments.

Perkins and Jinks (1968) discussed the linear sensitivity to change in environment, measured by the regression coefficient $B_{i,}$ was considered as stability adjusted for location effects and regression coefficient in modified form was calculated by

$$B_i = \frac{\sum_j (GE)^2 (\bar{y}_{.j} - \bar{y}_{..})}{\sum_j (\bar{y}_{.j} - \bar{y}_{..})^2}$$

An additional measure of non-linear sensitivity to the environmental change was also considered by them. The GEI component of each genotype was considered as a linear function of the additive environmental component. The deviation from the regression line for each environment was treated as a fixed effect rather than random effect. The stability statistics was defined as

$$\delta_i^2 = \frac{1}{(n-2)} \sum_j (GE)^2 - \frac{B_i^2}{(n-2)} \sum_j (\bar{y}_{.j} - \bar{y}_{..})^2$$

A genotype was considered stable when $B_i = 0$and $\delta_i^2 = 0$. Shukla (1972) proposed a stability measure by partitioning the GE sum of square into component for each genotype separately. He defined the stability variance of i^{th} genotype as its variance across environments after the main effect of environment. Since the genotype main effect is constant, the stability variance is thus based on the residual matrix in a two way classification. The stability statistics is termed stability variance (σ^2) and is estimated as follows

$$\sigma_i^2 = \frac{1}{(m-2)(m-1)} \sum_j (GE)^2 - \frac{SSGE}{(m-1)(m-2)(m-3)}$$

A genotype is called stableif its stability variance is equal to environmental variance which means that $\sigma_i^2 = 0$. negative estimate of σ_i^2maybe take be equal to zero as usual.

Laxmi (1992) proposed a stability measure by giving weightage to environmental conditions. The genotypes having the maximum yields in all the environments under trial are most stable and therefore stability factor had been considered the weighted men value of standardized yields over the environments.

$$Z_i = \frac{(y_{ij} - \bar{y}_{.j})}{\sqrt{V_j}}$$

and the stability factor for the genotype was defined as

$$G_i = \sum_j w_j \frac{(y_{ij} - \bar{y}_{.j})}{\sqrt{V_i}}$$

wherew_j is weight coefficient, V_j is environmental variance For comparison she suggested the critical difference which is given by

$$CS(G_i) = t_\alpha \left[\frac{M_e'(n+1)}{nm}\right]^{1/2}$$

Where $M_e' = \frac{\sum_j w_j M_{e_j}}{n\sqrt{v_j}}$, is the modified mean square error and t_α is student's t-value for the given significance level. If $G_i \geq C.D(G_i)$, the genotype having the values are characterized with higher stability. In case of $G_i \leq CD(G_i)$, the genotypes having the values are characterized with lower stability. The remaining genotypes lying in between values are considered as having average stability.

Parmita (2012) modified the stability parameters obtained by Eberhart and Rusell (1966) for neighbour effects by considering right and left neighbour effect of treatments. For the i^{th} genotype the modified stability measures are given by

$$\beta_i^N = \frac{\sum_j y_{ij} E_j}{\sum_j E_j^2}$$

And

$$\eta_i^2 = E_j y_{ij.} - \left(\frac{\bar{y}_{i.}^2}{r} - \sum_j \bar{y}_{j.}^2\right) \frac{\sum_j \bar{y}_{ij}.E_j}{\sum_j E_j^2}$$

Where E_j is the effect of j^{th} environment. These stability measures are tested against given mean square errors.

2. Materials and Methods

The data in Table 1 is the pod yield of 15 varieties (G1,G2,…,G15) of ground nut crop raised at 20 locations (L1,L2,…,L20). The experimental design used is RCBD at each locations with three replication.[Rao et al. (2004)]

Table 1: Grand Nut Crop Yield

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
G1	1773	880	2841	2020	856	1382	1458	282	1190	1001
G2	1715	861	2497	2020	505	1104	1153	275	1394	882
G3	1241	424	3266	1717	1148	1225	1130	113	701	705
G4	1472	917	3172	2222	1505	1475	1222	632	1308	334
G5	1208	1435	3625	1919	903	1432	921	862	1081	539
G6	1893	1310	2716	2374	1320	1476	1482	680	1468	591
G7	1852	1169	2527	2222	903	1220	1407	455	1637	521
G8	1266	993	2245	1869	292	972	1171	275	1419	767
G9	1736	792	2376	2172	981	1113	1051	364	1579	364
G10	1442	695	2800	2071	1051	1890	1051	605	1684	67
G11	1530	1055	2643	2172	1412	1049	1051	567	1211	174
G12	1697	1222	2770	2273	1759	1343	1153	572	1169	353
G13	1637	1097	2715	2071	1806	1158	1199	636	1269	437
G14	1641	1403	2712	2071	792	1037	1199	757	1296	643
G15	1723	1139	2452	2071	481	883	1519	299	1330	366
	L11	**L12**	**L13**	**L14**	**L15**	**L16**	**L17**	**L18**	**L19**	**L20**
G1	2708	1832	1188	2252	1583	2014	2199	810	1033	992
G2	1956	1907	729	1658	1285	1986	2014	865	600	842
G3	1688	1568	1153	2073	1303	2361	2893	1028	1000	997
G4	2833	1157	792	956	1374	2570	611	486	333	1049
G5	2303	1778	577	1132	1368	2691	495	639	300	877
G6	2877	2333	1005	2636	1438	2812	1968	963	1100	1413
G7	2042	1732	1285	2046	1333	2500	2060	949	633	877
G8	2182	2037	799	1749	1368	2083	1537	732	667	965
G9	2940	1500	819	1668	1041	1944	2431	1000	633	967
G10	2083	1419	1146	1295	1750	2726	1713	50	600	1166
G11	1977	1963	1083	2063	1319	1789	1435	944	633	1109
G12	2014	2222	792	1634	1319	3371	2014	1176	1200	1026
G13	1574	1843	958	1719	1299	2014	2431	1014	1033	1379
G14	2347	1889	1035	1551	1375	1993	2222	875	933	1092
G15	1535	1574	1070	1940	1146	1514	2208	745	567	904

For the data different stability measures discussed above are calculated and summarized in the Table 2. In general, the variance S_i^2 of a genotype across environment \location has been largely used as a measure of stability with a simple logic that deviation from the average genotype effect is the rule to stability of genotype. Due to this reason, this measure is considered in first column of table 2 and calculated using

$$S_i^2 = \frac{1}{(n-1)} \sum_j \left(y_{ij} - \bar{y}_{i.}\right)^2$$

Comparison between the investigated estimators is calculated by the concept of rank correlation coefficient after η_s Spearman

$$\eta_s = 1 - \frac{6 \sum_i^n d_i^2}{n(n^2-1)}$$

Where d_i is the difference between two ranks of investigated stability measures.

Table 2: Estimated Stability Measures

Genotype Variation x10^7	Plaisted and Peterson's Measure x10^7	Plaisted's Measure x10^7	Wricke's Measure x10^8	Finlay and Wilkinson's Measure	Eberhart and Rusell's Measure x10^9	Perkins and Jinks's Measure x10^8	Shukla's Measure x10^8
5.2549	3.6237	3.0917	4.5567	-301.3285	-23.9701	-381.257	6.6350
4.4285	3.5925	3.1637	4.7040	-152.0036	-6.0713	-198.813	6.8503
4.2076	3.5868	3.1769	4.8048	-137.0393	-4.9311	-50.5815	6.9977
3.9548	3.5823	3.1872	4.9078	-132.6494	-4.6178	-37.1525	7.1482
3.9330	3.5813	3.1897	4.9762	-110.0241	-3.1684	-21.4355	7.2481
3.8195	3.5731	3.2086	4.9826	-62.8869	-1.9883	-9.8141	7.2575
3.5265	3.5684	3.2195	5.0223	-59.7382	-1.0038	-7.7965	7.3155
3.4599	3.5645	3.2285	5.4038	-44.9764	-0.9068	-7.5945	7.8731
3.4180	3.5573	3.2450	5.6120	-20.4967	-0.4929	-6.3507	8.1775
3.3868	3.5565	3.2468	5.8629	-16.2278	-0.3468	-3.2239	8.5441
3.2003	3.5564	3.2470	6.2985	-8.8778	-0.2151	-3.0900	9.1808
3.1587	3.5551	3.2500	6.3544	-4.5320	-0.0556	-2.9668	9.2625

3.1196	3.5532	3.2545	6.5927	30.6822	-0.0252	-2.7591	9.6108
2.9733	3.5513	3.2588	6.8972	38.0435	0.0195	-1.1151	1.0056
2.9551	3.5485	3.2652	8.5575	87.5385	0.0413	-0.9116	0.1248

3. Conclusion and Discussion

Analysis of stability is a biometrical method with great potential for characterization of the relative performance of a group of varieties under different environment conditions. A theoretical ideal, genotype, would be the one which possesses a relatively high yield and stable performance in the low yielding environments and the capacity to respond to favorable environment as well. In this way, several measures have been developed by different researchers for varying situations and conditions. The term stable variety has been to mean a variety that doses relatively the same over a wide range of environments. In other words, a stable variety performs well under adverse conditions but not so well in favorable environments, if increased inputs or technology are applied.

For the above data, different stability measures for all the fifteen genotypes are calculated and the genotype G8 is found most stable and G6 is found least stable when the genotypic variation is used as the stability measure. When the stability is calculated using the measures proposed by Plaisted and Peterson (1959), the genotype G15 is found most stable and reverse results are obtained when the Plaisted (1960) measure is used, which gives negatively correlation with the pervious. Using Wricke (1962) measure is used G15 is obtained most stable and G6 is least stable. Similarly results are obtained using statistics proposed by Shukla (1972)

When the concept of regression coefficient given by Ebarhart and Russell (1966) genotype G15 is found least stable while is found to least stable. But according to Perkins and Jinks (1968) all the genotypes G1 to G15 are in better yield environment.

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