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REPEATABILITY OF YIELD STABILITY STATISTICS IN COTTON

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Abstract

Several types of stability statistics can be used to estimate the stability of genotype performance. When we select stability indices, we want to consider the extent to which they are repeatable. In this study an effort was undertaken on assessing the repeatability of various stability indices in Greek and Spanish cotton growing locations. A five year data set obtained from Delta & Pine Land International Agronomic Services variety evaluation program in Greece and Spain from 2000 to 2004. Totally eight stability statistics indices, were estimated from balanced datasets of 1-yr and 2-yr results and rank correlated for estimating repeatability. The stability indices were: Eberhart and Russel sd^2, Shukla's stability variance, GGE Distance Model 1 and Model 2 (M_1D, M_2D respectively), GGE Instability Model 1 and Model 2 (M_1I, M_2I respectively), AMMI 1, and Kang's YS_i. Among the results the most significant were the following. Significant correlations were found between M_1D, M_2D, yield, and YS_i. M_1D had better correlation with yield, and YS_i than M_2D. GGE Instability indices correlated with indices that measure the GE effect like AMMI 1, Shukla, and sd^2. Both M_1I and M_2I, found to have better correlation with AMMI 1 (r=0.75 and 0.73 respectively). Shukla's index had also high correlation with AMMI1 (r=0.75). M_1D was more repeatable than M_2D. In years with high yield repeatability M_1D follows or exceeds yield repeatability. In the years with low yield repeatability M_1D had low repeatability like yield. As the number of testing environments increases (2-yrs data) on average AMMI 1 hand high repeatability (r=0.84 significant) followed by Shulka's (r=0.67 but non significant), regardless of how much repeatable is yield.

Introduction

Genotype x environment interactions (GEI) is an important issue faced by plant breeders and agronomists. A significant GXE interaction for a quantitative trait such as cotton yield can seriously limit progress in selection. In a trial of genotypes evaluated across environments, the main effect of a genotype is essential to predict future performance. Environment main effect would also be important in predicting future performance too, if it is associated with a repeatable fixed factor such as soil type or fertility. The presence of large GEI effects in a trial decreases the predictive value of a main effect model. A genotype is stable if its trait expression across environments contributes little to GEI and its performance should be more predictable from the main effects of genotypes and environments. Several types of stability statistics can be used to estimate the stability of genotype performance. The different stability types have been well reviewed (Lin et al., 1986). When selecting statistics to asses yield stability, a breeder or an agronomist will want to consider the extent to which the statistic is under genetic control and whether genotype ranking are repeatable (Sneller et al., 1997).

A commonly used measure of stability is the regression coefficient (b_i) from regressing the mean of the *i*th cultivar in an environmental index. Eberhart and Russell (1966) advocated using the mean of squared deviations (sd^2) from regression, as a stability statistics. The repeatability of sd^2 is generally low as reported by Helms, 1993; Jalaluddin and Harrison, 1993; Pham and Kang, 1988; Sneller et all., 1997. However Zavala – Garcia et all. (1992) reported that sd^2 had higher heritability that b_i. Shulka (1972) proposed a stability index that it is called "stability variance" σ_i^2, and it is based on the partitioning of the GEI sum of squares into components attributable to individual genotypes. A genotype is stable when its contribution to GEI is small. It has been used widely as a base index from several researchers though reported that the repeatability of genotype ranking is low (Eagles and Frey, 1977; Helms, 1993; Jalaluddin and Harrison, 1993; Pham and Kang, 1988; Sneller et al., 1997). Kang proposed the yield stability statistic (YS_i) (Kang, 1993), that selects for mean yield and stability, with cultivar ranking based on Shukla's stability index and mean performance ranking after a protected LSD adjustment.

The multivariate Additive Main Effects and Multiplicative Interaction (AMMI) model is more efficient in determining the most stable and high yielding genotypes in multi-environment trials compared to earlier procedures of regression (Gauch, 1992). The model uses the analysis of variance (ANOVA) approach to study the main effects of genotypes and environments, and a principal component analysis (PCA) for the residual multiplicative interaction between genotypes and environments. With the biplot facility from AMMI analysis, both genotypes and environments occur on the same scatter plot and inferences about their interactions can be made. In an AMMI analysis, genotypes with low scores for the principal components retained in the AMMI model would be stable as their future performance would be predictable from a main effects model. Zavala-Garcia et al. (1992), reported moderate heritability for the first IPC scores in two *Sorghum bicolor(L.) Moench* populations. Recently a new multivariate model, named GGE Biplot developed to address the interpretation of GEI (Yan, 2001). According to the GGE biolpot concept, the yield of a cultivar in a given environment is a mixed effect of genotype (G) and an environment effect (E) and their GEI interaction. With GGE Biplots model genotypes evaluated for their combined G and GE effect and thus the term GGE was adapted (Yan et al., 2000). Yan (2001) in the output of the GGE Biplots software, provides two indexes: the GGE instability index and the GGE distance. The GGE distance is a measure of the distance to the "ideal" genotype. The more desirable genotype is in terms of both mean performance and stability. The Instability index is a measure of the distance between the predicted and the actual values from the model. GGE Biplot is equipped with a variety of models, scaling, and data transformations to provide the user with a customized biplot. Four models can be used to generate a biplot: 1) Model 0 (M_0) generates biplots on Singular Value Decomposition (SVD) of the grand-mean centred data and is used only for datasets containing binary data, 2) Model 1 (M_1) generates bilpots on SVD of tester-centered data, commonly used for datasets in which all testers use the same unit, such as a genotype x environment table of a single trait, 3) Model 2 (M_2) generates bilpots on SVD of within-tester standard deviation, standardized data and is used for datasets in which different units are used for different testers or when all testers are assumed to be equally important, 4) Model 3 (M_3) generates biplots based on SVD of within-tester standard error-standardized data and is used only when replicated data are input and to remove heterogeneity among the testers. A biplot can scaled three ways: 1) entry – focused scaling, 2) tester-focused scaling, 3) symmetrical scaling. GGE biplot indices estimated from the respective models will be referred as M(0..3)I for Instability and M(0..3)D for the Distance index. Sterling (2005) found that differences in stability values between entry-focuced, tester-focuced, and symmetrical scaling are minimal, and suggested using the entry-focused scaling method for better characterization of genotypes. He also found M_2I index and M_3I were highly correlated (r=0.97) but M_1I, hand lower correlations, 0.79 and 0.82 with M_2I and M_3I respectively. Correlation coefficients between M_2I or M_3I with Shukla, sd^2, AMMI 1, YS_i, and M_2D, were 0.91, 0.86, -0.55, 0.63, 0.59. Correlation coefficients between M_2D was high with YS (r= 0.85) but low with AMMI 1 (r= -0.33).

This study aims at the assessment of the repeatability and the relations among Shukla's stability variance, Eberhart's and Russel sd^2, AMMI 1, Kang's YS, GGE Distance (M_1D, M_2D and GGE Instability M_1I, M_2I.

Materials and methods

A five year (2000 – 2004) data set from Delta & Pine Land International Agronomic Services cultivar evaluation program in Greece-and Spain was used. Twenty six cultivars were included in the evaluation during this period. Among all of them, four were included in every year testing, as common checks.
An RCB experimental design, with four replications, four row plots 10 meters long and 0.95 meter row spacing in each location was applied. Standard cultural practices followed throughout the growing season. The two central rows of each plot were hand picked for seedcotton yield determination.

Three data sets were constructed. The first set included data from all cultivars tested in each year. The number of cultivars and environments is summarized in Table 1. The second set included cultivars tested in the previous year or in the following year, Table 3. The third data set includes 2-yr data and constructed using data from four consecutive years, Table 4.

Analysis of variance was performed for each data set considering cultivars and environments as random effects. The sum of squares (SS) derived from ANOVA was partitioned into percent (%) SS of the treatment SS. The treatment SS_{TRTMT} was calculated as the sum $SS_{TRTMT} = SS_G + SS_E + SS_{GEI,}$ (Gauch, 1992) The respective symbols were SS_G for the genotype, SS_E for the environment and SS_{GE} for the interaction sum of squares.

Eberhart and Rusell sd^2 stability statistics was estimated from regressing yield of the *i*th cultivar on an environmental index (the mean of all cultivars in each environment). Regression analysis performed using the computer statistical software JMP (SAS Institute). The Shukla's stability variance index (Shukla, 1972) calculated by GGE Bioplot software. Kang's yield stability YS_i estimated as described by Kang (1993). The AMMI statistics was calculated using the Irristat statistical software (International Rice Research Institute, Manila, Philippines). The first AMMI1 principal component was used as an absolute value (|IPC1|). GGE biplot indices, GGE Distance and GGE Instability, were calculated with GGE biplot software (Yan, 2001). For the GGE biplot calculations were used: Model 1 which represents tester centering, zero scaling and entry focused singular value partitioning. Model 2, which represents tester centering, scaling standardized with standard deviation and entry focused singular value partitioning. We did not used Model 3 since concerns replicated data and wanted to use the same data we used for the rest indices. We neither used Model 0 since concerns binary data. Our scaling was entry-focused since there is not any difference in stability values regarding the rest scaling methods (tester or symmetrical).

To assess whether estimates of cultivar stability were repeatable across years, Spearman's rank correlations were calculated between the estimates of cultivar stability obtained in consecutive years for cultivars tested in both years (Steel and Torrie 1980). This analysis produced four correlations for each stability statistic (e.g 2003 with 2004, 2002 with 2003, 2001 with 2002 and 2000 with 2001) Table 3. The repeatability of cultivar stability estimated across environments from two consecutive years was also evaluated by using the 2-yr data sets containing data from cultivars tested in four consecutive years. This analysis produced two correlations for each statistic (e.g, 2001/2002 with 2003/2004 and 2000/2001 with 2002/2003): Table 4.

Results and Discussion

In 1-yr data sets (referring in all cultivars in a year) GEI was highly significant in four out of five years explaining on average 15.9% of the treatment SS_{TRTMT} sum of squares (Table 1). The relevant figure for Environment was on average 81.8% of the SS_{TRTMT}. This is in close agreement with reports by Kerby et al., (1996) and Kerby et al., (2001) who found that environment contributes on average 90% in variation of cotton yield. Genotype effect was not significant in 2001 (accounted 0.9% of the SS_{TRTMT}). Although it was significant in 2000 accounted only 1.95% of the SS_{TRTMT}. Average genotype effect (SS_G) was low (2.45%) indicating that genetic differences among cultivars were exposed, but it depends on the appropriate environments and the particular data set and its experimental accuracy to be identified. The number of cultivars within these particular years could have resulted in these data. It seems that the seven cultivars in 2001 and 2000 were not adequate to differentiate among them, probably because of being genetically related to each other. The small number of cultivars (many times with similar yield performance, tested every year in agronomic evaluation trials) reflects the real situation the extension agronomists are facing in agronomic evaluation trials.

AMMI partitioned the interaction GEI sum of squares (SS_{GEI}) into components attributable to IPC significant in all 1-yr data sets, (Table 1). On average the first IPC1 of AMMI, accounted for 44% of the SS_{GEI} and the IPC2 accounted for 18% of the SS_{GEI}. It is to mention that in year 2001 the IPC1 accounted for 77%, and the IPCI2 for only 8%, respectively of the SS_{GEI} , because of the very low genotype contribution (0.9) in this year. Moreover the low genotype contribution (1,95%) in 2000 was the reason of the high value of IPC1 (47%) in comparison with the rest years. Similar was the contribution of GGE biplot two first principal components PC1, PC2 that accounted on average 44% and 18.7% respectively of the G + GE sum of squares (SS_{G+GE}), Table 1. GGE biplot PC1 contribution was higher in 2001 (76%) and also in 2000 (47%) very similar with AMMI. On average the sum of PC1 +PC2 accounted for a 62.7% of the $SSG_{+ GE}$ value. This is considered low because, when the biplot explains only a small portion of the total variation (<75%), some genotypes may not be as stable as they appear, and they may have greater values in PC3 or PC4.

Table 1. Data set including seedcotton yield from all cultivars in a year. Summary of analysis of variance and sum of squares (SS) partitioning.

	Year					
	2004	2003	2002	2001	2000	
		Number of				
Cultivars	12	12	10	7	7	
Environments	17	16	16	15	17	
	Sum of squares of effect 1 as % of sum of squares of effect 2					Average
SS_G as % of SS_{TRTMT}	3.9**	2.7**	2.8**	0.9	1.95*	2.45
SS_E as % of SS_{TRTMT}	77**	82**	83**	83	83**	81.8
SS_{GEI} as % of SS_{TRTMT}	19.1**	15.3**	14.2*	16.1**	15**	15.9
AMMI 1 as % of SS_{GE}	31	35	29	77	47	44.0
AMMI 2 as % of SS_{GE}	18	17	20	8	26	18.0
GGE PC1 as % SS_{G+GE}	31	36	29	76	47	44.0
GGE PC2 as % SS_{G+GE}	21	20	21	8	22	18.7

* and ** indicate the significance at the 0.05 and 0.01 probability levels respectively.
SS_G= Sum squares (SS) of Genotype. **SS_E=** SS of Environment. **SS_{TRTMT}**= SS of Treatment. **SS_{GEI}**= SS of Interaction. **GGE PC1 as % SS_{G+GE}** = SS of PC1 as % of G + Interaction SS. **PC2 as % SS_{G+GE}** = SS of PC2 as % of Genotype + Interaction SS. **AMMI 1 as % of SS_{GE}** = SS of IPC1 as % of Interaction SS. **AMMI 2 as % of SS_{GE}** = SS of IPC2 as % of Interaction SS.

Correlations between stability indices

Significant rank correlations were found between the different measures of stability in 1-yr data sets including all the varieties, (Table 2). Correlation between seedcotton yield and YS was excellent (r=0.91), significant every year. M_1D correlated with yield for r=-0.82 significant in 3 out of 5 yr. M_2D correlated also with yield r=0.73 significant also in 3 out of 5 yr. Correlation for M_1D and M_2D, is negative because as the value of Distance index becomes higher, yield becomes lower. GGE Dinctance and YS_i indices combine the G+GE effects and for this reason correlates very good with the yield. M_1D has better correlation with both yield and YS and also in low SS_G% year, 2001 is correlated better with yield (r=-0.69) in comparison with M_2D (r=-0.39). The rest of the indices have no correlation with yield. Other authors also found that there was no correlation between yield and stability indices that are based on measuring the GE effect like Shukla, sd^2, and AMMI, since a low or high yielding cultivar can be stable or instable. Helms (1993), found that correlation of oat yield with Shukla and sd^2 was poor. Sneller (1997) found that correlation of soybean yield with AMMI, Shukla and sd^2 was null. Furthermore Jalaluddin (1993) found no correlation between whiter wheat grain yield, Shukla, and sd^2.

GGE biplot Instability indices correlated with indices that measure the GE effect. M_1I has good correlation with AMMI 1 (r=0.75) significant in 5 out of 6 yr, and also M_2I with r=0.73 significant in 3 out of 5 years. This is not in agreement with Sterling, (2005) that found no correlation with AMMI 1.

In this study also M_1I, and M_2I, correlated for an average of r=0.69., close to Sterling (2005) who found r=0.79. Moderate was the correlation of Instability indices with sd^2, Shulka, and Distance. GGE biplot Distance indices have better correlation with AMMI (r=0.43 and r=0.41) for M_1D and M_2D, respectively, in comparison with rest indices (Shukla, sd^2). M_1D and M_2D were high correlated (r =0.81), significant in 4 out of 5 years.

Shukla was high correlated with AMMI 1 (r= 0.75 significant in 5yrs), and sd^2 (r=0.77 significant in 3 out of 5 yr).

Table 2. Rank correlation among cultivar seedcotton yield and stability statistic estimates obtained from the data sets that contain data from all cultivars evaluated in a particular year.

Variable	by Variable	2004	2003	2002	2001	2000	Average
Sd^2	AMMI - 1	0.6	0.8**	0.28	0.05	0.73*	0.49
Shulka	AMMI - 1	0.74**	0.92**	0.38	0.95**	0.77**	0.75
Shulka	Sd^2	0.93**	1**	0.7	0.28	0.93**	0.77
M_1D	AMMI - 1	0.76**	0.38	0.25	0.2	0.54	0.43
M_1D	Sd^2	0.23	0.1	0.68*	0.19	0.32	0.30
M_1D	Shulka	0.47	0.26	0.1	0.11	0.27	0.24
M_2D	AMMI - 1	0.76**	0.49	0.25	0.11	0.42	0.41
M_2D	MS-DEV	0.33	0.27	0.69	0.46	0.12	0.37
M_2D	Shulka	0.45	0.39	0.19	0.3	0.1	0.29
M_2D	M_1D	0.97**	0.92**	0.98**	0.29	0.88**	0.81
M_1I	AMMI - 1	0.79**	0.84**	0.92**	0.79**	0.39	0.75
M_1I	Sd^2	0.7*	0.68**	0.36	0.07	0.32	0.42
M_1I	Shulka	0.86**	0.7**	0.3	0.69*	0.39	0.59
M_1I	M_1D	0.32	0.21	0.3	-0.1	-0.2	0.11
M_1I	M_2D	0.41	0.41	0.36	-0.13	-0.4	0.13
M_2I	AMMI - 1	0.58	0.63*	0.82**	0.82	0.77*	0.73
M_2I	Sd^2	0.27	0.35	0.3	0.5	0.46	0.38
M_2I	Shulka	0.33	0.38	0.1	0.89**	0.43	0.43
M_2I	M_1D	0.49	0.33	0.13	0.14	0.5	0.32
M_2I	M_2D	0.5*	0.53	0.16	0.27	0.54	0.40
M_2I	M_1I	0.58*	0.8	0.88	0.61	0.6	0.69
YS_i	AMMI - 1	-0.6*	-0.3	-0.35	0.14	0.47	-0.13
YS_i	Sd^2	-0.36	-0.38	-0.61*	-0.39	0.18	-0.31
YS_i	Shulka	-0.47	-0.39	-0.44	0.2	0.29	-0.16
YS_i	M_1D	-0.94**	-0.93	-0.84*	-0.43	-0.54	-0.74
YS_i	M_2D	-0.92**	-0.89	-0.85**	-0.52	-0.4	-0.72
YS_i	M_1I	-0.27	-0.34	-0.33	0.32	0.82**	0.04
YS_i	M_2I	-0.47	-0.34	-0.13	-0.11	0.3	-0.15
Yield	AMMI - 1	-0.68*	-0.42	-0.29	0.59	0.4	-0.08
Yield	Sd^2	-0.3	-0.3	-0.3	-0.18	0.18	-0.18
Yield	Shulka	-0.46	-0.3	-0.32	0.4	0.29	-0.08
Yield	M_1D	-0.99**	-0.94**	-0.87**	-0.69	-0.59	-0.82
Yield	M_2D	-0.9**	-0.87**	-0.80**	-0.39	-0.64	-0.73
Yield	M_1I	-0.25	-0.31	-0.25	0.7	0.82**	0.14
Yield	M_2I	-0.36	-0.31	-0.04	0.36	0.39	0.01
Yield	YS_I	1**	0.98**	0.96**	0.62*	1**	0.91

* and ** indicate the significance at the 0.05 and 0.01 probability levels respectively.

Repeatability of stability indices

In the 1-yr datasets repeatability of yield and stability indices was on average moderate to low (Table 3). The most repeatable indices were the two GGE Distance indices. M_1D was repeatable for r=0.66, followed by M_2D r=0.63 (both significant in 3 out of 4 datasets). Kang's YS_i follows with r=0.56, and yield with r=0.53. The interesting point is in 2000-2001 data set that the yield was not repeatable (yield r=-0.2) the M_1D and M_2D were higher r=0.33, and r=0.9 respectively. In the same years YS_i was not repeatable r=-0.01. This is an indication that the GE component of GGE Distance indices makes them better performing in low yield repeatability years than Kang's YS_i. Stability indices that measure the GE effect like Sd^2, AMMI1, Shulka had good repeatability only in low yield repeatability years (dataset 2000 – 2001). On average Sd^2 hand a repeatability of r=0.5, AMMI1 r=0.31 and Shukla lower r=0.29.

In Table 4 (2-yr datasets) in the good yield repeatability data set (2001/2002, 2003/2004, yield r=0.55) the M_1D was highly significant repeatable (r= 0.95) and M_2D r=0.69. In the low yield repeatability years (2000/2001, 2002/2003) M_1D performed better than yield (r= 0.2), but M_2D the same with yield r=-0.2. M_1D, hand better performance than M_2D. In the same 2-yr datasets AMMI 1 was highly repeatable (averaging for r= 0.84 significant in both data sets) followed by Shukla index (r=0.67 non significant in the two datasets). In both data sets of low and high yield repeatability AMMI was highly repeatable giving evidence that this index with higher number of environments become more repeatable. AMMI 1 in this study had better repeatability than studies by Annichiaricco, (2002) and Zavala – Garcia (1992). In our study, Shukla's index has pretty better performance than other studies (Eagles and Frey, 1997; Helms, 1993; Jalaluddin and Harisson, 1993, Pham and Kang, 1998; Sneller et al., 1997). Sd^2 performed well in the years with low yield repeatability (r=0.89 significant in data set 2000/2001, 2002/2003). M_1I and M_2I performance was variable and repeatable only in 2-yr data within years with low yield repeatability (model M_1 performance was better).

Table 3. Repeatability of 1-yr stability measures and yield. Data set including seedcotton yield results of cultivars tested in consecutive 1-yr data.

Variable	2003 - 2004	2002- 2003	2001 -2002	2000 -2001	Average
AMMI 1	0.06	0.93**	-0.35	0.6	0.31
Sd^2	0.3	0.58	0.1	1**	0.50
Shulka	-0.03	0.37	-0.15	0.95**	0.29
M_1D	0.87*	0.71**	0.73*	0.33	0.66
M_2D	0.75**	0.77**	0.1	0.9**	0.63
YS_I	0.8**	0.61	0.83	-0.01	0.56
M_1I	0.39	0.75	-0.2	-0.1	0.21
M_2I	0	0.6	-0.2	0.62	0.26
Yield	0.87**	0.65	0.81	-0.2	0.53
Cultivars	8	10	6	6	
Environments	17-17	16-16	15-16	17-15	

** and * indicate the significance at the 0.05 and 0.01 probability levels. respectively.

Table 4. Repeatability of 2-yr stability measures and yield. Data set including seedcotton data of cultivars tested in consecutive periods of 2-yrs data sets.

Variable	2001/2002, 2003/2004	2000/2001, 2002/2003	Average
AMMI 1	0.9*	0.82*	0.84
Sd^2	0.1	0.89*	0.48
Shulka	0.67	0.7	0.67
M_1D	0.95*	0.2	0.55
M_2D	0.69	-0.2	0.22
YS_i	0.55	-0.40	0.03
M_1I	-0.2	0.89*	0.33
M_2I	-0.52	0.76*	0.15
Yield	0.55	-0.2	0.22

Cultivars	6	6
Environments	20– 32	12-35

** and * indicate the significance at the 0.05 and 0.01 probability levels. respectively

Conclusions

Significant correlations were found between GGE Dist. indices, yield and Kang's YS_i. GGE M_1D hand better correlation with yield and YS_i than M_2D. GGE Inst., indices correlates with indices that measure the GE like AMMI, Shukla, and sd^2. Both M_1I and M_2I found to have good correlation with AMMI 1(r=0.73 to 0.75). Shukla had also good correlation with AMMI1 r=0.75, and sd^2 r=0.77. Regarding the models 1 and 2 we found the M_1I and M_2I correlated for r=0.69. M_1D and M_2D correlated for r=0.81.

Within 1-yr datasets when yield is repeatable M_1D follows or exceeds yield repeatability with a repeatability from r=0.71 to r=0.87 significant in all datasets and has better performance than M_2D. Kang's YSi had also very good performance when yield is repeatable since is highly correlated with yield. As the number of environment increases (2-year data) AMMI1 had significant repeatability regardless of how much repeatable is yield. Shukla's index is also good with 2-yrs results but not significant. Eberhart's and Russel sd^2 hand high repeatability only in low yield repeatability years. M_1I and M_2I performance was variable and were repeatable only in 2-yr data within years with low yield repeatability.

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