Pak. J. Sci. Ind. Res. 2006 **49**(5) 355-359

Multiple Parameters for Ascertaining Yield Stability of Upland Cotton Varieties Tested Over Number of Environments

Muhammed Jurial Baloch* and Nasreen Fatima Veesar
Department of Plant Breeding and Genetics, Sindh Agriculture University,
Tandojam, Sindh, Pakistan

(received October 5, 2005; revised August 16, 2006; accepted August 29, 2006)

Abstract. Thirteen upland cotton varieties were evaluated in 12 different environments of the Sindh province, Pakistan, so as to arbitrate their stability in yield performance. The regression coefficient (**b**) parameter was used as a measure of varietal adaptability, whereas the sum of squared deviations from regression (**s^2d**) and coefficient of determination (**r^2**) were implied as the measure of stability. The regression coefficients (**b**) of all the varieties, though did not deviate significantly from a unit slope (**b** = 1.0), yet varieties FH-1000, VH-142, BH-147 and FH-945 exhibited (**b**) values very close to a unit slope suggesting their better adaptation to the test environments. Varieties CRIS-467, DNH-57 and FH-945 displayed lower **s^2d** and higher **r^2** values implying that these varieties were relatively more stable in yield performance than others in the test environments. Generally, not all the stability and adaptability parameters simultaneously favoured the same variety except FH-945, which was thus considered more stable, based on majority of the parameters. Principal component analysis (**PCA**) revealed that latent vectors of first two components, i.e., **PCA-1** and **PCA-2** accounted for about 91.24 % of the total variation. The eigen vectors of first **PCA-1** were smaller and all were positive, which further suggested that the test varieties were quite adaptive to all the test sites. However, in **PCA-2**, some varieties gave positive and some negative eigen values, yet varieties FH-1000, CIM-499, CRIS-467 and FH-945 expressed smaller and positive **PCA-2** scores suggesting less genotype-environment interactions for these particular varieties.

Keywords: stability and AMMI analysis, genotype-environment interaction, upland cotton varieties, environmental index, multivariate analysis

Introduction

Cotton breeders are always tempted to assess the magnitude of genotype-environment interactions and their pattern. These attributes, of course, help plant breeders to decide whether the newly evolved varieties are suitable for multiple environments or for specific environments. To answer this complicated question, a broad range of multivariate statistical procedures has long been used. The most common and earlier approach was the regression analysis (Eberhart and Russell, 1966; Finlay and Wilkson, 1963). However, several researchers have pointed out some limitations of the regression method (Crossa, 1988). Lin and Binns (1988) concluded that the ten most commonly used parameters, representing stability and adaptability of genotypes are actually different approaches of statistics that measure the same attribute. Thus, among the ten parameters of stability analysis, the similar ones were grouped together. As a consequence, only three major groups, namely, deviation of average performance of genotypes, the genotype-environment interaction (G x E), and regression of environmental index were arbitrated. Lin *et al*. (1986) used multivariate analysis (MA), so as to ensure thorough elucidation of the response of cultivars within the scope of three new classifications representing the stability of genotypes. By regressing each variety over environmental index, Bilbro and Ray (1976) demonstrated regression coefficient (**b**) as a measure of adaptability, whereas coefficient of determination (**r^2**) and the sum of squared deviation (**s^2d**) were shown as a measure of stability. It is still, however, questionable whether these parameters are completely reliable in describing the stability and adaptability response of genotypes tested in both favourable and unfavourable environments. By using multivariate analysis, nevertheless, Lin *et al.* (1986) succeded to a large extent, in explaining the most complicated situation of genotype-environment interaction pattern. To further overcome the limitations of the previously used statistics, the additive main effects and multiplicative interaction (AMMI) as proposed by Gauch (1992) has been incarporated in the present studies. The important feature of the AMMI model is that it integrates the analysis of variance and principal component analysis (**PCA**) into a unified approach (Gauch, 1992; Crossa *et al.*, 1990), which better explains the genotype-environmental interaction pattern. However, Dos Santos Dias and Krzanowski (2006) compared AMMI models as proposed by Gabriel (2002), Cornelius and Crossa (1999), Eastment and Krzanowski (1982), and Gollob (1968) for the detection of interaction patterns between genotypes and environments. The authors observed that all the four statistical methods adopted by these researchers produced different results for the same set of data and yielded a rather mixed picture. They

*Author for correspondence; E-mail: dr_mjr@hotmail.com

also noted that the method of Eastment and Krzanowski (1982) was more stable and behaved appropriately when a small number of components was considered. The Gabriel model (Gabriel, 2002) was very volatile and tended to choose many components, whereas the method of Cornelius and Crossa (1999) was more suitable for more important components, but was less stable than the Eastment-Krzanowski method. The Gollob version was broadly similar to the Cornelius-Crossa model, yet slightly poor in stability. However, authors (Santos Dias and Krzanowski, 2006) concluded that Eastment-Krzanowski model produced better results for AMMI analysis. Thus, in the present studies, multiple parameters have been used to determine the yield stability of thirteen newly evolved varieties tested in twleve different environments of the Sindh province of Pakistan.

Materials and Methods

Thirteen cotton varieties (all hirsutum type), of which three belonged to the Sindh province (CRIS-168, CRIS-467, CRIS-468), while the other ten varieties were evolved in the Punjab (DNH-57, FH-1000, NIBGE-1, VH-142, CIM-499, BH-147, MNH-635, CIM-473, SLH-257, FH-945), were compared for their adaptation to a series of environments. The varieties were sown in six districts of Sindh for two consecutive years (2001-2002). The experiments at each site/location were carried out in a randomized complete block design (RCBD) and consisted of four repeats. The same plot size of 10 x 47 feet was kept at all the test sites. The usual inputs like fertilizer, irrigations and insecticides were given as and when required. The recommended distance of 2.5 feet between row to row and 9.0 inches between plant to plant was given for healthy plant growth and development. The seed cotton yield was recorded in kg/ha of two picks. In the first instance, individual site analysis of variance was carried out for determining homogeneity of error mean squares. This parameter was declared similar, which allowed to conduct combined analysis of variance over locations. The terms environments, locations and test sites, hereafter, will be used interchangeably. The years and locations were combined and treated as environments with random effects.

The combined ANOVA over environments was performed according to Steel and Torrie (1980). When the genotype x environment interaction mean squares were declared significant, stability and adaptability parameters were determined according to Eberhart and Russell (1966), and the principal component analysis by Zobel *et al*. (1988). Linear regression coefficient (**b**) and the sum of squared deviations from regression (**s^2d**) were calculated as suggested by Bilbro and Ray (1976). In addition to these statistics, principal component analysis (**PCA-1, PCA-2,** latent roots and latent vectors), means, and grand means were also calculated as supporting statistics for measuring the varietal stability.

Results and Discussion

In a combined ANOVA (Table 1), the variety x environment source of variation was declared significant, which allowed further partitioning of this term into: (i) environment linear, (ii) variety x environment linear, and (iii) pooled deviations. The main effects due to the variety and environments were also found significant, which suggested that varieties performed differently over test locations.

These results further implied that genotypes should be thoroughly tested before they could be cultivated to wider or specific areas. For this purpose, regression analysis as suggested by Zobel *et al*. (1988), Bilbro and Ray (1976) and Eberhart and Russell (1966), were carried out. In the ANOVA,

Table 1. Mean squares from stability and adaptability analysis for seed cotton yield in upland cotton varieties tested in twelve environments

Source of variation	Degrees of freedom	Mean squares
Total	155	
Variety	12	235138.73**
Environment + variety x environment	143	540345.77**
Environment linear	1	278552.52
Variety x environment linear	12	2520821.34**
Pooled deviations	130	74388.29
Deviations from regression of each variety		
CRIS-168	10	88595.29
DNH-57	10	31064.99
FH-1000	10	47272.65
CRIS-468	10	51405.46
NIBGE-1	10	113695.27
VH-142	10	132472.35
CIM-499	10	64990.31
CRIS-467	10	10493.47
BH-147	10	102698.36
MNH-635	10	78624.35
CIM-473	10	143994.65*
SLH-257	10	62701.59
FH-945	10	39038.75
Pooled error	144	75714.61

, * = significant at 1% and 5% probability levels, respectively the term, pooled deviation, was tested against pooled error, which was declared non-significant, suggesting linear response of varieties in the test environments. However, the significance of the term, variety x environment linear, when tested against pooled deviations implied the existence of genetic differences among genotypes for their regression on the environmental index and regression coefficient (b**). The deviation of each variety from regression was significant to only variety CIM-473, implying its more genotype-environment interaction.

The results presented in Table 2 show the stability and adaptability parameters of all the thirteen genotypes. The regression coefficient (**b**) accounted for the measure of adaptability, whereas the sum of squared deviations and coefficient of determination gave a measure of stability. The mean of varieties compared to grand mean was also used as the supporting statistics of varietal stability. A variety with regression coefficient (**b**) not significantly different from a unit slope (**b** = 1 . 0) could be considered adaptive to all types of environments, that is both the favourable and unfavourable ones.

The varieties with the (**b**) values higher than 1.0 means the varieties were more suitable to only highly favourable environments and the (**b**) values significantly less than 1.0 suggested that varieties performed well in less favourable environments. In the present studies, the values of regression coefficients (**b**) shown in Table 2 for all the test varieties evaluated, were not significantly different from the unit slope, hence, generally suggesting that the varieties were fairly adaptive to all the test sites. Nevertheless, the varieties FH-1000 (**b** = 1.059), VH-142 (**b** = 1.087), BH-147 (**b** = 1.078) and FH-945 (**b** = 1.065) gave the (**b**) values near to a unity, and were thus regarded as varieties with wider adaptability. The mean yields of these varieties were also higher or closer to the grand mean except VH-142, which also supported the wider adaptation of the above varieties. The mean yield of VH-142 was far below (1889.3 kg/ha) the grand mean (2001.42 kg/ha), but still displayed the (**b**) value near to unity (**b** = 1.087), which suggested that regression coefficient and mean yields were independent attributes for ascertaining yield stability of varieties. Variety CRIS-168 with regression coefficient **b** = 1.133 also gave mean yields (2251.3 kg/ha), which was higher than than the grand mean indicating that this variety was adaptive to highly favourable environments. Nonetheless, varieties CRIS-467 (**b** = 0.766) and SLH-257 (**b** = 0.774) displayed (**b**) values lower than the unity and gave mean yields lower than the grand means, which suggested that both the varieties may perform well in less favourable environments.

The stability indicators, such as the minimum sum of squared deviations ($\mathbf{s^2d}$) and values of coefficient of determination ($\mathbf{r^2}$) presented in Table 2 demonstrated that the varieties CRIS-467 and DNH-57 with minimum $\mathbf{s^2d}$ and higher $\mathbf{r^2}$ were well stable in less favourable environments, whereas CIM-473 and NIBGE-1 varieties with maximum $\mathbf{s^2d}$ and less $\mathbf{r^2}$ values were less stable in test environments. Though not all the stability and adaptability parameters discussed so far simultaneously favoured one variety over the others, yet on the basis of majority of the parameters, it is concluded that FH-945 is well adaptive to all types of environments, whether favourable or unfavourable, CRIS-168 to only highly favourable environments, and CRIS-467 to only less favourable environments. Similar to the present findings, Baloch (2003; 2001) and Geng *et al*. (1987) have also reported that not all the stability and adaptability parameters simultaneously favoured the same variety. The ($\mathbf{s^2d}$) and (**b**) for the most part were not correlated in the present studies, which is also in consonance with the results obtained by Baloch (2003) and Gutierrez *et al*. (1994). However, a negative correlation between ($\mathbf{s^2d}$) and ($\mathbf{r^2}$) in the present studies is a sort of an indication of wider stability, which was noted in the case of varieties DNH- 57, CRIS-467 and FH-945. Coefficient of determination ($\mathbf{r^2}$) being significantly higher for all the varieties also coincided with the regression coefficient (**b**) values, which further indicated that all the varieties were fairly stable in yield performance in the test environments.

In addition to stability and adaptability parameters, a principal component analysis (**PCA**), a part of AMMI model, has

Table 2. Stability and adaptability parameters of thirteen upland cotton varieties tested in twelve different environments

Variety	Variety means	Regression coefficient (**b**)	Sum of squared deviations ($\mathbf{s^2d}$)	Coefficient of determination ($\mathbf{r^2}$)
CRIS-168	2251.3	1.133	885952.9	0.870
DNH-57	2138.0	0.866	310649.9	0.924
FH-1000	1978.1	1.059	472726.5	0.937
CRIS-468	1976.9	1.152	514054.6	0.929
NIBGE-1	1984.7	1.108	1136952.7	0.846
VH-142	1889.3	1.087	1324723.5	0.821
CIM-499	1981.2	0.976	649903.1	0.884
CRIS-467	1846.3	0.766	104934.7	0.966
BH-147	2217.4	1.078	1026983.6	0.852
MNH-635	1765.2	0.834	786243.5	0.819
CIM-473	2027.9	1.102	1439946.5	0.812
SLH-257	1905.0	0.774	627015.9	0.835
FH-945	2057.2	1.065	390387.5	0.933
Grand mean 2001.42				

been worked out to further determine the pattern of interaction. The results shown in Table 3 indicate that latent vectors of the first two principal components (**PCA-1** and **PCA-2**) accounted for about 91.242% of the total variation. El-Shaarawy (2000) using multiplicative principal component analysis recorded 87.77 % of total variation in lint yield attributable to first three **PCAs**. The eigen values of first principal component analysis (**PCA-1**) of all the varieties were smaller and positive, hence suggesting that test varieties were highly stable in the test environments. While some varieties gave positive and others negative eigen values for **PCA-2**, smaller positive values were expressed by varieties FH-1000, CIM-499, CRIS-467 and FH-945, suggesting that these varieties had shown relatively less genotype-environment interaction, and were thus suitable to all the test environments. Palomo and Godoy (1996) also reported that varieties showing smaller **PCA** scores were more stable in their yield performance.

It may be generally concluded from the overall results, that variety CRIS-168 is suitable to highly favourable environments, CRIS-467 to less favourable environments, and FH-945 to all types of environments.

The AMMI biplot illustrates a significant portion of the genotype-environment interaction in a more comprehensible manner. Genotypes that appeared almost on a perpendicular or horizontal line have similar pattern of interaction. Genotypes with large **PCA-2** scores, either positive or negative, showed high interaction in test environments, whereas genotypes with **PCA-2** scores near to zero have small interactions. Varieties with a **PCA-2** score smaller or near to zero indicate their adaptability to all types of environments, while those with large **PCA-2** scores showed a specific adaptability in the environments. Four groups of genotypes are evident from the biplot (Fig. 1). In fact, all the **PCA-2** scores (Table 3) were multiplied with a common figure of 100, making the figures larger, hence easier to plot (Fig. 1).

Group-1 includes genotypes VH-142 and CRIS-468. These varieties showed a similar mean yield response (yields below the grand mean) and had also similar large negative interactions. **Group-2** consists of genotypes NIBGE-1, CIM-499 and FH-1000. The mean yields of these varieties were similar, but their interactions with the environments were quite different. The interaction **PCA-2** score of variety FH-1000 was smaller and positive, whereas positive and larger for variety NIBGE-1. The **Group-3** represents varieties MNH-635, CIM-499 and FH-945. These varieties had similar and smaller positive **PCA-2** scores, but were very different in mean yields. Variety CIM-499 has both the desirable attributes, that is, the **PCA-2** score and the mean yield. Hence, in the biplot (Fig. 1) it falls just at the junction of horizontal and vertical lines of the x and y axes. The variety had the mean yield near the grand mean and **PCA-2** score was near zero. Variety MNH-635, though gave smaller **PCA** score hence showing less genotype-environment interaction, yet its mean yield was far below the grand mean. The third variety of the group is FH-945, which gave smaller and positive **PCA** scores and also gave mean yields

Table 3. The eigen values, latent vectors (**PCA-1** and **PCA-2**) of varieties and percent variance determined by the principal component analysis

Order*	Variety+	Latent roots (eigen values)	Percent variance	Latent vectors (eigen vectors)	
				PCA-1	**PCA-2**
1	CRIS-168	6026132.52	87.484	0.315	-0.354
2	DNH-57	258903.25	3.759	0.241	-0.002
3	FH-1000	208248.42	3.023	0.255	0.091
4	CRIS-468	158050.43	2.294	0.321	-0.232
5	NIBGE-1	88059.72	1.278	0.307	0.433
6	VH-142	67971.88	0.987	0.302	-0.138
7	CIM-499	46842.76	0.680	0.269	0.044
8	CRIS-467	16957.69	0.246	0.212	0.057
9	BH-147	10699.82	0.155	0.300	0.364
10	MNH-635	4518.93	0.066	0.230	0.322
	CIM-473			0.309	-0.577
	SLH-257			0.214	0.175
	FH-945			0.296	0.020

* = corresponds to latent roots and percent variance; + = corresponds to latent vectors only

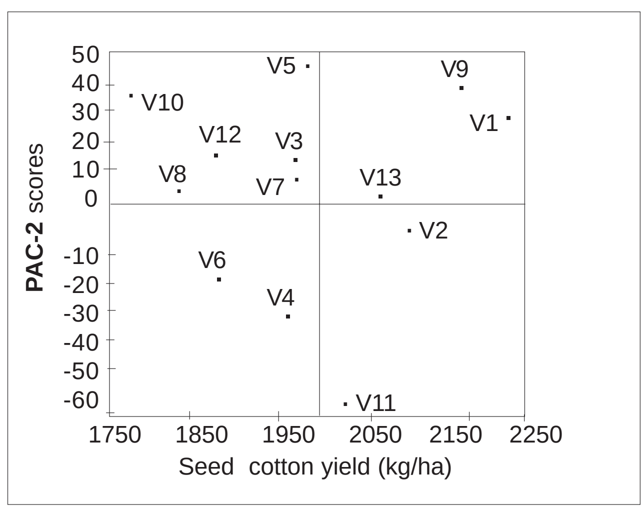

Fig. 1. Biplot of seed cotton yield and **PCA-2** scores for thirteen cotton varieties tested in twelve different environments (V1 to V13 represent the variety numbers).

higher than the grand mean showing high level of stabiligy in test environments. **Group-4** includes varieties CRIS-168 and CIM-473 with high positive and negative **PCA** scores, respectively, but had similar mean yields. Variety CRIS-467 gave mean yields near the grand mean, whereas CRIS-168 produced mean yields higher than the grand mean. Hence, both the varieties are suitable for specific environments as explained in previous paragraphs.

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