Genotype x environment interaction and stability analyses of yield of upland cotton (*Gossypium hirsutum* L.) in central Sudan

Hassan S. Ahmed[1], Mohamoud A. Mohamoud[2], Abu Elhassan S. Ibrahim[3] and Abbas M. Suliman[3]

[1]Rahad Research Station, Agricultural Research Corporation, Sudan.
[2]Sennar Research Station, Agricultural Research Corporation, Sudan.
[3] Faculty of Agricultural Sciences, University of Gezira, Wad Medani, Sudan.

ABSTRACT

Seed cotton yield stability of genotype over environments is a useful parameter for recommending cultivars for known cropping conditions. Fifteen upland cotton inbred lines and the check (commercial cultivar *Hamid* were evaluated. over two consecutive seasons (2013/14 and 2014/15) at three locations, Rahad, Gezira and Sennar Research Station of the Agricultural Research Corporation, Sudan. A randomized complete block design with four replicates was used. The objective was to assess the genotype by environment interaction and stability of seed cotton yield. The mean squares due to environment were significant while genotype and genotype x environment interaction were highly significant for seed cotton yield. Significant differences among genotypes for the studied characters were found in almost all seasons, indicating that these cotton genotypes were highly variable for the characters studied and, therefore, expected to respond to selection. The interaction effects of genotype x location were significant for all traits indicating that genotypes responded differently to different environments. Statistical models of stability analysis, i.e. Eberhart and Russel model as well as the additive main effect and multiplicative interaction (AMMI), indicated that genotypes RS-5, R-96, R-231, R-43 and R-1 revealed good stability and high seed cotton yields across environments. In conclusion, and based on stability parameters, genotypes R-6, R-40, R-231, and R-43 are recommended for further testing over a range of environments to examine their yield stability and suitability for large field production.

INTRODUCTION

Cotton is the natural source of fiber and secondly most important oil seed crop after soybean in the world. It belongs to the genus *Gossypium*, family *Malvaceae* (Fryxell, 1992).

The detection of significant genotype x environment interaction indicates that all phenotypic responses to changes in the environment are not the same for all genotypes. Genotype x environment interactions is important to geneticists and breeders because the magnitude of the interaction component provides information concerning the likely area of adaptation for a given cultivar. Because lint yield is considered by many breeders to be the most important single characteristic, yield is used as a reference point from which examines cotton genotype x environment interactions. If the interaction components are large relative to the genotypic components, and if they are related to predictable environmental factors (such as geographic areas, elevation, major pest problems, or soil differences), the breeder searches for a cultivar to meet the specific requirements of that environment. If the interaction is small and unpredictable, the breeder searches for a cultivar that has general adaptability and universal performance over the range of environments.

Several procedures have been proposed for evaluating stability of cultivars. Lin *et al*. (1986) had reviewed nine stability statistics. Liu and Sun (1993) evaluated 17 statistics recommended for description of cultivar stability. Nonparametric methods are growing in popularity and influence for a number of reasons because they are easy to apply and to understand. Additive main effect and multiplication Interaction analysis fits additive effects due to genotypes (G) and environments (E) by the usual additive analysis of variance procedure and then fits multiplicative effects for genotype-environment interactions (GE) by principal components analysis (PCA). AMMI analysis called GGE (genotype and genotype-environment interaction) that has been used for GE analysis. The GGE analysis pools genotype effect (G) with GE (multiplicative effect) and submits these effects to principal component analysis. According to Yan *et al*. (2000), this biplot is identified as a GGE biplot. The GGE biplot has been recognized as an innovative methodology in biplot graphic analysis to be applied in plant breeding. Gauch *et al*. (2008) questioned GGE analysis about the proportion of G + GE retained in the biplot. In other words, these authors claimed that GGE biplot always explained less G + GE than did the AMMI 2 mega-environment analysis.

The objective of this study was to assess genotypes x environment interaction and stability of seed cotton yield using regression method of Eberhart and Russel model (1966) and AMMI analysis.

MATERIALS AND METHODS

Location

The experiments were conducted over two consecutive seasons (2013/14 and 2014/15) in three locations in the Agricultural Research Corporation (ARC) of the Sudan. The three locations were: (1) Rahad Research Station (RRS) in the clay plains of east Sudan between latitude 13º 31'– 14 º 25' N, longitude 33 º 31' - 34 º 32' E and 570 masl. The soil is vertisol with 78% clay content, pH 7.8, 0.74%, O. C. and N% of 0.04%, the area has semi-arid climate with a summer rainfall of 300 - 600 mm; (2) Gezira Research Station Farm (GRSF), located in central clay plain of Sudan latitude 14º24'N,33º 29' E, longitude 33º 32'E and 407 masl with soil characterized by cracking heavy clay (vertisols), very low water permeability, pH of 8.3, organic matter (0.4%), nitrogen (0.04% ppm), and phosphorus (ESP, 4 ppm) and (3) Sennar Research Station (SRS) with soil characterized by cracking heavy clay (vertisols), with pH of 7.8, nitrogen of 0.025%0.07%, organic matter (0.6%) and (latitude 13 º 12' N, longitude 33 º 32' E and 417 msal) (Hammed, 2001).

Plant material

Fifteen inbred lines were selected from a certain genetic (Ahmed, 2007). The entries were R-6, R-1, R-43, R-42, R-93,R-114, R-200, R-43-1, R-187,R -96, R-231, R-240, RS-5,RS-2, RS-10, and the variety *Hamid* was used as a check. Continuous selfing up to F9 is used in the designated material.

Table1. Designation and description of the genotypes used in the study.

Genotype	Pedigree
1- R-6	Wagar x Barac(67)B
2- R-1	Wagar x Barac(67)B
3- R-43	Wagar x Barac(67)B
4- R-42	Wagar x Barac(67)B
5- R-93	Wagar x Shambat-B
6- R-114	Barac(67)B x Shambat-B
7- R-200	Barac(67)B x Acala(93)H
8- R-43-1	Wagar x Barac(67)B
9- R-187	Barac(67)B x Acala(93)H
10- R-96	Wagar x Shambat-B
11- R-231	Barac(67)B x Acala(93)H
12- R-240	Acala(93)H x Chandri
13- RS-5	Niab78 x BA1303
14- RS-2	Barac(67)B x Brycot
15- RS-10	Niab78 x BA1303
16- Hamid	Commercial variety

Cultural practices

The standard cultural practices adopted for cotton production at ARC were followed. Experiments were conducted using a randomized complete block design with four replications. Effective sowing dates were the first week of July at the three locations and during the two growing seasons. Hand weeding was carried out three times. Hand harvesting was done after boll opening. Data were selected for the fllowing characters; number of sympodia / plant, nuber of bolls / plant, seed cotton yield, ginning out-turn, lint index, seed index and boll weight.

Statistical analysis

The analysis of variance procedure was used to test differences among genotypes within each season, location and combined. Eberhart and Russel model (1966) was performed. In addition, AMMI was carried out to show the stability and pattern of adaptation of cotton genotypes in six environments (2 seasons x 3 locations).

RESULTS AND DISCUSSION

Genotype x environment interaction

The genotypes showed significant character variation in each location, in each season and across seasons and locations (Table 2). Seasonal variations were very highly significant for all characters studied while that of location were also significant. Though the separate effects of season, location and genotype on most characters were significant, but their second degree interaction effects (S x L x G) were significant only for number of sympodia/plant, plant height and seed cotton yield. Final results are difficult to explain because the first degree interaction effects of genotype with location (G x L) were significant for all characters while that of (G x S) were significant for only four characters (seed cotton yield was one of them) out of a total of nine characters (Table 2).

Concerning seed cotton yield, the current findings were in agreement with that of Killi and Gencer (1995) and Unay *et al*. (2004) who reported that genotype x location, genotype x year and genotype x location x year interactions components were significant for seed cotton yield.

Table 2. Mean squares of different cotton yield parameters of 16 genotypes grown at Rahad, Gezira and Sennar Research Stations for seasons, 2013/14 and 2014/15

SOV	NSP	NBP	PH	YI	GOT	LI	SI	BW
Season(S)	41.82**	27.5	23620***	4844635***	49.53***	32.8***	97.6***	19.75***
Location(L)	308.2	222.3***	29025***	333279244***	4.11	13.41***	35.33***	3.71***
Genotype(G)	17.65***	34.74***	1972.6***	484897*	69.6***	6.22***	6.00***	2.07***
LxS	761.3***	5774***	32993***	27411150***	31.27***	3.08***	37.12***	1.47***
GxS	14.15***	14.11	174.4	187695	2.69	0.58	1.03	0.11
LxG	8.5**	17.28*	252*	489300**	2.39*	0.55*	1.19***	0.3**
LxGxS	11.31***	15.26	270*	145307*	1.69	0.4	0.67	0.18
Error	4.53	11.35	153.64	246797	1.32	0.32	0.53	0.16

*, **, *** Significant at P = 0.05, 0.01 and 0.001 levels, respectively. NSP = number of sympodia per plant, NBP = number of bolls per plant, PH = plant height (cm), YI = Seed cotton yield (kg ha^{-1}), GOT = Ginning out-turn, LI = Lint index, SW = 100 seed weight (g), and BW = boll weight (g).

Seed cotton yield stability

Evaluation of varieties and hybrids of any breeding program aims at identifying genotypes that consistently produce stable yields over a range of diverse environments. The mean seed cotton yields of the tested genotypes over the environments ranged from 1907 kg/ha to the 2380 kg/ha with an average of 2143 kg/ha (Table 3).

The genotype x environment (G x E) was significant for seed cotton yield which justifies seed cotton yield stability analysis to identify the most stable and adapted genotype(s) to the test environments. Table 3 showed clear differences in slopes of the regression lines between tested genotypes and checks. Some regression coefficients (b) exceeded unity while others were less than one. The regression coefficient (slope) ranged from 0.607for line R-114 to 1.434 for RS-5 (Table 3).

From this study, the four genotypes, line R-6, R-40, R-231and R-43 showed higher mean yield than the overall mean and obtained regression coefficients of 0.753, 1.293, 1.034, 1.230, respectively, A ccordingly, the most stable genotypes were line R-231 and R-43. However, considering the three parameters of stability together, i.e. mean yield, regression coefficient and deviation from regression, lines R-231, R- 240 and R-1 were the most stable genotypes as proposed by Eberhart and Russell (1966).

Table 3. Mean seed cotton yield, slope and deviation from regression for 16 cotton genotypes evaluated across six environments according to Eberhart and Russell (1966) procedure.

Genotype	Yield Kg / ha	Slope (bi)	MS-DEV
1-R-6	2380	0.753	209727
2-R-1	2265	1.183	55760
3-R-43	2309	1.230	23371
4-R-40	2349	1.293	31783
5-R-93	2238	0.807	32071
6-R-114	2267	0.607	192527
7-R-200	2169	0.756	78119
8-R-43-1	2333	0.674	39006
9-R-187	2046	1.154	74365
10-R-96	2060	0.989	9600
11-R-231	1238	1.034	88145
12-R-240	2285	1.068	91088
13-RS-5	2236	1.434	10226
14-RS-2	2163	1.281	38830
15-RS-10	1906	0.794	30125
16-Hamid	1986	0.942	359315
Mean	2143		

Slope - slope of regressions of variety means on site index, MS-DEV – deviations from regression component of interaction.

AMMI cross site analysis

To analyze genotype-environment interaction and adaptation graphically, AMMI bi-plot was used with the principle component analysis (PCA1) score plotted against the mean yields (main effects). Therefore, a graphical display of the GE interaction of PCA1 and their effects (yields) is useful for revealing favorable pattern in genotypes response across environments (Crossa, 1990). The AMMI bi-plot of mean on yield explained large proportion of the treatment sum of squares. The more PCA score approximate to zero is the more stable or adapted genotype over all environments. Accordingly, the genotypes RS-5 - R-96 - R-43 and R-1 revealed good stability across environments and high seed cotton yields (Fig.1).

The combined analysis of variance according to the AMMI model is presented in Table 4. The partitioning of GE interaction through AMMI model analysis revealed that the multiplicative terms PCA1 was significant and it captured 49.7% of the variation due to GE interaction sum of squares but PCA2 was not significant and accounted for 20.9% together they accounted for 70.6 % of GE interaction sum of squares. However, most of the variation was explained by the first principle component (PCA1). According to Crossa *et al*. (1990), AMMI with two, three or four PCA1 axes is the best predictive model. Similarly, in the present study, the AMMI analysis further revealed that the first interaction principle component axes (PCA1and PCA2) explained 70.6% of the G x E sum of squares. This was in agreement with Sneller *et al.* (1997), who suggested that G x E pattern is collected in the first principal components of analysis.

Variation among the studied genotypes for seed cotton yield and their reactions to the environments were determined (Table 5). The highest average yield was shown in Rahad season 2013 (RAH13) (3122 kg/ha) followed by environment Sennar season 2014 (SEN14) (2647 kg/ha), whereas environments Gezira season 2013 (MED13) (2647 kg/ha) and season 2013 (SEN13) SEN13 (1838 kg/ha) gave the lowest seed cotton yield (Table 5). The best genotypes at MED13 and MED14 were R-114, R-43-1, R-93, and R-43, at RAH13 were R-43-1, R-40, R-114 and R-43, at RAH14 were R-40, RS-5, R-1 and R-43, at SEN13 R-6, R-240, R-231and R-200 and at SEN14 R-6, R-231, R-240 and RS-2. These results indicated that the best stable genotypes were R-43, R-43-1, R-114 and R-6 with highest seed cotton yield.

AMMI bi-plot analysis

To further explain the GE and stability, a bi-plot between the PCA1 and PCA2 scores were given in (Fig. 1). AMMI bi-plot of the first two principle component axes is a powerful way of detecting important scores of GE effects (Zobel *et al*., 1988). This analysis represents stability of the genotypes across environments in terms of principle component analysis. It is used to identify broadly adapted genotypes that offer stable performance across sites, as well as genotypes that perform well under specific conditions. In this study, the R-43, R-40, R-43-1 and R-93 responded positively to Rahad environment, RS-10, R-93, R-43-1, responded positively to Gezira environment and R-6, R-200, R-231 and R-240 responded positively to Sennar environment.

The analysis of the genotype and environment parameters resulting from AMMI showed that the best yielding and stable genotype was line R-231. The two models of stability used in this study suggested that line R-231 as the most high yielding as well as stable genotype over environments.

Table 4. AMMI analysis of variance of the significant effects of genotypes (G), and environment (E) and genotype-environment interaction (GE) on seed cotton yield (kg/ha) and the partitioning of GE into AMMI scores.

SOV	DF	SS	MS	F value	% explained
Total	383	237322212	619640		
Treatments	95	154760664	1629060	7.62***	
Genotypes	15	7163921	477595	2.23*	4.6
Environments	5	126180261	25236052	18.29***	81.5
Block	18	24829780	1379432	6.45***	
Interactions	75	21416482	285553	1.34*	13.8
IPCA1	19	10639334	559965	2.62**	49.7
IPCA2	17	4468457	262850	1.23	20.9
Residuals	39	6308691	161761	0.76	
Error	270	57731767	213821		

*, **, *** Significant at 0.05, 0.01, 0.001 probability levels, respectively.

Table 5. First four AMMI selections per environment.

Number	Environment	Mean	Score	1	2	3	4
1	MED13	1330	11.79	G6	G8	G5	G3
2	MED14	2036	12.64	G6	G8	G5	G3
3	RAH13	3122	4.97	G8	G4	G6	G3
4	RAH14	2280	16.22	G4	G13	G2	G3
5	SEN13	1838	-21.42	G1	G12	G11	G7
6	SEN14	2647	-24.19	G1	G11	G12	G14

MED13= Gezira research Farm season 2013/14, MED14= Gezira research Farm season 2014/15, RAH13= Rahad research Farm season 2013/14, RAH14 = Rahad research Farm season 2014/15, SEN13 = Sennar research Farm season 2013/14, SEN14 = Sennar research Farm season 2014/15, and G1 = genotype R6, G1 = genotype R-6 G2 = genotype R-1, G3 = genotype R-43, G4 = genotype R-42, G5 = genotype R-93, G6 = genotype R-114, G7 = genotype R-200, G8 = genotype R-43-1, G11 = genotype R-231, G12 = genotype R-240, G13 = genotype RS-5 and G14 = genotype Rs-2.

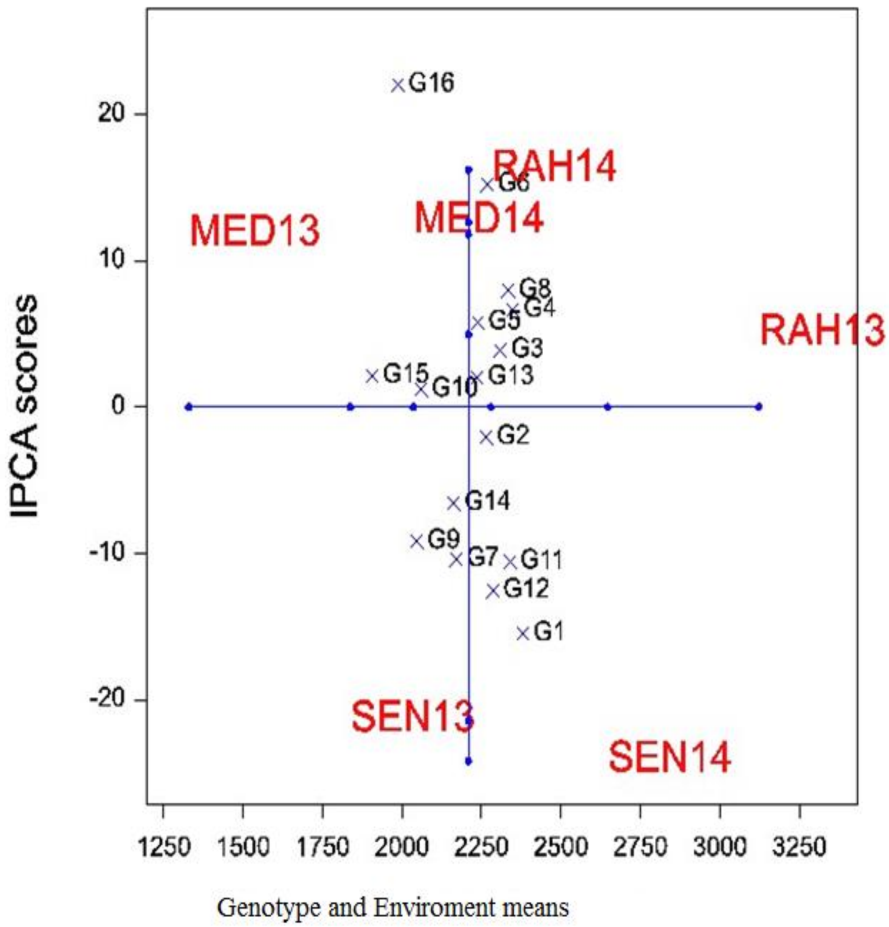

Fig. 1. Plot of Genotype and Environment IPCA 1 scores versus means.

CONCLUSION

Based on the results of this study, it could be concluded that AMMI stability analysis of variance and Eberhart and Russell model (1966) of stability indicated that lines R-231, R- 240 and R-1were the most stable genotypes over environments. Also, based on yield potential and yield stability, the genotypes R-6, R- 40, R-231, and R-43 recommended for further testing over a wide range of environments to examine their suitability for high stable yield and good quality products.

REFERENCES

Ahmed, H. S. 2007. Combining ability for yield and its components in half diallel crosses on local and introduced cultivars of upland cotton (*Gossypium hirsutum* L.). M. Sc. Dissertation Sudan Academy of science, Khartoum, Sudan.

Crossa, J. 1990. Statistical analysis of multi-location trials. Advances in Agronomy 44: 55-85.

Eberhart, S.A. and W.A. Russell. 1966. Stability parameters for comparing varieties. Crop Science. (6): 36-40.

Fryxell, P.A. 1992. A revised taxonomic interpretation of *Gossypium*, family Malvaceae. Rheedea 2:108-165.

Gauch H.G.Jr., H.P. Piepho, and P. Annicchiarico 2008. Statistical analysis of yield trials by AMMI and GGE: further considerations. Crop Science 48: 866-889.

Hammed, F. A. 2001. Characterization of green soils. Annual Report Season 2000/01. (A R C), New Halfa Research Station Sudan.

Killi, F. and O. Gencer. 1995. Determination of adaptation abilities of some cotton genotypes to environment using different stability parameters. Trinidad Journal of Agricultural Forestry 19:361-365.

Lin, C. S., M. R. Binns and L. P. Lefkovitch. 1986. Stability analysis: Where do we stand? Crop Science 26: 894-900.

Liu, L.X. and Sun, Q.X. 1993. A comparative study on different statistical measures of stability. Agronomy Abstracts Across environments. World Journal of Agricultural Science. 3(1):45-49.

Sneller,C. H., L.Kilgore-Norquest and D.Dombek. 1997. Repeatability of yield stability statistics in soybean. Crop Science 37:383-390.

Unay, A.H., A.E. Basal and Z. Yuksekkaya 2004. Stability analysis of upland cotton genotypes to the Aegean region in Turkey. Asian Journal of Plant Science 3:36-38.

Yan, W., L.A. Hunt, Q. Sheng and Z. Szlavnics. 2000. Cultivar evaluation and mega-environment investigation based on the GGE bi-plot. Crop Science 40:597–605.

Zobel, R.W., M.J Wright and H.G. Gauch 1988. Statistical analysis of a yield trial. Agronomy Journal 80: 388-393

تحليل التفاعل الور اثي_البيئ وثبات درجة انتاجية القطن زهره لبعض سلالات القطن الامريكي (*Gossypium hirsutum* L.) في وسط السودان

حسن سالم أحمد سالم[1] و محمود عبد الله محمود[2] و أبو الحسن صالح ابراهيم [3] و عباس محمد سليمان[3]
[1] هيئة البحوث الزراعية، محطة بحوث الرهد، الفاو، السودان.
[2] هيئة البحوث الزراعية ، محطة بحوث الرهد، الفاو، السودان.
[3] كلية العلوم الزراعية،جامعة الجزيرة وادمدني، السودان.

الخلاصة

يعتبر ثبات الانتاجية للقطن الزهرة من أفضل الطرق للتوصية بزراعة الاصناف حسب الظروف المحصولية لكل صنف. تم اختبار 15 سلالة نقية من القطن الأكالا (*Gossypium hirsutum* L.) بالأضافة الي الصنف حامد المنزرع تجاريا بالسودان في موسمي 2013/14 و 2014/15 في محطة بحوث الرهد و محطة بحوث الجزيرة و محطة بحوث سنار, هيئة البحوث الزراعية (ARC), السودان. استخدم تصميم القطاعات العشوائية الكاملة بأربعة مكررات. هدفت الدراسة لتقويم التفاعل الوراثي والبيئ وثبات درجة انتاجية القطن زهرة. أظهرتحليل التباين فروقات معنوية مع البيئات بينما أظهرت السلالات وتفاعل السلالات مع البيئات لانتاجية القطن زهره فروقات معنوية عالية. أيضا أظهرة الدراسة فروقات معنوية لمعظم الصفات التي درسة في كل موسم, وهذا يشير الي وجود فروقات عالية بين سلالات القطن التي درست, عليه يمكنها الاستجابة للانتخاب. أوضح التحليل الاحصائي ل Eberhart and Russel model (1966) و (AMMI) أن الطرز RS-5 و R-96 و R-231 وR-43 و R-1 أظهرت درجة ثبات وانتاجية عالية في كل البيئات. خلاصة البحث واستناداً علي متوسط الأداء وثبات الانتاجية يوصى باختبار ثبات انتاجية الطرز الوراثية R-6 وR-40 وR-231 وR-43 في عدة مواقع ومواسم للتأكد من نتائج هذه الدراسة والاستفادة منها في توصية باجازة بعض هذه الطرز لتناسب الظروف البيئية في السودان.