IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 10, Issue 12 Ver. II (December 2017), PP 08-13
www.iosrjournals.org

Joint regression analysis for metric and quality traits of sugarcane (*Saccharum officinarum* L.) in sub-tropics

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Abstract: *The investigation was undertaken to find out stable genotypes and to determine the magnitude of G×E interaction in ten mid-lategroup of sugarcane genotypes. The experimental material under AICRP was evaluated for their adaptability in respect of cane yield, CCS yield and sucrose % for two crop seasons(2010-11 and 2011-12) under three locations with three cuttings constituting nine environments. A joint regression analysis of variance suggested by Perkins and Jinks (1968) was used to ascertain stable genotypes and magnitude of G×E interaction. Genotype (G) and Environment (E) for all the three characters were significant. Heterogeneity of regression (Linear) and theremainder (Non–linear) both were significant and accounted for G×E interaction. The regression analysis of stability showed that genotypes CoP 05437 and CoP 9301 might be considered to the unfavourable environment for cane as well as CCS yield.While,CoP 9301, CoSe92423 and BO 91 were suitable and stable for sucrose % under varying environments.The genotypes which shown significant DMS were unstable and unpredictable across the environments.*

Keywords:*Regression analysis, stability, G x E interaction, Saccharum spp., genotype*

Date of Submission: 09-11-2017 Date of acceptance: 18-12-2017

I. INTRODUCTION

Sugarcane isa multi-facet cash crop cultivatedextensively in tropical and sub-tropical India.Around 66% production of sugarcane comes from sub-tropical states (Dubey et al. 2017). Inspite of occupation over 50.55 lakh hectares by sugarcane crop in the country with a production of 3481.87 lakh tones. India stood on thesecond pedestal in sugar production after Brazil. Sugarcane juice is being used in theproduction of sugar, jaggery, ethanol and liquor etc., while its baggasse obtained after extraction of juice in the sugar factories is used in pulp and paper industry and most importantly in co-generation of electricity in the energy deficient states like Bihar and Uttar Pradesh in India. The environment in sub-tropical India fluctuates widely in terms of temperature, photoperiod and relative humidity during crop growth period which tremendously affects cane yield and its contributory traits. Hence, tonnage is generally low in sub-tropical part of India (Tiawari et al. 2011). As a consequence, a genotype under varying environments performsdifferently over locations.

Breeding of varieties in sugarcane is a highly cumbersome task owing to its heterozygous nature coupled with higher polyploidy. The genotype x environment (G×E) interaction is a widely recognized phenomenon in sugarcane clonal evaluation multi-location trials (Kimbeng et al. 2002). G×E interactions are very important sources of variation among the genotype of a crop which make difficult for the breeder to decide the true genetic value of prospective genotypes and to select among them because gene expression of an individual may occur with thechange ofenvironments. However, sugarcane breeders are aware of the differences of its cultivars for yield and quality which varies from region to region due to thepersistence of G×E interaction. Hence, there is urgent need to breed stable genotype over awide range of environments and the term stability is often used to characterize a genotype, which shows a relatively constant yield irrespective of changing environmental conditions.

The phenotypic expression by the environment was recognized by Johannsen (1909) while working with dwarf bean (*Phaseolus vulgaris* L.). He reported that heritable and non-heritable differences were jointly responsible for the variation in seed weight of beans and were of the same order of magnitude in effect. The different analysis of continuous variation over a number of years in many plants and animal species revealed the combination of heritable and non-heritable components in the determination of continuous variation. Therefore, keeping into the account of above facts, the present experiments were undertaken to evaluate and detect stable genotypes and the magnitude of G×E interaction for cane and sugar yield across the nine environments.

II. MATERIALS AND METHODS

Study area

Seven genotypes of sugarcane (Mid-late group) bred by different research centers of North Central Zone along with three standard checks were evaluated for cane yield, sugar yield and sucrose % in juice under the All India Coordinated Research Project on Sugarcane for three crops(I Plant crop, II Plant crop and ratoon crop, respectively) during 2010-2011 and 2011-12 at three locations *viz*, ICAR-IISR, Regional Centre, Motipur (28°03′ latitude 81°4′ longitude), Sugarcane Research Institute, RAU, Pusa (25°9′ latitude 85°7′ longitude) and GSSBRI, Seorohi, Kushinagar (26°7′ latitude 84°2′ longitude).

Experimental material and design

The experimental material consisted of Co 05018, Co 05019, Co 05020, CoP05437, CoSe 05452, CoBln 05502 and CoBln 04174 along with three standard checks (BO 91, CoP 9301 and CoSe92423). The experiment at three different locations over two crop seasons with three cuttings of crops developed nine environments. The trial was laid out in a randomized block design (RCB) with three replications at all three locations. Plots size were of 6.0 m length having 8 rows with spacing 0.9 m between rows. Three bud setts were used for planting with aseed rate of 12 buds per m^2 at all three locations. Six rows were harvested for quantifying cane yield in each plot across replications and it was calculated as t/ha. A 10 stalk sample was randomly taken from each plot and weighed. CCS t/ha was computed as per standard formula. The clarified juice was analysed with digital automatic saccrimeterAutopol 880 and J 57 Automatic refractometer for sucrose % in juice. The joint regression analysis to study G×E interaction and ascertaining stable genotypes across the environments was doneas per the Perkins and Jinks (1968) model.

III. RESULTS

Joint regression analysis of variance in this investigation across nine environments of ten sugarcane genotypes for cane yield, CCS yield and sucrose % are shown in Table 1.It was clear from the table that Genotype (G) and environment (E) items were highly significant for all three traits when tested against within errorwhich indicated that there were real differences existed between the genotypes and between the effects of environments on the genotypes. Significant environmental effects in the study indicated that variability between the environment was large enough for proper estimation of regression coefficient (b_i) values.

The joint regression analysis G×E interaction sum of the square was partitioned into the heterogeneity of regression sum of square (Linear) and the remainder sum of square (Non-linear). In most of the case, both linear and non-linear regression was accounted for G×E interaction. The heterogeneity betweenregressions was significant for all three characters. The significant remainder item made complex the linear prediction for the G×E interaction existed in the genotypes (Table 1).

TABLE 1. Joint regression analysis forG×Einteraction for metric and quality traits in Sugarcane across nine environments

Source of variation	df	Mean sum of squares		
		Cane yield (t/ha)	CCS (t/ha)	Sucrose %
Genotypes (G)	9	170.30**	2.43**	1.83**
Environments (Joint Regression)	8	752.24**	14.78**	5.31**
G×E	72	53.05	0.77	0.23
Heterogeneity between regression	9	120.73**	1.43*	0.55**
Remainder	63	43.38**	0.68**	0.19**
Within Error	162	12.33	0.09	0.08

** 1% level of significance, * 5% level of significance

The genotypes CoBln 05502, CoP 05437, CoP 9301 and BO 91 were found on first, second, third and fourth place, respectively, for cane yield on the basis of stability parameters. The genotypes CoP 05437 and CoP 9301 were stable for cane yield under unfavourable environmental conditions,whileCoBln 05502 and BO 91 might be selected for the favourable environment. However, the genotype CoP 05437 did well consistently across the nine environments (Table 2).

The genotypes CoP 05437 and CoP 9301 again for CCS yield were found suitable and stable to the unfavourable environment, while CoBln 05502 might be considered for favourable environmental conditions. However, BO 91 showed poor adaptation for CCS yield across nine environments (Table 3).

CoP 9301 was the most stable for sucrose % across the nine environments and it can be grown in poor as well as favourable environmental conditions. While CoSe92423 and BO 91 were also stable and suitable for changing environments (Tabel 4).

TABLE 2. Performance of genotypes for cane yield (t/ha) and their rank of stability across nine environments

Genotypes/ Environments	E1 (First plant crop, Motipur)	E2 (Second plant crop, Motipur)	E3 (Ratoon crop, Motipur)	E4 (First plant crop, Pusa)	E5 (Second plant crop, Pusa)	E6 (Ratoon crop, Pusa)	E7 (First plant crop, Kushinagar)	E8 (Second plant crop, Kushinagar)	E9 (Ratoon crop, Kushinagar)	Grand Mean	b_i	DMS	Rank
Co 05018	48.31	53.55	28.21	61.10	58.10	52.90	64.38	66.09	59.57	54.69	1.15	20.74	5
Co 05019	52.69	74.47	55.00	59.85	57.60	50.95	59.85	63.39	60.93	59.44	0.40	25.97	6
Co 05020	54.65	79.72	61.76	66.99	63.50	56.92	67.47	61.30	57.84	63.35	0.44	33.23	7
CoP 05437	59.41	72.22	48.20	80.85	78.40	71.03	80.85	68.33	60.93	70.02	1.11	4.34	2
CoSe 05452	48.43	54.17	28.63	73.61	71.36	63.08	73.60	70.17	58.83	60.21	1.50	44.97	9
CoBln 05502	42.87	59.43	27.39	68.71	67.50	50.80	68.71	60.68	46.37	54.72	1.56	2.28	1
CoBln 04174	71.85	78.79	44.80	63.75	59.36	50.25	64.08	60.80	55.50	61.04	0.79	54.69	10
BO 91	58.53	75.00	40.68	66.76	62.81	57.10	66.76	54.88	50.81	59.26	1.02	10.76	4
CoP 9301	54.32	68.70	32.96	74.72	74.27	60.75	74.72	57.81	53.03	61.25	1.51	5.67	3
CoSe92423	64.39	52.53	42.95	61.48	59.20	57.00	61.65	71.53	65.24	59.55	0.51	39.06	8
Environmental index	-3.77	6.51	-19.30	7.43	4.86	-3.28	7.85	3.15	-3.45				
Mean	56.58	66.86	41.06	67.78	65.21	57.08	68.21	63.50	56.91				
C.V.	6.69	9.84	13.11	8.94	10.78	11.69	7.61	12.79	8.39				
SE of difference	3.09	5.37	4.39	4.94	5.74	5.45	4.23	6.63	3.90				

TABLE 3. Performance of genotypes for CCS yield (t/ha) and their rank of stability across nine environments

Genotypes/ Environments	E1 (First plant crop, Motipur)	E2 (Second plant crop, Motipur)	E3 (Ratoon crop, Motipur)	E4 (First plant crop, Pusa)	E5 (Second plant crop, Pusa)	E6 (Ratoon crop, Pusa)	E7 (First plant crop, Kushinagar)	E8 (Second plant crop, Kushinagar)	E9 (Ratoon crop, Kushinagar)	Grand Mean	b_i	DMS	Rank
Co 05018	5.50	6.05	3.22	7.81	7.13	6.19	7.64	7.45	7.37	6.48	1.05	0.49	7
Co 05019	6.10	8.42	5.94	7.67	7.38	5.19	7.75	7.20	7.42	7.01	0.62	0.48	6
Co 05020	6.02	8.90	6.62	8.25	7.89	6.55	7.77	6.90	6.65	7.28	0.55	0.45	5
CoP 05437	7.53	8.35	5.47	10.66	9.71	7.65	8.63	8.13	7.21	8.15	1.15	0.17	2
CoSe 05452	5.84	6.40	3.34	9.32	8.38	7.42	9.90	8.46	7.20	7.36	1.43	0.99	9
CoBln 05502	4.81	6.54	3.13	8.55	8.48	5.11	7.40	7.26	5.65	6.33	1.44	0.16	1
CoBln 04174	8.49	8.90	4.99	8.15	7.40	5.41	7.73	6.28	6.22	7.06	0.78	1.09	10
BO 91	6.97	8.47	4.70	8.50	7.92	6.44	7.12	6.53	5.98	6.96	0.89	0.30	3
CoP 9301	6.61	8.44	4.13	9.75	10.19	6.93	7.91	7.29	6.87	7.57	1.40	0.31	4
CoSe92423	7.67	6.11	4.79	7.84	7.52	6.57	8.24	8.34	7.94	7.23	0.67	0.72	8
Environmental index	-0.59	0.52	-2.51	1.51	1.06	-0.80	0.87	0.24	-0.29				
Mean	6.55	7.66	4.63	8.65	8.20	6.35	8.01	7.39	6.85				
C.V.	6.68	4.15	3.52	7.24	9.98	9.62	6.34	5.10	9.62				
SE of difference	0.36	0.26	0.13	0.51	0.67	0.50	0.42	0.31	0.54				

TABLE 4. Performance of genotypes for sucrose % in juice and their ranks in terms of stability across nine environments

Genotypes/ Environments	E1 (First plant crop, Motipur)	E2 (Second plant crop, Motipur)	E3 (Ratoon crop, Motipur)	E4 (First plant crop, Pusa)	E5 (Second plant crop, Pusa)	E6 (Ratoon crop, Pusa)	E7 (First plant crop, Kushinagar)	E8 (Second plant crop, Kushinagar)	E9 (Ratoon crop, Kushinagar)	Grand Mean	b_i	DMS	Rank
Co 05018	16.12	16.06	16.48	18.47	17.48	16.89	17.42	17.02	17.77	17.08	0.92	0.12	8
Co 05019	16.36	16.26	15.64	18.18	18.76	14.99	17.05	16.47	17.66	16.82	1.58	0.07	6
Co 05020	15.66	15.90	15.54	18.00	18.30	16.44	17.19	16.25	16.59	16.65	1.26	0.07	5
CoP 05437	15.34	16.64	16.52	18.45	18.11	15.89	17.15	17.20	17.07	16.93	1.23	0.09	7
CoSe 05452	17.36	17.19	16.98	18.17	17.10	17.66	17.46	17.45	17.71	17.45	0.18	0.04	3
CoBln 05502	16.10	16.10	16.55	17.90	18.09	15.81	16.52	17.28	17.55	16.88	1.05	0.05	4
CoBln 04174	16.72	16.32	16.10	17.93	18.00	15.94	17.25	15.69	16.24	16.69	0.95	0.19	9
BO 91	17.02	16.60	16.76	18.09	18.28	16.44	17.25	17.35	17.06	17.21	0.80	0.03	2
CoP 9301	17.38	17.65	18.22	18.40	19.80	16.59	18.57	18.24	18.70	18.17	1.00	0.23	10
CoSe92423	16.83	16.84	16.22	18.35	18.47	16.77	17.15	16.86	17.64	17.64	0.99	0.02	1
Environmental index	-0.62	-0.56	-0.61	1.08	1.13	-0.77	0.19	-0.13	0.29				
Mean	16.49	16.56	16.50	18.19	18.24	16.34	17.30	16.98	17.40				
C.V.	3.97	2.81	2.34	2.24	3.32	4.18	1.78	2.49	3.07				
SE of difference	0.54	0.38	0.32	0.33	0.49	0.56	0.25	0.35	0.44				

TABLE 5. Stability parameters for cane yield, CCS yield and sucrose % in 10 Sugarcane genotypes

	Cane yield (t/ha)			CCS (t/ha)			Sucrose % in juice		
Genotypes	Mean	b_i	DMS	Mean	b_i	DMS	Mean	b_i	DMS
Co 05018	54.57	1.15	20.74*	6.48	1.05	0.48**	17.07	0.92	0.11*
Co 05019	59.44	0.40	25.97**	7.00	0.62	0.48**	16.82	1.58	0.07
Co 05020	63.36	0.44	33.23**	7.28	0.55	0.45**	16.65	1.26	0.07
CoP 05437	70.02	1.11	4.34	8.15	1.15	0.17	16.93	1.23	0.09
CoSe 05452	60.21	1.50	44.97**	7.36	1.43	0.99**	17.45	0.18	0.03
CoBln 05502	54.72	1.56	2.28	6.32	1.44	0.16	16.88	1.05	0.04
CoBln 04174	61.08	0.79	54.69**	7.06	0.78	1.08**	16.69	0.95	0.19**
BO 91	59.26	1.02	10.76	6.96	0.89	0.30	17.21	0.80	-0.03
CoP 9301	61.25	1.51	5.67	7.57	1.40	0.31	18.17	1.00	0.23
CoSe92423	59.55	0.51	39.06**	7.22	0.67	0.72**	17.24	0.99	-0.02
Population mean	60.35			7.14			17.11		
SE (Mean)	2.20			0.28			0.15		
SE of b_i		0.25			0.23			0.20	

** 1% level of significance, * 5% level of significance

The higher mean value overpopulation mean with non-significant DMS and greater than 1.0 regression coefficient noticed by the genotypes CoP 05437 and CoP 9301 for cane yield. While genotypes CoBln 05502 and BO 91 showed regression coefficient higher than 1.0 and non-significant DMS with average mean cane yield. The genotypes (Co 05018, Co 05019, Co 05020, CoSe 05452, CoBln 04174 and CoSe 92423) exhibited significant DMS for cane yield. Indeed, CoP 05437 and CoP 9301 showed non-significant DMS and greater than 1.0 regression coefficient having mean value overpopulation mean for CCS yield also. Whereas, BO 91 is having lesser mean value than thepopulation mean exhibited lesser than 1.0 regression coefficient with non-significant DMS for CCS yield. Although rest of the genotypes for CCS yield showed significant DMS. On the other hand, CoP 9301, CoSe 92423 and BO 91 for sucrose % showed non-significant DMS and regression coefficient equal to 1.0 with higher mean performance than thepopulation mean (Table 5).

IV. DISCUSSION

In this investigation joint analysis of regression across nine environments of ten sugarcane genotypes for cane yield, CCS yield and sucrose % as shown in Table 1 made it clear that Genotype (G) and environment (E) items were noticed highly significant for all three traits when they were tested against within error it indicated that there were real differences existed between the genotypes and environments on the performance of genotypes (Khatod et al. 2006; Sagor et al. 2007). However, significant environmental effects reflected that variability between the environments was large for estimation of regression coefficient (b_i) values.Variability in environment is an important factor and its large part determines the usefulness of b_i-values (Pfahler and Linskens, 1979).

It was noticed that in most of the cases,the G x E interaction was due to linear and non-linear regression.However, the heterogeneity of regression for all three characters was significant. Further, asignificant remainder component made complex the linear prediction for the G x E interaction existed in the genotypes.Both linear and non-linear relationships with environments were reported by researchers in different crops (Singh and Gupta 1983; Ghosh and Singh 1996; Khatods et al. 2006; Tiawari et al. 2011; Alam et al. 2013 and Dubey et al. 2017).

Regression analysis quantify the character of the genotype in relation to the environment that show much genotypes depends on the environment to express its character and at the same time, genotypic and environmental effects were estimated by the method of regression analysis. However, in respect of stability measurement,there are various methods suggested by different research workers in a different investigation. Finlay and Wilkinson (1963) considered the linear regression (b_i) as a measure of stability while, Eberhart and Russell (1966) suggested the criteria of a stable genotype that regression coefficient (b_i) should be 1.0 and deviation mean of squares from regression (DMS) need to be zero with genotype mean greater than population mean/grand mean. Further, Breese (1969) stated that regression coefficient is a measure of effects to varying environments of a particular genotype. From their observations, it may be concluded that a genotype which has high mean performance, a nearly unit regression coefficient (b_i=1.0) and non-significant DMS is stable for varying environmental conditions. The genotype which exhibited higher mean performance below average b_i and non-significant DMS may be selected for the poor environment. The genotype which has high mean performance and b_i above unity and non-significant DMS indicated its adaptability to the unfavourable environment. The genotypes which have above average mean performance and b_i higher than unity and non-significant DMS are sensitive to the changing environment may be selected for the favourable environment. The genotype which exhibited less mean performance, b_i-value near to unity and non-significant DMS poorly adaptable to all environments. The genotype which had significant DMS would be unstable to varying environments. The grand mean performance of genotypes across nine environments, regression Coefficient (b_i) and deviation mean square from regression (DMS) are presented in Table 5.

The genotypes CoP 05437 and CoP 9301 showed non-significant DMS and regression Coefficient (b_i>1.0) with higher mean value than the population mean indicating their adaptability to unfavourable environment for cane yield. Genotypes CoBln 05502 and BO 91 exhibited regression Coefficient (b_i>1.0) and DMS non-significant with average mean cane yield indicated they are sensitive to the changing environments thereby may be selected for the favourable environment. Other genotypes exhibited significant DMS indicating their unstability over environments where they were tested. While both the genotypes (CoP 05437 and CoP 9301) for CCS yield showed non-significant DMS and regression Coefficient (b_i>1.0) having a mean value greater than the population mean indicating again their suitability and stability to unfavourable environmental conditions. The genotype BO 91 exhibited non-significant DMS and regression Coefficient (b_i<1.0) for CCS yield with lesser mean value than the population mean indicating poor adaptation for this trait in all the environments. The genotype CoBln 05502 showed DMS non-significant and (b_i>1.0) with less mean CCS yield compared to the population mean may be selected for the favourable environment. On the other hand, in terms of sucrose, the genotype CoP 9301 showed son-significant DMS and regression Coefficient (b_i=1.0) having higher mean performance than the population mean was found stable for varying environmental conditions. Another two genotypes namelyCoSe92423 and BO 91 showed higher sucrose % mean value than the population mean with non-significant DMS and regression Coefficient (b_i=1.0) indicated stability for changing environments. Such findings were earlier reported by Singh and Rai 1989; Singh et al. 1993; Islam et al. 2002; Khan et al. 2002; Khatod et al. 2006, Tiwari et al. 2011, Alam et al. 2013, Tahir et al. 2013 and Dubey et al. 2017. There areevidence that in sugarcane for different quantitative characters, some genotypes were adaptable in favourable and some were adaptable in unfavourable conditions, however, rest of the genotypes were found unstable and unpredictable due to their significant DMS for the traits under study.

V. CONCLUSION

Significant linear and non-linear components made the prediction of G×E interaction complex existed in the genotypes. The genotypes CoP 05437 and CoP 9301 were found best stable genotypes across the environments for cane yield and CCS yield respectively.Hence, they could be the most potential parent for the future breeding programme in sugarcane.

Acknowledgement

Authors are highly thankful to ICAR-IISR, Lucknow and Uttar Pradesh Council of Sugarcane Research, Shahajahanpur for providing logistic support in conducting multi-location trials under AICRP-Sugarcane.

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