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Simultaneous Selection for Yield and Stability in Sugarcane Using AMMI Model

Gulzar S Sanghera[1]*, Arvind Kumar[2] and Rajesh Kumar[3]

Punjab Agricultural University, Regional Research Station, Kapurthala, 144 601 (Punjab)

ABSTRACT

In present study, three early maturing clones CoPb 08211, CoPb 08212, CoS 08233 and two standards *viz.,* CoJ 64 and CoPant 84211 were evaluated in three crop cycles (I and II Plant crop and ratoon crop) at seven locations in North West Zone during 2012-14. Data on CCS (t/ha), cane yield (t/ha) and sucrose (%) were subjected to stability analysis using AMMI model and simultaneous selection of high yielding and stable clones was done by estimated index value based ranking. Based on index of simultaneous selection of high CCS (t/ha) and stable clones, it was found that the standard CoJ 64 and clones CoPb 08212 and CoS 08233 were at first, second and third rank, respectively. Considering top two high CCS (t/ha) and stable clones, CoPb 08212 and CoS 08233 were superior, but inferior to the standard CoJ 64. Results based on stability value and rank based on estimated value for high cane yield (t/ha) revealed that entries CoPb 08212 (80.39 t/ha) and CoS 08233 (76.02 t/ha) were at first and second rank, respectively and better than both the standards CoJ 64 and CoPant 84211. Simultaneous selection based on high sucrose (%) and stability revealed that the clones CoPb 08212 (18.10%), CoPb 08211and CoS 08233 were at first, second and third rank, respectively. All these clones were better than both the standards used. From the above analysis, it may be concluded that the entries CoPb 08212 and CoS 08233 were stable clones with high yield and sucrose (%) in early maturity group of North West Zone.

Key Words: AMMI Model, Sugarcane, Sucrose, Stability.

INTRODUCTION

Sugarcane (*Saccharum spp*. hybrid complex) is highly sensitive to environmental factors and therefore selection of location specific varieties is important aspect in its breeding programme (Anon, 2014). In recent past, a large number of improved varieties have been identified through AICRP trials, and some have occupied sizeable area in most parts of the country. Such varieties have contributed in improving the sugarcane productivity. Although a wide range of techniques to analyze G x E interactions are available, their application to sugarcane is limited in comparison with other field crops (Ramburan, 2012). The majority of studies of G x E interactions (GEI) of sugarcane fall within the empirical category, where the focus was on clone stability and identification of homogenous environments within breeding programs (Kang and Miller, 1984; Tai *et al,* 1982). Jackson *et al* (1995) used ANOVA, cluster analysis and PCA to investigate G x E interactions of three datasets of sugarcane pre-release trials in Australia. Stability in performance is one of the most desirable properties of a clone to be released as a variety for cultivation. In case, the variance due to G x E interaction is found significant, one of the various approaches known for measuring the stability of clones can be used and the variety may be ranked accordingly (Singh and Chaudhary, 1977). For a successful breeding of variety testing programme, both stability and yield (or any other trait) must be considered simultaneously. Under AICRP

*Corresponding author Email: sangheragulzar@pau.edu

[1]Punjab Agricultural University, Regional Research Station, Kapurthala, 144601, Punjab, India

[2]UP Council of Sugarcane Research, Shahjahanpur, 242001, UP, India

[3]ICAR-Indian Institute of Sugarcane Research, Lucknow, 226002, UP, India

on sugarcane, simultaneous selection indices using Additive Main Effects and Multiplicative Interaction (AMMI) model for Advanced Varietal Trial was initiated (Kumar and Sinha, 2015). AMMI model is a suitable technique to deal with multi-location trials, compared to traditional methods like ANOVA, Principal Component Analysis (PCA) and linear regression. Currently, selection of sugarcane clones is based on the performance of cane yield in different locations across the zone and ranking of clones is done on the basis of mean data. The analysis and ranking of clones based on simultaneous selection of high yielding and stable clones give better and reliable picture in identifying a variety for its release in a zone. The present study summarizes the results obtained from Advanced Varietal Trial (Early) conducted at seven locations in North West Zone during 2012-14, using AMMI model.

MATERIALS AND METHODS

The combined analysis of sets of experiments conducted in a randomized complete block design for three crop cycles (two plant crop and one ratoon) over seven locations (Faridkot; Karnal; Kapurthala; Lucknow; Muzaffarnagar; Shahjahanpur and Sriganganagar) in North West Zone was performed for cane yield (t/ha), commercial cane sugar (CCS) yield (t/ha) and sucrose (%). Integration of stability of performance with yield of clone through suitable measures will help in appropriate selection of a variety. One approach would be to integrate measures of performance and stability as a most informative index (Rao and Prabhakaran, 2005). A brief outline of AMMI and bio-plots procedure is discussed below.

AMMI and simultaneous selection procedure

The first part of AMMI uses the normal ANOVA procedures to estimate the clone and environment main effects. The second part involves the PCA of the interaction residuals (residuals after main effects are removed). The model formulation for AMMI shows its interaction part consisting of summed orthogonal products. Because of this form the interaction lends itself to graphical display in the form of so called bi-plots (Gabriel, 1971). Here, it is assumed that the first two PCA axes suffice for an adequate description of the GxE interaction. It is evident from earlier sections that the scope of bi-plots is very much limited. The inferences drawn from bi-plots would be valid only when the first two PCAs explain a large portion of interaction variation. In situations, where more than two PCA axes are needed to accumulate considerable portion of GEl variation, what should be the approach for identifying varieties which are high yielding as well as stable. Keeping this in mind, a new family of simultaneous selection indices was proposed by Rao and Prabhakaran (2005), which select varieties for both yield and stability and was applied in the present study. The proposed selection indices (Ii) consists of (i) a yield component, measured as the ratio of the average performance (i. Y) of the i-th clone to the overall mean performance of the clones under test, and (ii) a stability component, measured as the ratio of stability information (l/ ASTABi) of the i-th clone to the mean stability information of all the clones under test. The simultaneous selection index is given below:

$$I_i = \frac{\overline{Yi.}}{\overline{\overline{Y}}} + \alpha \frac{1/\text{ASTABi}}{\frac{1}{T}\sum_{i-1}^{T}\frac{1}{\text{ASTABi}}}$$

Where ASTABi is the stability measure of the i-th clone under AMMI procedure and Y is mean performance of i-th clone. α is the ratio of the weights given to the stability components (w2) and yield (w1) with a restriction that w1 + w2= 1.

The weights considered in the index are, in general, as per the plant breeders' requirement. By considering the values of a as 1.0 (w1= w2 =0.5), 0.66 (w1=0.6, w2=0.4), 0.43 (w1=0.7, w2=0.3) and 0.25 w1 = 0.8, w2 = 0.2), a new family of indices consisting of four indices I1, I2, I3 and I4 was proposed. Combination of two years of plant crops (2012-13 and 2013-14) and one ratoon crop during 2013-14 and seven locations were treated as 21 environments for stability analysis. At each location, the trial was conducted in randomized block design with four replications of gross plot size 8 rows of 6.0 m with 0.75 m row to row distance and seed rate using 12 buds per meter. Planting of crop was done during the month of February/March for plant crop. Data on cane yield (t/ha), sugar yield CCS (t/ha) and sucrose (%) were recorded at harvest stage both in AVT (300 d after planting of the crop) and in ratoon crop after 210 d of ratooning (after harvesting of plant crop. The planting and the harvesting were performed manually. For analysis of the data, the data of AVT- I were taken as AVT - II for cane yield (t/ha), CCS (t/ha) and sucrose (%). AMMI analyses and simultaneous selection indices analyses were performed with the help of SAS 9.3 (SAS Institute, 2002- 2010).

RESULTS AND DISCUSSION

Analysis of Variance Studies Using AMMI Model

The mean data for combined analysis on cane yield, CCS (t/ha) and sucrose content in juice of different locations were considered for AMMI and stability analysis. The significant interactions of clones × environments (locations and years combination) suggest that cane yield (t/ha), sugar yield CCS (t/ha) and sucrose (%) of clones varied in plant and ratoon crop. Significant differences for clones, environments and clones x environments interaction indicated the effect of environments in the GxE interaction, genetic variability among the entries and possibility of selection for stable clones with respect to cane yield (Table 1.1), CCS (t/ha) (Table 2.1) and sucrose per cent in juice (Table 3.1).

The AMMI analysis of variance for yield under 21 environments indicated that the effects of clone, environment and their interaction on cane yield were significant, with the proportion of the total treatment variation of 11.51per cent for clone, 47.57 per cent for the environment and 28.08 per cent for interaction (G x E) (Table 1.1). Similarly for CCS (t/ha), the effects of clone, environment and their interaction were significant, with the proportion of the total treatment variation of 11.83 per cent for clone, 48.86 per cent for the environment and 28.90 per cent for their interaction (Table

Table 1.1. AMMI analysis of cane yield (t/ha) of five clones/varieties over twenty one environments in North West Zone

Source	DF	SS	MSS	F at 5%	Per cent Contribution to SS	PCA Contribution	PCA Cumulative Contribution
Genotype	4	3061.12	765.28	31.41**	11.51		
Env.	20	15862.98	793.15	76.60**	47.57		
GxE	80	9114.72	113.93	7.18**	28.08		
PCA1	18	5393.69	299.65	15.80**	53.62	57.62	57.62
PCA2	16	2482.66	155.17	7.55**	27.92	25.92	85.54
PCA3	14	651.38	46.53	2.94**	7.19	7.19	92.72
PCA4	12	448.47	37.37	2.27**	4.87	4.85	97.56
Residual	10	130.52	13.05				
Average Error	225	3662.92	16.28		11.34		
Total	399	40808.46					

** - Significant at 1 % level of significance

DF-degree of freedom; SS- sum of square; MSS- mean sum of square; PCA- principal component analysis and GxE- genotype into environment.

Table 2.1 AMMI analysis of commercial cane sugar (t/ha) of five clones/varieties over twenty one environments in North West Zone

Source	DF	SS	MSS	F at 5%	% Contribution to SS	PCA Contribution	PCA Cumulative Contribution
Genotype	4	81.50	20.38	71.09**	11.83		
Env.	20	410.96	20.55	112.57**	48.86		
GxE	80	245.00	3.06	12.62**	28.90		
PCA1	18	174.06	9.67	36.54**	71.88	71.88	70.88
PCA2	16	38.71	2.42	10.58**	17.08	16.08	85.95
PCA3	14	17.10	1.22	4.46**	6.55	6.52	92.47
PCA4	12	10.99	0.92	3.56**	4.48	4.45	96.92
Residual	10	0.73	0.07				
Average Error	225	58.30	0.26		7.08		
Total	399	1037.55					

** - Significant at 1 % level of significance

DF-degree of freedom; SS- sum of square; MSS- mean sum of square; PCA- principal component analysis and GxE- genotype into environment

2.1). In case of sucrose (%), the effects of clone, environment and their interaction were significant, with the proportion of the total treatment variation of 19.86 per cent for clone, 47.46 per cent for the environment and 28.00 per cent for their interaction (Table 3.1). Further, 48.86 per cent of the total SS was attributable to environmental effects, 11.83 per cent to genotypic effects and 28.90 per cent to G × E interaction effects. Similar results in sugarcane crop were obtained by Silveira *et al* (2013) who observed that the AMMI analysis of variance of the variable tons of pol per ha (TPH) across two cuttings and seven environments, 73.36 per cent of the total SS was attributable to environmental effects, 12.01 per cent to genotypic effects and 14.63 per cent to G × E interaction effects.

For cane yield (t/ha), CCS (t/ha) and sucrose (%), the significant effect of the G × E interaction (Table 1.1, 2.1 and 3.1) revealed that the clones had variable performance in the tested environments of the Zone. Silveira *et al* (2013) also reported that a change in the average rank of clones was verified among the environments, justifying for more refined analysis to increase the efficiency of the selection of cultivars.

Based on the above conclusions, AMMI analysis is more appropriate. In this sense, AMMI analysis represents a potential tool that can be used for in-depth understanding of the factors involved in the manifestation of the G × E interaction. Silveira *et al* (2013) also indicated that the AMMI method allowed for easy visual identification of superior clones for each set of environments. In this study also, a large SS for environments indicated that the environments were diverse with cane yield ranging from 45.23 (CoPb 08211) to 109.99 t/ha (CoPb 08212) for plant crop and 44.23 (CoPb 08211) to 122.41 (CoS 08233) for ratoon crop. Similar observations were also noted for CCS (t/ha) parameters. In case of sucrose (%), the variation ranged from 16.20 per cent (CoPant 84211) to 19.62 per cent (CoPb 08211) for environments in plant crop and 16.36 % (CoPant 84211) to 19.17 per cent (CoPb 08212) in ratoon crop. According to Gauch and Zobel (1996), in standard multi-location trials, 80 per cent of the total sum of treatments

Table 3.1 AMMI analysis of sucrose (%) of five clones/varieties over twenty one environments in North West Zone

Source	DF	SS	MSS	F at 5%	Per cent Contribution to SS	PCA Contribution	PCA Cumulative Contribution
Genotype	4	51.17	12.79	274.94**	19.86		
Env.	20	136.09	6.80	255.22**	47.46		
GxE	80	81.23	1.02	39.42**	28.00		
PCA1	18	41.60	2.31	61.81**	54.10	52.10	53.10
PCA2	16	14.54	0.91	21.46**	17.87	17.87	68.97
PCA3	14	11.43	0.82	24.57**	14.49	16.49	84.46
PCA4	12	8.48	0.71	19.68**	11.53	11.53	94.99
Residual	10	3.24	0.32				
Average Error	225	8.47	0.04		3.08		
Total	399	356.25					

** - Significant at 1 % level of significance

DF-degree of freedom; SS- sum of square; MSS- mean sum of square; PCA- principal component analysis and GxE- genotype into environment

is due to environment effect and 10 per cent due to G x E. Bissessur *et al* (2001) also showed that AMMI method was more effective than ANOVA in identifying significant G x E interactions in a study of final stage selection trials in Mauritius. They found that AMMI method was effective at identifying cultivars with broad and specific adaptation and recommended that the technique be routinely used to obtain additional information on clones prior to their commercial cultivation.

Similarly, in North West Zone, G x E interaction portion is very high and significant which capture more than 92.72 per cent for cane yield (t/ha), 92.47 for CCS (t/ha) and 84.46 per cent for sucrose (%) by only three significant PCA axis (Tables 1.1, 2.1 and 3.1). It indicated that non-linear component of G x E interaction in sugarcane is very high and routine analysis is not appropriate for screening of clones at final stage of selection. Hence, it is suggested that AMMI analysis and simultaneous selection of clones is more appropriate in sugarcane. In this study, only two to four axis are appropriate for drawing the conclusion. Cornelius (1993) also suggested that the number of multiplicative terms appropriate for a given data set may also be determined by a test of significance. By using principal component analysis, the first interaction axes contain a greater standard percentage, with a decrease in the subsequent axes. Thus, as the number of selected axes increases, the noise percentage also increases, reducing the predictive power of the analysis (Oliveira *et al,* 2003). In this case we have retained four significant axis in the model for cane yield (t/ha), CCS (t/ ha) and sucrose (%).

Ranking of Clones based on Stability and Selection Criteria

For simultaneous selection criterion proposed by Rao and Prabhakaran (2005) is used in this study which selects clones for both high yield and stability in multi environmental trials using AMMI model by assigning 80 per cent weight to yield and 20 per cent to stability value of the clones. Such weights were assigned because Hogarth (1976) inferred that 75 per cent of the gains in cane yield in Australia were attributed to the varietal improvement. Edme *et al* (2005) estimated that genetic improvement alone contributed 69 per cent of sugarcane yield. Simultaneous selection criterion as discussed above has been used for selection of superior clones evaluated in Advanced Varietal Trial (Early) of I and II Plant and Ratoon crop in NWZ. Three entries viz. CoPb 08211, CoPb 08212, CoS 08233 and two standards, CoJ 64 and CoPant 84211 were evaluated during three crop cycles (I and II Plant and Ratoon crop) at seven locations. The data on cane yield (t/ha), sugar yield CCS(t/ha) and sucrose (%) were subjected to stability analysis by the use of additive main effects and multiplicative interaction (AMMI) criterion and simultaneous selection of high yielding and stable clones was done by the use of index value based ranking proposed by Rao and Prabhakaran (2005). Estimated Index value, yield values and stability value of different clones for cane yield (t/ha), sugar yield CCS (t/ha) and sucrose (%) along with their ranks are presented in Tables 1.2, 2.2 and 3.2.

The results based on index of simultaneous selection of high cane yield (t/ha) and stable genotypes revealed that both the standards CoJ 64 and CoPant 84211 were at the first and second rank, followed by the entries CoPb 08212 and CoS 08233. Such a ranking differs with the ranking based only on mean data (Table 1.2). Two entries namely CoPb 08212 (80.39 t/ha) and CoS 08233 (76.02 t/ha) were better than the standards for this trait. Both these standards were at rank one and two, respectively in the trial. If clones are compared based on only yield values, the entry, CoPb 08212 was found top ranking in the trials with highest cane yield of 80.39 t/ha, but was unstable entry in the trial. Results based on index of simultaneous selection of high CCS (t/ha) and stable genotypes revealed that the standard CoJ 64 and the entries CoPb 08212 and CoS 08233 were at the first, second and third rank, respectively. Such a ranking differs with the ranking based only on mean data (Table 1.2) of CCS (t/ha). Considering top two high CCS (t/ha) and stable genotypes, CoPb 08212 (10.05 t/ha) and CoS 08233 (9.29 t/ha) were superior, but inferior to the best standard CoJ 64 (Table 2.2). Among the entries, CoPb 08212 may be considered as the best entry for CCS (t/ha). For sucrose, CoPb 08211 (18.20%) was high scoring clone. However, CoPb 08212 was second best clone in trial because it was at first rank for index & stability value and second for sucrose content (18.10%). It may be considered as the best stable clone in the trial as it recorded second best values of index and stability. Kumar and Sinha (2015) have also identified high yielding and stable clones viz. Co 06031 and CoC 09337 for East Coastal Zone using similar selection criteria. Based on above analysis, the entry CoPb 08212 may be considered as good entry as it was at rank one for CCS (t/ha) and cane yield (t/ha) and two for sucrose

Table 1.2. Ranking of AVT (early) genotypes of North West Zone according to their (i) mean performance, (ii) stability and (iii) simultaneous indices in respect of cane yield (t/ha).

Variety	Estimated value			Rank based on estimated value			PI (CI) report based rank
	Index Value	cane yield (t/ha) value	Stability value	Index value based rank	cane yield (t/ha) based rank	Stability based rank	
CoPb 08211	1.07	65.84	228.36	5	5	5	-
CoPb 08212	1.28	80.39	228.12	3	1	4	1
CoS 08233	1.26	76.02	173.42	4	2	3	2
Standards							
CoJ 64	1.34	69.93	96.69	1	3	2	-
CoPant 84211	1.30	66.15	93.82	2	4	1	-

Table 2.2. Ranking of AVT (early) genotypes of North West Zone according to their (i) mean performance, (ii) stability and (iii) simultaneous indices in respect of CCS(t/ha) .

Clone/ varieties	Estimated value			Rank based on estimated value			PI (CI) report based rank
	Index Value	CCS (t/ha) value	Stability value	Index value based rank	CCS (t/ha) based rank	Stability based rank	
CoPb 08211	1.12	8.29	4.17	5	4	4	3
CoPb 08212	1.32	10.05	4.17	2	1	5	1
CoS 08233	1.24	9.29	3.96	3	2	3	2
Standards							
CoJ 64	1.34	8.66	2.09	1	3	1	-
CoPant 84211	1.23	7.88	2.25	4	5	2	-

Table 3.2. Ranking of AVT (early) genotypes of North West Zone according to their (i) mean performance, (ii) stability and (iii) simultaneous indices in respect of Sucrose (%)

Variety	Estimated value			Rank based on estimated value			PI (CI) report based rank
	Index Value	Sucrose (%) value	Stabili-ty value	Index value based rank	Sucrose (%) based rank	Stability based rank	
CoPb 08211	1.27	18.20	1.61	2	1	3	1
CoPb 08212	1.28	18.10	1.47	1	2	1	2
CoS 08233	1.24	17.71	1.56	3	4	2	-
Standards							
CoJ 64	1.24	17.88	1.64	4	3	5	-
CoPant 84211	1.21	17.33	1.62	5	5	4	-

(%). Based on the consistent performance of clone CoPb 08212 for cane yield, CCS (t/ha) and sucrose (%) in 2 plant + ratoon crop across locations, it has been indentified for commercial cultivation in North West Zone of the country. So, AMMI model can be used as a suitable technique to deal with multi-location trials, front line demonstrations, adaptive trials conducted by different extension agencies in comparison to traditional methods for commercialization of any variety/ technology.

CONCLUSION

A successful evaluation of genotypes for stable performance under varying environmental conditions based on information on genotype × environment interaction for yield is an essential part of any sugarcane varietal development programme. The selection of sugarcane genotypes is based on the performance of cane yield at different locations across the zone and ranking of genotypes is done on the basis of mean data. Selection indices using Additive Main Effects and Multiplicative Interaction (AMMI) model has been applied for simultaneous selection of high yielding and stable sugarcane genotypes. Clones are considered best, high yielding and stable, if their respective ranks were found better than the ranks of best standard or at least one of the standards. If their ranks are inferior to the best standard, then top ranking ones among the tested clones are adjudged. Based on the above analysis, the entry CoPb 08212 may be considered as good entry as it was at rank one for CCS (t/ha) and cane yield (t/ha) and two sucrose (%) among the entries. Currently, selection of any improved technology/ intervention / variety is based on the performance over locations on the basis of mean data. The analysis and ranking of technologies/ varieties based on simultaneous selection using AMMI model give better and reliable picture in identifying a variety/technology for its commercialization on large scale to achieve sustainable benefits.

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