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ENVIRONMENTAL INTERACTIONS OF SUGARCANE GENOTYPES AND YIELD STABILITY ANALYSIS OF SUGARCANE

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Abstract

Five selected genetically diversified sugarcane clones were tested for yield stability for two consecutive years at six locations in Sindh. The objective of the study was to evaluate variability, effect of environmental factors and their relationship between the various quantitative and qualitative traits. Significant differences were observed between clones for all traits. Environmental interaction had significant effects on most of the traits under study. The important yield components were positively correlated at 5% level of significance. The correlation coefficients revealed that stalk weight, stalk height, number of stalks per stool and sugar percentage were the major traits contributing to cane and sugar yields. Path analysis of sugar yield exhibited maximum direct effect of cane yield followed sugar recovery.

Introduction

Sugarcane, in Pakistan, holds the position of second major cash crop and is currently serving as the raw material for the production of white sugar (Khan *et al.,* 2009, 2010). Besides this, valueable byproducts one for pharmaceutical industries (alcohol), fuel production (ethanol), organic matter and nutrient for crop production (press mud) and manufacture of chip board and papers (baggase). Sugarcane contributes about 3.7% in value added agriculture and about 0.8% in GDP (Anon., 2011-12).

The changes in the varietal performance under the influence of different environmental conditions are defined as Genotype by environment (G x E) interaction (Baker, 1988). GXE interaction complicates selection and testing of plant genotypes. The selection of genotypes to maximize yield when genotype rank changes occur across environments is complicated because of the complexity of genotype responses. Genotypes adaptable to target environments are selected under an optimum strategy, this strategy is determined by measuring GxE. In plant breeding programs, desirable genotypes are selected after evaluation of many potential genotypes under different environments (locations and years). GXE interaction may affect the heritability as component of phenotypic variance. It would be difficult for a breeder to estimate the genetic heritability if there is larger GXE interaction (Wen & Zhu 2005). If this GE is large, it may result in failure to differentiate performance of genotypes across environments, and it can reduce the precision of the selection across the environments.

Most of the yield component of sugarcane is highly influenced by the environmental factors such as germination, tillering, and stalk elongation rates (Smith *et al*., 2005). The crop is harvested when sucrose accumulation within the stalks reaches a peak, and the time to maturity also varies depending on genotype and growing conditions. As sugarcane is a perennial crop, GxE interactions studies could be utilized for developing and selecting genotypes under particular environment (Rea & De Sousa-Vieira 2002). Jackson & Hogarth (1992), stated that genotype x location (GxL) interactions is of greater importance than other interactions such as genotype x years (GxY) and genotype x location x years (GxLxY). The supported testing on several locations and testing multiple crops on same location was found to be the reason of minimal gain. Similar results were reported by Milligan *et al*., (1990). In contrast to these finding Rattey & Kimbeng (2001) found that when sugarcane is grown under irrigation, then GxY is of significant magnitude than GxL which was negligible to affect response to slection in the Burdekin region of Queensland. Hence, the results from GxE studies are not universal because the implications and potential selection strategies developing from them may differ among sugarcane improvement programs.

In Sindh province of Pakistan, sugarcane is grown as a major crop on a variety of soils under environments. Therefore, cane and sugar yield also vary with the changing environment. The objective of the present study was to determine GxE interactions for sugar yield and its two main component traits (cane yield t/ha and sucrose %) in advanced stage selection trials in Sindh with relative importance of testing across locations and years.

Materials and Methods

During 2008-09 and 2009-10, evaluations were made at 6 different locations between sugarcane clone NIA0819/P5 along with four commercial varieties NIA-2010, NIA-2004, Thatta10 and SPF-234 in the Province of Sindh viz., Tandojam, Pangrio, Tando Allah yar, Sheikh Burkhio, Matiari & Benazirabad (Nawabshah) for two consecutive years. The experimental layout and agronomic practices was carried as demonostrated by Khan *et al*., 2009. Sugar content was analysed according to Khan *et al*., 2010. The data were statistically analysed according to Steel & Torrie (1960). Stability parameters were estimated by using the methods of Eberhart & Russell (1966). Correlation and path coefficient analyses were also carried out.

Results and Discussion

G x E studies: Highly significant differences were observed among varieties, environment and varieties x environments interaction through factorial analysis of variance (Table 1). Genetic make up and diverse nature of origin suggest differences in the genotype (Thippeswamy *et al*., 2003). Variation in locations manifested in performance of the genotype as presented in Table 2 this interaction may be either a cross over G x E interaction or a non cross over nature. According to crossover nature, performance from one environment to another is the significant change (Matus *et al*., 1997). In non cross over, G x E interaction, ranking of genotypes remains constant across environments and the changes in the magnitude of response keeps the interaction significant (Baker, 1988). highly significant differences were shown by Genotype NIA0819/P5 in sugar yield performance at all the locations (Table 2). Highly significant differences were also shown by varieties in case of pooled analysis of variance (Table 3). Variety NIA-2010 and NIA0819/P5 produced significantly highest cane and sugar yield respectively, followed by NIA-2004. The lowest performing genotype was Thatta-10 (Table 2). Quality character was significantly influenced by the environment as compared to quantitative traits in this trail (Table 2). This may be due to the differential adaptiveness of the genotypes.

Cane yield and its components: Tables 2 & 3 presents the data regarding average performance of all genotypes. Stalks /stool were significantly ($p\leq0.05$) higher in NIA-2010 at all locations followed by NIA0819/P5 and lowest value were observed in both the checks (Tables 2 & 3). Highest stalk per stool was observed at Mehran sugar Mills, Tando Allahyar and lowest at Pangrio Sugar Mills, Farm (Table 2). NIA-2010 showed maximum plant height (ft) at Mehran sugar Mills, Farm (16.24) and minimum was recorded in CPF-234 at Pangrio Sugar Mills, Farm (6.24). Highest cane thickness (cm) was observed in control CPF-234 (2.82) at all locations and lowest in Thatta-10 (2.56). Stalk weight (kg) were significantly higher in NIA-2010 at all locations followed by NIA0819/P5 (Table 3). Minimum stalk weight was observed in Thatta-10 (17.00). NIA-2010 (219.83) produced highest cane yield (t/ha), followed by NIA-2004 (204.16) and NIA0819/P5 (203.83) (Table 5). Clone AEC82-1026/P5 remained consistently superior at all locations. It showed increases of 29%, 30%, 28%, 21%, 37% and 25% over Thatta-10 at Tando Jam, Matiari, Faran, Mehran, Pangrio and Habib sugar Mills Farms, respectively (Table 2). Equal to or higher than 10% value of yield differences shows its impact on the economic benefit. The higher values of cane yield contributing components in NIA-2010 gave higher cane yield as compared to other lines in the trial.

Sugar recovery and sugar yield (CCS t/ha): Amongst all the entries under trials at different locations for sugar recovery % and sugar yield, significant ($p\leq0.05$) differences were recorded. Clone NIA0819/P5 showed the highest sugar recovery % in the month of October (9.89%) (Table 3), followed by clone NIA-2004 (9.24%) and CPF-234 (9.25%) (Table 3). The highest sugar recovery % of NIA0819/P5 was observed at Faran Sugar Mills Farm (10.95%) and lowest at Pangrio Sugar Mills Farm (8.54%) (Table 2). NIA0819/P5 (20.16) produced the maximum sugar yield (CCS t/ha), followed by NIA-2010 (19.22) whereas, Thatta-10 (15.49) produced lowest sugar yeild (Table 3). Mehran Sugar Mills Farm, Tando Allahyar recorded highest sugar yield (23.20) (t/ha) and the lowest by Thatta-10 at Pangro Sugar Mills, Farm (12.10) (Table 2). Clone NIA0819/P5 showed 9.6% and 30% increase over Thatta-10 in sugar recovery % and sugar yield, respectively (Table 3).

Correlation studies: Genetic correlation coefficients were found to be similar to the corresponding phenotypic correlation coefficients (Table 4). It was implied that genetic correlation attributes the phenotypic correlation between the two traits. Unlike all the genetic and phenotypic correlation coefficients, genetic correlation showed higher magnitude than corresponding phenotypic correlations. Similar results were reported by Kimbeng *et al.,* (2009). Thus, genetic correlation coefficients provides the heritable amount of correlation between two traits. However, the unstable G x E interaction effects, affect the genetic correlation coefficients.

The correlation coefficient results (Table 4) indicated that the cane yield was correlated positively with tillers/plant (0.959**), cane length (0.993**) and weight per stool (r = 0.909**), and non-significantly correlated with cane girth and sugar recovery. Due to weight per stool, maximum plant height and tillers/plant the increase in cane yield might be observed. In 1994, Chaudhry & Singh concluded that the increment in cane yield was because of the combined effect of length of stalk, stalks per stool and weight per stool. According to Raman (1985) and others, the biggest factor that contributed was the amount of stalks per stool followed by height and then came cane girth. Singh *et al.,* (1985) concluded that the yield of cane exhibited phenotypic association with stalks per stool. Our results do not agree with these workers as far as contribution of cane girth to cane yield is concerned. Sugar yield showed significant positive correlation with tillers/ plant, cane length, weight / stool, cane yield and negatively correlated with cane girth (Table 4).

Table 1. Factorial analysis of variance.

Source	Degree of freedom	Sum of square	Mean square	F value
Total	29	18473.750	637.026	
Environments	5	7896.200	1579.240	
Varieties	4	10253.875	2563.469	268.974
Var.x Env.	20	323.675	16.184	
Env.+ Var.x Env	25	8219.875	328.795	
Env. (Lin.)	1	7896.113	7896.113	
Var.x Env. (Lin.)	4	133.151	33.288	3.493
Pooled Dev.	20	190.611	9.531	1.418
Pooled error	60	403.320	6.722	

Table 2. Performance of 5 promising sugarcane clones at 6 different locations in Sindh during 2008-09 and 2009-10.

Clones / Locations	Stalk / stool (m^2 Nos)	Cane length (ft)	Cane girth (cm)	Weight/ stool (kg)	Cane yield (t/ha)	Sugar recovery % (Oct)	CCS (t/ha)
	NIA Farm, Tando Jam						
NIA0819-P5	25a	9.16a	2.53	20.60b	202b	9.89a	19.98a
NIA-2010	26a	9.46a	2.78	22.00a	220a	8.34b	18.34b
NIA-2004	21b	9.06a	2.86	20.70b	206b	8.48b	17.46c
Thatta -10	18c	8.63ab	2.57	16.53c	170c	8.13b	13.82e
CPF-234	19c	8.40b	2.81	17.00c	175c	8.24b	14.42d
	Matiari Sugar Mills farm Matiari						
NIA0819-P5	24b	10.53b	2.56	21.90b	210b	8.94a	18.77a
NIA-2010	26a	14.26a	2.78	25.63a	230a	8.01b	18.42a
NIA-2004	22c	10.32b	2.84	21.43b	209b	8.21ab	17.15b
Thatta -10	18e	10.12b	2.58	17.56c	176c	8.14ab	14.32c
CPF-234	20d	9.86c	2.80	17.86c	179c	8.28ab	14.82c
	Faran Sugar Mills Farm, Sheikh Burkhio						
NIA0819-P5	22b	8.24b	2.55	20.59b	207b	10.95a	22.66a
NIA-2010	25a	8.96a	2.67	22.13a	219a	9.98b	21.85b
NIA-2004	20c	8.10b	2.73	20.78b	210b	10.54a	22.13a
Thatta -10	16d	8.13b	2.61	16.89c	171c	10.23ab	17.49c
CPF-234	14e	8.16b	2.81	17.56c	179c	10.58a	18.93c
	Mehran Sugar Mills Farm, Tando Allahyar						
NIA0819-P5	27b	11.96c	2.68	22.68b	215b	10.79a	23.20a
NIA-2010	32a	16.24a	2.74	25.36a	240a	9.23b	22.15b
NIA-2004	26b	13.24b	2.83	22.57b	218b	10.45a	22.78b
Thatta -10	22c	12.56bc	2.68	19.34c	198c	10.20a	20.19c
CPF-234	23c	12.54bc	2.91	21.86bc	200c	10.46a	20.92c
	Pangrio Sugar Mills Farm, Pangrio						
NIA0819-P5	19a	8.23a	2.43	19.54ab	174b	9.82a	17.08a
NIA-2010	20a	8.78a	2.51	19.86a	186a	8.54c	15.88b
NIA-2004	16b	7.56b	2.68	18.89b	173b	9.12b	15.77b
Thatta -10	13c	7.12b	2.35	14.32c	135c	8.97c	12.10c
CPF-234	10d	6.24c	2.78	14.42c	138c	9.26b	12.77c
	Habib Sugar Mills, Benazirabad (Nawabshah)						
NIA0819-P5	26a	9.89ab	2.59	21.36b	215ab	8.97a	19.28a
NIA-2010	26a	10.24a	2.71	23.85a	224a	8.34b	18.68b
NIA-2004	22b	9.34b	2.69	21.84b	209b	8.69ab	18.16b
Thatta -10	17c	8.89c	2.62	17.88c	178c	8.45b	15.04c
CPF-234	17c	8.90c	2.81	18.24c	184c	8.69ab	16.00c

DMR test (0.05): Different letters show significant differences at $p \leq 0.05$

Table 3. Pooled mean performance for 7 traits of 5 sugarcane clones grown at 6 locations for 2 years (2008-09 and 2009-10).

Clone	Stalk / stool (m^2 Nos)	Cane length (ft)	Cane girth (cm)	Weight/ stool (kg)	Cane yield (t/ha)	Sugar recovery % (Oct)	CCS (t/ha)
NIA0819-P5	23.83b	9.67b	2.56c	21.11b	203.83b	9.89a	20.16a
NIA-2010	25.83a	11.32a	2.69b	23.13a	219.83a	8.74c	19.22ab
NIA-2004	21.17c	9.60b	2.77b	21.03b	204.16b	9.24b	18.90b
Thatta -10	17.33d	9.24b	2.56c	17.00c	171.33c	9.02b	15.49c
CPF-234	17.17d	9.02b	2.82a	17.82c	175.85c	9.25b	16.31c

DMR test (0.05): Different letters show significant differences at p≤0.05

Table 4. Phenotypic and Genotypic correlation (r) analysis of sugarcane somaclones.

Traits	Variation	Tillers/ plant	Cane length	Cane girth	Weight/ stool	Cane yield (t/ha)	Sugar recovery %
Tillers/plant	Phenotypic	1					
	Genotypic						
Cane length	Phenotypic	0.962**	1				
	Genotypic	0.991					
Cane girth	Phenotypic	-0.111	0.149	1			
	Genotypic	-0.121	0.187				
Weight/stool	Phenotypic	0.960**	0.965**	0.141	1		
	Genotypic	0.998**	0.995**	0.173			
Cane yield	Phenotypic	0.959**	0.993**	0.129	0.909**	1	
	Genotypic	0.994**	0.999**	0.134	0.991**		
Sugar recovery %	Phenotypic	0.075	-0.085	-0.480*	-0.006	0.008	1
	Genotypic	0.105	-0.121	-0.487*	-0.018*	0.101	
Sugar yield	Phenotypic	0.897**	0.862**	-0.083	0.900**	0.907**	0.427*
	Genotypic	0.913**	0.891**	-0.127*	0.974**	0.963**	0.491*

* = Significance at 5 % level, ** = Significance at 1% level, ns = Non-significant

Stability studies: In crop plants stability is measured by 'b' known as regression coefficient. A stable genotype may be identified by considering both deviation from regression coefficient 'S^2d' and regression coefficient 'b'(Jackson & McRae. 2001). The value of 'b' for cane yield was 0.843, for CCS was 0.871 and for sugar yield was 0.849 while, for the mentioned characters the 'S^2d' values were 0.095, 0.158 and 0.085, respectively, for clone NIA0819/P5 (Table 5). The studies indicated that even under the agro climatic conditions of Sind, NIA0819/P5 has the capability for producing higher amounts of cane and sugar. Moreover, while considering the estimates of stability parameters, it may be found that the clone NIA0819/P5 has good adjustment potential under prevailing environments of the Sind Province.

Taking deviation from regression coefficient is equal to 0, a greater value (more than 1) of b will mean more change in y for a unit change in (b), which means that the variety is more responsive. Such variety may, hence, be suitable only for highly favorable environments, such as extreme fertility situations (Bull *et al.,* 2000). A relatively less value of regression coefficient, suppose value 1, means less reacting to the environmental change and therefore, more adaptive. If, in case, b is very low i.e., negative, the variety may be seen only in poor environment. The insignificancy of S^2d from value 0, will invalidate the linear prediction. However, If S^2d is non-significant the genotype shows predictable performance for a given environment. Accordingly, a variety with predictable performance is said to be stable. Variety NIA0819/P5 showed non significant differences of standard deviation to regression coefficient from zero. Stability parameters provided clear evidence that variety NIA0819/P5 produced maximum stable yield. From the above results of stability it may be found that at all locations studied here, the newly evolved somaclone NIA0819/P5 can be grown safely for obtaining more economical yield. Moreover, these studies provided a hint that breeding techniques other than conventional (Biotechnology) could be successfully employed for the induction of variation to select the new genotypes with improved agronomic and physiological characters.

Table 5. Regression coefficient 'b' and variance due to deviation from regression for 3 traits of 5 sugarcane clones grown at 6 locations for 2 years.

Clone	Cane yield (t/h)		C.C.S. (%)		CCS (t/h)	
	S^2d	B	S^2d	b	S^2d	b
NIA0819-P5	0.095	0.843	0.158	0.871	0.082	0.849
NIA-2010	0.078	1.012	0.098	0.769	0.068	0.863
NIA-2004	0.074	0.862	0.050	1.122	0.068	1.054
Thatta-10	0.079	1.135	0.072	1.080	0.087	1.061
CPF-234	0.057	1.149	0.088	1.158	0.065	1.173

Path coefficient analysis for sugar yield: Yield is affected by numerous components and environments and is a complex resultant character. The internal adjustments between components causes increment in one component and thus resulting decrement in the other, causing no change in resultant yield (Wen & Zhu, 2005). However, Under such complex situations where direct effect of character and indirect effect by other character is to be analyzed, path analysis is proved to b very useful. Path coefficient analysis tells if the association of sugar yield with its components is because of the direct effect of component characters on cane yield or if it is a result of its indirect effect with some other traits. The maximum correlation of sugar yield was observed with cane yield (0.8827) followed by sugar recovery % (0.4104) (Table 6). Punia *et al*., (1983), Reddy & Reddy (1986) and Hooda *et al*., (1988) showed effect on sugar yield by single cane weight. A direct effect on sugar yield of millable cane was also reported by Balasundarum & Bhagyalakshmi (1978), Kang *et al*., (1989), Punia *et al.,* (1983) and Chaudhary & Singh (1994). The other yield contributing traits which showed positive correlation with cane yield were stalk length and stalk diameter. Whereas, cane length showed highly significant correlation with sugar yield. Significant correlation was due to indirect effect of single cane weight. This implied that selection of sugarcane genotypes may be emphasized on the basis of cane yield contributing factors and sugar recovery %, to harvest maximum sugar yield.

Table 6. Path coefficient analysis of different traits on sugar yield in sugarcane.

Variables	Stalk / stool	Cane length	Cane girth	Weight/ stool	Cane yield	Sugar recovery %
Stalks/stool	-0.0965	0.0067	0.0025	0.1077	0.8409	0.0302
Cane length	-0.0987	0.0066	-0.005	0.1181	0.9216	-0.0408
Cane girth	0.0086	0.0012	-0.0287	0.0200	0.1405	-0.2026
Weight / stool	0.0002	0.0069	-0.0051	0.1128	0.8820	-0.0035
Cane yield (t/ha)	-0.092	0.0069	-0.0046	0.1127	0.8827	0.0040
Sugar recovery %	-0.0071	-0.0007	0.0142	-0.001	0.0086	0.4104

Sugar yield is the focal point in the sugar cane research and this trait is the outcome of the different traits under the study. Hogarth (1971), explored the relationships between sugar yield and its component traits in sugarcane. Simple approach of correlation analysis was applied to evaluate the relationships between sugar yield and its six component traits. According to Wen & Zhu (2005) simple correlation analysis between two traits may confound the effects of other related traits and thus provide biased estimates of the true correlations. The present study conclusion is that sugar yield was significantly positively correlated with its five component traits and negatively correlated with cane girth.

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