

Inter-relationships among cane yield and commercial cane sugar and their component traits in autumn plant crop of sugarcane

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Summary

Seventeen diverse clones of sugarcane (*Saccharum* spp.) (7 early, 6 mid season and 4 late) were planted in October 1991 and 1992 in flooded (FE) and non flooded (NFE) environments for evaluation of cane yield, commercial cane sugar (CCS), internode length, internode number, stalk length, stalk thickness (circumference), stalk number, sugar recovery, and stalk weight. Cane yield showed significant positive phenotypic correlation coefficient (PCC) with stalk number in FE ($P \leq 0.05$) and NFE ($P \leq 0.01$). Stalk length had a significant positive PCC with stalk weight in both environments, and with internode length in FE ($P \leq 0.05$). Commercial cane sugar also expressed significant positive PCC with cane yield in both environments ($P \leq 0.01$), but with stalk number only in NFE ($P \leq 0.05$). Genotypic correlation coefficients were generally in the same direction as PCC but higher in magnitude. In both environments, stalk number and stalk weight had relatively high positive direct effects on cane yield. However, flooding tended to enhance the direct effect of stalk weight and diminish the direct effect of stalk number on cane yield. Only cane yield and sugar recovery had high direct effects on CCS. Selection for improvement of cane yield can be based on stalk number and stalk weight in both environments. High yielding clones can be further screened for more sugar recovery to improve CCS.

Introduction

Sugarcane (*Saccharum* spp.) occupies substantial acreage in flood prone areas. Flooding or waterlogging of sugarcane growing areas is a common problem throughout the world (Carter, 1976; Deren et al., 1993; Lal & Patrick, 1965; Roach & Mullins, 1985; Sartoris & Belcher, 1949) resulting in yield reduction. Sugarcane shows wide variability for flooding, and narrow sense heritability for flood tolerance ranges from 0.29 to 0.51 (Deren et al., 1991, 1993). Sukhchain & Thind (unpublished data) observed that the autumn-planted (September-October) crop was more flood tolerant than the spring-planted (February-March) crop. In response to flooding, the spring-planted crop showed a significant decrease ($P \leq 0.05$) in cane yield and commercial cane sugar (CCS), while the autumn-planted crop showed a significant increase ($P \leq 0.01$) in these traits. During the last decade, early varieties of sugarcane were recommended for planting in the autumn season

in Punjab, India (Anonymous, 1991). Autumn crop is harvested beginning in early November, while harvesting of the spring crop starts in mid November. Thus due to its early harvesting, the autumn crop enhances the period of crushing by mills.

As cane yield and commercial cane sugar are complex traits, therefore, selections for these traits are generally done on the basis of such component traits as stalk number, stalk diameter, stalk length, stalk weight, and fiber content. Effects of these traits on cane yield have been previously studied in the spring crop (Brown et al., 1969; Hogarth, 1971; James, 1971; Kang et al., 1983; Legendre, 1970; Mariotti, 1972; Miller & James, 1974; Milligan et al., 1990; Singh et al., 1983; Smith & James, 1969; Reddy & Reddy, 1986). Likewise, effects of cane yield, fibre content, brix and sucrose % on sugar yield were studied in the spring crop (Gravois & Milligan, 1992; Kang et al., 1989; Reddy & Somarajan, 1994). Singh & Khan (1990) reported that number of internodes is an important component trait in

sugarcane. The present investigation was taken up to study inter-relationships among cane yield and CCS, and their component traits, namely, internode length, internode number, stalk length, stalk thickness, stalk number, stalk weight, and sugar recovery (%), of the autumn-planted crop in flooded (FE) and non flooded (NFE) environments.

Materials and methods

The experiment was conducted twice in plant cane (1991 and 1992) at the experimental farm of Punjab Agricultural University, Regional Research Station, Ropar. The test clones were 7 early (CoJ 64, CoJ 78, CoJ 83, Selections 82-557, 82-2504, 84-4152 and 83-6050), 6 mid-season (CoJ 79, CoJ 82, CoJ 84, Selections 83-95, 85-5435 and 86-194), and four late (CoS 767, CoJ 77, CoJ 81 and CO 1148). The clones having 16–17 pol in juice in the months of November, January, and March have been categorised as early, mid-season, and late, respectively (Anonymous, 1991). The test clones were planted on October 31, 1991 and again on October 15, 1992 in a randomised complete block design with two separate but adjacent environments, flooded vs. non flooded control. Within each environment, clones were planted in 3 replications in a two-row 10 m long plot. Rows were 90 cm apart. A two-metre alley was provided at the end of each plot and sugarcane was planted in buffer rows at sides of the experiments. We followed the recommended agronomic practices (Anonymous, 1991). Irrigation was applied at an interval of 10–15 d during May–June in 1992 and 1993 to both environments.

In 1992, the rainy season commenced in July and no irrigation was applied to the crop during July to Sept in NFE. However, in FE, water was pumped on to the field and maintained at a depth of 15–30 cm during August and September. There was no further flooding of the crop. In 1993, heavy rainfall in early July flooded the experimental plots in both environments with as much as 120 cm deep water. Flood water receded after a week and plots in NFE were completely drained. Plots in FE were in a low lying area and water remained in these plots for nearly one month. There was no further watering of plots in NFE. However, plots in FE were kept saturated through frequent irrigations in August and September.

The early clones were harvested manually in November–December, mid-season clones in January, and late clones in March. Cane yield was recorded after

topping and stripping the canes of trash. Only millable canes were considered for stalk number. A 5-stalk sample was taken at random from each plot for determining internode number, internode length, stalk length, stalk weight, and stalk thickness (circumference). The 5-stalk sample was milled in a lab-crusher installed at the Co-op. Sugar Mill, Morinda, for obtaining data on brix and polarity. Sugar recovery was calculated on the basis of Winter-Carp formula (Geerlings, 1904): Sugar recovery (SR) = [Pol in juice-(Brix-Pol in juice) × 0.4] × 0.63. Commercial cane sugar t/ha (CCS) was calculated as follows: CCS = Cane yield t/ha × SR.

Phenotypic and genotypic correlation coefficients, and path coefficients were determined from data combined over 2 plant crops in each environment (Dewey & Lu, 1959).

Results and discussion

Cane yield showed significant positive phenotypic correlation coefficient (PCC) only with stalk number in FE and NFE (Table 1). Several other studies have reported positive association between these traits (Gravois, 1988; James, 1971; Kang et al., 1983, 1989; Legendre, 1970; Milligan, 1988; Milligan et al., 1990). Commercial cane sugar was positively correlated with cane yield ($P \leq 0.01$) in both environments, but with stalk number ($P \leq 0.05$) only in NFE. Stalk weight showed significant positive PCC with stalk thickness in both environments, but with stalk length only in FE. Stalk length also had significant positive ($P \leq 0.05$) PCC with internode length only in FE. However, Kang et al. (1983) and Milligan et al. (1990) reported that stalk weight was positively correlated with both traits i.e. stalk thickness and stalk length. These authors also reported negative association between stalk number and stalk thickness, sugar content and cane yield, and positive association between stalk thickness and cane yield, and sugar content and sugar yield. These associations were not significant in the present study. This may be due to the different clones studied. Genotypic correlation coefficients (GCCs) were generally in the same direction as PCCs but higher in magnitude than the corresponding PCCs.

Path coefficients analysis revealed that only stalk number and stalk weight had relatively high positive direct effects on cane yield in both environments (Table 2). The previous studies have also indicated that cane yield is dependent upon stalk number and stalk

Table 1. Phenotypic and genotypic correlation coefficients of cane yield and commercial cane sugar with various component traits in flooded and non flooded environments in autumn-planted sugarcane (pooled over two crop years)

Traits	Env.	Internode length (cm)	Internode number	Stalk length (m)	Stalk thickness (cm)	Stalk number	Sugar recovery	Stalk weight (kg)	Cane yield (kg)
Internode number	N	-0.238 (-0.315)							
	F	-0.233 (-0.267)							
Stalk length	N	0.469 (0.533)	0.336 (0.231)						
	F	0.520* (0.568)	0.391 (0.388)						
Stalk thickness	N	0.000 (-0.045)	0.208 (0.092)	0.055 (0.052)					
	F	0.075 (0.133)	0.097 (0.105)	0.254 (0.235)					
Stalk number	N	0.233 (0.285)	0.096 (0.109)	0.363 (0.441)	-0.021 (-0.122)				
	F	0.136 (0.150)	0.141 (0.163)	0.343 (0.399)	-0.074 (-0.092)				
Sugar recovery	N	-0.184 (-0.224)	0.019 (0.018)	-0.188 (-0.261)	0.055 (0.117)	-0.229 (-0.299)			
	F	-0.193 (-0.231)	-0.236 (-0.322)	-0.319 (-0.369)	0.140 (0.135)	-0.270 (-0.096)			
Stalk weight	N	0.172 (0.216)	0.247 (0.145)	0.381 (0.402)	0.632** (0.701)	-0.003 (-0.041)	-0.040 (-0.034)		
	F	0.106 (0.161)	0.373 (0.298)	0.529* (0.532)	0.604* (0.619)	-0.018 (0.019)	-0.036 (-0.080)		
Cane Yield	N	0.382 (0.416)	0.002 (-0.051)	0.451 (0.518)	0.112 (0.125)	0.616** (0.671)	-0.251 (-0.347)	0.354 (0.340)	
	F	0.295 (0.333)	0.066 (0.012)	0.467 (0.493)	0.273 (0.327)	0.504* (0.569)	-0.260 (-0.278)	0.438 (0.491)	
Commercial cane sugar	N	0.319 (0.374)	0.006 (-0.043)	0.373 (0.453)	0.141 (0.190)	0.548* (0.620)	0.126 (-0.012)	0.357 (0.352)	0.925** (0.945)
	F	0.207 (0.234)	-0.040 (0.132)	0.325 (0.336)	0.357 (0.416)	0.359 (0.386)	0.252 (0.247)	0.425 (0.473)	0.860** (0.855)

* $P \leq 0.05$, ** $P \leq 0.01$.

N = Non flooded, F = Flooded. Values within parentheses represent genotypic correlation coefficients, and other values represent phenotypic correlation coefficients.

weight (Kang et al., 1983, 1989; Milligan et al., 1990). Internode number and sugar recovery had some negative direct effects on cane yield. Their magnitude was slightly higher in FE. Stalk length and stalk thickness had some positive indirect effects on can yield through stalk weight. In this case also, their magnitude was higher in FE. Stalk length had some indirect effect on cane yield through stalk number, its magnitude was higher in NFE. Indirect effects of other traits were negligible. It was observed that stalk number generally

tended to decrease more in FE than that in NFE as more number of the side shoots died due to submergence. Extent of mortality of the side shoots may depend upon time, duration, and intensity of floods. Data collected in 1991 planting revealed that 33% of the side shoots died in FE while only 19.6% died in NFE. It was not possible to collect data on plant mortality in the 1992 planting due to unexpected flash floods. Stalk weight tended to increase at a rapid pace to compensate for the loss in the cane yield due to higher mortality of the

Table 2. Path coefficients showing direct and indirect effects of various component traits on cane yield in flooded and non flooded environments in autumn-planted sugarcane

Traits	Env.	Internode (length) (cm)	Internode number	Stalk length (m)	Stalk thickness (cm)	Stalk number	Sugar recovery	Stalk weight (kg)
Internode	N	<u>0.098</u>	0.032	0.041	-0.001	0.130	0.012	0.069
length	F	<u>-0.080</u>	0.048	0.021	0.004	0.065	0.028	0.048
Internode	N	-0.023	<u>-0.135</u>	0.030	-0.022	0.054	-0.001	0.099
number	F	-0.019	<u>-0.208</u>	0.016	0.006	0.068	0.034	0.169
Stalk	N	0.046	-0.045	<u>0.088</u>	-0.006	0.203	0.012	0.153
length	F	0.042	-0.081	<u>0.041</u>	0.015	0.166	0.046	0.240
Stalk	N	0.001	-0.028	0.005	<u>-0.103</u>	-0.012	-0.004	0.254
thickness	F	0.006	-0.201	0.010	<u>0.059</u>	-0.036	-0.020	0.273
Stalk	N	0.023	-0.013	0.032	0.022	<u>0.558</u>	0.015	-0.001
number	F	0.011	-0.029	0.014	-0.004	<u>0.483</u>	0.039	-0.008
Sugar	N	-0.018	-0.003	-0.016	-0.006	-0.128	<u>-0.065</u>	-0.016
recovery	F	-0.015	0.049	-0.013	0.008	-0.130	<u>-0.143</u>	-0.016
Stalk	N	0.017	-0.033	0.034	-0.065	-0.002	0.026	<u>0.402</u>
weight	F	0.008	-0.077	0.021	0.036	-0.009	0.005	<u>0.453</u>

Explained variation: N = 56.8%, F = 52.4%.

N = Non flooded, F = Flooded.

Underlined values represent direct effects, while other values represent indirect effects.

Table 3. Path coefficients showing direct and indirect effects of various component traits on commercial cane sugar in flooded and non flooded environments in autumn-planted sugarcane

Traits	Env.	Internode (length) (cm)	Internode number	Stalk length (m)	Stalk thickness (cm)	Stalk number	Sugar recovery	Stalk weight (kg)	Cane yield (kg)
Internode	N	<u>0.012</u>	-0.001	-0.017	-0.001	0.006	-0.070	0.006	0.384
length	F	<u>0.005</u>	-0.004	0.017	0.001	-0.002	-0.100	-0.003	0.291
Internode	N	-0.004	<u>-0.017</u>	-0.020	0.004	0.008	0.007	0.019	0.002
number	F	-0.001	<u>0.015</u>	0.012	0.002	-0.002	-0.122	-0.009	0.065
Stalk	N	0.005	0.001	<u>-0.037</u>	-0.001	0.010	-0.072	0.013	0.453
length	F	0.003	0.006	<u>0.032</u>	0.005	-0.004	-0.165	0.013	0.461
Stalk	N	0.000	0.001	-0.002	<u>-0.012</u>	-0.001	0.021	0.022	0.112
thickness	F	0.000	0.001	0.008	<u>0.019</u>	0.001	0.073	-0.014	0.270
Stalk	N	0.002	0.000	-0.013	0.000	<u>0.027</u>	-0.088	-0.001	0.619
number	F	0.001	0.002	0.011	-0.001	<u>-0.013</u>	0.140	0.000	0.499
Sugar	N	-0.002	0.001	0.007	-0.001	-0.006	<u>0.382</u>	-0.001	-0.253
recovery	F	-0.001	-0.004	-0.010	0.003	0.003	<u>0.517</u>	0.001	-0.257
Stalk	N	0.002	0.001	-0.014	-0.008	-0.001	-0.015	<u>0.034</u>	0.356
weight	F	0.001	0.006	0.017	0.011	0.000	-0.019	<u>-0.024</u>	0.433
Cane	N	0.004	0.000	-0.017	-0.001	0.016	-0.096	0.012	<u>1.006</u>
yield	F	0.001	0.001	0.015	0.005	-0.006	-0.135	-0.010	<u>0.989</u>

Explained variation: N = 99.3%, F = 98.3%.

N = Non flooded, F = Flooded.

Underlined values represent direct effects, while other values represent indirect effects.

side shoots in FE. This higher increase in stalk weight is generally accompanied with increase in stalk length, which is further associated with increase in the internode length, as is evident from the significant positive PCC in both cases. Thus, flooding tends to undermine the direct effect of stalk number but it tends to enhance the direct effect of stalk weight on cane yield. However, the broad framework of inter-relationships among traits does not undergo any significant change. It may be due to a number of factors like inadvertent selection for flood tolerance in sugarcane (Deren et al., 1991), and modern cane cultivars are generally derivatives of interspecific crosses involving *S. spontaneum* as one of the parents, which carries genes for tolerance to various abiotic stresses like flooding (Roach & Mullins, 1985), cold and drought.

For cane yield, path coefficients analysis explained only 56.8% variation in NFE and 52.4% of the variation in FE. Thus there is need to identify some more traits so that selections based on component traits can be more effective for improvement of cane yield.

For CCS, path coefficients analysis explained 99.3% variation in NFE and 98.3% variation in FE, which was quite high, and only cane yield and sugar recovery had high direct effects on CCS in both environments (Table 3). Positive correlations between cane yield and sucrose yield have also been reported in many other studies (Gravois, 1988; Kang et al., 1983, 1989; Milligan, 1988; Milligan et al., 1990), and cane yield was generally found to be the primary determinant and sugar content the secondary determinant of sugar yield. While sugar recovery also had some negative indirect effects, all morphological traits had some positive indirect effects, through cane yield on CCS. Further, as sugarcane grows rapidly under flooding. Thus the upper portion of the stalk may remain immature and low in sugar content. That is why stalk length has higher negative indirect effects on CCS through sugar recovery in FE as compared to that in NFE. Selection for high sugar recovery by using a morphological trait as an indicator can be of great practical value but no morphological trait was correlated with sugar recovery to a sufficiently high degree so as to be useful in selection for this trait in sugarcane.

In both environments, selection for improvement of cane yield can be based on stalk number and stalk weight. The high yielding clones can be further screened for more sugar recovery to improve CCS.

References

- Anonymous, 1991. Package of practices for crops of Punjab: *kharif* 1991. Punjab Agric University, Ludhiana, Punjab, India, 150 pp.
- Brown, A.H.D., J. Daniels & B.D.H. Lather, 1969. Quantitative genetics of sugarcane. II. Correlation analysis of continuous characters in relation to hybrid sugarcane breeding. *Theor Appl Genet* 39: 1–10.
- Carter, C.E., 1976. Excess water decreases cane and sugar yields. *Proc Am Soc Sugarcane Tech* 6: 44–51.
- Deren, C.W., G.H. Snyder, J.D. Miller & P.S. Porter, 1991. Screening for and heritability of flood tolerance in the Florida (CP) sugarcane breeding population. *Euphytica* 56: 155–160.
- Deren, C.W., R.H. Cherry & G.H. Snyder, 1993. Effect of flooding on selected sugarcane clones. *J Amer Soc Sugar Cane Technol* 13: 22–26.
- Dewey, D.R. & K.H. Lu, 1959. A correlation and path coefficients analysis of crested wheatgrass seed production. *Agron J* 51: 515–518.
- Geerlings, H.C.P., 1904. Chemical control in use in the Java factories. *Int Sugar J* 6: 437–444.
- Gravois, K.A., 1988. Path-coefficients analysis: A study of phenotypic, broad-sense & narrow-sense variation in sugarcane. Ph D diss Louisiana State Univ., Baton Rouge (Diss Abstr 89–17818).
- Gravois, K.A. & S.B. Milligan, 1992. Genetic relationships between fiber and sugarcane yield components. *Crop Sci* 32: 62–67.
- Hogarth, D.M., 1971. Quantitative inheritance studies in sugarcane. II. Correlation & predicted response to selection. *Aust J Agri Res* 22: 103–109.
- James, N.I., 1971. Yield components in random and selected sugarcane populations. *Crop Sci* 11: 906–908.
- Kang, M.S., J.D. Miller & P.Y.P. Tai, 1983. Genotypic and phenotypic path analysis & heritability in sugarcane. *Crop Sci* 23: 643–647.
- Kang, M.S., O. Sosa & J.D. Miller, 1989. Path analysis for per cent fiber and cane and sugar yield in sugarcane. *Crop Sci* 29: 1481–1483.
- Lal, G. & W.H. Patrick Jr., 1965. Soil moisture and sugarcane yield in Louisiana. *Sugar Journal* 27: 88–90.
- Legendre, B.L., 1970. Association involving yield of sugar per acre and its components in sugarcane hybrid progenies. Ph D diss Louisiana State Univ, Baton Rouge (Diss Abstr 70–18541).
- Mariotti, J.A., 1972. Association among yield and quality components in sugarcane hybrid progenies. *Proc Int Soc Sugarcane Tech* 14: 297–302.
- Miller, J.D. & N.I. James, 1974. The influence of stalk density on cane yield. *Proc Int Soc Sugarcane Tech* 15: 177–184.
- Milligan, S.B., 1988. The genetic variance-covariance structure of a Louisiana sugarcane breeding population. Ph D diss Louisiana State Univ, Baton Rouge (Diss Abstr 88–19963).
- Milligan, S.B., K.A. Gravois, K.P. Bischoff & F.A. Martin, 1990. Crop effects on genetic relationships among sugarcane traits. *Crop Sci* 30: 927–931.
- Reddy, O.U.K. & K.G. Somarajan, 1994. Genetic variability and character association in interspecific hybrids of sugarcane. *Indian J Genet* 54: 32–36.
- Reddy, C.K. & M.V. Reddy, 1986. Multiple regression analysis for cane yield in twelve intervarietal crosses in sugarcane. *Indian J Genet* 46: 315–318.
- Roach, B.T. & R.T. Mullins, 1985. Testing sugarcane for waterlogging tolerance. *Proc Aust Soc Sugar Cane Tech*, 95–102 pp.
- Sartoris, G.B. & B.A. Belcher, 1949. The effect of flooding on flowering and survival of sugarcane. *Sugar* 44: 36–39.

Singh, H.N., S.B. Singh, R.V.S. Chauhan & Viswakarma, 1983. Variability for yield and quality in sugarcane. *Indian J Agric Sci* 53: 786-789.

Singh, Sarvjit & A.Q. Khan, 1990. Genotypic diversity in sugarcane. *Crop Improv* 17: 12-16.

Smith, G.A. & N.I. James, 1969. Association of characters within and repeatability between years in progenies of four sugarcane crosses. *Crop Sci* 9: 819-821.