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RESEARCH ARTICLE

Genetic and phenotypic correlation and path coefficient analysis for traits in sugarcane

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Abstract

Sugarcane is one of the two main sources of raw sugar that is grown in Upper Egypt. Information about trait relationships and direct and indirect effects of yield contributing would greatly improve the process of cultivar development. An experiment comprising 52 sugarcane clones coupled with the check cultivar GT 54/9 was conducted in a randomized complete block design with 3 replications at Kom-Ombo Agricultural Research Station, Aswan Governorate during 2016/17 (plant cane) and 2017/18 (first ratoon) growing seasons. Data were collected on yield and some of its attributes. Phenotypic and genotypic correlations between certain stalk related traits (stalk height, stalk weight and stalk number), and cane yield were positive and significant in both plant cane and ratoon crops. positive and significant correlations at the phenotypic and genotypic levels were found between all quality traits studied (Brix, sucrose, juice purity and sugar recovery) and sugar yield in both plant cane and ratoon crops. Positive and significant phenotypic and genotypic correlations were observed between sugar recovery and each of Brix, sucrose and juice purity in both plant cane and ratoon crops. Cane yield showed the highest positive and significant correlation coefficient values with sugar yield at the phenotypic and genotypic levels in both crops. Phenotypic and genotypic path coefficients revealed that stalk weight and stalks number had positive direct effects on cane yield. Cane yield was the primary direct determinant of sugar yield. Applying correlation determination followed by path coefficient analyses could be a worthwhile selection strategy.

Keywords: Path coefficient; Sugarcane; Trait relationships.

1. Introduction

The sugarcane crop is the main source of sugar production in Egypt, and is limited to the Upper Egypt region, in addition to sugar beet in the Delta and Lower Egypt. The characteristics of the cane yield and the theoretical sugar yield are the determinants of the productivity of sugarcane varieties and its acceptable by farmers, Therefore, sugarcane breeders must choose an effective breeding program to ensure an improvement in the production of new varieties with high yield and quality. Therefore, the breeder must select for the traits that are positively correlated with Reed yield such as stem height, stem thickness, stem weight and number of juicy stalks, and on the other sides selection for brix, sucrose and purity, which are positively correlated with the characteristic of theoretical sugar products as indicated by the studies conducted by (Milligan *et al.*, 1990; Kang *et al.*, 1991; El–Taib, 2009; Masri *et al.*, 2015).

El –Taib (2009) and Masri *et al.* (2015) indicated that cane yield had positive correlation with stalk height, stalk weight and number of millable cane at both phenotypic and genetic levels while it had positive correlation with stalk diameter at genetic level only. The correlation among cane yield components indicated that stalk weight had

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positive correlation with stalk height and stalk diameter at phenotypic and genetic levels. The association between stalk height with stalk diameter was positive at phenotypic and genetic levels. The correlation between stalk diameter or stalk weight with number of millable cane was negative at both phenotypic and genetic levels. Sugar recovery had positive correlation with Brix and sucrose at phenotypic and genetic levels. Also, similar correlation has been observed between Brix and sucrose.

Path coefficient analysis can be relied upon to clarify direct and indirect causes to link between characters and determine the degree of gene contribution for each trait in the trait that is attached to it. El–Taib (2009) showed that the direct effect of cane yield and sugar recovery on sugar yield was positive and the direct effect of cane yield on sugar yield was one and half as much as that of sugar recovery at both phenotypic and genetic levels. The direct effect of stalk weight on cane yield was similar to that of number of millable cane on cane yield at phenotypic level and too close at genetic level. Also, the data revealed that, at phenotypic and genetic levels, Brix had negative direct effect on sugar recovery while sucrose had a positive direct effect on sugar recovery. The effect of cane yield and sugar recovery on sugar yield, Brix and sucrose on sugar recovery were under genetic control with little or no environmental effects. At phenotypic and genetic levels, the path coefficient accounted for a large proportion of variation for cane yield and almost 100% of variation of sugar yield in addition to 100% of variation of sugar recovery was explained. All the variation in stalk weight explained at genetic level and the path coefficient failed to account. The objective of this study was to identify the association and relative contribution of cane yield, sugar recovery and their components on sugar yield through correlation and path coefficient analysis technique.

2. Materials and Methods

The study was carried out on eight bi-parental sugarcane crosses at Kom-Ombo Agricultural Research Station, Aswan Governorate, Egypt (latitude of 24o 28′ N and longitude of 32o 57′ E) during 2016/2017 as plant cane crop and 2017/2018 as ratoon crop. Materials of sugarcane crosses could be considered representative of the sort of breeding materials processed in the sugarcane breeding program in Egypt. Each cross combination was represented in the experiment by a variable number of clones (Table 1). Therefore; each cross was represented by different number of rows within replicate during planting. Therefore, fifty tow clones were included in this study. Each sugarcane clone was planted in two-five meter rows 3m in length with 1.0 m spacing between rows. The commercial cultivars GT 54/9 was planted throughout crosses as check cultivar. Planting was achieved during the second week of March by placing twenty-five 3-budded cane cuttings in each row. The experimental design was randomized complete block with three replications. The field was irrigated right after planting and all other agronomic practices were carried out as recommended. Plant cane was allowed to ratoon. Harvest took place twelve months after planting in the plant cane, and 12 months after harvesting of the plant cane for the first ratoon. At harvest, the following traits were measured; Cane yield (ton feddan^{-1}) and its contributing traits viz. stalk height (cm), stalk diameter (cm), stalk weight (kg) and number of millable stalks feddan^{-1}. Sugar yield and juice quality traits viz. total soluble solids (TSS), sucrose content, juice purity and sugar recovery. TSS (Brix) was determined with brix hydrometer after temperature correction to 20℃. Sucrose percentage of clarified juice was determined by using automated sacharimeter according to A.O.A.C. (1995). Juice purity was calculated as: [(Sucrose / Brix) x 100]. Sugar recovery% (SR) was calculated according to the formula described by Yadav and Sharma (1980):

SR= [Sucrose % - 0.4 (Brix – Sucrose %)] x 0.73.
Sugar yield (ton/fed) was estimated by multiplying net cane yield (ton $feddan^{-1}$) by sugar recovery %.

Table 1. Experimental sugarcane crosses and their number of clones

Cross No.	Cross	No. of clones/cross
1	EH 94 - 181-1 X EH 94 -119-72	6
2	Mex 58 - 1866 X Ph 8013	5
3	79 D1 X PH 8013	12
4	F 153 X BO3	4
5	CP57 - 614 X BO 3	3
6	CO 622 X G 85-37	12
7	CO1075 X CP 31-294	7
8	G 85 - 37 X CP 31 – 294	3

EH and D = Haomdea, Egypt; MEX= Mexico; Phil= Philippines; F= Formosa, Taiwan BO= Bihar– Orissa, India; Co= Coimbatore, India; CP= Canal point, Florida, USA; G =Giza, Egypt.

Genotypic and phenotypic correlation coefficients among all studied traits were determined from the variance and co-variance components according to Falconer (1989). The significance of genotypic correlation coefficient was tested with the following formula forwarded by Robertson (1959).

rgxy = genotypic correlation coefficient between character x and y

SErgxy: Standard error of genotypic correlation coefficient between character x and y.

h2x: Heritability for character x

h2y: Heritability for character y

The calculated absolute t-value was tested against the tabulated t-value at n - 2 d.f., where n is the number of observations per each trait

Direct and indirect path coefficients were calculated as described by Dewey and Lu (1959) and Li (1975). The use of path analysis requires an additive cause and effect relation among the variables involved (Sidwell *et al.*, 1976) which is shown in Figure 1.

$$t = \frac{r_{g_{xy}}}{SE_{r_{g_{xy}}}}$$

where,

$$SE_{r_{g_{xy}}} = \sqrt{\frac{1 - r_{g_{xy}}^2}{2h_x^2 h_y^2}}$$

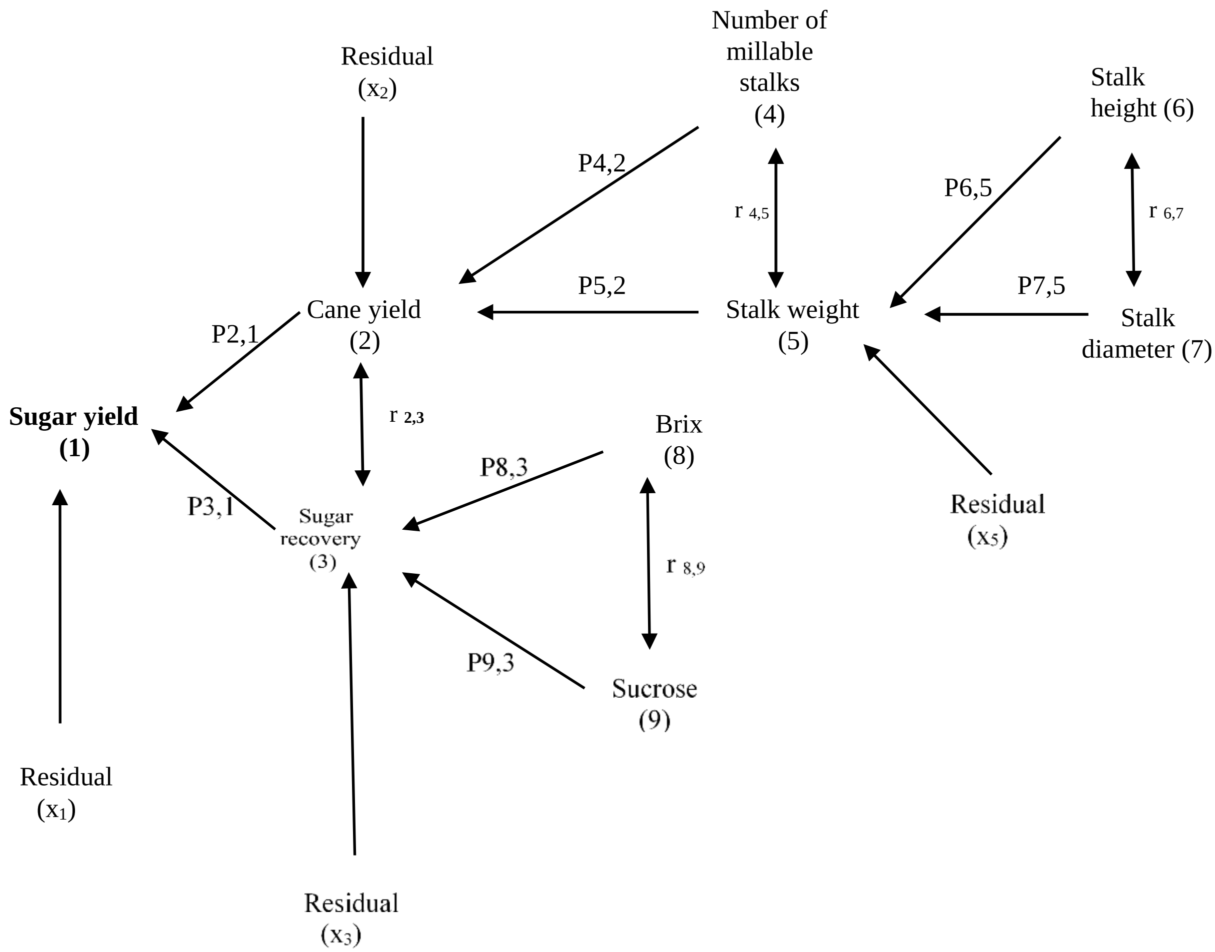

Figure 1. Path diagram showing interrelationships of (a) cane yield and sugar recovery with sugar yield, (b) number of millable stalks and stalk weight with cane yield and (c) stalk length and stalk diameter with stalk weight and (d) Brix and sucrose with sugar recovery, (p and r, indicate direct path coefficient and correlation coefficient, respectively).

3. Results and Discussion

3.1. Correlation coefficients

3.1.1. Correlation between cane yield and its components

Phenotypic (rp) and genotypic (rg) correlation coefficients among various traits were calculated in plant cane crop and presented in Tables (2, 3). Phenotypic and genotypic correlations between certain stalk related traits (stalk height, stalk diameter, stalk weight and stalk number), and cane yield were positive and significant except for stalk diameter at phenotypic level which was positive but non-significant. Phenotypic (rp) and genotypic (rg) correlation coefficients in ratoon crop (Tables 4,5) followed the same trend as in plant cane crop except for stalk diameter which was negative but non-significant. Correlation between stalk number and cane yield and stalk weight and cane yield agreed with the data of Patel *et al.* (2006), Masri *et al.* (2008), El-Taib (2009) and Masri (2015). In both plant cane and ratoon crops, correlations at phenotypic and genotypic levels between stalk diameter and stalk weight were positive and significant, while correlations between stalk diameter and stalk number were negative and significant and was similar to those reported by El-Taib (2009) and Masri *et al.* (2015). Genotypic correlation indicated that emphasis should be placed on selection for stalk height, stalk weight and stalk number to improve cane yield.

3.1.2. Correlation between sugar yield and its components

Data presented in Tables (2, 3, 4, 5) revealed that positive and significant correlations at the phenotypic and genotypic levels were found between all quality traits studied (Brix, sucrose, juice purity and sugar recovery) and sugar yield in both plant cane and ratoon crops. Correlation coefficient between the different pairs of quality traits was positive and significant, except between Brix and purity which was non-significant in both crops but negative in plant cane crop. Positive and significant phenotypic and genotypic correlations were observed between sugar recovery and each of Brix, sucrose and juice purity in both plant cane and ratoon crops. Cane yield showed the highest positive and significant correlation coefficient value with sugar yield at the phenotypic level (0.928 and 0.944) and genotypic level (0.939 and 0.952) in plant cane and ratoon crop, respectively.

However, all studied traits revealed significant and positive correlation with sugar yield, except for stalk diameter which revealed non-significant, but positive in plant cane and negative in ratoon crop. A limitation in this study is that sugar yield was obtained as a product of cane yield and sugar recovery. This method of calculating sugar yield may cause an artificial correlation between cane yield and sugar yield and between sugar recovery and sugar yield. Kang *et al.* (1983) concluded that an artificial correlation tended to inflate the relative importance of cane yield and sugar recovery may not be far from reality because cane yield and sugar recovery were determined independently.

Several researchers reported phenotypic and genotypic correlations among sugarcane traits. However, Milligan (1988) showed that the genetic variance and covariance of traits changed with selection. Thus, accurate variance-covariance estimates should be selection- stage specific. Therefore, our results of trait interrelationships may be similar or different, higher or lower than that reported from other studies. Chaudhary and Joshi (2005), Masri *et al*. (2008), Tahir *et al.* (2014) and Masri (2015) concluded differences of correlation among studies because of differences in the degree of prior selection in the population, and differences in the environmental conditions among the studies.

3.2. Path coefficient analysis

Path coefficient analysis was carried out in accordance with the causal relationships shown in path diagram (Fig.1) dividing genotypic correlation coefficient into direct and indirect causal effects. Indirect effects are due to correlation between the cause of interest and other effects affecting the dependent trait. Coefficients are interpreted on a relative scale and have little intrinsic meaning.

Table 2. Phenotypic correlation coefficients between ten traits in sugarcane in plant cane crop.

	Stalk diameter	Stalk weight	Stalk number	Cane yield	Brix %	Sucrose %	Purity %	Sugar recovery %	Sugar yield
Stalk height	0.179*	0.104	0.355**	0.358**	-0.233**	-.0234**	-0.062	-0.209**	0.290*
Stalk diameter		0.394**	-0.277**	0.152	-0.226**	-0.162*	0.031	-0.120	0.088
Stalk weight			-0.288**	0.639**	-0.057	0.058	0.159*	0.094	0.621**
Stalk number				0.533**	0.033	-0.135	-0.255**	-0.183*	0.461**
Cane yield					-0.009	-0.046	-0.066	-0.055	0.928**
Brix %						0.782**	-0.096	0.616**	0.218**
Sucrose %							0.544**	0.973**	0.308*
Purity %								0.723**	0.194*
Sugar recovery %									0.309*

*,** indicate significance at 0.05 and 0.01 levels of probability, respectively. n = 159

Table 3. Genetic correlation coefficients between ten traits in sugarcane in plant cane crop.

	Stalk diameter	Stalk weight	Stalk number	Cane yield	Brix %	Sucrose %	Purity %	Sugar recovery %	Sugar yield
Stalk height	0.182*	0.111	0.371**	0.377**	-0.280**	-0.280**	-0.078	-0.251**	0.306**
Stalk diameter		0.445**	-0.296**	0.176*	-0.241**	-0.157*	0.050	-0.110	0.117
Stalk weight			-0.289**	0.634**	-0.054	0.069	0.173*	0.107	0.624**
Stalk number				0.539**	0.040	-0.154*	-0.293**	-0.209*	0.470**
Cane yield					0.005	-0.047	-0.084	-0.061	0.939**
Brix %						0.786**	-0.075	0.626**	0.213*
Sucrose %							0.556**	0.974**	0.282**
Purity %								0.729**	0.166*
Sugar recovery %									0.278**

*,** indicate significance at 0.05 and 0.01 levels of probability, respectively. n = 159

Table 4. Phenotypic correlation coefficients between ten traits in sugarcane in first ratoon crop.

	Stalk diameter	Stalk weight	Stalk number	Cane yield	Brix %	Sucrose %	Purity %	Sugar recovery %	Sugar yield
Stalk height	0.147	0.327*	0.169*	0.263**	-0.286**	-.0367**	-0.262**	-0.365**	0.172*
Stalk diameter		0.226**	-0.273**	-0.055	-0.120	-0.005	0.140	0.032	-0.027
Stalk weight			0.040	0.622**	-0.174*	-0.104	0.055	-0.073	0.592**
Stalk number				0.719**	0.036	-0.143	-0.280**	-0.189*	0.646**
Cane yield					-0.037	-0.091	-0.094	-0.102	0.944**
Brix %						0.819**	0.120	0.699**	0.182*
Sucrose %							0.682**	0.983**	0.222**
Purity %								0.804**	0.167*
Sugar recovery %									0.218**

*,** indicate significance at 0.05 and 0.01 levels of probability, respectively. n = 159

Table 5. Genetic correlation coefficients between ten traits in sugarcane in first ratoon crop.

	Stalk diameter	Stalk weight	Stalk number	Cane yield	Brix %	Sucrose %	Purity %	Sugar recovery %	Sugar yield
Stalk height	0.166*	0.369**	0.190*	0.291**	-0.305**	-.0386**	-0.282**	-0.386**	0.206*
Stalk diameter		0.245**	-0.292**	-0.059	-0.142	-0.007	0.171*	0.037	-0.030
Stalk weight			0.051	0.619**	-0.198*	-0.139	0.023	-0.112	0.587**
Stalk number				0.730**	0.040	-0.152*	-0.311**	-0.203*	0.666**
Cane yield					-0.043	-0.112	-0.126	-0.127	0.952**
Brix %						0.837**	0.118	0.729**	0.171*
Sucrose %							0.693**	0.985**	0.182*
Purity %								0.807**	0.154*
Sugar recovery									0.174*

*,** indicate significance at 0.05 and 0.01 levels of probability, respectively. n = 159

3.2.1. Relative contribution of cane yield and sugar recovery on sugar yield

Data presented in Table (6) indicated that the direct effect of cane yield and sugar recovery on sugar yield was positive at genetic and phenotypic level in plant cane and first ratoon crops. The direct effect of cane yield was higher than that of sugar recovery at both levels in plant cane and first ratoon crops. The higher direct effect of cane yield on sugar yield probably attributed to that the selection in the studied genotypes depended on improving sugar yield through improving cane yield since the direct effect of cane yield on sugar yield was almost (0.939 and 0.947) at genetic level and (0.990 and 0.976) at phenotypic level in plant cane and first ratoon crops respectively as much as that of sugar recovery (0.278 and 0.361) at genetic level and (0.300 and 0. 318) at phenotypic level in plant cane and first ratoon crops respectively. This result in the line with those reported by Mohamed (2007), Masri *et al.* (2008), El –Taib (2009) and Masri *et al.* (2015). The indirect effect of cane yield via sugar recovery and sugar recovery via cane yield at genetic and phenotypic levels were negative in plant cane and first ratoon. These results indicated that sugar yield could be improved by improving cane yield and /or sugar recovery and suggested that sugar recovery should receive great emphasis for improving sugar yield. In addition, simultaneous selection for cane yield and sugar recovery could be possible since the indirect effect via one another was positive at phenotypic and genetic levels.

Table 6. Genetic and Phenotypic path coefficient of sugar yield and its components

Pathway	Genetic		Phenotypic	
	Plant cane	First ratoon	Plant cane	First ratoon
Sugar yield vs cane yield				
Direct effect P 2,1	0.959	0.990	0.947	0.976
Indirect effect				
Sugar recovery r 2,3 P 3,1	-0.020	-0.038	-0.020	-0.032
Correlation r 1,2	0.939	0.952	0.928	0.944
Sugar yield vs sugar recovery				
Direct effect P 3,1	0.336	0.300	0.361	0.318
Indirect effect via				
Cane yield r2,3 P 2,1	-0.058	-0.126	-0.052	-0.010
Correlation r 1,3	0.278	0.174	0.309	0.218
Residual (PxI)	0.074	0.073	0.094	0.095
1- p2 X 1	0.994	0.995	0.991	0.991

The difference between direct effect of cane yield and sugar recovery magnitude on sugar yield at genetic levels and phenotypic level was small. The variation at phenotypic and genetic levels was explained since the residual was too small at phenotypic and genetic level in plant cane and first ratoon crops. This result was similar to those obtained by Patel *et al.* (2006), El- Taib (2009) and Masri *et al.* (2015).

3.2.2. Relative contribution of cane yield components to cane yield

The selected traits; stalk weight and number of millable stalks showed positive direct effects on cane yield (Table 7) at both phenotypic and genotypic levels in plant cane and ratoon crops. The direct effects of stalk weight and stalk number on cane yield were similar to the findings of El-Hinnawy *et al.* (2001) and Masri (2015). The indirect effect of stalk weight on cane yield via number of millable stalks and the indirect effect of number of millable stalks on cane yield via stalk weight was negative at genetic and phenotypic level in plant cane crop. However, more than 95% of variance in cane yield in plant cane and 85 % in ratoon crop could be explained by the selected traits.

Table 7. Genetic and Phenotypic path coefficient of cane yield and its components.

Pathway	Genetic		Phenotypic	
	Plant cane	First ratoon	Plant cane	First ratoon
Cane yield v.s number of millable stalk				
Direct effect P 4,2	0.788	0.700	0.782	0.695
Indirect effect via				
Stalk weight r4,5 P5,2	-0.249	0.030	-0.249	0.024
Correlation r 2,4	0.539	0.730	0.533	0.719
Cane yield vs stalk weight				
Direct effect P5, 2	0.862	0.583	0.864	0.954
Indirect effect via				
Number of millable stalk r 4,.5 P4,2	-0.228	0.036	-0.225	0.028
Correlation r 2,5	0.634	0.619	0.639	0.622
Residual (Px2)	0.170	0.357	0.176	0.361
1- p2 X 2	0.971	0.872	0.969	0.870

3.2.3. *Relative contribution of stalk weight components on stalk weight*

Data presented in Table (8) showed that the direct effect of stalk diameter was (0.445 and 0.388) at genetic and phenotypic level while the direct effect of stalk height was (0.031 and 0.041) at genetic and phenotypic levels in plant cane crop. The direct effect of stalk diameter was (0.189 and 0.182) at genetic and phenotypic levels while the direct effect of stalk height was (0.338 and 0.300) at genetic and phenotypic levels in ratoon crop. Also, data in Table (8) indicated that the indirect effect of stalk height on stalk weight via stalk diameter was mostly higher than that of stalk diameter on stalk weight at genetic and phenotypic levels.

3.2.4. *Relative contribution of Brix and sucrose on sugar recovery*

Data shown in Table (9) indicated that Brix had negative direct effect on sugar recovery except for at genetic levels in plant cane crop, while sucrose had a positive direct effect on sugar recovery. The indirect effect of Brix on sugar recovery via sucrose was positive with low magnitude value at genetic (0.235 and 0.277) phenotypic levels (0.109 and 1.021) in plant cane and ratoon crops, respectively. The indirect effect of sucrose on sugar recovery via Brix was negative except at the phenotypic levels in plant cane crop where it was positive (0.052).

Table 8. Genetic and Phenotypic path coefficient of stalk weight and its components.

Pathway	Genetic		Phenotypic	
	Plant cane	First ratoon	Plant cane	First ratoon
Stalk weight v.s Stalk height				
Direct effect P6, 5	0.031	0.338	0.034	0.300
Indirect effect via				
Stalk diameter r 6,7 p 7,5	0.080	0.245	0.069	0.027
Correlation r 5,6	0.111	0.369	0.104	0.327
Stalk weight v. s Stalk diameter				
Direct effect P7,5	0.445	0.189	0.388	0.182
Indirect effect via				
Stalk height r 6,7 p 6,5	0.006	0.056	0.006	0.044
Correlation r 5,7	0.445	0.032	0.394	0.226
Residual (Px5)	0.895	0.911	0.918	0.928
1- p2 X 5	0.199	0.170	0.157	0.139

Table 9. Genetic and Phenotypic path coefficient of sugar recovery and its components.

Pathway	Genetic		Phenotypic	
	Plant cane	First ratoon	Plant cane	First ratoon
Sugar recovery v.s Brix				
Direct effect P8,3	-0.023	0.062	-0.059	-0.322
Indirect effect via:				
Sucrose r 8,9 P 9,3	0.235	0.109	0.277	1.021
Correlation r 3,8	0.213	0.171	0.218	0.699
Sugar recovery % vs. sucrose %				
Direct effect P 9,3	0.300	0.130	0.354	1.247
Indirect effect via				
Brix r 8,.9 P 9,.3	-0.018	0.052	-0.046	-0.264
Correlation r 3,9	0.282	0.182	0.308	0.983
Residual (Px3)	0.959	0.983	0.951	0.0001
1- p2 X 3	0.080	0.034	0.096	0.999

4. Conclusion

Cane yield showed the highest positive and significant correlation coefficient values with sugar yield at the phenotypic and genotypic levels in both crops. Phenotypic and genotypic path coefficients revealed that stalk weight and stalks number had positive direct effects on cane yield. Cane yield was the primary direct determinant of sugar yield. Applying correlation determination followed by path coefficient analyses could be a worthwhile selection strategy.

Authors' Contributions

Authors are contributed in this research.

Funding

No fund in this research.

Institutional Review Board Statement

All Institutional Review Board Statement are confirmed and approved.

Data Availability Statement

All Data presented in this study are available on fair request from the respective authors.

Ethics Approval and Consent to Participate

This work carried out at Agronomy and Sugar Crops departments and followed all the departments instructions.

Consent for Publication

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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