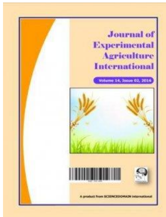

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Interrelationship Patterns among Cane Yield Attributes and Physiological Traits in Sugarcane under Normal and Water Stress Conditions

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Authors' contributions

This work was carried out in collaboration between all authors. Author GSS Conceptualized and designed the study and protocol. Authors HS and VT performed the statistical analysis, wrote the first draft of the manuscript. Authors RPS and KST managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Differential pattern of association assessed in sugarcane under two water regimes revealed that cane yield had highly significant positive correlation with stalk length, stalk diameter and single cane weight under both the environments. Physiological traits like relative water content at 60 days after planting had a positive correlation with stalk length under both the environments whereas, it was positively correlated with stalk diameter (0.46) and single cane weight (0.45) under water stressed environment. Path analysis revealed that number of tillers at 240 days had maximum positive direct effect on cane yield followed by relative water content (RWC) at 60 days, stalk length, RWC at 120 days, number of shoots at 120 days and single cane weight. Stalk length, stalk diameter, number of millable cane (NMC), number of tillers at 240 days were found important for cane yield improvement, and low number of stomata, chlorophyll, specific leaf weight (SLW) and RWC at 120 days are associated with stress tolerance.

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Keywords: Correlation; path analysis; physiological traits; sugarcane; water stress.

1. INTRODUCTION

Sugarcane (*Saccharum* spp. complex) is widely grown in both tropics and sub tropics as a source of energy providing food and fuel. In India, sugar industry being the second largest agro-based industry next to textile. Abiotic stresses are the main causes of major crops productivity losses that cause negative impacts on crop adaptation and productivity [1]. With the increases in climate change, soil water deficit is one of the biggest challenges for crop productivity. In the face of a global scarcity of water resources and the increased salinization of soil and water, water-deficit and salinity are widespread in many regions of world, and are expected to cause serious problem of more than 50% of all arable lands by the year 2050 [2]. In present scenario, drought figures as the most significant stress and is considered an extremely important factor when it comes of losses in the productivity of sugarcane [3]. Projections show an increase in intense rain events and at the same time reduction in the number of rain days that leads to increased risk of drought [4]. Further, scarcity of fresh water is affecting the productivity and profitability of sugarcane growers and millers in India. Due to glycophytic nature of sugarcane, drought conditions interfere with sugar production by affecting growth rate, yield of the cane, juices of lower sucrose contents, purity, higher acidity and the sucrose content of the stalk [5]. Thus drought may reduce sugarcane yield up to 50% or even more. Sugarcane drought tolerant varieties have the ability to reduce transpiration losses and these varieties maintain a fairly adequate absorption of water from the soil. Efforts should be intensified to identify/evolve agronomic and physiological traits, which could lead to adaptation to different conditions or be correlated to drought tolerance that could be used for breeding and development of new varieties [6]. The tillering and grand growth stages (sugarcane formative phase) have been identified as the critical water demanding period [7] because during this stage 70-80% of cane yield is produced [8]. Photosynthetic responses and water relations to water deficit stress during this growth stage could therefore be useful in identifying drought tolerant genotypes. So, there is an urgent need to identify sugarcane varieties adapted to moisture stress in order to sustain sugarcane production and sugar recovery in the country. Genetic improvement in cane yield may be achieved by targeting traits closely associated with cane yield. Knowledge of interrelationship among the various characters and their direct and indirect effects is considered to be important in devising proper selection strategies in sugarcane breeding for water stress conditions. So, to identify the different crop parameters responsible for the higher productivity and growth under water stress conditions, the present study was planned to assess interrelation patterns of different agro-morphological and physiological traits with cane yield (t/ha) under normal irrigated (E_1) and water stressed (E_2) conditions.

2. MATERIALS AND METHODS

The experimental plant materials consisted of 30 diverse sugarcane genotypes comprising nine commercial varieties (Co238, CoJ88, CoS8436, CoPb91, CoPb92, CoPb93, Co118, CoJ85 and CoJ64), twelve local elite clones (CoPb13181, CoPb10181, CoPb13182, CoPb13183, CoPb11214, CoPb11211, CoPb12181, CoPb12182, CoPb14212, CoPb14211, CoPb12212 and L818/07), five new introductions (KV2012-1, KV2012-2, KV2012-3, KV2012-4 and KV2012-5) and four inter specific hybrid (ISH) clones viz. ISH148, ISH159, ISH135 and ISH07 were planted under subtropical conditions of India during 2016-17 in randomized complete block design having a plot size of 21.6 m^2 with two replications. Seed setts of each genotype at the rate of 12 buds per running meter were planted. Data from different clones were recorded for various growth and cane yield parameters viz. germination (%), cane yield (t/ha), number of shoots at 120 days (000/ha), number of millable canes (NMC) at maturity (000/ha), cane length (cm), cane diameter (cm), single cane weight (kg), no. of tillers at 240 days (000/ha) and physiological parameters viz. relative water content (RWC) at 60 and 120 days (%), total chlorophyll content (mg/l), stomatal frequency (no.) and specific leaf weight (g) under normal (E_1) and water stress (E_2) environments. Cane yield (t/ha) was recorded from final harvested crop, number of millable canes were counted at maturity of crop per plot and converted in to number of millable canes (NMC '000/ha). Other cane characters were recorded as per standard procedures from five randomly selected canes taken from each genotype, in each replication in both the environments, to measure cane length and cane diameter. Physiological traits namely relative water content

(RWC) (%) at 60 and 120 days after planting (DAP) [9], chlorophyll a (mg/l), chlorophyll b (mg/l), total chlorophyll (mg/l) were recorded [as per 10] while stomatal frequency (no.), specific leaf weight (g) were evaluated following standard procedures under both the environments as follows.

2.1 Relative Water Content (%)

Fresh leaves were collected from five randomly selected plants from each clone in each replication in early morning hours and brought to laboratory. 10 g leaf discs (fresh weight) from each genotype from each plot were submerged in distilled water in test tubes till saturation. After 6 hrs the leaf discs were removed from test tubes. Surface water of the discs was blotted off without putting any pressure and then they were weighed to obtain saturated weight. After drying the discs at 70°C for 72 hours their dry weight was determined. From these data RWC was calculated as:

RLWC (%) = (Fresh weight - Dry weight) / (Saturated weight - Dry weight) x 100

2.2 Chlorophyll Content (mg/l)

Chlorophyll content was estimated by following dimethyl sulphoxide (DMSO) method and readings were taken using spectrophotometer. Five leaves were collected from five randomly selected seven month old plants from each clone in each replication in early morning hours and brought to lab. 0.1 g of leaf tissue of each sugarcane clone were cut in smaller pieces and placed in test tubes containing 10 ml of solvent (DMSO). Test tubes were incubated in a water bath at 60-65ºC for an hour. From preliminary studies this time was judged satisfactory for the full decolourization of tissues. Cooling at room temperature was followed for 30 min, filtration and absorption measured at 665 nm and 648 nm by being the final stages. Blank determination was carried out with DMSO. Absorption measurement was carried out with a spectrophotometer. The absorbance of the blank sample was subtracted from the absorbance readings of each sample before calculations.

2.3 Calculations

Chlorophyll concentration (a, b and total) was calculated as mg /g fresh weight by the following formulae [11] and expressed as mg/l.

Chlorophyll a (mg/g F.W) = (14.85 A665 - 5.14 A648)

Chlorophyll b (mg/g F.W) = (25.48 A665 – 7.36 A648)

Total chlorophyll (mg/g F.W) = (7.49 A665 + 20.34 A648)

Where: A665 = absorption value at 665 nm, A648= absorption value at 648 nm.

2.4 Stomatal Frequency (No.)

Leaves from five randomly selected plants of a clone from each replication were taken and brought to lab. The leaf membrane from the lower side of each leaf was peeled off by applying thinner on it followed by removal of leaf membrane by using cello tape. The cello tape containing the leaf membrane was placed on a glass slide and observed under compound microscope. Stomatal frequency was calculated by counting the number of stomata per microscopic field of the compound microscope. The mean of four microscopic fields considered as stomatal frequency of the genotype under study in both the environments and expressed as number of stomata per microscopic field.

2.5 Specific Leaf Weight (SLW) (g)

For this all the leaves of a genotype from each plot at 120 days after planting were counted in field and carried to lab where they were kept in oven at 50°C for 24 hours. The dry weight of oven dried leaves was taken and specific leaf weight (SLW) was calculated using the following formula:

Specific leaf weight (g) = Dry weight of leaves per plant (g)/ Total no. of leaves per plant

2.6 Statistical Analysis

The mean values of all the traits from each genotype in each replication were used for analysis of variance as per Fisher [12] carried out with CPCS1 software ver. 1.0 [13]. However, phenotypic and genotypic correlation coefficients of different traits with cane yield were worked out by the formulae suggested by Al-Jibouri et al. [14] and path coefficient analysis was done following Dewey and Lu [15] under normal (E_1)

and water stress (E_2) environments using MVM software [16] and interpretations were made accordingly.

3. RESULTS AND DISCUSSION

From correlation matrix of cane yield, its components and physiological traits at phenotypic and genotypic levels (Table 1), it was evident that genotypic correlation coefficients, in general under both the environments, were higher in magnitude than the corresponding phenotypic correlations. This indicated that there was an inherent association among various characters under study, which was depressed due to environmental influence and ultimately resulted in low phenotypic expression of the correlation. Khan et al. [17] also reported lower estimates of phenotypic correlation indicated that these relationships were affected by environment at phenotypic level.

At Phenotypic level, under normal (E_1) and water stress (E_2) environments cane yield had significant and positive association with stalk length (0.254, 0.378), stalk diameter (0.329, 0.373), single cane weight (0.301, 0.541) and chlorophyll content (0.202, 0.413). Kumar et al. [18] reported close association of cane yield with number of tillers, number of millable canes per plot, germination per cent, length of internodes and single cane weight under moisture deficient conditions. Sanghera et al. [19] also reported that cane yield was significantly and positively correlated with NMC at 10 months, stalk length, single cane weight, stalk diameter and germination percentage at 45 days under irrigated conditions. Similarly, cane yield was found significantly and positively associated with stalk length (0.558 and 0.463), stalk diameter (0.565 and 0.488), single cane weight (0.512 and 0.652) and chlorophyll content, (0.289 and 0.757) at genotypic level, normal (E_1) and water stress (E_2) environments, respectively. However, it had negative significant correlation with number of stomata (-0.556) under water stress (E_2) environment. These results are in agreement with earlier studies [19,20,21] who found positive and highly significant genotypic associations of cane yield with single cane weight, number of millable canes per plot and germination percent.

Interrelations among cane yield components revealed that at phenotypic level, stalk length was positively correlated with number of tillers at 240 days (0.339) and number of millable canes (0.429) and at genotypic level it was positively correlated with germination percent (0.398), number of shoots at 120 DAP (0.348), number of tillers at 240 DAP (0.416) and number of millable canes (0.568) under water stress (E_2) environment. The stalk diameter was positively correlated with stalk length under normal (E_1) environment but was negatively correlated with germination percent, number of shoots at 120 days, number of tillers at 240 days and number of millable canes at maturity under water stress environment (E_2) at genotypic level. Earlier correlation study for characters under normal and drought conditions by Hemaprabha et al. [22] also reported significant association for NMC, cane length and internode length confirming the importance of quantifying NMC, cane length and single cane weight as important parameters to be considered in drought screening. Germination percentage was highly significant positively correlated with number of shoots at 240 days in thousand per hectare under both the environments at both phenotypic as well as genotypic levels. Similarly, number of millable canes was highly positively associated with germination in percentage, number of shoots at 120 days in thousand per hectare and number of tillers at 240 days in thousand per hectare under both the environments at both phenotypic and genotypic level. Results shown by Tena et al. [23] indicated that cane yield had a strong positive and highly significant correlation with millable cane number, single cane weight, stalk height and sugar yield.

Physiological traits showed differential pattern of associations with cane yield component traits in this study. Relative water content (RWC) at 60 days after planting had a positive correlation with stalk length (0.332 and 0.553) under both E_1 and E_2 environments, respectively whereas it was positively correlated with stalk diameter (0.463) and single cane weight (0.447) under water stress (E_2) environment at phenotypic level. At genotypic level, RWC had positive significant correlation with stalk length and single cane weight under both the environments but it was negative and significantly correlated with number of shoots at 120 days, number of tillers at 240 days and number of millable canes under normal water (E_1) conditions and positive significantly correlated with these characters under water stress (E_2) conditions.

Table 1. Genotypic and Phenotypic correlation coefficients among different morpho-physiological traits of sugarcane under normal (E_1) and water stress (E_2) environments

Traits	Env.	Germination	No. of shoots	No. of tillers	NMC	Stalk length	Stalk diameter	SCW	RWC 60 days	RWC 120 days	Chlorophyll	No. of stomata	Specific leaf wt	Cane yield (t/ha)
Germination	E_1		0.5420**	0.6043**	0.5804**	-0.0842	-0.2610*	-0.2041	-0.0951	0.0629	-0.0702	0.2716*	-0.4140**	0.245
	E_2		0.8519**	0.8165**	0.9911**	0.3984**	0.067	0.2201	0.4425**	0.5929**	0.3492**	-0.1618	0.1442	0.1015
No. of shoots	E_1	0.5412**		0.9857**	0.9597**	-0.0255	-0.5602**	-0.3724**	-0.6595**	0.0276	-0.0913	0.0745	-0.1844	0.1445
	E_2	0.6198**		0.9125**	0.9325**	0.3481**	0.0591	0.3489**	0.4373**	0.3323**	0.4290**	-0.0642	0.3243*	0.1828
No. of tillers	E_1	0.5569**	0.9403**		0.9639**	-0.0269	-0.4857**	-0.4808**	-0.6525**	-0.0328	-0.1972	-0.04	-0.2870*	0.2674*
	E_2	0.6733**	0.8987**		0.9532**	0.4169**	0.0489	0.3166	0.4862**	0.5261**	0.5518**	-0.0673	0.2452	0.1993
NMC	E_1	0.4694**	0.8806**	0.9308**		-0.0511	-0.6104**	-0.4652**	-0.7544**	0.0685	-0.0682	-0.0132	-0.2365	0.2513
	E_2	0.5093**	0.7748**	0.7433**		0.5685**	0.1358	0.3670**	0.4761**	0.5052**	0.8384**	-0.2644*	0.4197**	0.3289*
Stalk length	E_1	0.1002	0.1336	0.1828	0.1154*		0.3583**	0.5082**	0.5809**	-0.0042	0.3695**	-0.3537**	0.4166**	0.5584**
	E_2	0.2151	0.4329	0.3395**	0.4293**		0.7442**	0.7595**	0.9321**	0.6470**	0.9522**	-0.4460**	0.5867**	0.4630**
Stalk diameter	E_1	-0.1186	-0.4043	-0.2870*	-0.3486**	0.2942**		0.4912**	0.2528	-0.2654*	0.2045	-0.4129**	-0.0016	0.5657**
	E_2	0.0336	0.0262	0.026	0.0937	0.5146**		0.8832**	0.8868**	0.7395**	0.8694**	-0.5714**	0.4280**	0.4887**
SCW	E_1	-0.194	-0.1548	-0.1535	-0.1731	0.4606**	0.5611**		0.3726**	-0.0935	0.24	-0.0673	0.3222*	0.5128**
	E_2	0.1118	0.2478	0.2364	0.2914*	0.5677**	0.6066**		0.8879**	0.8750**	0.9107**	-0.4210**	0.5249**	0.6523**
RWC 60 days	E_1	-0.0089	-0.1426	-0.135	-0.1471	0.3315**	0.1844	0.213		-0.135	-0.3376**	0.3297*	0.9567**	-0.0311
	E_2	0.0393	0.2458	0.1528	0.2754*	0.5532**	0.4634**	0.4475**		0.8669**	0.9054**	-0.3030*	0.8300**	0.0719
RWC 120 days	E_1	0.0882	0.0232	0.0415	0.1088	-0.0175	-0.0058	0.0417	-0.0159		0.008	-0.2810**	-0.1667	-0.1473
	E_2	0.1576	0.2725*	0.1282	0.4665**	0.4369**	0.2555*	0.3781**	0.4106**		0.9178**	-0.5062**	0.6646**	0.248
Chlorophyll	E_1	0.0396	0.1169	0.069	0.0887	0.1127	0.1126	0.2157	0.0467	0.0342		-0.1503	0.2282	0.2897*
	E_2	0.208	0.3066*	0.1441	0.3202*	0.6022**	0.4154**	0.4770**	0.2853*	0.4434**		-0.6168**	0.6512**	0.7572**
No. of stomata	E_1	0.1352	0.115	0.0361	0.0048	-0.1032	-0.2519	0.0184	0.1306	-0.099	-0.0897		0.127	-0.1804
	E_2	-0.1461	-0.0443	-0.1192	-0.2033	-0.3501**	-0.3948**	-0.3481**	-0.0587	-0.1596	-0.2609*		-0.2819*	-0.5563**
Specific leaf wt	E_1	-0.077	-0.0415	-0.047	-0.0591	0.1753	0.1622	0.3001*	0.2146	0.0567	0.0146	0.1596		0.1148
	E_2	0.1514	0.1755	0.1458	0.1958	0.3952**	0.3046*	0.3852**	0.3495**	0.1606	0.2416	-0.1495		0.2996*
Cane yield (t/ha)	E_1	0.1568	0.1594	0.2229	0.2509	0.2543*	0.3290*	0.3014*	0.1008	-0.0997	0.2022	-0.184	0.782	
	E_2	0.0785	0.1476	0.2072	0.2286	0.3781**	0.3734**	0.5411**	0.0966	0.1377	0.4130**	-0.4479**	0.2256	

Critical value of 'r' at 5%=0.2541 (*) and at 1%=0.3301 (**), above diagonal Genotypic correlation coefficients

Table 2. Estimates of direct and indirect effects of different agro-physiological traits of sugarcane genotypes on cane yield (t/ha) at phenotypic level under normal (E_1) and water stressed (E_2) environments

Traits	Env.	Germination (%)	No. of shoots at 120 days (000/ha)	No. of tillers at 240 days (000/ha)	NMC at maturity (000/ha)	Stalk length (cm)	Stalk diameter (cm)	SCW (kg)	RWC at 60 DAP (%)	RWC at 120 DAP (%)	Total Chlorophyll (mg/l)	Stomatal frequency (no.)	Specific leaf wt (g)	Correlation with cane yield (t/ha)
Germination (%)	E_1	**0.096**	-0.026	-0.153	0.314	0.0004	-0.039	-0.003	-0.0006	-0.016	0.003	-0.017	0.002	0.1568
	E_2	**-0.164**	-0.222	0.299	0.040	0.006	0.0001	0.042	-0.006	-0.014	0.059	0.031	0.006	0.0785
No. of shoots at 120days (000/ha	E_1	0.052	**-0.048**	-0.258	0.589	0.0006	-0.133	-0.023	-0.009	-0.004	0.009	-0.014	-0.001	0.1594
	E_2	-0.102	**-0.359**	0.400	0.061	0.012	0.0001	0.093	-0.038	-0.025	0.088	0.009	0.007	0.1476
No. of tillers at 240 days (000/ha)	E_1	0.053	-0.045	**-0.274**	0.622	0.0008	-0.094	-0.023	-0.008	-0.007	0.005	-0.004	-0.001	0.2229
	E_2	-0.110	-0.323	**0.445**	0.058	0.009	0.0001	0.089	-0.023	-0.012	0.041	0.026	0.006	0.2072
NMC at maturity (000/ha)	E_1	0.045	-0.042	-0.255	**0.669**	0.005	-0.114	-0.026	-0.009	-0.020	0.007	-0.0006	-0.001	0.2509
	E_2	-0.083	-0.278	0.331	**0.079**	0.012	0.0003	0.110	-0.043	-0.043	0.092	0.044	0.008	0.2286
Stalk length (cm)	E_1	0.009	-0.006	-0.050	0.077	**0.004**	0.096	0.070	0.021	0.003	0.009	0.013	0.004	0.2543
	E_2	-0.035	-0.155	0.151	0.033	**0.029**	0.014	0.214	-0.086	-0.041	0.173	0.076	0.017	0.3781
Stalk diameter (cm)	E_1	-0.011	0.019	0.078	-0.233	0.001	**0.329**	0.085	0.012	0.001	0.009	0.032	0.004	0.3290
	E_2	-0.005	-0.009	0.011	0.007	0.015	**0.002**	0.229	-0.072	-0.024	0.119	0.086	0.013	0.3734
SCW (kg)	E_1	-0.001	0.007	0.042	-0.115	0.002	0.184	**0.153**	0.014	-0.007	0.018	-0.002	0.007	0.3014
	E_2	-0.018	-0.089	0.105	0.023	0.016	0.001	**0.377**	-0.069	-0.035	0.137	0.076	0.016	0.5411
RWC at 60 DAP (%)	E_1	-0.0009	0.006	0.037	-0.098	0.001	0.060	0.032	**0.065**	0.003	0.003	-0.016	0.005	0.1008
	E_2	-0.006	-0.088	0.068	0.021	0.016	0.001	0.168	**-0.156**	0.038	0.082	0.012	0.015	0.0966
RWC at 120 DAP (%)	E_1	0.008	-0.001	-0.011	0.072	-0.0001	-0.001	0.006	-0.001	**-0.189**	0.002	0.012	0.001	-0.0997
	E_2	-0.026	-0.098	0.057	0.036	0.012	0.0007	0.142	-0.064	**-0.093**	0.127	0.034	0.006	0.1377
Total Chlorophyll (mg/l)	E_1	0.003	-0.005	-0.019	0.059	0.0005	0.037	0.033	0.003	-0.006	**0.084**	0.011	0.0004	0.2022
	E_2	0.034	-0.110	0.064	0.025	0.017	0.001	0.180	-0.044	-0.041	**0.288**	0.057	0.010	0.4130
Stomatal frequency (no.)	E_1	0.013	-0.005	-0.009	0.003	-0.0004	-0.082	0.002	0.008	0.018	-0.007	**0.128**	0.004	0.1840
	E_2	0.024	0.015	-0.053	-0.016	-0.010	-0.011	-0.131	0.009	0.015	-0.075	**-0.218**	-0.006	-0.4479
Specific leaf wt (g)	E_1	-0.007	0.002	0.012	-0.039	0.0008	0.053	0.045	0.014	-0.010	0.001	-0.020	**0.026**	0.782
	E_2	-0.024	-0.063	0.065	0.015	0.011	0.0008	0.145	-0.054	-0.015	0.069	0.032	**0.042**	0.2256

Unexplained variation at phenotypic level under E_1 = 0.14
Unexplained variation at phenotypic level under E_2 = 0.16

Table 3. Estimates of direct and indirect effects of different agro-physiological traits of sugarcane genotypes on cane yield (t/ha) at genotypic level under normal (E_1) and water stressed (E_2) environments

Traits	Env.	Germination (%)	No. of shoots at 120 days (000/ha)	No. of tillers at 240 days (000/ha)	NMC at maturity (000/ha)	Stalk length (cm)	Stalk diameter (cm)	SCW (kg)	RWC at 60 DAP (%)	RWC at 120 DAP (%)	Total Chlorophyll (mg/l)	Stomatal frequency (no.)	Specific leaf wt (g)	Correlation with cane yield (t/ha)
Germination (%)	**E_1**	**-0.286**	-0.178	-3.055	4.345	-0.030	-0.832	0.020	0.010	0.028	0.067	0.330	-0.175	0.2450
	E_2	**-2.607**	0.654	2.594	-2.302	0.693	-0.166	0.099	0.854	0.904	-0.781	0.353	-0.194	0.1015
No. of shoots at	**E_1**	-0.155	**-0.329**	-4.983	7.185	-0.009	-1.786	0.038	0.072	0.012	0.087	0.090	-0.078	0.1445
120days (000/ha	**E_2**	-2.221	**0.768**	3.437	-2.512	0.606	-0.146	0.158	0.844	0.506	-0.960	0.140	-0.4373	0.1828
No. of tillers at	**E_1**	-0.173	-0.324	**-5.055**	7.254	-0.009	-1.549	0.049	0.071	-0.014	0.189	-0.048	-0.121	0.2674
240 days (000/ha)	**E_2**	-2.129	0.831	**3.177**	-2.750	0.725	-0.121	0.143	0.938	0.802	-1.235	0.147	-0.330	0.1993
NMC at maturity	**E_1**	-0.166	-0.316	-4.898	**7.487**	-0.018	-1.947	0.047	0.082	0.030	0.065	-0.016	-0.100	0.2513
(000/ha)	**E_2**	-2.584	0.831	3.762	**2.322**	0.989	-0.337	0.166	0.919	0.770	-1.877	0.577	0.565	0.3289
Stalk length (cm)	**E_1**	0.024	0.008	0.135	-0.382	**0.356**	1.143	-0.052	-0.063	-0.001	-0.354	-0.430	0.176	0.5584
	E_2	-1.039	0.267	1.324	-1.320	**1.741**	-1.847	0.344	1.954	0.986	-2.131	0.974	-0.791	0.4630
Stalk diameter	**E_1**	0.074	0.184	2.455	-4.570	0.127	**3.189**	-0.050	-0.027	-0.118	-0.196	-0.502	-0.0007	0.5657
(cm)	**E_2**	-0.174	0.045	0.155	-0.315	1.295	**2.482**	0.400	1.711	1.128	-1.946	1.248	-0.577	0.4887
SCW (kg)	**E_1**	0.058	0.122	2.430	-3.483	0.181	1.567	**-0.102**	-0.040	-0.041	-0.230	-0.082	0.136	0.5128
	E_2	-0.573	0.268	1.005	-0.852	1.322	-2.192	**0.453**	1.714	1.334	-2.039	0.919	-0.707	0.6523
RWC at 60 DAP	**E_1**	0.027	0.217	3.298	-5.648	0.206	0.806	-0.038	**-0.109**	-0.060	0.324	0.401	0.548	-0.0311
(%)	**E_2**	-1.154	0.336	1.544	-1.105	1.762	-2.201	0.402	**1.930**	1.322	-2.308	0.661	-1.119	0.0719
RWC at 120	**E_1**	-0.018	-0.009	0.165	0.512	-0.001	-0.846	0.009	0.014	**0.445**	-0.007	0.342	-0.070	-0.1473
DAP (%)	**E_2**	-1.546	0.255	1.671	-1.173	1.126	-1.836	0.397	1.673	**1.525**	-2.054	1.105	-0.896	0.2480
Total	**E_1**	0.020	0.030	0.997	-0.510	0.131	0.653	-0.024	0.036	0.003	**-0.960**	-0.183	0.096	0.2897
Chlorophyll(mg/l)	**E_2**	-0.910	0.329	1.753	-1.947	1.657	-2.158	0.413	1.989	1.399	**-2.239**	1.347	-0.878	0.7572
Stomatal	**E_1**	-0.077	-0.024	0.202	-0.098	-0.125	-1.317	0.006	-0.036	-0.125	0.144	**1.217**	0.058	-0.1804
frequency (no.)	**E_2**	0.421	-0.049	0.213	0.614	-0.776	1.418	-0.191	0.584	-0.772	1.381	**-2.184**	0.380	-0.5563
Specific leaf	**E_1**	0.118	0.060	1.451	-1.770	0.148	-0.005	-0.032	-0.140	-0.074	-0.219	0.154	**0.423**	0.1148
wt(g)	**E_2**	-0.376	0.249	0.779	-0.974	1.021	-1.062	0.238	1.602	1.013	-1.458	0.615	**-1.348**	0.2996

Unexplained variation at genotypic level under E_1 = - 0.16

Unexplained variation at genotypic level under E_2 =0.20

At phenotypic level, under E_2 environment total chlorophyll content had significant positive correlation with stalk length, stalk diameter and single cane weight while at genotypic level it was significant and positively correlated with germination percentage, number of shoots at 120 days, number of tillers at 240 days, number of millable canes at maturity, stalk length, stalk diameter, single cane weight and RWC at 60 and 120 days after planting. Under E_1 conditions, it had significant positive correlation with stalk length and negative significant correlation with RWC at 60 days after planting. Similar results were obtained by Silva et al. [24] who found positive significant correlation among total chlorophyll content and RWC under water stress conditions.

Number of stomata was significant and negatively correlated with stalk length, stalk diameter and single cane weight under both water stress (E_2) and normal (E_1) conditions at phenotypic and genotypic levels. At phenotypic level, specific leaf weight had significant positive correlation with stalk length (0.395), single cane weight (0.385) and RWC at 60 days after planting (0.349) under water stressed (E_2) conditions and at genotypic level it had significant positive correlation with number of millable canes, stalk length, stalk diameter, single cane weight RWC at 60 and 120 days after planting and total chlorophyll content under same environment. On the basis of correlation studies, stalk length, stalk diameter, number of millable canes and number of tillers at 240 days were identified as important traits which can be selected for cane yield improvement under both the environments. While the number of stomata, chlorophyll content, specific leaf weight and RWC at 60 and 120 days are identified as important physiological traits for cane yield under water stress (E_2) environment.

Path analysis is useful in finding out direct and indirect causes of associations and allows a precise perception of specific forces acting to produce a given correlation. The relative importance of each causal factor also becomes evident. In present investigation, the direct and indirect effects of different traits on cane yield at phenotypic and genotypic levels were worked out both under normal (E_1) and water stressed (E_2) conditions (Tables 2 & 3). A perusal of direct and indirect effects at phenotypic level delineate that under normal (E_1) conditions, number of millable canes exhibited highest positive direct effect (0.669) on cane yield followed by stalk diameter (0.329), number of stomata (0.128), RWC at 60 days (0.065), specific leaf weight (0.026) and stalk length (Table 2). The characters with negative direct effects on cane yield were number of shoots at 120 days, germination percentage, RWC at 60 days and chlorophyll content. However, under water stressed (E_2) conditions number of tillers at 240 days had maximum positive (0.445) direct effect on cane yield followed by single cane weight (0.337), total chlorophyll (0.288) and specific leaf weight (0.042). These results were similar to as reported by Tena et al. [23], Singh et al. [25], Mali et al. [26] and Sanghera et al. [27]. Similarly, direct and indirect effects at genotypic level (Table 3) revealed that under normal (E_1) conditions, number of millable canes (7.487) exhibited highest positive direct effect on cane yield followed by stalk diameter (3.189), number of stomata (1.217), RWC at 120 days (0.445), specific leaf weight (0.423) and stalk length (0.356). The character with negative direct effects on cane yield were number of tillers at 240 days, number of shoots at 120 days, germination percentage, RWC at 60 days and chlorophyll content. However, under water stressed (E_2) conditions number of tillers at 120 days (3.177) had maximum positive direct effect on cane yield followed by relative water content at 60 days (1.930), stalk length (1.741), RWC at 120 days (1.525), number of shoots (0.768) and single cane weight (0.453). The above results are in accordance with the earlier studies of Khan et al. [17] and Das et al. [28]. Among indirect effects, germination percentage had positive indirect effect via NMC, chlorophyll content and specific leaf weight under both E_1 and E_2 environments and via number of tillers at 240 days, single cane weight, stalk length and number of stomata under water stress (E_2) conditions. However, this trait exhibited negative indirect effect via number of shoots at 120 days, number of tillers at 240 days, stalk diameter, single cane weight, RWC at 60 and 120 days and number of stomata under normal (E_1) conditions, while under water stress conditions (E_2) this trait exhibited negative indirect effect via number of shoots at 120 days and RWC at 60 and 120 days. Single cane weight had positive indirect effect on cane yield via stalk diameter and negative indirect effect via NMC under normal water conditions whereas it had negative indirect effect via number of shoots at 120 days and positive indirect effect via stalk length under water stressed conditions. The results were similar to earlier reported by Sanghera et al. [19], Kumar and Singh [29] and Madhavi et al. [30] for cane yield and component traits under irrigated conditions.

Among indirect effects, germination percentage had positive indirect effects on cane yield via NMC, single cane weight, chlorophyll content under E_1 and via number of tillers at 120 days, number of tillers at 240 days, stalk length and RWC at 60 days after planting under E_2 environment. Number of shoots at 120 days had positive indirect effect via NMC, SCW and chlorophyll content and had negative effects via number of tillers at 240 days and stalk diameter under normal water conditions whereas under water stressed conditions it had positive indirect effect via number of tillers at 240 days, SCW, stalk length, RWC at 60 and 120 days and number of stomata and negative indirect effect via germination percentage, NMC, stalk diameter and chlorophyll content. The genotypic correlation coefficients indicated that NMC, stalk weight, and stalk height had significant and positive association with cane yield as well as sugar yield [21,31] so these traits have high direct and indirect effects. Stalk length had negative indirect effect via NMC, chlorophyll content under both the environments however; it had positive indirect effect via number of tillers at 240 days and number of shoots at 120 days. Singh et al. [25] reported that two characters namely NMC and single cane weight showed significant positive direct contribution towards cane yield. Under both the environments, stalk diameter had positive indirect effect via stalk length, number of shoots at 120 days and number of tillers at 240 days however, under water stress (E_2) conditions, it had positive indirect effect on cane yield via single cane weight, RWC at 60 and 120 days and number of stomata. Under E_2 environment SCW and RWC at 60 and 120 days had negative indirect effect on cane yield via germination percentage and positive indirect effect via number of shoots at 120 days, number of tillers at 240 days, stalk length and number of stomata. Sanghera et al. [19] partitioned association into their direct and indirect effects and reported that high positive indirect effects are exerted by growth characters like number of shoots 240 days, number millable canes, single cane weight and stalk diameter. In case of physiological traits under water stress (E_2) environment, RWC at 60 and 120 days after planting had negative direct effect but it shows positive indirect effect on cane yield via single cane weight and number of tillers at 240 days. The chlorophyll content had negative indirect effect via number of shoots at 120 days and positive direct effect via single cane weight. The number of stomata had negative direct effect on yield but it had positive indirect effect via number of shoots at 120 days. The chlorophyll content had negative indirect effect via number of tillers at 240 days and positive indirect effect via stalk diameter and number of millable canes. Similar results have been reported [24] under water stress conditions. The residual (unexplained) variation in path analysis signified that unexplained and unaccounted variation left among the genotypes could be explained by including some more agro-physiological traits.

4. CONCLUSIONS

Present study reveals that stalk length, stalk diameter, number of millable canes, number of tillers at 240 days are important for cane yield improvement and low number of stomata, high chlorophyll content, specific leaf weight and RWC at 120 days are physiological traits associated with stress tolerance and could be used as selection criteria for cane yield improvement under water stress (E_2) conditions for sustainable sugarcane production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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