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Agronomic and biochemical attributes and economic indices of sugarcane (*Saccharum officinarum*) in saline *vis-a-vis* non-saline soils

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Sugarcane (*Saccharum officinarum* L.), a commercial crop of tropical to sub-tropical environments is cultivated for sugar and ethanol production (Singh and Singh 2011). It is typically a glycophyte and exhibit stunted growth, leaf chlorosis, necrosis, and death of salinity prone varieties (Brindha *et al.* 2019). In India ~9 million hectare (Mha) is salt-affected, of which ~5.5 Mha are saline (Brindha *et al.* 2019). Besides, Punjab, ~33% of the cane area in Tamil Nadu, ~40% in Andhra Pradesh and ~48% of cane in Karnataka has salinity stress and yield losses (Sundara and Vasantha 2004). Salinity impacts tillering, stalk growth, leaf area, and physiologic–metabolic activities (Costa *et al.* 2016, Endres *et al.* 2018, Santos *et al.* 2019).

A soluble salt tolerance limit (i.e. E.C.$_{1:2}$) at which growth/productivity is reduced by ~50% varied between 8.6–15.5 dS/m (Wahid and Rao 1997), and is variety specific. Cane productivity decreases by ~50% at E.C.=7.0 dS/m (Gomathi and Thandapani 2004); with every unit increase in E.C., a significant reduction by ~13.7 Mg/ha occurs. Build-up of salt stress in root-zone leads to several physiological changes, e.g. reductions of photosynthetic rate and an enzymatic activity (Gomathi and Thandapani 2004, Alam *et al.* 2018). Nonetheless, biochemical quality of juice decreased by ~0.6% with each dS/mm rise in E.C. Salinity in the root-zone decreases the sucrose yield of juice (Lingle and Wiegand 1997). Suppressed plant growth and deteriorated juice quality is ascribed to the accumulation of toxic ions under saline soils (Lingle and Wiegand 1997). Sugarcane varieties behave differentially in response to salinity, therefore, evaluation of different germplasm with respect to ecosystem resilient traits is essentially required. The present study was therefore, conducted to evaluate eight different sugarcane cultivars in saline and non-saline soils based on agronomic and biochemical attributes to screen out cultivars for increased economic returns.

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Study was conducted at Punjab Agricultural University, Punjab farms at village-Ratta Khera (Sri Muktsar Sahib; 29°54`N, 74°15`E) and at village-Ruldu Singh Wala (Bathinda; 29°54`N, 74°15`E) (Avtar-Singh *et al.* 2022, Madiwalar *et al.* 2022). Surface soil (0–15 cm) was sandy loam with $pH_{1:2}$=8.3 and 8.2, E.C.$_{1:2}$=3.40 and 0.774 dS/m, organic C=1.50 and 7.65 g/kg, available-P =14.0 and 6.9 mg/kg and available-K=63.5 and 109.0 mg/kg, respectively in saline and non-saline soils. Experiment (initiated in March-2019) included eight varieties (CoPb-18211, CoPb-18212, CoPb-18213, CoPb-18214, CoPb-19211, CoPb-19212, CoPb-19213 and CoPb-19214) grown in both soils. Agronomic attributes, viz. plant height (with/without leaves), tillers/plant, 5-cane weight, inter-nodes count and length, and cane diameter (at ground surface/breast height) were recorded from 10 plants. Cane yield was recorded at harvesting, and the maximum accumulation rate was estimated as a ratio of total productivity and crop duration.

For assessment of juice quality, 10 canes from each plot were crushed. Brix, sucrose, total soluble sugars (TSS), total reducing sugars (TRS) and purity were estimated (Meade and Chen 1971). The commercial cane sugar and recovery were also estimated (Eq 1 and 2).

$$\text{Commercial cane sugar (\%)} = [\text{Sucrose (\%)} - (\text{Brix (\%)} - \text{Sucrose (\%)}) \times 0.4] \times 0.74 \quad (1)$$

Where, 0.4 is the multiplication and 0.74 is the crushed factor.

$$\text{Sugar recovery (\%)} = [\text{Sucrose (\%)} - 0.4\,(\text{Brix (\%)} - \text{Sucrose (\%)})] \times 0.73 \quad (2)$$

Cost of cultivation (CCI) was estimated as sum of expenses for purchasing agri-inputs (1US$=80INR) and labour cost. The CCI of 1622 US$/ha was uniformly considered for all varieties. Average gross returns (AGRs) were calculated by multiplying yield with its selling price (38.75 US$/Mg), and net returns (ANRs) by subtracting CCI from AGRs. Economic efficiency was estimated by dividing AGRs with crop duration. Benefit-cost ratio was estimated as a ratio of AGRs and CCI. Data were statistically analyzed by analysis of variance (ANOVA) in RBD using SPSS 16.0 (SPSS Inc., Chicago) with Least Significant Difference (LSD) test at $P<0.05$.

Sugarcane varieties differ significantly for agronomic attributes in saline and non-saline soils (Table 1). Plant height was significantly higher for CoPb-18212, and lowest for CoPb-19214. Plant height without leaves was decreased by ~13.6% and with leaves by ~66.6% in saline than non-saline soils. The tillers/plant was significantly higher for CoPb-19214, and was decreased by ~36% in saline soils than non-saline soils. The 5-cane weight was ~1.95-times higher in non-saline. Salinity decreased the inter-nodes length by ~60.1% than non-saline soils. In saline soil, CoPb-18211 and CoPb-19214 had lowest nodes/plant than others. Cane diameter at ground surface was significantly lowest for CoPb-19214 in saline soil and CoPb-19211 in non-saline soil. Cane diameter at ground surface and at breast height was decreased by ~79.8 and 93.1%, respectively under saline than non-saline soils. Fig 1 illustrates the highest maximum accumulation rate for CoPB-19211, while the lowest for CoPB-19212/18214. Salinity decreases the plants ability to absorb water causing ionic toxicity/injury to cells of leaves, besides causing stomatal closure to check transpiration and photosynthetic activity (Bliss *et al.* 2019).

Salinity significantly decreased the TSS content in juice of all varieties by ~7.1% than non-saline soils (Table 2). Sucrose content in juice was significantly lower for CoPb-18213, while highest for CoPb-18214 in saline soil. About

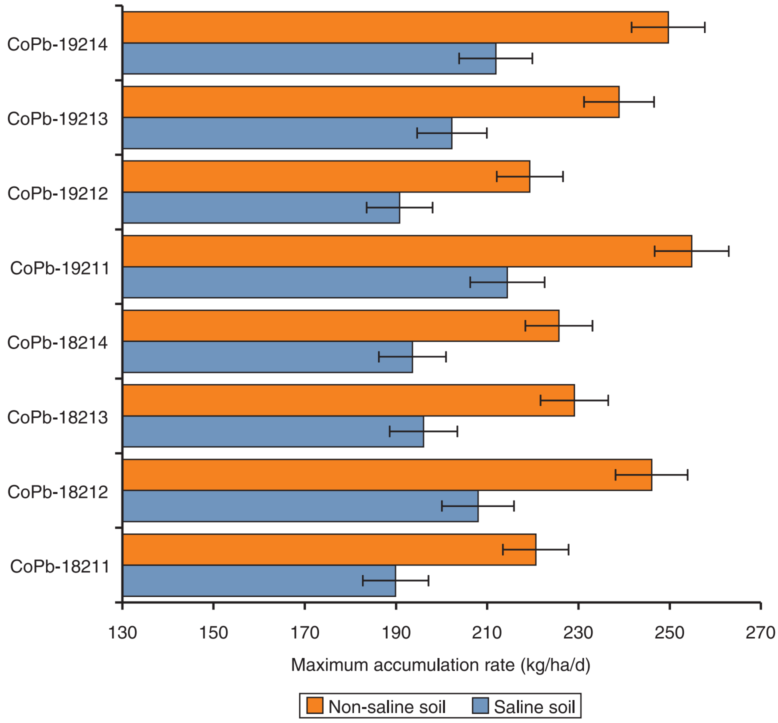

Fig 1 Maximum accumulation rate of different varieties in saline and non-saline soils.

Table 1 Agronomic attributes of different sugarcane varieties cultivated in saline and non-saline soil

Variety	Plant height without leaves (cm)		Plant height with leaves (cm)		Tillers/ plant		5-cane weight (kg)	
	Saline	Non-saline	Saline	Non-saline	Saline	Non-saline	Saline	Non-saline
CoPb-18211	$2.18^{aB\dagger}$	2.52^{bB}	3.69^{aB}	5.98^{bB}	4.75^{aB}	6.00^{bB}	2.65^{aB}	4.85^{bC}
CoPb-18212	2.73^{aC}	3.04^{bC}	4.13^{aC}	6.34^{bC}	5.25^{aC}	6.50^{bB}	2.87^{aC}	5.89^{bDE}
CoPb-18213	2.08^{aB}	2.37^{bB}	3.73^{aB}	5.92^{bB}	3.25^{aA}	4.50^{bA}	3.19^{aC}	5.34^{bD}
CoPb-18214	2.36^{aB}	2.65^{bB}	3.82^{aB}	6.01^{bB}	4.75^{aB}	6.00^{bB}	2.74^{aC}	6.32^{bE}
CoPb-19211	2.06^{aB}	2.35^{bB}	3.61^{aB}	5.81^{bB}	6.75^{aE}	8.00^{bC}	2.56^{aB}	4.98^{bC}
CoPb-19212	2.33^{aB}	2.62^{bB}	3.73^{aB}	5.90^{bB}	2.30^{aA}	3.00^{bA}	2.98^{aC}	5.56^{bD}
CoPb-19213	2.32^{aB}	2.61^{bB}	3.42^{aB}	5.64^{bB}	3.50^{aA}	8.00^{bC}	2.21^{aB}	3.98^{bB}
CoPb-19214	1.52^{aA}	1.81^{bA}	2.87^{aA}	5.08^{bA}	5.85^{aD}	7.50^{bC}	1.45^{aA}	3.42^{bA}
	Inter-nodes length (cm)		*Inter-nodes count*		*Cane diameter at ground surface (mm)*		*Cane diameter at breast height (mm)*	
CoPb-18211	7.85^{aA}	14.0^{bC}	16.0^{aB}	18.0^{bB}	13.8^{aC}	24.8^{bD}	11.5^{aBC}	22.0^{bC}
CoPb-18212	8.84^{aB}	17.0^{bD}	24.7^{bE}	21.3^{aD}	12.7^{aB}	22.8^{bC}	11.9^{aC}	22.8^{bC}
CoPb-18213	10.2^{aD}	14.5^{bC}	16.7^{aB}	18.7^{bC}	12.3^{aAB}	22.2^{bC}	10.3^{aB}	19.8^{bB}
CoPb-18214	9.12^{aC}	16.5^{bD}	18.7^{aC}	20.7^{bD}	13.6^{aC}	24.4^{bD}	10.6^{aB}	20.4^{bB}
CoPb-19211	8.54^{aB}	13.3^{bB}	18.0^{aC}	17.9^{aB}	11.0^{aA}	19.8^{bA}	10.7^{aB}	20.6^{bB}
CoPb-19212	8.98^{aBC}	13.4^{bB}	19.3^{aC}	20.9^{bD}	17.8^{aD}	32.0^{bE}	15.1^{aD}	29.0^{bD}
CoPb-19213	8.32^{aB}	11.9^{bA}	19.7^{aCD}	22.6^{bE}	11.6^{aA}	20.8^{bB}	9.5^{aA}	18.2^{bA}
CoPb-19214	7.65^{aA}	10.7^{bA}	13.9^{aA}	17.0^{bA}	11.1^{aA}	20.0^{bB}	9.4^{aA}	18.0^{bA}

Table 2 Biochemical and economic indices of different varieties cultivated in saline and non-saline soils

Sugarcane varieties	TSS (%)		Sucrose (%)		TRS (%)		Purity (%)	
	Saline	Non-saline	Saline	Non-saline	Saline	Non-saline	Saline	Non-saline
CoPb-18211	22.1^{aA}	24.5^{bD}	16.3^{aC}	21.0^{bB}	0.17^{aA}	0.16^{aA}	70.5^{aB}	90.1^{bA}
CoPb-18212	22.4^{aB}	23.1^{bB}	11.2^{aB}	21.2^{bB}	0.16^{aA}	0.16^{aA}	47.9^{aA}	91.9^{bA}
CoPb-18213	20.9^{aA}	23.3^{bC}	7.9^{aA}	21.6^{bB}	0.17^{aA}	0.18^{aA}	37.9^{aA}	94.1^{bB}
CoPb-18214	21.4^{aAB}	22.7^{bBC}	22.0^{aD}	20.9^{bA}	0.17^{aA}	0.16^{aA}	98.7^{aC}	93.0^{bB}
CoPb-19211	21.7^{aAB}	22.0^{bA}	10.7^{aB}	20.7^{bA}	0.18^{aA}	0.18^{aA}	49.7^{aA}	93.5^{bB}
CoPb-19212	20.4^{aA}	23.8^{bC}	14.9^{aC}	21.4^{bB}	0.19^{aA}	0.16^{aA}	73.0^{aB}	89.8^{bA}
CoPb-19213	21.6^{aAB}	23.1^{bB}	10.4^{aB}	20.6^{bA}	0.13^{aA}	0.14^{aA}	48.9^{aA}	88.9^{bA}
CoPb-19214	21.9^{aAB}	22.1^{bA}	15.1^{aC}	21.4^{bB}	0.15^{aA}	0.16^{aA}	68.9^{aB}	96.4^{bB}
	TA (%)		*TP (%)*		*Commercial cane sugar (%)*		*Sugar recovery (%)*	
CoPb-18211	0.80^{aB}	0.92^{bB}	79.6^{aA}	71.6^{aA}	10.3^{aB}	14.5^{bA}	14.4^{aB}	16.9^{bB}
CoPb-18212	0.70^{aA}	0.82^{bA}	112.2^{aC}	104.2^{aC}	5.0^{aA}	15.1^{bA}	13.1^{aA}	16.3^{bAB}
CoPb-18213	0.91^{aBC}	1.09^{bC}	120.2^{aC}	112.2^{aC}	2.0^{aA}	15.5^{bA}	11.5^{aA}	16.5^{bAB}
CoPb-18214	0.86^{aB}	0.90^{bB}	79.9^{aA}	71.9^{aA}	16.5^{aC}	14.9^{bA}	15.8^{aC}	16.0^{bA}
CoPb-19211	0.85^{aB}	0.89^{bB}	83.2^{aA}	75.2^{aB}	4.7^{aA}	14.9^{bA}	12.6^{aA}	15.7^{bA}
CoPb-19212	0.99^{aC}	0.99^{bC}	87.1^{aB}	79.1^{aB}	9.4^{aB}	15.1^{bA}	13.3^{aA}	16.7^{bB}
CoPb-19213	0.85^{aB}	1.02^{bC}	88.2^{aB}	80.2^{aB}	4.4^{aA}	14.5^{bA}	12.5^{aA}	16.1^{bA}
CoPb-19214	0.92^{aBC}	1.01^{bC}	81.2^{aA}	73.2^{aA}	9.2^{aB}	15.6^{bA}	14.0^{aB}	15.9^{bA}
	Average gross returns (AGRs; US$/ha)		*Average net returns (ANRs; US$/ha)*		*Benefit-cost (B:C) ratio*		*Economic efficiency (US$/ha/d)*	
CoPb-18211	2679^{aA}	3292^{bA}	1057^{aA}	1670^{bA}	1.65^{aA}	2.03^{bA}	7.36^{aA}	8.55^{bA}
CoPb-18212	2933^{aC}	3671^{bE}	1312^{aD}	2049^{bD}	1.81^{aD}	2.26^{bB}	8.06^{aB}	9.53^{bB}
CoPb-18213	2765^{aA}	3418^{bC}	1143^{aB}	1796^{bB}	1.70^{aB}	2.11^{bA}	7.60^{aA}	8.88^{bA}
CoPb-18214	2731^{aA}	3367^{bB}	1109^{aB}	1746^{bB}	1.68^{aB}	2.08^{bA}	7.50^{aA}	8.75^{bA}
CoPb-19211	3024^{aD}	3801^{bG}	1403^{aE}	2180^{bE}	1.86^{aD}	2.34^{bB}	8.31^{aB}	9.87^{bB}
CoPb-19212	2691^{aA}	3272^{bA}	1069^{aA}	1651^{bA}	1.66^{aA}	2.02^{bA}	7.39^{aA}	8.50^{bA}
CoPb-19213	2853^{aB}	3564^{bD}	1231^{aC}	1942^{bC}	1.76^{aC}	2.20^{bB}	7.84^{aA}	9.26^{bB}
CoPb-19214	2989^{aC}	3725^{bF}	1367^{aD}	2103^{bE}	1.84^{aD}	2.30^{bB}	8.21^{aB}	9.67^{bB}

55.6% decrease in sucrose content was observed in saline than non-saline soils. Juice purity showed large variation in saline (37.9–98.7%) than non-saline soil (88.9–96.4%), and was decreased by ~48.4% in saline than non-saline soil. Salinity decreased the titratable acidity (TA) by ~11.0% than non-saline soil. These results corroborate earlier research with decreased TSS, sucrose and purity due to increased E.C. of the juice (Lingle *et al.* 2000). These results corroborate the biochemical response of juice to salt stress (Wiedenfeld and Enciso 2008). Watanabe *et al.* (2020) reported decreased sucrose concentration in cane juice due to increasing concentration of soluble salts. Mean total phenols (TP) content was increased by ~9.6% in saline than the non-saline soil; with significantly higher TP for CoPB-18213 (Table 2). The increased TP in sugarcane varieties grown under saline soil was attributed to their defensive response towards salinity stress (Hanen *et al.* 2008). In saline soil, commercial cane sugar was significantly higher for CoPb-18214, while lowest for CoPb-18213. Average commercial cane sugar was ~95.3% higher in non-saline than saline soil. The decreased sugar content under saline soil environment was ascribed to the activation of enzymes involved in sugar metabolism (Gomathi and Thandapani 2004).

AGRs were significantly higher for CoPb-19211, compared with others (Table 2). About 24% decrease in AGRs was observed under saline than non-saline soil. ANRs of 1211.4 US$/ha for saline, and 1892.1 US$/ha for non-saline soil showed ~56.2% decrease for saline soils. Economic efficiency of 7.78 US$/ha/d for saline, and 9.13 US$/ha/d showed ~17.2% increase for non-saline soil. On an average, ~24% decrease in AGRs was observed under saline than non-saline soil. These results revealed that soil salinity has significant impact on agronomic attributes as well as the biochemical quality indices of different sugarcane varieties tested. Juice purity showed large variation in saline soils than the non-saline soil, and was significantly lowest for CoPb-18213, and highest for CoPb-18214. Sugar recovery was decreased by ~21.4% in saline soil. Average gross returns were significantly higher for CoPb-19211, compared with the others.

SUMMARY

The study evaluated the yield and biochemical attributes of eight sugarcane (*Saccharum officinarum* L.) cultivars (CoPb-18211, CoPb-18212, CoPb-18213, CoPb-18214, CoPb-19211, CoPb-19212, CoPb-19213 and CoPb-19214) in saline and non-saline soils during 2019–20 at Punjab Agricultural University, Punjab farms at village-Ruldu Singh Wala (Bathinda) and at village-Ratta Khera (Sri Muktsar Sahib). Soil salinity significantly ($P<0.05$) decreased the plant height (by ~66.6%), tillers/plant (~36%), cane diameter at ground surface (~79.8%) and diameter at breast height (~93.1%) than the non-saline soil. Soil salinity significantly decreased the TSS content in juice (by ~7.1%), sucrose (~55.6%) and titratable acidity (~11.0%) than the non-saline soil. Juice purity showed large variation in saline soils (37.9-98.7%) than the non-saline soil (88.9–96.4%), and was significantly lowest for CoPb-18213, and highest for CoPb-18214. Sugar recovery was decreased by ~21.4% in saline soil. Average gross returns were significantly higher for CoPb-19211, compared with the others. Mean economic efficiency of 7.78 US$/ha/d for saline and 9.13 US/ha/d showed ~17.2% increase for non-saline soil.

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