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Nutrient constraints limiting performance of sugarcane genotypes under simulated saline soil environment

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Abstract
The effect of salinity levels on various promising sugarcane genotypes under NaCl induced salt stress condition has been evaluated under controlled condition at Sugarcane Research Institute, RPCAU, Pusa. The salt stress up to ECe value 5.0 dS/m favors buildup of moderately alkaline soil environment (pH 8.4) with accumulation of soluble salts in root zone (EC 3.0 dS/m). The cations viz. Ca^{2+} + Mg^{2+} decreased while Na^{+} and anions viz. carbonate, bicarbonate, chloride and SAR were increased in soil saturation extract due to salt stress. The mean available macronutrients content of soil varied significantly for available N (221-240), available P (18.4-20.0) and available K (99.8-121.8) kg/ha. The micronutrients of post harvest soil Fe (7.9-9.0), Zn (0.65-0.74), Cu (0.99-1.2) and Mn (4.0-4.7) mg/kg, also varied significantly. The result indicated that available macro and micronutrients content of soil decreased with increase in toxic ions significantly with increasing levels of salinity. The increasing salinity significantly decreased concentration and uptake of NPK by sugarcane plant. The brix, pol and purity coefficient of sugarcane juice was adversely affected due to salinity. The deterioration in juice quality parameters due to toxic effect of NaCl resulted in low cane juice extraction (39 %). The reduction in mean cane yield (28.1%) and sugar yield (33.2 %) was observed due to salinity over control. Among sugarcane genotypes, performance of BO154 followed by CoP112 recorded significantly superior as compared to rest of the genotypes in terms of cane and sugar yield under saline soil environment as compared to rest of the genotypes under study. The result indicated that salinity of ECe value 5dS/m leads to accumulation of toxic ions and nutrient constraints in soil and their associated affect hindering performance of promising genotypes in terms of cane yield, sugar yield coupled with deterioration in juice quality as compared to the respective attributes in normal soil.

Keywords: genotypes, salinity, nutrient availability, yield, uptake, sugarcane quality

Introduction
Sugarcane (*Saccharum* spp. hybrid complex) is an important cash crop of India. The crop is long duration and nutrient exhaustive grown extensively in tropical and subtropical climate. Under Indian condition, the threshold salinity value for sugarcane is ECe 1.7 dS/m and relative yield at ECe value 3.0, 5.9 and 10.1 dS/m were 90%, 75% and 50%, respectively (Singh, 1998)[11]. The salt affected soils pose a global problem for limiting agricultural production. In India, about one third of sugarcane cultivable area is affected due to salinity. In semi arid condition the accumulation of salts in the root zone is mainly due to poor surface and internal drainage condition. In arid and semi arid regions, with the introduction of irrigation projects fertile lands are getting affected due to soil salinization. Salinity may cause damage to the plants through osmotic stress, nutrient imbalance and specific ion toxicity. The ion toxicity was the main determinant of salt tolerance at the grand growth stage, while the osmotic component of NaCl mainly appeared to affect the transport of sucrose to stalks followed by stimulated sucrolytic activity in the internodes; resulting in reduced final cane yield (Wahid 2004) [17].
The salt affected soil in the state of Bihar is widespread in the northern flood plain of the Ganges covering larger area affected with salinity. The productivity of sugarcane of Bihar is low (50 t/ha) as compared to national average (68.8 t/ha).The potential yield of sugarcane is 100-150 t/ha. There is huge gap between potential and actual yield. The erratic rainfall pattern, reduction in mean annual rainfall coupled high temperature during the last decade's further leads to expansion of salt affected soil leading to poor productivity and recovery of sugarcane. Saline soils are generally low in organic matter and adversely affect the solubility and availability of nutrients (Rozeff, 1995) [10]. The poor drainage system and drought resulted in deposition of salts on the soil surface. The growth and yield components were reduced as compared to the respective attributes in normal soil under simulated saline condition at EC

value of 8 dS/m (Singh *et al*., 2015) [12]. The quantification of loss in yield and deterioration in juice quality of sugarcane coupled with nutrient constraints limiting cane production is important for adaptability of various promising sugarcane genotypes developed by Sugarcane Research Institute, Pusa, Bihar for saline soil under agro climatic condition of Bihar. The evaluation of sugarcane genotypes is thus needed for its performance under saline soil environment. The introduction of salt tolerant sugarcane genotype would be one of the best ways to reduce the loss in cane productivity and cost of reclamation. The build-up of toxicity and nutrient constraints in soil and associated affects due to salinity will be helpful in management of saline soil for crop production and development of genotypes suitable for saline soil.

Materials and Methods

The experiment on sugarcane crop was conducted in sub-tropical humid climate in glasshouse, Sugarcane Research Institute, RPCAU, Pusa during the year 2016-17, to evaluate the performance of sugarcane genotypes in relation to nutrient availability under simulated saline soil environment. The site has hot and humid summers and too cold winters with average rainfall of 1200 mm of which 75% received during the monsoon period (mid June - mid September). The mean annual temperature is 24.5º C with maximum 38.6º C during April and minimum 7.4ºC in January. The treatment consisted of three salinity levels (0, 2.5 and 5.0 dS/m) and five sugarcane genotypes (CoP 9702, CoP 112, B.O. 154, B.O 153 and CoP 9301) with three replication in CRD. Bulk soil sample (0-15cm) was collected from crop research farm, Pusa from medium upland and having uniform topography for filling of pot. The soil samples were grouped in three separate parts for salinity development. The experimental soil was sandy loam in texture with moderately alkaline pH (8.18), low in organic carbon (0.45%), SAR (9.0) and ECe (0.27 dS/m) and low in available N-P-K (234.3- 18.1-114.6 kg/ha).The salinity of ECe 2.5 dS/mand ECe 5.0 dS/m was developed by mixing the suitable amount of NaCl. The initial soil was treated as control. The sugarcane was planted in cemented pit having capacity of 100 kg soil. The Fe, Zn Cu and Mn content of initial soil was 8.79, 0.79, 1.02 and 4.62 mg/kg, respectively. NPK was applied as per recommendations (150-85-60). The one budded setts were planted. Half of N was top dressed in two equal splits. The first top dressing was done after 60 days after planting and second at the time of earthing-up. The cane yield for each treatment was recorded. The plant samples collected after harvest were analyzed for NPK in di-acid digestion mixture using standard procedure. Soil samples (0-15 cm) were collected before initiation and after harvest of crop. The soil samples were analyzed for pH and EC in saturation extract (Jackson, 1973) [5], available N (Subbiah and Asija, 1956) [15], available Na, K (Jackson, 1973) [5], Ca+Mg (Versenate titration EDTA method (Cheng and Bray, 1951) [1] and available P (Olsen *et al*. 1954) [9]. The anions viz. carbonate, bicarbonate and chloride in soil was analyzed in soil after crop harvest using standard procedure. The DTPA extractable micronutrient in soil was analyzed (Lindsay and Norvell, 1979) [6]. The SPAD- 502 meter was used to measurement of leaf relative chlorophyll concentration at grand growth stage of crop at 120 days after planting. The cane juice quality viz. brix, pol and purity coefficient was determined using procedure outlined by Spencer and Meade (1964) [13] and sugar yield was calculated. The data were analyzed statistically.

Results and Discussion

Soil properties

Cations, anions and SAR of soil

The data pertaining to cations viz. Ca^{2+}+Mg^{2+}, Na^+ and SAR value of saturation extract of soil significantly affected by salinity levels (Table 1). The Na^+ content varied significantly (22.6 - 27.7 me/l) of saturation extract of soil. The Ca^{2+} + Mg^{2+} content of soil decreased significantly while, Na^+ content increased with increasing level of salinity. The mean value of pH (8.2 - 8.4) and ECe (0.30 - 3.0 dS/m) and sodium adsorption ratio (SAR 9.6-14.1) varied significantly (Table 1). However, increase in SAR value was within permissible limit (<13) at EC value of 2.5 dS/m and being highest at EC value of 5.0 dS/m. However, effects of genotypes were non-significant. The CO_3^{-2}, HCO_3^- and Cl^- content of saturation extract of soil varied significantly due to salinity (Table 1). The carbonate varied from 12.6 - 16.7, bicarbonate 22.5 - 28.5 and chloride 16.5 - 26.7 me/l due to salinity. The result indicated that increasing salinity increased anions concentration of post harvest soil. The salinity resulted in accumulation of these toxic ions in soil unfavorable for plant growth. The salt stress also resulted in increase sodium adsorption ratio (SAR) of soil due to change in pH and exchangeable Na^+ and decreased Ca^{2+}+Mg^{2+} content of soil. The higher pH favors accumulation of Na in salt treated plots. The higher soluble salt content at ECe 5.0 dS/m cause injury to the plants through osmotic stress, nutrient imbalance and specific ion toxicity as reflected from present findings. The increased Cl^- ions due to salinity adversely affected the growth of sugarcane plant and its injury was observed during the growth period. Rozeff (1995) [10] and (Wahid, 2004) [17] reported similar findings.

Table 1: Effect of salinity on soil physico-chemical properties and cations, anions and SAR of post-harvest soil.

Salinity levels ECe (dS/m)	pH	ECe (dS/m)	Cation and anion content of soil saturation extract (me/l)					SAR
			$CO3^{-2}$	Cl^-	$HCO3^-$	Ca^{+2}+Mg^{+2}	Na^+	
0	8.1	0.3	12.6	16.5	22.5	11.0	22.6	9.6
2.5	8.2	1.6	14.0	21.6	25.1	9.7	25.3	11.5
5.0	8.4	3.0	16.7	26.7	28.5	7.7	27.7	14.1
CD (P = 0.05)	0.02	0.02	1.1	1.0	1.2	0.7	1.4	1.1

Available NPK content of soil

The available N, P and K content of post harvest soil decreased significantly with increasing salinity level (Table 2). The mean available macro nutrient content of soil varied significantly for available N (221-240), available P (18.4-20.0) and available K (99.82-121.8) Kg/ ha. The data indicated that salt stress resulted in decreased availability of NPK in soil. The salinity of soil decreased at harvest stage over the initial value. The high soil pH and EC of soil resulted in reduction in availability of several essential plant nutrients. The post-harvest soil recorded high pH and EC with low availability of nutrients. The similar findings were reported by Takkar and Mishra (2004) [15].

Micronutrient content of soil

The micronutrients of post-harvest soil Fe (7.9- 9.0), Zn (0.65-0.74), Cu (1.0- 1.2) and Mn (4.0-4.7) mg /kg, varied significantly (Table 2). The available Fe, Zn, Cu and Mn content of post-harvest soil decreased significantly with increasing salinity level over control. At higher pH, micronutrients are precipitated and became unavailable. The result indicated that addition of NaCl resulted in nutrient imbalance in soil which adversely affects performance of crop under study. The moderately alkaline soil environment and increased anions in soil resulted in decreased availability of micronutrient in salt treated soil.

Table 2: Effect of salinity on availability of macro and micro nutrient content of post-harvest soil

Salinity levels ECe (dS/m	Macro nutrients (Kg/ha)			Micro nutrients (mg/kg)			
	N	P	K	Fe	Zn	Cu	Mn
0	240.0	20.0	123.8	9.0	0.74	1.2	4.7
2.5	228.4	19.1	111.4	8.7	0.69	1.1	4.3
5.0	221.0	18.4	99.8	7.9	0.65	1.0	4.0
CD (P = 0.05)	2.3	0.7	6.8	0.6	0.03	0.03	0.2

Concentration of N P K and SPAD value

The NPK concentration in plant leaf significantly decreased with increasing level of salinity (Table 3). However, the difference between treatment 2.5 and 5.0 dS/m ECe for P and K concentration was found non-significant. The relative chlorophyll content of sugarcane plant as reflected from SPAD value at grand growth stage (Fig 1.1 and 1.2) varied significantly due to salinity and genotypes. Measurement with the SPAD meter value produces relative proportion to the amount of chlorophyll present in leaf. The SPAD value varied from 30.3-37.7 and 32.2-35.0 due to salinity and genotypes, respectively. The SPAD value for genotype BO 154 was highest among rest of the genotypes indicating presence of relatively high chlorophyll concentration in leaf and closely related to nutritional condition of plant. The decreased SPAD value coupled with low concentration and uptake of nutrients by plant indicating poor plant growth in salt treated plots. The salinity decreased N, P and K concentration as reported by Malik *et al*. (1977) [7] and Dang *et al*. (1999) [2]

Table 3: Effect of salinity on nutrient concentration and uptake by sugarcane plant at harvest stage.

Salinity levels ECe (dS/m)	N	P	K	N	P	K
	Concentration in plant (%)			Uptake by plant (g/kg)		
0	0.86	0.077	0.89	13.2	1.20	13.6
2.5	0.81	0.074	0.87	10.8	1.00	11.5
5.0	0.74	0.071	0.77	8.7	0.80	9.2
CD (P = 0.05)	0.03	0.002	0.03	0.4	0.03	0.6

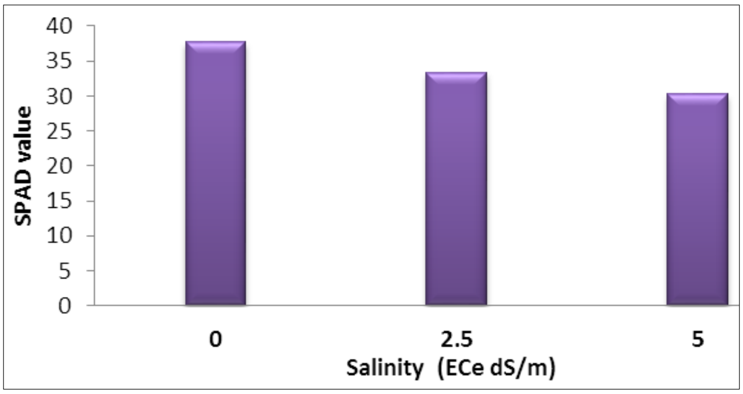
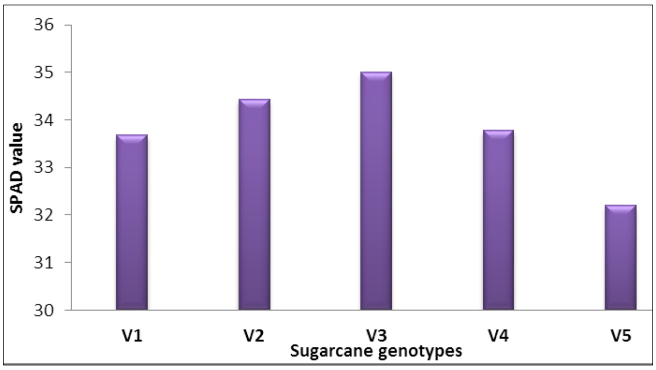


Fig 1.1: Effect of salinity on SPAD value of sugarcane plant at grand growth stage of sugarcane



V_1- CoP 9702, V_2- CoP112, V_3- BO154, V_4- BO153, V_5 -CoP 9301

Fig 1.2: SPAD value of various sugarcane genotypes at grand growth stage of sugarcane Uptake of N, P and K by plants

The uptake of N, P and K by plant significantly decreased with increasing levels of salinity (Table 3). The saline soil condition significantly influenced the total nitrogen, phosphorus and potassium concentration and its uptake by sugarcane genotypes (Table 4). The maximum reduction in concentration and uptake of N, P and K by sugarcane plant was recorded at salinity level of 5.0 dS/m treatment over control. Among genotypes, highest uptake of N (12 g pot^{-1}), P (1.1 g/pot) and K (12.5 g /pot) was recorded by sugarcane genotype BO154. The nutrient uptake by sugarcane plant followed the similar trend as cane yield. The higher cane yield in BO154 resulted in more uptakes of nutrients. Whereas, lower cane yield resulted in lower uptake of N, P, and K in CoP 9301 and BO153 as compared to other varieties indicating that these genotypes were sensitive under saline soil. The results are in agreement with the reports of Nimbalkar *et al*. (2011) [8].

Table 4: Nutrient concentration and uptake as affected by sugarcane genotypes

Genotypes	N	P	K	N	P	K
	Concentration in plant (%)			Uptake by plant (g/pot)		
CoP 9702	0.79	0.08	0.84	10.7	1.00	11.3
CoP 112	0.82	0.07	0.86	11.2	1.00	12.1
BO 154	0.83	0.08	0.87	12.0	1.10	12.5
BO 153	0.79	0.07	0.84	10.5	1.00	11.0
CoP 9301	0.79	0.07	0.82	10.0	0.90	10.1
CD (P = 0.05)	NS	NS	NS	0.5	0.03	0.8

Cane yield

The cane yield significantly decreased with increasing salinity levels (Table 5). The reduction in yield due to salinity at 2.5 dS/m and 5.0 dS/m over control was to the extent of 17.1 % and 28.1 %, respectively. Among genotypes mean cane yield varied significantly from 3.4 - 3.8 kg/ pot. The performance of genotypes BO154 and CoP 112 significantly superior over rest of the genotypes (Table 6). Excess salts adversely affect the growth and development of crop which ultimate results in poor crop growth yield. The buildup in salinity and pH coupled with reduction in available nutrient content of soil resulted in low yield in salt treated plots. Salinity may cause damage to the plants through osmotic stress, nutrient imbalance and specific ion toxicity. The ion toxicity was the main determinant of salt tolerance at the grand growth stage as observed in present experiment. The data indicated that genotypes BO154 and CoP 112 performed well against salinity. Gomathi and Thandapani *(*2014) [4] also reported varietal difference in terms of cane yield. The growth and yield components were reduced as compared to the respective attributes in normal soil under saline condition (ECe 5dS/m) by mixing sodium chloride in required amounts against control. The results were supported by the findings of Singh *et al*., (2015) [12]. The threshold salinity value for sugarcane is ECe 1.7 dS/m and relative yield at ECe value 3.0, 5.9 and 10.1 dS/m were 90%, 75% and 50%, respectively under Indian condition (Singh, 1998) [12].

Juice quality

Brix of juice

The value of brix in sugar cane juice varied significantly (18.3-18.5) decreased with increasing level of salinity (Table 5). The highest brix of juice was recorded in control, moderate at ECe 2.5 dS/m and being lowest at ECe 5.0 dS/m. The mean brix value varied significantly (18.0-18.7%) due to genotypes (Table 6). In case of genotypes CoP 9301 recorded highest brix (18.7%) followed by genotype BO154 (18.3%) and lowest in CoP 9702 (18.0%). Lower content of brix in saline soil might be due to toxic effects of ions and osmotic component affects transport of sucrose in plant due to addition of NaCl. Wahid (2004) [17] reported similar findings.

Pol of juice

The pol in juice varied significantly (15.6-16.1 %) and decreased with increasing levels of salinity (Table 5). The maximum pol was recorded in control (16.1 %) and lowest at salinity level of 5.0 dS/m (15.6%).The sucrose content varied significantly (Pol 15.7-1.4%) for sugarcane genotypes (Table 6). CoP 9301 was significantly superior (16.4 %) than rest of the sugarcane genotypes in terms of pol. The lower pol content might be because of salt induced stimulation of sucrolytic activities of acid and neutral invertase activities (Tazuke and Wada, 2002) [16].

Purity coefficient of juice

The purity coefficient of sugarcane juice was found non-significant due to salinity levels and genotypes (Table 5 and 6). In general, numerical reduction in purity coefficient was observed with increasing salinity. Similar to brix and pol, the highest purity coefficient was observed in sugarcane genotype CoP 9301. The minimum purity coefficient was recorded in genotype BO154 due to low brix and pol.

Recovery of juice

The cane juice recovery significantly influenced by salinity and different sugarcane genotypes (Table 5 and 6). The significant reduction in juice extraction was recorded with increasing salinity levels from 0 to 5.0 dS/m. The mean cane juice recovery varied significantly (39.0-45.5%) due to salinity. Among sugarcane genotypes, CoP112 recorded maximum juice recovery (43.6%) as compared to rest of other genotypes. The deterioration in juice quality parameters viz. brix, pol and purity coefficient due to toxic effect of NaCl resulted in low cane juice extraction. Gomathi and Thandapani (2005) [3] also reported deterioration in juice quality due to salinity.

Table 5: Effect of salinity on yield and juice quality of sugarcane.

Salinity levels (ECe dS/m)	Juice quality (%)			Juice recovery (%)	Cane yield (kg/pot)	Sugar yield (g/pot)	Decrease in yield over control (%)	
	Brix	Pol	Purity				Cane yield	Sugar yield
0	18.5	16.4	87.3	45.5	4.1	450.4	-	-
2.5	18.3	15.9	86.9	42.9	3.5	385.7	17.1	16.8
5.0	18.0	15.6	86.8	39.0	3.2	338.0	28.1	33.2
CD(P = 0.05)	0.2	0.2	NS	2.6	0.13	16.3	-	-

Sugar yield

The data revealed that sugar yield reduced due to salinity levels at 2.5(16.7%) and 5.0 (33.3 %) dS/m over control. Among sugarcane, genotypes BO 154 recorded significantly highest sugar yield followed by CoP112 and lowest in BO 153 (Table 6). The mean sugar yield increased by 9.7 % in BO 154 and 5.4 % in CoP 112 over BO 153. The sugar yield is the function of cane yield. The higher cane yield resulted in higher sugar yield. Salinity in the root zone decreases sucrose yield, through its effect on both, biomass and juice quality and yield components (Wiegand *et al.*, 1996) [19]. These reductions reduce the tonnage harvested from salt affected fields. The result indicated that NaCl salinity buildup up to ECe 5.0 dS/m resulted in accumulation of toxic cations and anions coupled with reduced availability and uptake of nutrients which adversely affects the performance of sugarcane genotypes. The increasing salinity significantly decrease uptake of NPK by sugarcane plant. The yield and quality parameters were reduced under saline stress as compared to the respective attributes in normal soil due to nutrient constraints. Under saline soil environment BO154 and CoP112 performed better in terms of yield and quality. Similar findings were reported by Gomathi and Thandapani (2014) [4] and Gomathi and Thandapani (2005) [3].

The result indicated that salinity (ECe value 5dS/m) leads to accumulation of toxic ions and nutrient constraints in soil and their associated affects hindering performance in terms of yield and quality of promising sugarcane genotypes under study. The present findings will be helpful in management of saline soil for obtaining higher cane productivity and development of genotypes suitable for saline soil.

Table 6: Cane yield and juice quality as affected by sugarcane genotypes

Genotypes	Juice quality (%)			Juice recovery (%)	Cane yield (Kg/pot)	Sugar yield (g/pot)
	Brix	Pol	Purity			
CoP 9702	18.0	15.6	87.1	41.4	3.6	382.8
CoP 112	18.1	15.7	86.9	43.6	3.7	399.5
BO 154	18.3	15.8	86.6	41.6	3.8	415.5
BO 153	18.1	15.8	87.0	43.2	3.5	378.9
CoP 9301	18.7	16.4	87.4	42.8	3.4	380.3
CD (P = 0.05)	0.3	0.2	NS	NS	0.2	21.1

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