

Original Research

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Waterlogging effects on leaf element concentrations and cane weight of sugarcane genotypes

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Abstract

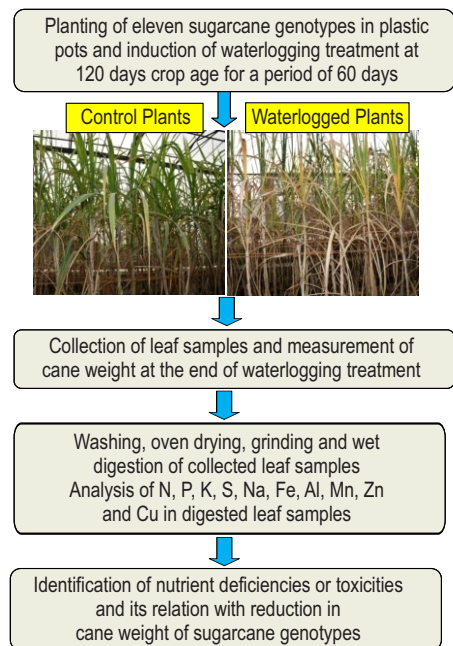
Aim: The aim of the present experiment was to examine whether waterlogging induced deficiency or excess of elements, is the cause for reduction in cane weight of sugarcane genotypes under waterlogged conditions.

Methodology: The experiment was conducted in pots with eleven sugarcane genotypes grown under control and waterlogged conditions. Waterlogging treatment was imposed at 120 days crop age for a period of 60 days. Cane weight and element concentrations were measured at the end of waterlogging.

Results: Compared to control, reduction in cane weight of sugarcane genotypes under waterlogging varied from 5.3% (A-46-11) to 32.3% (CoJ 64). Waterlogging caused a significant decrease in leaf N, P, K, S, Zn and Cu concentrations of sugarcane genotypes; the extent of decreases in leaf N and S were more and values for these elements dropped below their reported critical deficiency level for most genotypes. There was a significant inverse correlation between leaf K and S concentration, and reduction in cane weight of sugarcane genotypes, indicating that genotypes with high leaf K and S under waterlogging have relatively less reduction in cane weight. There were significant increase in the leaf Fe, Al, Mn and Na concentrations under waterlogging, however, increase in these elements were not correlated with reduction in cane weight of sugarcane genotypes.

Interpretation: The results suggest that deficiencies of N, K and S rather than excess of Fe, Al and Mn is a major cause for reduction in cane weight of sugarcane genotypes under waterlogged condition. The genotypes tolerant to N, K and S deficiencies under waterlogging can be utilized in breeding program for developing sugarcane varieties with improved waterlogging tolerance.

Key words: Cane weight, Element deficiencies, Element toxicities, Sugarcane, Waterlogging



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Introduction

Waterlogging is one of the serious environmental constraints to sugarcane production which causes 18–64% reduction in cane yield depending upon the genotypes, environmental conditions, stage of development and stress duration (Gilbert *et al.*, 2008; Glaz and Lingle, 2012). In India, physical degradation of soil due to waterlogging accounts about 11.6 mha of which 10-30% comes under sugarcane cultivation (Gomathi *et al.*, 2015). The major effects of waterlogging in sugarcane crop include higher rate of stalk mortality, low relative growth rate, reduced cane yield, poor juice quality and recovery (Viator *et al.*, 2012; Gomathi *et al.*, 2015). Waterlogging causes hypoxic or anoxic soil conditions as diffusion of oxygen through water is 10,000 times slower than in air (Armstrong and Drew, 2002), that results in accumulation of phytotoxins (Armstrong and Armstrong, 2001), cause a sequence of physico-chemical and microbial changes in the soil (Ponnamperuma, 1984), severe deficiency of energy and eventual death of the plants (Greenway and Gibbs, 2003). Oxygen deficiency during waterlogging may inhibit nutrient uptake and transport in plants by altering root function due to the death of root system (Stepniewski and Przywara, 1992), causing nutrient leakage due to loss of membrane integrity (Resen and Carlson, 1984) and by impeding ATP dependent active uptake of ions (Setter and Belford, 1990).

Nutrient uptake of crop plants in waterlogged soils is largely influenced by the initial status of soil nutrients, changes in the physico-chemical properties of soil and tolerance ability of crop varieties (Kozłowski, 1990). The element toxicities and deficiencies are considered as one of the major growth limiting factors under waterlogging. The decreased redox potential during waterlogging causes reduction of elements like iron, manganese and aluminum ions which increases their availability in soil beyond plant nutritional requirements (Yadavanshi *et al.*, 2012; Ma *et al.*, 2003; Rengaswamy, 2004); this increases the concentration of these elements into high to toxic range in the plants. Many fold increase in the leaf/shoot concentrations of Fe, Mn and Al have been observed in waterlogged wheat (Khabaz-Saberi *et al.*, 2006; Singh and Setter, 2017 and 2017a). Some crop species like rice, avoid the accumulation of Fe and Mn by releasing oxygen into the rhizosphere for Fe and Mn oxidation (Mengel and Kirkby, 2001); while crops like wheat and barley are not able to oxidize Fe and Mn so that toxicity of these elements occur under waterlogging. The increase in Fe, Mn and P concentration in root samples have been used as an indicator of waterlogging intolerance in wheat (Musgrave and Ding, 1998).

In addition to toxicity problems, waterlogging also causes deficiencies of several elements in different crops. The decrease in leaf K, P, S and Zn concentrations have been reported in waterlogged wheat (Sharma and Swarup, 1988; Singh and Setter, 2017). A decrease in the leaf N, P, K, Ca, Mg, S, Mn and Zn concentrations have been observed in soybean under waterlogging and decrease in leaf N content was found to be

associated with waterlogging induced yield losses (Board, 2008). The waterlogging treatment in cotton reduced the leaf N, K, P, Ca, Mg, Mn and S concentrations and increased the Fe concentration as compared to control (Conaty *et al.*, 2008). It is suggested that waterlogging tolerance is often a product of tolerance to anaerobiosis and to element deficiencies and toxicities of several elements (Setter *et al.*, 2009). Unlike other crops, information available for sugarcane on the uptake and accumulation pattern of different elements under waterlogged conditions is meagre. In view of the above, the present work was undertaken with objective to identify major element deficiencies or toxicities occurring in sugarcane under waterlogged condition and also to evaluate whether differences in element deficiencies/toxicities among sugarcane genotypes are associated with reduction in their cane weight under waterlogging.

Materials and Methods

Plant material and growth conditions: The experiment was conducted in pots at ICAR- Indian Institute of Sugarcane Research, Lucknow under glass house conditions during spring season of 2017-18. The seedlings of eleven sugarcane (*Saccharum* spp. hybrid) genotypes; CoLk 94184, BO 91, CoS 767, CoJ 64, CoLk 12204, CoLk 07201, LG 04439, LG 03040, A-46-11, A-27-12 and UP 9530 were raised from single bud setts in plastic trays filled with soil, sand and FYM (1:1:1). Thirty-days-old seedlings were then transplanted in plastic pots (10" diameter) filled with 8 kg clay loam soil having pH 7.6 and EC 0.18. In each pot, nitrogen, phosphorus and potassium were supplied as 1.30 g urea, 1.50 g single superphosphate and 0.40 g muriate of potash, respectively equivalent to recommended dose of N, P and K (150:60:60 kg ha⁻¹). Half of the urea, full amount of single superphosphate and muriate of potash (as basal) were thoroughly mixed in soil before filling the pots. The remaining urea was applied in two equal split doses, one at 30 days and other at 90 days after transplanting. Single plant was maintained in each pot and tillers were instantly removed after its emergence throughout the experiment period. Irrigation and other cultural practices were done as and when required.

Treatment imposition: The experiment consisted two treatments viz., (i) Control (non waterlogging) and (ii) Waterlogging. The waterlogging treatment was imposed at 120 days plant age (90 days after transplanting) for a period of 60 days by shifting the planted pots in larger plastic buckets (15" diameter and 19" depth) and maintaining water 20 cm above the soil surface. The control plants (non waterlogging) received normal irrigation during this period. After completion of waterlogging treatment, the pots were taken out from the buckets and excessive water in pots was drained off and thereafter, during remaining crop period pots were irrigated normally like control plants. Thus eleven genotypes and two stress treatments constructed a total of 22 treatment combinations. Under each treatment, 10 pots were maintained so that, on each sampling occasion three replicates was available. The whole experiment was planned under completely randomized design (factorial).

Leaf sampling and element analysis: Leaf samples for element analysis were collected at the end of waterlogging treatment from both non waterlogged (control) and waterlogged sets. Eighteen leaves (third and fourth lower leaf from top visible dewlap leaf) per treatment in three replicates (6 leaves per replicate) were collected. Thereafter, leaf samples were thoroughly rinsed thrice in distilled water to remove any soil contamination. Excess water on leaves was wiped off with the help of a blotting paper and then leaves were placed in a paper bag, oven dried at 70°C for 48 hr, grinded and digested using the di-acid mixture of nitric acid and perchloric acid (10:1 ratio).

The Na and K content in digested leaf samples were estimated with the help of a flame photometer whereas Mn, Zn and Cu were measured with atomic absorption spectrophotometer. The analysis for Fe and Al content was done by Central Instrumentation Facility Laboratory, CSIR-National Botanical Research Institute, Lucknow using ICP-MS. The N content in the leaf samples was determined by Kjeldahl method using di-acid mixture of sulphuric and perchloric acid (5:2 ratio) as described by Humphries (1956). The sulphur content was estimated by turbidetric method (Chesnin and Yien, 1950) using HNO₃ - HClO₄ digest. The phosphorus content was analyzed by colorimetric method as given by Fiske and Subba Row (1925). The critical deficiency level for different elements have been cited in the results as described by Anderson and Bowen (1990) and McCray and Mylavarapu (2010).

Measurement of cane weight: Cane weight was measured at the end of waterlogging treatment. Three canes per replicate (total, three replicates per treatment) were selected and cut from the base. The whole cane up to the top dewlap leaf was cleaned by removing the attached leaves and leaf sheaths. The cane weight was measured with the help of a digital balance and expressed as kg per cane.

Statistical analyses: The data were analyzed using complete randomized design based on factorial experiment and mean comparison was done using least significant difference test (Gomez and Gomez, 1984). The summary of analysis of variance for different parameters has been presented in Table 1.

Results and Discussion

Waterlogging caused a significant decrease in the cane weight of sugarcane genotypes (Table 2). Compared to control, the decrease in cane weight of sugarcane genotypes due to waterlogging varied from 5.3% (A-46-11) to 32.3% (CoJ 64). The mean cane weight (across the varieties) decreased by 17.1% in waterlogging relative to control. The reduction in cane weight due to waterlogging was lower in genotypes, A-46-11, UP 9530, CoLk 94184 and BO 91 (5.3 to 13.0%), whereas greater reduction was found for genotypes LG 03040, A-27-12 and CoJ 64 (27.0 to 32.3%). The mean effect of variety showed highest cane weight in LG 04439 which was at par with CoLk 94184 and A-46-11, while other genotypes had significantly lower values. UP 9530, CoLk 94184 and BO 91 used in the present experiment are released waterlogging tolerant genotypes (Solomon *et al.*, 2014), these genotypes showed relatively less reduction in cane weight under waterlogging. CoJ 64 showing highest reduction in cane weight has been identified as one of the most waterlogging intolerant genotype in earlier work (Singh *et al.*, 2019). The reduction in cane weight caused by waterlogging may be attributed to hypoxia/anoxia induced energy crisis which decreases the water and nutrient supply to the shoot, decrease photosynthetic rate and effective leaf area, impaired root growth and functioning and lower crop growth rate (Setter and Waters, 2003; Jiaphong *et al.*, 2017; Gomathi *et al.*, 2015; Viator *et al.*, 2012). The decrease in cane weight of sugarcane due to waterlogging has been also reported previously (Manoharan *et al.*, 1990; Gilbert *et al.*, 2007; Singh *et al.*, 2019).

Waterlogging decreased the leaf N concentration of sugarcane genotypes by 31.6% to 57.3% (Fig. 1). The leaf N concentration was in sufficiency range in control plants, however it decreased below the critical deficiency concentration (<1.80%) in all sugarcane genotypes under waterlogging. The mean leaf N concentration (across the genotypes) in waterlogging was 1.11% against 2.02% in control (Table 3). The values for leaf N under waterlogging were higher for CoLk 94184, BO 91, CoLk 07201, LG 04439 and A-46-11 and waterlogging induced cane weight losses were relatively less in these genotypes. CoJ 64 with lowest leaf N concentration (0.79%) under waterlogging recorded highest reduction in cane weight (32.3%). However, in some

Table 1: Summary of analysis of variance for cane weight and different elements based on genotype and waterlogging treatments

Source of variation	d.f.	Cane weight (Kg/cane)	Leaf N (%)	Leaf P (%)	Leaf K (%)	Leaf S (%)	Leaf Na (ppm)	Leaf Fe (ppm)	Leaf Al (ppm)	Leaf Mn (ppm)	Leaf Zn (ppm)	Leaf Cu (ppm)
Water logging	1	0.359**	13.609**	0.140**	3.274**	0.165**	811855**	145137**	82751**	2602.6**	1931.05**	54.764**
Genotype	10	0.101**	0.162**	0.007**	0.075**	0.003**	14693**	712 NS	942**	319.0**	55.38**	6.192**
Water logging x Genotype	10	0.005 NS	0.028 NS	0.003**	0.017 NS	0.001**	23789**	1224**	774**	36.1 NS	22.35**	0.200 NS
Error	42	0.005	0.023	0.001	0.010	0.000	5961	417	164	22.3	8.67	0.634

**significant at 1% levels of probability; NS- non significant

Table 2: Cane weight of sugarcane genotypes in control and waterlogged treatments (after 60 days of waterlogging imposed at 120 days crop age)

Genotypes	Cane weight (kg per cane)		Mean
	Control	Waterlogged	
CoLk 94184	0.96	0.86 (10.4)	0.91
BO 91	0.69	0.60 (13.0)	0.65
CoS 767	0.83	0.69 (16.9)	0.76
CoJ 64	0.65	0.44 (32.3)	0.55
CoLk 12204	0.80	0.62 (22.5)	0.71
CoLk 07201	0.73	0.58 (21.2)	0.65
LG 04439	1.01	0.85 (15.8)	0.93
LG 03040	0.74	0.54 (27.0)	0.64
A-46-11	0.94	0.89 (5.3)	0.91
A-27-12	0.83	0.59 (28.9)	0.71
UP 9530	0.87	0.78 (10.3)	0.83
Mean	0.82	0.68 (17.9)	-
C.D. at 5 %	Waterlogging (WL) = 0.04, Genotype (G) = 0.09,		WL x G = NS

Values in parentheses indicate percent reduction in waterlogged treatment over control

Table 3: Range and mean leaf element concentration of eleven genotypes in control and waterlogged treatments

Elements	Range		Mean	
	Control	Waterlogged	Control	Waterlogged
Nitrogen (%)	1.76-2.27	0.79-1.40	2.02	1.11 (-45)
Phosphorus (%)	0.25-0.38	0.13-0.26	0.32	0.23 (-28)
Potassium (%)	1.29-1.60	0.70-1.12	1.43	0.99 (-31)
Sulphur (%)	0.18-0.27	0.08-0.15	0.22	0.12 (-45)
Sodium (ppm)	700-900	960-1250	808	1030 (+27)
Iron (ppm)	160-201	246-316	184	278 (+51)
Aluminium (ppm)	90-127	152-215	107	177 (+65)
Manganese (ppm)	34.0-59.7	44.1-69.8	49.4	61.9 (+25)
Zinc (ppm)	32.3-44.1	22.0-30.2	36.6	25.7 (-30)
Copper (ppm)	6.00-9.03	4.09-7.06	7.19	5.37 (-25)

Values in parentheses indicate percent increase (+) or decrease (-) in waterlogged treatment over control

genotypes the values for leaf N under waterlogging were not consistent with the waterlogging induced reductions in cane weight. For example, UP 9530 with 1.04% leaf N concentration showed second-lowest reduction in cane weight (10.3%) while A-27-12 higher in leaf N concentration (1.2%) exhibited second-highest reduction in cane weight (28.9%). A marginal inverse correlation ($r = -0.589$) was detected between leaf N concentration and reduction in cane weight of genotypes under waterlogging (Table 4). The results of present study are supported by earlier works in sugarcane (Gomathi *et al.*, 2010; Singh *et al.*, 2019) and other crops (Khabaz-Saberi *et al.*, 2006; Board, 2008). The decline in leaf nitrogen concentration under waterlogging may be a consequence of reduced availability of the nitrogen to plants due to hypoxia/anoxia induced promotion of denitrification of nitrate ions (Hamonts *et al.*, 2013).

The leaf P concentration of sugarcane genotypes decreased significantly in response to waterlogging (Fig 2).

Compared to control, waterlogging decreased leaf P by 16.1% (CoLk 94184) to 56.7% (CoLk 12204) with a mean decrease of 28% across the genotypes (Table 3). However, the values for leaf P for most genotypes were not in deficient range under waterlogged condition. This suggests that as compared to N, the waterlogging effects on leaf P were to a smaller extent. The decrease in phosphorus concentration observed in sugarcane leaves under waterlogged condition may be attributed to reduced uptake of phosphorus due to anaerobiosis (Drew and Lynch, 1980), impaired root functioning (Trought and Drew, 1980), and lack of energy for ion uptake (Barrett-Lennard *et al.*, 1990). Similar results were also reported for waterlogged wheat (Steiger and Feller, 1994; Singh and Setter, 2017), sorghum (Maranville *et al.*, 1986) and cotton (Board, 2008).

The vacuole and the cytosol are considered as major K reservoirs in plant cell. Maintenance of constant cytosolic K concentration is essential for normal plant metabolism. The

Table 4: Correlation between percent reduction in cane weight and concentration of different elements under waterlogged treatment

	1	2	3	4	5	6	7	8	9	10	11
1. Reduction in cane weight (%)	1.000										
2. N (%)	-0.589	1.000									
3. P (%)	-0.552	0.658*	1.000								
4. K (%)	-0.808*	0.626*	0.617*	1.000							
5. S (%)	-0.697*	0.298	0.103	0.448	1.000						
6. Na (ppm)	-0.347	0.432	0.031	0.289	0.350	1.000					
7. Fe (ppm)	0.062	0.437	0.018	-0.131	0.220	0.420	1.000				
8. Al (ppm)	0.315	0.433	-0.050	-0.140	-0.310	0.013	0.545	1.000			
9. Mn (ppm)	0.062	0.010	0.264	-0.118	-0.002	-0.074	0.252	-0.260	1.000		
10. Zn (ppm)	-0.307	0.279	0.220	0.221	0.214	0.069	-0.267	0.116	-0.608*	1.000	
11. Cu (ppm)	-0.093	0.463	0.241	-0.184	-0.021	0.119	0.379	0.427	0.303	0.040	1.000

*indicates significant at 5% level of probability

higher K uptake plays an important role in osmotic adjustment by maintaining cell turgor. However, K deficiency intensifies the adverse effects of waterlogging by disturbing the water balance of plants. Similar to nitrogen and phosphorus, a significant decline was apparent in leaf K concentration under waterlogging (Fig. 3). The values for leaf K in control ranged from 1.29% to 1.60%, while in waterlogging from 0.70% to 1.12%. An average decrease of 31.2% was recorded in leaf K concentration under waterlogging. (Table 3). The genotypes CoJ 64, CoLk 12204 and A-27-12 showed relatively more reduction in leaf K concentrations under waterlogged condition. CoJ 64 with lowest leaf K concentration (0.70%) showed highest reduction in cane weight (32.3%) under waterlogging, while A-46-11 having highest leaf K concentration (1.12%) showed lowest reduction in cane weight (5.3%).

A significant inverse correlation ($r = -0.808$) was found between leaf K concentration and reduction in cane weight of genotypes under waterlogging (Table 4). This suggests that genotypes with higher leaf K concentration have less cane weight reduction under waterlogging. The waterlogging induced decrease in leaf K are most likely attributable to the effects of anaerobiosis on uptake mechanisms of roots (Trought and Drew, 1980 and 1980a). Other possible factors include hypoxia/ anoxia induced membrane depolarization (channel opening), changes in non-specific membrane permeability to K and loss of K through ROS-activated channels (Shabala *et al.*, 2014). The results are in agreement with previous work in sugarcane (Singh *et al.*, 2019) and wheat (Singh and Setter, 2017).

Waterlogging markedly reduced the leaf sulphur concentration of sugarcane genotypes (Fig. 4). Under control condition, the leaf S concentration of genotypes varied from 0.18 to 0.27% which decreased to the tune of 0.08 to 0.15% under waterlogging (Table 3). The values for leaf S content under waterlogging were in normal range for the genotypes CoLk 94184, BO 91, CoS 767 and LG 04439 while values for other genotypes were in deficient range. The mean leaf sulphur concentration in waterlogging was 0.12% as compared to 0.22%

in control and showed a decrease of about 45%. There was a significant inverse correlation between leaf sulphur concentration and reduction in cane weight of genotypes under waterlogging ($r = -0.697$) suggesting that leaf sulphur concentration has role in explaining the cane weight reduction caused by waterlogging (Table 4). The sulphate assimilation and reduction takes place in the leaves. Waterlogging causes leaf chlorosis and it has been reported that sulphur assimilation genes including sulfite reductase are down regulated in leaves under waterlogged condition (Christianson *et al.*, 2010). This may be one of the possible reasons for severe decrease in leaf sulphur concentration during waterlogging. Similar decrease in sulphur concentration under waterlogging has been also observed in cotton (Conaty *et al.*, 2008; Milroy *et al.*, 2009), wheat (Khabaz-Saberi *et al.*, 2006; Singh and Setter, 2017) and soybean (Board, 2008).

A considerable increase of 15.1% to 78.6% was recorded in the leaf Na concentration of sugarcane genotypes after exposure to waterlogging stress (Table 5). The leaf Na content in control ranged from 700 to 900 ppm, which increased to the level of 960 to 1250 ppm under waterlogging (Table 3). Among the genotypes evaluated, BO 91, CoLk 07201 and CoLk 12204 showed higher increases in leaf Na concentration due to waterlogging as compared to other genotypes. The mean effect of waterlogging and genotype was found significant (Table 1). The leaf Na concentration did not show any correlation with reduction in cane weight under waterlogging (Table 4). Similar to our results, significant increase in leaf Na concentration was observed during waterlogging in wheat (Khabaz-Saberi *et al.*, 2006; Singh and Setter, 2017a).

Under waterlogged condition, depolarization of hypoxic root plasma membrane does not inhibit uptake of Na ions; indeed facilitates more entry of Na ions via non selective cation channels; while limited H^+ -ATPase activity decrease the active Na exclusion across the plasma membrane and results in accumulation of Na ions in roots (Shabala and Mackay, 2011). This may be the reason for increased leaf Na concentration of

Table 5. Concentration of microelements in leaf tissue of sugarcane genotypes in control and waterlogged treatments (after 60 days of waterlogging imposed at 120 days crop age)

Genotypes	Na (ppm)		Fe (ppm)		Al (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)					
	Control	Water-logging	Control	Water-logging	Control	Water-logging	Control	Water-logging	Control	Water-logging	Control	Water-logging				
CoLk 94184	900	1120	1010	276	97	175	136	52.41	64.24	58.33	38.14	30.15	34.15	9.03	7.06	8.05
Bo91	700	1250	975	312	91	176	134	52.00	64.30	58.15	34.06	22.20	28.13	6.05	5.03	5.54
CoS 767	840	970	905	273	123	163	143	54.14	59.87	57.01	34.23	29.31	31.77	6.10	4.12	5.11
CoJ 64	860	1010	935	286	117	178	148	48.30	69.60	58.95	36.16	24.10	30.13	8.04	6.10	7.07
CoLk 12204	740	1040	890	254	123	173	148	34.00	44.11	39.06	44.12	28.07	36.10	6.00	4.09	5.05
CoLk 07201	700	1000	850	273	127	215	171	36.22	54.23	45.23	34.08	28.11	31.10	8.12	6.08	7.10
LG 04439	820	970	895	286	98	185	142	50.46	68.09	59.28	40.15	22.23	31.19	6.67	5.15	5.91
LG 03040	840	970	905	246	98	152	125	55.90	69.80	62.85	32.26	22.34	27.30	6.52	4.20	5.36
A-46-11	880	1050	965	271	109	169	139	50.21	58.33	54.27	40.37	30.16	35.27	6.44	5.05	5.75
A-27-12	860	990	925	316	90	209	149	49.80	62.28	56.04	36.18	24.42	30.30	8.02	6.00	7.01
UP 9530	750	960	855	269	100	157	128	59.66	66.40	63.03	32.34	22.00	27.17	8.06	6.13	7.10
Mean	808	1030	-	278	107	177	-	49.37	61.93	-	36.55	25.74	-	7.19	5.36	-

C.D. at 5%
 Waterlogging (WL) = 38, Waterlogging (WL) = 10, Waterlogging (WL) = 6, Waterlogging (WL) = 1.46, Waterlogging (WL) = 0.40,
 Genotype (G) = 90, Genotype (G) = NS, Genotype (G) = 15, Genotype (G) = 5.50, Genotype (G) = 3.43, Genotype (G) = 0.93,
 WL x G = 127, WL x G = 34, WL x G = 21, WL x G = NS, WL x G = 4.85, WL x G = NS

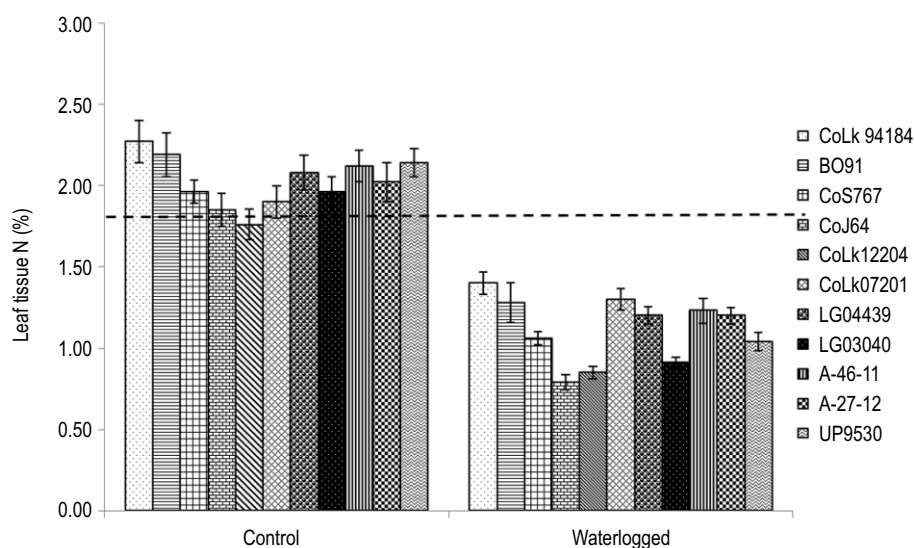


Fig. 1: Leaf tissue nitrogen concentration in sugarcane genotypes under control and waterlogged conditions (after 60 days of waterlogging imposed at 120 days crop age). Capped lines on bars represent standard error of means of three replicates. The horizontal dashed line indicate the critical deficiency level of N (1.80 %).

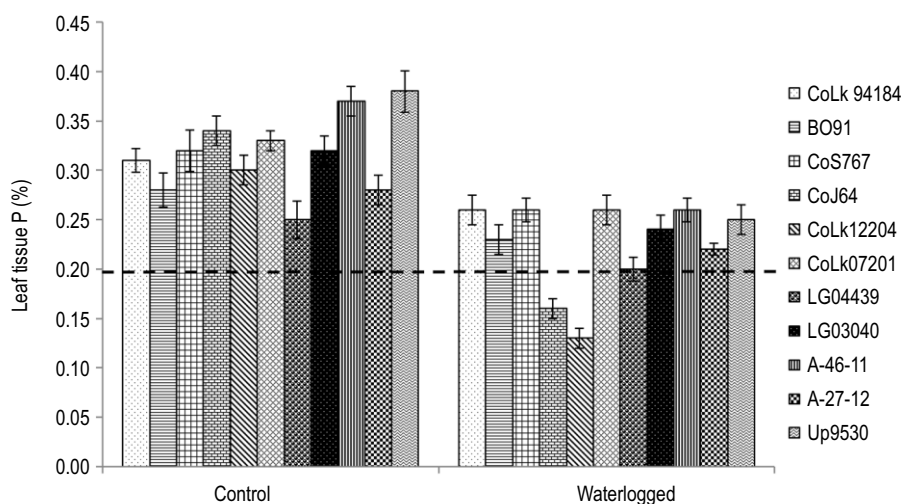


Fig. 2: Leaf tissue phosphorus concentration in sugarcane genotypes under control and waterlogged conditions (after 60 days of waterlogging imposed at 120 days crop age). Capped lines on bars represent standard error of means of three replicates. The horizontal dashed line indicate the critical deficiency level of P (0.19 %).

sugarcane genotypes during waterlogging. It is also suggested that retrieval of Na from anoxic stele to aerobic cortex might also be responsible for enhanced Na transport towards the shoot under waterlogging (Colmer and Greenway, 2011).

Waterlogging caused a significant increase in leaf Fe, Al and Mn concentration of sugarcane genotypes (Table 5). The mean leaf Fe, Al and Mn concentration in control and

waterlogging treatments was 184 ppm and 278 ppm, 107 ppm and 177 ppm, and 49.4 ppm and 61.9 ppm, respectively (Table 3). There was an average increase of 51% in Fe, 65% in Al and 25% in Mn content under waterlogged condition. As far as genotypic response was concerned, the highest increase in leaf Fe concentration was found in BO91 (95.5%), while LG03040 (31.5%) showed lowest increase. The highest increase in leaf Al content under waterlogging was observed in A-27-12 (131.7%)

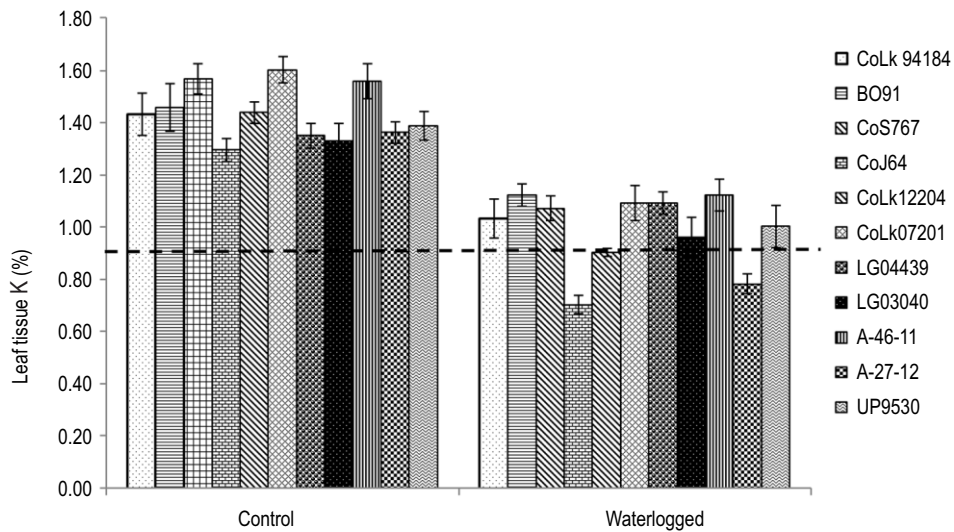


Fig. 3: Leaf tissue potassium concentration in sugarcane genotypes under control and waterlogged conditions (after 60 days of waterlogging imposed at 120 days crop age). Capped lines on bars represent standard error of means of three replicates. The horizontal dashed line indicate the critical deficiency level of potassium (0.90 %).

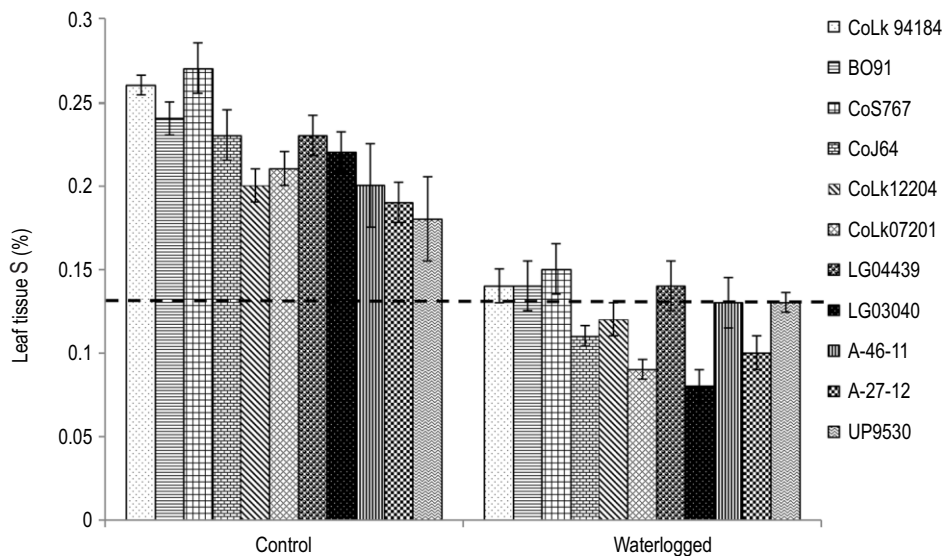


Fig. 4: Leaf tissue sulphur concentration in sugarcane genotypes under control and waterlogged conditions (after 60 days of waterlogging imposed at 120 days crop age). Capped lines on bars represent standard error of means of three replicates. The horizontal dashed line indicate critical deficiency level of sulphur (0.13 %).

and lowest in CoS 767 (32.7%). In case of Mn content, the highest and lowest increase were recorded in CoLk 07201(49.7%) and CoS 767 (10.6%), respectively. There was little or no correlation between leaf Fe, Al and Mn concentration with reduction in cane weight under waterlogging (Table 4). This indicates that increase in concentration of these elements under waterlogging do not

have any role in explaining the waterlogging induced reduction in cane weight. Waterlogging causes a series of chemical and microbial changes in soil leading to the reduction of iron, manganese and aluminium ions which increases the availability of these elements in soil (Yaduvanshi *et al.*, 2012; Ma *et al.*, 2003; Rangaswamy, 2004). This may be the reason for increased

concentration of these elements in the leaf of sugarcane genotypes in waterlogging treatment. Similar to above results, a high to toxic level increase in Fe, Al and Mn concentrations have been reported in wheat (Khabaz-Saberi *et al.*, 2006; Singh and Setter, 2017 and 2017a) and maize (Srivastava *et al.*, 2010) under waterlogged condition.

The leaf Zn and Cu concentration of sugarcane genotypes declined significantly under waterlogging (Table 5). The leaf Zn concentration in control ranged from 32.3 ppm to 44.1 ppm while in waterlogging from 22 ppm to 30.2 ppm (Table 3). There was a decrease of 14.4% (CoS 767) to 44.6% (LG 4439) in leaf Zn concentration under waterlogging relative to control, however the values for leaf Zn under waterlogging were in sufficiency range for all genotypes. The leaf Cu concentration of sugarcane genotypes dropped by 16.9% (BO 91) to 35.6% (LG 03040) under waterlogging. The mean leaf Cu concentration was 7.19 ppm in control and 5.37 ppm in waterlogging. The values for leaf Cu content under both control and waterlogging treatments were in normal range for all the genotypes. There was non significant correlation between leaf Cu and Zn concentration, and cane weight reduction under waterlogging (Table 4). The results of present experiment show that despite of significant reduction in concentration of leaf Zn and Cu under waterlogging, the values for both elements were not in deficient range so they were not a limiting factor for cane growth under waterlogging.

The low leaf Zn concentration observed in waterlogging may be partly ascribed to decreased availability of Zn due to its bonding to oxides and hydroxides of iron (Loneragan *et al.*, 1979) and to free organic oxides and bicarbonates (Forno *et al.*, 1975) in waterlogged soils. Low zinc uptake in waterlogged soils is also due to the co-precipitation of zinc with soluble iron and aluminium in the soil (Sadeghzadeh, 2013). Decreased Zn and Cu concentration due to waterlogging has been also reported in wheat (Khabaz-Saberi *et al.*, 2006; Tarekegne *et al.*, 2000). Huang *et al.* (1995) reported higher reduction in shoot Zn concentration of sensitive genotypes than tolerant genotypes of wheat under waterlogging. Similarly significant variations among sorghum genotypes were found for Cu and Zn concentrations in waterlogged soil. A reduction of more than 50% was found in Cu concentration of sorghum genotypes in response to waterlogging (Maranville *et al.*, 1986). The interaction between waterlogging x genotype was significant for leaf P, S, Na, Fe, Al and Zn (Table 1), which indicates that genotypes varied differentially for these nutrients under waterlogged conditions. However, a non-significant interaction between waterlogging x genotype was detected for leaf N, K, Mn and Cu.

The results of present experiment demonstrate that waterlogging significantly decreased the leaf N, P, K, S, Zn and Cu concentrations, and increased the leaf Fe, Al, Mn and Na concentrations of sugarcane genotypes. The extent of decrease in leaf N and S was more under waterlogging and values for these elements dropped below their reported critical deficiency levels. A significant inverse correlation was found between leaf K and S

concentrations, and reduction in cane weight under waterlogging suggesting that the genotypes with ability to maintain high leaf K and S concentrations under waterlogging have relatively less cane weight reduction. The increase in the leaf Fe, Al, Mn and Na concentration during waterlogging did not show any correlation with waterlogging induced reductions in cane weight. Thus, nutrient deficiencies rather than excess of elements were recognized as a major cause for reduction in cane weight of sugarcane under waterlogging.

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Add-on Information

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