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Yield and Osmoregulation of Sorghum Grown in Saline Soils

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An experiment was conducted to check the performance and osmoregulation of three commonly grown sorghum varieties (Hytech, Laxmi and Mahalaxmi) at different salinity levels in a factorial complete randomized design with three replications during *Rabi* 2015-2016 at Department of Soil Science and Agricultural Chemistry, Agricultural College, Bapatla. The proline and total sugar in leaves and calcium, magnesium, sodium and potassium in the diacid extract of plant samples were analysed following standard methods. Considerable reduction in yield was observed at the highest salinity tested. The per cent reduction in grain yield from lowest to highest salinity level was 60.92 while, the per cent reduction in stover yield from lower salinity level to higher salinity level was 51.07. The maximum grain (21.93 g pot^{-1}) and stover (48.23 g pot^{-1}) yield was observed in treatment combination 1.5 dS m^{-1} x Hytech variety. Proline and sugar content followed an increasing trend with salinity at all stages of plant growth. The cultivar Hytech recorded maximum proline content at all stages of plant growth while, it contained maximum sugars at flowering and intermediate values at other two stages. Significantly higher Ca^{2+}/Mg^{2+} and Na^{+}/K^{+}ratios at 30 DAS, flowering and maturitywere recorded at higher salinity level of 12 dS m^{-1} than at other salinity levels. The Ca^{+2}/Mg^{+2} ratio was high at flowering and maturity, while Na^{+}/K^{+} was intermediate in Hytech variety compared to others. The study indicated that the Hytech variety performed better at high salinity compared to Laxmi and Mahalxmi due to its high capacity to maintain higher proline and Ca^{+2}/Mg^{+2} ratio.

*(**Key words:** Ionic composition, Osmoregulation, Proline content, Sorghum, Total sugar content, Yield)*

In arid and semi-arid regions, the annual rainfall is not sufficient to leach down salts to deeper layers and further high evaporation in these areas result in accumulation of salts making the soils saline. Soil salinity is one of the most serious factors limiting the productivity of agricultural crops with adverse effects on germination, plant vigour and crop yield. The inhibitory effects of salinity on plant growth include ion toxicity, osmotic influence and nutritional imbalance leading to reduction in photosynthetic efficiency and yield.

However, there are many defence mechanisms such as osmoregulation, ion homeostasis, antioxidant and hormonal systems in plants, which impart tolerance to water-deficit and salt stresses (Mahajan and Tuteja, 2005), helping plants to survive and grow under severe environmental conditions prior to their reproductive stages. In contrast, the defence mechanisms in sensitive plant species are weaker, leading to growth retardation and yield reduction. Plant salt tolerance has been generally studied in relation to regulatory mechanisms of ionic and osmotic homeostasis (Ashraf and Harris, 2004). Among them osmoregulation is one of the mechanisms of plant tolerance to salinity that allows plants to accumulate various organic (proline and sugars) and inorganic solutes (K^{+}, Na^{+}, Cl^{-}), which have been reported to contribute to such osmotic adjustment (Lacerda *et al*., 2001). Keeping this in view, the present study was conducted to check the performance and osmoregulation of three commonly grown sorghum cultivars at different salinity levels.

MATERIAL AND METHODS

The experiment was conducted in the green house facility of Department of Soil Science and Agricultural Chemistry, Agricultural College, Bapatla, by growing three sorghum cultivars (Hytech, Laxmi and Mahalaxmi) in soils of similar characteristics but variable salinity (EC_e of 1.5, 5, 8 and 12 dS m^{-1}) collected from Uppugunduru region in a completely randomized design with factorial concept replicating thrice. Grain yield and stover yield (g pot^{-1}) were recorded at harvest stage. Proline content, sugar concentration in leaves and calcium and magnesium in the diacid extract of whole plant part were analysed at 30 DAS, flowering and at maturity. The proline content was estimated by following the method of Bates *et al.* (1973). Sugar concentration in leaves of the plant samples was estimated by using anthrone method described by Hedge and Hofreiter (1962). Calcium and magnesium in the diacid extract of plant samples were estimated by Versenate method while, sodium and potassium in the diacid extract of plant

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samples were measured with a flame photometer (Tandon, 1999).

RESULTS AND DISCUSSION

Grain and stover yield

The data pertaining to grain and stover yield (g pot^{-1}) was found to be significantly influenced by salinity levels, sorghum cultivars and also by their interaction (Table 1). The maximum grain and stover yield of 20.93 and 46.62 g pot^{-1} respectively was recorded with the salinity level of 1.5 dS m^{-1} (S_1), which was significantly superior to the remaining salinity levels. The per cent reduction in grain and stover yield from lowest to highest salinity level was 60.92 and 51.07, respectively. The lowest grain and stover yield of 8.18 and 22.81 g pot^{-1} was observed at the highest salinity level of 12 dS m^{-1} (S_4). The grain yield of sorghum cultivars (Hytech, Laxmi and Mahalaxmi) followed the inverse linear relation with the salinity of soil (Fig. 1). The grain yield levels of 90, 75 and 50 per cent were observed at the salinity (EC_e) of 2.7, 5.4 and 9.8 dS m^{-1}, respectively

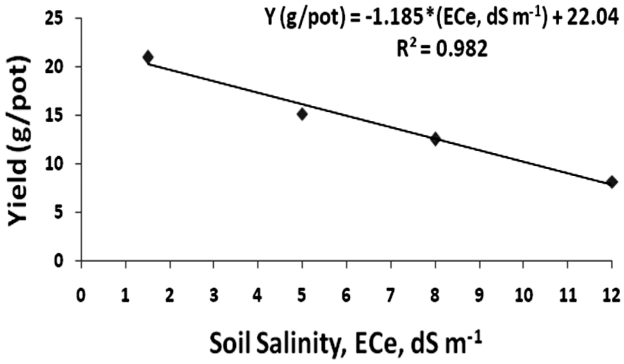

Fig. 1. Sorghum yield (g pot^{-1}) at different salinity (ECe, dS m^{-1}) levels

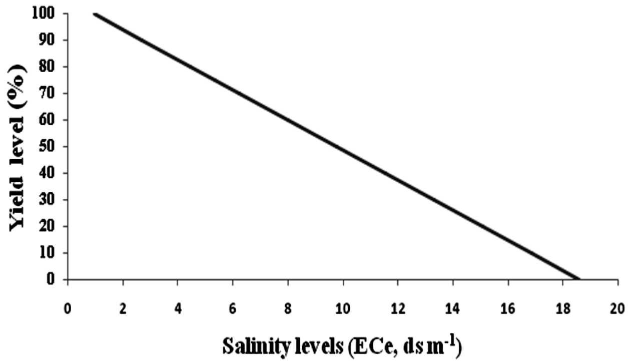

Fig. 2. Sorghum yield level (%) at different salinity (ECe, dS m^{-1}) levels

(Fig. 2). Among the three sorghum cultivars, Hytech (V_1) produced the highest grain and stover yield of 14.76 and 36.05 g pot^{-1} followed by Laxmi (13.98 g pot^{-1}and 34.47 g pot^{-1}) whereas, the lowest grain and stover yield of 13.82 and 34.05 g pot^{-1} was recorded by Mahalaxmi (V_3). The interaction between salinity and varieties (S X V) indicated that, the maximum grain and stover yield of 21.93 and 48.23 g pot^{-1} was attained in the combination S_1V_1 (1.5 dS m^{-1} x Hytech), which was significant over remaining treatment combinations. The minimum grain and stover yield of 7.95 and 22.45 g pot^{-1} was obtained in the combination S_4V_2 (12 dS m^{-1} x Laxmi).

The reduction in yield at high salinity could be due to presence of excess soluble salts in the root zone, which negatively affects plant growth and yield through osmotic effects, nutritional imbalances and specific ion toxicities (Tahir *et al.*, 2006). Pollen viability, a very important trait, governing the ultimate grain yield was found to be greatly influenced by the ionic toxicity under salinity (Mohammadinejada *et al.,* 2010).

Table 1. *Grain and stover yield of sorghum cultivars as influenced by soil salinity*

Salinity levels (dS m^{-1})	Grain yield (g pot^{-1})				Stover yield (g pot^{-1})			
	Sorghum cultivars				Sorghum cultivars			
	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean
S_1 (1.5)	21.93	20.79	20.08	20.93	48.23	46.66	44.96	46.62
S_2 (5)	16.03	14.68	14.75	15.15	39.05	36.08	35.58	36.90
S_3 (8)	12.52	12.51	12.43	12.49	33.61	32.70	32.97	33.09
S_4(12)	8.55	7.95	8.03	8.18	23.30	22.45	22.68	22.81
Mean	14.76	13.98	13.82		36.05	34.47	34.05	
	SEm±	CD (0.05)	CV%		SEm±	CD (0.05)	CV%	
Factor S	0.15	0.43			0.18	0.53		
Factor V	0.13	0.37	3.13		0.16	0.46	1.56	
S X V	0.26	0.75			0.31	0.92		

Osmoregulation

Proline content

Data pertaining to proline content estimated at different growth stages of crop as affected by salinity levels and expressed in μg g^{-1} on fresh weight basis as presented in Table 2 indicated that the proline content was significantly influenced by different salinity levels in all sorghum cultivars and their interaction was also significant. The highest proline content (54.67, 353.34 and 209.38 μg g^{-1}) was recorded at higher salinity level of 12 dS m^{-1} (S_4) whereas, the lowest proline (14.75, 99.82 and 69.75 μg g^{-1}) was recorded at the lowest salinity level of 1.5 dS m^{-1} (S_1) at 30 DAS, flowering and maturity, respectively. Accumulation of proline was to the extent of 73.02, 71.75 and 66.69 per cent at 30 DAS, flowering and maturity, respectively at the highest salinity level of 12 dS m^{-1} (S_4) compared to the lowest salinity of 1.5 dS m^{-1} (S_1). At 30 DAS the highest proline content of 35.02 μg g^{-1} was observed in cultivar Hytech (V_1) whereas, the lowest proline content of 25.00 μg g^{-1} was observed in cultivar Mahalaxmi (V_3). Similar trend was observed at flowering and maturity stages also.

The interaction between two factors (salinity levels x cultivar) at all stages, indicated that the highest proline content was recorded by the treatment combination S_4V_1 whereas, the lowest proline content was recorded by the treatment combination S_1V_3. The maximum proline content was observed at flowering compared to other two stages. Critical observation of the data indicated that the plants accumulated more proline at higher salinity levels. Hytech cultivar recorded maximum proline content at all stages of plant growth, which might be a reason for its better performance in terms of yield. This is an osmoregulation mechanism in plants as proline is considered to regulate potential balance of cytoplasmic and vacuolar infiltration in cells under salt stress. Under salt and drought stress conditions, large accumulation of intracellular soluble sugar and proline improves the cell sap concentration, maintains normal cell turgor, prevents excessive water loss and enhances the resistance of plants (Shi *et al.,* 2007).

Total sugars

The content of total sugars estimated at different crop growth stages *viz.,* at 30 DAS, flowering and maturity as affected by salinity levels in sorghum cultivars expressed in mg g^{-1} on dry weight basis are presented in Table 3. The total sugars content was significantly affected by different salinity levels in all sorghum cultivars and their interaction was also significant. The total sugars increased with increasing salt concentration. The highest total sugar content of 11.27, 30.16 and 25.33 mg g^{-1} was recorded at higher salinity level of 12 dS m^{-1} (S_4) whereas, the lowest total sugar content of 4.49, 20.85 and 19.97 mg g^{-1} was recorded at lower salinity level of 1.5 dS m^{-1} (S_1) at 30 DAS, flowering and maturity, respectively. The increase in sugar content to a tune of 60.16, 30.87 and 21.16 per cent was observed at 30 DAS, flowering and maturity, respectively in high salinity treatment (12 dS m^{-1}) compared to the lowest salinity of 1.5 dS m^{-1}. This might be due to increase in solute potential under salt stress

Table 2. *Proline content (μg g^{-1}) of sorghum cultivars as influenced by soil salinity at different growth stages*

Salinity levels (dS m^{-1})	Proline (μg g^{-1}) at 30 DAS				Proline (μg g^{-1}) at flowering stage				Proline (μg g^{-1}) at maturity stage			
	Sorghum cultivars				Sorghum cultivars				Sorghum cultivars			
	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean
S_1 (1.5)	15.06	14.73	14.47	14.75	101.56	98.98	98.93	99.82	80.58	72.02	56.64	69.75
S_2 (5)	20.73	20.56	19.74	20.34	122.10	121.16	112.98	118.74	112.18	100.75	96.62	103.18
S_3 (8)	32.56	26.08	24.89	27.84	268.57	245.65	210.96	241.73	161.40	124.63	120.89	135.64
S_4 (12)	71.72	51.39	40.89	54.67	372.96	348.15	338.93	353.34	226.02	217.25	184.88	209.38
Mean	35.02	28.19	25.00		216.30	203.48	190.45		145.04	128.67	114.76	
	SEm±	CD (0.05)	CV%		SEm±	CD (0.05)	CV%		SEm±	CD (0.05)	CV%	
Factor S	0.31	0.90			2.18	6.35			1.57	4.57		
Factor V	0.27	0.78	3.15		1.88	5.50	3.21		1.36	3.96	3.63	
S X V	0.53	1.56			3.77	11.00			2.71	7.92		

***Table 3.** Total sugars (mg g^{-1}) content of sorghum cultivars as influenced by soil salinity at different growth stages*

Salinity levels (dS m^{-1})	Total sugars (mg g^{-1}) at 30 DAS				Total sugars (mg g^{-1}) at flowering stage				Total sugars (mg g^{-1}) at maturity stage			
	Sorghum cultivars				Sorghum cultivars				Sorghum cultivars			
	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean
S_1(1.5)	4.74	4.26	4.46	4.49	20.49	20.70	21.35	20.85	18.92	20.01	20.98	19.97
S_2(5)	4.90	4.48	4.87	4.75	24.58	23.42	23.38	23.79	22.69	22.43	23.31	22.81
S_3(8)	9.43	9.49	9.62	9.51	25.81	23.76	25.33	24.97	24.35	23.46	24.50	24.10
S_4(12)	11.04	11.41	11.36	11.27	33.08	29.26	28.14	30.16	25.20	25.21	25.58	25.33
Mean	7.53	7.41	7.58		25.99	24.28	24.55		22.79	22.78	23.59	
	SEm±	CD (0.05)	CV%		SEm±	CD (0.05)	CV%		SEm±	CD (0.05)	CV%	
Factor S	0.05	0.14			0.27	0.79			0.18	0.51		
Factor V	0.04	0.12	1.91		0.23	0.68	3.24		0.15	0.44	2.29	
S X V	0.08	0.24			0.47	1.36			0.30	0.89		

conditions. Similar increase in total sugars with increase in salt stress was reported by Gill *et al.* (2003) in sorghum.

Among different cultivars tested, at 30 DAS and at maturity, the highest total sugar content of 7.58 and 23.59 mg g^{-1}, respectively was observed in cultivar Mahalaxmi (V_3), which was on par with Hytech at 30 DAS and superior to other two cultivars at maturity. However at flowering, the highest total sugar content of 25.99 (mg g^{-1}) was observed in cultivar Hytech (V_1), which was statistically superior to the other two varieties. The lowest total sugar content of 7.41, 24.28 and 22.78 (mg g^{-1}) was recorded in cultivar Laxmi (V_2) at all growth stages.

At 30 DAS, the highest total sugar was recorded by the treatment combination S_4V_2 while, the lowest by the treatment combination S_1V_2. At flowering and maturity, the treatment combination S_4V_1 and S_4V_3 recorded the highest total sugar content whereas, the lowest was recorded by the treatment combination S_1V_1 and S_1V_2, respectively. Critical observation of data indicated that though the Hytech variety recorded maximum proline content at all stages, it was not the same related to sugars because only at flowering it recorded the highest sugar. However it was in second place after Mahalaxmi at 30 DAS and maturity. More accumulation of sugar, a compatible solute, lowers the osmotic potential in the cytoplasm and thus increasing the ability of the cytoplasm to retain water under reduced water supply in tolerant genotypes under saline stress conditions (Abede *et al*., 2003). However in the present study though sugars were more the water content is less in Mahalaxmi compared to Hytech which has more proline accumulation.

Ca^{2+}/Mg^{2+} ratio

The Ca^{2+}/Mg^{2+} ratio was significantly affected by different salinity levels in all sorghum cultivars and their interaction was also significant (Table 4). The maximum Ca^{2+}/Mg^{2+} ratios of 1.718, 2.528 and 2.161 were recorded at higher salinity level of 12 dS m^{-1} (S_4), which were significantly higher than at other salinity levels at all growth stages. Whereas, the minimum Ca^{2+}/Mg^{2+} ratios of 1.193, 1.411 and 1.288 were recorded at lower salinity level of 1.5 dS m^{-1} (S_1), the ratio was increased by 30.56, 44.19 and 40.40 per cent at 30 DAS, flowering and harvest, respectively at the highest salinity tested over the lowest salinity of 1.5 dS m^{-1} (S_1).

Among the three cultivars, Laxmi recorded maximum ratio at 30 DAS whereas, at flowering and maturity the highest ratio was observed in Hytech (V_1). The lowest Ca^{2+}/Mg^{2+} ratio was observed in cultivar Mahalaxmi (V_3) at all stages. Among different interactions, the treatment combination of S_4V_2 recorded the highest Ca^{2+}/Mg^{2+} ratio. At flowering and maturity S_4V_1 recorded the highest Ca^{2+}/Mg^{2+} ratio. Detailed observation of data indicated that there was a positive relationship between Ca^{2+}/Mg^{2+} ratio and salinity levels. Sorghum varieties under study recorded varying ratios at different salinity levels. The Ca^{2+}/Mg^{2+} ratio was found to be maximum at flowering compared to other stages.

Table 4. *Ratio of Ca^{+2}/Mg^{+2} in sorghum cultivars as influenced by soil salinity at different growth stages*

Salinity levels (dS m^{-1})	Ca^{+2}/Mg^{+2} ratio at 30 DAS				Ca^{+2}/Mg^{+2} ratio at flowering stage				Ca^{+2}/Mg^{+2} ratio at maturity stage			
	Sorghum cultivars				Sorghum cultivars				Sorghum cultivars			
	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean
S_1(1.5)	1.164	1.269	1.144	1.193	1.453	1.351	1.430	1.411	1.297	1.281	1.285	1.288
S_2(5)	1.374	1.319	1.299	1.331	1.645	1.603	1.486	1.578	1.436	1.402	1.370	1.403
S_3(8)	1.589	1.559	1.522	1.557	1.764	1.757	1.734	1.752	1.662	1.570	1.536	1.590
S_4(12)	1.687	1.737	1.730	1.718	2.603	2.527	2.453	2.528	2.303	2.170	2.011	2.161
Mean	1.453	1.471	1.424		1.866	1.809	1.776		1.675	1.606	1.551	
	SEm±	CD (0.05)	CV%		SEm±	CD (0.05)	CV%		SEm±	CD (0.05)	CV%	
Factor S	0.014	0.041			0.015	0.044			0.014	0.040		
Factor V	0.012	0.035	2.88		0.013	0.038	2.51		0.012	0.035	2.57	
S X V	0.024	0.070			0.026	0.077			0.024	0.070		

Table 5. *Ratio of Na^+/K^+ in sorghum cultivars as influenced by soil salinity at different growth stages*

Salinity levels (dS m^{-1})	Na^+/K^+ ratio at 30 DAS				Na^+/K^+ ratio at flowering stage				Na^+/K^+ ratio at maturity stage			
	Sorghum cultivars				Sorghum cultivars				Sorghum cultivars			
	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean	V_1 (Hytech)	V_2 (Laxmi)	V_3 (Mahalaxmi)	Mean
S_1(1.5)	0.454	0.498	0.497	0.483	0.421	0.397	0.405	0.408	0.650	0.661	0.629	0.647
S_2(5)	0.558	0.568	0.503	0.543	0.420	0.425	0.439	0.428	0.756	0.728	0.741	0.741
S_3(8)	0.603	0.604	0.541	0.583	0.463	0.401	0.457	0.440	0.733	0.755	0.768	0.752
S_4(12)	0.653	0.640	0.623	0.638	0.428	0.436	0.495	0.453	0.695	0.894	0.922	0.837
Mean	0.567	0.578	0.541		0.433	0.415	0.449		0.709	0.759	0.765	
	SEm±	CD (0.05)	CV%		SEm±	CD (0.05)	CV%		SEm±	CD (0.05)	CV%	
Factor S	0.009	0.026			0.006	0.018			0.010	0.029		
Factor V	0.008	0.022	4.74		0.005	0.016	4.29		0.009	0.025	4.01	
S X V	0.015	0.045			0.011	0.031			0.017	0.050		

Calcium is important during salt stress, e.g. in preserving membrane integrity (Rengel, 1992), signalling in osmoregulation (Mansfield *et al.*, 1990) and influencing K/Na selectivity (Cramer *et al.*, 1987). Due to this reason more Ca might have been transferred to leaves. Calcium is strongly competitive with Mg^{2+} and the binding sites on the root plasma membrane appear to have less affinity for the highly hydrated Mg^{2+} than for Ca^{2+} (Marschner, 1995). Thus, high concentrations of substrate Ca^{2+} often result in increased leaf-Ca along with a marked reduction in leaf-Mg. High Ca^{2+}/Mg^{2+} indicates the better regulation of cells than lower rates.

Na^+/K^+ ratio

The data presented in Table 5, indicated that Na^+/K^+ ratio was significantly affected by different salinity levels in all sorghum cultivars and their interaction was also significant. The maximum Na^+/K^+ ratio was recorded at higher salinity level of 15 dS m^{-1} (S_4) whereas, the minimum Na^+/K^+ ratio was recorded at lower salinity level of 1.5 dS m^{-1} (S_1) at all stages. The per cent increase in ratio (S_1 to S_4) was 24.29, 9.93 and 22.70 at 30 DAS, flowering and maturity, respectively. This increase in Na^+/K^+ ratio with increase in salinity suggests that, Na was transported in greater proportion than K in to the plant parts. Finally the above results suggest that, there were no effective mechanisms to control net uptake of Na on root plasma membrane and subsequently its transport to leaf tissue with respect to increase in salinity. Similar findings of increase in Na^+/K^+ ratio with increasing salinity was reported by Mamta *et al.* (2008).

The highest yield producing Hytech cultivar occupied second position in Na^+/K^+ ratio at 30 DAS and flowering while it recorded the lowest ratio at maturity. At 30 DAS, the highest Na^+/K^+ ratio of 0.653 was recorded by the treatment combination S_4V_1 whereas, the lowest Na^+/K^+ ratio of 0.454 was recorded by the treatment combination S_1V_1. At flowering stage the highest Na^+/K^+ ratio of 0.495 was recorded by the treatment combination S_4V_3 whereas, the lowest Na^+/K^+ ratio of 0.397 was recorded by the treatment combination S_1V_2. At maturity the ratio was highest in treatment combination S_4V_3 and lowest in S_1V_3. It is generally accepted that increased K^+/Na^+ selectivity and reduced Na^+ translocation from the root to the leaves contribute to the overall salt tolerance in plants (Tester and Davenport, 2003) but the above data have shown that K^+ uptake and transport to the aerial part of the plant leaves were significantly reduced with increased salinity in all cultivars. This implies a competition between Na^+ and K^+ absorption in plant, resulting in a Na^+/K^+ antagonism. The reduction in K^+ uptake caused by Na^+ is likely to be the result of the competitive intracellular influx of both ions (Cerda *et al*., 1995).

The present study indicated considerable reduction in yield of all the three sorghum cultivars with increase in soil salinity. Further, the Hytech cultivar performed better than Laxmi and Mahalaxmi due to high proline, total sugars and Ca^{2+}/Mg^{2+} ratio.

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