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Influence of Sodium Chloride on Ion Accumulation and Fibre quality in Cotton (*Gossypium hirsutum* L.)

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Abstract: Three salt tolerant cultivars/lines (B-557, Culture-728-4 and MNH-156) and three salt sensitive cultivars/lines (B-1580 (ne), Culture-604-4 and MNH-147) were grown in salinized soil under greenhouse conditions. Four treatments of NaCl, i.e., 16 (control), 70, 140, 210 mol m^{-3} were applied after 10 days of initial growth, and experiment continued till maturity. Determination of ions at seedling stage showed that the salt tolerant and the salt sensitive cultivars did not differ significantly in accumulation of leaf. The salt sensitive cultivars had more concentration of Cl^- in leaves than those of the salt tolerant lines at the highest salt level. The salt tolerant cultivars had generally higher concentrations of K^+, Ca^{2+} and K/Na ratios in the leaves than those of salt sensitive lines at the highest NaCl concentration (210 mol m^{-3}). Ginning out-turn and fibre fineness increased with the increasing concentrations of salt, whereas staple length, fibre maturity and fibre strength showed decreasing trend at higher salt concentrations (140 and 210 mol m^{-3}). The salt tolerant cultivars/lines had lower ginning out-turn, but better fibre fineness, higher staple length, fibre maturity and fibre strength compared with those of the salt sensitive cultivars. The salt tolerance in cotton is thus associated with higher uptake of K^+, Ca^{2+}, low accumulation of Cl^- in the leaves, and low ginning out-turn but higher staple length, fibre maturity and fibre strength.

Key words: Cotton, ions, fibre quality, salinity

Introduction

It is now well evident that most plant species can tolerate high regimes of salinity either by partial salt exclusion or salt inclusion (Greenway and Munns, 1980; Schachtman and Munns, 1992 and Glenn ***et al.***, 1996). The mechanism of ion uptake and pattern of accumulation of ions in different parts of plant is very important for making distinction between salt tolerant and salt sensitive genotypes. For instance, higher accumulation of Na^+ in leaves of salt tolerant varieties of cotton has also been reported by different researchers (Leidi and Saiz, 1997 and Chen ***et al.***, 1996). The other studies conducted on the relative salt tolerance of crops, cotton, maize, soybean and wheat showed that salt tolerance was associated with high Na^+ accumulation (Chen and Zhao., 1996). In contrast, in another study with the same crop, no clear correlation between salt tolerance and Na^+ accumulation was observed (Jafri and Ahmad, 1994). In general, there is

positive correlation between ion exclusion and salt tolerance (Ashraf and O'Leary, 1996; Ashraf and Sharif, 1997 and Khan ***et al.***, 1998). In contrast, negative correlation between ion exclusion and salt tolerance has also been reported by Ashraf and Waheed (1993) and Gulati and Jaiwal (1993).

Low concentration of leaf Cl^- was found in the most salt tolerant variety of cotton, NIAB-78, followed by MNH-93 (Qadir and Shams, 1997). Abdullah and Ahmad (1986) calculated high K^+/Na^+ ratio and low Cl^- in cotton seeds of salt tolerant varieties subjected to salinity which showed low retranslocation of Na^+ and Cl^- in phloem. Total K^+ content and Ca^{2+} concentrations decreased with an increase in salinity level in the rooting medium.

Thus one of the primary objective to undertake this study was to determine whether lines differing in salt tolerance use ion exclusion or ion inclusion to tolerate high levels of salt.

In view of different studies relating to assessing the effect of salinity on fibre characteristics of cotton, high salinity medium had been reported to adversely affect fibre length and fibre maturity (Longenecker, 1973, 1974; Abdullah and Ahmad, 1986 and Razzouk and Whittington, 1991); but increasing effect on fibre fineness and lint percentage or ginning out turn (Razzouk and Whittington, 1991) and Ye ***et al.*** (1997) found that soil salinity had an increasing effect on fibre length and fibre fineness. Reduction in fibre length with an increase in salinity has also been reported by Banks ***et al.*** (1997). These contrasting reports were the basis of our second objective of the present study to elucidate the effect of salinity on some cotton lines differing in degree of salt tolerance and whether these characteristics could be useful in discriminating between these lines.

Materials and Methods

The seeds of B-557, MNH-147 and MNH-156 (Pakistan) and those of Culture 604-4 and Culture 728-4 (Puerto Rico) and B-1580 (ne) (USA) were obtained from Central Cotton Research Institute, Multan, Pakistan. In a previous study, eighty cultivars/lines of cotton were screened at three growth stages, i.e., germination, seedling and adult (Ahmad ***et al.***, 2002). The six cultivars/lines (three salt tolerant, B-557, Culture 728-4 and MNH-156, and three salt sensitive, B-1580 (ne), Culture 604-4 and MNH-147) used in this study were among those which maintained their degree of salt tolerance at all growth stages. The seed samples of all the six cultivars/lines were surface sterilized with 5% sodium hypochlorite solution for 5 minutes.

Mosaic-cemented pots of 30 cm diameter were filled with 15 kg of soil (ECe=1.6 dS m^{-1}, saturation percentage=30.65). They were arranged in randomized complete block design with four replications. Twenty seeds of each line were sown in each pot. Before sowing, the pots were irrigated with tap water. Sowing was done in proper moisture condition of soil. The experiment was conducted in a naturally-lit greenhouse during the summer 1998 at a mean day temperature of 40±4.0°C and night temperature of 28±4°C, and day length from 12-14 h. The relative humidity ranged from 28.5-46.6%. When the seedlings emerged, all the pots were treated once with Hoagland's nutrient solution. Thinning of plants was done after 13 days to keep 6 plants in each pot.

Salt treatment was started two weeks after sowing. The appropriate salt solutions were

applied considering the saturation percentage of the soil. There were four treatments, i.e., control (ECe = 1.6 dS m^{-1}) 70, 140 or 210 mol m^{-3} prepared in full strength Hoagland s nutrient solution. The salt levels of soil in the pots of different treatments were checked fortnightly and the deficiency in the salt level was overcome by the addition of appropriate amount of NaCl, but during the week all the pots were kept at field capacity. All the agronomic practices (hoeing etc.) were kept same for all the treatments.

Four plants, from each pot, were harvested six weeks after the start of salt experiment, just before the initiation of flowering. The plants were removed carefully from the pots and separated into shoots and roots. The shoots and roots were washed with distilled water. Fresh weights of shoots and roots of all the six lines were recorded. The experiment continued till maturity. This experiment was repeated once to confirm the results. The parameters determined are given as under:

Biochemical/physiological

Na^+, K^+, Ca^{2+}

100 mg well ground leaf or root samples were digested in 4 ml of sulphuric-peroxide mixture following Allen ***et al.*** (1986). After digestion the volume of each sample was made up to 100 ml. Na^+, K^+ and Ca^{2+} were determined with flame photometer (Jenway, PFP-7).

Cl^-

50 mg of leaf and root samples were ground and heated in distilled deionized water for three hours at 80°C. The Cl^- contents of the extracts were then determined with a chloride analyzer (Corning, 925).

Fibre Quality Characteristics

Following quality characters were determined after picking of seed cotton at maturity.

Ginning out-turn

It is defined as lint percentage. Seed cotton samples from each plant were taken, weighed, ginned with a roller machine and ginning out-turn calculated.

Staple length

The length of staple of any cotton is the normal length by measurement, without considering the quality or value of a typical portion of its fibres under a relative humidity of atmosphere 65% and temperature 70°F. Tuft method was used to determine staple length of the material under study.

Fibre maturity

It was determined by the Shirley Maturity Tester.

Fibre fineness

Micronaire apparatus was used for testing fibre fineness.

Fibre strength

The Pressley Strength Tester was used for testing strength of the fibre for material under study.

Results and Discussion

Leaf Na^+ concentrations (Table 2) increased significantly with an increase in external salt concentration in all cultivars/lines, but the cultivars/lines, showing genotypic differences for leaf Na+ accumulation (Table 1), did not differ significantly at the two higher salt regimes, 70 and 210 mol m^{-3} (Table 2). However, at 70 mol m^{-3} NaCl, the salt tolerant MNH-156 accumulated significantly greater Na+ (12.27 g kg^{-1} d.wt., Table 2) in leaves followed by the salt sensitive B-1580 (11.01 g kg^{-1} d.wt., Table 2) than that of the other lines. This pattern of Na accumulation in leaves can be related to the earlier findings of Lessani and Marschner (1978) who found no difference between salt tolerant and salt sensitive lines of cotton, maize, ***Phaseolus vulgaris*** and sunflower in accumulation of shoot Na^+.

The lines also differed significantly in root Na^+ (Table 1). The salt tolerant line Culture-728-4 was the highest in accumulation of Na+ (11.38, 13.38 and 17.19 g kg^{-1} d.wt.) in the roots at all salt concentrations (Table 2) of the rooting medium.

All the three salt tolerant lines had generally lower leaf Cl^- than the salt sensitive lines at all external NaCl regimes (Table 3). The salt tolerant cultivar B-557 had the lowest leaf Cl^- accumulation (38.95 and 44.9 g kg^{-1} d.wt.) at 70 and 140 mol m^{-3} NaCl followed by another salt tolerant line MNH-156 (39.55 and 50.78 g kg^{-1} d.wt.). However at the highest level of salinity (210 mol m^{-3} NaCl), Culture-728-4 with leaf Cl^- concentration of 62.50 g kg^{-1} d.wt., was the second lowest to MNH-156 (57.77 g kg^{-1} d.wt.). This is in conformity with the previous findings of Qadir and Shams, (1997) who also observed lower concentration of leaf Cl^- in the salt tolerant varieties of cotton.

The difference between salt tolerant and salt sensitive lines in root Cl^- was not consistent (Table 3). However, B-557 and B-1580 and MNH-147 were the highest in root Cl^-concentration (41.88, 41.41 and 40.12 g kg^{-1} d.wt. respectively) of all the cultivars/lines at the highest external salt concentration (210 mol m^{-3}). But at 140 mol m^{-3} NaCl, MNH-147, B-557 and B-1580 (ne) accumulated higher root Cl^- with values of 33.19, 32.74 and 32.39 g kg^{-1} respectively (Table 3).

Leaf K^+ (Table 4) was significantly higher in the leaves of the salt tolerant lines than that of the salt sensitive lines at the highest salt regime of 210 mol m^{-3} NaCl (Table 4). But at external salinity level of 70 mol m^{-3}, the difference between the salt tolerant and the salt sensitive lines was not consistent (Table 4). Nevertheless, Culture-604-4 was the lowest in leaf K^+ (14.01, 8.53 and 7.30 g kg^{-1}) of all the lines at all external salt regimes (Table 4). Root K^+, 13.21, 11.03 and 10.42 g kg^{-1}, was highest in the salt tolerant B-557 followed by the salt sensitive B-1580 having 11.52, 9.98 and 9.52 g kg^{-1} root K^+, of all the lines at all external NaCl levels.

Leaf Ca^{2+} concentrations (Table 5) in all the three salt tolerant cultivars/lines was significantly higher than in the salt sensitive lines at varying external salt concentrations

Table 1: Analyses of variance (mean squares) of data for Na^+, Cl^-, K^+, Ca^{2+}, K/Na and Ca/Na of leaves and roots of six cultivars/ lines of cotton (3 tolerant and 3 sensitive) after 45 days growth at 0, 70, 140 or 210 mol NaCl m^{-3}

		Na^+		Cl^-		K^+		Ca^{2+}		K/Na		Ca/Na	
S.O.V.	df	Leaf	Root	Leaf	Root	Leaf	Root	Leaf	Root	Leaf	Root	Leaf	Root
Rep	3	2.04^{ns}	0.51^{ns}	89.1^{ns}	10.2^{ns}	31.9^{ns}	2.99*	38.0^{ns}	6.42*	0.38^{ns}	0.02^{ns}	0.19^{ns}	0.032^{ns}
T	3	344.6**	364.3***	11407.00***	2902.00***	1271.00***	87.3***	897.6***	194.3***	73.4***	6.73****	108.7***	0.11^{ns}
L	5	3.79^{ns}	12.8***	1000.00***	226.00***	511.00***	79.6***	2315.0***	94.9***	7.07***	1.15***	38.98***	1.26***
T×L	15	6.69*	3.0***	323.8***	39.4^{ns}	41.8***	3.01***	376.8***	17.6***	3.0***	0.103***	8.90***	0.98***
Error	69	3.66	0.92	49.65	26.5	13.2	0.84	20.6	1.99	0.29	0.02	0.58	0.21

*,**,*** = Significant at 0.05, 0.01 and 0.001 levels, respectively, ns= Non-significant, T= treatment, L= lines, Rep= Replications

Table 2: Na^+ concentrations (g kg^{-1} d. wt.±SE) of leaves and roots of six cultivars/lines of cotton (*Gossypium hirsutum*) when grown in soil salinized with 0 (control, ECe=1.6 dS m^{-1}), 70, 140 or 210 mol NaCl m^{-3}. (n=4)

	NaCl concentrations (mol m^{-3})							
Cultivars/lines	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210
Leaf Na^+					Root Na^+			
B-557	6.78±0.088aby	9.38±0.25bx	12.1±0.39aw	14.60±0.204aw	6.21±0.066bz	7.87±0.25by	11.27±0.30bx	14.08±0.12bcw
Culture 728-4	6.44±0.191by	8.58±0.255by	12.99±0.303ax	16.10±0.22aw	7.76±0.322abz	11.38±0.15ay	13.38±0.1ax	17.19±0.21aw
MNH-156	4.94±0.112by	12.27±0.02ax	12.96±0.75awx	15.63±0.99aw	8.74±0.085ay	10.81±0.1ax	13.38±0.08aw	13.34±0.10cw
B-1580 (ne)	5.86±0.055by	11.01±0.08abx	12.74±0.15ax	16.85±0.21aw	6.78±0.06bcz	9.08±0.21by	12.35±0.19abx	14.78±0.14bw
Culture 604-4	6.67±0.07abx	7.69±0.13bx	12.86±0.21aw	14.3±0.86aw	6.96±0.25bz	8.16±0.06by	12.30±0.19abx	15.0±0.06bw
MNH-147	9.17±1.10ay	9.73±0.43abxy	11.45±0.256ax	15.0±0.40aw	7.62±0.37aby	8.05±0.30by	12.66±0.23ax	14.20±0.11bcw
	LSD 5% (T×L)=2.71				LSD 5% (T×L)=1.36			

Means with the same letters in each column (a-c) and each row (x-z) do not differ significantly at 0.05

Table 3: Cl^- concentrations (g kg^{-1} d. wt.±SE) of leaves and roots of six cultivars/lines of cotton (***Gossypium hirsutum***) when grown in soil salinized with 0 (control, ECe=1.6 dS m^{-1}), 70, 140 or 210 mol NaCl m^{-3}. (n=4)

	NaCl concentrations (mol m^{-3})							
Cultivars/lines	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210
Leaf Cl^-					Root Cl^-			
B-557	17.12±0.90a y	38.95±0.96b x	44.9±0.54c x	57.77±2.27c w	10.64±0.31	20.5±1.6	32.74±0.3	41.88±1.9
Culture 728-4	21.86±0.66a y	45.75±1.74b x	60.0±0.60b w	62.50±2.61bc w	11.45±0.64	19.5±0.3	28.10±0.5	31.40±2.5
MNH-156	18.99±0.66a z	39.55±0.91b y	50.78±0.61c x	66.29±2.28bc w	8.96±0.39	21.3±0.8	25.92±0.9	30.45±0.4
B-1580 (ne)	19.15±0.97a y	48.72±0.82b x	54.13±1.34bc x	70.37±9.38b w	9.76±0.54	28.8±0.9	32.39±1.1	41.41±1.4
Culture 604-4	15.0±0.36a z	59.21±0.48a y	79.8±1.30a x	97.81±2.98a w	8.60±0.31	30.3±0.6	20.41±0.9	28.22±0.6
MNH-147	19.74±0.70a z	48.63±1.06b y	61.88±2.92b x	98.80±0.75a w	10.85±0.32	20.5±0.3	33.19±2.1	40.12±2.1
	LSD 5% (T×L)=9.96				T×L=Non-significant			

Means with the same letters in each column (a-c) and each row (w-z) do not differ significantly at 0.05

Table 4: K^+concentrations (g kg^{-1} d. wt. ±SE) of leaves and roots of six cultivars/lines of cotton (***Gossypium hirsutum***) when grown in soil salinized with 0 (control, ECe=1.6 dS m^{-1}), 70, 140 or 210 mol NaCl m^{-3} (n=4)

	NaCl concentrations (mol m^{-3})							
Cultivars/lines	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210
Leaf K^+					Root K^+			
B-557	26.24±1.29dw	20.95±0.7cx	16.13±0.7by	15.21±0.20aby	12.45±0.34bw	13.21±0.08aw	11.03±0.23ax	10.42±0.195ax
Culture 728-4	28.17±0.99cdw	24.28±1.38bcwx	19.30±0.77abx	18.62 ±1.02ax	12.72±0.73bw	11.35±0.26bw	9.3±0.15bcx	8.72±0.175bx
MNH-156	35.74±1.03bw	27.02±0.66bx	18.64±0.68by	16.57±0.38aby	8.26±0.15dw	7.38±0.29dw	5.99±0.15ax	5.16±0.35dx
B-1580 (ne)	42.53±0.42aw	32.28±1.68ax	24.51±1.73ay	13.64±0.15abz	14.03±0.065aw	11.52±0.084bx	9.98±0.16aby	9.52±0.22ay
Culture 604-4	16.43±0.33ew	14.01±0.42dw	8.53±0.46cy	7.30±0.24cy	10.55±0.11cw	6.24±0.16dx	5.50±0.11dx	4.59±0.12dy
MNH-147	32.8±0.66bcw	23.57±0.20bcx	18.13±0.69by	12.85±0.05bz	13.30±0.32abw	9.55±0.05cx	8.18±0.06cxy	7.22±0.27cy
	LSD 5% (T×L)=5.14				LSD 5% (T×L)=1.30			

Means with the same letters in each column (a-e) and each row (w-z) do not differ significantly at 0.05

(Table 5). In contrast, the difference between the salt tolerant and the salt sensitive lines in root Ca^{2+} was not consistent at any external salt regime.

Addition of NaCl to the growth medium reduced significantly leaf and root K/Na ratios (Table 6) in all six cultivars/lines differing in salt tolerance. All the three salt tolerant cultivars/lines, B-557, Culture-728-4 and MNH-156, had slightly higher leaf K/Na ratios (1.03, 1.16 and 1.06, respectively) than the salt sensitive cultivars/lines, B-1580, Culture-604-4 and MNH-147 showing 0.81, 0.51 and 0.83 ratios respectively at the highest NaCl regime of 210 mol m^{-3} NaCl (Table 6). The salt tolerant cultivars/lines maintained K/Na ratio greater than 1 at the highest external salt treatment. These results are in accordance with the previous studies of Abdullah and Ahmad (1986) who found a positive relationship between high K^+/Na^+ ratio and salt tolerance in cotton. Maintenance of higher K/Na ratio in salt tolerant cultivars/lines may have been one of the factors for their relative superiority in growth under saline conditions, since Wyn Jones ***et al.*** (1979) suggested a minimum value for K/Na of 1 for normal growth of plants subjected to saline substrate.

K/Na ratios of roots of all six cultivars/lines were comparatively much lower than those of leaves. Although NaCl salinity reduced K/Na ratios in all six lines the discrimination between salt tolerant and salt sensitive cultivars/lines on the basis of this variable was not easy.

Leaf Ca/Na ratios (Table 7) of all the salt tolerant cultivars/lines were significantly higher than those of the salt sensitive cultivars/lines at all external NaCl regimes except at the highest NaCl treatment (210 mol m^{-3}) in which B-557 and Culture-604-4 had same value of 0.98 (Table 7). These results suggest that Ca^{2+} may have played an important role in maintaining the proper functioning of biological membranes and their permeability (Hanson, 1984; Kent and Läuchli, 1985), thereby causing relatively normal growth in the salt tolerant cultivars/lines compared with the salt sensitive cultivars/lines in saline medium.

The root Ca/Na ratios were much lower than those of leaves in all six cotton cultivars/lines differing in salt tolerance (Table 7). Although cultivars/lines were significantly different for Ca/Na ratios, no consistent pattern of difference among the cultivars/lines was observed.

All the cultivars/lines differed significantly at ($p \leq 0.001$) (Table 8) for all fibre traits. Salt stress had a significant increasing effect on ginning out-turn of all the cultivars/liners (Fig.1). However, ginning out-turn of the salt tolerant cultivars/lines was generally lower than those of the salt sensitive cultivars/lines under saline conditions. The salt sensitive MNH-147 had the highest value (>60%) of ginning out-turn (of all the cultivars/lines, whereas Culture-604-4 and B-1580 (ne) were almost at par for this trait. Other research workers (Razzouk and Whittington 1991) also reported similar results. Reduction in the staple length, fibre maturity and fibre strength of all the cultivars/lines was observed with an increase in NaCl of the rooting medium (Fig. 1). The salt tolerant line Culture 728-4 had the highest staple length at 70 mol m^{-3} NaCl (Fig. 1), but at 70 and 140 mol m^{-3} NaCl B-557 was at top in respect of this trait (Fig. 1). The lowest staple length was observed for Culture 604-4 at the salt regime (210 mol m^{-3} NaCl0). The fibre fineness of all the cultivars/lines (Fig. 1) increased (low values of micronaire represent higher fineness) with the addition of NaCl in the rooting medium, but the differences between salt tolerant and salt sensitive lines were not consistent. The present findings regarding the effect of salinity on staple length, fibre fineness, fibre strength and fibre maturity are in conformity with the former reports

Table 5: Ca^{2+} concentrations (g kg^{-1} d.wt.±SE) of leaves and roots of six cultivars/lines of cotton (***Gossypium hirsutum***) when grown in soil salinized with 0 (control, ECe=1.6 dS m^{-1}), 70, 140 or 210 mol NaCl m^{-3}. (n=4)

	NaCl concentrations (mol m^{-3})							
Cultivars/lines	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210
Leaf Ca^{2+}					Root Ca^{2+}			
B-557	39.2±0.51cw	35.75±0.67bw	29.27±0.45bx	14.50±0.52cy	7.4±0.105ay	8.5±0.04cxy	10.08±0.7bcx	19.8±0.56aw
Culture 728-4	48.9±1.82bx	59.4±1.32aw	43.0±0.85axy	40.5±0.91ay	6.35±0.11aby	7.75±1.2cdxy	8.85±0.13bwx	9.2±0.26dw
MNH-156	56.72±0.8aw	38.9±1.29bx	35.65±0.61bx	27.3±0.63by	4.01±0.11cy	8.33±0.25bcx	9.2±0.24bwx	10.25±1.27dew
B-1580 (ne)	22.20±0.67dw	18.0±0.37cwx	15.9±0.34cxy	13.40±0.41cy	5.11±0.23bcx	5.80±0.05dx	6.80±0.09cx	8.05±0.165ew
Culture 604-4	22.20±0.67dw	18.0±0.37cwx	15.90±0.34cxy	13.40±0.414cy	6.65±0.10aby	11.59±0.39ax	15.9±0.84aw	17.3±0.74bw
MNH-147	38.0±1.58cw	16.5±0.37cx	7.70±0.04dy	5.92±0.24dy	6.65±0.06aby	8.55±0.102bcxy	10.40±0.18bwx	11.80±0.195cw
	LSD 5% (T×L)=6.42				LDS 5% (T×L)=1.95			

Means with the same letters in each column (a-e) and each row (w-y) do not differ significantly at 0.05

Table 6: K/Na ratios of leaves and roots of six cultivars/lines of cotton (***Gossypium hirsutum***) when grown in soil salinized with 0 (control, ECe=1.6 dS m^{-1}), 70, 140 or 210 mol NaCl m^{-3}. (n=4)

	NaCl concentrations (mol m^{-3})							
Cultivars/lines	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210
Leaf					Root			
B-557	3.89±0.18cw	2.23±0.01abx	1.33±0.01aby	1.03±0.01ay	2.01±0.07aw	1.68±0.05ax	0.98±0.02ay	0.74±0.022aw
Culture 728-4	4.73±0.27bw	2.83±0.22ax	1.48±0.01ay	1.16±0.06ay	1.64±0.04bcw	0.99±0.01cx	0.69±0.01by	0.51±0.02by
MNH-156	7.23±0.24aw	2.20±0.04abx	1.44±0.04aby	1.06±0.03ay	0.94±0.01dw	0.68±0.14dx	0.92±0.24aw	0.39±0.03cy
B-1580 (ne)	7.26±0.01aw	2.93±0.06ax	1.92±0.01ay	0.81±0.01az	2.07±0.002aw	1.27±0.003bx	0.81±0.02aby	0.64±0.027ay
Culture 604-4	2.46±0.02dw	1.82±0.02bx	0.66±0.01by	0.51±0.03ay	1.51±0.004cw	0.74±0.001dx	0.45±0.01cy	0.31±0.045cy
MNH-147	3.37±0.08cw	2.42±0.01abx	1.58±0.02ay	0.83±0.16ay	1.74±0.006bw	1.19±0.01bx	0.65±0.02bcy	0.51±0.02bcy
	LSD 5% (T×L) = 0.81				LDS 5% (T×L) = 0.21			

Means with the same letters in each column (a-e) and each row (w-z) do not differ significantly at 0.05

Table 7: Ca/Na ratios of leaves and roots of six cultivars/lines of cotton (***Gossypium hirsutum***) when grown in soil salinized with 0 (control, ECe=1.6 dS m^{-1}), 70, 140 or 210 mol NaCl m^{-3}. (n=4)

	NaCl concentrations (mol m^{-3})							
Cultivars/lines	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210	0 (Control) (ECe=1.6 dS m^{-1})	70	140	210
Leaf					Root			
B-557	5.78±0.08cw	3.81±0.08bx	2.42±0.07ay	0.98±0.12bz	1.19±0.01ax	1.36±0.03awx	0.89±0.02ay	1.41±0.036aw
Culture 728-4	7.59±0.42bw	6.92±0.25aw	3.31±0.13ax	2.48±0.07ax	0.86±0.04abw	0.68±0.02bwx	0.66±0.02abwx	0.54±0.02bx
MNH-156	11.45±0.07aw	3.27±0.13bx	2.8±0.31axy	1.75±0.02ay	0.46±0.03bx	0.77±0.03bw	0.64±0.002abwx	0.77±0.03bw
B-1580 (ne)	3.79±0.05dw	1.63±0.01cx	1.24±0.12bxy	0.79±0.08by	0.75±0.01abwx	0.85±0.02bw	0.55±0.001bx	0.54±0.02bw
Culture 604-4	3.79±0.02dw	2.34±0.06cx	1.24±0.02bxy	0.98±0.02by	0.99±0.01aby	1.66±0.04aw	1.29±0.06ax	1.15±0.04abxy
MNH-147	4.14±0.13dw	1.69±0.37cx	0.67±0.002b y	0.38±0.001b xy	0.85±0.002ab x	1.12±0.06ab w	0.82±0.02ab x	0.83±0.02abx
	LSD 5% (T×L)=1.15				LDS 5% (T×L)=0.69			

Means with the same letters in each column (a-e) and each row (w-z) do not differ significantly at 0.05

Table 8: Analyses of variance (mean squares) for ginning out-turn, staple length, fibre fineness, fibre maturity and fibre strength of six cultivars/lines of cotton (3 tolerant and 3 sensitive) after 140 days growth at 0, 70, 140 and 210 mol m^{-3}

Source of variation	Degrees of freedom	Ginning out-turn (%)	Staple length (mm)	Fibre Fineness (m.n.v)	Fibre Maturity (%)	Fibre Strength (tppsi)
Replications	3	13.320^{ns}	1.166^{ns}	0.118^{ns}	1.171^{ns}	4.73^{ns}
Treatments (T)	3	1403.75***	77.64***	5.74***	280.07***	1318.18***
Lines (L)	5	164.70***	35.05***	3.42***	116.52***	349.66***
T × L	15	29.66***	4.52***	0.157***	24.43***	64.19***
Error	69	8.93	0.589	0.051	3.874	2.67

***= Significant at 0.001 level, ns= Non-significant, m.n.v= Micronaire value, tppsi= Thousand pounds per square inch

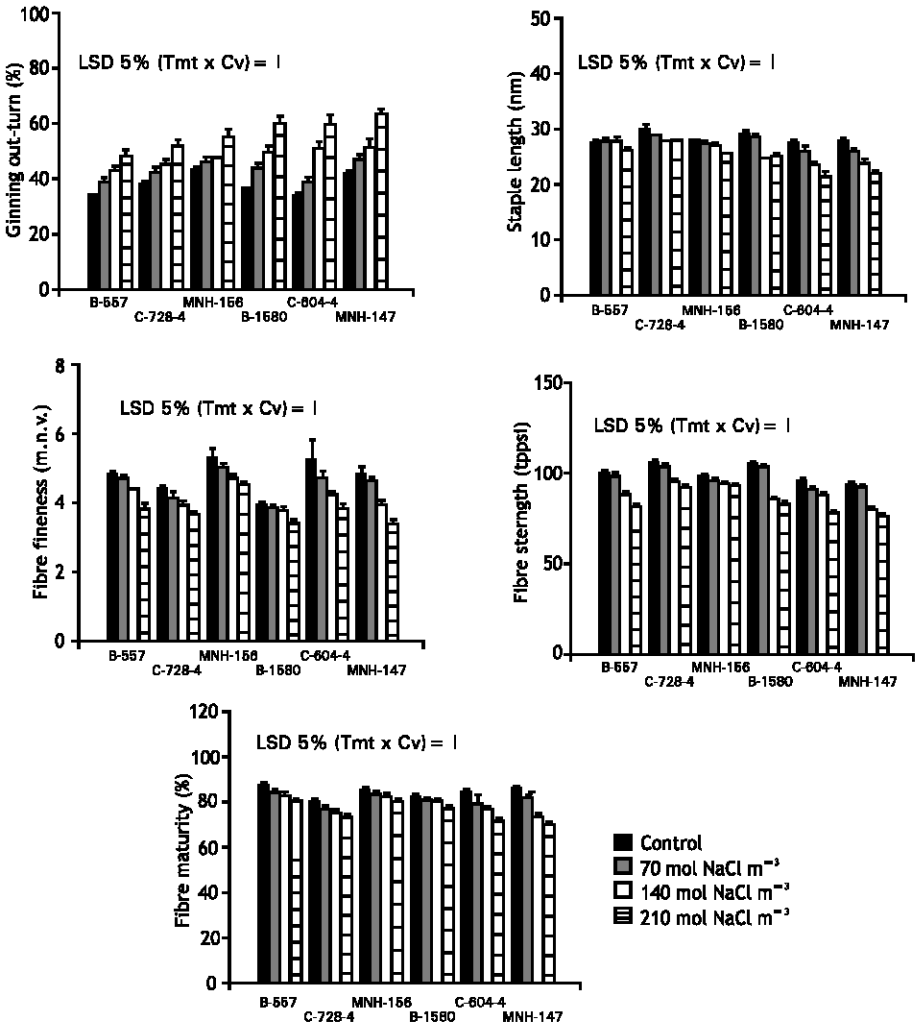

Fig. 1: Ginning out-turn (%±SE), staple length (mm±SE), fibre fineness (mnv±SE), fiber strength (tppsi±SE) and fibre maturity (%±SE) of six cultivars/lines of cotton grown in soil salinized with 0 (control, ECe=1.6 dS m^{-1}), 70, 140 or 210 mol NaCl m^{-3}

of Longenecker (1973, 1974); Abdullah and Ahmad (1986), Razzouk and Whittington (1991), Banks ***et al.*** (1997) and Ye ***et al.*** (1997).

Summing up the results, it is possible to conclude that salt tolerance in cotton is associated with low accumulation of Cl^- but high uptake of K^+ and Ca^{2+}, and maintenance of high K/Na ratios in the leaves. Although fibre characteristics were adversely affected in all the lines due to salt, they proved useful in discriminating between salt tolerant and salt sensitive lines of cotton.

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