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Salt Tolerance of Cotton (*Gossypium hirsutum* L.)

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Abstract: Salinity is a big threat to world agriculture. It imposes a major setback in increasing the yield of cotton. This crop is very sensitive to salinity at germination and seedling stage. Salt stress adversely affects the biomass production, i.e., decrease in leaf area, stem thickness, shoot and root weight and ultimately brings about decrease in seed cotton yield. A threshold salinity level at which initial yield of cotton declines is 7.7 dS m^{-1} with a 50% reduction in yield at 17.0 dS m^{-1}. Reduction in fibre length, fibre strength and micronaire values, whereas an increase in ginning out-turn have been reported under saline conditions in both *Gossypium hirsutum* and *Gossypium barbadense*. High salinity level adverse affects photosynthesis. Research studies indicate decrease in nitrogen of leaf cotton with increasing salinity levels. Salinity increases Na^+ and Cl^- and decreases K^+, Ca^{2+} and Mg^{2+} in leaves of cotton. Slight increase in K^+ and modest accumulation of Na^+ with increase in salinity have also been found in literature. K^+/Na^+ ratio has been used as a successful selection criterion for salt tolerance in some crops. Generally salt tolerance in cotton has been associated with Na^+ exclusion. High salinity reduces N and P uptake in cotton, whereas low salinity does not have a significant effect on the absorption of either of the ions.

Key words: Cotton, salinity, yield, fibre quality, physiology

Introduction

Salinity is one of the major hazards, usually confined to arid or semi-arid regions of the world, constitute a primary limit on the crop productivity (Ashraf, 1994; Lin *et al.*, 1997).

Out of total agricultural land available in the world (14 billion ha), 6 billion ha are arid and semi-arid and 0.1 billion ha are affected by excessive salts (Christiansen, 1982). Massoud (1974) examined the distribution of salt affected soils throughout the world (Table 1). There is a deterioration of 20 million ha of land (worldwide) leading to no or less productivity on an annual basis, in addition to precisely existing salt effected soils (Choukr-Allah, 1995).

Table 1: Distribution of salt affected area throughout the world

Continent/country	Salt affected area (million ha)
Africa	53.5
Australia	17.4
Mexico and Central America	19.6
North America	6.2
South America	69.4
North and Central Asia	91.7
Southern Asia	83.3
South East Asia	20.2
Total	361.3

Source: Massoud (1974)

In Pakistan, salinity hazard on about 7.0 million ha (Toenniessen 1984). About 60.5 % of soil is saline sodic or sodic and 39.5 % is saline (Javed and Javaid, 1995). It has been estimated that 40000 ha are annually lost due to salinity in Pakistan. It means a loss of Rs. 20 billion (Qayyum and Malik, 1988).

Cotton is one of the major fibre crops of the world. Although it is classified as salt tolerant crop (Maas and Hoffman, 1977), yet it is sensitive at germination stage (Carter, 1981). Therefore there is dire need to focus efforts for developing salt tolerant varieties of cotton. For this purpose, prior information regarding the response of plant towards salinity stress at various growth stages is pre-requisite for successful breeding of this crop for salt tolerance. The present review on salt tolerance of cotton covers the work done on this important crop in respect of its response towards salinity.

Germination and emergence: The germination of cotton seed and emergence of seedling is generally delayed and reduced by salinity (Qadir and Shams, 1997). However, varietal differences in response to salinity have been observed. For instance, NIAB-78 (Chaudhry *et al.*, 1989; Khan *et al.*, 1998), MNH-93 (Malik and Makhdum, 1987) and PH-36 (More and Malewar, 1988) have been found the most tolerant at germination. Better results of germination of Allan 33-57 than Acala de Cerro or SU 450-8909 over three selection cycles at 9 bars with 1:1 (w/w) mixture of NaCl + $CaCl_2$ have been reported by DaSilva (1992). *Gossypium barbadense* varieties exhibited more tolerance than *Gossypium hirsutum* or *Gossypium arboreum* cottons and the seedling growth was more sensitive than the germination to salt stress (Abul-Naas and Omran, 1974). The work on heritability of salt tolerance to germination and emergence in short staple cottons (*Gossypium hirsutum*) has been carried out by Ledbetter (1987). He found that parental cultivars exhibited 15 % emergence at -12 MPa NaCl treatment. The surviving plants were subjected to another cycle of selection in the field, using -12, -14, -16 and -18 MPa NaCl. The emergence of tolerant accessions, from first cycle of selection, ranged from 3.1 to 25.8 %. The average emergence of all accessions taken over all four salinity levels was 8.9 % from first cycle plants. Average emergence of second cycle plants was 13 % (range 0.7 - 32.6 %). Narrow sense heritability for salt tolerance during germination and emergence was estimated to be 0.38. The salt tolerance studies of 15 cultivars of cotton in sand culture (0, 150, or 250 mol NaCl m^{-3}) and 9 cultivars of cotton in soil (ECe = 2.8, 15, or 25 dS m^{-1}), showed that in sand culture, seed germination at 150 and 250 mol m^{-3} NaCl was 68-89 % and 24-40 % of the control levels, but in soil, the germination at 15 and 25 dS m^{-1} was 72-89 and 20-53 % respectively (Khan *et al.*, 1995).

In another study, some agronomic aspects of four cotton cultivars, B-557, MNH-93, NIAB-78 and S-12 were compared on a sandy clay loam soil (ECe = 1.9 dS m^{-1}) salinized with a mixture (Na_2SO_4, NaCl and $MgSO_4$ in the ratio of 9:5:5:1 on equivalent weight basis) to ECe levels of 10 and 20 dS m^{-1}. The crop was raised to flower initiation stage. Salinity decreased germination and vegetative growth, with significant differences among the cultivars. Seed germination at 10 and 20 dS m^{-1} salinities was 47-84 and 17-54 %, respectively. NIAB-78 showed the least decline followed by MNH-93 (Qadir and Shams, 1997).

Root growth: Although salinity generally causes reduced development of root (Raia and Azimov, 1988; Zhong and Läuchli, 1993), but there are some findings which show increase in root growth in mild salinity. For instance, NIAB-78 and Qalandri cultivars of cotton exhibited increase in the growth of roots but not shoot (Jafri and Ahmad, 1994). Similarly, Leidi (1994) reported longer primary roots in two genotypes of cotton when treated with 100 mol m^{-3} NaCl but not in control. An inhibition, both in length and number of secondary roots was also observed at both salt concentrations.

Germination and growth of root in *Gossypium barbadense*, at different salinity levels, were poorer in sand than in loam or clay loam which may be due to low Ca^{2+} and cation exchange capacity of sand (Soliman *et al.*, 1980). According to the findings of Silberbush and Ben-Asher (1987), the growth of root was very poor at high salinity level (>282 mol NaCl m^{-3}. In another study, cotton cultivar Acala SJ-2, when treated with 75, 150, 225, 300 or 375 mol NaCl m^{-3}, showed delayed primary root growth and reduced peak elongation rates (Reinhardt and Rost, 1995).

Shoot growth: Cotton is one of the salt tolerant crops (Pearson 1960; Maas, 1990). Generally, the salinity reduces vegetative growth of cotton (Qadir and Shams, 1997; Ye *et al.*, 1997) but increase in growth with low concentration of salts has also been observed (Pessarakli, 1995; Gorham, 1996a). Salinity decreases shoot/root ratio because shoots are sensitive than roots to salt stress (Leidi *et al.*, 1991; Brugnoli and Björkman, 1992).

In three year trials with cotton, it was found that irrigation with saline water caused decrease in plant height, number of bolls per plant, seed cotton yield and staple length (Babu *et al.*, 1987). The cultivar sangam proved tolerant. In another study, Lira and Hernandez (1988) performed an experiment with 15 cultivars of cotton grown in hydroponic culture of with or without NaCl at a concentration of 8000 ppm causing an osmotic potential of -0.7 MPa. Salinity induced phytotoxicity including necrosis of apices and leaf margins, stunted growth, and leaf chlorosis. The advanced lines, Roelca, 1656- 52- 36 and Paymaster 404 were the most tolerant and Deltapine 80, C310 × 24, Q SU16-1 and Acala SJ-2 were the most susceptible to high salinity. Adverse effects of salt stress on the biomass production of cotton has been found (Kuznetsov *et al.*, 1990). They applied water with salt solution, to the field (cv. T-61, 149 F and B3 of *Gossypium hirsutum* and Ash-25 and 9871-1 of *Gossypium brabadense*) during the first two months of growth to give a final concentration of 1.2 % NaCl and 1.4 % Na_2SO_4 (air dry soil basis). A second group of plants was subjected to a sudden high intensity stress at the budding stage. Cultivars 9871-1 and Ash-25 showed high constitutive resistance and little synthesis of new macromolecules in response to salinity. 149-F and B-3 showed low constitutive resistance with a decrease in biomass to 18 % of control. In another study, reduction in shoot fresh weights and dry weights of 15 cotton cultivars (13 *Gossypium hirsutum* and 2 *Gossypium arboreum*) were observed with an increase in salt concentration (0, 150 or 250 mol NaCl m^{-3}) and NIAB-78 was found the most salt tolerant of all the cultivars (Khan *et al.*, 1995).

At (ECe=10-20 dS m^{-1}), decrease in leaf area, stem thickness, shoot and root weights of four cotton cultivars, B-557, MNH-93, NIAB-78 and B-557, have been reported (Qadir and Shams, 1997). In another study, Khan *et al.* (1998) found different response of cotton cultivars, D-9, MNH-93, NIAB-78 and Ravi when subjected to solutions of NaCl: $CaCl_2$ (3:1, 1:1, or 1:3), NaCl alone or a salt mixture of Na_2SO_4: NaCl: $MgCl_2$at 0, 150 or 250 meq l^{-1}. Sodium chloride brought about decrease in shoot growth. This effect was partly overcome by the addition of Ca^{2+} to the rooting medium. NIAB-78 was found as the most salt tolerant followed by MNH-93.

Seed cotton yield: Crop yield has been reported as linear function of soil solution in terms of ECe for various field, forage, fruit, vegetables and ornamental crops. A threshold salinity level, at which initial yield of cotton declines, is 7.7 dS m^{-1} with a 50% reduction in yield at 17.0 dS m^{-1} (Maas and Hoffman, 1977; Maas, 1985).

Decrease in seed cotton yield with increasing salinity (7.5 -20 dS m^{-1}) has been reported by El-Hifny *et al.* (1975) and Volkan-Levy *et al.* (1989). Similar results were obtained when decline in initial yield of seed cotton occurred on soil with ECe of 3.5 dS m^{-1} (Thomas, 1980) and 50% seed cotton yield reduction at ECe of 16.75 dS m^{-1} (Ali *et al.*, 1986). When cotton was irrigated with high saline water at budding stage, it suffered 90 % reduction in yield (El-Saidi and Hegazy, 1980). Russo and Bakker (1987) found that salt concentration ranging from 6.7-10.5 dS m^{-1} brought about 6.5 to 30 % decrease in seed cotton yield of cultivar SJ-2. Reduction in number of bolls with increasing salinity has been found due to both decreased fruiting positions and increased in the percentage of bolls shedding (Longenecker, 1974). Seed weight per boll was less affected by salinity than the number of bolls (Abdullah and Ahmad, 1986). Moderate salinity with adequate nutrition, did not have toxic effects on growth but at higher salt concentration, shedding and pre-mature leaf senescence was observed (Brugnoli and Björkman, 1992). The findings of El-Gharib and Kadry (1983) and Salih and Abdul-Halim (1985) indicated that low salinity, with optimal supply of nutrients, increased the yield of seed cotton. Experiments conducted on various crops under saline conditions revealed that yield was depressed more in warm than in cold climate (Majistid *et al.*, 1943). Khan *et al.* (1995) compared the performance of two cotton cultivars, NIAB-78 and Ravi, at different growth stages (seedling, 6 leaf, pre-flowering, flowering and boll formation) in pot culture (150 mol NaCl m^{-3}). It was observed that 6-leaf seedling stage was the most sensitive to salinity and seed cotton yield was the lowest when plants were stressed at this stage. The seed cotton yield of NIAB-78 was slightly higher than that of Ravi when stressed at boll formation. In another experiment, three cotton cultivars. Sarvottam (*Gossypium herbaceum*), Laxmi (*Gossypium hirsutum*), and *Gossypium arboreum* were grown in field trial in low (< 5.1 dS m^{-1}), medium (5.1-7.67 dS m^{-1}) and high (7.67-14.6 dS m^{-1}) salinity levels at Gangavati and Karnataka during 1992/1993. With increasing salinity, all the growth and yield parameters were reduced (Uma and Patil, 1996).

Fibre quality: Adverse effects of salinity on fibre quality have been reported by Chowdhry (1972). Fibre length, strength and micronaire values reduced under saline conditions in both *Gossypium hirsutum* (Acala1517D) and *Gossypium barbadense* (Pima S-2) (Longenecker, 1974). Increasing salinity tended to decrease seed index and increase fibre fineness (Korkor *et al.*, 1974). At higher salinity levels, lint percentage, staple length, fibre fineness and seed weight were adversely affected while fibre strength was increased (Latif, 1977). Increasing levels of salinity (542- 20.31 dS m^{-1}) made the fibres course and decreased bundle length but no effect on fibre length or maturity percentage was observed (Ray, 1989). Four cotton cultivars Acala1577-88, DPL-50, MAR and Coker-312 when grown in culture media of 100 mM NaCl, all the cultivars except Acala1577-88, exhibited a decrease in fibre growth (Banks *et al.*, 1997). Increase in fibre length, fibre fineness and reduction in fibre elongation rate have been observed in upland cotton under soil salinity of 0.42 % (Ye *et al.*, 1997).

Seed oil content: Oil content decreased with increasing salinity in cotton (Kholbeknov, 1991). Ahmad and Abdullah (1980) found an increase in oil contents at low concentrations of sea water, but a decrease at higher salinity level (>1600 mg L^{-1}). Gradual increase in salinity increased the oil contents but sudden shock of salinity decreased the quantity of oil (Abdullah and Ahmad, 1986).

Physiology: The causes of reduced growth due to salinity have been reported to be due to osmotic effects, nutritional imbalance, and toxicity of Na^+ and Cl^- to metabolism of plants. Alteration of cell wall extensibility (Pritchard *et al.*, 1991) and accumulation of salt in the apoplast (Flowers *et al.*, 1991) have been found the other possible causes. Increasing salinity (NaCl) decreased the protein content in seedlings and increased the enzyme activity in salt tolerant (Zhimian-3) and salt sensitive (Lumian-1024) cultivars of cotton (Lin *et al.*, 1995).

Photosynthesis: Moderate salinity has no adverse effects on photosynthesis or transpiration (Rehab and Wallace, 1979) but adverse effects on photosynthesis have been reported at higher salinity levels in greenhouse experiment (Brugnoli and Lauter, 1991). Decrease in nitrogen of cotton (either leaf area or dry weight basis) with increasing salinity has been reported by Brugnoli and Björkman (1992). Ahmad and Abdullah (1980) found that low concentrations of sea water salts increased chlorophyll contents but reduction occurred at 16,000 mg L^{-1} of salts. Cotton plants subjected to slowly increased salinity had higher CO_2 fixation rate than those subjected to rapid (1-2 days) salinization particularly at -0.6 to -0.9 MPa (-6 to -9 bars). Na^+ and Cl^- accounted for most of osmotic adjustment (Plaut and Federman, 1991).

Inorganic ions: Many research studies (Plaut and Federman, 1991; Gouia *et al*., 1994; Jafri and Ahmad, 1994) reported variation in inorganic ion contents in the leaves of cotton subjected to salinity stress. Increase in Na^+ and Cl^- and decrease in K^+, Ca^{2+} and Mg^{2+} in leaves of cotton (Rathert, 1982), whereas slight increase in K^+ and modest accumulation of Na^+ (Jafri and Ahmad, 1994) were investigated. Under moderate salinity, Na^+ concentration in leaves can be modest and Ca^{2+} and K^+ concentration higher than Na^+ with Ca^{2+} being dominant (Thomas, 1980). Joham (1986) reported that Na^+ caused K^+ deficiency in cotton.

Khan *et al*. (1998) reported different response of cotton towards solutions of $NaCl + CaCl_2$ (3:1, 1:1, 1:3 ratios) and NaCl alone, or salt mixture of Na_2SO_4, NaCl and $MgCl_2$ at 0, 150 or 250 meq l^{-}. NIAB-78 accumulated the lowest shoot Na^+, especially with NaCl alone and the salt mixture. NIAB-78, the most salt tolerant cultivar, retained higher Na^+ concentration in the roots than MNH-93 and Ravi. D-9 was the most salt sensitive. Retention of high Na^+ in the roots could be the mechanism of salt tolerance in cotton.

K^+/Na^+ ratio: The screening of a large number of cultivars/lines for salt tolerance in laboratory and field is a cumbersome work. The rapid technique for distinguishing tolerant and sensitive material, is required for different breeding programmes. K^+/Na^+ ratio has been used as a successful criterion for selection for salt tolerance in some crops (Murthy *et al*., 1979; Chhipa and Lal, 1995).

Low accumulation of Na^+ and high concentration of K^+ was found in the shoot of cotton subjected to soil salinity than in salinized solution (Eaton and Bernardin, 1964). Na^+ exclusion was associated with salt tolerance in four Indian cotton varieties (Janardhan *et al*., 1976). The salt tolerant variety of *G. barbadenes* (Giza-45) showed less Na^+ and more K^+ in its leaves compared with the sensitive variety, dandara (Rathert, 1982). A positive correlation ($r = 0.762$) between dry matter yield and shoot K^+/Na^+ ratio has been reported in 14 cotton commercial varieties (Nawaz *et al*., 1986). Abdullah and Ahmad (1986) calculated high K^+/Na^+ ratio and low Cl^- in cotton seeds subjected to salinity which showed low retranslocation of Na^+ and Cl^- in phloem. Reduced K^+ uptake at all external K^+ concentrations in saline medium have been reported by Silberbush and Ben-Asher (1987). Reboucas *et al*. (1989) subjected seedlings of three cotton cultivars to -0.05 or -0.85 MPa (values adjusted by addition of NaCl). Chemical composition of leaves were analyzed 34 and 42 days after sowing. The apparent degree of salt tolerance changed during growth. The cultivar Br-1 made the most vigorous early growth but after 42 days total dry matter was reduced by 43, 54 and 57 % in cultivars, Taxes, Deltapline and BR-1 respectively, compared with growth in non-saline nutrient solution. Relative growth rate (RGR) for BR-1 and DPL varieties decreased after 34-42 days of sowing. N, P and K contents in roots and shoots were similar in control and saline solutions. The most sensitive cultivar Br-1 showed significantly higher Na^+ accumulation with shoot N concentration over 500 % higher than that in plants grown in normal nutrient solutions. In another study, no clear correlation between ion accumulation and relative salt tolerance of four upland varieties of cotton could be ascertained (Jafri and Ahmad, 1994). Qadir and Shams (1997) reported a lower Na : K ratio and lower concentration of Cl^- in the leaves of NIAB-78 (the most salt tolerant variety), followed by MNH-93. Higher accumulation of Na^+ than K^+, in the seedlings of salt tolerant cultivars of cotton was observed (Leidi and Saiz, 1997). 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). Total K^+ content and Ca^{2+} concentrations decreased with an increase in salinity level in the rooting medium.

There is a competition for uptake between chloride and nitrate in cotton (Kafkafi *et al*., 1982.). High salinity (-1.2 MPa) reduced ^{15}N uptake in cotton, whereas low salinity (-0.4 MPa and -0.8 MPa) did not have a significant effect on the absorption of ^{15}N (Pessarakli and Tucker, 1985a). In another study, Brugnoli and Björkman (1992) found a decrease in N content (leaf area or dry weight bases) with increasing salinity. Increase in soil salinity decreased N, P and K uptake in cotton in some pot experiments (Subbaiah *et al*., 1995).

Inverse relationship between Ca^{2+} and Na^+ in cotton plant subjected to 100 mol m^{-3} NaCl and reduction in the Na^+ and K^+ concentrations with increasing concentrations of $CaCl_2$ has been obtained (Joham and Calahan, 1978). The Na:Ca ratio of 3:1 was found to have an ameliorating effect but 1:1 or 1:3 ratios had no ameliorating effect on the shoot growth of cotton cultivars, D-9, MNH-93, NIAB-78 and Ravi (Khan *et al*., 1998).

Decrease in translocation of P^{32} from root to shoot and re-circulation from cotyledons to young leaves of Acala SJ-2 in a saline medium of 150 mol m^{-3} NaCl was found (Martinez and Läuchli, 1991). The older leaves had high P than the young leaves in salt treated plants of cotton. High NaCl reduced ^{32}P uptake in mature root zone but increased uptake at the root tip (Martinez and Läuchli, 1994). The degree of inhibition of P^{32} incorporation into organic phosphorus compounds, in saline medium, depended upon varietal behaviour (Nazirov *et al*., 1981). Salinity induced considerable increase in leaf phosphorylase in cotton (Rathert, 1982).

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