



Ameliorative effects of potassium nutrition on yield and fiber quality characteristics of cotton (*Gossypium hirsutum* L.) under NaCl stress

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Abstract

Cotton (*Gossypium hirsutum* L.) being moderately tolerant to salinity has been extensively grown in arid and semiarid regions where soil salinization is a major threat to plant growth and soil productivity. Excess salts in the growth medium may interfere with growth processes of cotton, leading to a severe decline in yield and fiber quality characteristics. Adequate mineral nutrient status of plants can provide an important strategy to improve plant tolerance to salinity. A pot experiment was planned to evaluate the ameliorative effects of additional potassium (K) applied at 50 and 100 mg K₂O kg⁻¹ soil as potassium sulfate against NaCl stress of 100 and 180 mM in cotton. The experiment was conducted according to completely randomized design with five replications. NaCl caused a significant ($P \leq 0.05$) increase in shoot sodium (Na⁺) and chloride (Cl⁻) with a corresponding decrease in shoot K⁺, K⁺: Na⁺ ratio, calcium (Ca²⁺) and magnesium (Mg²⁺). Plant growth, yield and fiber quality characteristics were also declined significantly by increasing external NaCl concentration. Additional K reduced shoot Na⁺ while increased K⁺, K⁺: Na⁺ ratio, Ca²⁺ and Mg²⁺ with the consequent improvement in plant growth, lint yield and yield attributes as well as fiber quality characteristics at both levels of NaCl. Results revealed that K nutrition improved shoot K⁺: Na⁺ ratio by 116 and 246% at NaCl₁₀₀ while 188 and 294% at NaCl₁₈₀ with K₅₀ and K₁₀₀, respectively as compared to NaCl treated plants without additional K. Likewise, lint yield was improved by 38.27 and 60.49% at NaCl₁₀₀ while 75.12 and 136% at NaCl₁₈₀ with K₅₀ and K₁₀₀, respectively compared to NaCl stressed plants without additional K. Ameliorative effects of K against NaCl stress were relatively more prominent at higher K application at both NaCl levels. In conclusion, K-induced decrease in Na⁺, increase in Ca²⁺, K⁺, K⁺: Na⁺ ratio, relative water content and membrane stability index provide protective mechanisms against NaCl stress. However, the results need to be confirmed under field conditions and the economic feasibility should be worked out.

Keywords: MSI; Plant growth; Plant tolerance; Potassium; RWC; Salinity; Sodium

Introduction

Soil salinity is one of the most damaging environmental factors which inhibit plant growth, yield and quality in wide variety plant species, particularly in arid and semiarid regions of the world where evapotranspiration is greater than precipitation. Globally, about 20% of the cultivated land and greater than half of the irrigated land are currently affected by salts to varying degree (Arzani, 2008). Furthermore, there is an annual increase of about 10% in soil salinization, and it is expected that more than 50% of the world arable land will be affected with salts by the year 2050 (Jamil *et al.*, 2011). The build-up of salt ions, particularly Na⁺ and Cl⁻ in the rooting medium and their subsequent accumulation by plant can affect plant growth and metabolism through ion toxicity, nutrient imbalances, reduction in water uptake and alteration in enzyme activities (Ashraf *et al.*, 2015a). In saline environment, plants usually face certain unfavorable

conditions such as low soil water potential, Na⁺ and Cl⁻ toxicity, Ca²⁺ and K⁺ deficiency, altered metabolism, membrane destabilization, reduction in cell division and expansion, all of these ultimately lead to marked reduction in plant growth and yield (Ashraf *et al.*, 2012). In saline environment, different growth and developmental processes including seed germination, seedling establishment, vegetative development, flowering, fruit formation and quality are adversely influenced by increasing salinity (Sairam and Tyagi, 2004).

Cotton (*Gossypium hirsutum* L.) is moderately tolerant to salinity with a threshold level of 7.7 dS m⁻¹ electrical conductivity (EC) beyond which its yield reduces by about 5.2% per unit dS m⁻¹ increase in EC (Maas, 1986). Reduction in cotton growth and yield in saline environment is mainly due to reduced germination and subsequent poor plant establishment (Ashraf, 2002). Jafri and Ahmad (1994)

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reported that long-term exposure of cotton plants to salinity stress often caused deferred fruit initiation, reduction in fruit development, enhanced fruit shed and delayed maturity with the subsequent reduction in boll number, boll weight, seed cotton yield, lint percentage, staple length, and fiber strength. Chen *et al.* (2010) found that cotton yield was reduced by 10, 25 and 50% at 10, 12 and 16 dS m⁻¹ EC, respectively. Khorsandi and Anaghali (2009) also reported that salinity stress delayed and reduced germination and seedling emergence, decreased vegetative and reproductive growth, and ultimately led to a marked reduction in cotton yield and fiber quality characteristics at moderate to high levels of soil salinization. In saline environment, excess Na⁺ or deficiency of K⁺, particularly at reproductive stage can damage the structure of fruit-bearing organs, and decrease the seed cotton yield and fiber quality (Zhang *et al.*, 2014). Relative water content (RWC) and membrane stability index (MSI) are usually greatly influenced by salinity, and considered as important criteria for evaluating the plant's capability to endure salinity stress (Win *et al.*, 2011; Ghogdi *et al.*, 2012). Adequate plant nutrition can provide an effective strategy for improving plant growth and development in saline environment (Waraich *et al.*, 2011, Ashraf *et al.*, 2015b). Among the mineral nutrients, potassium (K) uptake and accumulation by plants is particularly influenced by high salinity, particularly Na⁺ in the growth medium depending upon many plant and soil factors (Shirazi *et al.*, 2005). In saline environment, Na⁺ has antagonistic effects with K⁺, and therefore plant's capabilities to adapt saline environment may be associated with plant's selectivity to prefer K⁺ over Na⁺. This hypothesis provides the base for the protective role of K against salinity stress. (Ashraf *et al.*, 2010; Ashraf *et al.*, 2012; Ashraf *et al.*, 2015a; 2015b). Potassium generally makes an important contribution to osmotic adjustment in plants that is vital for water balance within the plant body which otherwise severely disturbed under saline conditions (Marschner, 1995; Mengel and Kirkby, 2001). Potassium also helps to improve Ca²⁺ accumulation within plants which improves membrane structure and reduces boll abscission. Cotton is considered to be relatively more sensitive to K deficiency, often exhibits the deficiency symptoms on soils not usually regarded as K deficient (Cassman *et al.*, 1989). On the other hand, saline environment is mostly characterized by K deficiency. Accordingly, a pot experiment was planned to evaluate the effects of K nutrition for improving growth, yield and fiber quality of cotton under NaCl stress.

Materials and Methods

Soil characteristics

A pot experiment with cotton was carried out to evaluate the protective role of K for reversing the damaging effects of NaCl on yield and yield attributes as well as fiber

quality characteristics. Soil used in this study was sandy clay loamy having, pH 7.9, EC 1.3 dS m⁻¹, sodium adsorption ratio (SAR) 6.4 (mmol L⁻¹)^{1/2}, organic matter 0.71%, nitrogen (N) 337 mg kg⁻¹, phosphorus (P) 4.3 mg kg⁻¹, K 122 mg kg⁻¹ and saturation percentage 38.4%.

Plant growth

Cotton seeds of cultivar BT-Super 101 were sown in earthen glazed pots filled with 12 kg soil, collected from the top 20 cm depth of a cultivated field. After germination, two healthy plants were maintained in each pot. The plant protection measures were adopted uniformly for all treatments. N at 100 mg as urea, P at 40 mg P₂O₅ as single super phosphate and K at 40 mg K₂O as potassium sulfate kg⁻¹ soil were applied. Whole P, K and one third N were applied at the time of sowing while remaining N was added in two splits, at flowering and boll formation stages. Harvesting was done in two phase, one plant from each pot was harvested 50 days after treatment completion while 2nd plant was allowed to mature.

Treatment plan

Seven treatments, T₁ Control (no NaCl, no additional K), T₂ NaCl₁₀₀: 100 mM NaCl, T₃ NaCl₁₀₀+K₅₀: 100 mM NaCl+50 mg K₂O kg⁻¹ soil, T₄ NaCl₁₀₀+K₁₀₀: 100 mM NaCl+100 mg K₂O kg⁻¹ soil, T₅ NaCl₁₈₀: 180 mM NaCl, T₆ NaCl₁₈₀+K₅₀: 180 mM NaCl+50 mg K₂O kg⁻¹ soil, T₇ NaCl₁₈₀+K₁₀₀: 180 mM NaCl+100 mg K₂O kg⁻¹ soil, were arranged according to completely randomized design with five replications. Additional K as potassium sulfate was added according to treatment plan at the time of planting. At 10th day after seedling emergence, the required amount NaCl salt was dissolved in water and drenched into respective pots gradually within 48 hours.

Relative water content (RWC)

Forty two days after treatment completion, 3rd leaf from the shoot tip of both plants were sampled and weighed immediately to record fresh weight (FW). For recording turgid weight (TW), the leaves were dipped in distilled water for about 4 h and weighed after removing the water from the leaf surface with tissue paper. The leaves were then oven dried at 70°C for 48 h to record oven-dried weight (ODW). RWC was determined according to Yamasaki and Dillenburg (1999):

$$\text{RWC (\%)} = \frac{(\text{FW} - \text{ODW})}{(\text{TW} - \text{ODW})} \times 100$$

Membrane stability index (MSI)

Fourth leaf from the shoot tip of both plants were collected 42 days after treatment completion. The leaves were cut into 1.0 cm diameter pieces and put in test tubes having 10 mL distilled water in two sets. One set of test



tubes were kept in water at 40°C for 30 min and the EC of water having leaf sample was measured (C_1). The second set of test tubes were incubated at 100°C in boiling water for 15 min and their EC was measured (C_2). MSI was calculated according to Sairam *et al.* (1997):

$$\text{MSI} (\%) = [1 - C_1/C_2] \times 100$$

Ionic characteristics

Fifty days after treatment completion, one plant from each pot was harvested and used to determine Na^+ , Cl^- , K^+ , Ca^{2+} and Mg^{2+} concentrations in plant shoots. After thorough washing with distilled water, plant samples were first air-dried and then oven dried at 70°C for 48 h. After grinding, 0.5 g portion of ground shoot samples was digested in 10 mL mixture of concentrated nitric acid and perchloric acid (2:1, v/v) at 250°C. Flame photometer was used to estimate shoot K^+ and Na^+ , atomic absorption spectroscopy for Ca^{2+} and Mg^{2+} while chloride analyzer for Cl^- .

Fiber quality characteristics

Ginning out turn was recorded as ratio between weight of the lint and weight of the seed cotton. Fiber length was measured by Fibrograph (ASTM, 1994a), fiber fineness by Micronaire Tester (ASTM, 1994b) and fiber strength by Pressley Fiber Bundle Tester (ASTM, 1994c).

levels of NaCl and additional K in the growth medium (Table 1). NaCl development in soil caused a marked increase in shoot Na^+ and Cl^- while decrease in shoot Ca^{2+} , Mg^{2+} , K^+ and $\text{K}^+:\text{Na}^+$ ratio as compared to control. Addition of K in both levels reversed the deleterious effects of NaCl, with greater amelioration at higher level of additional K at both NaCl concentrations. Shoot Na^+ concentrations were decreased by 26.90 and 42.69% at NaCl_{100} while 38.97 and 51.02% at NaCl_{180} , shoot Cl^- 12.86 and 24.37% at NaCl_{100} while 13.09 and 21.70% at NaCl_{180} with K_{50} and K_{100} , respectively compared to salt treated plants without additional K. In contrast, shoot K^+ was increased by 57.98 and 94.68% at NaCl_{100} while 77.27 and 92.72% at NaCl_{180} , $\text{K}^+:\text{Na}^+$ ratio 116 and 246% at NaCl_{100} while 188 and 294% at NaCl_{180} , Ca^{2+} 23.96 and 47.92% at NaCl_{100} while 37.24 and 64.22% at NaCl_{180} , Mg^{2+} 15.29 and 22.35% at NaCl_{100} while 42.10 and 59.21% at NaCl_{180} with K_{50} and K_{100} , respectively compared to NaCl treated plants without additional K.

Relative water content and membrane stability index

Maximum RWC were found in control which were declined by 16.78% at NaCl_{100} and 28.02% at NaCl_{180} . Additional K improved RWC by 6.41 and 15.86% at

Table 1: Shoot ionic concentration (%) of cotton (*Gossypium hirsutum* L.) grown under NaCl stress by supplying K

Treatments	K^+	Na^+	$\text{K}^+:\text{Na}^+$ ratio	Cl^-	Ca^{2+}	Mg^{2+}
Control	2.50bc	1.33e	1.886a	1.83f	2.80a	0.214ab
NaCl_{100}	1.88d	3.42b	0.554cd	3.41cd	1.88cd	0.170bc
$\text{NaCl}_{100}+\text{K}_{50}$	2.97b	2.50cd	1.196b	2.97de	2.33abc	0.196abc
$\text{NaCl}_{100}+\text{K}_{100}$	3.66a	1.96de	1.918a	2.58e	2.78a	0.208ab
NaCl_{180}	1.10e	4.90a	0.226d	5.04a	1.64d	0.152c
$\text{NaCl}_{180}+\text{K}_{50}$	1.95d	2.99bc	0.652c	4.38b	2.25bc	0.216ab
$\text{NaCl}_{180}+\text{K}_{100}$	2.12cd	2.40cd	0.890bc	3.95bc	2.69ab	0.242a

Values in a column followed by the same letter are not significantly different at $P \leq 0.05$. Control: no NaCl, no additional K, NaCl_{100} : 100 mM NaCl, $\text{NaCl}_{100}+\text{K}_{50}$: 100 mM NaCl+50 mg K_2O kg^{-1} soil, $\text{NaCl}_{100}+\text{K}_{100}$: 100 mM NaCl+100 mg K_2O kg^{-1} soil, NaCl_{180} : 180 mM NaCl, $\text{NaCl}_{180}+\text{K}_{50}$: 180 mM NaCl+50 mg K_2O kg^{-1} soil, $\text{NaCl}_{180}+\text{K}_{100}$: 180 mM NaCl+100 mg K_2O kg^{-1} soil

Statistical analysis

Data were statistically analyzed according to Mstat-C. The effects of treatments were compared using analysis of variance. Least significant difference test (LSD, $P \leq 0.05$) was used to compare the difference between means.

Results

Shoot ionic concentration

Shoot ionic concentrations including Na^+ , Cl^- , K^+ , Ca^{2+} and Mg^{2+} were significantly ($P \leq 0.05$) affected by different

NaCl_{100} while 11.19 and 22.16% at NaCl_{180} by K_{50} and K_{100} , respectively compared to NaCl treated plants without additional K (Fig. 1). MSI was decreased by 13.29 and 29.78% at NaCl_{100} and NaCl_{180} , respectively compared to control. K nutrition interfered with Na^+ , and improved MSI at both levels of NaCl and added K. However, ameliorative effect of additional K was relatively more prominent at higher additional K compared to lower level at both NaCl concentrations in the growth medium (Fig. 2). There was a significant positive correlation of shoot K^+ with RWC ($R^2 = 0.659$, Fig. 3) MSI ($R^2 = 0.684$, Fig. 4).



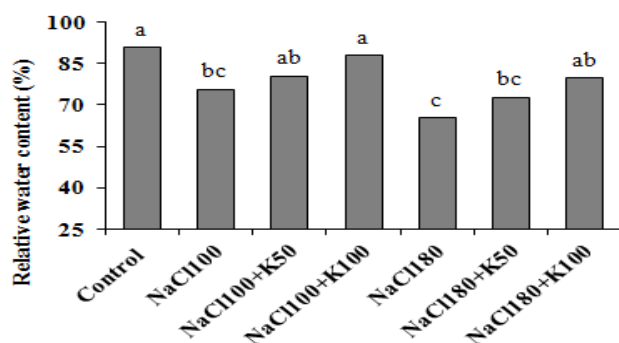


Figure 1: Relative water content of cotton (*Gossypium hirsutum* L.) grown under NaCl stress by supplying K. Values followed by the same letter are not significantly different at $p \leq 0.05$.

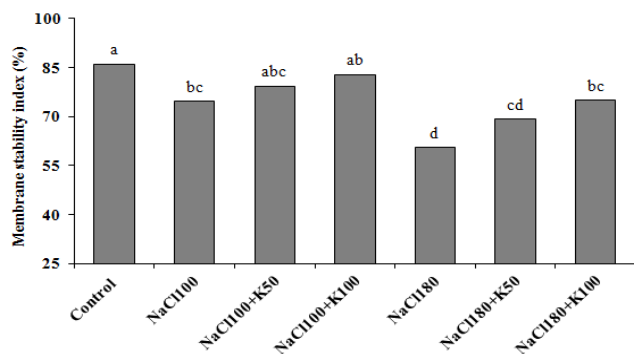


Figure 2: Membrane stability index of cotton (*Gossypium hirsutum* L.) grown under NaCl stress by supplying K. Values followed by the same letter are not significantly different at $P \leq 0.05$.

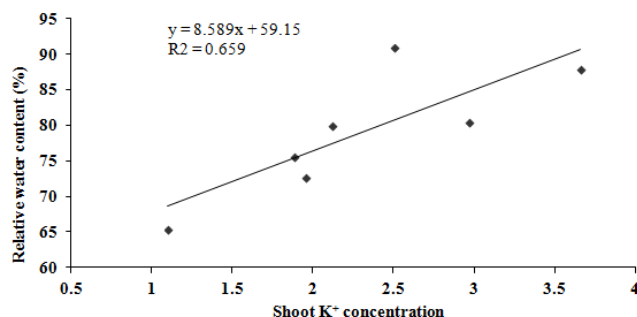


Figure 3: Correlation between shoot K^+ concentration and relative water content in cotton grown under NaCl stress by supplying K

Growth and yield characteristics

Plant growth and yield characteristics in term of plant height, boll number plant⁻¹, boll diameter, seed cotton weight boll⁻¹, seed cotton weight plant⁻¹, seed weight plant⁻¹

and lint yield plant⁻¹ were significantly ($P \leq 0.05$) influenced by NaCl and additional K (Table 2). At NaCl₁₀₀, plant height was decreased by 26.36% compared to control which was improved by 13.03 and 22.32% with K₅₀ and K₁₀₀, respectively compared to NaCl₁₀₀ without additional K. At NaCl₁₈₀, plant height was decreased by 40.28% compared to control.

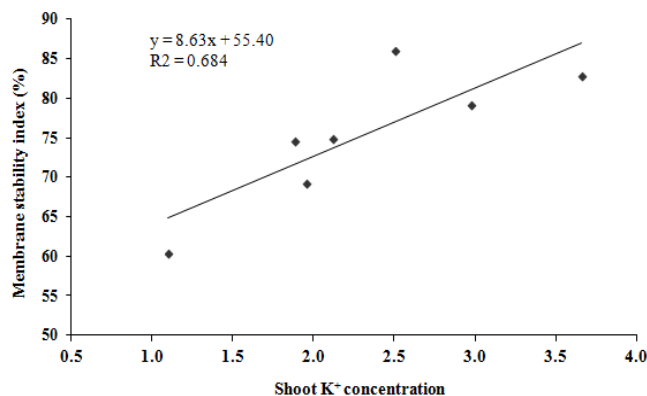


Fig. 4: Correlation between shoot K^+ concentration and membrane stability index in cotton grown under NaCl stress by supplying K

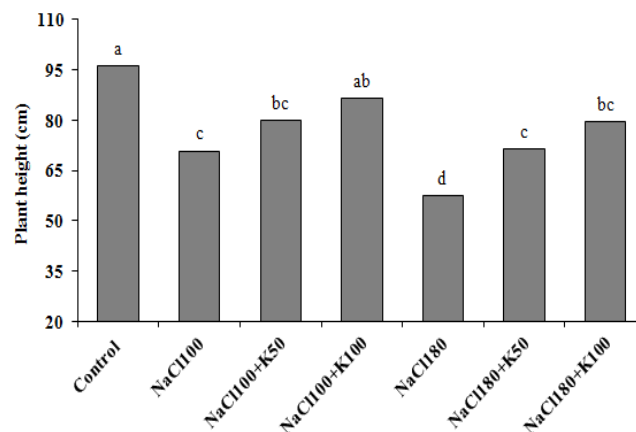


Fig. 5: Plant height of cotton (*Gossypium hirsutum* L.) grown under NaCl stress by supplying K

However, K nutrition reversed the deleterious effects of NaCl and improved plant height by 24.56 and 38.36% with K₅₀ and K₁₀₀, respectively compared to NaCl₁₈₀ plants without additional K (Fig. 5). Boll number per plant was decreased by 35.21 and 53.52% by NaCl₁₀₀ and NaCl₁₈₀, respectively compared to control. Additional K improved boll number plant⁻¹ by 21.74 and 30.43% at NaCl₁₀₀ while 53.52 and 60.60% at NaCl₁₈₀ with K₅₀ and K₁₀₀, respectively compared to NaCl treated plant without K. Boll diameter and seed cotton weight per boll were markedly reduced by NaCl₁₀₀ and NaCl₁₈₀ compared to control. Additional K



Table 2: Yield and yield characteristics of cotton (*Gossypium hirsutum* L.) grown under NaCl stress by supplying K

Treatment	Boll number plant ⁻¹	Boll diameter (cm)	Seed cotton weight boll ⁻¹ (g)	Seed cotton weight plant ⁻¹ (g)	Seed weight plant ⁻¹ (g)	Lint yield plant ⁻¹ (g)
Control	14.20a	2.73a	2.51a	35.79a	24.28a	11.51a
NaCl ₁₀₀	9.20cd	2.04bc	2.04bc	18.80c	11.51cd	7.29bc
NaCl ₁₀₀ +K ₅₀	11.20bc	2.23b	2.22bc	24.38bc	14.36bc	10.08a
NaCl ₁₀₀ +K ₁₀₀	12.00ab	2.36b	2.33ab	27.88b	16.38b	11.70a
NaCl ₁₈₀	6.60d	1.83c	1.71d	11.18d	7.08d	4.10d
NaCl ₁₈₀ +K ₅₀	9.00cd	2.11bc	2.01c	18.11cd	10.93cd	7.18c
NaCl ₁₈₀ +K ₁₀₀	10.60bc	2.30b	2.23abc	23.57bc	13.89bc	9.68ab

Table 3: Fiber quality characteristics of cotton (*Gossypium hirsutum* L.) grown under NaCl stress by supplying K

Treatments	Ginning out turn (%)	Staple length (mm)	Fiber strength (g/tex)	Fiber fineness (Micronaire value)
Control	43.61a	28.78a	98.40a	4.76a
NaCl ₁₀₀	38.76bc	26.24cd	92.00bcd	3.62cd
NaCl ₁₀₀ +K ₅₀	41.35ab	27.22bc	95.24ab	4.06bc
NaCl ₁₀₀ +K ₁₀₀	42.02ab	28.06ab	95.82ab	4.34ab
NaCl ₁₈₀	36.68c	25.46d	87.96d	3.00e
NaCl ₁₈₀ +K ₅₀	39.62bc	26.48cd	90.60cd	3.48d
NaCl ₁₈₀ +K ₁₀₀	41.01ab	27.30bc	92.32bc	3.92bcd

Control: no NaCl, no additional K, NaCl₁₀₀: 100 mM NaCl, NaCl₁₀₀+K₅₀: 100 mM NaCl+50 mg K₂O kg⁻¹ soil, NaCl₁₀₀+K₁₀₀: 100 mM NaCl+100 mg K₂O kg⁻¹ soil, NaCl₁₈₀: 180 mM NaCl, NaCl₁₈₀+K₅₀: 180 mM NaCl+50 mg K₂O kg⁻¹ soil, NaCl₁₈₀+K₁₀₀: 180 mM NaCl+100 mg K₂O kg⁻¹ soil.

improved both of these characteristics at both NaCl levels. However, alleviative effect of K was relatively more at higher K level. Seed weight per plant was decreased by 52.59% at NaCl₁₀₀ and 70.84% at NaCl₁₈₀ compared to control. K nutrition improved the seed weight per plant by 24.76 and 42.31% at NaCl₁₀₀ while 54.38 and 96.18% at NaCl₁₈₀ with K₅₀ and K₁₀₀, respectively compared to NaCl treated plants without additional K. Maximum seed cotton weight per plant was found in control which was reduced by 47.47% at NaCl₁₀₀ and 68.76% at NaCl₁₈₀. Additional K improved seed cotton weight per plant by 29.68 and 48.30% at NaCl₁₀₀ while 61.98 and 111% at NaCl₁₈₀ with K₅₀ and K₁₀₀, respectively compared to control. Lint yield per plant was declined by 36.66% at NaCl₁₀₀ and 64.37% at NaCl₁₈₀ compared to control. K nutrition alleviated the adverse effects of NaCl on plant growth and development and improved lint yield by 38.27 and 60.49% at NaCl₁₀₀ while 75.12 and 136% at NaCl₁₈₀ with K₅₀ and K₁₀₀, respectively compared to NaCl treated plants without additional K.

Fiber quality characteristics

Results presented in Table 3 revealed that fiber quality characteristics were significantly ($P \leq 0.05$) affected by different levels of NaCl and additional K. Ginning out-turn was decreased by 11.12 and 15.89% by NaCl₁₀₀ and

NaCl₁₈₀, respectively compared to control. K nutrition in saline environment improved ginning out-turn by 6.68 and 8.41% at NaCl₁₀₀ while 8.01 and 11.80% at NaCl₁₈₀ with K₅₀ and K₁₀₀, respectively compared to NaCl treated plants without additional K. Staple length, fiber strength and fiber fineness were also decreased linearly by increasing NaCl concentration in the growth medium. Application of additional K at both levels of NaCl reversed the adverse effects of NaCl and improved the fiber quality characteristics. It was interesting that adverse effects of NaCl and ameliorative effect of additional K on fiber quality was relatively small when compared with growth and yield characteristics of cotton at both levels of NaCl and K.

Discussion

Understanding the salinity-nutrients relationships is of great economic importance because nutrients could provide protective mechanisms against salinity stress by reducing ion toxicity through competitive ion uptake and dilution effect, maintaining ionic balance, contribution to osmotic adjustment and scavenging of reactive oxygen species under saline conditions (Marschner, 1995). In present study, NaCl caused a marked increase in shoot Na⁺ and Cl⁻ while decrease in Ca²⁺, Mg²⁺, K⁺ and K⁺: Na⁺ ratio in cotton grown at NaCl₁₀₀ and NaCl₁₈₀ compared to control. The



major mechanisms of salt effects on ion uptake and accumulation within plant were the ion antagonism, reduction in water availability and absorption, disruption of root membrane integrity and reduction in relative growth rate that resulting in a lower nutrient demand. Chen *et al.* (2010) demonstrated that Na^+ uptake was increased with increasing salinity and the displacement of $\text{K}^+/\text{Ca}^{2+}$ by Na^+ under salt stress could cause nutritional imbalances. Ashraf *et al.* (2015b) also observed that increasing NaCl concentration in the growth medium enhanced the uptake of Na^+ while decreased K^+ , showing an apparent antagonism between Na^+ and K^+ in sunflower. Therefore, plant's capabilities to endure salt stress could be related to its ability for limiting Na^+ uptake and/or transport from roots to shoots, and increasing K^+ content (Siringam *et al.*, 2011). Exogenous application of K at both levels reduced Na^+ accumulation, increased Ca^{2+} , K^+ concentration and $\text{K}^+:\text{Na}^+$ ratio, all these played an important role in improving plant tolerance to salinity. Alleviative effect of added K in reversing the adverse effects of NaCl was relatively more prominent at higher K level. Ashraf *et al.* (2015a) found that K addition to saline environment increased K^+ and $\text{K}^+:\text{Na}^+$ ratio which were subsequently responsible for enhanced salt tolerance in sugarcane.

Reduction in RWC under NaCl stress might be attributed to salt-induced reduction in water potential in the root zone which inhibited the plant's ability to extract water from soil and transport to aerial plant parts. Ashraf *et al.* (2015b) reported that salinity stress caused a marked decrease in RWC in sunflower. Additional K improved RWC through its direct involvement in osmotic adjustment or by improving Ca^{2+} accumulation under salinity stress. Cakmak (2005) also reported K contribution to water economy under salt stress. NaCl-induced reduction in MSI was attributed to displacement of Ca^{2+} by Na^+ from membrane structure which caused disorganization of membrane structure and decreased MSI. Potassium nutrition under salinity stress improved Ca^{2+} uptake and accumulation, and increased MSI. In addition, K could also improve MSI through its protective role against oxidative stress in saline environment. These findings were in accordance with Cakmak (2002; 2005); Gunes *et al.* (2007); Ashraf *et al.* (2015b).

Inhibition in plant growth, yield and yield attributes of cotton including plant height, boll number plant^{-1} , boll diameter, seed cotton weight boll^{-1} , seed cotton weight plant^{-1} , seed weight plant^{-1} and lint yield plant^{-1} at both levels of NaCl was attributed to ion toxicity, reduced RWC, MSI and disturbed ionic balance. In saline environment, salt ions strongly competed with essential mineral nutrients, particularly Ca^{2+} and K^+ resulting in their reduced uptake and accumulation. Consequently, excess of Na^+ and Cl^- or deficiency of K^+ , Ca^{2+} and Mg^{2+} or any other essential

nutrient disturbed growth processes and causing severe decline in plant growth and yield (Ashraf *et al.*, 2015a). Furthermore, salinity-induced reduction in water and K^+ uptake by plants usually interfered with cell division and/or extension because of reduced turgor, leading to reduced plant growth and development (Ashraf *et al.*, 2008). Addition of plant mineral nutrients through soil or foliar spray could provide protective mechanisms against salinity stress (Kaya *et al.*, 2007; Murillo-Amador *et al.*, 2007; Ashraf *et al.*, 2012; Ashraf *et al.*, 2015b). It was found that application of additional K (K_{50} and K_{100}) to salt-stressed medium (NaCl_{100} and NaCl_{180}) reduced the uptake of Na^+ and Cl^- , and improved cotton growth and yield. Lint yield plant^{-1} was positively correlated with shoot K^+ concentration ($R^2 = 0.702$, Fig. 6).

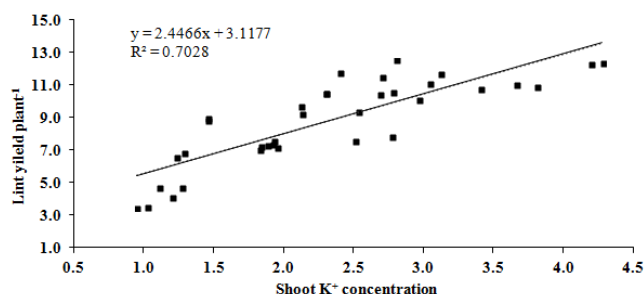


Fig. 6: Correlation between shoot K^+ concentration and lint yield plant^{-1} in cotton grown under NaCl stress by supplying K

These findings were contradicted to earlier research which reported that higher K application in saline environment hastened the deleterious impacts of salinity on plant growth causing severe decline in plant growth and development in sorghum (*Sorghum bicolor* L.) under salt stress (Jafari *et al.*, 2009).

Decline in fiber quality characteristics including ginning out-turn, staple length, fiber strength and fiber fineness of cotton at both levels of NaCl was mainly attributed to antagonistic effects of Na^+ with K^+ and Ca^{2+} accumulation by plant under salinity stress. During the formation and development of fruit, K^+ and Ca^{2+} are required for carbohydrate metabolism and transfer of metabolites from leaves to developing bolls. Salinity-induced K^+ and Ca^{2+} deficiency, particularly during reproductive phase could damage the fruit organs, decreased seed cotton yield and fiber quality. Sawan (2014) demonstrated that K^+ and Ca^{2+} deficiency affected boll structure and caused abscission of young bolls, and consequently reduced seed cotton yield and quality. Potassium nutrition at both levels of NaCl alleviated the adverse effects of Na^+ and improved fiber quality characteristics. Some past studies, for example Gormus (2002); Aneela *et al.* (2003); Pervez *et al.* (2004);



Pettigrew *et al.* (2005); Sharma and Sundar (2007) also reported an improvement in cotton growth, lint yield and fiber quality by K nutrition.

Conclusion

External NaCl markedly increased shoot Na^+ and Cl^- while decreased K^+ , $\text{K}^+:\text{Na}^+$ ratio, Ca^{2+} , Mg^{2+} , RWC and MSI with a subsequent decline in yield and yield attributes as well as fiber quality characteristics. Potassium nutrition at both levels of NaCl stress interfered with Na^+ , reduced its accumulation with a corresponding increase in shoot K^+ , $\text{K}^+:\text{Na}^+$ ratio and Ca^{2+} , and ultimately reversed the damaging effects of NaCl on yield attributes and fiber quality. The protective role of K in cotton plants suffering from salinity stress has been attributed to maintenance of lower Na^+ , higher Ca^{2+} , K^+ , and $\text{K}^+:\text{Na}^+$ ratio accompanied by greater RWC and MSI.

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