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RESPONSE OF COTTON (*GOSSYPIUM HIRSUTUM* L.) GENOTYPES TO SALT STRESS

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Abstract

The response of 15 cotton (*Gossypium hirsutum* L.) genotypes to salt stress was studied in terms of their biomass production and reduction ratios under salt stress. The cotton varieties were grown at different salt concentrations (0, 125 and 250 mM NaCl) in completely randomized split-plot design with 10 replications. Plant height, stem diameter, shoot fresh and dry weight, leaf area, and total dry weight were determined to compare their relative performance at salinity. Significant variations occurred among 15 cotton genotypes for all investigated traits with increasing salt level in growing medium. The cotton genotypes with good vegetative growth without salt stress had also good vegetative growth under salt stress. Based on biomass production and reduction ratios of cotton genotypes in salt stress conditions, it is concluded that Delta Opal, Golden West, and Deltapine 50 are salt sensitive Sahin-2000, Nazilli M 503 and TAM94L-25 are salt tolerant, while rest of the cotton genotypes are considered as moderately salt tolerant.

Introduction

Excessive salt (NaCl), accumulation in soils causes a serious reduction in the yield of a wide variety of crops. Over 800 million hectares of land throughout the world are salt-affected either by salinity (397 million ha) or the associated condition of sodicity (434 million ha). Of the current 230 million ha of irrigated land, 45 million ha are salt-affected (20%) (Anon., 2005). In Turkey, irrigated agricultural areas are threatened by salt accumulation in soils due to the poor irrigation management. Cultivated crop pattern has been changed with the irrigation under the Southeastern Anatolia Project (GAP). It is estimated that in the GAP, having 40-50 % cotton production area of Turkey, soil salinity is the most important problem due to the heavy irrigation or poor water management and high evaporation. Salinity problem in the GAP reduced the cotton yield up to 29.6 % (Cullu, 2003). Since salinity limits the agriculture production (up to 40%) all over the world (Serrano & Gaxiola, 1994), salt tolerant cultivars need to be improved to utilize saline soils and to meet the demands of the world's increasing population (Holmberg & Bulow, 1998). A number of researches have been reported with regard to the effects and response mechanisms of salinity on plants (Hasegawa *et al.*, 2000; Pessarakli, 2001; Munns & James, 2003; Cha-Um & Kirdmanee, 2009; Noreen *et al*., 2009).

Cotton is considered to be moderately tolerant to salinity, ranked second behind barley (Soltanpour & Follett, 1995). However, variation in salt-tolerance has been observed among different cotton cultivars (Gosset *et al*., 1994; Khan *et al*., 1995; Leidi & Saiz, 1997). Under saline condition absolute or relative growth or yield is usually the ultimate goal (Shannon, 1984). Biomass production at high salinity (up to 250 mM NaCl) has been proposed as a selection criterion for salt tolerant (Kingsbury & Epstein, 1984; Martin *et al*., 1994; Jafri & Ahmad, 1994). In the study reported herein, 15 commercially cultivated cotton genotypes were evaluated for salt-tolerance during early seedling growth.

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Materials and Methods

Seeds of 15 cotton genotypes viz., Nazilli-84, Carmen, Sahin-2000, Ozbek-142, Nazilli M-503, BA-119, Cukurova-1518, Sure Grow 125, Stonville-453, Delta Opal, Golden West (Teks), Ersan-92, Maras-92, Deltapine 50 and TAM94L-25 were planted in a walking-greenhouse on July 11, 2006. Four seeds were planted in pots (26 cm ht x 11 cm diam; volume: 1.5 l) filled with a 3/1 mixture of sand:perlite. After emergence, plants were thinned to one plant per pot. The experimental design was completely randomized split-plot design, with salinity as main plots and cultivars as subplots. Ten pots were established for each genotype. The conditions in greenhouse were 31/21 °C and 55/61% relative humidity (day/night). The plants were watered per day with 300 mL half strength Hoagland solution (Hoagland & Arnon, 1950) containing no NaCl until the plants reached the beginning first true-leaf stage. Subsequently, 14 days after planting, seedlings were subjected to the salt stress gradually by adding 50 mM NaCl at 24 h intervals until the final concentrations of 125 and 250 mM NaCl were reached. Fully expanded 3^{rd} main stem leaves were excised from each plant and each leaf was immediately weighted to determine leaf fresh weight 45 days after planting. Leaf area was measured by using scanner with Flaeche packing programme (Kraft, 1995). Ten leaves were dried for 24 hours at 72ºC and dry weight was recorded. The plants were harvested 47 days after planting (DAP) on 25-26 August 2005. Plants were taken from pots and washed free of sand: perlite mixture. Plant height was measured by ruler and stem diameter was measured above the first real leaf by using caliper ruler with 0.001 mm sensitivity. Plants were cut into root and shoot, and shoot fresh weight measured. Shoot and roots were dried for 48 hours at 90 ºC and dry weight recorded. Genotypes were evaluated for plant height (PH), stem diameter (SD), shoot fresh weight (SFW), shoot dry weight (SDW), leaf area (LA), and total dry weight (TDW). Percentage of reduction due to the salinity stress in relation to the non-saline (NS) condition was also determined for different traits. Data were analyzed by a completely randomized split-plot design using the GLM procedure of SAS program (Anon., 1999).

Results and Discussions

Variation among 15 upland cotton genotypes and interaction between salt treatments and genotype was significant for plant height (PH), stem diameter (SD), shoot fresh weight (SFW), shoot dry weight (SDW), leaf area (LA), and total dry weight (TDW) (Table 1).

Table 1. Mean square values of 15 upland cotton genotypes when grown under salt stress.

Source	Mean squares						
	d.f.	**PH†**	**SD**	**SDW**	**SFW**	**LA**	**TDW**
Salt	2	11801**	54.77**	107.8**	115.1**	195.2**	95.2**
Error I	27	66.66	0.361	1.099	26.40	215.7	1.651
Genotype	14	140**	1.057**	9.095**	8.612**	4.940**	9.516**
Salt x Genotype	28	11.37**	0.233**	1.904**	1.804**	2.137**	1.754*
Error	378	3.789	0.118	0.357	7.096	60.3	0.555

* and ** indicate significance at p=0.05 and 0.01 level, respectively.

†: Plant height (PH), stem diameter (SD), shoot fresh weight (SFW), shoot dry weight (SDW), leaf area (LA), total dry weight (TDW).

Genotypic variation exists among 15 cotton varieties for all investigated characters under control and salt treatments (Table 2). The mean values of investigated traits were significantly affected by genotype and increasing salinity levels. In the control pots, the genotypes had plant height in the range of 38.15-29.55 cm with Ozbek-142 having the maximum while Stoneville 453 having the minimum values (Table 2). At 125 mM NaCl salinity level, pH ranged between 28.25 (Sahin-2000) and 20.05 cm (Stonville-453). With increasing salt level to 250 mM NaCl, Deltapine 50 was in the last rank (12.70 cm), while Ozbek-142 (18.40 cm), Nazilli M-503 (18.25 cm), Nazilli 84 (17.35 cm) and Sahin-2000 (16.10 cm) were in the first statistical group in terms of pH. The highest reduction in pH was found in Delta Opal (35%) and Golden West (34%), and lowest reduction was observed for Sahin-2000 (19%) followed by Nazilli-84 (24%) and Nazilli M-503 (23%) at 125 mM NaCl salinity level. With increasing salt level from 0 to 250, decrease in of pH was over 50%, and differences among cotton genotypes are not significant.

Significant differences were observed in SD among cotton genotypes with or without salt treatments (Table 2). Under non-stressed conditions, stem diameter of the genotypes varied from 4.30 mm (Ozbek-142) to 3.42 mm (BA-119). At 125 mM NaCl level, Nazilli M-503 had the highest stem diameter value (3.84 mm), while BA-119 exhibited the lowest stem diameter value (3.05 mm). Salih & Halim (1985) reported that stem diameter is one of the most important and sensitive parameters in cotton. When the cotton genotypes were grown in 125 mM NaCl level, the highest reduction in SD was in Carmen (18%), and the lowest in TAM94L-25 (2.7%). However, at 250 mM NaCl, Sahin-2000 had the highest reduction ratio (39%) in SD, while the lowest SD reduction (23%) was observed for BA-119.

Mean shoot fresh and dry weight (stem Faculty of Agriculture + leaves) values of genotypes were significantly affected by salinity stress. A decrease in shoot fresh weight and dry weight of 15 cotton cultivars was observed with increase in salt concentration of the growth medium (Table 2). Ozbek-142 and Nazilli 84 had the highest SFW (17.99 g) and SDW (3.76 g) values under control condition, respectively. However, Nazilli M-503 produced maximum SFW (14.37 g) and SDW (3.06 g), and Delta Opal had minimum value of SFW (7.06 g) and SDW (1.46 g) at 125 mM NaCl salt level. When the cotton genotypes were grown in 125 mM NaCl salt level, the highest reduction in SFW (41%) and SDW (35%) was in Delta Opal and Golden West (39% for SFW and 34% for SDW), while Nazilli M 503, TAM94L-25 and Sahin-2000 had lowest reduction ratio values for both SFW and SDW. No differences were observed for SFW and SDW production values or reduction ratios among cotton genotypes grown in 250 mM NaCl. The expected reduction in SFW and SDW could result from shrinkage of cell contents, unbalanced nutrition, ion imbalance and hyperosmotic stress in plants; and oxidative damage to enzymatic proteins and membrane integrity (Kent & Lauchli, 1985; Zhu, 2001; Xiong & Zhu, 2002).

Leaf area per plant of all cotton genotypes progressively decreased with the increase in salinity level from 0 to 125 and 250 mM NaCl (Table 2). The initial growth response of plants to salinity is generally seen as slow leaf growth (Munns & Termaat, 1986). Significant differences were observed in LA among genotypes under control and with increasing salinity to 125 mM NaCl. However, no significant differences were found among cotton genotypes for LA at 250 mM NaCl salt level. Leaf area per plant ranged between 59.9 cm^2 (Carmen) and 45.2 cm^2 (Delta Opal) under non-stressed growing condition. At 125 mM NaCl level, Sahin-2000 produced maximum LA (43.4 cm^2) while Delta Opal had the smallest leaf area (22.72 cm^2). Genotypic variation also exists among cotton cultivars in terms of reduction ratio in LA under salt stressed condition. The largest reduction in LA was in Delta Opal (47%) and DPL 50 (44%). The lowest reduction in LA was observed for Sahin-2000 (16%), Nazilli-84 (21%) and Nazilli M-503 (23%) under 125 mM NaCl treatment.

Table 2. Means of different growth parameters of 15 upland cotton genotypes grown under non-stress and salt stress conditions.

Genotypes	PH (cm)			SD (mm)		
	Control	125mM NaCl	250mM NaCl	Control	125mM NaCl	250mM NaCl
Nazilli-84	34.35 abc†	26.10 abcd	17.35 abc	4.17 ab	3.73 ab	2.90 a
Carmen	33.80 bc	22.40 de	12.95 ef	4.15 ab	3.38 abc	2.75 a
Sahin-2000	35.65 abc	28.25 a	16.10 a-d	3.98 abc	3.49 abc	2.41 a
Ozbek-142	38.15 a	27.80 a	18.40 a	4.30 a	3.50 abc	2.76 a
Nazilli M-503	36.75 ab	27.75 ab	18.25 ab	4.22 ab	3.84 a	2.91 a
S. Grow 125	34.35 abc	23.15 cd	14.55 c-f	3.82 a-d	3.22 bc	2.55 a
Cukurova-1518	32.65 cd	23.60 bcd	15.25 a-f	3.77 a-d	3.37 abc	2.68 a
Stonville-453	29.55 e	20.05 e	13.15 f	3.81 a-d	3.52 abc	2.61 a
Delta Opal	33.15 bcd	21.30 de	14.95 b-f	3.55 cd	3.11 c	2.66 a
Golden West	32.60 cde	21.25 de	15.40 a-f	3.92 a-d	3.26 abc	2.72 a
Ersan-92	32.75 cd	23.30 cd	15.80 a-e	3.66 bcd	3.26 bc	2.77 a
Maras-92	32.65 cd	23.30 cd	15.85 a-e	3.74 a-d	3.46 abc	2.46 a
BA-119	30.25 de	21.45 de	14.95 b-f	3.42 d	3.05 c	2.56 a
Deltapine 50	30.08 de	20.75 de	12.70 f	3.72 a-d	3.09 c	2.38 a
TAM94L-25	30.40 e	22.70 cde	15.65 a-f	3.43 d	3.55 abc	2.62 a
	SFW (g)			SDW (g)		
Nazilli-84	17.71 ab†	12.66 ab	6.20 a	3.76 a	2.81 ab	1.36 a
Carmen	15.09 a-d	9.15 bcd	4.02 a	2.97 abc	1.86 b-e	0.85 a
Sahin-2000	12.69 cd	11.38 abc	4.58 a	2.52 c	2.46 a-d	0.93 a
Ozbek-142	17.99 a	11.79 ab	6.28 a	3.65 ab	2.61 abc	1.29 a
Nazilli M-503	15.95 abc	14.37 a	6.41 a	3.15 abc	3.06 a	1.44 a
S. Grow 125	13.21 a-d	8.50 bcd	4.31 a	2.40 c	1.70 cde	0.89 a
Cukurova-1518	13.24 a-d	10.52 a-d	4.47 a	2.34 c	2.17 a-e	1.01 a
Stonville-453	13.19 bcd	10.41 a-d	4.84 a	2.42 c	2.10 a-e	1.01 a
Delta Opal	12.54 cd	7.06 d	4.89 a	2.41 c	1.46 e	1.06 a
Golden West	14.56 a-d	8.42 bcd	4.55 a	2.77 abc	1.72 cde	0.92 a
Ersan-92	13.82 a-d	9.29 bcd	5.19 a	2.61 bc	2.11 a-e	1.14 a
Maras-92	14.13 a-d	9.72 a-d	4.93 a	2.86 abc	2.04 a-e	0.97 a
BA-119	11.28 d	8.53 bcd	4.82 a	2.32 c	1.82 b-e	1.06 a
Deltapine 50	12.33 cd	7.32 cd	4.01 a	2.46 c	1.57 de	0.89 a
TAM94L-25	11.32 d	10.15 a-d	4.92 a	2.39 c	2.39 a-e	1.10 a
	LA (cm$^{2)}$			TDW (g)		
Nazilli-84	54.83 ab†	41.01 ab	21.12 a	4.81 a	3.64 ab	1.91 a
Carmen	59.91 a	37.28 abc	14.00 a	3.72 abc	2.35 b-e	1.16 a
Sahin-2000	53.17 ab	43.40 a	17.69 a	3.22 c	3.03 a-d	1.29 a
Ozbek-142	51.34 ab	38.47 abc	19.78 a	4.53 ab	3.30 abc	1.71 a
Nazilli M-503	54.50 ab	40.51 abc	22.25 a	3.96 abc	3.74 a	1.94 a
S. Grow 125	50.22 ab	33.82 a-d	17.39 a	2.91 c	2.06 cde	1.20 a
Cukurova-1518	50.29 ab	37.02 abc	17.79 a	2.88 c	2.71 a-e	1.38 a
Stonville-453	53.13 ab	38.02 abc	19.02 a	3.04 c	2.70 a-e	1.36 a
Delta Opal	45.20 b	22.72 d	18.07 a	3.01 c	1.88 e	1.42 a
Golden West	54.99 ab	30.27 a-d	18.18 a	3.50 abc	2.22 cde	1.32 a
Ersan-92	56.55 ab	30.83 a-d	20.01 a	3.38 bc	2.75 a-e	1.58 a
Maras-92	49.98 ab	30.04 bcd	17.36 a	3.68 abc	2.65 a-e	1.30 a
BA-119	47.94 ab	28.28 cd	16.57 a	3.15 c	2.29 b-e	1.46 a
Deltapine 50	53.02 ab	28.32 cd	22.74 a	3.28 bc	1.99 de	1.19 a
TAM94L-25	46.03 b	30.65 a-d	16.09 a	3.34 bc	3.13 a-e	1.52 a

†Values within columns followed by the same letter are not different according to Duncan's multiple range test $p \leq 0.05$.

Table 3. Correlation coefficients of shoot dry weight and total dry weight in salt-stressed with all investigated traits under non-stressed conditions.

		Non-stressed (control)					
		PH†	**SD**	**SDW**	**SFW**	**LA**	**TDW**
125 mM NaCl	SDW	0.40‡	0.20	0.26	0.25	0.15	0.22
		<0.01§	0.01	<0.01	<0.01	0.08	<0.01
	TDW	0.37	0.20	0.25	0.26	0.15	0.24
		<0.01	0.01	<0.01	<0.01	0.07	<0.01
250 mM NaCl	SDW	0.21	0.16	0.25	0.27	0.16	0.27
		0.01	<0.01	<0.01	<0.01	0.05	<0.01
	TDW	0.17	0.12	0.22	0.24	0.12	0.25
		0.03	0.15	<0.01	<0.01	0.01	<0.01

†: Plant height (PH), stem diameter (SD), shoot fresh weight (SFW), shoot dry weight (SDW), leaf area (LA), total dry weight (TDW).
‡ Pearson correlation coefficient
§ Probability of a larger r value

The most general effect of salinity on plant is a reduction in growth (total biomass production) and growth rate. Total (shoot + root) dry weight decreased progressively as the salinity level increased from 0 to 125 and 250 mM NaCl salinity levels (Table 2).

Significant variations were observed among 15 cotton genotypes for TDW at control and 125 mM NaCl salt level but no differences were observed for TDW among cotton genotypes when grown in 250 mM NaCl salt level (Table 2). The highest TDW values were observed from Nazilli 84 (4.81 g) and Nazilli M-503 (3.74 g) under control and 125 mM NaCl salt level, respectively. Delta Opal produced the lowest TDW at non-stressed (3.01g) as well as at 125 mM NaCl salt level (1.88 g). As the concentration of NaCl increased from 0 to 125 mM NaCl levels, the highest and the lowest reduction ratio in TDW occurred in DPL 50 (35%) and Nazilli M-503 (0.1%) relative to control, respectively.

Salinity tolerance is usually assayed in terms of absolute or relative growth (Mass & Hoffman, 1977; Shannon, 1984). Thus, correlation coefficients of SDW and TDW under salt stress with all investigated traits under non-stressed condition were determined (Table 3). Shoot dry weight and total dry weight at 125 mM NaCl salt level were positively and significantly correlated with PH, SFW, SDW, and TDW values at non-stressed condition. Similarly SDW and TDW at 250 mM NaCl salt level were positively and significantly correlated with SFW, SDW, and TDW in non-stressed condition. The positive correlation between biomass production under non-saline irrigation and under the two levels of salinity was supported by the findings of Foolad (1996). Thus cotton genotypes with good vegetative growth without salt stress had also good vegetative growth under salt stress.

Conclusion

Under saline condition absolute or relative growth or yield is usually the ultimate goal (Shannon, 1984). Ashraf & Ahmad (2000) reported that salt-tolerant cotton varieties (*G. hirsutum* L.) had higher shoot biomass production than salt-sensitive varieties at the vegetative stage. Based on the data of present studies were evaluated together, it is concluded that genotypes Delta Opal, Golden West, and DPL 50 are salt sensitive, and Sahin-2000, Nazilli M 503, and TAM94L-25 are salt tolerant, while rest of the cotton genotypes are considered a moderately salt tolerant.

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