

The Effect of Salinity on Cotton (*Gossypium hirsutum* L.) Growth and Physiology at Seedling Stage Under Hydroponic Conditions

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Abstract: This study was carried out to determine the tolerance of 5 cotton varieties grown in hydroponics conditions to salt stress and to determine plant growth parameters and some physiological characteristics in plants grown in saline environments. The experiment was established in a hydroponic medium containing 5 cotton varieties (BA 1010, Fiona, May 455, Novelia and Orion) and 2 salt concentrations (Control and 100 mM NaCl). Plants were grown in a growth chamber at 16/8-hour photo period, 25/20°C (day/night) temperature and 40±2% humidity. Salinity induced morphological and physiological changes, including a reduction in the root length, shoot dry weight and leaf area, but root fresh weight was increased with salt application, on the other hand, shoot length, shoot fresh weight, root dry weight, root/shoot ratio, root surface area and chlorophyll content (SPAD value) were not affected. It was determined that there were significant statistical differences among the varieties in terms of all the characteristics except the root/shoot ratio. The interaction between variety x salt applications was significant in root length, root fresh and root dry weight, root/shoot ratio, root surface area and SPAD value. The results of this study indicated that the Novelia variety was prominent in terms of root fresh weight, shoot fresh weight, root dry weight, shoot dry weight, root surface area and leaf area, while Fiona and Novelia were prominent in terms of root length. It was concluded that Novelia and Fiona varieties had better performance than other varieties for saline conditions because they have better root properties under salt stress conditions.

Keywords: Cotton, salinity, hydroponic, physiology, plant growth

Hidroponik Koşullarda Tuzluluğun Pamuğun (*Gossypium hirsutum* L.) Fide Döneminde Büyüme ve Fizyolojisi Üzerindeki Etkisi

Öz: Bu çalışma, hidroponik koşullarda yetiştirilen 5 pamuk çeşidinin tuz stresine toleransını belirlemek ve tuzlu ortamlarda yetiştirilen bitkilerde bitki büyüme parametreleri ve bazı fizyolojik özelliklerini belirlemek amacıyla yürütülmüştür. Deneme, 5 pamuk çeşidi (BA 1010, Fiona, May 455, Novelia ve Orion) ve 2 tuz konsantrasyonu (Kontrol ve 100 mM NaCl) içeren hidroponik ortamda kurulmuştur. Bitkiler 16/8 saatlik fotoperiyot, 25/20 °C (gündüz/gece) sıcaklık ve %40±2 nem içeren bir büyüme kabinde yetiştirilmiştir. Tuzluluk, kök uzunluğu, sürgün kuru ağırlığı ve yaprak alanında azalma gibi morfolojik ve fizyolojik değişikliklere neden olmuş, ancak kök taze ağırlığı tuz uygulaması ile artmış, buna karşın sürgün uzunluğu, sürgün taze ağırlığı, kök kuru ağırlığı, kök/sürgün oranı, kök yüzey alanı ve klorofil içeriği (SPAD değeri) etkilenmemiştir. Kök/sürgün oranı hariç tüm özellikler bakımından çeşitler arasında istatistiksel olarak önemli farklılıklar olduğu belirlenmiştir. Çeşit x tuz uygulamaları arasındaki interaksiyon kök uzunluğu, kök taze ve kök kuru ağırlığı, kök/sürgün oranı, kök yüzey alanı ve SPAD değeri açısından önemli bulunmuştur. Bu çalışmanın sonuçları Novelia çeşidinin kök taze ağırlığı, sürgün taze ağırlığı, kök kuru ağırlığı, sürgün kuru ağırlığı, kök yüzey alanı ve yaprak alanı açısından öne çıktığını, Fiona ve Novelia'nın ise kök uzunluğu açısından öne çıktığını göstermiştir. Novelia ve Fiona çeşitlerinin tuz stresi koşullarında daha iyi kök özelliklerine sahip olmaları nedeniyle tuzlu koşullara karşı diğer çeşitlerden daha iyi performans gösterdikleri sonucuna varılmıştır.

Anahtar Kelimeler: Pamuk, tuzluluk, hidroponik, fizyoloji, bitki büyümesi

INTRODUCTION

Salinity stress has been the primary limiting factor for agricultural productivity across the biosphere (Patil et al., 2024). Around 20% of the world's cultivated area is impacted by salinity (salt) stress. Cotton germination is influenced by environmental conditions, while seedling development depends on the genetic makeup, seed quality, and environmental conditions (Rehman and Farooq, 2019). Salinity reduces germination, plant development and yield. The main reason for the decrease in germination is reported to be the inhibition of water intake due to the high salt concentration or the toxic effect of salt. Salt can inhibit the activities of some enzymes that play an important role in seed germination. Germination and emergence of cotton seeds are both reduced and delayed due to the excessive salt

(Rezaee et al., 2015). Cotton is one of the major fiber crops of the world which is classified as a salt-tolerant crop (Saghir et al., 2002; Fowler, 1986; Maas, 1986; Anonymous, 2006). The threshold for salt damage is 7.7 dS/m (Ashraf, 2002) and yield decreases by around 50% at 17dS/m salt concentration (Maas, 1986). Hassan et al. (2014) reported that cotton is fairly salt-tolerant but its growth and productivity are affected at a physiological level which alters molecular response. The quantity and quality of irrigation water, the kind of soil, the amount of irrigation water that evaporates,

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The submitted date: April 25, 2025

The accepted date Tarihi: October 21, 2025

the temperature and density of the irrigation water, the surface geology, and even the influx of salt water from the seas all affect salinity concentration (Chaudhary et al., 2024).

Salinity-induced morphological and physiological changes, including a reduction in the dry weight of leaves and roots, root length, root volume, average root diameter, chlorophyll and proline contents, net photosynthesis and stomatal conductance (Zhang et al., 2014). Salt stress negatively affects plant growth and development by causing osmotic and ionic stress, these negative effects alter depending on the type of applied salt, the intensity and duration of the stress, the genotype and the development stage of plant exposure to the stress (Higbie et al., 2010, Culha and Cakirlar, 2011).

The roots of the cotton plant are the first organs affected by salt (Reinhardt and Rost, 1995). Salinity generally affects root development negatively (Raia and Azimov, 1988). Increases in salt concentration delays root development and reduce elongation. In soils with moderate salt concentrations, salt increased root development, but negatively affected shoot development (Jafri and Ahmet, 1994; Leidi, 1994). Cotton growth and plant development comprising plant height, fresh and dry weights, plant weight, root-to-shoot ratio, leaf area and canopy development, and other physiological parameters were severely affected by salinity (Loka et al., 2011, Munawar et al., 2021; Afzal et al., 2023).

Higbie et al. (2010) reported that the response to salt stress can vary depending on the variety. It has been reported that salinity causes a yield decrease of 8.3% to 23.1% in cotton varieties (Uzen, 2009). In a study examining the effects of four cotton varieties and 6 salt concentrations on germination, it was reported that PG2018 and Flash varieties showed higher germination rates than other cotton varieties, while the Lydia variety showed the lowest germination rate (Sahin and Akcali, 2016). Sharif et al., 2019 revealed that salt tolerance is a complex quantitative trait that is controlled by many genes each of which has a small effect.

Many studies have investigated agronomic and physiological responses of cotton cultivars to salinity under controlled conditions using soil, potting soil, or hydroponics (Qadir and Shams, 1997, Mahmood et al., 2022). Javid et al. (2002) investigated the changes in germination, seedling length and seedling weight of cotton seeds at 1.5, 5, 10, 15, 22 and 30 dS/m salt concentrations.

According to the research results, germination, seedling length and weight values were maximum at 1.5 and 5 dS/m salt concentrations, and decreases were experienced in the specified criteria as the salt concentration increased. The lowest values were determined at 30 dS/m. While the germination rate varied between 47-84% at 10 dS/m density, it decreased to 17-54% among varieties at 20 dS/m dose (Qadir and Shams, 1997). Salt stress imposes specific ions toxicity, somatically induced water stress and nutrient imbalance which impart adverse effects on plant growth, development and ultimately crop establishment. Salt stress affects the metabolic activities of enzymes, impairs nutrient uptake and results in nutritional disorders which leads to yield reduction and fiber quality deterioration (Sharif et al., 2019). Stress due to the soil salinity constrains plant growth, primarily by inhibiting leaf expansion and reducing the net photosynthetic rate (Pn) (El-Sabagh et al., 2022). There are plenty of studies about effect of salinity on cotton growth and physiology, but limited investigations have been carried out under hydroponic conditions.

The objectives of the present study were to compare the tolerance of 5 cotton varieties grown in hydroponics conditions to salt stress and to determine plant growth parameters and some physiological characteristics in plants grown in saline environments.

MATERIAL and METHODS

The study was conducted in the laboratory of the Department of Field Crops, Faculty of Agriculture, Siirt University according to a 2-factor experimental design in randomized plots with 4 replications. The experiment was established in a hydroponic medium containing 5 different cotton varieties which commonly planted (BA 1010, Fiona, May 455, Novelia and Orion) and 2 different salt concentrations (Control and 100 mM NaCl) as described by Mahmood et al., 2022. In the study, cotton seeds were first sterilized with 10% sodium hypochlorite (bleach) for 5 minutes. Then, each variety was germinated in separate containers containing perlite. Then, cotton plants of equal size were fixed in 0.5-liter transparent plastic containers containing nutrient solution, with the root part in the liquid. After their development for 1 week, the nutrient solution was renewed. Then, they were subjected to 100 mM NaCl and control applications. The content of the nutrient solution used; NO₃ (160 ppm), P₂O₅ (100 ppm), K₂O (360 ppm), CaO (120 ppm), Mg (40 ppm), B (0.4 ppm), Cu (0.4 ppm), Mn (0.4 ppm), Zn (0.8 ppm) and Fe (0.4 ppm).

Plants were grown in the growth chamber under a plant 16/8 hour photoperiod, 25/20 °C (day/night) temperature and 40±2% humidity conditions and 900 lux light intensity. In the study, plant development was examined after a 25-day plant development period. In this period plants had 4-5 leaves.

The green plant parts were cut at the water surface and fresh weight was then measured before removing leaves for further study (Figure 1). In the study, root length (cm), shoot length (cm), root surface area (cm²) and leaf area (cm²) were measured using the image j program. The shoot fresh and shoot dry weight (g) and root fresh and root dry weight (g) were measured on a precision scale.

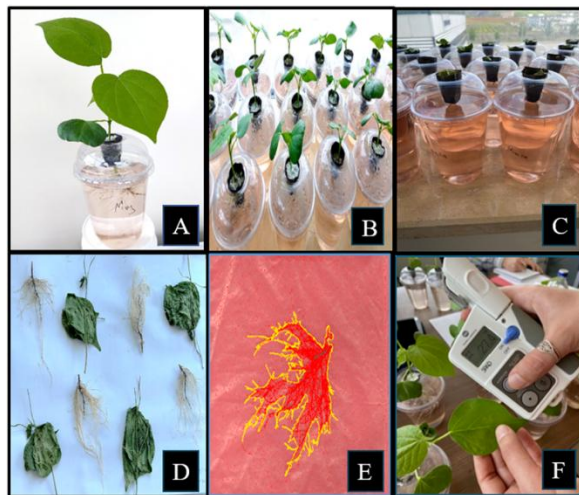


Figure 1. A: Seedling stage of cotton plant, B: Cotton grown under hydroponic medium, C: Plant growing medium, D: Root and stem measurements E: Root image F: Measurement of chlorophyll content with SPAD meter

The root/shoot ratio was determined by dividing the root length by the shoot length. Chlorophyll content (SPAD value) was determined using the Minolta SPAD-502 instrument (Minolta Camera Co., Osaka, Japan). Chlorophyll measurements were taken on the second or third newly opened but fully grown leaf from the top of the plant. The data obtained as a result of the experiment were subjected to variance analysis according to the random parcels factorial experimental design. Statistical analysis was performed with the help of the JMP package program, and the LSD (0.05) test was used to compare the means.

RESULTS and DISCUSSION

The differences between investigated traits and LSD (0.05) test results are shown in Table 1; 2; 3; 4; 5.

Root Length (cm)

In the study; variety, salt and variety x salt interaction were found to be significant for root length. It was determined that the mean root length was 10.02 cm in the control application and 8.77 cm when salt was applied and that salt

application reduced the root length by approximately 12.5 %. The root length of varieties ranged from 7.79 to 10.26 cm. When we compared the varieties, the highest root length was obtained from the Fiona variety (10.26 cm), followed by the Novelia variety (10.12 cm), and the lowest value was obtained from the BA 1010 variety (7.79 cm). Variety x salt interaction was found to be significant at the $p < 0.01$ probability level, the highest value was obtained from the control application of the Fiona variety (11.74 cm) and the lowest value (6.58 cm) was obtained from the control application of the BA 1010 cotton variety. The significant interaction between variety and salt application shows that root length values of varieties may vary depending on the applications. Silberbush and Ben-Asher (1987), confirmed these findings, who revealed that salinity usually reduces root growth due to the inhibition of root length and reduction in the number of secondary roots. Zhang et al. (2014), reported that salinity induced morphological and physiological changes, including a reduction in the root length. Min et al. (2014), confirmed these findings in their study, they reported that salinity inhibited root growth of cotton. However, Leidi (1994), reported that higher concentrations of salinity inhibited the primary root length, but the length of secondary roots was also retarded at mild salt stress. In this study, it was observed that root length decreased by 12.5% with salt application. Yadav and Vamadevaiah (2017), reported that salt application caused a decrease in root length in 27 different cotton varieties and this decrease varied between 3 and 52.04%.

Shoot Length (cm)

In the study, it was observed that the differences between the varieties were significant at the 5% probability level in terms of shoot length. Salt applications and variety x salt interactions were not found to be significant. The shoot length of the varieties varied between 8.73 and 11.42 cm, the highest shoot length was obtained from the Orion variety (11.42 cm) while the lowest value (8.73 cm) was obtained from the BA 1010 cotton variety. The findings of this study are consistent with the results of Munawar et al. (2021), who reported that salinity did not affect shoot length but different results were reported by Rafique et al. (2024), who observed highly significant decreases in shoot length. Khan et al. (1995) reported that shoot growth is more sensitive to salinity than roots. Yadav and Vamadevaiah (2017), observed a 4.23 to 78.02% decrease in shoot length in 27 cotton genotypes. Rafique et al. (2024), confirmed these findings. Farooq et al. (2021), revealed that salt stress adversely affects biomass production and ultimately brings about a decrease in seed cotton yield. Muhammad et al. (2025), indicated that increasing salinity levels, particularly through NaCl treatments, result in reduced shoot length and overall plant growth.

Table 1. Average values of root length and shoot length of the cotton varieties under salt stress

Variety	Root Length (cm)			Shoot Length (cm)			
	Control	100 mM NaCl	Mean	Control	100 mM NaCl	Mean	
BA 1010	6.58 e	9.00 bd	7.79b	8.64	8.82	8.73 b	
Fiona	11.74 a	8.78 ce	10.26 a	9.34	9.89	9.62 b	
May 455	11.23 ab	7.04 de	9.13 ab	10.20	8.67	9.44 b	
Novelia	10.07 ac	10.17 ac	10.12 a	9.26	9.34	9.30 b	
Orion	10.48 ac	8.82 ce	9.65 a	11.82	11.02	11.42 a	
Mean	10.02 a	8.77 b	9.39	9.86	9.55	9.70	
CV (%)	16.72			14.97			
LSD _(0,05) Variety	1.59*			1.46*			
LSD _(0,05) NaCl	0.99*			ns			
LSD _(0,05) Variety×NaCl	2.26**			ns			

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Table 2. Average values of root fresh weight and shoot fresh weight of the cotton varieties under salt stress

Variety	Root Fresh Weight (g)				Shoot Fresh Weight (g)			
	Control	100 mM NaCl	Mean		Control	100 mM NaCl	Mean	
BA 1010	0.63 bc	0.68 bc	0.66 bc		1.93	2.12	2.03 b	
Fiona	0.74 b	0.73 b	0.74 ab		2.30	2.20	2.25 b	
May 455	0.51 c	0.51 c	0.51 c		2.18	1.91	2.04 b	
Novelia	0.57 bc	1.08 a	0.83 a		2.59	3.36	2.98 a	
Orion	0.54 bc	0.56 bc	0.55 c		2.56	2.28	2.42 b	
Mean	0.60 b	0.72 a	0.66		2.31	2.38	2.34	
CV (%)	21.53				20.08			
LSD _(0,05) Variety	0.14**				0.46**			
LSD _(0,05) NaCl	0.08*				ns			
LSD _(0,05) Variety×NaCl	0.20**				ns			

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Root Fresh Weight (g)

In the study, variety, salt and variety x salt interaction were found to be significant for root fresh weight. It was determined that the mean root fresh weight was 0.60 g in the control application and 0.72 g when salt was applied and that salt application increased the root fresh weight under hydroponic conditions. Root fresh weight of varieties ranged from 0.51 to 0.83 g. Between the cotton varieties, the highest fresh root weight was obtained from the Novelia variety (0.83 g), and the lowest was obtained from the MAY 455 cotton variety with 0.51 g. Variety x salt interaction was found significant at the $p \leq 0.01$ probability level, the highest value was obtained from the salt application of the Novelia cotton variety with 1.08 g and the lowest value was obtained from the control application of the May 455 and salt application of the same variety.

In this study, it was observed that root fresh weight was not adversely affected by salt application. However, it has been reported in many studies that root fresh weight decreased

with salt application (Yadav and Vamadevaiah, 2017; Rafique et al., 2024).

Shoot Fresh Weight (g)

In the study, it was observed that the differences between the varieties were significant at the 1% probability level. Salt and variety x salt interaction was not found to be significant for this trait. The shoot fresh weight of the varieties varied between 2.03 and 2.98 g, the highest shoot fresh weight value was obtained from the Novelia variety (2.98 g) while the lowest value (2.03 g) was obtained from the BA 1010 cotton variety. Munawar et al. (2021), reported that in cotton plants, NaCl treatment significantly reduced plant biomass in two genotypes IR-NIBGE-13 and BS-2018 however NIAB-135, NIAB-512 and GH-HADI had the least difference in fresh weight between non-NaCl and NaCl-treated plants. Yadav and Vamadevaiah (2017), reported that they observed the salt tolerance of 27 cotton genotypes in vitro and found that the seedling fresh weights of the varieties decreased by 3.17 to 75.58% due to the salt application. In this study, it was determined that salt did not

have a significant effect on seedling fresh weight, but there was a slight increase in some genotypes (BA 1010 and Novelia) and a decrease in other genotypes, it is thought that this difference is due to the conditions of growing the plants in water and soil. Rafique et al. (2024), observed a highly significant decrease in shoot fresh weight. Rafiq et al. (2024), explained that the cotton plant development and fresh shoot and root weight are reduced due to the impact of salt on leaves.

Root Dry Weight (g)

In terms of root dry weight; variety and variety x salt interaction was found to be significant for root dry weight. It was determined that the root dry weight was 0.046 g in the

control application and 0.050 g when salt was applied and that salt application slightly increased the root dry weight under hydroponic conditions. The root dry weight of varieties ranged from 0.037 to 0.057 g. Between the cotton varieties, the highest dry root weight was obtained from the Novelia variety (0.057 g), and the lowest value was obtained from the MAY 455 cotton variety with 0.037 g. Variety x salt interaction was found significant at the $p \leq 0.01$ probability level, the highest value was obtained from the salt application of the Novelia cotton variety with 0.071 g and the lowest value was obtained from the control application of the May 455 and salt application of the same variety. Zhang et al. (2014), observed that salinity significantly reduced the root dry weights.

Table 3. Average values of root dry weight and shoot dry weight of the cotton varieties under salt stress

Variety	Root Dry Weight (g)			Shoot Dry Weight (g)		
	Control	100 mM NaCl	Mean	Control	100 mM NaCl	Mean
BA 1010	0.046 bd	0.043 bd	0.045 bc	0.22	0.18	0.20 b
Fiona	0.049 bc	0.057 b	0.053 ab	0.24	0.21	0.22 b
May 455	0.040 cd	0.034 d	0.037 c	0.22	0.17	0.19 b
Novelia	0.044 bd	0.071 a	0.057 a	0.27	0.30	0.29 a
Orion	0.050 bc	0.044 bd	0.047 b	0.26	0.19	0.23 b
Mean	0.046	0.050	0.048	0.24	0.21	0.23
CV (%)	20.13			20.79		
LSD _(0,05) Variety	0.010**			0.046**		
LSD _(0,05) NaCl	ns			0.030*		
LSD _(0,05) Variety×NaCl	0.013**			ns		

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Shoot Dry Weight (g)

In the study, it was observed that the differences between the varieties were significant at the 1% probability level and salt treatment was significant at the 5% probability level, variety x salt interactions were not found to be significant for this trait. The shoot dry weight of the varieties varied between 0.19 and 0.29 g, the highest shoot dry weight value was obtained from the Novelia variety (0.29 g) while the lowest value (0.19 g) was obtained from the MAY 455 cotton variety. The salt application resulted in a decrease in shoot

dry weight compared to the control, only the Novelia variety was not adversely affected by the salt application. Habib et al. (2014), compared the performance of 10 different cotton lines under salinity stress and the results showed that shoot dry weight was reduced due to the effect of salinity they recommended the BH-172 cotton variety as best against salinity stress. Yadav and Vamadevaiah (2017), observed a reduction in shoot dry weight of different cotton varieties varied between 0.91 and 72.49% in their in-vitro studies. Similar results were also reported by Munawar et al. (2021), who revealed a significant decrease in shoot dry weights.

Table 4. Average values of root/shoot ratio and root surface area of the cotton varieties under salt stress

Variety	Root/Shoot Ratio			Root Surface Area (cm ²)		
	Control	100 mM NaCl	Mean	Control	100 mM NaCl	Mean
BA 1010	0.77 d	1.03 ad	0.90	11.83 e	18.97 cd	15.40 b
Fiona	1.27 a	0.90 bd	1.09	20.46 bd	25.92 ab	23.19 a
May 455	1.10 ac	0.81 cd	0.95	19.20 cd	15.12 de	17.16 b
Novelia	1.16 ab	1.09 ac	1.12	21.16 bc	26.35 ab	23.76 a
Orion	0.89 bd	0.81 cd	0.85	29.14 a	17.22 ce	23.18 a
Mean	1.04	0.93	0.98	20.36	20.72	20.54
CV (%)	20.40			20.15		
LSD _(0,05) Variety	ns			4.22**		
LSD _(0,05) NaCl	ns			ns		
LSD _(0,05) Variety×NaCl	0.28*			5.95**		

*, **, Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Root/Shoot Ratio

In terms of root/shoot ratio; variety and salt were not found to be significant, variety x salt interaction was found significant at the 5% probability level. It was determined that the root/shoot ratio was 1.04 in the control application and 0.93 when salt was applied, on the other hand mean of variety ranged from 0.90 to 1.12. Variety x salt interaction was found significant, the highest value was obtained from the control application of the Fiona cotton variety with 1.27, while the lowest value was obtained from the control application of the BA 1010 cotton variety with 0.77. Min et al. (2014), indicated that the root/shoot ratio increased significantly as irrigation water salinity increased.

It has been reported that the root/shoot ratio decreases due to the salinity and saline irrigation water (Farooq et al., 2021). Salt stress reduces the root/shoot ratio, indicating that shoot growth is more sensitive to salt stress compared to root growth (Khan et al., 1995, Anwar et al., 2023).

Several researchers have reported that root/shoot ratio increased as soil salinity increased (Min et al., 2014; Meloni et al., 2001). Upreti and Murti, 2010 explained the reasons, the one is that salinity causes greater damage to shoots than to roots, the other, it is possible that plants respond to high

salt concentrations by allocating a greater proportion of photosynthates to roots.

Root Surface Area (cm²)

In the study, it was observed that the differences between the varieties were significant at the 1% probability level and variety x salt interaction was found to be significant for root surface area. It can be seen from Table 4 that the root surface area was not affected by the salt application. The root surface area of the varieties varied between 15.40 and 23.76 cm², the highest root surface area was obtained from the Novelia (23.76 cm²), followed by Fiona and Orion cotton varieties and they shared the same statistical group, while the lowest value (15.40 cm²) was obtained from the BA 1010 cotton variety. For this trait variety x salt interaction was found significant, the highest value was observed from the control application of the Orion variety with 29.14 cm², while the lowest value was observed from the control application of the BA 1010 cotton variety with 11.83 cm². Zhang et al. (2014), observed two cotton cultivars for salinity tolerance and revealed that the root surface area was reduced from the salt application. In this study, root surface area decreased in May 455 and Orion cultivars, but increased in BA 1010, Fiona and Novelia cultivars.

Table 5. Average values of leaf area and SPAD value of the cotton varieties under salt stress

Variety	Leaf Area (cm ²)				SPAD value			
	Control	100 mM NaCl	mM	Mean	Control	100 mM NaCl	mM	Mean
BA 1010	31.84	25.58		28.72 b	30.00 a	25.80 b		27.90 b
Fiona	42.08	33.66		37.87 a	28.87 a	29.90 a		29.38 a
May 455	40.41	20.83		30.62 b	26.82 b	30.07 a		28.45 ab
Novelia	46.26	32.06		39.16 a	26.27 b	26.42 b		26.35 c
Orion	46.69	29.41		38.05 a	26.40 b	25.57 b		25.98 c
Mean	41.46 a	28.31 b		34.88	27.67	27.55		27.61
CV (%)	14.42				4.52			
LSD_(0,05) Variety	5.12**				1.26**			
LSD_(0,05) NaCl	3.24**				ns			
LSD_(0,05) Variety×NaCl	ns				1.79**			

*, **, Significant at p ≤ 0.05 and p ≤ 0.01, respectively

Leaf area (cm²)

It is observed that there are significant differences at a 1% significance level between salt application and varieties in terms of leaf area, and the salt x variety application interaction is not significant. It was determined that the mean of leaf area was 41.46 cm² in the control application and 28.31 cm² in the salt application. These findings indicated that salt treatment had a significant decrease in leaf area (31.72%). Leaf area values of the varieties varied between 28.72 and 39.16 cm². Among the varieties the highest leaf area was recorded in the Novelia cotton variety (39.16 cm²) followed by Orion and Fiona (38.05 and 37.87 cm²), these varieties were shared the same group, on the other hand, the lowest leaf area was recorded in the BA 1010 cotton variety with 28.72 cm² value. It is observed that the variety x salt interaction is insignificant in terms of leaf area. These findings show that the responses of the varieties to salt application are stable. In this study conducted in a hydroponic environment, it was revealed that salt application reduced leaf area. The decreasing in the leaf area due to the salt application was highest in MAY 455 (48.45%), followed by Orion (37.01%) and Novelia (30.69%), while the lowest was observed in BA 1010 (19.67%) and Fiona (20.00%). Similar results were obtained in the study conducted by Saleh (2012), and similar findings were also reported by Ahmad et al. (2019), who revealed that salt stress leads to a decrease in leaf area. Zhang et al. (2014), also revealed similar results when observed the highest leaf areas in the control group, whereas leaf areas decreased continuously as salinity increased and also they observed significant differences between cultivars for leaf area.

Chlorophyll Content (SPAD value)

In the study, it was observed that the differences between the varieties were significant at the 1% probability level and variety x salt interaction were found to be significant for chlorophyll content. It can be seen from Table 5, that SPAD values were not affected by the salt application. The SPAD values of the varieties varied between 25.98 and 29.38, the highest SPAD value was obtained from the Fiona (29.38), followed by the MAY 455 cotton variety and they shared the same statistical group, while the lowest value (25.98) was obtained from the Orion cotton variety. For SPAD value variety x salt interaction was found significant, highest value was observed from the salt application of the MAY 455 variety with 30.07, while the lowest value was observed from the salt application of the Orion cotton variety with 25.98. Similar results were reported by Munawar et al. (2021), they revealed that chlorophyll content did not differ significantly in all the genotypes between salt-treated and non-treated plants before and after salt stress was applied. This indicated that NaCl does not effect on the efficacy of light during photosynthesis. However, some researchers

reported that salt stress significantly increased leaf chlorophyll content (Saleh, 2012; Ma et al., 2021).

Zhang et al. (2014), revealed that salt treatment decreased the chlorophyll content of cotton. It is seen that different findings from the literature were obtained in the researches, the difference of this study from the others is that the research was conducted in a growth chamber and hydroponic environment.

CONCLUSION

Salinity is among the most important abiotic stresses and negatively affects yield, plant development and physiological characteristics of cotton. Therefore, this study was carried out to investigate the effects of salt stress on plant development and some physiological properties in 5 cotton varieties grown in hydroponics. In the study, it was determined that the effect of the salt application on root length, root fresh weight, shoot dry weight and leaf area was significant, on the other hand, shoot length, shoot fresh weight, root dry weight, root/shoot ratio, root surface area and SPAD values were not significantly affected from the salt application under hydroponic ambient conditions. It was determined that there was a decrease in root length of the varieties with salt application and this decrease was approximately 12.50%, root fresh weight increased by 20% in salt application compared to the control. The root fresh weight increased by 20% in salt application compared to control. The shoot dry weight decreased with salt application and this decrease was observed to be 12.5%. It was determined that the most significant decrease was observed in the leaf area with 31.72%. Salt application x variety interactions were also significant for root length, root fresh weight, root dry weight, root/shoot ratio, root surface area and SPAD value. The fact that interactions between salt application and varieties are significant indicates that the reactions of varieties to salt may vary and are not stable.

In the study, it was determined that there were significant differences among the varieties in all traits examined except root/ shoot ratio. From the study, it was observed that the Novelia variety was prominent in terms of root fresh weight, shoot fresh weight, root dry weight, shoot dry weight, root surface area and leaf area, while Fiona and Novelia varieties were prominent in terms of root length and Fiona variety for chlorophyll content and Orion variety for shoot length. It was concluded that Novelia and Fiona varieties had better performance than other varieties for saline conditions because they have better root properties under salt stress conditions.

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