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Original article

Effect of Water Deficit and Sulfur Doses on Fiber Yield and Quality in Cotton

Berkant Ödemiş [a, *], Batuhan Akgöl [b], Deniz Can [b] & Yaşar Akışcan [c]

[a] Department of Biosistem, Faculty of Agriculture, University of Mustafa Kemal, Hatay, Türkiye
[b] Progen Seed Company, Hatay, Türkiye
[c] Department of Field Crops, Faculty of Agriculture, University of Mustafa Kemal, Hatay, Türkiye

Abstract

The study was carried out in the Eastern Mediterranean Region (Amik Plain) using the Carisma cotton variety with a randomized block design, split plots, and three replications. Various irrigation levels were implemented: full field capacity (I100), 66% (I66), 33% (I33), and non-irrigated (I0). Additionally, sulfur doses were applied as foliar sulfur at 150 ml da^{-1} (S1), 250 ml da^{-1} (S2), 350 ml da^{-1} (S3), and a control (S0). The impact of these treatments was evaluated based on factors such as fiber yield, evapotranspiration, leaf sulfur concentration, and fiber quality characteristics.

Evapotranspiration (ET) ranged from 299 mm to 1096 mm in the first year and from 247 mm to 995 mm in the second year. In comparison to the control (K0), evapotranspiration slightly decreased with increasing sulfur doses in the first year but increased in the second year. Water restriction led to a reduction in both fiber yield and evapotranspiration in both years. Fiber yield decreased in the first year but increased in the second year with higher sulfur doses. The highest fiber yield was observed in the fully irrigated (I100) treatments in both years (227.2 kg da^{-1} and 230.2 kg da^{-1}). Among sulfur doses, the highest fiber yield was obtained with S0 (175.8 kg da^{-1}) in the first year and S1 (185.5 kg da^{-1}) in the second year. With an increase in water restriction, ginning percentage efficiency improved in the first year but displayed an inconsistent trend in the second year. The highest ginning percentage efficiency was achieved with the S2 dose in the first year and the S1 dose in the second year, on average.

The effects of irrigation water deficit and sulfur doses on fiber quality varied by year. Water stress influenced the spinning consistency index, fiber fineness, fiber length, and fiber uniformity in both years. In the first year, short fiber content and fiber strength were affected, while in the second year, fiber elongation and fiber brightness showed significant changes. Sulfur doses had fewer effects on the parameters; in the first year, fiber fineness and yellowness were impacted, whereas in the second year, the spinning consistency index, fiber uniformity, short fiber content, and fiber strength were influenced.

Keywords: Cotton, Water deficit, Sulfur, Fiber quality traits.

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*** Corresponding author:**

Berkant Ödemiş, Department of Biosistem, Faculty of Agriculture, University of Mustafa Kemal, Hatay, Türkiye.
Email: bodemisenator@gmail.com

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is one of the most important industrial crops in the world, producing approximately 25.8 million tons of fiber across 33.4 million hectares. Its fiber is primarily used in the textile industry, while the seeds serve as raw materials for the oil industry, and the meal contributes to livestock production. Thus, cotton holds a significant place in the economies of the countries where it is cultivated (Anonymous, 2017). In terms of production volume, Turkey ranks first in Europe and sixth globally. The average fiber yield of cotton grown on approximately 372,000 hectares in Turkey is 1,229 kg ha^{-1}, although this yield varies from year to year. The Eastern Mediterranean Region, where this study was conducted, accounts for 9.06% of Turkey's cotton production (Anonymous, 2013).

Cotton consumes more water compared to many other plant groups. Although water requirements vary depending on the climate, cotton typically requires about 985 to 1,100 mm of water during an irrigation period (Baştuğ & Tekinel, 1989). The high irrigation water consumption of cotton is one of the main limiting factors for its productivity, particularly during the hot and dry summer months in the Mediterranean Region. With the intensifying impacts of global climate change and water scarcity/drought, crop production is declining worldwide. This issue is especially critical for crops like cotton, where both yield and fiber quality are significantly affected by water deficiency. Cotton growth and development are greatly influenced by water stress, with the pre-flowering period being the most sensitive to drought stress (Loka, 2012). Water stress during this period can lead to significant yield losses (Orgaz et al., 1992). The effects of water stress depend on its severity, duration, the growth stage during which the stress occurs, and the plant genotype (Loka & Oosterhuis, 2012). Severe water stress reduces leaf area, dry matter accumulation, the number of nodes, boll production, and boll weight (Pettigrew, 2004). However, it has been reported that applying 20% to 25% less water than full irrigation (deficit irrigation) does not significantly affect cotton yield (Karam et al., 2006).

Since cotton is a raw material for the textile industry, it is essential to identify factors that affect fiber quality and yield. Research shows that water stress influences fiber quality, though the results are often conflicting and limited. Previous studies have indicated that cotton varieties respond differently to water stress (Penna et al., 1998), highlighting the importance of improving the response and adaptation abilities of different genotypes to deficit irrigation (Campbell & Bauer, 2007).

One of the most important options for mitigating the adverse effects of water stress on plants is fertilizer management (Ma et al., 2004; Garg et al., 2004; Hu et al., 2008). However, fertilizer management becomes more complex in drought conditions due to the simultaneous presence of salinity issues in many arid areas. Despite this complexity, many studies have shown that appropriate timing, doses, and forms of fertilizers during drought/water stress periods can enhance plant resilience. These studies have demonstrated that potassium regulates stomatal function and increases drought tolerance in plants under drought conditions (Studer, 1993), while phosphorus improves water use efficiency (WUE), stomatal conductance (Brück et al., 2000), and photosynthesis rates (Ackerson, 1985). Another nutrient that has been shown to reduce the effects of drought stress is sulfur. Sulfur plays a key role in preventing or mitigating the decline of leaf chlorophyll content under water stress conditions, thus maintaining a healthy photosynthetic process (Li-na et al., 2005). Chlorophyll reduction during water deficiency is more pronounced in functional (photosynthetically active) leaves (Dietz, 1989). In such conditions, sulfur application can increase chlorophyll content and alleviate the severity of abiotic stress (Jie et al., 2008). While sulfur takes approximately 20 days to be absorbed and become useful to the plant when applied to the soil, this process is reduced to just 8 hours with foliar application (Kaçar & Katkat, 2007). Very little research has been published in the last decade on sulfur fertilization in cotton-growing regions, despite the importance of sulfur fertilization for optimal plant productivity (Chan et al., 2013). The lack of information on the effects of sulfur deficiency on cotton yield components highlights the need for long-term studies in different climatic areas. Therefore, it is crucial to determine the benefits of foliar sulfur application during short drought periods when plants enter stress conditions.

This study aims to determine the effects of foliar sulfur application on leaf sulfur concentrations, fiber yield, evapotranspiration, ginning efficiency, and fiber quality characteristics in cotton plants under deficit irrigation in field conditions. The study seeks to evaluate the role of sulfur in enhancing drought tolerance rather than simply serving as a plant nutrient.

MATERIALS and METHODS

Experimental site

The research was conducted in 2015 and 2016 under the conditions of Amik Plain, located in the Eastern Mediterranean Region (Hatay Province). Amik Plain is one of the most intensively cotton-cultivated regions in Turkey and is situated in the Mediterranean climate zone. The long-term average temperature is 20 °C, the relative humidity is 54%, and total precipitation is 391 mm. The mean temperature ranged from 26.09 to 25.93 °C, total precipitation ranged from 20.6 to 149.2 mm, relative humidity ranged from 52% to 56%, solar radiation ranged from 266 to 277 W m^{-2}, soil temperature ranged from 28.89 to 27.48 °C, and wind speed ranged from 6.55 to 5.95 km h^{-1} during the experimental years. The soil texture was silty clay loam, with irrigation water classified as C2S1, soil water electrical conductivity (ECe) of 0.65 dS m^{-1}, pH 7.70, and organic matter content of 0.35%. No sulfur was detected in the soil using the turbidimetric barium method (Fox et al., 1964).

Experimental design

In the experiment, the 'Carisma' cotton cultivar, which is early maturing, has less hairy leaves, has a plant height classified as "medium-long," has a conical plant structure, is tolerant to wilt disease, and is suitable for machine harvesting, was used as the material. The research was conducted in a randomized block design with split plots, using three different doses of elemental sulfur applied via foliar application, under four different irrigation levels with three replications. Irrigation treatments began when 50% of the available soil moisture was depleted in the full irrigation treatment, restoring the soil moisture to field capacity. Aside from the non-irrigated control (I0), the treatments were designed as full irrigation (I100), where the deficit moisture was replenished to field capacity, and deficit irrigation levels of 66% (I66) and 33% (I33) of the full irrigation. Soil moisture was measured weekly using the gravimetric method.

Laterals with a flow rate of 1.8 l/h and 40 cm dripper spacing were used to apply irrigation water. Each irrigation treatment consisted of four rows, with plot lengths of 15 m and replication lengths of 5 m. The plots were separated by two buffer rows. The distance between plants was 70 cm between rows and 15 cm within rows.

Since the aim was for the plant to recover from stress in a shorter time, sulfur fertilizer was applied in its pure elemental form as a foliar application. The sulfur treatments were S0 (application of N, P, and K to the soil), S1 (S0 + 150 ml da^{-1} sulfur), S2 (S0 + 250 ml da^{-1} sulfur), and S3 (S0 + 350 ml da^{-1} sulfur). The flowering and squaring stages are the most sensitive to water stress and are the periods during which yield is most affected (Loka & Oosterhuis, 2014; Krieg, 1997). Therefore, foliar sulfur fertilization was carried out only during the squaring and flowering stages (from 10% squaring to 10% boll formation).

The seasonal fertilizer requirement for the plant was divided equally according to the number of irrigations to be carried out during the squaring and flowering stages, and was then applied to the plants. Fertilization was performed in the middle of the two irrigations (3 or 4 days after irrigation) in the early morning (6:00-6:30) when the wind did not adversely affect fertilizer distribution. To avoid variations in fertilizer concentration during each application, the amount of water consumed from the backpack sprayer before the application was tested with a water-filled sprayer in another area of the same size. After determining the amount of water consumed, the calculated amount of liquid sulfur was mixed into this volume for application. Cotton is typically irrigated five times under the conditions of our region (Akgöl, 2012). In this study, similarly, five irrigations were made, and each sulfur dose (150, 250, 350 ml da^{-1}) was divided into five equal applications. In the application with a backpack sprayer, the application was performed by the same person to ensure consistency in walking speed among applicators. Before planting, 20 kg da^{-1} of 18-46-0 (DAP) fertilizer was applied, and after planting, 4 kg da^{-1} of pure nitrogen was applied using the fertigation method (Burt et al., 1995) during each of the first four irrigations.

Measurements

Plant water consumption was determined according to the "Soil Water Budget" method. For this purpose, soil moisture was measured using the gravimetric method before each irrigation at depths of 0-30, 30-60, and 60-90 cm from the second replicate of all treatments (Equation 1) (Bos et al., 2009).

$$Et = S + R + Cr - Dp - Rf \pm \Delta S \quad (1)$$

In the equation; Et = Plant water consumption (mm); S = Amount of irrigation water applied (mm); R = Rainfall (mm); Cr = capillary rise (mm); Dp = deep infiltration (mm); Rf = surface runoff (mm); ΔS = Moisture change in soil profile (mm/90 cm). In this equation, rainfall (R) was measured using a pluviometer in the research area, and ΔS was determined using the gravimetric method. Surface runoff (Rf) was not calculated because the drip irrigation method was used.

Fiber Yield (kg da^{-1}): Since each irrigation level consists of four rows, during harvest, one row from the right and one from the left were skipped, along with a 1-meter distance at the beginning and end of each row. The remaining area was manually harvested, and the total seed cotton yield per decare was calculated. After the harvest, the collected seed cotton samples were processed in a roller gin machine to separate the lint from the seeds. The lint was then weighed to determine the lint yield.

Ginning percentage (%): The seed cotton samples collected before harvest were processed in the roller gin machine. Using the obtained fiber and seed weights, the gin percentage was calculated using the following equation (Equation 2):

$$\text{Ginning percentage (\%)} = (\text{Fiber weight (g)} / \text{Seedcotton weight (g)}) \times 100 \quad (2)$$

Fiber Properties

To determine the technological properties of the fibers, the fiber samples were analyzed using the USTER HVI-1000 device, and the values obtained were interpreted according to the ranges provided below (Anonymous, 2024b).

Spinning consistency index: This index measures the fiber's ability to be spun into yarn, with a higher value preferred. The classification is as follows: Very Poor: <129, Average: 130-140, Good: 141-159, Very Good: >160.

Fiber length (mm): This is considered one of the most important fiber quality characteristics. Long fibers are highly desirable for commercial production. Short: ≤25.15; Medium: 25.15-27.94; Long: 27.94-32.00; Very Long: ≥32.00.

Fiber fineness (Micronaire): The fineness of the fiber affects the quality of the products produced in the textile industry. Very Fine: ≤3.0; Fine: 3.0-3.6; Medium: 3.7-4.7; Coarse: 4.8-5.4; Very Coarse: ≥5.5.

Fiber strength (g tex^{-1}): This parameter is important for indicating the durability of the fiber during yarn production. Very Weak: ≤21; Weak: 22-24; Medium: 25-27; Strong: ≥31 g tex^{-1}.

Fiber elongation (%): This metric shows the resistance of the fibers to breakage during mechanical processes. Very Low: ≤5.0; Low: 5.0-5.8; Medium: 5.9-6.7; High: 6.8-7.6; Very High: ≥7.7.

Fiber Uniformity (%): This indicates the fibers' ability to maintain uniformity. Fiber uniformity is the percentage ratio of the difference between fiber length and average length. Very Low: ≤77%; Low: 77-80%; Medium: 81-84%; High: 85-87%; Very High: ≥87%.

Short fiber content (%): A low short fiber content indicates higher quality fiber that is more suitable for yarn production, resulting in less waste during yarn manufacturing and lower costs. Very Low: ≤6; Low: 6-9; Medium: 10-13; High: 14-17; Very High: ≥18.

Fiber Brightness (rd): This indicates the degree to which the fiber reflects light and determines the brightness of cotton. A higher value is preferred. Matte: 40-55; Semigloss: 55-65; Medium Bright: 65-70; Bright: 70-80; Extra Bright: 80-85.

Fiber Yellowness (+b): This indicates the pigment/color value of the cotton. A lower value is desired. White: 4-8; Light Yellow: 8-10.5; Yellow: 11-13; Very Yellow: 13-18.

Data Analysis and Evaluation

All data measured during the experiment were evaluated using analysis of variance (ANOVA). The means of the data obtained from the measurements and analyses were compared using the least significant difference (LSD) test (Bek & Efe, 1988).

RESULTS and DISCUSSION

Evapotranspiration

Evapotranspiration was determined to be 525–558 mm, 797–817 mm, and 995–1,096 mm in the first and second years for the I33, I66, and I100 treatments, respectively. In the non-irrigated I0 treatment, evapotranspiration was measured at 299 mm in the first year and 247 mm in the second year. In the same area, evapotranspiration for cotton was reported to be between 290–678 mm and 283–677 mm using the drip irrigation method in 2012–2013. When the irrigation studies conducted in the region are examined, it is observed that evapotranspiration has increased compared to previous years. Climate change has altered precipitation patterns, especially affecting air temperature and the timing of rainfall, causing the planting time for cotton, which could be planted in April 30 years ago, to extend until the end of May today.

Sulfur doses did not cause significant differences in evapotranspiration (ET). Increasing sulfur doses slightly reduced ET in the first year, while in the second year, ET increased in the S1 (150 ml da^{-1}) treatment but decreased in the higher doses (S2 and S3). Although there were no application differences that could explain this change, it was suggested that variations in sulfur application timing by a few days between years, along with minor short-term fluctuations in air temperature and wind speed, may have contributed to the observed effects. There has been no research specifically addressing the effect of sulfur on evapotranspiration in cotton. However, in a separate study conducted during the same years (2015–2016), it was found that ET decreased in the first year as sulfur doses increased and also decreased in the second year (Kazgöz, 2017).

Fiber yield: Fiber yield increased with the amount of irrigation water in both years, while sulfur application reduced fiber yield in the first year but increased it in the second year (Table 1). Fiber yields for the I0, I33, I66, and I100 treatments were 65.3 kg da^{-1}, 140.0 kg da^{-1}, 195.9 kg da^{-1}, and 227.2 kg da^{-1}, respectively, in the first year, and 82.0 kg da^{-1}, 161.3 kg da^{-1}, 216.4 kg da^{-1}, and 230.2 kg da^{-1}, respectively, in the second year. Due to the decrease in yield associated with sulfur application in the first year, the highest yield was recorded in the S0 treatment (175.8 kg da^{-1}), while the lowest was in the S2 treatment (149.6 kg da^{-1}). In the second year, the highest average yield was observed in the S1 dose (160.7 kg da^{-1}). The effects of interactions were not found to be statistically significant. Average fiber yields were higher in the second year across all irrigation treatments.

Table 1. Variation of evapotranspiration and fiber yield depending on treatments$^{*, \beta}$

Treatment	Amount of Irrigation Water$^{\#}$ (mm)		Evapotranspirasyon$^{\#}$ (mm)		Fiber Yield (kg da^{-1})	
	2015	2016	2015	2016	2015	2016
I_0	90.60	149.20	299	247	65.3 d	82.0 d
I_{33}	422.60	455.65	525	558	140.0 c	161.3 c
I_{66}	754.83	771.45	817	796	195.9 b	216.4 b
I_{100}	1097.06	1077.85	1096	995	227.2 a	230.2 a
S_0	591.27	613.54	701.82	627.85	175.8 a	160.7 c
S_1	591.27	613.54	685.40	677.34	153.0 b	185.5 a
S_2	591.27	613.54	682.81	650.90	149.6 b	167.2 bc
S_3	591.27	613.54	668.09	641.48	150.2 b	176.6 ab

[*]The values for irrigation water and evapotranspiration presented in the table were previously published by Ödemiş et al., 2022. [β]Since the effects of interactions were not found to be statistically significant, only the average values were given. [#]Differences between values indicated by different letters are statistically significant.

Water deficit significantly reduced cotton yield, and foliar application of sulfur did not significantly mitigate the effects of stress. The fact that most studies suggesting sulfur's effectiveness in reducing stress were conducted under controlled conditions—while ignoring the cumulative effects of factors such as temperature, wind, and insolation intensity—may have exaggerated the perceived benefits of sulfur. In this study, it was believed that high temperature, wind speed, and relative humidity, along with the elemental form of sulfur and low leaf moisture content, hindered the diffusion of sulfur in the leaves.

Ginning percentage (%): Ginning percentage was influenced by irrigation levels, sulfur doses, and the interaction between irrigation levels and sulfur doses only in the first year ($p < 0.01$). The highest and lowest ginning yields were recorded at irrigation levels I0 (44.12%) and I100 (41.43%), and sulfur doses S0 (42.52%) and S3 (43.33%) in the first year.

It was observed that the variation in ginning percentage among the treatments was wide, ranging from 36.26% (S0K0, 2016) to 44.26% (S33K2, 2015). Although it has been suggested that water deficit negatively affects ginning percentage (Karademir et al., 2011), deficit irrigation was effective only in the first year. In a study conducted at the same location and during the same period with a different irrigation strategy, the ginning percentage was measured at 42.95% when cotton was irrigated during the flowering period and at 45.40% when it was not irrigated during that period (Kazgöz, 2017). Ginning percentages were found to range from 38.80% to 41.53% and from 37% to 48% in studies conducted in different regions (Çoşkun, 2015). In general, foliar fertilizer applications did not cause significant differences in ginning yield. In studies conducted in different climatic regions, the differences in ginning yields can be attributed to the irrigation water, methods, and programs applied, as well as climatic differences between years.

Table 3. Ginning percentage values

Treatments	2015	2016
I_0S_0	44.13 ab	36.26
I_0S_1	44.00 ab	42.22
I_0S_2	44.33 a	43.28
I_0S_3	44.00 ab	40.89
$I_{33}S_0$	43.13 bd	42.86
$I_{33}S_1$	43.80 ac	42.80
$I_{33}S_2$	44.53 a	41.06
$I_{33}S_3$	42.40 df	42.46
$I_{66}S_0$	41.87 eg	42.26
$I_{66}S_1$	42.47 df	42.40
$I_{66}S_2$	42.87 ce	40.80
$I_{66}S_3$	42.67 de	42.93
$I_{100}S_0$	40.93 g	42.13
$I_{100}S_1$	41.07 g	41.40
$I_{100}S_2$	41.60 fg	41.93
$I_{100}S_3$	42.13 df	42.13
I_0	44.12 a	40.66
I_{33}	43.47 b	42.30
I_{66}	42.47 c	42.10
I_{100}	41.43 d	41.90
S_0	42.52 b	40.88 d
S_1	42.83 ab	42.20 a
S_2	43.33 a	41.77 c
S_3	42.80 b	42.10 b

[#]Differences between values indicated by different letters are statistically significant.

Fiber Quality traits

The spinning consistency index (SCI) is a criterion used not only to calculate the spinnability of fibers but also to determine yarn fiber strength and spinning potential. From a textile industry perspective, higher spinnability indicates better fiber quality in cotton (Avşar & Karademir, 2022). In general, SCI decreased as water stress increased in both years. Despite receiving 33% less water than the I100 treatment in the second year, the highest SCI was recorded in the I66 treatment, which was grouped with I100 (141.83 and 143.5). In the second year, SCI reached as high as 158.67 in the I66S1 treatment. No significant effect of sulfur doses on SCI was observed in either year.

Table 4. Fiber quality parameters (2015)

Treatments		Spinning consistency index#	Fiber fineness(mic.)	Fiber length (mm)	Fiber uniformity (%)	Short fiber content(%)	Fiber strength (g tex^{-1})	Fiber elongation(%)	Fiber brightness (Rd)	Fiber yellowness (+b)
I0		108.55 **c**	5.00 **b**	25.67 d	81.62 d	**8.77 a**	26.78 c	**5.75**	80.22	**9.50 a**
I33		114.96 **c**	**5.41 a**	26.18 c	82.51 c	8.08 b	28.66 b	5.62	79.67	9.46 a
I66		131.94 **b**	5.07 **b**	27.99 b	83.51 b	7.18 c	**30.47 a**	5.72	80.24	8.93 b
I100		**139.90 a**	4.98 **b**	**29.30 a**	**84.61 a**	6.26 d	30.29 a	5.52	**80.56**	8.90 b
Irrig. Level		**	**	**	**	**	**	ns	ns	**
S0		**125.18**	4.95 c	27.40	82.53	**7.64**	**29.73**	5.68	**80.49**	8.99 b
S1		121.50	**5.31 a**	27.13	83.13	7.42	28.93	**5.76**	79.85	**9.40 a**
S2		124.75	5.08 bc	**27.44**	**83.40**	**7.64**	28.64	5.56	80.21	9.18 ab
S3		123.92	5.11 b	27.18	83.19	7.60	28.90	5.62	80.13	9.22 ab
Sulfur Doses		ns	**	ns	ns	ns	ns	ns	ns	*
I0	S0	108.20	4.92	25.54	80.93	8.89	27.57	6.42	80.57	9.33
	S1	110.33	5.18	25.87	82.30	7.73	26.97	5.43	79.57	9.73
	S2	108.67	4.81	25.67	81.47	9.70	26.50	5.43	80.10	9.63
	S3	107.00	5.08	25.60	81.80	8.77	26.10	5.70	80.63	9.30
I33	S0	120.17	5.14	26.87	82.21	7.90	29.46	5.34	80.49	9.25
	S1	106.67	5.58	25.89	81.83	8.73	27.87	6.03	78.90	9.40
	S2	119.67	5.43	26.03	83.70	7.20	28.50	5.53	79.70	9.70
	S3	113.33	5.49	25.95	82.30	8.50	28.80	5.57	79.57	9.50
I66	S0	133.43	4.89	28.07	83.20	7.27	30.96	5.75	80.07	8.58
	S1	133.67	5.25	28.13	84.27	6.93	30.23	5.43	80.43	9.33
	S2	126.33	5.19	27.89	82.97	7.40	29.90	5.73	80.50	8.63
	S3	134.33	4.93	27.87	83.60	7.13	30.77	5.97	79.97	9.17
I100	S0	138.93	4.86	29.11	83.78	6.49	30.94	5.19	80.84	8.78
	S1	135.33	5.23	28.62	84.13	6.30	30.63	6.13	80.50	9.13
	S2	144.33	4.91	30.18	85.47	6.27	29.67	5.53	80.53	8.77
	S3	141.00	4.94	29.30	85.07	6.00	29.93	5.23	80.37	8.90
Irrig. Level x Sulfur Doses			ns	ns	ns	ns	ns	ns	ns	ns

Differences between values indicated by different letters are statistically significant. ns: not significant; *; $p<0.05$, **; $p<0.01$.

When considering the non-irrigated (I0) treatment as the baseline, the Spinning Consistency Index (SCI) increased by 5.5% in I33, 21% in I66, and 29% in I100 during the first year. In the second year, the increases were 12% in I33, 21% in I66, and 19% in I100. Sulfur doses had an effect on SCI in the second year; as sulfur doses increased, SCI decreased in the S1 and S2 treatments but increased in the S3 treatment. Additionally, compared to S0, SCI decreased by 2.2% in S1 and 15% in S2.

Table 5. Fiber quality parameters (2016)

Treatments		Spinning consistency index[#]	Fiber fineness (mic.)	Fiber length (mm)	Fiber uniformity (%)	Short fiber content (%)	Fiber strength ($g\ tex^{-1}$)	Fiber elongation (%)	Fiber brightness (Rd)	Fiber yellowness (+b)
I0		118.5 c	**5.19 a**	25.9 c	82.95 b	**8.05**	28.71	**6.96 a**	**79.56 a**	**9.19**
I33		132.42 b	5.03 a	27.79 b	83.82 b	7.09	30.56	6.25 b	79.00 ab	8.48
I66		**143.5 a**	4.55 b	28.29 b	84.92 a	7.35	**30.89**	6.00 b	78.22 bc	7.58
I100		141.83 a	4.51 b	**29.27 a**	**84.80 a**	7.18	29.97	6.45 ab	77.44 c	7.70
Irrig. Level		**	**	**	**	ns	ns	**	**	**
S0		**142.3 a**	4.74	**28.17**	**84.51 a**	7.11 b	**31.77 a**	6.17	78.18	**8.38**
S1		138.9 ab	4.82	27.93	84.5 a	7.31 b	30.97 a	6.54	78.63	8.23
S2		123.6 c	4.78	27.18	83.08 b	**8.33 a**	28.49 b	**6.64**	78.5	8.13
S3		131.4 bc	**4.95**	27.97	84.4 a	6.93 b	28.9 b	6.31	**78.91**	8.21
Sulfur Doses		**	ns	ns	**	**	**	ns	ns	ns
I0	S0	130.33	5.28 a	26.36	84.20	7.10	30.63	6.00	79.1	10.00 a
	S1	113.00	5.23 ab	26.21	82.30	8.27	27.80	7.37	79.73	8.87 b
	S2	111.00	5.19 ab	24.63	81.73	9.43	29.17	7.10	79.17	8.97 b
	S3	119.67	5.04 ac	26.39	83.57	7.40	27.23	7.37	80.23	8.93 b
I33	S0	143.33	5.08 ac	28.57	83.97	6.93	33.93	6.27	77.73	8.4 bc
	S1	133.33	4.77 cd	27.68	84.00	7.30	29.87	6.23	78.77	7.87 ce
	S2	121.33	5.28 a	26.79	83.20	7.70	28.97	6.27	80.13	8.93 b
	S3	131.67	5.01 ac	28.12	84.10	6.43	29.47	6.23	79.37	8.70 b
I66	S0	149.00	4.22 fg	27.95	85.17	6.77	31.50	6.37	78.13	7.30 ef
	S1	158.67	4.89 bd	28.75	86.27	6.97	34.60	6.00	78.37	8.27 bd
	S2	123.67	4.11 f	27.59	82.67	8.80	27.10	6.20	77.2	6.93 f
	S3	142.67	4.98 ac	28.87	85.57	6.87	30.37	5.43	79.17	7.80 ce
I100	S0	146.67	4.37 fg	29.78	84.70	7.63	31.00	6.03	77.77	7.80 ce
	S1	150.67	4.38 eg	29.10	85.43	6.70	31.60	6.57	77.63	7.93 ce
	S2	138.33	4.52 df	29.71	84.70	7.40	28.73	7.00	77.5	7.67 de
	S3	131.67	4.75 ce	28.49	84.37	7.00	28.53	6.20	76.87	7.4 ef
Irrig. Level x Sulfur Doses		ns	**	ns	ns	ns	ns	ns	ns	**

[#] Differences between values indicated by different letters are statistically significant. ns: not significant; *; $p<0.05$, **; $p<0.01$.

Fiber fineness: Micronaire is a quality parameter associated with fiber fineness and maturity (Abbas & Ahmed, 2018). The fineness of the fibers is crucial for yarn quality, particularly in the rotor spinning method. Fiber fineness increased as water stress increased in both years. The finest fibers were measured in the full irrigation treatment (I100), while the thickest fibers were observed in the I33 (5.41 mic.) treatment during the first year and in the I0 (5.19 mic.) treatment in the second year (Tables 4-5). Increasing sulfur doses also led to an increase in fiber fineness, though this increase was statistically significant only in the first year ($p < 0.01$); in the second year, it was not significant (Tables 4-5). Osborne et al. (2006) suggested that water stress in cotton triggers a trend toward increased fiber fineness compared to stress-free conditions. Similarly, Bakhsh (2019) stated that water stress increased fiber fineness by up to 6%, depending on genotype. Our results align with those of Davis et al. (2014), Lokhande & Reddy (2014), and Wiggins et al. (2014). Overall, the findings confirm that water stress generally increases fiber fineness, and irrigation constraints significantly affect fiber quality.

Fiber length: Fiber length is one of the most important quality characteristics in cotton. Long-fiber cotton varieties are highly desirable for commercial production. As the irrigation level increased, fiber length also increased. However, sulfur doses did not have a significant effect on fiber length (Tables 4-5). The longest fibers were measured in the S2 dose in the first year and in the untreated control group in the second year. Luz et al. (1997) and Karademir et al. (2011) reported that fiber length was not influenced by increased irrigation, while other researchers found that water stress reduced fiber length in cotton (Pettigrew, 2004; Mahmood et al., 2006; Osborne et al., 2006). Bakhsh et al. (2019) highlighted the importance of genotypic differences in fiber length, noting that in some genotypes, fiber length remained consistent under both water-stressed and fully irrigated conditions, while in others, it varied significantly—being either shorter or longer. These findings suggest that while irrigation positively influences fiber length, the impact of sulfur and water stress on fiber quality may depend on the specific cotton genotype.

Fiber uniformity: Uniform spinning is essential for high-quality textile products. The more uniform and longer the fibers, the better the yarn's smoothness and strength, with uniform fibers exhibiting less deviation (Özgen, 2022). Fiber uniformity increased with higher irrigation levels, with the highest uniformity observed in the I100 treatment in both years (84.61% and 84.80%). While sulfur doses caused statistically significant differences in fiber uniformity in the second year, the highest uniformity was measured in the treatment without sulfur application (84.51%). In the first year, the highest uniformity was recorded in the S2 dose (83.40%). Bakhsh et al. (2019) stated that water application had no effect on fiber uniformity across different genotypes, but our results align with studies by Marur (1991), Luz et al. (1997), Pettigrew (2004), and Karademir et al. (2011), which reported that water stress reduces fiber uniformity. This indicates that water availability plays a crucial role in maintaining fiber quality.

Short fiber content: A low short fiber content increases efficiency in yarn production and reduces costs; therefore, having a low short fiber content is a desirable trait. The short fiber content ranged between 6.00 (I100S3) and 9.70 (I0S2) in the first year, and between 6.43 (I33S3) and 9.43 (I0S2) in the second year (Tables 4-5). It has been noted that the values obtained are considered "short fibers" in the textile industry (Anonymous, 2024a). The short fiber content was affected by irrigation levels in the first year and by sulfur doses in the second year. The average short fiber content increased as water stress increased, significantly in the first year ($p < 0.01$) and overall in both years. In the first year, the average short fiber content decreased by 40%, from 8.77 in the I100 treatment to 6.26 in the I0 treatment. In the second year, the short fiber content increased from 7.11 in the S0 sulfur dose to 8.33 in the S2 dose but decreased again at the S3 dose to 6.93. In both years, the short fiber content values measured in irrigation level x sulfur dose interactions did not show significant changes. Kazgöz Candemir and Ödemis (2021) suggested that water stress applied during different growth stages of cotton affected the short fiber content, with the highest values obtained from fully irrigated treatments during the vegetative period and non-irrigated treatments during other periods. They also noted that sulfur doses had no effect on short fiber content and that as fiber strength increased, the short fiber content decreased.

Fiber Strength: Fiber strength was influenced by irrigation levels in both years and by sulfur doses in the first year. The highest values for irrigation levels were measured in the I66 treatment (30.47 and 30.89 g tex^{-1}). In the second year, the highest fiber strength was obtained from the treatment without sulfur. It is believed that the lower water consumption in this treatment, compared to others, increased fiber strength due to reduced water stress. Changes in fiber strength in cotton related to different irrigation practices have been highlighted in studies by Osborne et al. (2006), Karademir et al. (2011), and in our research; however, Pettigrew (2004) reported that irrigation practices did not affect fiber strength. Moreover, it has been noted that genotypic differences are significant in fiber strength under stress conditions (Bakhsh et al., 2019).

Fiber elongation: Fiber elongation enables effective bending of fibers, and fibers with low elongation values tend to break easily (Mathangadeera et al., 2020). In our study, fiber elasticity was generally categorized into low (5.0–5.8%) and medium (5.9–6.7%) groups (Anonymous, 2024a). Fiber elasticity varied between 5.52% and 5.75% in the first year and between 6.00% and 6.96% in the second year for irrigation levels, as well as between 5.56% and 5.76% and between 6.17% and 6.64% for sulfur doses. It was determined that only the sulfur doses applied in the second year had a significant effect on fiber elasticity. Avşar & Karademir (2022) reported that fiber elasticity under fully irrigated (I100) and 75% irrigation (I75) conditions was similar (5.50% and 5.47%, respectively), while the I50 treatment (5.28%) fell into the low elasticity group. They noted that 25% water stress (I75 treatment) did not negatively affect fiber elongation.

Fiber color is a fundamental criterion in cotton classification according to the Universal Cotton Standards (UCS). While fiber yellowness is related to cotton pigmentation, reflectance is associated with the brightness of the cotton fiber, which is an important parameter for cotton pricing. High fiber brightness indicates superior quality in cotton, contributing to increased value and price. Additionally, cotton color aids in the absorption and retention of dyes in the final product. Therefore, processing efficiency depends on these two parameters (Mathangadeera et al., 2020). In the trial, fiber brightness ranged from 78.90 to 80.57 in the first year and from 76.87 to 80.23 in the second year, placing it in the 'bright' (70–80%) and 'extra bright' (80–85%) categories. Fiber brightness was affected only by irrigation levels in the second year; as water stress increased, the "bright" level increased slightly (Table 5).

Fiber yellowness increased as water stress intensified in both years and was generally classified within the ‘white’ (4–8) and ‘light yellow’ (8–10.5) categories (Alhalabi, 2007). Although sulfur doses statistically affected fiber yellowness values, they did not result in a significant difference. Sulfur doses were found to be higher than irrigation levels in both years, and it was observed that the fibers tended to shift from the ‘light’ to the ‘light yellow’ category (Tables 4–5). The color of cotton fibers can be influenced by staining due to rain, frost, insects, fungi, and contact with soil, grass, or the leaves of the cotton plant. Excessive moisture and temperature levels during pre- and post-ginning storage can also affect color. Color deterioration caused by environmental conditions impacts the fibers' ability to absorb and retain dyes, potentially reducing processing efficiency (Anonymous, 2024a).

Conclusion

Cotton is a high water-consuming and important industrial crop. Its substantial water requirement negatively impacts both cultivation and fiber yield and quality in areas where water is limited. The Amik Plain, where this research was conducted, is one of the regions in Turkey where cotton farming is widely practiced. Since nearly all the irrigation water in the Amik Plain is sourced from wells, the increasing effects of climate change in recent years have led to challenges in water usage. Decreasing water resources affect the yield and quality of many crops, particularly cotton. This situation has brought options such as foliar sulfur application to the forefront of research as a means to mitigate stress effects. Although previous studies have identified positive effects of foliar-applied sulfur, our research did not yield the expected level of positive results. The earlier studies were conducted under controlled conditions, whereas our research was carried out in field conditions influenced by various abiotic stress factors, making it difficult to achieve favorable outcomes. In our study, sulfur doses did not significantly impact plant water consumption. Increasing sulfur doses led to a decrease in evapotranspiration in the first year, an increase at the S1 (150 ml da^{-1}) dose in the second year, and a decrease at the S2 and S3 doses. Yield decreased as sulfur doses increased in the first year, while yield increased as the amount of irrigation water increased. In the second year, both irrigation water amount and sulfur doses contributed to an increase in yield.

The effects of water restriction and sulfur doses on fiber quality varied for some fiber characteristics from year to year. The spinning consistency index, fiber fineness, fiber length, and fiber uniformity were affected by water restriction in both years, while the short fiber ratio and fiber strength were impacted only in the first year. Additionally, fiber elasticity and fiber brightness were influenced solely in the second year. In contrast, sulfur doses affected fewer parameters: in the first year, they influenced fiber fineness and fiber yellowness, while in the second year, the spinning consistency index, fiber uniformity, short fiber ratio, and fiber strength were impacted. Given that fiber quality is extremely important for the textile industry, further research is critically needed to mitigate the negative effects of water stress on cotton cultivation.

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REFERENCES

Abbas, Q., & Ahmad, S. (2018). Effect of different sowing times and cultivars on cotton fiber quality under stable cotton-wheat cropping system in Southern Punjab, Pakistan. *Pakistan Journal of Life & Social Sciences, 16*(2), 77-84.

Anonymous (2013). Aydın ticaret borsası 2013 yılı pamuk raporu. http://aydinicaretborsasi.org .tr/pdf/pamuk-raporu.pdf

Anonymous (2017). [Title not provided]. http://www.cukobirlik.com.tr/?tekd=777&ikid=1& syf=*PAMUK*23.03.2017 16:19

Anonymous (2024a). [Title not provided]. https://kadirbolukbasi.wordpress.com/2008/08/09/ pamuk-lif/

Anonymous (2024b). Classification of cotton. America's Cotton Producers and Importers. Service marks/trademarks of Cotton Incorporated. https://www.cottoninc.com/wp-content/uploads/2017/02/Classification-of-Cotton.pdf

Ackerson, R. C. (1985). Osmoregulation in cotton in response to water-stress. III. Effects of phosphorus fertility. *Plant Physiology, 77*, 309–312.

Akgöl, B. (2012). Pamukta (*Gossypium hirsutum* L.) verim, kalite ve kuraklığa dayanıklılık özelliklerinin kalıtımı. [Doctoral dissertation, Çukurova University].

Alhalabi, K. (2007). Suriye ve Türkiye'de üretilen pamuk liflerinin özelliklerinin ve eğrilme yeteneklerinin karşılaştırılmalı incelemesi. [Master's thesis, Çukurova University, Adana].

Avşar, O., & Karademir, E. (2022). Evaluation of quality parameters in cotton production (Gossypium hirsutum L.) under water stress conditions. *Journal of Applied Life Sciences and Environment, 55*(1), 45-61.

Bakhsh, A., Rehman, M., Salman, S., & Ullah, R. (2019). Evaluation of cotton genotypes for seed cotton yield and fiber quality traits under water stress and non-stress conditions. *Sarhad Journal of Agriculture, 35*(1), 161-170.

Bastug, R., & Tekinel, O. (1989). Water production functions of cotton under limited irrigation water conditions. *Doga Turkish Journal of Agriculture and Forestry, 13*, 163-168.

Bek, Y., & Efe, E. (1988). *Araştırma ve deneme metotları I*. Çukurova Üniversitesi Ziraat Fakültesi, Ders Kitabı: No:71, 395 s.

Bos, M. G., Richard, K., Allen, G., & Molden, D. J. (2009). Evapotranspiration: Water requirements for irrigation and the environment.

Brück, H., Payne, W. A., & Sattelmacher, B. (2000). Effects of phosphorus and water supply on yield, transpirational water-use efficiency, and carbon isotope discrimination of pearl millet. *Crop Science, 40*, 120–125.

Burt, C. M., O'Connor, K., & Ruehr, T. (1995). *Fertigation*. Irrigation Training and Research Center, California Polytechnic State University.

Campbell, B. T., & Bauer, R. J. (2007). Improving the precision of cotton performance trials conducted on highly variable soils of the southeastern USA coastal plains. *Plant Breeding, 126*, 622–627. https://doi.org/10.1111/j.1439-0523.2007.01397.x

Chan, K. X., Wirtz, M., Phua, S. Y., Estavillo, G. M., & Pogson, B. J. (2013). Balancing metabolites in drought. *The Sulfur Assimilation Conundrum, 18*(1), 18–29.

Çoşkun, Z. (2015). Harran ovasında damla sulamanın pamuk verimine etkisi. [Master's thesis, Harran University].

Davis, R. F., Earl, H. J., & Timper, P. (2014). Effect of simultaneous water deficit stress and *Meloidogyne incognita* infection on cotton yield and fiber quality. *Journal of Nematology, 46*(2), 108-118.

Dietz, K. J. (1989). Recovery of spinach leaves from sulfate and phosphate deficiency. *Journal of Plant Physiology, 134*, 551-557.

Fox, R. L., Olson, R. A., & Rhoades, H. F. (1964). Evaluating the sulfur status of soils by plants and soil tests. *Soil Science Society of America Proceedings, 28*, 243-246.

Hu, Y., Burucs, Z., & Schmidhalter, U. (2008). Effect of foliar fertilization application on the growth and mineral nutrient content of maize seedlings under drought and salinity. *Soil Science and Plant Nutrition, 54*, 133–141.

Jie, X., Dong, Q., Li-Na, Z., & Zhou, L. (2008). Effects of sulfur nutrition on the chlorophyll content of maize leaf under zinc and drought stress. *Agricultural Research in the Arid Areas*.

Kacar, B., & Katkat, V. (2007). *Bitki besleme*. Nobel Yayınları.

Karademir, Ç., Karademir, E., Ekinci, R., & Berekatoğlu, K. (2011). Yield and fiber quality properties of cotton (Gossypium hirsutum L.) under water stress and non-stress conditions. *African Journal of Biotechnology, 10*(59), 12575-12583.

Karam, F., Lahoud, R., Masaad, R., Daccache, A., Mounzer, O., & Rouphael, Y. (2006). Water use and lint yield response of drip irrigated cotton to the length of irrigation season. *Agricultural Water Management, 85*, 287–295.

Kazgöz, C. D. (2017). Yapraktan uygulanan farklı kükürt dozlarının pamuk bitkisinin (Gossypium hirsutum L.) değişik gelişme dönemlerindeki su stresinin azaltılması üzerine etkileri. [Master's thesis, Mustafa Kemal University, Hatay].

Kazgöz Candemir, D., & Odemis, B. (2021). Effects of foliar sulfur applications on the quality of cotton plant fiber under water stress conditions. *Fibres & Textiles in Eastern Europe, 29*(6), 37-43. https://doi.org/10.5604/01.3001.0015.2720

Krieg, D. R. (1997). Genetic and environmental factors affecting productivity of cotton. *Proceedings of the Beltwide Cotton Production Research Conference*, 1347.

Li-Na, Z., Dong, Q., Li-Li, S., & Wei-Jie, Y. (2005). Effects of sulfur fertilization on the contents of photosynthetic pigments and MDA under drought stress. *Acta Botanica Boreali-Occidentalia Sinica*.

Loka, D. A. (2012). Effect of water-deficit stress on cotton during reproductive development. [Ph.D. dissertation, University of Arkansas, Fayetteville].

Loka, D. A., & Oosterhuis, D. (2012). Water stress and reproductive development in cotton. Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR 72704.

Loka, D. A., & Oosterhuis, D. M. (2014). Water-deficit stress effects on pistil biochemistry and leaf physiology in cotton (Gossypium hirsutum L.). *South African Journal of Botany, 93*, 131–136.

Lokhande, S., & Reddy, K. R. (2014). Reproductive and fiber quality responses of upland cotton to moisture deficiency. *Agronomy Journal, 106*(3), 1060-1069. https://doi.org/10.2134/agronj13.053

Luz, M. J., Bezerra, J. R. C., Barreto, A. N., Santos, J. W., & Amorim, N. M. S. (1997). Effect of water stress on cotton yield and fibre quality. *Revista de Oleaginosas e Fibroras, 1*, 125-133.

Ma, Q. F., Turner, D. W., Levy, D., & Cowling, W. A. (2004). Solute accumulation and osmotic adjustment in leaves of Brassica oilseeds in response to soil water deficit. *Australian Journal of Agricultural Research, 55*, 939–945.

Mahmood, S., Irfan, M., Raheel, F., & Hussain, A. (2006). Characterization of cotton (Gossypium hirsutum L.) varieties for growth and productivity traits under water deficit conditions. *International Journal of Agriculture and Biology, 8*, 796-800.

Marur, C. J. (1991). Comparison of net photosynthetic rate, stomatal resistance, and yield of two cotton cultivars under water stress. *Pesquisa Agropecuária Brasileira, 26*, 153-161.

Mathangadeera, R. W., Hequet, E. F., Kelly, B., Dever, J. K., & Kelly, C. M. (2020). Importance of cotton fiber elongation in fiber processing. *Industrial Crops and Products, 147*, 112217. https://doi.org/10.1016/j.indcrop.2020.112217

Osborne, S., & Banks, J. C. (2006). The effects of water stress during bloom on lint yield, fiber quality and price. *Beltwide Cotton Conferences*, San Antonio, Texas, 1679-1780.

Orgaz, F., Mateos, L., & Fereres, E. (1992). Season length and cultivar determine optimum evapotranspiration deficit in cotton. *Agronomy Journal, 84*, 700-706.

Ödemiş B., Akışcan Y., Akgöl B., Can D. (2022) Su stresi koşullarında uygulanan yapraktan kükürt uygulamasının pamuğun verim, bitki su tüketimi ve bazı fizyolojik özelliklerine etkileri. Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi, 27(2) : 202-212. DOI: 10.37908/mkutbd.1076251

Özgen, B. (2002). Comparison of quality characteristics of yarns spun from Aegean cotton fibres and their mixtures with Southeast Anatolian cotton fibre. [Master's thesis, Dokuz Eylul University].

Penna, J. C. V., Verhalen, L. M., Kirkham, M. B., & McNew, R. W. (1998). Screening cotton genotypes for seedling drought tolerance. *Plant Genetics, Genetics and Molecular Biology, 21*(4), 433-440. https://doi.org/10.1590/S1415-47571998000400023

Pettigrew, W. T. (2004). Physiological consequences of moisture deficit stress in cotton. *Crop Science*, 10.2135/cropsci2004.1265.

Studer, C. (1993). Interactive effects of N-, P-, K-nutrition and water stress on the development of young maize plants. [Ph.D. thesis, ETH Zurich, Switzerland].

Wiggins, M. S., Leib, B. G., Mueller, T. C., & Main, C. L. (2014). Cotton growth, yield, and fiber quality response to irrigation and water deficit in soil of varying depth to a sand layer. *Journal of Cotton Science, 18*, 145-152.

Xinhua, Y., Gwathmey, O., Main, C., & Johnson, A. (2011). Effects of sulfur application rates and foliar zinc fertilization on cotton lint yields and quality. *Agronomy Journal, 103*(6), 1794-1803.

Zonta, J. H., Brandão, Z. N., Rodrigues, J. I. S., & Sofıattı, V. (2017). Cotton response to water deficits at different growth stages. *Mossoró, 30*(4), 980–990.

Nazar, A., Iftikhar, M., Shahbaz, B., & Ishaq, W. (2012). Influence of irrigation water types and stress levels on cotton fiber and yarn quality for different varieties. *Pakistan Journal of Agricultural Sciences, 49*(4), 597-601.