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Effects of Foliar Sulfur Applications on the Quality of Cotton Plant Fibre Under Water Stress Conditions

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Abstract
The research was conducted to determine the effects of Sulfur foliar applications on the fibre quality of cotton plants exposed to water stress at different growth stages in the Amik Plain (Hatay province, Turkey) in 2015 and 2016. Cotton plants were studied in three different developmental stages (vegetative growth period (VG); flowering and boll development period (FB) and boll opening period (BO)) and full irrigation was applied in some periods, while deficit irrigation was applied in the others. Sulfur fertiliser from foliar was applied in different doses (S_0: 0 ml da^{-1}, S_1: 150 ml da^{-1}, S_2: 250 ml da^{-1}, S_3: 350 ml da^{-1}). The study was carried out with three replications according to the split plot design. In the research, the effects of the water deficit and sulfur dose applications on gin turnout and fibre quality characteristics at different growth stages were investigated. Results showed that the average spinning consistency index (SCI) decreased by 11.75% due to the water deficit (compared to the treatment of TTT, irrigation in all three crop developmental stages). Similar effects were observed in the fibre length, micronaire, fibre strength and uniformity index values, which were decreased by 7.31%, 4.07%, 5.89% and 2.17%, respectively. The average gin turnout of the irrigated treatment (TTT), in which there is no deficit irrigation, decreased by 2.5% compared to the control treatment (OOO). Similar effects were observed in fibre elongation and short fibre content values which were decreased by 8.43% and 14.60%, respectively. The average S_1 and S_3 sulfur doses increased the gin turnout by 0.44% and 0.35%, respectively, and the S_2 dose decreased it by 0.79%.

Key words: *cotton, deficit irrigation, different growth stages, fibre quality, foliar sulfur application, gin turnout.*

Introduction

Cotton is one of the most important industrial plants in the world, which is cultivated on approximately 33.4 million hectares of land with 25.8 million tons of fibre from this area [1]. The cotton plant has an important place in the national economy due to the fact that it is a raw material in the textile and oil industries with its fibre and seed, respectively and it also contributes to the development of animal husbandry with its residue [2].

Turkey is the ninth country in the world in terms of cotton acreage, second in the yield of cotton fibre obtained per unit area, seventh in the amount of cotton production, fourth in cotton consumption and fifth in cotton imports [3].

Cotton has three different growth stages from sowing to harvest: a) the vegetative growth period (VG): the time from few leaves of the plant until the first flowers appear, b) the flowering and boll development period (FB): the time from the first flowers to the first boll cracking, and C) the boll opening period (BO): the time from the first boll crack to the last hand harvest [4].

In recent years, the problems encountered in meeting the water needs of plants have led to an increase in research aimed at eliminating the negative effects of water stress.

As in all agricultural products, the main objective in cotton farming is to obtain more yield and higher quality products per unit area [5]. High-quality fibre in cotton is very important for the textile industry. Irrigation water is reported to be effective in increasing fibre quality [6, 7].

The aim of this study was to determine whether foliar sulfur application affects the fibre quality properties in cotton plants exposed to water stress at different developmental stages.

Materials and methods

Material

The research was carried out at the research station of the ProGen seed company, located in Hatay province in the Eastern Mediterranean Region in 2015 and 2016. The soil texture was silty clay loam (SiCL), and irrigation water was determined as C_2S_1 ECw: 1397 (μmhos cm^{-1}). The bulk density of the soil in the research area was between 1.49-1.68 gr cm^{-3}, while the field capacity (FC) and permanent wilting point (PWP) values ranged between 21.3-25.2 and 13.4-14.7, respectively, as dry weight percentages. The average temperature recorded during the growing seasons (May, June, July, August, September) was 26.9 °C and 25.9 °C in 2015 and 2016, respectively, while total precipitation amounts were recorded as 21 mm and 149 mm, respectively. The Carisma cotton plant variety was used as cotton plant material.

Methods

Experimental design

The experiment was carried out in randomised blocks according to the split plot design with three repetitions. Each treatment was 6 row and the parcel length 15 meters. No interim was left between the repetition plots. The cotton plant interrow spacing was 70 cm, while the inrow spacing was 15 cm. Thus, approximately 100 plants were kept in each row. Sowing was carried out on May 18 and June 3 in the first and second experiment years. The last hand harvest was carried out on October 14 in both study years.

Irrigation treatments

The cotton plant was studied in three different developmental periods: a) the vegetative growth period (VG), b) the flowering and boll development period (FB), and c) the boll opening period (BO) [4]. Full irrigation was applied (T) in some

Table 1. Water stress treatments applied in different cotton crop developmental stages. ***Note:*** *(+) irrigation, (–) non-irrigation, (T) irrigation treatments irrigated at field capacity level, (O) non-irrigation treatments.*

Treatments	VG	FB	BO
OOO	–	–	–
TTT	+	+	+
TOO	+	–	–
OTT	–	+	+
OTO	–	+	–
TOT	+	–	+

Table 2. Analysis of variance table for the gin turnout, spinning consistency index, fibre length, fibre fineness and fibre strength values of the fibres based on the crop development period (DP) and sulfur doses (SD). ***Note:*** *(DP) development period, (SD) sulfur doses, (df) degree of freedom, (***) p < 0.001, (**) p < 0.01, (*) p < 0.05 significant, (ns) not significant.*

Year	Source of variation	df	Gin turnout, %	Spinning consistency index, SCI	Fibre length, mm	Fibre fineness, Mic.	Fibre strength, g/text
2015	DP	5	***	***	***	***	**
	SD	3	*	ns	ns	ns	ns
	DP*SD	15	**	ns	ns	ns	ns
	Error	48					
2016	DP	5	***	***	***	***	***
	SD	3	ns	ns	*	ns	ns
	DP*SD	15	ns	ns	ns	ns	ns
	Error	44					

developmental periods, while the crop was not irrigated (O) in some periods to create water stress (***Table 1***).

Irrigations were applied once a week by bringing the current humidity to the field capacity with reference to the control TTT treatment. Since the drip irrigation method was used in the study, the water application efficiency (Ea) was taken as 0.95 [8].

Sulfur treatments

It was determined that the amount of sulfur in the soil of the experiment area was negligible. When sulfur is applied to the soil, the absorption by the plant and its usefulness to the plant takes place in about 20 days, while this time period decreases by up to 8 hours in foliar application [9]. Since it was intended to recover the crop from stress in a shorter time, sulfur was applied from the leaves. All experiment parcels were equally fertilised with 20 kg da^{-1} 18-46-0 (DAP) of fertiliser per decare before planting as the dose rate commonly used in the region and with 4 kg da^{-1} of pure nitrogen fertigation in each of the first four irrigations after sowing according to the four-quarter rule (S_0) [10]. In addition, 150 ml da^{-1} (S_1), 250 ml da^{-1} (S_2), and 350 ml da^{-1} (S_3) of pure elemental sulfur were applied as foliar in all treatments. Sulfur was applied in all developmental periods except in that of the emergence of the plant, once in the middle of each developmental period three or four days after irrigation in the early morning (6:00- 6:30) to prevent the wind's possible adverse effect on the sulfur distribution.

Harvest and post-harvest analysis

The names and details of the parameters to evaluate the effects of different foliar sulfur applications under water stress on the cotton yield and fibre qualities used in the study are explained below:

Gin turnout, %: Cotton samples collected after harvesting were processed on a roller-gin ginning machine. The cotton samples were separated into fibre and cotton seed, and the gin turnout was calculated by the following equation ***(Equation (1))***:

$$\text{Gin turnout} = (\text{fibre weight (g)}/\text{unginned weight (g)}) \times 100 \quad (1)$$

Other fibre properties: In order to determine the technological properties of the fibres, mass samples collected and ginned in the first hand harvest were analysed on an USTER HVI-1000 instrument, and the values obtained were interpreted according to the ranges given below:

Spinning consistency index (SCI): SCI values were calculated using the equation given below: and fibre bales were taken in 3 replications for each object.

$$\text{SCI} = -414.67 + 2.9 \times \text{fibre strength} - 9.32 \times \text{micronaire} + 49.17 \times \text{upper half average length (inch)} + 4.74 \times \text{uniformity} + 0.65 \times \text{reflectance} + 0.36 \times \text{yellowness [11]} \quad (2)$$

Fibre length: short: ≤ 25.15; medium: 25.15-27.94; long: 27.94-32.00; very long: ≥ 32.00 [12].

Fibre fineness (Micronaire): very fine: ≤ 3.0; fine: 3.0-3.6; medium: 3.7-4.7; coarse: 4.8-5.4; very coarse: ≥ 5.5 [11].

Fibre Strength: very weak: ≤ 21; weak: 22-24; medium: 25-27; very strong: ≥ 31 [11].

Fibre elongation: very low: ≤ 5.0; low: 5.0-5.8; medium: 5.9-6.7; high: 6.8-7.6; very high: ≥ 7.7 [11].

Uniformity index: very low: ≤ 77%; low: 77-80%; medium: 81-84%; high: 85-87%; very high: ≥ 87% [11].

Short fibre content: very low: ≤ 6; low: 6-9; medium: 10-13; high: 14-17; very high: ≥ 18 [11].

Data Analysis

Statistical evaluation was performed by applying the Duncan test in the SPSS 18 package program [13].

Results and discussion

Gin turnout (%): It was determined that irrigation was effective for gin turnout in both study years of 2015 and 2016 ($p < 0.001$), while sulfur doses were partially effective ($p < 0.05$) in the first year (2015) and not effective in the second year (2016) (***Table 2***).

The turnout values ranged from 42.95% – 45.40% in 2015 and 41.30% – 44.38% in 2016 (***Table 3***). In another study conducted with the Carisma cotton variety, gin turnout was determined as 41.66% [14]. Odemiş et al. [15] stated that the amount of irrigation water does not have a significant effect on the gin turnout and that the gin turnout value can be the same in fully irrigated treatments during the season, even in rain-fed treatments. Odemiş et al. [15] found that the amount of irrigation water was not effective for gin turnout values measured between 36.8% and 44.1%. In the current study, however, the effect of sulfur doses and irrigation levels on the gin turnout was investigated, and it was determined that the applications were effective in the first year and did not have a significant effect in the second. It is seen that the varieties, their characteristics and adaptation conditions are more effective than differences in irrigation applications for gin turnout values. However, there are also studies indicating that the amount, method and programs of irrigation water applied and the climatic differences between years are effective for different gin turnout values [16]. Gin turnout values in these studies were reported as 38.80-41.53% [16], 37-48% [17], 38.84-41.35% [18], 41.54-43.76% [19] and 33.86% [20].

Spinning consistency index (SCI)

The spinning consistency index (SCI) is a parameter used to estimate the spinnability of fibres as well as to determine the yarn fibre strength and spinning potential. For the textile industry, high spinnability means that the cotton fibre is of better quality [21]. In the present study, it was determined that irrigation was effective for the spinning consistency index in both study years and that sulfur doses were not effective (***Table 2***). Average SCI values between treatments were 113.19-135.05 in the first year, while those in the second year ranged between 113.85-142.74, with the forming of two statistically different groups in the first year and three groups in the second in terms of the spinning consistency index (***Table 3***). In the mean values, the highest SCI was achieved from the TTT treatment (139.64), while the lowest was obtained from the TOT treatment (119.37) in which water restriction was applied only during the flowering and boll development (FB) period. When TTT and OOO treatments were compared, it was seen that the water application increased the SCI value by 1.74% from 132.60 to 134.91. Applying periodic water deficits adversely affected SCI values. Also, no effect of sulfur doses on SCI was observed. However, when the treatments were compared to one another, it was found that sulfur application was effective for SCI values in TTT (2015) and that the effect increased in S_1, S_2 & S_3 doses by 5.45%, 5.20% and 7.61%, respectively.

Table 3. *Gin turnout and spinning consistency index values of fibres as a result of experimental treatments.* ***Note:*** *(*) mean, (**) not significant.*

Treatments	Gin Turnout (%)		Spinning Consistency Index (SCI)	
	2015	2016	2015	2016
$OOOS_0$	44.40	43.73	136.04	117.33
$OOOS_1$	44.27	44.80	125.44	116.91
$OOOS_2$	42.87	44.20	137.13	112.38
$OOOS_3$	42.33	44.80	131.78	108.80
$TTTS_0$	45.27	40.80	129.02	146.01
$TTTS_1$	43.67	41.33	136.06	139.76
$TTTS_2$	43.80	41.40	135.73	145.53
$TTTS_3$	44.67	41.67	138.84	146.18
$TOOS_0$	44.40	42.00	119.36	124.09
$TOOS_1$	44.13	42.40	112.18	123.45
$TOOS_2$	44.13	41.07	125.37	134.64
$TOOS_3$	44.73	41.60	115.80	126.15
$OTOS_0$	44.93	42.40	133.01	129.30
$OTOS_1$	44.67	42.47	136.70	132.97
$OTOS_2$	43.40	41.20	133.71	125.93
$OTOS_3$	45.07	42.00	117.25	142.01
$OTTS_0$	42.73	41.00	138.18	139.77
$OTTS_1$	43.33	41.60	137.84	144.13
$OTTS_2$	42.67	41.40	131.33	148.31
$OTTS_3$	43.07	41.40	132.86	138.74
$TOTS_0$	44.87	41.60	112.16	124.17
$TOTS_1$	45.67	42.13	105.39	144.60
$TOTS_2$	45.60	42.40	115.40	116.98
$TOTS_3$	45.47	43.20	119.82	116.42
OOO*	43.47 c	44.38 a	132.60 a	113.85 c
TTT*	44.35 b	41.30 c	134.91 a	144.37 a
TOO*	44.35 b	41.77 bc	118.18 b	127.08 b
OTO*	44.52 b	42.02 bc	130.17 a	132.55 b
OTT*	42.95 c	41.35 c	135.05 a	142.74 a
TOT*	45.40 a	42.33 b	113.19 b	125.54 b
S_0^*	44.43 a	41.92 a	127.96**	130.11**
S_1^*	44.29 a	42.46 a	125.60**	133.64**
S_2^*	43.74 b	41.94 a	129.78**	130.63**
S_3^*	44.22 a	42.44 a	126.06**	129.71**

Fibre length (mm)

Long fibres are more preferred because they are easier to process and have higher strength than short fibres. The length of cotton fibres is an inherited property. and it may vary to a certain extent as a result of the influence of environmental conditions [22]. However, the timing and duration of water stress occurring during the fibre elongation period have an effect on the fibre length [23, 24]. It was determined in the present study that that irrigation was effective for the fibre length, as seen in the average values in both study years: 2015 and 2016 ($p < 0.001$), and that the sulfur doses were partially effective in 2016 ($p < 0.05$) but not in 2015 (***Table 2***). Fibre length values were 26.29-28.68 mm in 2015 and 25.97-29.33 mm in 2016. forming three statistically different groups in the both years in terms of fibre length (***Table 4***). When TTT and OOO were compared, the fibre length was observed to be higher by 3.2% in 2015 and 12.93% in 2016 for TTT. Previous research results show that fibre length increases with water application [25, 26]. In 2015, OOO, TOO, OTO and TOT treatments resulted in ‘medium’ fibre lengths, while TTT and OTT yielded ‘long’ fibre lengths; whereas in the second year, the OOO, TOO, OTT and TOT treatments resulted in ‘medium’ fibre lengths, TTT and OTO yielded ‘long’ fibre lengths. It was observed that sulfur doses generally had no significant effect on the average fibre length. However, the fibre length increased by 3.29% from 27.65 mm to 28.56 mm with the S_2 dose and by 2.38% from 27.65 mm to 28.31 mm with the S_3 dose of OOO treatment in 2015 (Table 4). When the same comparison was made for the TTT treatment, it was seen that the S_1, S_2 & S_3 doses increased the fibre length from the ‘medium’ fibre length category to ‘long’

Table 4. *Fibre length, fibre fineness and fibre strength values of fibres as a result of experimental treatments.* ***Note:*** *(*) mean, (**) not significant.*

Treatments	Fibre length, mm		Fibre fineness, Mic.		Fibre strength, g/tex	
	2015	2016	2015	2016	2015	2016
$OOOS_0$	27.65	26.05	4.38	5.23	32.38	27.83
$OOOS_1$	26.63	25.94	4.44	5.19	28.01	27.04
$OOOS_2$	28.56	26.58	4.08	4.94	28.66	26.17
$OOOS_3$	28.31	25.33	4.34	5.17	28.71	27.54
$TTTS_0$	27.92	29.77	5.15	5.05	30.07	29.72
$TTTS_1$	29.37	29.40	4.84	4.93	29.69	29.58
$TTTS_2$	28.72	28.84	4.90	4.84	29.96	31.18
$TTTS_3$	28.71	29.31	4.86	4.79	29.58	30.73
$TOOS_0$	26.26	27.26	4.55	4.85	28.78	27.89
$TOOS_1$	25.95	28.38	4.62	4.64	26.81	25.57
$TOOS_2$	27.25	27.84	4.57	4.42	27.79	29.13
$TOOS_3$	26.54	26.79	4.60	4.46	26.49	27.77
$OTTS_0$	28.14	27.14	5.07	4.93	30.75	29.09
$OTTS_1$	28.14	28.15	4.91	5.31	30.47	30.21
$OTTS_2$	28.56	27.86	5.00	5.26	28.52	29.28
$OTTS_3$	27.28	28.07	5.08	5.09	28.88	31.60
$OTOS_0$	27.43	29.08	4.08	5.28	30.13	28.10
$OTOS_1$	27.92	29.64	3.90	4.95	29.40	31.10
$OTOS_2$	27.98	28.88	4.11	5.10	29.29	31.86
$OTOS_3$	27.66	27.72	3.92	4.94	28.43	30.20
$TOTS_0$	26.43	27.85	5.31	5.18	27.07	27.76
$TOTS_1$	26.05	28.31	5.25	5.18	28.31	31.53
$TOTS_2$	26.29	27.38	5.21	5.34	29.34	27.77
$TOTS_3$	26.38	27.71	5.20	5.27	29.42	26.70
OOO*	27.79b	25.97c	4.31d	5.13ab	29.44a	27.14c
TTT*	28.68a	29.33a	4.94b	4.91c	29.82a	30.30ab
TOO*	26.50c	27.57b	4.59c	4.59d	27.47b	27.59c
OTT*	28.03ab	27.80b	5.02b	5.15ab	29.66a	30.04ab
OTO*	27.75b	28.83a	4.00e	5.07bc	29.31a	30.31a
TOT*	26.29c	27.81b	5.24a	5.24a	28.53ab	28.44ab
S_0*	27.31**	27.86ab	4.76**	5.09**	29.86**	28.40**
S_1*	27.34**	28.30a	4.66*	5.03**	28.78**	29.17**
S_2*	27.89**	27.90ab	4.65**	4.98**	28.93**	29.23**
S_3*	27.48**	27.48b	4.67**	4.95**	28.59**	29.09**

fibre length category, with an increase of 5.19%, 2.86% and 2.83%, respectively. Ozdemir et al. [16] reported fibre length values between 27.70-30.11 mm in the 'long' fibre length category in their study under Aydın province conditions. Sahito et al. [20] determined that the fibre length was 26.97 mm under Pakistani conditions.

Fibre fineness (micronaire)

For fibre fineness, irrigation applications during different cotton crop development periods were found to be effective in both years; however , sulfur doses were not effective in the present study (***Table 2***). Fibre fineness values were determined within 4.00-5.24 mic in 2015 and 4.59-5.24 mic. in 2016, forming five statistically different groups in the first year and three groups in the second in terms of fibre fineness (***Table 4***). When the average values of the first year for OOO (control) and TTT treatments were compared, it was found that water application thickened (4.31 vs. 4.94) the fibres by 14.6% (***Table 4***). This result was in parallel with the findings of the study of Ozdemir et al. [16], who determined the highest fibre fineness of 5.22 mic. with full irrigation water application, and the lowest fibre fineness of 4.94 mic. with the use 25% of the total water. The researchers stated that as the amount of irrigation water was decreased, fibre fineness values also decreased. However, the fibre fineness values in the current study decreased in 2016 even with an increase in the amount of irrigation water. Similar results were found in the studies of Price [27] and Baskuru [28]. Baskuru [28] reported that limited irrigation thickened fibres by 2.5% compared to full irrigation. According to the cotton fibre fineness classification specified in the method section in this present study, OOO, TOO and OTO treatments yielded 'medium' and TTT, OTT and TOT treatments 'coarse' fibres in the first year of the study, while in the second year, TOO treatment yielded 'medium' and all other treatments 'coarse' fibres. On the other hand, sulfur doses were not effective for fibre fineness. However, in the case of TOO (in 2016), doses of S_1, S_2 and S_3 reduced the fibre fineness by 4.32%, 8.86% and 8.04%, respectively, causing it to change from the 'coarse' fibre to 'medium' fibre group (***Table 4***). According to these findings, it can be said that the application of sulfur only in the vegetative development period and that of sulfur without irrigation water in other development periods affected the fibre fineness positively.

Fibre strength (g text^{-1})

It was determined that irrigation during different development periods had an effect on fibre strength in both years (***Table 2***). Fibre strength values in the first year were between 27.47 and 29.80 tex^{-1}, while in the second year, they were between 27.14 and 30.31 g tex^{-1} (***Table 4***). When TTT and other irrigation treatments (OOO, TOO, OTT, OTO & TOT) were compared, it was found that the fibre strength decreased by 5.88%, 8.41%, 0.69%, 0.83% and 5.22%, respectively. The results obtained are in line with researches reporting that water stress adversely affects fibre strength [29] and reduces it [30]. According to the fibre strength classification; in 2015 all treatments were in the 'strong' range with the exception of TOO (medium), while in 2016, except for the OOO and TOO treatments (medium), the other treatments were in the 'strong' fibre group. Ozdemir et al. [16] reported a fibre strength value between 29.53 and 34.00 g tex^{-1} and stated that they belong to the 'very strong' group. Hussein et al. [31] applied water with 4 different application rates of 50%, 65%, 80% and 100% of soil water depletion and stated that there were no differences in fibre length, durability, uniformity and elongation in 100% and 80%. treatments. İzci [7] stated that fibre strength was affected by irrigation levels and that the most durable fibres were obtained from 66% of the available water capacity.

In the current study, it was determined that sulfur doses had no effect on fibre strength (***Table 4***). However, when the sulfur applications (S_1, S_2, S_3) in OOO and TOO were compared to one another, it was found that they adversely affected the fibre strength, resulting in 13.49%; 6.84%, 3.43% and 7.95% reduction. On the contrary, in the TOT treatment, sulfur application positively affected the fibre strength and caused a 4.58%, 8.38% and 8.68% increase.

Fibre elongation (Elg, %)

It was determined that irrigation during different development periods had no effect on fibre elongation in 2015 and a partial effect in 2016, with sulfur doses not being effective in both years (***Table 5***).

Among the treatments, the average fibre elongation ranged between 5.19% and 5.56% in 2015 and between 4.81% and 6.43% in 2016 (***Table 6***). When the values of OOO and TTT were compared, water application caused a decrease of 1.10%, 14.77% and 8.43% (2015, 2016 and average), respectively. However, it was suggested that an increase in the irrigation water level increases fibre elongation [32]. In the present study, in the first year of the experiment, fibre elongation values were 'low' in 2016, where OOO treatment resulted in 'medium' and OTO treatment 'very low' fibre elongation values, while all of the other treatments were in the 'low' group. Sulfur doses were found to be ineffective for fibre elongation values. However, it was found that the S_3 dose of sulfur applied in OOO water treatment had a positive effect on fibre elongation in 2016. It was also determined that the same sulfur dose increased the fibre elongation by 13.19% from 6.29% to 7.12% and was classified as being in the 'medium' to 'high' group (***Table 6***).

Uniformity index, %

Uniformity is one of the most important characteristics affecting yarn yield. The fibres should be uniform in terms of spinning for better quality products. The longer and more uniform the fibres, the higher the yarn smoothness and strength; and uniform fibres provide less deflection [21].

In the current study, it was determined that irrigation was effective and sulfur doses not so for the uniformity index in both study years – 2015 and 2016 (***Table 5***). Average uniformity index values as a result of the treatments ranged from 81.86 to 84.00% in 2015 and from 82.91 to 85.73% in 2016 (***Table 6***). When the average of OOO (control) and TTT treatments were compared; that of the uniformity index value decreased by 2.17%, from 84.70% to 82.86%, with periodic water deficit application. The result was valid both in 2015 and 2016, and the uniformity index value decreased by 1.42% and 2.91%, respectively. The results obtained in the present study are in parallel with those of previous studies, which reported a decrease in the uniformity index value as a result of decreasing the irriga-

Table 5. *Analysis of variance table for fibre elongation, the uniformity index and short fibre content of fibres based on the crop development period (DP) and sulfur doses (SD).* ***Note:*** *(DP) development period, (SD) sulfur dose, (df) degree of freedom, (***) p < 0.001, (**) p < 0.01, (*) p < 0.05 significant, (ns) not significant.*

Year	Source of variation	df	Fibre elongation (%)	Uniformity index (%)	Short fibre content (%)
2015	DP	5	ns	***	***
	SD	3	ns	ns	ns
	DP*SD	15	ns	ns	ns
	Error	48			
2016	DP	5	**	***	***
	SD	3	ns	ns	ns
	DP*SD	15	ns	ns	ns
	Error	44			

Table 6. *Fibre elongation, uniformity index and short fibre content values of fibres as a result of experimental treatments.* ***Note:*** *(*) mean, (**) not significant.*

Treatments	Fibre elongation, %		Uniformity index, %		Short fibre content, %	
	2015	2016	2015	2016	2015	2016
$OOOS_0$	5.41	6.29	81.99	83.27	7.46	7.43
$OOOS_1$	5.24	6.51	82.88	83.77	7.93	7.95
$OOOS_2$	5.54	5.80	83.46	82.40	7.32	7.41
$OOOS_3$	5.57	7.12	82.87	82.21	6.80	9.04
$TTTS_0$	5.28	5.30	83.41	86.34	7.14	5.99
$TTTS_1$	5.32	5.30	83.83	84.92	6.93	6.45
$TTTS_2$	5.22	5.40	83.99	85.22	6.86	6.67
$TTTS_3$	5.71	5.90	84.75	85.12	6.34	6.03
$TOOS_0$	5.36	5.2	81.77	83.61	8.55	7.44
$TOOS_1$	5.30	5.49	81.61	83.92	9.26	7.51
$TOOS_2$	4.92	5.57	83.06	83.78	7.09	7.73
$TOOS_3$	5.19	4.90	82.19	83.37	8.02	7.47
$OTTS_0$	5.27	6.51	83.48	84.01	7.16	7.50
$OTTS_1$	5.53	5.86	83.95	84.30	6.33	7.25
$OTTS_2$	5.50	5.93	84.54	83.74	6.17	7.12
$OTTS_3$	5.76	5.08	81.73	84.98	8.13	6.29
$OTOS_0$	5.65	5.44	83.29	86.57	7.00	6.55
$OTOS_1$	5.85	4.56	83.06	85.32	7.63	6.17
$OTOS_2$	5.08	4.11	82.22	85.84	7.21	6.12
$OTOS_3$	5.67	5.15	82.74	85.18	7.44	5.99
$TOTS_0$	5.38	5.46	82.58	84.32	7.75	7.29
$TOTS_1$	6.01	4.85	80.43	85.71	8.67	6.27
$TOTS_2$	5.81	5.29	81.92	82.99	7.83	7.56
$TOTS_3$	4.84	6.42	82.52	83.12	7.23	7.82
OOO*	5.44**	6.43a	82.80bc	82.91d	7.38bc	7.96a
TTT*	5.38**	5.48b	84.00a	85.40ab	6.82c	6.29cd
TOO*	5.19**	5.29bc	82.16c	83.67cd	8.23a	7.54ab
OTT*	5.52**	5.84ab	83.43ab	84.26bc	6.95c	7.04bc
OTO*	5.56**	4.81c	82.83bc	85.73a	7.32bc	6.21d
TOT*	5.51**	5.50b	81.86c	84.03cd	7.87ab	7.24ab
S_0*	5.39**	5.70**	82.75**	84.69**	7.51ab	7.03**
S_1*	5.54**	5.43**	82.63**	84.66**	7.79a	6.93**
S_2*	5.35**	5.35**	83.20**	83.99**	7.08b	7.10**
S_3*	5.46**	5.76**	82.80**	84.00**	7.33ab	7.10**

tion water dose by 50% [33], stating that the uniformity index value is adversely affected by water stress [29]. Furthermore, Peynircioglu [29] stated that the uniformity index value in a cotton plant decreased from 84.36% to 85.32% under limited water conditions. All uniformity index values in the first year of the current experiment were found to be in the 'medium' group, while in the second year, TTT and OTO treatments yielded a 'high' value group, and the other treatments were in the 'medium' group.

Short fibre content (SF), %

In the present experiment, it was determined that irrigation during the development periods had an effect on the short fibre content in both years (2015 and 2016) and that the sulfur doses were not effective (***Table 5***). As a result of the different treatments applied, the average short fibre content values were between 6.82 and 8.23% in the first year, while in the second they ranged between 6.21 and 7.96%, forming two statistically different groups in both years in terms of short fibre (***Table 6***). It was also found that deficit water application increased the short fibre content, as seen in ***Table 6***. According to the short fibre content classification in both years, all treatments fell into the 'low' group. Since the fibre strength decreases when the short fibre content is higher, short fibre content is desirable for the textile industry [11]. This is valid in our study with the lowest fibre strength value in the case of TOO treatment, having the highest short fibre average. When the values of TTT were examined in the second year of the experiment, the short fibre content of sulfur application (S_1, S_2, S_3) had adverse effects, increasing by 7.67%, 11.35% and 0.66%, respectively, while the S_3 dose (compared to S_0) of OTO treatment had a positive effect by reducing the short fibre content by 8.5%.

Conclusions

The study results showed that the irrigation water stress created by not applying water in some developmental periods of the cotton crop had a significant effect on the spinning consistency index, fibre length, fibre fineness, fibre strength, fibre elongation, uniformity index, and short fibre content characteristics. On the other hand, no effect of foliar sulfur application on fibre quality properties was determined (except for the gin turnout and fibre length).

When the fibre quality parameters were evaluated on a yearly basis, the spinning consistency index, fibre length, fibre fineness (only in 2015), fibre strength, and uniformity index were positively affected by water application, while the fibre fineness (only in 2016), fibre elongation and short fibre content were adversely affected.

Regarding the sulfur doses applied in the study (S_0: 0 ml da^{-1}, S_1: 150 ml da^{-1}, S_2: 250 ml da^{-1}, S_3: 350 ml da^{-1}), the application of S_2 fertilizer in dry conditions (OOO) was expected to affect fibre length and fineness, the S_3 dose – fibre elongation and the S_1 dose – the uniformity index, but it was concluded that the sulfur applications also adversely affected the fibre strength value. In this case, it is concluded that the application of foliar sulfur in fields where anhydrous or periodic water restrictions take place can provide important advantages for farmers.

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References

1. Turktob. [cited 2020 Feb 17]. Available from: https://www.turktob.org.tr/dergi/makaleler/dergi21/8-13.pdf.
2. Cukobirlik. [cited 2017 Mar 17]. Available from: http://www.cukobirlik.com.tr/?tekd=777&ikid=1&syf=* PAMUK*.
3. Ministry of Customs and Trade General Directorate of Cooperatives. Cotton Report of 2015. [cited 2017 Jan 30]. Available from: http://koop.gtb.gov.tr/data/56e95b3a1a79f5b210d9176f/2015%20Pamuk%20Raporu.pdf.
4. Doorenbos J, Kassam AH. Yield Response to Water. FAO 1979; 33: p. 193, Rome.
5. Yasar M, Basbag S, Ekinci R. Effects of Topping at Different Times on Fibre Yield and Quality Traits on Cotton. *Iğdır Univ. J. Inst. Sci. & Tech*. 2017; 7(2): 327-333. (in Turkish).
6. Oosterhuis D. Physiology and Nutrition of High Yielding Cotton in the USA 2001; http://www.malavolta.com.br /Pdf/Physiologi. Pdf. 24.
7. İzci B. Different Levels of İrrigation Effects of Cotton (*Gossypium Hirsutum* L.) Fibre Quality Conditions Grown İn Çanakkale. *Journal of Alınteri* 2014; 26 (B): 25-31. (in Turkish).
8. Yildirim O. Design of İrrigation Systems. *Ankara University Agricultural Faculty* 2008; Publication no: 1565, p. 354. (in Turkish).
9. Kacar MM, Katkat V. İnvestigation of Cotton Water Stress İndex Variations Under Different Water and Fertilizer Systems. Cukurova University Institute of Science and Technology Agricultural Structures and Irrigation Department. 2007; (M.Sc. Thesis). (in Turkish).
10. Burt CM, O'connor K, Ruehr T. Fertigation. irr. *Training and Research Center. Cal. Polytec. St. Univ*. 1995; San Luis Obispo, Ca 93407, Isbn 0-9643634-1-0. 295 P.
11. Uster HVI Test result 2014
12. Cotton Incorporated U.S Cotton fibre Chart 1988; New York: Maclean Hunter Publishing Co.
13. Bek Y, Efe E. Research and Experiment Medoths I. Cukurova University, Faculty of Agriculture Adana, Turkey. *Textbook* 1988; p. 395 (in Turkish).
14. Yildiz Z, Haliloglu H. Profitable Approach İn Cotton Cultivar Preferences. *Journal of Nevsehir Science and Technology* (ICAFOF 2017 Special issue) 2017; 261-270. (in Turkish).
15. Odemis B, Akıscan Y, Akgol B, Can D. The Effect of Sulfur Doses Applied from the Leaf Under the Deficit İrrigation Conditions on the Drought Tolerance of the Cotton Plant. Scientific and Technological Research Council of Turkey (TUBITAK) (Project No: 214O254) 2017; (in Turkish).
16. Ozdemir Y, Dagdelen N. Effects of Different Drip İrrigation Applications on Cotton Fibre Quality, Yield Characteristics and Net İncome. *Journal of Adnan Menderes University Agricultural Faculty* 2016; 13(1): 79-88. (in Turkish).
17. Coskun Z. The Effect of Drip İrrigation on Cotton Yield İn The Harran Plain. Harran University Institute of Science and Technology Agricultural Structures and Irrigation Department 2015; (M.Sc. Thesis). (in Turkish).
18. Haliloglu H, Yilmaz A, Beyyavas V. Effect of Foliar Fertilizers Applied at Different Stages on Agronomic and Lint Characters of Cotton (Gossypium Hirsutum L.). *J Agr Sci* 2006; 12 (1) 1-7. (in Turkish).
19. Karademir C, Karademir E, Gençer O. Yield and Fibre Quality of F1 and F2 Generations of Cotton (*Gossypium hirsutum* L.) Under Drought Stress Conditions, *Bulg J Agric Sci* 2011; 17 (6): 795-805.
20. Sahito A, Baloch ZA, Mahar A, et al. Effect of Water Stress on the Growth and Yield of Cotton Crop (*Gossypium hirsutum* L.). *Am J Plant* SC 2015; 6: 1027-1039.
21. Ozgen B. Comparison of Quality Characteristics of Yarns Spinned from Aegean Cotton Fibres and their Mixtures with Southeast Anatolian Cotton Fibre. Dokuz Eylül University Institute of Science and Technology 2002; (M.Sc. Thesis). (in Turkish).
22. Alhalabi K. A Comparable İnvestigation on the Properties of Cotton Fibres Pro-

duced in Syria and Turkey and Their Spinning Capabilities. Deparment of Textile Engineering Institute of Naturel and Applied Science University of Çukurova 2017; (M.Sc Thesis) (in Turkish).
23. McWilliams D. Drought Strategies for Cotton. Cooperative Extension Service Circular College of Agriculture and Home Economics 2004; http://www.cahe.nmsu.edu/pubs/circulars.
24. İsotcu C, Basal H. The Comparison of Yield and Fibre Quality of Cotton (Gossypium Hirsutum L.) Progeny Rows Under Full and Deficit İrrigation. *Journal of Adnan Menderes University Agricultural Faculty* 2016; 13(2): 71-77. (in Turkish).
25. Kanber R. A Lysimeter Research on the Effects of İrrigation on Cotton Yield and Evapotranspiration of Some Soil Series at Different Usable Humidity Levels in Çukurova Conditions. TOPRAKSU Directorate of Research Institute, Tarsus 1977; (Ph.D. Thesis) (in Turkish).
26. Bastug R. A Study on Determining the Water Production Function of Cotton Under Cukuorova Conditions. Cukurova University, Faculty of Agriculture Adana, Turkey 1987; (Ph.D. Thesis) (in Turkish).
27. Price K. Investigation of Methods to Evaluate Drought Tolerance in Cotton. Texas Tech University. USA. 2009; (Ph.D. Thesis).
28. Baskuru İ. Determination of Responses of Cotton (*Gossypium Hirsutum* L.) Hybrid Populations to Water Stres. Adnan Menderes University Institute of Science and Technology, Department of Field Crops 2015; (M.Sc. Thesis). (in Turkish).
29. Peynircioglu C. The Determination of Cotton (*Gossypium Hirsutum* L.) Genotypes for İmprovement of Drought Tolerant Cotton Varieties. Adnan Menderes University Department of Field Crop Sciences 2014; (M.Sc. Thesis). (in Turkish).
30. Rai E. Mechanism of Drought Tolerance İn Cotton- Response of Cotton Cultivars to İrrigation in the Texas High Plains 2011; Master of Science, Texas Tech University. USA. P:97.
31. Hussein F, Janat M, Yakoub A. Assessment of Yield and Water use Efficiency of Drip İrrigated Cotton (*Gossypium Hirsutum* L.) As Affected By Deficit İrrigation. *Turk J Agric For* 2011; 35: 611-621
32. Karademir E, Karademir C, Ekinci R, Sevilmis U. Determination of Yield and Fibre Quality Properties in Advanced Generation Lines in Cotton (*Gossypium hirsutum* L.). *Turk J Agric Res* 2015; 2: 100-107. (in Turkish).
33. Basal H, Dagdelen N, Unay A, Yilmaz E. Effects of Deficit Drip İrrigation Ratios on Cotton (Gossypium hirsutum L.) Yield and Fibre Quality. *J. Agron. Crop Sci.* 2009; 195: 19-29.

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