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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Evaluation of the Effects of Foliar Sulfur Applications on Yield, Evapotranspiration and Water Use Efficiency of Cotton (*Gossypium hirsutum* L.) Under Different Irrigation Regimes

Farklı Sulama Rejimleri Altında Yapraktan Kükürt Uygulamalarının Pamuğun (*Gossypium hirsutum* L.) Verim, Evapotranspirasyon ve Su Kullanım Randımanına Etkilerinin Değerlendirilmesi

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Abstract

In this study, it was aimed to determine the effects of foliar sulphur applications on cotton plants exposed to water stress. It was carried out on 'Carisma' variety cotton plant with 3 irrigation level, 3 sulfur doses and 3 replicates, except for control treatments, in split plots experimental design in randomized blocks. Sulfur in elemental form was applied at doses of 150 ml da^{-1} (S_1), 250 ml da^{-1} (S_2) and 350 ml da^{-1} (S_3), except for the control (S_0) and at I_{100}, I_{66}, I_{33} irrigation levels of the available capacity and in the non-irrigated treatment (I_0). Irrigation water amounts varied between 332-1006 mm and 306-928 mm in the 2015 and 2016, and evapotranspiration ranged between 299-1096 mm and 247- 995 mm, respectively. Evapotranspiration decreased slightly in the first year and increased in the second year as the sulphur doses increased. The highest yields were 5871 kg ha^{-1} ($I_{100}S_0$) and 6148.7 kg ha^{-1} ($I_{100}S_1$) in 2015 and 2016, respectively. In comparison to I_{100}, yield decreased by 70%, 39% and 14% in 2015, 67%, 33% and 8% in 2016 in I_0, I_{33} and I_{66}, respectively. Sulphur doses caused yield to decrease in 2015 and increase in 2016. Compared to S_0 treatment, yield increased by 14%, 1.9% and 8.6% at S_1, S_2 and S_3 in 2016. With the decrease in ET, yield (relative to I_{100}) decreased by 73%-70% at I_0, 52%-39% at I_{33} and 26%-15% at I_{66} in the first year, by 75%-67% at I_0, 44%-33% at I_{33} and 20%-8% at I_{66} in the second year, and by 74%-68% at I_0, 48%-36% at I_{33} and 23%-11% at I_{66}. Water use efficiency (WUE) was approximately the same in sulfur doses, while the lowest was determined at I_{100} and the highest was determined at I_0 and I_{33}. WUE increased as the amount of irrigation water increased in the second year, but did not show a stable change in the first year. The highest WUE was calculated in the first year on I_{33} (6.3 kg ha^{-1}mm^{-1}) and in the second year on I0 (7.5 kg ha^{-1}mm^{-1}). Sulphur doses did not cause a significant difference in WUE and the highest WUE was determined at S_0 (6.0 kg ha^{-1}mm^{-1}) in the first year and in the second year at S_1 (6.5 kg ha^{-1}mm^{-1}). Sulphur doses did not affect leaf sulphur concentration in the first year, but statistically in the second year. Mean of two years, the highest leaf sulphur concentration was measured in S_3.

Keywords: Drought tolerance, Foliar application, Sulfur, Irrigation level, Cotton

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Öz

Bu çalışmada, su stresine maruz bırakılmış pamuk bitkisine yapraktan kükürt uygulamalarının etkilerinin belirlenmesi amaçlanmıştır. Araştırma, Carisma çeşidi pamuk bitkisinde 3 sulama düzeyi, 3 kükürt dozunda 3 tekerrürlü olarak tesadüf bloklarında bölünmüş parseller deneme deseninde yürütülmüştür. Denemede, elverişli kapasitenin 3 farklı sulama düzeyinde (I_{100}, I_{66}, I_{33}) ve susuz konuda (I_0) pamuk bitkilerine tanık (S_0) konusu dışında 150 ml da^{-1} (S_1), 250 ml da^{-1} (S_2) ve 350 ml da^{-1} (S_3) dozlarında elementel formda kükürt uygulanmıştır. Sulama suyu miktarları 2015 ve 2016'da sırasıyla 332-1006 mm ile 306-928 mm, evapotranspirasyon 299-1096 mm ile 247- 995 mm arasında değişmiştir. Evapotranspirasyon (ET), kükürt dozları arttıkça ilk yıl azalmış, ikinci yılda ise artmıştır. En yüksek verim 2015 ve 2016'da sırasıyla 5871.3 kg ha^{-1} ($I_{100}S_0$) ve 6148.7 kg ha^{-1} ($I_{100}S_1$) ölçülmüştür. I_{100}'e göre verim 2015'de I_0, I_{33} ve I_{66} konularında sırasıyla %70, %39 ve %14, 2016'da %67, %33 ve %8 azalmıştır. Kükürt dozları verimin ilk yıl azalmasına ikinci yılda artmasına neden olmuştur. Verim 2016'da (S_0'a göre) S_1, S_2 ve S_3 dozlarında %14, %1.9 ve %8.6 artmıştır. ET'deki azalma ile verim (I_{100}'e göre) ilk yıl I_0'da %73 - %70, I33'te %52 - %39 ve I66'da %26 - %15, ikinci yılda ise I_0'da %75-67, I_{33}'te %44-%33 ve I66'da %20-%8 ve ortalama I0'da %74 - %68, I_{33}'te %48 - %36 ve I_{66}'da %23 - %11 azalmıştır. Su kullanım etkinliği (WUE), kükürt dozlarında yaklaşık aynı, sulama konularında en düşük I_{100}'de en yüksek I_0 ve I_{33}' de belirlenmiştir. İkinci yılda sulama suyu miktarı arttıkça WUE artmış ancak ilk yıl kararlı bir değişim göstermemiştir. En yüksek WUE ilk yıl I_{33} konusunda (6.3 kg $ha^{-1}mm^{-1}$) ikinci yıl I_0 konusunda (7.5 kg $ha^{-1}mm^{-1}$) hesaplanmıştır. Kükürt dozları WUE'nde önemli bir fark oluşturmamış ve en yüksek WUE ilk yıl S_0 konusunda (6.0 kg $ha^{-1}mm^{-1}$) ikinci yıl S_1 konusunda (6.5 kg $ha^{-1}mm^{-1}$) belirlenmiştir. Kükürt dozları yaprak kükürt konsantrasyonunu ilk yıl etkilemezken ikinci yılda istatistiksel olarak etkilemiştir. İki yılın ortalamasına göre en yüksek yaprak kükürt konsantrasyonu S_3 konusundan ölçülmüştür.

Anahtar Kelimeler: Kuraklık toleransı, Yapraktan uygulama, Kükürt, Sulama düzeyi, Pamuk

1. Introduction

Fertilizer management may reduce, increase, or have no effect on the drought tolerance of plants, depending on the level of water available. This management in drought conditions is complicated, and salinity problems are also observed in most arid areas. In studies conducted for the relationship between drought and plant nutrients, it was reported that nutrients could provide additional benefits to the plant apart from their usual functions (Ma et al., 2004; Garg et al., 2004; Hu et al., 2008; Ürkmez et al., 2024). Especially during short dry periods, fertilizer applications that will prevent physiological decline in the plant and ensure that it remains healthy can increase yield when the plant is under stress. However, the effectiveness of fertilizers on the plant may change in foliar and soil applications.

The application of foliar fertilization to alleviate physiological stress has enormous potential (Fernandez et al., 2013). This is due to the fact that as a plant transitions from vegetative to reproductive stages, the quantity of photosynthate generated by the leaves is preferentially relocated to the developing fruit and seed, while the amount reaching to the roots is substantially reduced.

Sulfur is one of the key elements that can be used to increase drought tolerance (Jie et al., 2008). Sulfur, which activates in 20 days in the soil applications and 8 hours in the foliar applications, plays a significant role in the realization of photosynthesis (Kacar and Katkat, 2007). It prevents the reduction of chlorophyll content and can increase the yield of crops by increasing the amount of chlorophyll under stress conditions (Lina et al., 2005). The decrease in leaf chlorophyll concentration in water and sulfur deficiency is more pronounced in active photosynthesizing (functional) leaves (Dietz, 1989). In this case, the amount of chlorophyll can be increased with the sulfur application, and the severity of abiotic stress can be alleviated (Jie et al., 2008). Sulfur also builds protein structure and plays a fundamental role in the chlorophyll structure (Duke and Reisenaue, 1986). The most typical symptoms of sulfur deficiency in plants are yellowing of young leaves due to a decline of protein and chlorophyll synthesis, decrease in hydraulic root permeability, stomatal openings, net photosynthesis, and chloroplast numbers, and decrease in leaf area (Marschner, 1995). It was determined that the chlorophyll content of wheat under drought stress increases with the sulfur application (Lina et al., 2005), and the chlorophyll content of functional leaves decreases in cases of sulfur deficiency (Jie et al., 2008). Researchers suggested that with the application of sulfur, stress is reduced, and productivity is increased. Ghaznavi and Abdolshahi (2011) reported that drought stress reduces yield by 39.37% in wheat, and with 100 kg ha^{-1} potassium sulfate application, the yield increases by 8% in full irrigation and 10% under drought stress. The increase in yield under stress depends on sulfur metabolism, sulfate transport, and sulfate assimilation in the leaves. Besides, sulfur deficiency causes a decrease in protein synthesis and the activities and efficiency of sulfur-containing amino acids in the structure of amino acids (Chan et al., 2013).

In this study, the effect of foliar sulfur applications was investigated to reduce the effect of stress on cotton plants exposed to water stress. This research also determined the effects of sulfur applications on evapotranspiration, water use efficiency, and leaf sulfur concentration as well as seed yield.

2. Materials and Methods

2.1. Study area

The research was conducted in the Amik Plain in the Eastern Mediterranean Region. The soils of the experiment area were determined as silty clay loam, and the irrigation water was determined as C_2S_1 (*Table 1*). According to long-year (1945 - 2006) climate data, the average temperature is 20°C. The climate data measured during the experiment are given in *Table 2*.

2.2. Experimental design

The research was carried out with foliar applications of 3 doses of elemental sulfur, 4 irrigation levels, and 3 replicates for each irrigation level, in split plot experimental design in randomized blocks. Since the primary purpose of the experiment was to determine the contribution of sulfur doses to drought tolerance, irrigation levels were the main experiments, and sulfur doses were the sub-experiments. Each irrigation plot was created from 4 plant rows. The plot lengths were determined as 15 m, and the replicate plot lengths were determined as 5 meters. Two meter rows of buffer plants were left between the plots, and 2 rows of buffer plants were left between the irrigation plots. The interrow spacing was arranged as 0.70 m and the intra-row spacing as 15 cm. Thus, approximately 100 plants were planted in each row. Carisma variety cotton with high adaptability and yield potential was used as the research material.

2.3. Irrigation treatments

The first irrigation was performed when 50% of the available water was consumed, and subsequent irrigations were performed to replenish the deficit soil moisture (approximately 6 days apart). The experiments were arranged as a no-irrigation treatment (I_0), a full irrigation treatment (I_{100}) in which deficit moisture was brought to field capacity, and 66% (I_{66}) and 33% (I_{33}) of the full irrigation treatment. Soil moisture content was measured weekly by gravimetric method in all experiments and replications and the required amount of irrigation water was calculated using Equation 1.

$$I = (d * A * P)/ Ea \qquad \text{(Eq.1).}$$

I: Amount of irrigation water to be applied to full irrigation treatment (100%), d: The amount of irrigation water required (mm), A: Plot area (m^2), Ea: Water application efficiency, (0.95). P: Percentage of wetted area (%). Whether or not the targeted irrigation area was reached was checked after irrigation.

Table 1. Some soil characteristics of the experimental field

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	pH	ECe	$CaCO_3$ (%)	N (%)	Org. Mat. (%)	FC (g g^{-1})	PWP (g g^{-1})	As
0-30	59.52	15.28	25.2	SiCL	7.55	1124	2.265	1.42	0.33	21.3	13.4	1.660
30-60	57.52	19.28	23.2	SiCL	7.62	560	0.680	1.65	0.34	24.1	14.2	1.676
60-90	53.52	17.28	29.2	SiCL	7.80	429	0.905	2.01	0.38	25.0	14.5	1.540
90-120	61.52	15.28	23.2	SiCL	7.65	400	0.300	2.12	0.37	25.2	14.7	1.489

FC: field capacity and PWP: permanent wilting point are given as the percentage of water by weight. As: bulk density (g cm^{-3}), ECe: Electrical conductivity of soil paste (µmhos cm^{-1}).

Table 2. Climate data of experimental years (2015 – 2016)

Years	Climate Parameters	May	June	July	August	September	Mean
2015	Temperature (°C)	21.92	24.59	27.35	28.95	27.60	26.09
	Precipitation (mm)	19.4	0.00	0.00	1.2	0.00	20.6
	Solar Rad. (wm^{-2})	278.88	295.92	294.20	261.63	199.99	266.108
	Soil Temp. (°C)	24.88	27.74	30.17	31.57	30.09	28.89
	Wind Speed (km $h^{-1)}$	5.59	8.20	8.39	6.40	4.17	6.55
2016	Temperature (°C)	21.26	26.41	28.39	28.46	25.13	25.93
	Precipitation (mm)	3.23	14	16	119.2	0.0	149.2
	Solar Rad. (wm^{-2})	256.36	305.12	311.56	279.32	234.00	277.27
	Soil Temp. (°C)	22.44	27.37	30.29	30.63	26.65	27.48
	Wind Speed (km $h^{-1)}$	5.31	6.19	7.59	6.60	4.06	5.95

2.4. Sulfur treatments

Sulfur was not detected in the soil of the area where the experiment was conducted as a result of the analysis of the turbidimetric barium method (Kowelenko et al., 2014). A large part of Turkey's soils is insufficient in terms of sulfur content. While the absorption time of sulfur by the plant in soil application is about 20 days, this period is only 8 hours in the foliar application (Kacar and Katkat, 2007). Therefore, since it is aimed that the plant recovers from the stress in a shorter time, sulfur applications are realized only as foliar applications. The sulfur doses applied in the experiment were determined in line with the recommendations of the academicians working on sulfur.

S_0: N, P, K soil application

S_1: N, P, K soil application + 150 ml da^{-1} foliar elemental sulfur application

S_2: N, P, K soil application + 250 ml da^{-1} foliar elemental sulfur application

S_3: N, P, K soil application + 350 ml da^{-1} foliar elemental sulfur application

Liquid elemental sulfur in a volume of 720 g sulfur l^{-1} was used in the experiment. The most sensitive period to water stress in cotton plants is the flowering period (Loka and Oosterhuis, 2012). Hence, sulfur applications were applied only during the square and flowering periods of the cotton plant (10% from square to 10% boll growth). In the cotton experiments carried out before in the experimental area, it was determined that 5 irrigations were made with the drip irrigation method during the square and flowering period (Akgöl, 2012). The amount of seasonal fertilizer required for the plant was applied by dividing it equally by the number of irrigations to be made during the square and flowering periods. Fertilization was done in the middle of the two irrigations (3 or 4 days after irrigation) in the early morning hours (6.00-6.30), when the wind did not affect the fertilizer distribution adversely. In order to prevent differences in the concentration of fertilizer applied to the same experiment on different dates, the amount of water consumed from the portable pulverizator was tested with a water-filled sprayer in another area of the same size before each application, and after determining the amount of reduced water, the calculated liquid sulfur amount was mixed into this volume, and the application was carried out. Since it was planned to realize approximately 4 irrigations during the flowering period, the application was made by dividing each sulfur dose into 4. In the application with the portable pulverizator, the same person fertilized so that there was no difference between the walking speeds of the practitioners.

Nitrogen (N), Phosphorus (P), and Potassium (K) fertilizers required by cotton are equal to all experiments and at the dose rate commonly used in the region: Before planting, 20 kg da^{-1} of 18-46-0 (DAP) fertilizer was applied, and after planting, 4 kg da^{-1} of nitrogen fertigation method was applied in each of the first 4 irrigations (Singh et al., 2021).

2.5. Leaf Sulfur Analysis

Leaf samples were collected at different plant growth stages (square, flowering initiation, full flowering, and boll formation periods) to determine the effects of the applications on the sulfur concentration in the leaves. In the sampling, 5 upper leaves, which were functional in 2 plants, were collected in each replicate. The collected samples were crushed with a mortar in the laboratory, and 2-3 milligram samples for each replicate were analyzed in the Truspec CHNS Analyzer device.

2.6. Harvest

Irrigation treatments (6 plant rows and 0.70 m interrows) were formed from 4.2 m wide and 5 m long replicate plots. The harvest was made from the remaining 14 m^2 replicate area after removing 1 m from the beginning and end of each row and 1 row from the right and left. Since each treatment has 3 replicates, the total harvest area is calculated as 42 m^2.

2.7. Evapotranspiration (ET)

From the beginning of the trial to the harvest date, changes in soil moisture were measured with the gravimetric method before each irrigation, and the weekly evapotranspiration was calculated according to the "Soil Water Budget" method (Equation 2).

$$ET = I + R + Cr - Dp - Rf \pm \Delta S \qquad \text{(Eq.2).}$$

In equation, ET: Evapotranspiration (mm); I: Amount of applied irrigation water (mm); R: Precipitation (mm); Cr: Capillary rise (mm); Dp: Deep percolation (mm) (Measured from 120 cm depths of full irrigation treatments approximately 24 hours after irrigations); Rf: Runoff flow (mm); ±ΔS: The moisture changes in the soil profile (mm 90 cm^{-1}). In the equation, precipitation (R) was determined from the pluviometer in the research area, and ΔS was determined by the gravimetric method. Since drip irrigation is used in the system, the runoff flow (Rf) was not calculated.

2.8. Water Use Efficiency

Water use efficiency (WUE) was calculated using evapotranspiration and yield values (Howell et al., 1984). (Equation 3).

$$WUE = Ya \, / \, ET \qquad \text{(Eq. 3).}$$

In the equation, WUE: Water use efficiency (kg ha^{-1} mm^{-1}), Ya: Cotton yield from treatments (kg ha^{-1}), ET: Evapotranspiration (mm)

2.9. Analysis and Evaluation of Data

All data measured during the experiment were evaluated by statistical method in accordance with the split-plot experimental design in randomized blocks and subjected to analysis of variance. The averages of the data obtained as a result of measurement and analysis were compared by Duncan Test (Bek and Efe, 1988).

3. Results and Discussion

3.1. Irrigation Water

Irrigation water amounts were at the same level on average in both years. In the first and second years, 91 - 149 mm, 423 - 456 mm, 755 - 771 mm, and 1097 - 1078 mm irrigation water (including precipitation) was applied to I_0, I_{33}, I_{66}, and I_{100} irrigation experiments, respectively (*Table 3*). Full irrigation treatment (I_{100}) received 1097 mm and 1078 mm irrigation water in the first and second year. The maximum irrigation water requirement was calculated during the flowering period in both years. In the first year, 591 mm of irrigation water was applied to the sulfur treatments, and 613 mm in the second year. In the previous studies carried out in the experimental area, the irrigation water requirement was determined as 483-602 mm in 6-7 irrigations in 2012 (Can, 2017), and at the level of 1135 mm in 10 irrigations in 2017 (Kazgöz Candemir and Ödemiş, 2018). This indicates that the amount and number of irrigation water applied to cotton increases over time in the Amik Plain. Although the soil, plant variety, and irrigation method are the same, it is thought that the most important factor in increasing the irrigation water requirement is the change in climate parameters. The Amik Plain is the second region in Turkey, with continuous wind throughout the year. The fact that the plain has a large area significantly increases the cumulative temperature and the amount of evaporation in the wind direction. This causes the irrigation water requirement to be higher than other plains. Studies conducted in other regions also suggest that factors such as seasonal temperature fluctuations, wind speed, and soil moisture differences in planting dates cause changes in irrigation water requirement and irrigation number (Yavuz, 1993; Çetin and Bilgel, 2002; Yazar et al., 2002; Ünlü et al., 2011).

Table 3. Mean values of irrigation water, yield, and WUE in irrigation level and sulfur doses*

Treat.	**Amount of irrigation water (mm)**		**Evapotranspiration (mm)**		**Yield (kg ha^{-1})**		**WUE (kg ha^{-1}mm^{-1})**	
	2015	2016	2015	2016	2015	2016	2015	2016
I_0	91	149	299	247	1630.4 d	1859.7 d	5.4	7.5
I_{33}	423	456	525	558	3308.4 c	3707.8 c	6.3	6.6
I_{66}	755	772	817	797	4652.8 b	5097.0 b	5.7	6.4
I_{100}	1097	1078	1096	996	5421.6 a	5555.2 a	4.9	5.6
S_0	591	614	702	628	4222.3 a	3815.6 c	6.0	6.1
S_1	591	614	685	677	3635.2 b	4369.2 a	5.3	6.5
S_2	591	614	683	651	3599.3 b	3889.8 bc	5.3	6.0
S_3	591	614	668	641	3556.5 b	4145.1 ab	5.3	6.5

Treat.	**2015-2016 (mean)**	**2015-2016 (mean)**	**2015-2016 (mean)**	**2015-2016 (mean)**
I_0	120	273	1745.1 d	6.4
I_{33}	439	542	3508.1 c	6.5
I_{66}	763	807	4874.9 b	6.0
I_{100}	1087	1046	5488.4 a	5.2
S_0	602	665 a	4019.0 a	6.0
S_1	602	681 a	4002.2 a	5.9
S_2	602	667 b	3744.5 c	5.6
S_3	602	655 c	3850.8 b	5.9

WUE: Water use efficiency, *The values for yield and evapotranspiration presented in the table were previously published by Ödemiş et al., 2022.

3.2. Evapotranspiration

The highest and lowest evapotranspiration (ET) were measured from the I_{100} and I_0 treatments in both years. Evapotranspiration in the first and second years was determined as 299 - 247 mm in I_0, 525 - 558 mm in I_{33}, 817 - 797 mm in I_{66}, 1096 - 996 mm in $I1_{00}$ (*Table 3*). Evapotranspiration decreased slightly as the sulfur dose increased in the first year but was higher in the second year (compared to S_0). In the second year, lower ET was realized in S_1 (150 ml da^{-1}) than other doses. On average, evapotranspiration at sulfur doses ranged from 681 mm (S_1) to 655 mm (S_3). It was determined that the amount of irrigation water was more effective on the difference in evapotranspiration between the treatments, while sulfur applications did not make a significant difference. Evapotranspiration decreased as the sulfur dose increased in the cotton plant exposed to the same sulfur doses and longer stress in the same area. Especially in the vegetative period, the K_2 dose (250 ml da^{-1}) of the treatments that was non-irrigated during the other growth periods decreased by 15.35% (Kazgöz Candemir and Ödemiş, 2018). The decline in soil moisture causes a decrease in leaf water content. In cotton leaves exposed to stress, wax content (Wullschleger and Oosterhuis, 1987) and leaf cuticle thickness increase (Oosterhuis et al., 1991), transpiration, and thus evapotranspiration may decrease. Therefore, when environmental pollutants are considered in plants exposed to water stress, foliar fertilization can partially reduce evapotranspiration.

3.3. Yield

The yield was affected negatively by sulfur doses and positively by irrigation levels in the first year, while positively affected by both sulfur doses and irrigation levels in the second year (*Table 4*). The most important factor affecting yield in cotton is water stress. The yield decreases depending on the severity and duration of the stress and the plant development period in which it occurs. The water stress experienced from the square initiation period to the period when the first flower appears causes a great decrease in yield (Krieg, 1997).

Table 4. Variance analysis table for cotton yield and leaf sulfur content

Years	**Yield (kg ha^{-1})**			**Leaf sulfur content (%)**	
	Source of Variation	**df**	**F**	**df**	**F**
2015*	Irrig. lev (I)	3	***	3	***
	Sulfur Dose(S)	3	***	3	ns
	I*S	9	ns	9	**
	Error	32		155	
2016	Irrig. lev (I)	3	***	3	***
	Sulfur Dose(S)	3	**	3	**
	I*S	9	ns	9	ns
	Error	32		167	
2015 -2016	Irrig. lev (I)	3	***	3	***
	Sulfur Dose(S)	3	**	3	***
	Year (Y)	1	***	7	***
	I*S	9	ns	9	***
	I*Y	3	ns	18	***
	S*Y	3	***	19	***
	I*S*Y	9	ns	48	***
	Error	64		323	

df: degrees of freedom, ns: non significant *Sulfur doses in the first year negatively affected the yield.

In the first year, the highest yield was obtained from $I_{100}S_0$ with 5871 kg ha^{-1}, and in the second year from $I_{100}S_1$ with 6148.7 kg ha^{-1}. The average yield value of both years was determined for the highest $I_{100}S_1$ treatment (5653 kg ha^{-1}). Average seed yields were higher in the second year (*Tablo 5*). The highest and lowest yields for sulfur treatments were determined for S_0 and S_3 (3557 kg ha^{-1} and 4222.3 kg ha^{-1}). The lowest yield S_0 (3816 kg ha^{-1}) and the highest yield S_1 (4369 kg ha^{-1}) were determined in the second year. Öztürk and Korkut (2018) reported that under fully drought stress condition grain yield of wheat decreasing was 40.1%, under shooting stage of drought 28.0%, and during grain filling period of drought 26.2%.

3.4. Water use efficiency (WUE)

WUE generally increased as the amount of irrigation water decreased. It decreased linearly as the irrigation water increased in the second year, while an unsteady change was found in the first year. The mean highest WUE was calculated for the first year in the I_{33} treatment (6.3 kg ha^{-1}mm^{-1}) and the I_0 treatment for the second year (7.5 kg ha^{-1}mm^{-1}) (*Table 3*).

Sulfur doses did not cause significant differences in mean WUE. WUE was determined at the same level (5.3 kg ha^{-1}mm^{-1}) in treatments other than S_0 in the first year. In the second year, the highest WUE was observed in S_2 and S_3 doses (6.5 kg ha^{-1}mm^{-1}). The average WUE values of both years were at approximately the same level.

Table 5. Values in the experimental years of evapotranspiration, yield, and water use efficiency

Treat.	2015	2016	Mean	2015	2016	Mean	2015	2016	Mean
		ET			Yield			WUE	
I_0S_0	305.88	205.86	255.87	2060.0	1824.3	1942.2	6.7	8.9	7.6
I_0S_1	304.73	276.08	290.40	1530.8	1902.3	1716.6	5.0	6.9	5.9
I_0S_2	292.73	235.70	264.21	1309.5	1743.0	1526.3	4.5	7.4	5.8
I_0S_3	294.10	271.25	282.67	1621.4	1969.0	1795.2	5.5	7.3	6.4
$I_{33}S_0$	530.73	535.68	533.20	3752.6	3336.0	3544.3	7.1	6.2	6.6
$I_{33}S_1$	524.73	575.96	550.34	3262.2	3930.0	3596.1	6.2	6.8	6.5
$I_{33}S_2$	523.73	572.05	547.89	3097.8	3682.7	3390.2	5.9	6.4	6.2
$I_{33}S_3$	521.73	549.26	535.50	3121.1	3882.3	3501.7	6.0	7.1	6.5
$I_{66}S_0$	836.96	763.02	799.99	5205.3	5180.3	5192.8	6.2	6.8	6.5
$I_{66}S_1$	825.54	835.80	830.67	4591.1	5495.7	5043.4	5.6	6.6	6.1
$I_{66}S_2$	815.42	800.47	807.95	4499.2	4800.7	4649.9	5.5	6.0	5.8
$I_{66}S_3$	790.96	787.02	788.99	4315.5	4911.3	4613.4	5.5	6.2	5.8
$I_{100}S_0$	1133.73	1006.8	1070.2	5871.3	4921.7	5396.5	5.2	4.9	5.0
$I_{100}S_1$	1086.60	1021.5	1054.2	5156.6	6148.7	5652.6	4.7	6.0	5.4
$I_{100}S_2$	1099.35	995.40	1047.4	5490.4	5332.7	5411.5	5.0	5.4	5.2
$I_{100}S_3$	1065.57	958.38	1011.9	5168.2	5817.7	5492.9	4.9	6.1	5.4

ET: Evapotranspiration (mm), Yield, kg ha^{-1}, WUE: Water Use Efficiency, kg ha^{-1} mm^{-1}

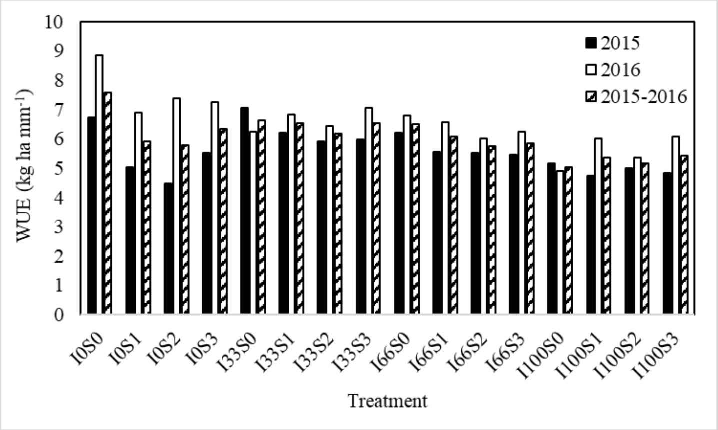

Figure 1. WUE values of irrigation and sulfur treatment

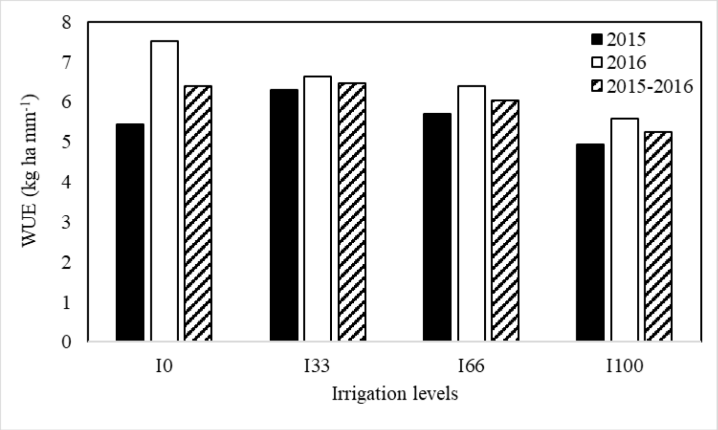

Figure 2. Mean values of WUE in irrigation treatment

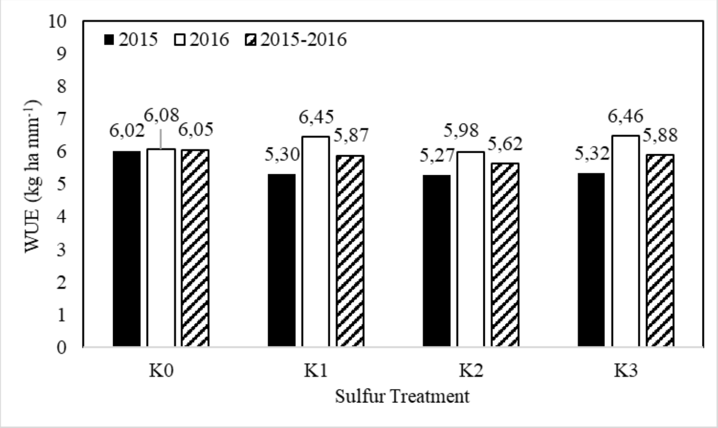

Figure 3. Mean values of WUE in sulfur doses

In the interactions of irrigation level x sulfur dose, the highest was determined for WUE $I_{33}S_0$ at 7.1 kg ha^{-1} mm^{-1} in the first year, and the lowest was determined for I_0S_2 (4.5 kg ha^{-1} mm^{-1}) (*Table 5*). WUE ranged from 8.9 kg ha^{-1} mm^{-1} (I_0S_0) to 4.9 kg ha^{-1} mm^{-1} ($I_{100}S_0$) in the second year. In the average values of both years, the highest and lowest WUE was calculated as 7.6 kg ha^{-1} mm^{-1} for I_0S_0 and 5.2 kg ha^{-1} mm^{-1}for $I_{100}S_2$.

Studies report that WUE varies depending on the plant variety, leaf shape, amount of water stored in the soil, climatic conditions, and plant development periods. Karam et al. (2006) determined WUE values as 1.3, 1.1, 1.0, and 0.80 kg ha^{-1} mm^{-1} in cotton during the first boll opening, boll formation, and the middle of the boll formation, and control. Hussein et al. (2011) determined the WUE value as 0.65 and 0.70 kg m^{-3} in the first year and as 0.65 and 0.72 kg m^{-3} in the second year in the full irrigation treatment and 80% of the full irrigation was applied, respectively. Zonta et al. (2017) calculated the WUE value between 0.39 and 0.84 kg m^{-3} in 8 cotton varieties. In studies conducted in Turkey, WUE was determined between 4.87 kg ha^{-1} mm^{-1} and 12.6 kg ha^{-1} mm^{-1} in different climatic regions (Çetin and Bilgel, 2002; Dağdelen et al., 2006). These results obtained in the literature were found to be in line with the results of current study.

3.5. Irrigation Water - Yield Relationships

As the amount of irrigation water increased in both years of the study, the seed yield also increased (*Figure 4*). Polynomial and significant regression relationships were found between irrigation water and yield in both years. The highest yield (I_{100}=5422 kg ha^{-1}) on average in the first year was obtained from the full irrigation treatment. Based on I_{100}, yield values decreased by 70%, 39%, and 14%, respectively, in I_0, I_{33}, and I_{66} treatments. It was determined that when the amount of irrigation water decreased by 31% in I_{66}, the yield decreased by 14%, and in I_{33}, when the irrigation water decreased by 61%, the yield decreased by 39%. In the second year, the yield decreased 67% in I_0, 33% in I_{33}, and 8% in I_{66}, compared to the full irrigation treatment (I_{100}= 5555 kg ha^{-1}), where the highest yield was obtained. Compared to I_{100} treatment, 28% (I_{66}) and 58% (I_{33}) reduction amounts in irrigation water caused an 8% and 33% decrease in yield.

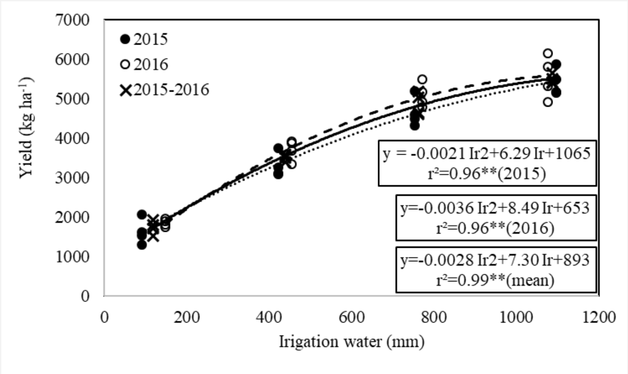

Figure 4. The relationships between the amount of irrigation water and yield

Vegetative and generative characteristics are significantly reduced in drought-exposed plants (Oguz et al., 2022). Before study indicates that irrigation has a decisive role in cotton yield. It was also reported that water stress, which occurs in conditions where irrigation is not done or not sufficient, disrupts the hormonal balance that is a key element in the shedding of square and bolls in cotton (Guin et al., 1990), irrigation increased the number of bolls per unit area by 30% and the fiber yield by 35%, but it did not change the boll seed weight (Pettigrew, 2004). Another study determined that the irrigation water requirement increased significantly in the Harran Plain, where the average temperature and vapor pressure deficit were high, and a cotton yield of 5850 kg ha^{-1} was obtained at 868 mm irrigation water requirement (Yazar et al., 2002). However, in Çukurova Plain, where the relative humidity and temperature are high, the yield was obtained between 1970-4220 kg ha^{-1} in the irrigation water requirement varying between 322 - 472 mm (Ertek and Kanber, 2003). Again, in the Harran Plain, the highest yield in irrigation applications made with row, sprinkler, and drip methods was obtained from the drip irrigation method, which is 30% higher than sprinkler irrigation and 21% higher than furrow irrigation (Çetin and Bilgel, 2002). The results of the water-yield relationship obtained in areas similar to the climate of the region where the research was conducted are in harmony with each other. However, in the area where this research was conducted, it was observed that the irrigation water requirement for cotton increased almost every year. While the irrigation water requirement was 589 mm in 6 irrigations in 2012 (Can, 2017), it increased to 1135 mm in 10 irrigations in 2017 (Kazgöz Candemir and Ödemiş, 2018). It is considered that the increase in the need for irrigation water is due to the increase in the amount of evaporation and transpiration due to the extraordinary increases in temperature and wind speed in the irrigation season in some years.

3.6. Evapotranspiration- Yield Relationships

A high correlation coefficient was obtained between evapotranspiration (ET) and yield (*Figure 5*). A 1 mm increase in ET led to an increase of 4.7 kg ha^{-1} in the first year and 5.1 kg ha^{-1} in the second year. The increase in sulfur doses did not cause a significant change in evapotranspiration. Compared to the I_{100} treatment, the yield reduction due to the decrease in ET was 73% - 70% in I_0 in the first year, 52% - 39% in I_{33}, and 26% - 15% in I_{66}. In the second year, compared to the I_{100} treatment, the reduction rate in ET decreased by 75%-67% in I_0, 44% - 33% in I_{33}, and 20% - 8% in I_{66}. The mean values of both years decreased by 74% - 68% in I_0, 48% - 36% in I_{33}, and 23% - 11% in I_{66}.

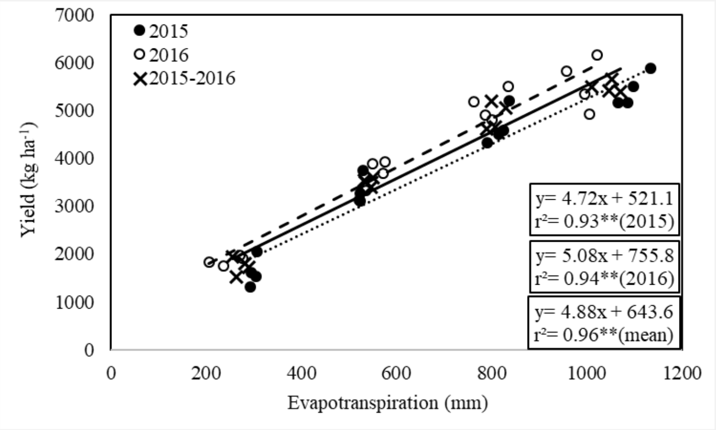

Figure 5. The relationships between evapotranspiration-yield

3.7. Sulfur Doses - Yield Relationships

The average highest yield in sulfur doses was obtained from the S_0 experiment (4222.3 kg ha^{-1}) in the first year and the S_1 treatment (4369.2 kg ha^{-1}) in the second year (*Table 5*).

It is thought that the air temperature was higher than expected in the first year of the experiment, and the desert dust that stormed in some periods partially prevented the foliar sulfur intake. This situation caused instability in the contribution of sulfur doses to yield.

The highest yield (except for I_0S_3) was obtained in the second year from the S_1 (150 ml da^{-1}) doses of irrigation treatments. The $I_{100}S_1$ treatment was the one with the highest yield (6148.7 kg ha^{-1}). Compared to the S_0 dose, the yield of the S_1 dose increased 18% in I_{33}, 6% in I_{66}, and 25% in I_{100}. The lowest average yield was obtained from a non-sulfur (S_0) treatment (3815.6 kg ha^{-1}). In the second year, the increase of the sulfur doses only up to the S_1 dose was evaluated as the result of the stress in the plant after a certain level of the sulfur dose. On the other hand, the S_1 dose caused higher efficiency than other doses in I_{33} and I_{66} treatments with deficit irrigation. Sulfur is an effective element in increasing the amount of yield (Jie et al., 2008; Lina et al., 2005). However, foliar and soil application cause differences in the assimilation time of sulfur. Kacar and Katkat (2007) expressed that sulfur can be used effectively in the plant in 20 days in the soil applications and 8 hours in the foliar applications. Xinhua et al. (2011) pointed out that the soil application of 22 and 34 kg of S ha^{-1} increased the yield by 8 - 10% on average compared to the control (non-sulfur) application, and it partially affected the fiber quality characteristics. On the other hand, Hu et al. (2008) found out that although there was a decrease in evapotranspiration, shoot fresh and dry weight, leaf fresh and dry weight in maize plant under drought and salinity stress; foliar fertilization did not improve plant growth and development under short-term drought or salt stress. It was also determined that the application of sulfur in the form of elemental S or sulfate compounds affects the usefulness, and elemental sulfur is less effective than sulfate-S fertilizer in increasing the seed yield of the canola plant. Elemental sulfur was generally found to be less effective than sulfate-S fertilizer, even after perennial applications, especially when applied in the spring (Malhi et al., 2005).

In the same period as this research, in another study conducted at the same doses and in adjacent parcels, the response of foliar application of elemental sulfur to long-term water stress was researched (Kazgöz Candemir and Ödemiş, 2018). In that study, full irrigation was applied to the cotton plant during the emergence period, and the development periods were divided into 3 (vegetative development period, flowering and boll growth period, and boll opening period). In some of these periods, full irrigation (T) was applied, and in some periods, non-irrigation (O) was applied. The study concluded that the effect of foliar application of sulfur on OOO, TTT, TOO, and TOT treatments was evident. The highest yield was determined for TTTS$_2$ (5600 kg ha^{-1}) treatment. These results show that many factors are instrumental in the effectiveness of sulfur on the plant. In addition to stress conditions, air quality also plays an important role in foliar fertilizer application. Besides the decreased transpiration due to stress, dust accumulated in the leaf surface layer prevents sulfur assimilation from the leaves.

The effect of the applied sulfur doses on the sulfur concentrations (Lsc) in the leaves differed depending on the years (*Table 4*). The foliar sulfur application did not affect the leaf sulfur concentration in the first year, but it was effective in the second year. Foliar sulfur concentration increased in the first year at I_0 and I_{33} irrigation levels depending on the sulfur doses, while it decreased at I_{66} irrigation levels. The increase in irrigation level in the second year caused a linear increase in leaf sulfur concentrations (*Table 6*). A similar case was observed in the average values of both years. The highest leaf sulfur content was measured from the treatments to which the S_3 dose was applied. Nutrients penetrate the leaf in two ways: passing through the stoma or outer cuticle. It is generally accepted that most of the nutrient uptake occurs through the cuticle (Fernandez et al., 2013), but solutions can also enter the leaf indirectly through the stoma (Fernandez and Eichert, 2009). The cuticle, in general, has a feature that limits the penetration rate of the nutrient element into the leaf (Fernandez et al., 2017). The surface tension properties of the element in the applied solution are important in stoma penetration. While the surface tension of surfactants in chemical sprays is about 30 Mn m^{-1}, organosilicon surfactants can reduce their aqueous surface tension to about 20 Mn m^{-1} and allow nutrient entry through stomata (Stevens et al., 1992). Ion uptake rates in foliar fertilization are higher at night when the stomata are closed than during the day when it is open (Oosterhuis, 2009). In cotton, nutrients dissolved in the foliar application are unlikely to penetrate directly into leaf tissue through open stomata. This is because cotton has prominent stomatal protrusions and an inner cuticular layer covering the stoma (Wullschleger and Oosterhuis, 1989). The cuticle layer here is considered a limiting factor for foliar penetration (Fernandez et al., 2017). In our study, since foliar applications were made in the morning hours, the penetration of sulfur into the leaf was possible via cuticle rather than stoma. The contraction of the cuticle caused by water stress and the atmospheric dust that limits the penetration made the penetration of sulfur through the cuticle layer almost impossible in the first year. Less exposure of the atmosphere to dust during the fertilization process in the second year may have partially facilitated the penetration of sulfur.

Table 6. Leaf Sulfur Content (%)

Treat.	2015	2016	Mean
I_0S_0	0.4406	0.7567	0.5987
I_0S_1	0.6387	0.7650	0.7018
I_0S_2	0.7148	0.7450	0.7299
I_0S_3	0.7254	0.7583	0.7419
$I_{33}S_0$	0.3766	0.7017	0.5391
$I_{33}S_1$	0.7391	0.9275	0.8333
$I_{33}S_2$	0.7421	0.7867	0.7644
$I_{33}S_3$	0.8531	0.8342	0.8436
$I_{66}S_0$	0.8124	0.7917	0.8020
$I_{66}S_1$	0.4206	1.0117	0.7161
$I_{66}S_2$	0.4082	0.8942	0.6512
$I_{66}S_3$	0.9018	0.9292	0.9155
$I_{100}S_0$	1.3364	0.9300	1.1332
$I_{100}S_1$	1.2469	1.0375	1.1422
$I_{100}S_2$	0.4703	1.0458	0.7580
$I_{100}S_3$	1.0764	0.9858	1.0311
S_0	0.7184 ab	0.7950 b	0.7567 b
S_1	0.7519 ab	0.9354 a	0.8437 a
S_2	0.5939 b	0.8679 ab	0.7309 b
S_3	0.8766 a	0.8769 a	0.8767 a
I_0	0.630 b	0.756 c	0.6930 c
I_{33}	0.678 b	0.813 c	0.7455 b
I_{66}	0.636 b	0.907 b	0.7715 b
I_{100}	1.033 a	1.000 a	1.0165 a

The relationship between leaf sulfur content and yield was significant in the second year and insignificant in the first year (*Figure 6*).

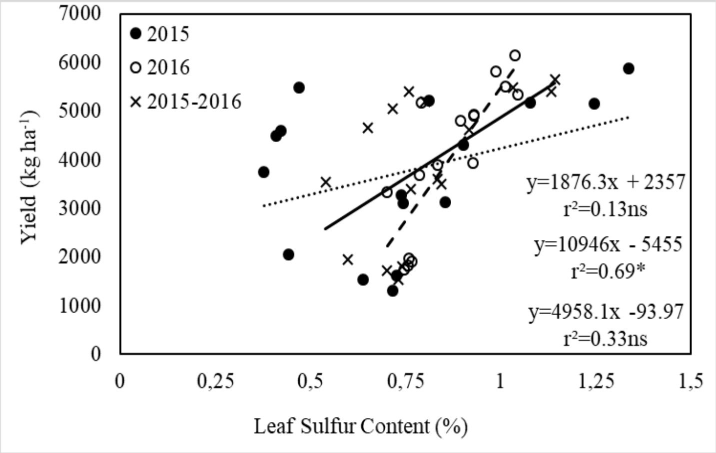

Figure 6. The relationships between yield and leaf sulfur content

4. Conclusions

The decrease in the amount of chlorophyll in drought stress causes a decrease in photosynthesis. Past research concluded that with sulfur applications, chlorophyll concentration could be increased, and the reduction of photosynthesis can be prevented. The inactivity of sulfur poses a disadvantage in soil application, and environmental conditions (atmospheric pollution, extreme temperature, and cultural practices) must be suitable for successful foliar application. To this end, the decrease in leaf moisture content due to the decrease in soil moisture content reduces the penetration area by disrupting the physical structure of the leaf cuticle (Kannan and Charnel, 1986) and may prevent the penetration of nutrients into the leaf (Oosterhuis et al., 1991). Therefore, in addition to the stressful conditions in the first year, it was thought that atmospheric dust caused stress by making it difficult to penetrate sulfur in the leaf surface layer. Besides, atmospheric dust and sulfur application caused layering on the leaf surface and decreased evapotranspiration and WUE. The absence of atmospheric pollutants (desert dust) seen in the first year during the growing period of cotton in the second year increased the penetration ability of sulfur. About 150 mg elemental sulfur application per decare increased the yield significantly. Especially at the I_{33} irrigation level, yield increased from 3340 kg ha^{-1} (S_0) to 3930 kg ha^{-1} (S_1) in the second year was evaluated as a significant increase, and it was determined that the mentioned dose could be used in the short-term drought stress condition.

Despite the necessity of S fertilization for optimum plant productivity (Chan et al., 2013), very few research was published on the use of S fertilizer in the last 10 years in cotton-growing climatic regions. The lack of information on the effects of sulfur deficiency on cotton yield elements shows a need for long-term studies in different climatic areas.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

The author declares that they have no conflict of interest.

Authorship Contribution Statement

Concept: Ödemiş, B.; Design: Ödemiş, B.; Data Collection or Processing: Ödemiş, B., Akgöl, B., Can, D.; Statistical Analyses: Ödemiş, B.; Literature Search: Ödemiş, B.; Writing, Review and Editing: Ödemiş, B.

References

Akgöl, B. (2012). Inheritance of drought resistance, yield and quality parameters in cotton (*Gossypium hirsutum* L.). (Ph.D. Thesis) Çukurova University, The Institute of Natural Sciences, Adana, Türkiye. (In Turkish)

Bek, Y. and Efe, E. (1988). Experimental Design and Methods I. Çukurova University, Faculty of Agriculture 71: 395. (In Turkish)

Can, D. (2017). *The investigation of possibilities of use of irrigation water requirements related to pan and soil moisture deficiency in drought and sensitive cotton* (*Gossypium hirsutum* L.) *varieties*. (MSc Thesis) Mustafa Kemal University, The Institute of Natural Sciences, Hatay, Türkiye. (In Turkish)

Çetin, O. and Bilgel, L. (2002). Effects of different irrigation methods on shedding and yield of cotton. *Agricultural Water Management*, 54(1): 1-15.

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

Dağdelen, N., Yılmaz, E., Sezgin, F. and Gürbüz, T. (2006). Water-yield relation and water use efficiency of cotton (*Gossypium hirsutum* L.) and second crop corn (*Zea mays* L.) in western Turkey. *Agricultural Water Management*, 82(1-2): 63-85.

Dietz, K. J. (1989). Recovery of spinach leaves from sulfate and phosphate deficiency. *Journal of Plant Physiology*, 134(5): 551-557.

Duke, S. H. and Reisenauer, H. M. (1986). Roles and requirements of sulfur in plant nutrition. *Sulfur in Agriculture*, 27: 123-168.

Ertek, A. and Kanber, R. (2003). Effects of different irrigation programs on the lint out-turn of cotton under drip irrigation. *Kahramanmaras Sutcu Imam University Journal of Engineering Sciences*, 6: 106-116.

Fernandez, V. and Eichert, T. (2009). Uptake of hydrophilic solutes through plant leaves: current state of knowledge and perspectives of foliar fertilization. *Critical Reviews in Plant Science*, 28:36–68.

Fernandez, V., Bahamonde, H.A., Peguero-Pina, J. J., Gil-Pelegrín, E., Sancho-Knapik, D., Gil, L., Goldbach, H. E. and Eichert, T. (2017). Physico-chemical properties of plant cuticles and their functional and ecological significance. *Journal of Experimental Botany*, 68 (19): 5293–5306.

Fernandez, V., Sotiropoulos, and T., Brown, P. (2013). Foliar Fertilization: Scientific Principles and Field Practices. International Fertilizer Industry Association 28, Paris, France. ISBN 979-10-92366-00-6

Garg, B. K., Burman, U. and Kathju, S. (2004). The influence of phosphorus nutrition on the physiological response of moth bean genotypes to drought. *Journal of Plant Nutrition and Soil Science*, 167(4): 503-508.

Ghaznavi, A. F. and Abdolshahi, R. (2011). Study on effect of potassium sulfate application on drought tolerance of bread wheat (*Triticum aestivum* L.). *Plant Ecophysiology*, 3: 87-93.

Guin, G., Dunlap, J. R. and Brummett, D. L. (1990). Influence of water deficit on the abscisic acid and indole- 3- acetic acid contents of cotton flower buds and flowers. *Plant Physiology*, 93(3): 1117-1120.

Howell, T. A., Davis, K. R., McCormick, R. L., Yamada, H., Walhood, V. T. and Meek, D. W. (1984). Water use efficiency of narrow row cotton. *Irrigation Science*, 5:195-214.

Hu, Y., Burucs, Z. and Schmıdhalter, 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(1): 133-141.

Hussein, F., Janat, M. and Yakoub, A. (2011). Assessment of yield and water use efficiency of drip irrigated cotton (*Gossypium hirsutum* L.) as affected by deficit irrigation. *Turkish Journal of Agriculture and Forestry*, 35(6): 611-621.

Jie, X., Dong, Q. and Li-Na, Z. (2008). Effects of sulfur nutrition on the chlorophyll content of maize leaf under zinc and drought stress. *Agricultural Research in the Arid Areas,* 2008: 1-2.

Kacar, B. and Katkat, V. (2007). Plant Nutrition. Nobel Publications. Ankara, Turkey. (In Turkish)

Kannan, S. and Charnel, A. (1986). Foliar transport of in organic nutrients. *Critical Reviews in Plant Sciences*, 4(4): 341-375.

Karam, F., Lahoud, R., Masaad, R., Daccache, A., Mounzer, O. and Rouphael, Y. (2006). Water use and lint yield response of drip irrigated cotton to the length of irrigation season. *Agricultural Water Management*, 85(3): 287-295.

Kazgöz Candemir, D. and Ödemiş, B. (2018). Effects of foliar sulfur applications in reducing water stress applied to the cotton plant (*Gossypium hirsutum* L.) during different development periods. *Horticultural Studies,* 35(2): 161-172 (In Turkish).

Kowalenko, C. G., Bittman, S., Neilsen, G. H., Kenney, E., Hunt, D. E. and Neilsen, D. (2014). Potential for improving sulfur tests on agricultural soils in contrasting ecoregions of British Columbia, Canada. *Geoderma Regional,* 1: 10-20.

Krieg, D. R. (1997). Genetic and Environmental Factors Affecting Productivity of Cotton. *Proceedings of the Beltwide Cotton Conference,* 2:1347, 7-10 January, National Cotton Council of America, New Orleans, L.A., U.S.A.

Lina, Z., Dong, Q., Lili, S. and Wei-Jie, Y. (2005). Effects of sulfur fertilization on the contents of photosynthetic pigments and MDA under drought stress. *Acta Botanica Boreali-Occidentalia Sinica,* 12:148-156.

Loka, D. A. and Oosterhuis, D. M. (2012). Water stress and reproductive development in cotton. In: Flowering and Fruiting in Cotton, Eds: Cordova: Oosterhuis, D. M. and Cothren, J. T. The Cotton Foundation Cordova, Tennessee, U.S.A.

Ma, Q. F., Turner, D. W., Levy, D. and 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(9): 939-945.

Malhi, S. S., Schoenau, J. J. and Grant, C. A. (2005). A review of sulphur fertilizer management for optimum yield and quality of canola in the Canadian Great Plains. *Canadian Journal of Plant Science*, 85(2): 297-307.

Marschner, H. (1995). Mineral Nutrition of Higher Plants. Academic Press. New York, U.S.A.

Ödemiş, B., Akışcan Y., Akgöl B. and Can D. (2022). The effects of foliar sulfur application under water stress conditions on yield, evapotranspiration and some physiological properties of cotton. *Mustafa Kemal University Journal of Agricultural Sciences*, 27(2): 202-212. https://doi.org/10.37908/mkutbd.1076251 (In Turkish)

Oguz, M. C., Aycan, M., Oguz, E., Poyraz, I. and Yildiz, M. (2022). Drought stress tolerance in plants: interplay of molecular, biochemical and physiological responses in important development stages. *Physiologia,* 2: 180–197.

Oosterhuis, D. (2009). Foliar Fertilization: Mechanisms and Magnitude of Nutrient Uptake. *Proceedings of the Fluid Forum*, Phoenix, AZ, 15-17 February, Arizona, U.S.A.

Oosterhuis, D. M., Hampton, R. E. and Wullschleger, S. D. (1991). Water deficit effects on the cotton leaf cuticle and the efficiency of defoliants. *Journal of Production Agriculture,* 4(2): 260-265.

Öztürk, İ. and Korkut, K. Z. (2018). Drought effects on yield and yield components in different growing periods of some bread wheat (*Triticum aestivum* L.) genotypes. *Journal of Tekirdag Agricultural Faculty*, 15(2): 128-137. (In Turkish)

Pettigrew, W. T. (2004). Physiological consequences of moisture deficit stress in cotton. *Crop Science*, 44(4): 1265-1272.

Singh, K., Rathore, P., Singh Brar, A. and Kumar Mishra, S. (2021). Drip fertigation improves seed cotton yield, water productivity and profitability of cotton raised under high density planting system in semi-arid environment. *Emirates Journal of Food and Agriculture*, 33(9): 781-793.

Stevens, W. E., Johnson, J. R., Varco, J. J. and Parkman, J. (1992). Tillage and winter cover management effects on fruiting and yield of cotton. *Journal of Production Agriculture*, 5(4): 570-575.

Ünlü, M., Kanber, R., Koç, D. L., Tekin, S. and Kapur, B. (2011). Effects of deficit irrigation on the yield and yield components of drip irrigated cotton in a Mediterranean environment. *Agricultural Water Management*, 98(4): 597-605.

Ürkmez, İ., Sevim, A. and Çatık, A. N. (2024). The relationship between agriculture and carbon dioxide emission in Türkiye: a non-linear evidence. *Journal of Tekirdag Agricultural Faculty*, 21(1): 94-109.

Wullschleger, S. D. and Oosterhuis, D. M. (1987). Electron microscope study of cuticular abrasion on cotton leaves in relation to water potential measurements. *Journal of Experimental Botany*, 38(4): 660–667.

Wullschleger, S. D. and Oosterhuis, D. M. (1989). The occurrence of an internal cuticle in cotton (*Gossypium hirsutum* L.) leaf stomates. *Environmental and Experimental Botany*, 29(2): 229-235.

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

Yavuz, M. Y. (1993). *The effects of different irrigation methods on the yield and water use efficiencies of cotton*. (Ph.D. Thesis) Çukurova University, Natural and Applied Sciences Agricultural, Structure and Irrigation, Adana, Türkiye. (In Turkish)

Yazar, A., Sezen, S. M. and Sesveren, S. (2002). LEPA and trickle irrigation of cotton in the southeast anatolia project area in Turkey. *Agricultural Water Management,* 54(3): 189-203.

Zonta, J. H., Brandão, Z. N., Rodrigues, J. I. S. and Sofiatti, V. (2017). Cotton response to water deficits at different growth stages. *Revista Caatinga,* 30(4): 980-990.