Water-Yield Relation of Deficit Drip Irrigated Cotton Cultivars in a Semi-arid Environment

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Abstract
This study was carried out the May 455, Sasha-09 Sahra and Özaltın 404 cotton cultivars in 2024 at the Research and Application Farm of the Agriculture Faculty of Aydın Adnan Menderes University, Aydın-Türkiye. The applications of water significantly affected seed cotton yield. A randomized complete block design was used with three replications and two factors. Irrigation was begun in the control plots (IR-100) with 40% of available water holding capacity of the soil at a depth of 0.90 m taken up, and 50% of the water applied to the control plots was applied to the other plot. Seasonal crop water use varied between 449 and 788 mm according to cultivars. The highest average seed cotton yield was obtained from IR-100 treatment as averaging 435.9 kg/da. The lowest yield was obtained from IR-50 treatment as averaging 323.5 kg/da. Examining these results from the point of view of varieties, it is seen that May-455 formed the first group and the Özaltın-404 the last group. Average WUE values varied between 0.528 and 0.766 kg/m^3. According to growing year, the yield response factor (k_y) was found to be 0.55 (May-455), 0.70 (Sahra), 0.64 (sahra-09) and 0.63 (Özaltın-404). It may be concluded that the treatment which gave the best performance whether for high seed cotton yield was treatment IR-100 when the water source was not limited and it completely met the irrigation water needs of the crop. On the other hand, treatment which gave the best performance whether for water saving or for high water use efficiency was treatment IR-50 treatment if irrigation water in the area was limited and water was applied at a rate of 50%.

Keywords Cotton varieties, drip irrigation, water use efficiency, yield response factor

Introduction

Cotton (*Gossypium hirsutum* L.) is the most significant fibre crop in the world, meeting the natural fibre needs of the textile industry (Rehman and Azhar, 2021). Cotton is an industrial plant that directly concerns many countries around the world in terms of production and consumption. Nearly all of global cotton production (99.5%) is concentrated in a select group of countries that rank among the top ten cotton producers worldwide. These nations include China, India, the United States, Brazil, Australia, Türkiye, Pakistan, Uzbekistan, Argentina, and Greece. The top cotton producing countries are China (5,730,000 tonnes), India (5,366,000 tonnes) and the USA (3,815,000). In Türkiye, cotton cultivation occurs in an area of 480,000 hectares, and 833,000 tonnes of cotton fibre are produced (Anonymous, 2022). Almost all cotton cultivation in Türkiye is carried out in the Aegean Region, Southeastern Anatolia Region, Çukurova and Antalya regions (Anonymous, 2018). Cotton cultivation areas by region are given in Table 1. Accordingly, it is seen that the region with the highest cotton cultivation area in 2023 is the Southeastern Anatolia Region with an area of 2 million 998 thousand decares and a share of 60.27% (Anonymous, 2014). (Table 1).

Table 1. Cotton cultivation areas by regions (decares) (TUİK, 2024)

Regions	2020	2021	2022	2023	Average	%
Mediterranean	679.991	722.016	929.841	680.658	753.127	16,35
Aegean	1.011.626	979.762	1.211.686	1.093.400	1.074.119	23,32
Southeast Anatolia	1.895.537	2.619.897	3.587.358	2.998.800	2.775.398	60,27
Other regions	5.046	1.115	2.728	1.526	2.604	0,06
TÜRKİYE'S TOTAL	**3.592.200**	**4.322.790**	**5.731.613**	**4.774.384**	**4.605.247**	**100,00**

When cotton production amounts by regions are analyzed, the cotton production amount of the Southeastern Anatolia Region in 2023 is 1 million 293 thousand tons and ranks first in terms of production amount. In the average of 2020-2023, the Southeastern Anatolia Region (58.38%) is followed by the Aegean Region (24.53%) and the Mediterranean Region (17.05%) (Table 2).

Table 2. Amount of cotton production by regions (tonnes) (TUİK, 2024)

Regions	2020	2021	2022	2023	Average	%
Mediterranean	356.311	382.648	460.539	313.407	378.226	17,05
Aegean	527.244	542.832	613.729	492.581	544.097	24,53
Southeast Anatolia	888.035	1.324.004	1.674.630	1.293.458	1.295.032	58,38
Other regions	2.056	516	1.102	554	1.057	0,05
TÜRKİYE'S TOTAL	**1.773.646**	**2.250.000**	**2.750.000**	**2.100.000**	**2.218.412**	**100,00**

Reductions in the areas planted, while at the same time an increase in consumption and a reduction in yield because of drought, have necessitated the development of high-yield drought-resistant cultivars of cotton (Başal and Sezener, 2012).

Water shortages are predicted in many areas as a result of climate change, and particularly in tropical and subtropical regions, including Turkey and the Mediterranean basin, a reduction in the availability of water is expected. The areas of Turkey most affected by this drying trend are the Aegean, Mediterranean, Marmara and Southeast Anatolian regions (Türkeş, 2008; Türkeş, 2012). Limited availability of irrigation water requires fundamental changes in irrigation management or urges the application of water saving methods. Common irrigation methods practiced for cotton production in this region are wild flooding, basin and furrow methods. In general, the farmers over irrigate, resulting in high water losses and low water use efficiencies and thus creating drainage and salinity problems (Yazar *et al*. 2002). However, the use of drip irrigation techniques is inevitable in the near feature because of the salinity problem caused by traditional irrigation methods (Dağdelen *et al*., 2009).

Numerous studies have reported how cotton reproductive growth, yield, and fibre quality are affected by moisture deficits. However, little attempt has been made to assess deficit irrigation regimes for cotton varieties under drip irrigation in the Aegean region of Turkey. Karam *et al*. (2006), in two yearly studies in the Bekaa valley of Lebanon, compared the effects on cotton of ending irrigation when bolls first opened (550 mm), in the early boll filling period (633 mm), in the middle period of boll filling (692 mm), and in full irrigation conditions (739 mm). They concluded that as the amount of irrigation water increased, fibre yield fell and the highest yield was obtained in conditions in which irrigation was not applied after the first boll opening. Basal *et al*. (2009), in a study to determine the effect of five different doses of water in a drip irrigation system on water use efficiency, yield, yield components and fibre quality characteristics, found that when the dose of water was reduced from 100% to 75%, water use efficiency rose from 0.62 to 0.71 kg/m^3. Dağdelen *et al.* (2009) conducted field trials in the Aegean region in 2004-2005 to determine the effect of various levels of water using the drip irrigation method on water use efficiency and fibre quality parameters. They reported variations of 256-753 mm in average seasonal plant water consumption, 2550-5760 kg/ha in average cotton yield, and 0.76-0.98 kg/m^3 in water use efficiency. Hussein *et al.* (2011), in a study conducted on cotton under Syrian conditions to determine the effect of different irrigation doses on water use efficiency, cotton yield and fibre quality, found variations of 408-773 mm in crop water consumption and 2909-5090 kg/ha in average cotton yield. Ünlü *et al.* (2011) conducted a four-year study to determine the effects of 0%, 50%, 70% and 100% irrigation doses on the yield components of cotton using drip irrigation under Çukurova-Türkiye conditions. Their results showed that as the irrigation dose was reduced, there was a decline in plant height, buildup of dry matter, leaf area index and the number of bolls per plant. Nazar *et al.* (2012), analyzed the effect of different type of water and water stress levels on fibre and yarn quality characteristics for some varieties of cotton in Faisalabad-Pakistan conditions. The study revealed that effect of different cotton varieties, water types and water stress levels on fibre and yarn quality was highly significant. Irfan *et al.* (2014), conducted to attain efficient irrigation water utilization and saving without affecting crop yield or quality and to quantify the amount of irrigation water required for cotton crop sown under different planting methods. Conclusively, bed sowing proved to be more beneficial for higher water use efficiency as compared to ridge and flat sowing of cotton.

The aim of this study were to create a suitable irrigation programme by the drip irrigation method for the May 455, Sasha-09 Sahra and Özaltın 404 cultivars of cotton, which are widely grown in this area and to research the water-yield relationship of irrigation treatments.

Materials and Methods

This study was conducted under field conditions at the research and application farm of the Agriculture Faculty of Aydın Adnan Menderes University on its southern campus during the growing seasons of 2024. The research area is located in the Büyük Menderes Lower Basin, at a latitude of 37^o 51' North and a longitude of 27^o 51' East (Aksoy and Seferoğlu, 1998).

The Lower Büyük Menderes Basin has a Mediterranean climate of hot and dry summers and cool wet winters. There was no waterlogging problem and the average annual rainfall was 644.7 mm with a mean monthly temperature of 17.8 ^{o}C according to long-term meteorological data (2014-2023) in the experimental area. There was no rainfall during the growing periods in 2024 (Anonymous, 2024).

The water content at field capacity varied from 18.4- 23.1 % and wilting point varied from 7.2-10.1 % on dry weight basis in the field where the experiment was conducted. The soils of the experimental area contain sand percentage between 49.7-68.2 %, which was followed by silt percentage 19.2-32.0 % and clay percentage 13.6-17.5 %. The soils could be classified as loam. Throughout the soil profile reaching up to 1.2 m depth, the dry soil bulk densities ranged from 1.35 to 1.52 g/cm^3. The available soil water content of the soil profile was 221 mm within the top 1.2 m depth.

A drip irrigation system was designated for the experiment. Irrigation water was supplied by a pump applied to a reservoir placed near the experimental site. The control unit consisted of screen filter with 10 l s^{-1} capacity, control valves, manometers mounted on the inlet and outlet of each unit. Distribution lines consisted of PVC pipe manifolds for each plot. The diameters of the laterals were 16 mm PE and each lateral irrigated one plant row. The inline emitters were used with a discharge rate of 2 L/h above 10 m operating pressure. In the system, emitter and the lateral spacing were chosen as 0.20 and 0.70 m, respectively.

The May-455, Sahra, Sasha-09 and Özaltın-404 cotton varieties were used as research material. Cotton plants were thinned to a spacing of 0.70 m × 0.10 m when the plants were about 0.15 m in height. A compound fertilizer (15 % N, 15 % K, and 15 % P) was applied at a rate of 40 kg/da pure N, P and K at planting. The required remaining portion of nitrogen 25 kg N kg/da was applied as 33 % ammonium nitrate before the first irrigation. Seeds were sown with a pneumatic seed drill with 70 cm between the rows on 11 May 2024. At the same time, 40 kg/da of (15-15-15) NPK fertilizer was added to the experimental plots. At the second hoeing, 33% ammonium nitrate fertilizer was applied at a rate of 25 kg/da.

The trial was designated in randomized complete block design with three replications. In the study, two different irrigation levels (IR-100 and IR-50) was investigated. The gravimetric method was used to determine irrigation time. The treatments were irrigated using the drip irrigation method and irrigation was started when 40% of the available water retention capacity of the soil had been used up. Consecutive irrigations were applied at 7 day irrigation interval. Water was applied at 100% of the water needed to reach field capacity to the plots which were to be fully irrigated, and at 50% proportion of this amount to plots that were to receive partial irrigation.

Crop water consumption under varying irrigation regimes was calculated using the soil water balance equation (Heerman, 1985) as;

$$\mathbf{ET} = \boldsymbol{R} + \boldsymbol{I} - \boldsymbol{D} \pm \boldsymbol{\Delta W} \qquad \mathbf{(2)}$$

Where, ET is the water use (mm), R is the rainfall (mm), I is the depth of irrigation (mm), D is the depth of drainage (mm), and ΔW is the change of soil water storage in the measured soil depth.

WUE was calculated as yield (kg/da) divided by seasonal water use (mm). IWUE was determined as yield (kg da) per unit irrigation water applied (mm) (Howell *et al.,* 1990). Regression analysis was used to evaluate the water use-yield relationships derived from seasonal crop water use and yield data obtained from the experiment. Seasonal values of the yield response factor (k_y), which represent the relationship between relative yield reduction [1-(Ya/Ym)] and relative evapotranspiration deficit [1-(ETa/ETm)], were determined using equation 3 given by Doorenbos and Kassam, 1986:

$$1-(Ya/Ym)=k_y(1-ETa/ETm) \qquad \mathbf{(3)}$$

Where, ETa and ETm are the actual and maximum seasonal crop water use values (mm), respectively, and Ya and Ym are the corresponding actual and maximum yields (kg/da).

At harvesting, the plants in the two middle rows were harvested on November 17, 2024 by hand and weighed, and the cotton yield of the plots (kg/da) were determined. In order to determine the differences between irrigation treatments, the data relating to seed cotton yield was subjected to variance analysis. The Least Significant Differences (LSD) test was used for comparing and ranking the treatments. Differences were declared significant at $p < 0.05$. Variance analysis and LSD tests were carried out with the use of the TARİST program, which was developed for this purpose (Açıkgöz, 1994).

Results & Discussion

Water use- yield relationship of cotton varieties

The total irrigation water amounts applied, seasonal water use and water use efficiency values (WUE, IWUE) were presented in Table 3. The amount of irrigation water applied two different drip treatment ranged from 658 to 329 mm in 2024. The first irrigation was applied on June 29 and irrigations were lasted on August 17, in 2024, respectively. Seasonal plant water use values varied in connection with the irrigation water applied to the treatments and the amount of moisture at planting and harvest. At the same time, although it has a great effect on plant water consumption, there was no rain on the experimental area during the growing season. Water use values increased with increasing irrigation levels in each cotton varieties. Seasonal water use ranged from 788 mm in May 455 variety IR-100 treatment to 449 mm in Sasha-09 variety in the growing season (Table 3).

Seasonal water use of cotton under the same region has been reported as 899 mm by Sezgin *et al.* (2001) and as 855-882 mm by Dağdelen *et al*. (2006) under furrow irrigation system and as 265-753 mm by Dağdelen *et al*. (2009); and as 268-754 mm Başal *et al.* (2009) under drip irrigation system. Once the results of this study are compared with those of furrow irrigation studies at the same region, it is clear that drip irrigation systems are able to save substantial amount of water. Under drip irrigation applications, seasonal water use of cotton was obtained by Ünlü *et al.* (2011) as 287-584 mm in Çukurova-Adana-Türkiye conditions. Water use ranged from 410 to 725 mm reported by Colaizzi *et al*. (2005) in the High Texas Plains. On the other hand, Ibragimov *et al.* (2007) found that seasonal water use in cotton varied between 432 and 739 mm depending on irrigation regimes in Uzbekistan conditions by using drip and furrow irrigation methods. Yazar *et al.* (2002) applied a total of 814 mm irrigation water amount to LEPA and drip irrigated cotton in southeast Türkiye. In another study, Karam *et al.* (2006) applied a total of 738 mm irrigation water amount to drip irrigated cotton in the Bekaa Valley of Lebanon. The results observed in this research were in agreement with the others given above.

Table 3. Cotton yield, water use and water use efficiency values as influenced by cotton varieties and water levels

Varieties	Irrigation Levels	Seed cotton yield (kg/da)	Irrigation water applied (mm)	Water use (mm)	Water use efficiency (kg/m^3)	Irrigation water use efficiency (kg/m^3)
May 455	IR-100	470	658	788	0.596	0.714
	IR-50	367	329	479	0.766	1.115
Sahra	IR-100	443	658	780	0.567	0.673
	IR-50	319	329	469	0.680	0.969
Sasha-09	IR-100	421	658	778	0.541	0.640
	IR-50	307	329	449	0.683	0.933
Özaltın-404	IR-100	409	658	774	0.528	0.621
	IR-50	301	329	454	0.663	0.914

The response of cotton seed yield to different irrigation treatments are given in Table 4. Data obtained from the growing year study showed that seed cotton yield was significantly affected ($P< 0.01$) by cotton varieties and irrigation levels. No interactions between cotton varieties (V) and irrigation levels (IR) were observed in growing year. Cotton varieties had significant effect on seed yield. The May 455 variety resulted in higher yield than the others. Cotton seed yield was found to increase with irrigation water applied. Especially, as the irrigation level increased, cotton seed yields were increased in all cotton varieties. The highest average yield was obtained from IR-100 treatment as averaging 435.9 kg da^{-1}. The lowest yield was obtained from IR-50 treatment as averaging 323.5 kg/da. Examining these results from the point of view of varieties, it is seen that May-455 formed the first group and the Özaltın-404 formed the last group. In terms of irrigation levels, two groups formed in year. The first group consisted of the 100% treatments where no water restriction had been applied in the whole growing season, treatments in which water had been applied at the 50% level were second group.

Table 4. Seed cotton yield as influenced by cotton varieties and water levels

		Seed cotton yield (kg/da)
Factor		2024
Varieties (V)	May 455	418.3 a
	Sahra	380.8 b
	Sasha-09	364.3 bc
	Özaltın-404	355.3 c
$LSD_{\%5}$		23.681
Irrigation Levels (IR)	IR-100	435.9 a
	IR-50	323.5 b
$LSD_{\%5}$		16.745
Analysis within year	V^a	**
	IR^b	**
	V x IR^c	ns^d

V^a, varieties; IR^b, irrigation levels; V x IR^c, ,varieties x irrigation levels ; ns^d , not significant.
*,**Significant at $P< 0.05$ and $P< 0.01$.
In a column values with a common letter are not significantly differ from one another using $LSD_{.05}$

At the same time, making a general assessment, it was found that the findings in relation to yield were similar to the findings of researchers performing studies on different irrigation programmes. For example, in studies which achieved effective irrigation water savings related to differences in irrigation programme, choice of cultivar and regional conditions, Dağdelen *et al.* (2005), according to the results of a study conducted on cotton irrigated by drip irrigation in the Aydın-Türkiye area, achieved the highest yield of cotton with irrigation at eight-day intervals from a treatment in which 100% of the amount of evaporation from a class A evaporation pan was applied. On the other hand, Yazar *et al.* (2002) found the highest seed cotton yield (5870 kg/ha) in the Harran-Türkiye plain from the full irrigation treatment (100 %) with 6-day irrigation intervals followed by 3-day irrigation intervals (5040 kg/ha) using drip irrigation method. Dağdelen *et al*. (2008) obtained the average seed cotton yield as 5760 kg/ha under drip irrigated treatment in the western Türkiye. Another Aydın plain conditions the highest average raw cotton yield was obtained from S_1 treatment (Carisma-V1) as averaging 6300 kg/ha. It was determined Carisma (V1) cultivar performed higher yields than Candia (V2) and Gloria (V3) (Dağdelen *et al*. 2009). Similar results were obtained by Erten and Dağdelen (2020) as 5985 kg/ha at the same conditions.
The results observed in this research were in agreement with the others given above. In evaluations conducted previously, it has been found that both varieties and the level of irrigation applied are important in increasing seed cotton yield. It has been concluded that the most suitable irrigation programme in terms of cotton yield would be using the May-455 variety in conditions where there was no irrigation water restriction in the area, and a treatment (IR-100) where water was applied fully.

Water-yield relationship results
In order to evaluate the effects of water use on seed cotton yield regression analysis was conducted. There was a significant linear relationships were found between seasonal water use and seed cotton yield in irrigation treatments (Fig 1). Similar observations were made in other cotton studies (Yazar *et al*., 2002, Dağdelen *et al.,* 2009; Ünlü *et al*., 2011, Erten and Dağdelen 2020).

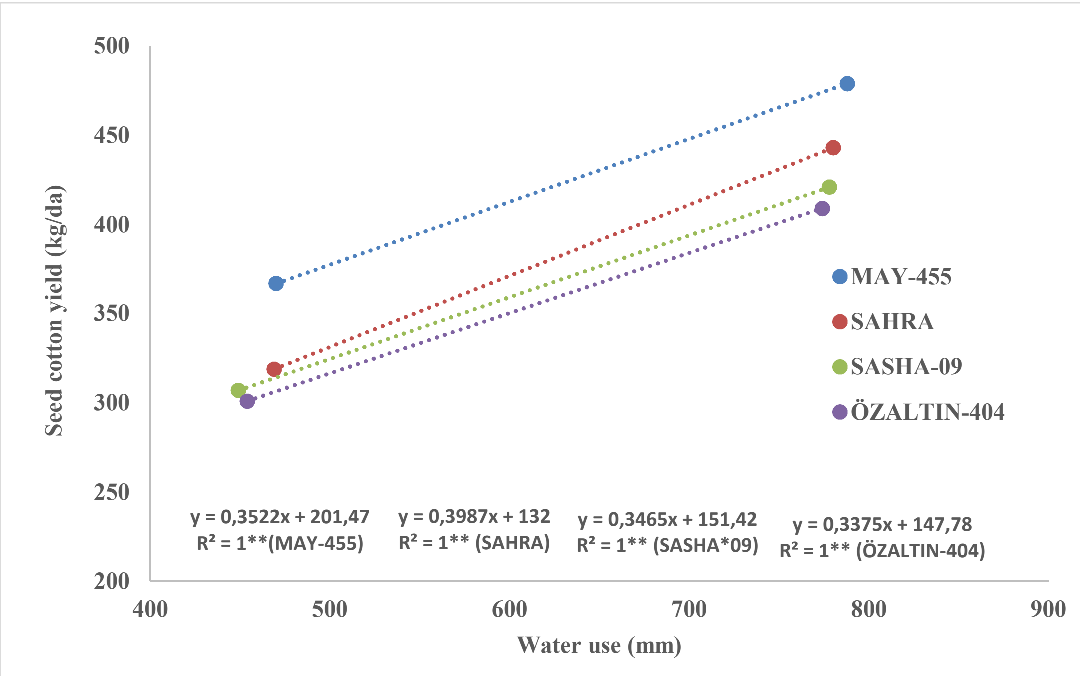

Figure 1: The relationship between plant water use and seed cotton yield

The k_y factor which represents the slope of the relationship between relative ET and relative yield, was determined from the all varieties. The yield response factor (k_y) was determined to be 0.55 for the May 455 variety, 0.70 for the Sahra variety, 0,64 for Sasha-09 and 0.63 for Özaltın-404 variety, respectively (Fig. 2).

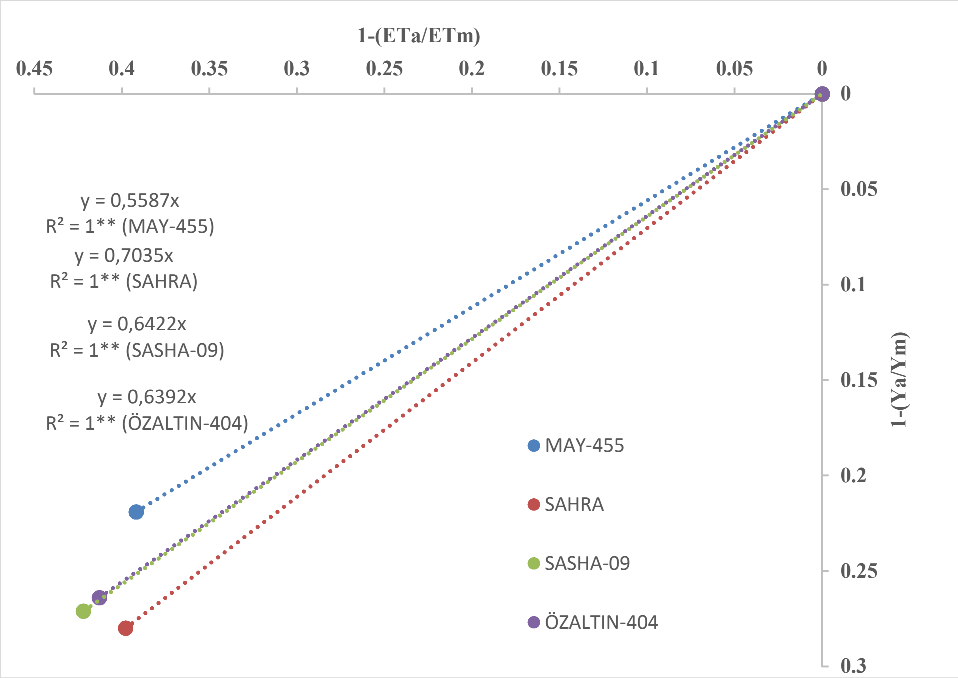

Figure 2 : The yield response factors (ky) of cotton varieties

The average yield response factor *(ky)* for the whole growing season according to varieties in the study were found to be 0.84 by Doorenbos and Kassam (1979), 0.89 by Yazar *et al.* (2002), and 0.78 by Dağdelen *et al*. (2009) in Aydın-Türkiye.

Water use (WUE) and irrigation water use (IWUE) efficiencies of cotton vaerieties

As Table 3 shows, IWUE and WUE values varied by irrigation treatment year. IWUE and WUE were higher in year for the May-455 variety than for the other varieties (Sahra, Sasha-09 and Özaltın-404). The lowest WUE and IWUE values for all cultivars were obtained from the IR-100 treatments. Thus, these values varied between 0.528 and 0.714 kg/m^3 in treatment year. As the amount of water applied increased, IWUE decreased. The highest WUE value was 1.115 kg/m^3 from treatment IR-50. It can be said that from the point of view of water saving, treatment IR-50 used water more efficiently. Thus, when water was restricted under these conditions, a reduction of 21.9 % was seen in average yield. Yazar *et al.* (2002) reported that WUE under drip irrigation was 0.55-0.67 kg/m^3 in the Çukurova conditions and Ünlü *et al.* (2011) found the same values as 0.60-0.48 kg/m^3 in the Çukurova conditions. Ibragimov *et al.* (2007) determined that the WUE ranged from 0.77 to 0.96 kg/m^3. Similar results were reported by Dağdelen *et al.* (2009) as 0.62-0.85 kg/m^3 in the Aydın-Türkiye plain conditions.

Conclusion

Finally, it may be concluded that as cotton is a crop which is sensitive to shortages of moisture in the soil, it is necessary to fully meet its water needs throughout the growing season in order to obtain high seed cotton yield. However, if water sources in the area are limited, then restricting water to a level of only 50% (IR-50) may produce acceptable results. According to evaluations conducted until now, both cultivars and the irrigation level applied are important in increasing seed cotton yield. In this regard it was concluded that the most suitable irrigation programme from the point of view of seed cotton yield in a semi-arid environment without irrigation water restrictions was the treatment (IR-100) in which water was fully applied, using the May 455 variety.

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