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Response of Different Cotton Cultivars to Water Stress on Water-Yield Relations Under Drip Irrigation Conditions

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Abstract: In order to observe the effects of deficit irrigation on water-yield relations and water use efficiency of May 455 and Sasha-09 cotton cultivars, a field trial was conducted in year 2023 at the Aydın plain conditions. The trial was designated in randomized complete block design with two factors and three replications. In the trials, irrigation water was applied to cotton cultivars using drip irrigation method as 100%, 67%, 33% and 0% of evaporation from Class A Pan corresponding to 7-day irrigation frequencies. The applications of water significantly affected raw cotton yield. The seasonal water use of cotton varied between 201 and 719 mm according to cultivars. The average seed cotton yield varied from 153.6 – 539.3 kg da^{-1}. The highest average seed cotton yield was obtained from IR-100 treatment (May 455) as averaging 539.3 kg da^{-1}. It was determined May 455 cultivar performed higher yields than Sasha-09. Average water use efficiency (WUE) values varied between 0.722 and 0.859 kg m^{-3}. Average yield response factor (ky) was found to be 0.84 for May 455 and Sasha-09. It may be concluded that the treatment which gave the best performance whether for water saving or for high WUE was treatment IR-100 (May 455) when the water was abundant. In the case of water scarcity, IR-67 (May 455) treatment resulted in reasonable yield and WUE.

Keywords: Cotton; deficit irrigation; water use efficiency; yield response factor

1. Introduction

Türkiye's cotton production meets approximately 44% of the needs of its domestic market. In 2018, and area of 518 000 ha was used for cotton production, and in 2021 this figure was 432 000 ha. 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 [1]. Drought not only affects yield but also fibre quality. It is reported that drought in the period when the cotton fibre is beginning to grow affects fibre length, strength and maturity [2, 3, 4, 5]. It has been found that drought in the end of the flowering period affects the development of the bolls, and thus increases the proportion of low-strength and immature fibres [4]. Water shortages are predicted in many areas as a result of climate change, and particularly in tropical and subtropical regions, including Türkiye and the Mediterranean basin, a reduction in the availability of water is expected. The areas of Türkiye most affected by this drying trend are the Aegean, Mediterranean, Marmara and Southeast Anatolian regions [6, 7]. 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 [8] (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 [9].

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 Türkiye. [10], 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. [11], 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. [9] 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. [12], 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. [13] 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 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. [14], 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. [15], 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 and Sasha-09 cultivars of cotton, which are widely grown in this area and to research the water-yield relationship of irrigation treatments.

2. Materials and Methods

This study were conducted during the growing seasons of 2023 at the Agricultural Research Station of Aydın Adnan Menderes University, Aydin-Turkey at 37° 51' N latitude, 27°51' E longitude. There was no waterlogging problem and the average annual rainfall was 644.7 mm with a mean monthly temperature of 17.8 oC according to long-term meteorological data (2014-2021) in the experimental area. Total rainfall during the growing periods was 127,4 mm in 2023.

The soil type of the experiental area was loam and sandy loam in texture. For the cotton experiment area, water content at field capacity varied from 18.4 to 23.1 % and wilting point varied from 7.2 to 10,1 % on dry weight basis. The dry soil bulk densities ranged from 1.35 to 1.52 g/ cm3 throughout the 1.2 m deep profile. The total available soil water contents within the top 1.2 m of the soil profile was 221 mm.

The May 455 and Sasha-09 cotton varieties were planted on 11 May 2023, with 0.70 × 0.20 m spacing. A compound fertilizer (each included 15 % composite) 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.

The trial was designated in randomized complete block design with two factors and three replications. In the study, four different irrigation levels (IR-100, IR-67, IR-33 and IR-00) and two cotton varieties (May 455 and Sasha-09) were investigated. Irrigation water quantity based on cumulative evaporation from class A pan at 7 day irrigation interval was applied through drip system. Full (IR-100) and traditional deficit irrigation (IR- 67, IR-33) treatments received 100, 67 and 33% of 7 day cumulative evaporation from Class A pan located at the experimental station, respectively.

Equation (1) was used to calculate the irrigation water amount for two approaches;

$$V = P \times A \times E_{pan} \times WL \quad (1)$$

Where V is the volume of irrigation water (L), P wetting percentage (taken as 100 % for row crops), A is plot area (m^2), E_{pan} is the amount of cumulative evaporation during a 7-day irrigation interval (mm), WL represents irrigation levels (0.33, 0.67 and 1.00).

Drip laterals were placed at the center of adjacent crop rows 0.70 m apart in the experimental plots. Experimental plots were 5 m long and 4 crop rows wide (2.8 m). Irrigation water was used from a deep well located near the experimental site. The control unit consisted of screen filter with 10 L/s 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 4 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.

Crop water consumption under varying irrigation regimes was calculated using the soil water balance equation [16] as;

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

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) [17]. 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 [18]:

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

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).

Seed cotton yield was determined by hand harvesting in the two center rows of each plot on November 17, 2023 (Fig. 1).

Figure 1: Hand harvesting in the two center rows of each plot

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 [19].

3. 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 1. The amount of irrigation water applied for different drip treatment ranged from 552

to 182 mm in 2023. The first irrigation was applied on July 14 and irrigations were lasted on September 01, in 2023, 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 127.4 mm rain on the experimental area during the growing season. The amount of irrigation water applied for different drip treatment ranged from 552 to 182 mm in 2023. Water use values increased with increasing irrigation levels in each cotton varieties. Seasonal water use ranged from 719 mm in May 455 variety IR-100 treatment to 201 mm in May 455 variety IR-00 (rain fed treatment) plots and 711 mm in Sasha-09 variety IR-100 treatment to 205 mm in Sasha-09 variety IR-00 (rain fed treatment) plots in the growing season (Table 1). This was followed by IR-67 irrigation levels treatments.

Seasonal water use of cotton under the same region has been reported as 899 mm by [20] and as 855-882 mm by [21] under furrow irrigation system and as 265-753 mm by [9] and as 268-754 mm [11] 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 [13] as 287-584 mm in Çukurova-Adana Türkiye conditions. Water use ranged from 410 to 725 mm reported by [22] in the High Texas Plains. On the other hand, [23] 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. [8] applied a total of 814 mm irrigation water amount to LEPA and drip irrigated cotton in southeast Turkey. In another study, [10] 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 1: Cotton yield, water use and water use efficiency values as influenced by cotton varieties and water levels

Year/Varieties	Irrigation Levels	Seed cotton yield (kg da^{-1})	Irrigation water applied (mm)	Water use (mm)	Water use efficiency (kg m^{-3})	Irrigation water use efficiency (kg m^{-3})
2023	IR-100	539.3	552	719	0.749	0.976
May 455	IR-67	429.4	370	548	0.783	1.160
	IR-33	323.5	182	376	0.859	1.777
	IR-00	171.7	-	201	0.852	-
2023	IR-100	513.9	552	711	0.722	0.931
Sasha-09	IR-67	410.3	370	544	0.754	1.109
	IR-33	310.5	182	377	0.822	1.706
	IR-00	153.6	-	205	0.747	-

The response of cotton seed yield to different irrigation treatments are given in Table 2. 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 both years. Cotton varieties had significant effect on seed yield. The May 455 variety resulted in higher yield than the Sasha-09 variety. Cotton seed yield was found to increase with irrigation water applied. Especially, as the irrigation level increased, cotton seed yields were increased in both cotton varieties. The highest average yield was obtained from IR-100 treatment as averaging 526.6 kg da-1, followed by IR-67 treatment as averaging 419.9 kg da-1. The lowest yield was obtained from IR-00 rain fed treatment as averaging 162.7 kg da-1. Examining these results from the point of view of varieties, it is seen that May 455 formed the first group and the Sasha-09 the second group. In terms of irrigation levels, four groups formed in each 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 67% level were second, and treatments which had received water at the 33% level formed the third group.

Table 2: Seed cotton yield as influenced by cotton varieties and water levels

		Seed cotton yield (kg da^{-1})
Factor		**2023**
Varieties (V)	May 455	366.0 a
	Sasha-09	347.1 b
$LSD_{\%5}$		10.648
Irrigation Levels (IR)	IR-100	526.6 a
	IR-67	419.9 b
	IR-33	317.0 c
	IR-00	162.7 d
$LSD_{\%5}$		15.058
Analysis within years	V[a]	**
	IR[b]	**
	V x IR[c]	ns[d]

Va, varieties; IRb, irrigation levels; V x IRc, varieties x irrigation levels; nsd , 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, [24], according to the results of a study conducted on cotton irrigated by drip irrigation in the Aydın 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, [8] found the highest seed cotton yield (5870 kg ha-1) 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-1) using drip irrigation method. [9] obtained the average seed cotton yield as 5760 kg ha-1 under drip irrigated treatment in the western Türkiye. Another Aydın plain conditions the highest average raw cotton yield was obtained from S1 treatment (Carisma-V1) as averaging 6300 kg/ha. It was determined Carisma (V1) cultivar performed higher yields than Candia (V2) and Gloria (V3) [25]. Similar results were obtained by [26] 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 second order polynomial relationships were found between seasonal water use and seed cotton yield in irrigation treatments (Fig 1). Polynomial relationships of water use and seed cotton yield for drip irrigated cotton were given by [8, 9, 13, 26].

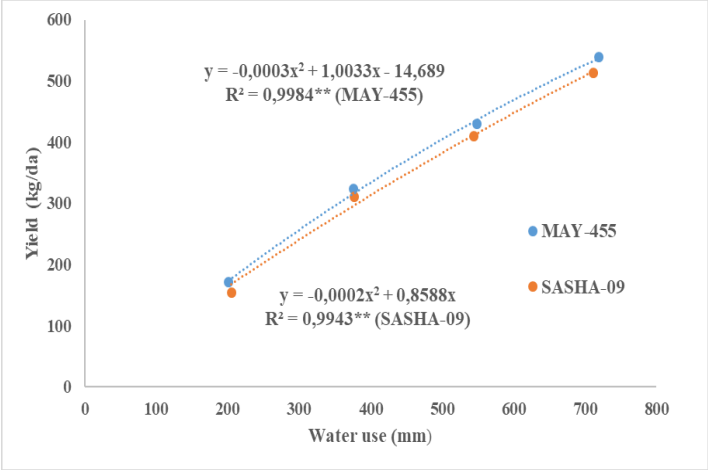

Figure 1: The relationship between plant water use and seed cotton yield

The k_y factor which represents the slope of the relationship between relative ET and relative yield, was determined to be 0.84 for the combined data from both varieties. The yield response factor (k_y) was determined to be 0.8436 for the May 455 variety and 0.8456 for the Sasha-09 variety, respectively. The average ky for the whole growing season were found to be 0.84 by [18], 0.89 by [8] and 0.78 by [9] in Aydın conditions.

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

As Table 1 shows, IWUE and WUE values varied by irrigation treatment year. IWUE and WUE were higher in both years for the May 455 variety than for the Sasha-09 variety. The lowest WUE and IWUE values for both cultivars were obtained from the IR-100 treatments. Thus, these values varied between 0.722 and 1.777 kg/m^3 in treatment year. As the amount of water applied increased, IWUE decreased. The highest WUE value was 0.859 kg/m^3 from treatment IR-33. It can be said that from the point of view of water saving, treatment IR-33 used water more efficiently. Thus, when water was restricted under these conditions, a reduction of 40 % was seen in yield, [8] reported that WUE under drip irrigation was 0.55-0.67 kg m-^{3} in the Çukurova conditions and [13] found the same values as 0.60-0.48 kg m-^{3} in the Çukurova conditions. [23] determined that the WUE ranged from 0.77 to 0.96 kg m-^{3}. Similar results were reported by [9] as 0.62-0.85 kg m-^{3} in the Aydın 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 33% may produce acceptable results. According to evaluations conducted until now, both cultivar 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 region without irrigation water restrictions was the treatment (IR-100) in which water was fully applied, using the May 455 variety.

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