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Research Article

Yield and Water Relations of Drip Irrigated Cotton under Various Irrigation Levels

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Abstract This study was carried out on the Gloria cotton cultivars in 2018 at the Research and Application Farm of the Agriculture Faculty of Aydın Adnan Menderes University. The study was conducted according to a random block experimental design with three replications. Irrigation was begun in the control plots (S_1) with 40% of usable water holding capacity of the soil at a depth of 1.20 m taken up, and 75%, 50% and 25% of the water applied to the control plots was applied to the other plots. The applications of water significantly affected raw cotton yield. Average cotton yield varied between 1685 and 5985 kg ha^{-1}. The highest yield was obtained from treatment S_1 where there was no water restriction. Seasonal irrigation water and crop water consumption varied between 154-616 mm and 195-801 mm, respectively. Average WUE and IWUE values varied between 0.747-1.120 and 0.972-2.503 kg m^{-3} respectively. The yield was directly correlated with seasonal water use values and the second order polynomial equation "$Y = -0.0014ET^2 + 2.088ET – 179,68$"can be used to predict the yield potential of cotton under the semiarid climate. It may be concluded that the treatment which gave the best performance for high cotton yield was treatment S_1 when the water source was not limited and it completely met the irrigation water needs of the crop. On the other hand S_2 treatment, water was applied at a rate of 75%, had significant benefits in terms of saved irrigation water and high WUE indicating a definitive advantage of deficit irrigation under limited water supply conditions.

Keywords Cotton, Drip Irrigation, Deficit Irrigation, Semiarid Climate

Introduction

Water resources decrease due to global warming, excess water using and water pollution while water consumption increase with increasing population. We have to preserve our water sources and develop new irrigation techniques for the best water evaluation. In addition to this, the effects of global warming are more and more being felt, and one of the most important of these is drought. This has a negative effect on crop production. Thus although cotton (*Gossypium hirsutum* L.) has relatively high drought resistance when compared with other crop plants, the length of a drought and its occurrence in the growing season can cause reductions in yield by as much as 70-80% [1]. Irrigation water availability is a major concern in cotton production during the dry summer period of the Aegean region [2]. Limited availability of irrigation water requires fundamental changes in irrigation management and 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 [3]. However, the use of drip irrigation techniques is inevitable in the near future because of the salinity problem caused by traditional irrigation methods [4]. Also, drip irrigation has been suggested as a means of supplying most types of crops with frequent and uniform applications of water, adaptable over a wide range of topographic and soil conditions [5]. [3] studied the effect of irrigation methods, irrigation frequency and pan coefficients under Southeast Anatolia conditions of Turkey. Highest seed cotton yield of 5850 kg ha^{-1} was obtained from the full irrigation treatment (100 %) in trickle-irrigated plots with 6-day intervals.

In previous cotton studies, [6] tested drip and furrow methods for cotton irrigation and found that there were no yield differences between both methods. On the other hand, [7] compared furrow and drip irrigation methods and found that water use efficiencies (WUE) were 0.223 and 0.189 kg m^{-3} for drip and furrow irrigation methods, respectively. [5] in a study conducted to determine effective irrigation methods for cotton in the Southeast Anatolia Project (GAP) area, found that cotton yield in areas where drip irrigation was used were higher than in areas of furrow and sprinkler irrigation. [8] carried out a study to determine the effect of different intervals between two drip irrigations (5 and 10 days) on yield in cotton under Çukurova conditions, and found that as the irrigation dose and interval increased, the number of bolls increased, and as a result of this, cotton yield increased. [9] 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. [10] 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}. It was also found that raw cotton yield, the number of bolls and the weight of cotton per boll fell in parallel with the reduction in irrigation dose. [11] 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^{-1} in average cotton yield, and 0.76-0.98 kg m^{-3} in water use efficiency. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) varied from 0.58 to 0.62 kg m^{-3} and 0.75 to 0.94 kg m^{-3}, respectively in cotton irrigated by using the drip system [12].

Aegean region is one of the most important agricultural and industrial region in Turkey. All cotton production areas of western Turkey receive inadequate amounts or inadequate distribution of rainfall. The dependence of crop yields on water supply is a critical issue due to the increasingly limited water resources for irrigation in the Aegean region and its semi-arid climate. The aim of this study was to create a suitable irrigation programme by the drip irrigation method for Gloria cultivar of cotton, which are widely grown in this area, to investigate the water-yield relationship.

Materials and Methods

Field experiments of drip-irrigated cotton were conducted at the Agricultural Research Station of Aydın Adnan Menderes University, Aydin-Turkey at 37° 51’ N latitude, 27°51’ E longitude and 56 m altitude during the 2018 growing season. Climate in this region is semi-arid with total annual precipitation of 657 mm. The Lower Büyük Menderes Basin has a Mediterranean climate of hot and dry summers and cool wet winters. The climatic variables for experimental year and long-term means for May-September are given in Table 1 [13].

Table 1: Weather conditions prevailed during the experiments compared to the long-run at the experimental site.

Long terms (1970-2017)					
Month	**[a]T_{min} (°C)**	**T_{max} (°C)**	**$T_{average}$ (°C)**	**RH (%)**	**Rainfall (mm)**
May	14.3	28.3	21.0	56.9	52.7
June	18.3	33.6	26.0	49.2	35.6
July	20.7	36.3	28.6	48.6	16.6
August	20.4	35.8	27.6	52.9	7.5
September	16.8	32.1	23.3	55.9	5.3
2018					
Month	T_{min} (°C)	T_{max} (°C)	$T_{average}$ (°C)	RH (%)	Rainfall (mm)

May	17.1	31.7	23.2	57.1	8.6
June	19.7	33.4	25.8	57.1	71.0
July	22.3	37.4	29.2	49.4	28.5
August	22.6	36.9	28.5	56.4	5.8
September	19.1	33.9	25.3	55.2	16.3

[a]T_{min}= Minimum temperature; T_{max} = Maximum temperature

$T_{average}$ = Average temperature; RH = Relative humidity.

For the experiment area, water content at field capacity varied from 20.3 to 23.1 % and wilting point varied from 7.2 to 10.1 % on dry weight basis. Research area soil contains high percentages of sand (49.7-68.2 %), followed by silt (19.2-32.0 %) and clay (13.6-17.5 %) and could be classified as Sandy-loam. The dry soil bulk densities ranged from 1.35 to 1.52 g cm^{-3} throughout the 1.2 m deep profile. The total available soil water content within the top 1.2 m of the soil profile was 221.0 mm. (Table 2).

Table 2: Some principle properties of the experimental soil

Depth (cm)	**Soil Texture (%)**	**Field capacity (%)**	**Wilting point (%)**	**Bulk density (gcm^{-3})**
0-30	SL	23.1	10.1	1.35
30-60	SL	22.9	9.4	1.45
60-90	SL	18.4	7.3	1.52
90-120	SL	20.3	7.2	1.50

The Gloria cotton variety was planted on 20 April 2018. Cotton plants were thinned to a spacing of 0.70 m (row width) × 0.20 m when the plants were about 0.15 m in height. A compound fertilizer (each included 15 % composite) was applied at a rate of 40 kg ha^{-1} pure N, P and K at planting. The required remaining portion of nitrogen 25 kg N ha^{-1}, was applied as 33 % ammonium nitrate before the first irrigation.

The irrigation water needed to irrigate the experimental plots in the study was obtained from an underground water source within the farm. This water was raised from the well with a motor pump, and transferred to the study area in 63 mm external diameter braided PVC pipes. The drip irrigation method was used in the study, and in each plot of the study where the drip irrigation method was used, 16 mm external diameter polyethylene laterals were arranged in the experimental plots in such a way that a single lateral came to each plot. Lateral drip irrigation pipes were chosen with drippers with a flow rate of 4 l h^{-1} and a dripper spacing of 25 cm. Valves of 16 mm diameter were installed at the head of each lateral line in order to provide control over irrigation.

The experiment was set up in 2018 with a random block experimental design with three replications. The experimental blocks in the study were in four rows and had dimensions of 5.0 x 2.8 m, with a total area of 14.0 m^2. In order to prevent leakage, 3 m was left between blocks and 2 m between plots.

Five irrigation levels, 100%, 75%, 50%, 25% and 0% were applied in the experiment. 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 usable water retention capacity of the soil had been used up. Water was applied at 100% of the water needed to reach field capacity to the plots which were to be fully irrigated, and at 75%, 50%, 25% and 0% proportions of this amount to plots that were to receive partial irrigation. The fully (100%) irrigated plot was designated as the control plot, and the other plots were irrigated in the proportions mentioned above. At harvest time, the plants in the two middle rows were harvested by hand and weighed, and the cotton yield of the plot was found.

Crop water consumption under varying irrigation regimes was calculated using the soil water balance equation [14] as;

$$ET = R + I - D \pm \Delta W$$

where ET is the evapotranspiration (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.

When comparing the different irrigation treatments and irrigation water restrictions considered in the study, water use efficiency values were used in determining the most suitable irrigation programme. The water use efficiency values, which are also known as water usage rates, are calculated with the help of the equations given below, which express the ratio of the yields obtained with each irrigation treatment to the seasonal plant water consumption and the irrigation water applied. WUE was calculated as yield (kg ha^{-1}) divided by seasonal evapotranspiration (mm). IWUE was determined as yield (kg ha^{-1}) per unit irrigation water applied (mm) [15]. In addition, when regression analysis was carried out on yields obtained against plant water consumption, relationships were found between them. For this purpose, water yield functions were obtained which were used as a measure of the reaction of plants to water.

Cotton yield was determined by hand harvesting in each plot on 10 October 2018. In order to determine the differences between irrigation treatments, the data relating to raw 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 [16].

Results and Discussions

The total irrigation water amounts applied, seasonal water use and seed cotton yield values were presented in Table 3. The different amounts of water applied in the various irrigation treatments varied between 154 and 616 mm. In each year, irrigation water was applied seven times to the treatments over the growing season. The highest amount of water was applied to the S_1 the treatments which were irrigated fully. Along with this characteristic of the treatment, the highest yield and plant water consumption values in the study were obtained from this treatment. At the same time, 462 mm of irrigation water was applied to treatments S_2, which received 75% of the irrigation water applied to treatments S_1.

Table 3: Total number of irrigation, amount of irrigation, water use and yield of cotton

Treatments	**Number of irrigation**	**Irrigation water applied (mm)**	**Water saving (%)**	**Water use (mm)**	**Seed cotton yield (kg ha^{-1})**	**Relative yield (%)**
S_1	7	616	0.0	801	5985a	100.0
S_2	7	462	25	642	5750b	96.0
S_3	7	308	50	483	4994c	83.4
S_4	7	154	75	344	3856d	64.4
S_5	-	-	-	195	1685e	28.1
Treatments (S)					**	
$LSD_{0.05}$					13.765	

** significant at $P< 0.01$

Different letters indicate significant differences at $P< 0.05$ using LSD test.

Seasonal plant water consumption values varied in connection with the irrigation water applied to the treatments and the amount of soil moisture at planting and harvest date. The lowest plant water consumption value was obtained from treatments S_5 as 195 mm. This value was followed by treatments S_4, which received irrigation water at a level of 25% of that applied to treatments S_1. Water consumption values of 195 and 801 mm were obtained from these treatments. The highest seasonal water consumption values were obtained from treatments S_1 as 801 mm. As stated above, deficit irrigation applied to the treatments and seasonal climatic variation were responsible for the differences in the seasonal plant water consumption values according to the cotton cultivar. Under drip irrigation applications, seasonal water use of cotton was obtained by [17] as 287-584 mm in Adana conditions; as 410-725 mm by [18] in the High Texas Plains. On the other hand, [19] 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. In another study [9] applied a total of 738 mm irrigation water amount to drip irrigated cotton in the Bekaa Valley of Lebanon. The seasonal water use of cotton varied between 206 and 826 mm according to cotton cultivars under drip irrigation systems in Aydın plain conditions [20]. The results observed in this research were in agreement with the others given above.

Irrigation treatments significantly ($P<0.01$) affected seed cotton yield (Table 3). Highest yield averaging 5985 kg ha^{-1} was obtained from S_1 treatment. Minimum yield was obtained from S_5 treatment with averaging 1685 kg ha^{-1}. Seed cotton yields from other irrigation treatments varied between these values. As the irrigation level increased, seed cotton yield were significantly increased. Therefore, well irrigation treatment could be suitable for drip irrigated cotton in the region. Under this conditions, total number of irrigation applications was seven in total growing season for S_1 treatment. Therefore, it was observed that the ratio of decreases in seed cotton yield for each percent deficit rate was not constant. Maximum yield of 5760 kg ha^{-1} from well irrigated drip plots in Aydın plain was obtained [11]. Another Aydın plain conditions the highest average raw cotton yield was obtained from S_1 treatment (Carisma-V1) as averaging 6300 kg ha^{-1}. It was determined Carisma (V1) cultivar performed higher yields than Candia (V2) and Gloria (V3) [20]. On the other hand, the highest seed cotton yield (5870 kg ha^{-1}) in the Harran plain from the full irrigation treatment (100 %) with six day irrigation intervals followed by three day irrigation intervals (5040 kg ha^{-1}) using trickle irrigation method was determined by different researchers [3]. Also, the highest seed cotton yield of 4650 kg ha^{-1} using drip irrigation method under Harran plain conditions was observed [21]. Seed lint yields were reported to range from 3180 to 4030 kg ha^{-1} in the Uzbekistan conditions [19].

As Table 4 shows, WUE and IWUE values varied by irrigation treatments. The lowest WUE and IWUE values were obtained from the S_1 treatment as 0.747 kg m^{-3}. The amount of water applied increased, IWUE values decreased. The highest WUE value in the growing year was 1.120 kg m^{-3} from treatment S_4. It can be said that from the point of view of water saving, treatment S_4 used water more efficiently. Thus, when water was restricted under these conditions, a reduction of 35.6% was seen in seed cotton yield. In Çukurova conditions under drip irrigation, WUE of cotton was reported as 0.55-0.67 kg m^{-3} [3] and as 0.60-0.48 kg m^{-3} respectively [17]. In another study the WUE reported to range from 0.77 to 0.96 kg m^{-3} [19]. Similar results were reported by [11] as 0.62-0.85 kg m^{-3} and by [20] as 0.735-1.134 kg m^{-3} in the Aydın plain conditions.

Table 4: WUE and IWUE values of treatments

Treatments	**WUE (kg m^{-3})**	**IWUE (kg m^{-3})**
	2018	**2018**
S_1	0.747	0.972
S_2	0.895	1.244
S_3	1.033	1.621
S_4	1.120	2.503
S_5	0.864	-

Figure 1 and 2 shows the relationship between irrigation water amount and plant water consumption values obtained from the irrigation treatments and seed cotton yields. As can be seen in Figure 1 and 2, the both relationships for the Gloria cultivar were a relationship of statistically second order significance (polynomial) ($p<0.01$). In general, relationships between irrigation water and water use and yield reported in many studies, for example [3, 11, 22, 20] taking the cotton plant as material, were similar to and in accord with our results.

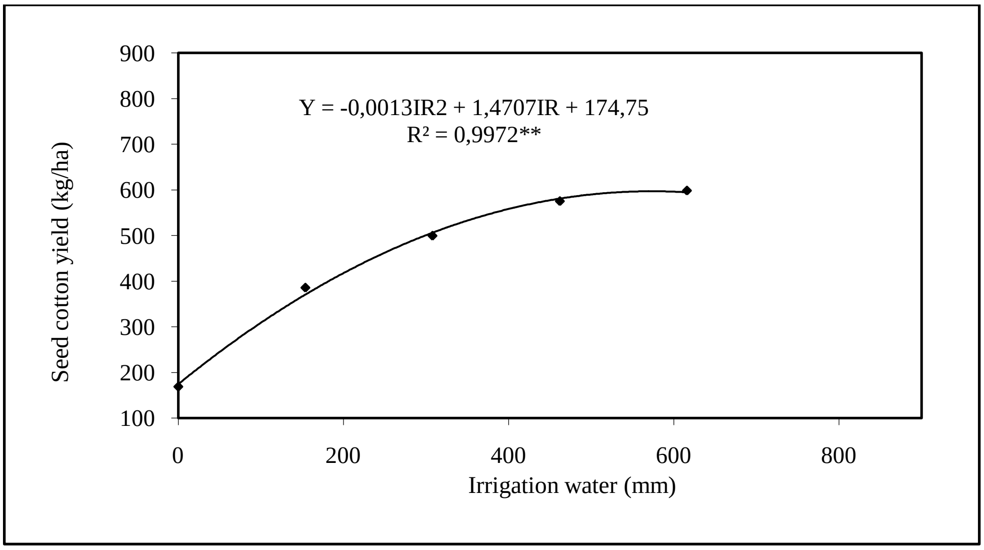

Figure 1: The relationship between irrigation water and seed cotton yield

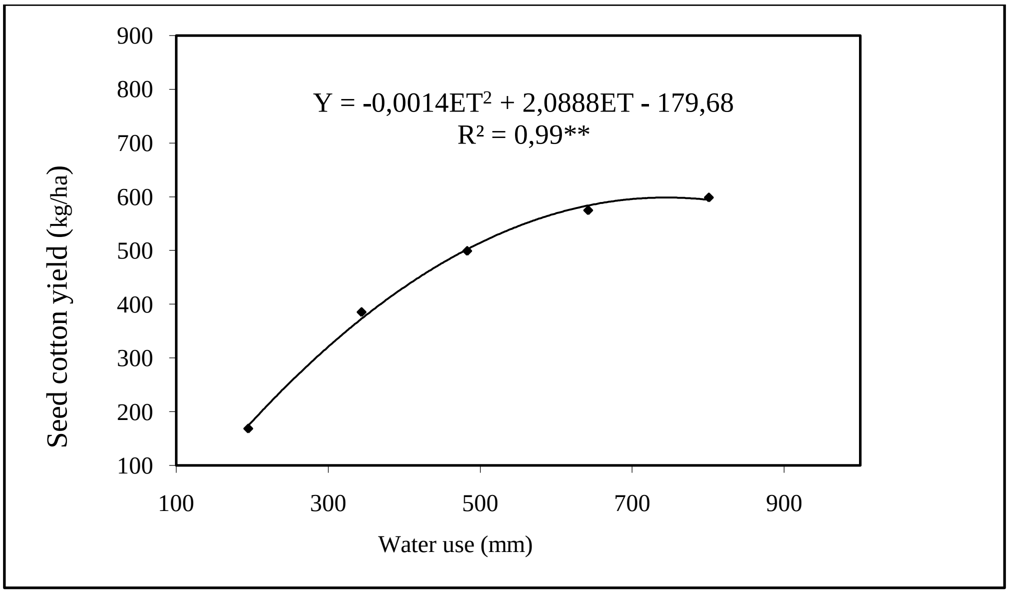

Figure 2: The relationship between water use and seed cotton yield

Conclusions

The amount of irrigation water applied to the irrigated plots varied from 154 to 616 mm in 2018. Irrigation water was applied to the plots seven times in growing season. The largest amount of irrigation water was applied to the S_1, which were fully irrigated. At the same time, treatments S_2 received 75% of the irrigation water supplied to treatments S_1 during the growing season, which totalled 462 mm in 2018. Seasonal plant water consumption values varied according to the irrigation programmes considered in the study and the year in which the study was conducted. The highest seasonal plant water consumption value was obtained from treatments S_1 as 801 mm. The lowest plant water consumption value was obtained from treatments S_5. Water consumption values of 195 to 801 mm were obtained in 2018 from treatments. The highest seed cotton yield was obtained from treatment S_1, which had the highest seasonal plant water consumption values. In 2018 the highest yield, in treatments S_1 in which water restriction was not applied during the growing season were 5985 kg ha^{-1}. The lowest seed cotton yield was obtained from treatments S_5 which water was not applied. Seed cotton yields for the other irrigation treatments varied between these values. The lowest WUE and IWUE values for cultivar were obtained from treatment S_1. These varied from 0.864 to 0.972 kg m^{-3} in 2018. The highest WUE value 1.12 kg m^{-3} was obtained from treatment S_4. From the point of view of water saving, it can be said that treatment S_4 used water most efficiently. In conditions where a lower reduction in yield is desired, it is seen that treatment S_2 would be suitable. In these conditions a 25% saving in water would result in a reduction in yield averaging 35.6%.

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 25% may produce acceptable results. According to evaluations conducted until now, both cultivar and the irrigation level applied are important in increasing seed cotton yield. Overall, the S_1 treatment (irrigation applied at the rate of 100 %) could be used for cotton grown in semiarid regions under no water shortage. On the other hand, results obtained from the S_2 treatment (irrigation applied at the rate of 75 %) could be used as a good basis for reduced drip irrigation strategy development in semiarid regions under water shortage.

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