Impacts of different water levels on yield, water use efficiency and fiber quality properties of cotton (*Gossypium hirsutum* L.) irrigated by drip systems

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Abstract

This study was conducted to determine effects of different deficit water level on yield, water use efficiencies and fiber quality parameters of cotton in the semiarid region of Turkey during 2017 and 2018. The irrigation treatments were based on soil water depletion replenishments. Irrigation was applied when ~50% of available soil moisture was consumed in the 1.20-m root zone at T_{100} treatment during the irrigation periods. Control treatment "T_{100}" was designated to receive 100 % soil water depletion. In treatments, T_{75}; T_{50}; T_{25} and T_{00} irrigations were applied at the rates of 75, 50, 25 and 0 % of control treatments, (T_{100}) on the same day, respectively. According to results, the average seasonal water use and seed cotton yield values ranged from 305 to 780 mm and 2913 to 5953 kg ha^{-1}, respectively. Water deficit significantly affected the crop yields. Highest average cotton yield was obtained from the full irrigation treatment (T_{100}). The average water use efficieny (WUE) values varied from 0.76 to 1.06 kg m^{-3} in both years respectively. Yield response factor (k_y) value of 0.70 was determined based on averages of two years. Fiber qualities were influenced by drip irrigation levels in both years. The results revealed that well irrigated treatments (T_{100}) could be used for the semiarid climatic conditions under no water shortage. On the other hand, the results also demonstrated that irrigation of cotton with drip irrigation regime at 75 % level (T_{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.

Key words: Cotton, drip irrigation, deficit irrigation, water consumption, yield and quality components

INTRODUCTION

The 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. Present cotton production in Turkey is about 602 000 tons of lint cotton from 450 000 ha. The Aegean region of western Turkey produces 41.2 % of the national cotton production of the country [1].

Irrigation water availability is a major concern in cotton production during the hot and dry summer period like Aegean region. Water shortage, increasing production cost and low water use efficiency (WUE) made the economical profit marginal and challenging to the end users. Thus new irrigation strategies must be established to use the limited water resource more efficiently. One of the new irrigation strategies is the deficit irrigation scheduling, which is a valuable and sustainable production strategy for dry regions [2]. However, the use of drip irrigation techniques is inevitable in the near feature because of the salinity problem caused by traditional irrigation methods [3]. Also, drip irrigation have 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 [4]. Under good management practices, deficit irrigation can result in substantial water savings with little impact on the quality and quantity of the harvested yield.

In previous cotton studies, tested drip and furrow methods for cotton irrigation were tested and there were no yield differences between both methods were found [5]. On the other hand, furrow and drip irrigation methods were compared and water use efficiencies (WUE) were determined to be 2.23 and 1.89 kg m^{-3} for drip and furrow irrigation methods, respectively [6]. Water use efficiency was 30% higher in the drip irrigation treatments, indicating a definitive advantage of this method under limited water supply was reported in another research [7]. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) varied from 0.58 to 0.62 kg/da/mm and 0.75 to 0.94 kg/da/mm, respectively in cotton irrigated by drip system [8]. According to the findings of a research, it was reported that deficit drip irrigation of cotton at 75% of full irrigation requirements did not decrease seed cotton yield and yield components for two growing seasons [9]. However, irrigation of cotton with four different rates (full irrigation and three deficit rates) for two seasons, the total irrigation depth ranged from 176 to 710 mm, and the highest yield obtained with the highest irrigation level [10]. In a different research using three irrigation levels and two irrigation intervals on drip irrigated cotton, significant difference in yields among crop pan coefficients of 0.33, 0.67 and 1.00 for a screened evaporation pan were determined [11].

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. However, little attempt has been made to assess deficit irrigation regimes for cotton under drip irrigation in the Aegean region. Therefore, this research was conducted to evaluate the water use efficiency, yield and fiber quality of cotton under different deficit drip irrigation regimes.

MATERIALS AND METHODS

This study was conducted during the growing seasons of 2017-2018 at the Agricultural Research Station of 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 668,4 mm with a mean monthly temperature of 17.96 ^{o}C according to long-term meteorological data (1975-2017) in the experimental area. Total rainfall during the growing periods was 135.3 and 171,2 mm in 2017 and 2018 respectively.

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 20.3 to 27.6 % and wilting point varied from 7.2 to 9.7 % on dry weight basis. The dry soil bulk densities ranged from 1.42 to 1.50 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 281 mm.

Carmen cotton variety was planted second week of May in 2017 and 2018, respectively. Cotton plants were thinned to a spacing of 0.70 m (row width) x 0.15 m when the plants were about 0.15 m in height. A compound fertilizer (each included 15 % composite) was applied at a rate of 60 kg ha^{-1} pure N, P and K at planting. The required remaining portion of nitrogen was followed by 82 kg ha^{-1} as ammonium nitrate 33 % before first irrigation.

Treatment layout was conducted to a randomised complete block design as three replications. There were 3.0 m apart between each plot in order to minimize water movement among treatments. Each experimental plot was designed as 6.0 x 4.2 m (6 rows per plot) and had a total area of 25.2 m^2 at sowing. In the study, five irrigation treatments, differing in irrigation rate was evaluated. The irrigation treatments were based on soil water depletion replenishments. Control treatment T_{100} was designated to receive 100 % soil water depletion and irrigation was applied when ~50% of available soil moisture was consumed in the 1.20 m root zone at T_{100} treatment during the irrigation periods. In treatments, T_{75}; T_{50}; T_{25} and T_{00} irrigations were applied at the rates of 75, 50, 25 and 0 % of control treatments (T_{100}) on the same day, respectively.

A drip irrigation system was designated for the experiment. Irrigation water was taken by a pump from a small reservoir near the experimental site. The control unit consisted of screen filter with 10 L s^{-1} capacity, control valves, manometers mounted on th inlet and outlet of each unit. The diameters of the laterals were 16 mm PE and each lateral irrigated one plant row. The inline emitters were used with discharge rate of 4 L h^{-1} above 10 m operating pressure. In the system, emitter and the lateral spacing were chosen as 0.25 and 0.70 m, respectively.

Soil water level was monitored by using the gravimetric method from the plots of the second replication of the various treatments. Cotton yield was determined by hand harvesting the two center rows in each plot on 16 September 2017 and on 17 September 2018. Crop evapotranspirations under varying irrigation regimes were calculated using the soil water balance equation as [12]:

$$\mathrm{ET} = R + I - D \pm \Delta W \quad (1)$$

where ET is the evapotranspirations (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. Since the amount of irrigation water was only sufficient to bring the water deficit to the field capacity, drainage was neglected.

Water use efficiency (WUE) was calculated as yield (kg ha^{-1}) divided by seasonal evapotranspiration (mm). Irrigation water use efficiency (IWUE) was determined as yield (kg ha^{-1}) per unit irrigation water applied[13] (mm).

Analysis of variance (ANOVA) was conducted to evaluate the effects of the treatments on seed cotton yield (kg ha^{-1}). Duncan's multiple range test was used to compare and rank the treatment means. Differences were declared significant at $P < 0.05$ or $P < 0.01$.

RESULTS AND DISCUSSION

Water use- yield parameters

The total number of irrigation, irrigation water amounts applied, seasonal water use and water use efficiency values of cotton for the experimental years were presented in Table 1. The amount of irrigation water applied for different treatment of cotton ranged from 700 to 175 mm in 2017 and from 690 to 173 mm in 2018. The results were similar for both years The seasonal irrigation water applied in T_{100} treatment was maximum in growing season suggesting that water applied was enough to meet the full crop water requirements in both years. Seasonal water use varied between 315 and 785 mm in 2017 and between 305 and 775 mm in 2018. This small difference in water use between the years can be attributed to the variations in climatic factors.

Table 1. Total number of irrigation, amount of irrigation, water use, seed cotton yield and water use efficiencies of cotton for the experiment period in 2017-2018

Year	**Treatment**	**Number of irrigation**	**Irrigation water applied (mm)**	**Water use (mm)**	**Seed cotton yield (kg ha^{-1})**	**IWUE (kg m^{-3})**	**WUE (kg m^{-3})**
2017	T_{100}	5	700	785	5980a**	0.85	0.76
	T_{75}	5	563	670	5740b	1.02	0.85
	T_{50}	5	350	520	5050c	1.44	0.97
	T_{25}	5	175	395	4240d	2.42	1.07
	T_{00}	-	-	315	2985e	-	0.94
2018	T_{100}	5	690	775	5925a**	0.86	0.76
	T_{75}	5	518	650	5640b	1.09	0.87
	T_{50}	5	345	510	4980c	1.44	0.98
	T_{25}	5	173	380	3950d	2.28	1.04
	T_{00}	-	-	305	2840e	-	0.93

** - different letters indicate significant differences at $P < 0.01$ using Duncan's multiple range test

Seasonal water use of cotton under the same region has been reported as 899 mm and between 855-882 mm under furrow irrigation system [14,15]. 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 as 435-615 mm in Çukurova conditions, and 456-868 mm in southeast Turkey [16,17]. In addition, water use of cotton was determined as 265-753 mm for a 2 year study of deficit and full irrigation in Aydın province and with values of approximately 748-760 mm for the Aydın Plain conditions by using drip syste [9,10]. On the other hand, the 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 [18]. In southeastern Turkey, a total of 814 mm irrigation water was applied to LEPA and drip irrigated cotton [17]. In another study, a total of 738 mm irrigation water amount was applied to drip irrigated cotton in the Bekaa Valley of Lebanon [19]. Much higher seasonal irrigation water and seasonal water use values have been reported for the southeast Turkey under different deficit irrigation conditions [20,21]. 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 1). Highest yield averaging 5953 kg ha^{-1} (5980 kg ha^{-1} in 2017 and 5925 kg ha^{-1} in 2018) was obtained from T-100 treatment. Minimum yield was obtained from T-00 plots with averaging 2913 kg ha^{-1}. 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 five in total growing season for T_{100} 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 [10]. Also, in Bornova conditions highest yield (3450 kg ha^{-1}) was determined under furrow method [22]. 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 [17]. Also, the highest seed cotton yield of 4650 kg ha^{-1} using drip irrigation method under Harran plain conditions was observed [20]. Seed lint yields were reported to range from 3180 to 4030 kg ha^{-1} in the Uzbekistan conditions [18].

In order to evaluate the effects of water use on seed cotton yield regression analysis was conducted. There was a curvelinear relationship between seasonal water use and seed cotton yield at 0.01 level of significance (Fig 1).

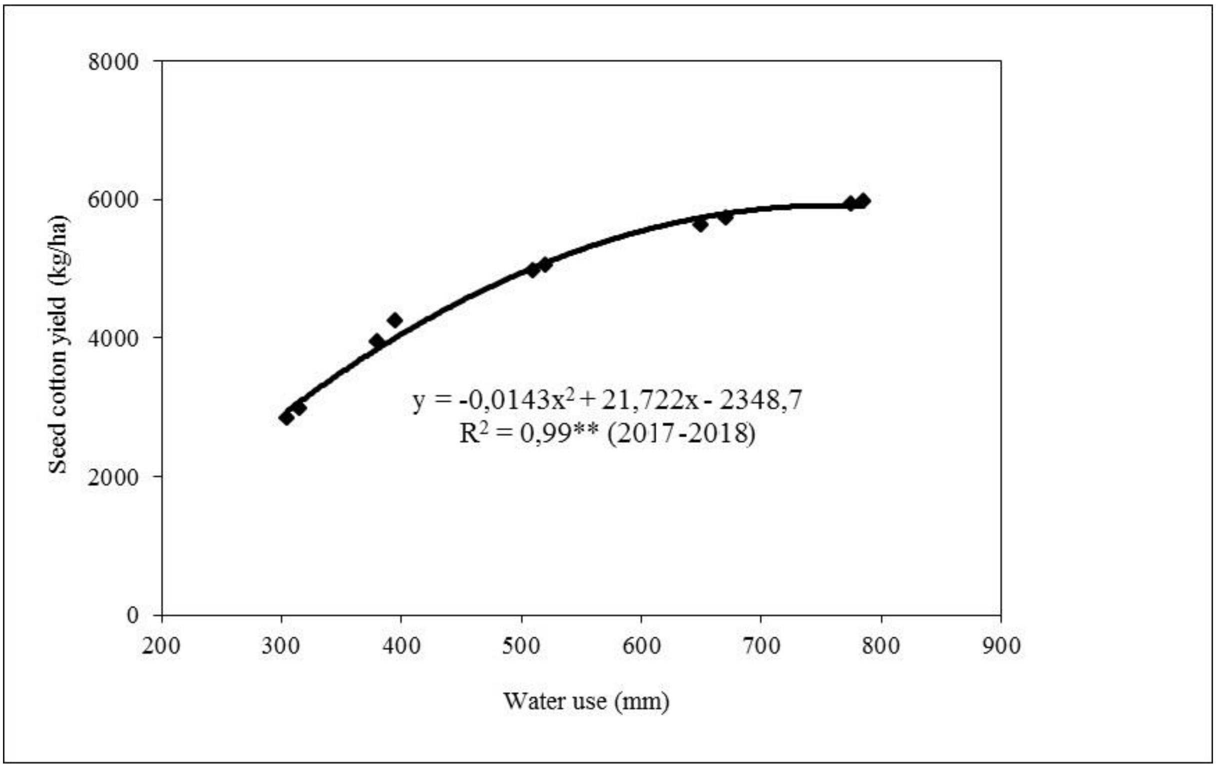

Fig. 1. Relationship between seed cotton yield and water use in 2017-2018.

Water use and irrigation water use efficiency (WUE, IWUE) were listed in Table 1 for drip irrigation treatmeants. The irrigation water use efficiencies (IWUE) of the both treatments were higher than the water use efficiencies (WUE). This could be attributed to water used from soil stroge. The average WUE values varied from 0.76 to 1.06 kg m^{-3} in both years respectively. WUE for T_{25} treatment was the highest, while for T_{100} was the lowest in both years for cotton. In general, WUE values decreased with increasing water use. The values of WUE in our present results for cotton were different than those of other previous researchers in different regions. The reported WUE values for furrow irrigated cotton was 0.38-0.46 kg m^{-3} in Bornova conditions [22]. However, the WUE values in the different drip irrigation treatments were higher as compared to WUE values of cotton irrigated by furrow system in the same region [9,10,11,14,15]. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) varied from 0.58 to 0.62 kg m^{-3} in cotton irrigated by drip system [8]. The WUE values of cotton irrigated by LEPA and drip method were 0.55-0.67 kg m^{-3} and 0.50-0.74 kg m^{-3} in Harran plain conditions[17]. On the other hand, WUE values of cotton were obtained as 0.223 kg m^{-3} for trickle irrigated cotton (lint) [6]. In another study, WUE values of drip irrigated cotton (lint) was found to be 0.80 kg m^{-3} in the Bekaa valley of Lebanon [19]. The WUE values of drip irrigated cotton (seed) was obtained as 0.63-0.88 kg m^{-3} in Uzbekistan [18].

Crop response to water stress (k_y)

Yield response factor (k_y) was determined for cotton by taking into consideration all the data in both years together[23]. The relationship between relative yield decrease ($1-Y_a/Y_m$) and relative evapotranspirasyon deficit ($1-ET_a/ET_m$) was plotted in Fig. 2. The relative yield decrease increased linearly with relative evapotranspiration deficit and linear regression equation fitted to the data. When combined values of two years, the coefficient of determination (R^2) was 0.88; and the relationship was statistically significant at the level of $P<0.01$. According to the regression equations, yield response factors (k_y) was 0.70 when the experimental years were considered together. Many researchers reported that in the case that $k_y < 1$; decrease in yield is of less importance than the decrease in ET, otherwise ($k_y > 1$) yield loss is of greater importance than the decrease in ET. Similar relationships were obtained in the other cotton studies. For instance, the avarege k_y value of cotton 0.70 determined from our study was consistent with the ones obtained as 0.84, 0.86, 0.89 and 0.78 respectively [10,17,26,25].

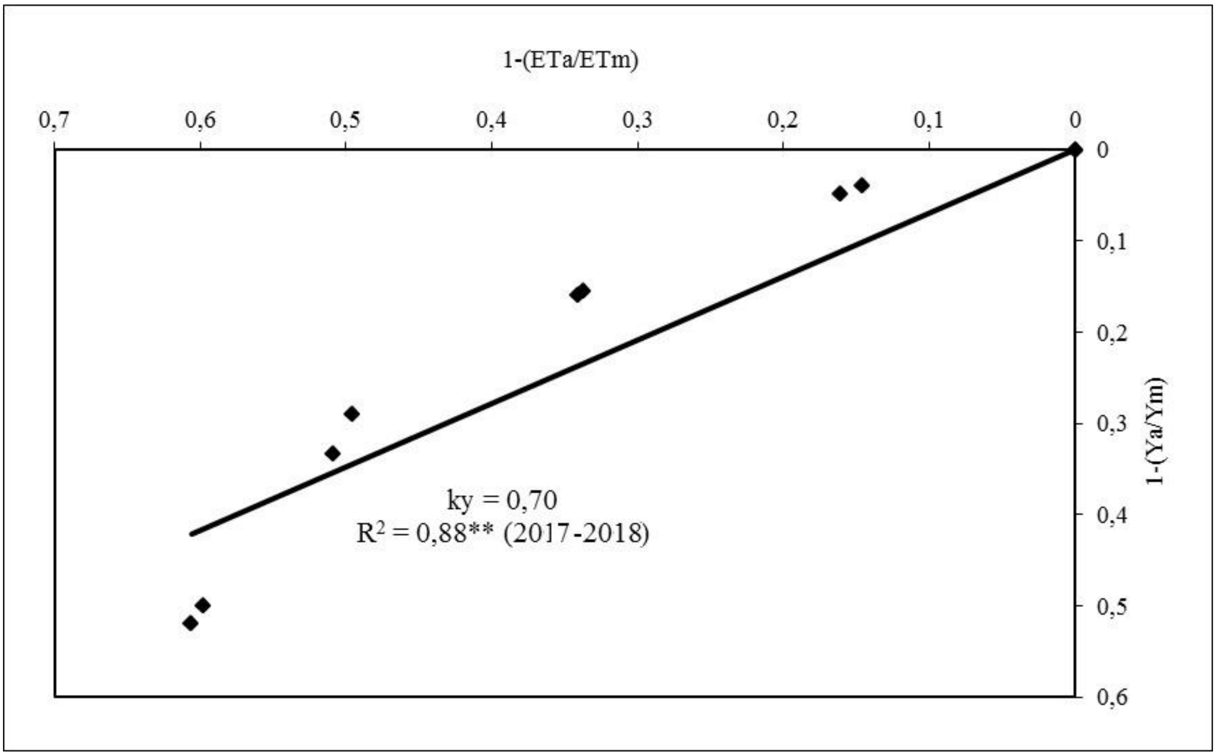

Fig. 2. Relationship between relative evapotranspiration deficit and relative yield decrease in 2017-2018.

Fiber quality parameters

Fiber quality response averaged across years differed significantly among irrigation levels (Table 2).

Table 2. Some fiber quality parameters under different drip irrigation levels in 2017 and 2018

Year	Treatments	Fiber length (mm)	Fiber strength (g/tex)	Fiber fineness (micronaire)
2017				
	T_{100}	30.8a*	32.1a*	4.94a*
	T_{75}	30.0ab	31.9ab	4.88ab
	T_{50}	29.5ab	29.5b	4.80ab
	T_{25}	28.6b	28.0c	4.60bc
	T_{00}	28.0c	27.8c	4.51c
	T_{100}	29.7a*	31.8a*	5.01a*
2018	T_{75}	28.5ab	30.5a	4.94ab
	T_{50}	26.7bc	28.9b	4.83bc
	T_{25}	25.8c	28.0c	4.71bc
	T_{00}	25.3c	27.8c	4.63c

* - different letters indicate significant differences at $P< 0.05$ using Duncan's multiple range test

Fiber length was generally shortened in response to deficit irrigation treatments. Cotton cultivar produced longer fiber, 30.8 mm and 29.7 mm, respectively, under full irrigation level (T_{100}) than all deficit irrigation levels in 2017 and 2018. Different researchers reported that as irrigation increased, which implies higher soil moisture contents, fiber length increased [26,29]. The fiber strength response to water stress was consistent throughout years. T_{100} treatment produced higher fiber strength (32.1 g/tex in 2017 and 31.8 g/tex in 2018) than rest of the drip irrigation regimes in both growing seasons. Fiber strength generally decreased as water deficit level increased during both growing seasons in this study. This response is in contrary with the result of a study that showed the irrigation had no effect on fiber strength. On the other hand, it was found that fiber strength was well correlated with soil water, which is similar to the finding of this study [31]. Drip irrigation treatments also affected micronaire during 2017 and 2018 growing seasons (Table 3). The effect of water deficient on micronaire was consistent throughout the years. Micronaire values varied from 4.94 to 4.50 in 2017 and ranged between 5.01 and 4.61 in 2018. The findings of this study show similarity to those that micronaire was not affected by the water rate [32].

CONCLUSİONS

It is concluded that seed cotton yield and fiber qualities were significantly affected by drip irrigation application rate in 2017 and 2018. Seasonal water use was 315-785 mm and 305-775 mm in 2017 and 2018, respectively. Seed cotton yields were positively influenced by increased irrigation levels in both growing seasons. The highest seed cotton yield was obtained from the T_{100} treatment for both years. Maximum seed cotton yield was obtained from the T_{100} treatment, with 700 and 690 mm irrigation water resulting in 5980 and 5925 kg ha^{-1}. WUE and IWUE values decreased with increase in irrigation water applied in both years. The average yield response factor (k_y) was determined to be 0.70. The WUE and k_y values obtained here could be used for the purposes of irrigation management and water allocation scheduling for irrigation schemes under limited irrigation water supply. A positive linear relationship between seasonal water use rate and yield existed during the experimental years. Overall, the T_{100} 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 T_{75} treatments (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. In this study, investigated fiber quality parameters responded to different drip irrigation regimes. The highest fiber length, strength and fineness values were obtained in the fully irrigated treatment (T_{100}).

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