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The Effects of Different Drip Irrigation Levels and Irrigation Practices on Cotton Yield Components and Fiber Quality Parameters

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Abstract This study was conducted to observe the effects of different irrigation approaches on some cotton yield components and fiber quality parameters produced from May-505 cotton variety in the Aydın province of Turkey during the year of 2021. The trial was designated in randomized complete block design with two factors and three replications. In the study, four different irrigation levels (100, 67, 33 and 0%) and two different irrigation approaches (gravimetric and pan evaporation) were investigated. Irrigation levels (IL) had significantly effects on seed cotton yield. The highest seed cotton yield was obtained from IL-100% treatment as averaging 5029.1 kg ha^{-1}, followed by IL-67% treatment as averaging 4086.1 kg ha^{-1}. The lowest yield was obtained from IL-0% treatment as averaging 2141.6 kg ha^{-1}. It was determined gravimetric approache performed higher yields than pan evaporation approache. The applications of different irrigation approaches and drip irrigation levels significantly affected seed cotton yield and some agronomic parameters such as; number of bolls per plant, boll raw cotton weight, single plant yield, 100-seed weight and lint percentage. According to the results of ANOVA of fiber quality parameters (fiber strength, fiber length, fiber fineness, uniformity and elongation), the difference between irrigation application approaches were found to be insignificant, while the difference between irrigation levels were found to be significant at a level of $p < 0.01$. 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 and good fiber quality.

Keywords Cotton, drip irrigation, Aegean Region, lint quality parameters

1. Introduction

Aegean Region is one of the most important agricultural and industrial region in west part of Turkey. All cotton production areas of this region receive inadequate amounts or inadequate distribution of rainfall. Decreasing ground water supplies and the high cost of energy also affect production of irrigated cotton. Turkey must take urgent action to solve the water-shortage problem for important agricultural crops including cotton, wheat, and other crops in coming years. Nowadays limited availability of irrigation water requires fundamental changes in irrigation management and urges the application of water saving methods. Under such conditions, different irrigation systems such as drip irrigation, sprinkler irrigation, subsurface drip irrigation (SDI), and low energy precision applicators (LEPA) should be considered to provide growers with high irrigation efficiency. Especially, the use of drip irrigation techniques is inevitable in the near future because of the salinity problem caused by traditional irrigation methods [1, 2]. Water saving irrigation methods should be followed in order to save water and maximize yield. Due to the severe competition in urban and rural use and other sectors, the value of the water will most probably rise shortly [3]. Thus, appropriate irrigation scheduling is required for maximizing the yield and water use. In scheduling irrigation programs, methods based on gravimetric and pan evaporation have widespread usage due to their simple and easy application and low cost [4]. Thus, this creates the need for continuous improvement in irrigation practices, especially in the cotton production of the Aegean region. Turkey's seed cotton production meets approximately 44% of the needs of its domestic market. Turkey is among the top 11 cotton production countries in the world. In 2018/2019, seed cotton acreage and crop production of Turkey is 508 000 ha and 988 000 t, respectively. Average cotton lint yield is about 1944 kg ha^{-1} [5]. [6] indicated that the period from square initiation to first flower represents the most critical development period in terms of water supply affecting yield components. The peak flowering period was the most sensitive to drought and at this time water stress led to the greatest decrease in yield. Under water stress, decrease in seed cotton yield is primarily due to the reduction in number of bolls. Water stress affect lint quality; fiber length, strength and micronaire reading as well [7]. In this respect, [2] applied irrigation at five different rates (full irrigation and four deficit rates) to cotton and found that the highest application of water regime producing the highest yield, while [8] reported that no yield reduction in cotton with the deficit water.

Drought not only affects yield but also fiber quality. It is reported that drought in the period when the cotton fiber is beginning to grow affects fiber length, strength and maturity [7, 9, 10, 11]. 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 fibers [7]. At the head of other factors determining the yield potential of cotton in drought conditions comes the length of the growth period (early or late) of the cotton cultivar. In drought conditions, the long growth period of late cultivars may give them an advantage over early cultivars in terms of yield potential. But on the other hand, in conditions of acute or excessive drought, the yield of early cultivars may be low, but it is nevertheless higher than that of late cultivars [12, 13].

Water stress occurring during the cotton growing season may reduce final lint yield. Cotton yield is dependent on the production and retention of bolls, and both can be decreased by water stress [14]. 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. Besides different drip irrigation levels, with proper irrigation application approaches (such as gravimetric and pan evaporation) under various irrigation levels should be studied by the researchers. Therefore, limited availability of irrigation water requires fundamental changes in irrigation management or urges the application of water saving methods. The aim of this study was to investigate to research the effects of irrigation treatments on some yield components, and fiber quality parameters for May-505 cultivar of cotton in Aydın province of Turkey.

2. Materials and Methods

Field experiments was carried out 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 2021 growing season. Climate in this region is semi-arid with total annual precipitation of 657 mm. Average seasonal rainfall is 657 mm, with 90% of the rain occurring between November and March. Typical Mediterranean climate prevails in the experimental area. Table 1 summarizes the monthly mean climatic data compared with the long-term mean climatic data for Aydın [15]. The growing season temperatures were typical of long term-means (1970-2020) for Aydın located in the western Aegean region of Turkey.

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

		1970-2020		
Month	**Temperature (°C)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Evaporation (mm)**
May	21	56.9	35.6	161.3
June	26	49.2	16.6	222.1
July	28.6	48.6	7.5	257.5
August	27.6	52.9	5.3	231.6
September	23.3	55.9	15.1	161.9
		2021		
Month	**Temperature (°C)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Evaporation (mm)**
May	22.3	57.6	3.3	149.9
June	25.2	56.0	1.9	185.6
July	29.6	51.4	0.1	248.5
August	28.9	50.0	0.0	228.7
September	23.8	55.8	0.0	154.6

The soil texture, bulk density, field capacity, wilting point, and available water holding capacity values of each 30 cm layer of 0 - 120 cm soil depth in the experimental area are given in Table 2. The soil series in the research area was Büyük Menderes Basin developed on aluvial materials [16]. The soil of the experimental site is classified as Entisols and Fluvisols-Regosols silty-clay-loam with relatively high water holding capacity. For the 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. Research area soils contain 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.

Table 2. Some physical characteristics of experimental site soils

Soil depth (cm)	**Soil texture**	**Bulk density (g cm^{-3})**	**Field capacity (%)***	**Wilting point (%)***	**Available water holding capacity (mm)**
0-30	Sandy-Loam	1.35	23.1	10.1	52.6
30-60	Sandy-Loam	1.45	22.9	9.4	58.7
60-90	Sandy-Loam	1.52	18.4	7.3	50.7
90-120	Sandy-Loam	1.50	20.3	7.2	58.9
0-120					221.0

*on dry weight basis

The May 505 cotton variety was planted on 27 May 2021, with 0.70 × 0.20 m spacing. Before starting the field experiment, 60 kg ha^{-1} compound fertilizer (containing 15% pure N, 15% P, and 15% K) was applied to the planting area The required remaining portion of nitrogen was followed by 82 kg ha^{-1} as ammonium nitrate 33% before first irrigation.

The trial was designated in randomized complete block design with two factors and three replications. In the study, four different irrigation levels (100, 67, 33 and 0%) and two different irrigation approaches (gravimetric and pan evaporation) were investigated. There were 3 m between each plot. Each experimental plot had four cotton rows at 0.7 m spacing and 5 m in length. Irrigation water was applied when ~50% of available soil moisture was consumed in the 0.90-m root zone at C_1 gravimetric; and D_1 pan evaporation control treatments (100%) during the irrigation periods. Other gravimetric treatments (C_2, C_3 and C_4) irrigations were applied at the rates of 67 , 33 and 0% of C_1 control treatments on the same day, respectively. For pan evaporation treatments (D_2, D_3 and D_4) irrigations were applied at the rates of 67, 33 and 0% of D_1 (7 day cumulative pan evaporation amounts) control treatments on the same day, respectively.

A drip irrigation system was designated for the experiment. Irrigation water was used from a deep well located 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 4 L h^{-1} above 10 m operating pressure. In the system, emitter and the lateral spacing were chosen as 0.20 and 0.70 m, respectively.

Actual crop evapotranspiration (ET) of cotton plants under varying irrigation amounts was calculated with the water balance equation (Eq. 1) [17].

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

where; ET is actual crop 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.

Eq. (2 and 3) (Eq. 2 for pan evaporation method and Eq. 3 for gravimetric method) [18] were used to calculate the amount of irrigation water for two approaches;

$$V = P \times A \times E_{pan} \times IL \quad (2)$$

$$I = (FC-AW)/100 \times \gamma_t \times D$$

$$V = I \times A \times IL \quad (3)$$

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 an 7 day irrigation interval (mm), IL represents irrigation levels (0.33, 0.67 and 1.0), FC field capacity (mm), AW available water in the soil within 90 cm depth before irrigation applications (mm), γ_t bulk density (g cm^{-3}) and D effective root zone, taken as 90 cm. Class A Pan is located at the meteorological station next to the experimental plots.

Cotton was collected by hand harvesting in each plot on 16 November 2021. 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. At the first harvest, a sample of 500 g of raw cotton was taken from each plot and sent to the Fiber Quality Laboratory of the Nazilli Cotton Research Institute-Aydın/TURKEY for determination of fiber strength, fiber length, fiber fineness, uniformity and elongation. Fiber characteristics were determined using an HVI (High Volume Instrument) from fiber taken from each plot. The yield components examined in this study are; number of bolls per plant (no $plant^{-1}$), boll raw cotton weight (g), single plant yield (g $plant^{-1}$), 100-seed weight (g) and lint percentage (%). In order to determine the differences between irrigation treatments, the data relating to all the parameters described above were subjected to variance analysis. The Least Significant Differences (LSD) test was used for comparing and ranking the treatments. Differences were determined 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

The total irrigation water amounts applied, seasonal water use and seed cotton yield values were presented in Table 2. The first irrigation was applied on July 29, and irrigations were lasted on September 8, in 2021, respectively. Seasonal amount of irrigation water applied for different irrigation application treatments ranged from 169 to 627 mm in growing season. Irrigation water was applied seven times to the treatments over the growing season (Table 2).

Table 3: Seed cotton yield and seasonal water use values as influenced by seed applications and irrigation levels

Irrigation application approaches	Irrigation Levels (IL)	Seed cotton yield (kg ha^{-1})	Irrigation water applied (mm)	Water use (mm)
Gravimetric	100%	5115	513.0	569.0
	67%	4295	343.0	459.0
	33%	3768	169.0	380.0
	0%	2215	-	216.0
Pan evaporation	100%	4942	627.0	691.0
	67%	4115	420.0	540.0
	33%	3552	207.0	415.0
	0%	2067	-	217.0

The response of seed cotton yield to different irrigation treatments are given in Table 3. Data obtained from study showed that seed cotton yield was significantly affected by irrigation levels. No interactions between irrigation application approaches (App.) and irrigation levels (IL) were observed for any investigated parameters in year. Irrigation applications (App.) had no significant effect on seed yield. The gravimetric application resulted in higher yield than pan evaporation applications. Seed cotton yield was found to increase with irrigation water levels. Examining these results from the point of view of irrigation levels (IL), four 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 67 % level were second, and treatments which had received water at the 33 % level formed the third group. Especially, as the irrigation level increased, seed cotton yield were increased in all irrigation approaches. The highest average yield was obtained from IL-100 treatment as 5029.1 kg ha^{-1}, followed by IL-67 treatment as 4086.1 kg ha^{-1}. The lowest yield was obtained from IL-0 rain fed treatment as 2241.6 kg ha^{-1}.

Table 3 shows variance analysis and the LSD test results values relating to various agronomic characteristics obtained from the study. Regarding the number of bolls, the difference between irrigation application approaches was significant at a level of $p<0.05$ and irrigation levels was significant at a level of $p<0.01$(Table 3). The number of bolls fell in relation to a reduction in irrigation water applied. Generally, fewer bolls were obtained from both applications in treatments irrigated at 33% and 67%. A study conducted in different soil series with lysimeters in Çukurova conditions, it was found that boll numbers varied between 4.5 and 10.4 under the effects of the irrigation programme applied and the soil series [20]. In a study in which the furrow irrigation method was applied under Harran plain conditions, the number of bolls varied between 10 and 20 according to different irrigation applications [21], while these values varied on average between 14.1 and 14.8 under Nazilli conditions [22]. Under Aydın conditions, the average number of bolls per plant varied between 6.1 and 15.6 and between 5.9 and 16.6 and between 15 and 21 in relation to the cultivars and irrigation programmes [23, 24, 25, 26, 27]. Considering boll raw cotton weight, the difference between irrigation application approaches were found to be insignificant, while the difference between irrigation levels was significant at a level of $p<0.01$(Table 3). Examining the results from the point of view of irrigation levels, the first group consisted of the treatments which received full irrigation (IL-100). Generally, a lower boll raw cotton weight was obtained in all seed applications from treatments to which irrigation water had been applied at a proportion of 33% and 67%. In a study in which the drip irrigation method was applied under Aydın plain conditions, boll weights varied on average between 3.51 and 6.18 g; between 5.4 and 6.6 g; between 4.6 and 6.0 g according to different irrigation applications and cotton varieties, respectively [24, 26, 27, 28]. The single plant yield values varied from 28.66 to 71.53 g/plant in relation to the irrigation approaches and irrigation levels. Examining single plant yield values in the Table 3, it is seen that there is differences between applications at the level of $p<0.05$, on the other hand irrigation levels were significant at a level of $p<0.01$. Examining the results from the point of view of irrigation levels, the first group was formed from treatments which received full (100%) irrigation water, and the last group was formed from the treatments which received no irrigation water. Under Aydın conditions, the average single plant yields varied between 75 and 111 g and between 58 and 82 g in relation to the cultivars and irrigation programmes [25, 26, 27, 28]. Examining 100-seed weight in Table 3, the difference between irrigation application approaches were found to be insignificant, while the difference between irrigation levels was significant at a level of $p<0.01$. The highest value was obtained from the treatments which received the full amount of water (100%). Similar to the other quality characteristics, 100-seed weight values in all irrigation treatments showed a decline in relation to irrigation water restriction. In three different experiments in Aydın conditions, researchers determined different 100-seed weight values with an average of 9.80-11.24 g by [29]; 9.31-11.20 g by [18]; and 9.91-13.13 g by [30] in connection with different irrigation methods and irrigation programmes. Examining lint percentage values, the difference between irrigation application approaches were found to be insignificant, while the difference between irrigation levels was significant at a level of $p<0.01$. (Table 3). These values varied from 41 to 43.4 % in growing season. In a study carried out on the Nazilli 84 cultivar of cotton under Antalya conditions using furrow and drip irrigation methods, and reported of 41.42% with furrow irrigation and 42.06% with drip irrigation [31]. In the same way, values of 43-44% reported by [32]. In a study applying surface irrigation methods values of 44-45% and 41.6-44.3% were reported by [33] and [34]. In another study in the same region, using the drip irrigation method lint percentage values of 39.96-40.02% were determined by [30]. Also, in a study under restricted irrigation conditions, lint percentage values varied between 43% and 45% according to irrigation levels [35]. Another researcher in the same region reported these values as 39.8-41.7% [29].

Table 3: Seed cotton yield and some yield components of cotton influenced by different irrigation approaches and irrigation levels

		Seed cotton yield (kg ha^{-1})	**Number of bolls (number)**	**Boll raw cotton weight (g)**	**Single plant yield (g)**	**100-seed weight (g)**	**Lint percentage (%)**
Irrigation application approaches (App.)	**Gravimetric**	3789.3	13.00a	4.34	58.82a	9.49	42.19
	Pan evaporation	3669.5	11.66b	4.42	51.20b	9.52	42.31
LSD%5			1.009		2.106		
Irrigation Level (IL)	**% 100**	5029.1a	15.66a	5.07a	70.30a	9.66	43.54a
	% 67	4086.1b	12.83b	4.71ab	58.80b	9.56	42.56b
	% 33	3660.8c	10.83c	4.43b	51.15c	9.33	41.82c
	0%	2141.6d	10.00c	3.31c	29.81d	9.05	41.08d
LSD%5		204.515	1.427	0.393	2.979	0.118	0.730
	App.	ns	*	ns	*	ns	ns
	IL	**	**	**	**	**	**
	App. x IL	ns	ns	ns	ns	ns	ns

*$p< 0.05$; **$p< 0.01$; ns: not significant

In a column values with a common letter are not significantly differ from one another using LSD%5

Table 4 shows the values relating to cotton fiber quality obtained in the study, and also same table gives the results of variance and the LSD tests of this research. In the growing year, the fiber fineness values (ns) among the irrigation approaches were not statistically significant while irrigation levels were statistically significant at the $p<0.01$ level. The effect of water deficit on fiber fineness was not consistent throughout the year. Fiber fineness values varied from 5.74 (IL-%100) to 5.38 (IL-%0). These results were in agreement with the results reported by [2]; [24] and [36]. On the other hand, in Aydın conditions, reported fiber fineness values varied from 4.28 to 4.76 micronaire [26]. Examining fiber length in Table 4, it is seen that the difference between the irrigation approaches were insignificant, while the difference between irrigation levels were significant at the $p<0.01$ level. The highest fiber length (31.27 mm) was obtained from the IL-%100 irrigation level and occurred in the first group (a) (Table 4). IL-%100 treatment resulted in highest fiber length in the study and followed by IL-%67 and IL-%33 as shown in Table 4. The findings obtained in the study were similar to most of the previous research into determining the effects of different irrigation level on cotton cultivars [2, 24, 36, 37]. Examining fiber strength in Table 4, it is seen that the difference between the irrigation approaches were insignificant, while the difference between irrigation levels were significant at the $p<0.01$ level. From the point of view of irrigation levels, the highest value was obtained from the IL-%100 irrigation level as 35.41 g tex^{-1} and followed by IL-%67. Studies of gene action suggest that, within upland cotton genotypes there is little non-additive gene action in fiber strength [30]; that is, genes determine fiber strength. These results were in agreement with the results reported by [2, 24, 36, 37]. In addition, under Aydın conditions fiber strength values varied between 29.96 and 31.2 g tex^{-1} in 2018 according to drip irrigation treatments [26]. The effects on fiber elongation and uniformity index of the study treatments, from the point of view of the irrigation levels and irrigation approaches were found to be insignificant. In the year of the study, these values varied from 6.89 % to 7.45% and varied from 82.76% to 86.79%. These results were in agreement with the results reported by [26] in Aydın province.

Table 4: Cotton fiber quality as influenced by different irrigation approaches and irrigation levels

		Fiber fineness (micronaire)	Fiber length (mm)	Fiber strength (g/tex)	Uniformity percentage (%)	Fiber elongation (%)
Irrigation application approaches (App.)	**Gravimetric**	5.55	29.73	32.50	85.13	7.22
	Pan evaporation	5.58	29.88	33.10	85.73	7.22
LSD%5						
Irrigation Level (IL)	**% 100**	5.74a	31.27a	35.41a	86.57a	7.08
	% 67	5.62b	30.92a	34.06ab	86.37a	7.39
	% 33	5.53b	29.59b	32.47b	84.70b	7.21
	0%	5.38c	27.45c	29.26c	84.09b	7.21
LSD%5		0.107	0.899	2.222	1.225	
	App.	ns	ns	ns	ns	ns
	IL	**	**	**	**	ns
	App. x IL	ns	ns	ns	ns	ns

*p< 0.05; **p< 0.01; ns: not significant

In a column values with a common letter are not significantly differ from one another using LSD%5

4. Conclusion

According to the results obtained from the study, the highest seasonal plant water use value was obtained from IL-100 irrigation treatment for all application approaches. Seasonal water use varied from 216 to 691 mm in growing season. Irrigation levels (IL) had significant effects on the yield of cotton at a $p<0.01$ level. The highest average yield was obtained from IL-100 treatment as 5029.1 kg ha^{-1}, followed by IL-67 treatment as 4086.1 kg ha^{-1}. The lowest yield was obtained from IL-0 rain fed treatment as 2141.6 kg ha^{-1}.

Regarding the some yield components (number of bolls per plant, boll raw cotton weight, single plant yield, 100-seed weight and lint percentage) the difference between application approaches were found to be insignificant, while the difference between irrigation levels were significant at a level of p<0.01. According to the results of ANOVA of fiber quality parameters (fiber strength, fiber length, fiber fineness, uniformity index and elongation), the difference between irrigation application approaches were found to be insignificant, while the difference between irrigation levels were found to be significant at a level of $p < 0.01$. 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 and good fiber quality. However, if water resources in the area are limited, then restricting water to a level of only 33 % may produce acceptable results.

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