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The Effects of Different Drip Irrigation Practices on Water-Yield Relation of Cotton

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Abstract This study was conducted with May-505 cotton variety in the Aydın plain conditions during 2021. The purpose of this study is to evaluate different water levels with different irrigation programs in terms of seed cotton yield and water use efficiencies. The field trial, which was designed as two factors and three replications, was designed according to the randomized complete block trial pattern. Four different irrigation levels (100%, 67%, 33% and 0%) and two different irrigation approaches (gravimetric and pan evaporation) were investigated in the study. The applications of water significantly affected seed cotton yield and water use efficiency values. The highest irrigation water was given to the full irrigation (100%) subject in each irrigation approach. Seasonal water use values in the parcels varied between 216 (0%) and 691 (100%) mm during the production period. The average seed cotton yield varied from 2067 – 5115 kg ha^{-1}. The highest average seed cotton yield was obtained from C1 (100%) gravimetric treatment as averaging 5115 kg ha^{-1}. It was determined gravimetric approache performed higher yields than pan evaporation application. Average water use efficiency (WUE) values varied between 0.715 and 1.025 kg/m3. Yield response factor (ky) was found to be 0.88 for gravimetric and 0.80 for pan evaporation applications. In conclusion, the gravimetric approach with 100% treatment (C1) is suggested for cotton production in the parts of the Aydın plain conditions within the semi-arid climate zone, while water resources are sufficient. Else, IL-67% treatment with a gravimetric approach can be used for a deficit irrigation strategy.

Keywords Keywords Cotton, drip irrigation, irrigation levels, water use efficiency, Aydın

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]. 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} [2]. A reduction in underground water sources as a result of climate change and an increase in industrial and domestic water consumption have led to a reduction in the amount of water available for agricultural production. 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. Cotton is irrigated by the surface irrigation method in Turkey although sprinkler and drip irrigation have been suggested as a means of supplying most types of crops with frequent and uniform applications of water, since it is adaptable over a wide range of topographic and soil conditions [3, 4]. They also reported that cotton yield and water use efficiency was higher in drip irrigation than furrow and sprinkler irrigation. [5] reported that water use efficiency was 30% higher with drip irrigation treatments, indicating a definitive advantage of this method under conditions of limited water supply. Water availability is a major concern in cotton production. [6] 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 another study, the highest yield was found to be 4220 kg ha^{-1} with 5-day irrigation interval and seasonal water consumption was 511 mm under drip irrigated cotton in Çukurova plain-Turkey [7]. Efficient use of irrigation water is becoming increasingly important and alternative water application methods such as drip and sprinkler, may contribute substantially toward making the best use of water for agriculture and improving irrigation efficiency [8]. A number of previous studies reported the advantage of drip irrigation methods in terms of high WUE and cotton yield [5, 7, 3, 6, 9, 10]. [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}. 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 level. [12] 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. [13], 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-1 in average cotton yield. Also, in each of the years in which the study was conducted, the highest water use efficiency value, 0.71 kg m^{-3}, was obtained from a water level of D180. [14], conducted a study to determine the effects of 0%, 25%, 50% 75% and 100% irrigation levels on the yield of cotton using drip irrigation under Aydın-Turkey conditions. The researchers found average WUE and IWUE values varied between 0.747-1.120 and 0.972-2.503 kg m^{-3} respectively.

Cotton is an excellent candidate for irrigation. Besides different drip irrigation levels, with proper management such as different irrigation approaches 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 objectives of this study was to determine the effects of irrigation approaches and irrigation levels on the seed cotton yield and water use efficiency under drip irrigation system and to choose the most suitable irrigation schedule for cotton cultivar under semi-arid climatic conditions.

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 site

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 study, prepared as a randomized complete block design with three replications and two factors; four different irrigation levels (100, 67, 33, and 0%) and two different irrigation program techniques (gravimetric and pan evaporation) were investigated. There is 3 m space between each of the trial plots, and four cotton rows with 0.7 m intervals and 5 m lengths have been created within the plot. In the pan evaporation method, irrigation water was applied to D1 (control), D2, D3, and D4 subjects, respectively 100%, 67%, 33%, and 0% of the 7-day cumulative pan evaporation amounts measured from the class-A pan. When 50% of the moisture content of 0 – 90 m root zone in the soil in the parcels irrigated by the gravimetric method was consumed, irrigation water was applied to C1 (control), C2, C3, and C4 subjects, respectively 100%, 67%, 33% and 0% of the water needed.

Equation (1 and 2) was used to calculate the irrigation water amount for two approaches;

V = P x A x Epan x WL (1)

I= (FC-AW)/100 x ɣt x D

V= I x A x WL (2)

Where V is the volume of irrigation water (L), P wetting percentage (taken as 100 % for row crops), A is plot area (m2), Epan is the amount of cumulative evaporation during a seven-day irrigation interval (mm), WL represents irrigation levels (0.33, 0.67 and 1.00), FC field capacity (mm), AW available water in the soil within 90 cm depth before irrigation applications (mm), ɣt bulk density (g cm-3) and D effective root zone (mm). Class A pan, used to measure the evaporation, was placed next to the plots in the meteorology.

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.

Crop water consumption under varying irrigation regimes was calculated using the soil water balance equation [14] as; [17]

$$ET = R + I - D \pm \Delta W \quad (3)$$

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 ha^{-1}) divided by seasonal water use (mm). IWUE was determined as yield (kg ha^{-1}) per unit irrigation water applied (mm) [18]. 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 (ky), which represent the relationship between relative yield reduction [1-(Ya/Ym)] and relative evapotranspiration deficit [1-(ETa/ETm)], were determined using equation 2 given by Doorenbos and Kassam [19]:

1-(Ya/Ym)=ky(1-ETa/ETm) (4)

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 ha^{-1}).

Seed cotton yield was determined by hand harvesting in each plot on 16 Movember 2021. 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 [20].

Results & Discussion

The total irrigation water amounts applied, seasonal water use and water use efficiency values (WUE, IWUE) were presented in Table 3. 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 drip treatment ranged from 169 to 627 mm in growing season. Irrigation water was applied seven times to the treatments over the growing season (Table 3).

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

Irrigation application methods	Irrigation Levels	Seed cotton yield (kg ha^{-1})	Irrigation water applied (mm)	Water use (mm)	Water use efficiency (WUE) (kg m^{-3})	Irrigation water use efficiency (IWUE) (kg m^{-3})
Gravimetric	C_1-100%	5115	513.0	569.0	0.898	0.997
	C_2-67%	4295	343.0	459.0	0.935	1.252
	C_3-33%	3768	169.0	380.0	0.991	2.229
	C_4-0%	2215	-	216.0	1.025	-
Pan evaporation	D_1-100%	4942	627.0	691.0	0.715	0.788
	D_2-67%	4115	420.0	540.0	0.762	0.979
	D_3-33%	3552	207.0	415.0	0.855	1.715
	D_4-0%	2067	-	217.0	0.952	-

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 irrigation approaches.

Seasonal water use varied from 691 mm D1 treatment (pan evaporation) to 217 mm in D4 treatment (rain-fed) plots in the production period and 569 mm in C1 (gravimetric) treatment to 216 mm in C4 treatment (rain-fed) plots. This was followed by D2 and C2 treatments, 540 and 459 mm in the growing season, respectively (Table 3). The highest seasonal water use values were obtained from treatments D1 and C1 control treatments (100%) as 691 mm and 569 mm, respectively. Seasonal water use in the full irrigation treatment S1, was in agreement with results obtained by [14] in the Aydın plain with the drip system and who determined water use values as 800 mm. Seasonal water use of cotton under the same region has been reported as 899 mm by [21]; as 855-882 mm by [4] under furrow irrigation system; as 265-753 mm by [12] and as 268-754 mm by [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 [22] as 287-584 mm in Adana conditions; as 410-725 mm by [23] in the High Texas Plains. On the other hand, [10] 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 results observed in this research were in agreement with the others given above.

The response of seed cotton yield to different irrigation treatments are given in Table 4. Data obtained from study showed that seed cotton yield was significantly affected by irrigation levels. No interactions between irrigation application methods (App.) and irrigation levels (IL) were observed for any investigated parameters in year. Irrigation application methods (App) had no significant effect on seed cotton yield. The gravimetric method 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 applications. 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 treatment as 2141 kg ha^{-1}. The reduction rate was 42.5% between the highest and lowest seed cotton yield. When the amount of applied water through drip irrigation was reduced 33% (IL-67) the decrease in yield was about 18.7% in growing year. A significant decline in seed cotton yield under deficit irrigation treatment is reported in many previous researches.

Table 4: Seed cotton yield (kg ha^{-1}) as influenced by irrigation applications and irrigation levels

Irrigation application methods (App.)	**Gravimetric**	3789.3
	Pan evaporation	3669.5
F value (App.)		ns
LSD %5		
Irrigation levels (IL)	IL-100%	5029.1a
	IL-67%	4086.1b
	IL-33%	3660.8c
	IL-0%	2141.6d
F value (IL)		**
LSD %5		204.515
App. x IL		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

According to the results of a study conducted on drip irrigated cotton in Aydın area, the highest cotton yield was achieved from a treatment in which 100 % of the amount of evaporation from a class A-pan was applied at 8-day irrigation interval [24]. On the other hand, the highest seed cotton yield (5870 kg ha^{-1}) was reported in the Harran plain from the full irrigation treatment (100%) with 6-day irrigation interval using drip irrigation method [6]. The average seed cotton yield was obtained as 5760 kg ha-1 under drip irrigated treatment in western Turkey [12]. Another Aydın plain conditions the highest average raw cotton yield was obtained from S1 treatment (Carisma-V1) as averaging 6300 kg ha^{-1}. It was determined Carisma (V1) cultivar performed higher yields than Candia (V2) and Gloria (V3) [25]. Similar results were obtained by [14] as 5985 kg ha^{-1} 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 irrigation level have significant effect on seed cotton yield. It has been concluded that the most proper irrigation programme suggested for achieving highest cotton yield would be using the delinted seed applications under water abundant conditions in which the crop water requirements were fully met by IL-100 treatment (treatment D1).

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 [6, 12, 14, 22].

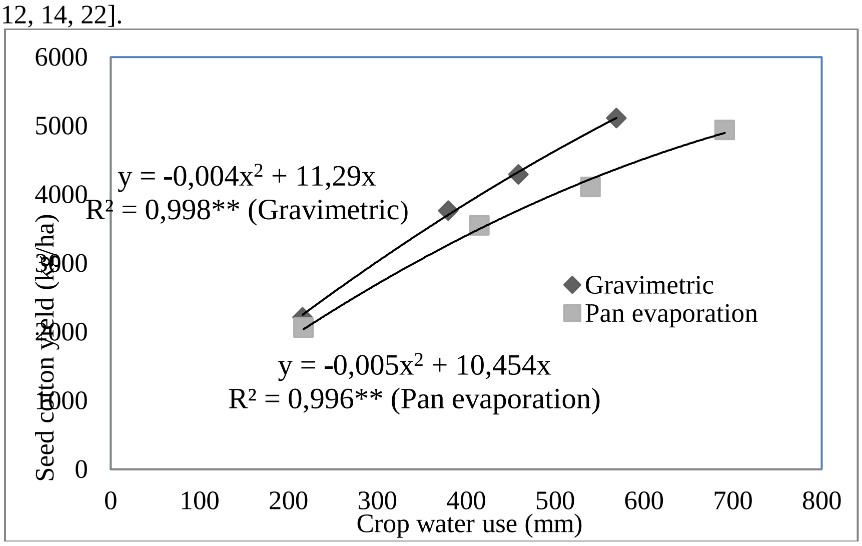

Figure 1: The relationship between water use and seed cotton yield

The ky factor which represents the slope of the relationship between relative ET and relative yield, was determined the methods of [26]. Yield response factor (ky) was found to be 0.88 for gravimetric and 0.80 for pan evaporation applications. The average ky for the whole growing season were found to be 0.84 by [19], 0.89 by [6] and 0.78 by [12] in Aydın conditions.

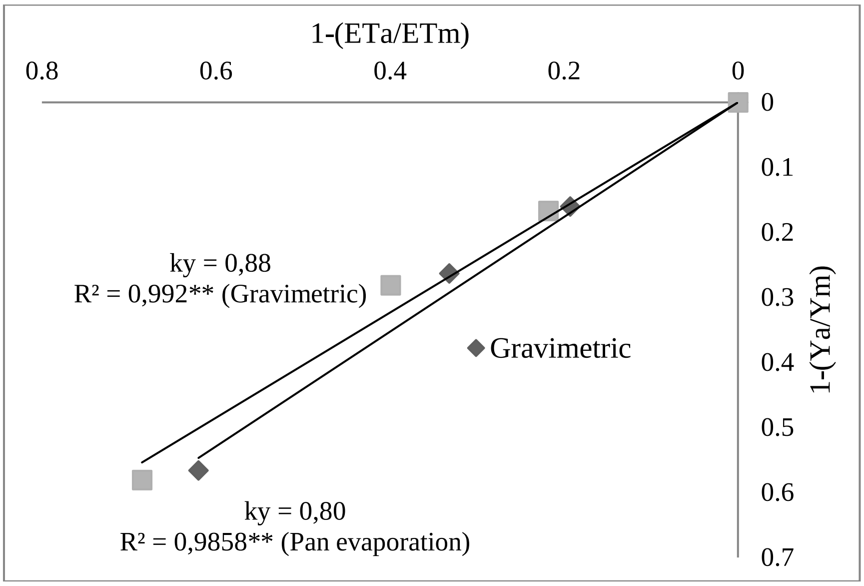

Figure 2: Yield response factor, ky, of cotton for different irrigation approaches

Water use and irrigation water use efficiencies (WUE, IWUE) values are listed in Table 4 for growing season. As the amount of water applied increased, WUE and IWUE decreased. In general, the IWUE values were higher than those of WUE in all treatments. This could be attributed to water used from soil storage. Water use efficiency (WUE) varied from 0.715 kg m^{-3} to 1.025 kg m^{-3} among treatments. The highest WUE was obtained as 1.025 from C4 (gravimetric-for IL-00) treatments and the lowest WUE was observed 0.898 kg m^{-3} from C1 (gravimetric for IL-100) treatments. Treatment IL-33% from all applications (C3 and D3) used to water more efficiently. Thus, when water was restricted under these conditions, a reduction of 26.3% and 28.1% were seen in seed cotton yield. Table 4 shows a comparison of the WUE and IWUE values obtained from our study and the water efficiency values reported by other researchers. The table shows that both WUE and IWUE values were similar to the findings of other researchers.

Table 4: The comparison of WUE and IWUE values for different research

Sources	Irrigation system	WUE (kg m^{-3})	IWUE (kg m^{-3})
Our research	Drip	0.71-1.02	0.78-2.22
[7]	Drip	0.58-0.62	0.75-0.94
[6]	Drip	0.50-0.74	0.60-0.81
[6]	Lepa	0.55-0.67	0.58-0.77
[9]	Drip	0.80-1.30	-
[10]	Drip	0.63-0.88	0.82-1.12
[12]	Drip	0.77-0.96	0.82-1.44
[11]	Drip	0.62-0.85	0.66-1.57
[27]	Drip	0.83-1.26	1.05-1.96
[25]	Drip	0.73-1.13	0.91-2.23
[14]	Drip	0.74-1.12	0.97-2.50

Conclusion

Our results significantly demonstrated that the effects of the amount of the irrigation water and seed-coated applications as well as water use are the prime factors in obtaining higher seed cotton yields of cotton under Aegean semi-arid climatic conditions. Irrigation levels (IL) had significant effects on the yield of cotton at a P<0.01 level. The highest seed cotton yield was obtained from IL-100 treatment as averaging 5029. kg ha^{-1}, followed by IL-67 treatment as averaging 4086.1 kg ha^{-1}. Irrigation application techniques had no significant effect on seed cotton yield. Moreover, gravimetric applications with IL-100 treatment (C1) performed higher yields than pan evaporation (D1) application. The results indicated that the WUE and IWUE values decreased with the increasing irrigation interval. The higher WUE and IWUE were obtained at the lowest irrigation level of each seed applications. However, the lowest irrigation levels resulted in lower seed cotton yields in all applications. Thus, the use of low irrigation levels for drip irrigated cotton production in the region is not recommended. Significant relationships between seed yield and the seasonal water use were found for each applications in this study. Overall, the results of this research indicated that gravimetric applications, with IL-100 treatment could be used for cotton grown in Aegean region similar to the area in Turkey under no water shortage. On the other hand, results obtained from the gravimetric applications, with IL-67 treatment could be used as a good basis for reduced drip irrigation strategy development in semi-arid regions under water shortage. Under these conditions, when the amount of applied water through drip irrigation was reduced 33% (IL-67) the decrease in seed cotton yield was about 18.7% in growing season.

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