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Original Research

Improving Cotton Yield, Water Use and Net Income in Different Drip Irrigation Systems Using Real-Time Crop Evapotranspiration

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Abstract

The purpose of this study was to improve irrigation water use and cotton yield using real-time crop evepotranspiration based on the FAO-56 Penman-Monteith and canopy cover using surface drip and subsurface drip irrigation. The experiments were conducted Southeast Anatolia Region of Turkey, during 2016 and 2017. The experimental design was split-plots in randomized blocks using three replications. The main plots were surface drip irrigation (SDI), subsurface drip irrigation (SSDI-30 cm) and SSDI-40 cm. Sub-plots were three different irrigation levels based on real crop evapotranspiration (ETc), 0.75×ETc, 1.00×ETc and 1.25× ETc. There were significant differences (657 kg ha^{-1}) between the seed cotton yield of SDI (3667 kg ha^{-1}) and SSDI with a 40-cm lateral depth (4323 kg ha^{-1}). Irrigation water and crop consumptive water use were 552 and 589 mm for the SSDI-40 cm recommended treatment, respectively. According to the projection using the results for cotton cultivation area in the study region, SDI and SSDI could save water about 37 and 42% compared to furrow irrigation, respectively. Net income based on unit area in SDI and SSDI was higher 20 and 69% than it in furrow irrigation, respectively. Irrigation scheduling based on real crop evapotranspiration (1.0×ETc) was more appropriate for water saving and increasing water productivity (0.84 kg m^{-3}). The use of drip irrigation systems (especially SSDI) is significantly important to improve cotton yield, water use and economic contribution considering possible water shortage, decreasing water resources, farmers conditions, irrigation schemes, regional and national incomes.

Keywords: canopy cover, cotton, FAO-56 Penman-Monteith, subsurface drip, surface drip

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Introduction

Agriculture is most water-demanding, compared to other sectors [1]. However, irrigation efficiency, in general, is far less than desired due to the use of inappropriate methods, mismanagement, and farmer customs for surface irrigation in the study region. Surface irrigation methods are still most widely used for irrigating cotton in Turkey [2].

In the previous study, cotton has been shown requiring ≥1000 mm (10000 $m^3 ha^{-1}$) water with surface irrigation methods in the study area [3]. In addition, the study region has been producing about 50% of the total seed cotton production in Turkey [4]. Thus, cotton is the main and most important crop and consumes a large amount of water with surface irrigation. Irrigation water productivity is low for surface irrigation in the study area for the cotton. Hence, the use of surface drip irrigation (SDI) [3, 5, 6] and/or subsurface drip irrigation (SSDI) plays a key role in saving water and increasing water productivity [7-9].

The use of drip irrigation systems in the world has immensely increased due to the developing plastic industry. The advantages of the drip irrigation systems, in general, include higher water and nutrient use efficiency, increased crop yield and quality, and water saving [5, 6, 10, 11]. Thus, drip irrigation systems have been widely used in arid and semi-arid regions in recent years in terms of both irrigation water and labor savings [12].

A decreased amount of irrigation water using drip irrigation could be possible because the whole surface area of the field is not irrigated [13]. This event specifically develops at the beginning of the growing season, which is when the canopy cover is not completely developed and evaporation from the soil surface could be decreased. Thus, drip irrigation methods save considerable water compared to surface irrigations. One of the most favorable ways of decreasing evaporation from the soil surface is to use SSDI [8, 14, 15].

Çetin & Bilgel [3] have shown that seed cotton yield increased by 21% for SDI compared to furrow irrigation and that SDI also saved 33% more amount of irrigation water compared to surface irrigation (furrow) in the study region. Thus, the significant amount of irrigation water, about 33% of 1000 mm, could be conserved each year by implementing proper irrigation techniques and scheduling for cotton irrigation. In addition, there have been several studies regarding the effect of SDI on cotton in Turkey, and the researchers have shown an increase in seed cotton yield and water saving using SDI [3, 5, 16]. Some researchers have shown that the use of SSDI for cotton has increased dramatically, especially in areas with water shortages [7, 17-19].

The highest seed cotton yield using SSDI in the different region of Turkey was obtained with a multiple of 0.90 of evaporation from the Class A Pan. However, the use of a lateral depth of 30 cm for SSDI has posed soil plough problems [20]. Although considerable studies have been carried out on surface drip and/or subsurface drip irrigation regarding irrigation water saving and increasing yield in recent years [5, 6, 15, 21 22], there have been no appropriate studies on the use of SSDI based on real-time water consumption by crop on cotton in the study region.

On the other hand, there were no major differences in crop evapotranspiration among the irrigation methods/systems. However, the wetted soil surface and the frequent or higher intervals of irrigation affect the evaporation; thus, these circumstances could be decreasing or increasing the effects of evapotranspiration [14]. Kamilov et al. [23] compared the use of furrow irrigation and SSDI on the cotton yield, and SSDI provided an added yield of 21%.

The accurate estimation of ETc is crucial for irrigation scheduling and efficient water management. Thus, different methods and measurements has been used to estimate ETc and water-saving potential and to develop irrigation scheduling for optimal crop production [22]. New approaches and strategies on efficient water use without decreasing yield should be forward.

There were, thus, many earlier studies on irrigation scheduling studies based on soil moisture deficit, class A pan and/or critical stages of the crop for cotton. The main purpose of this study is to improve water use efficiency and to save more irrigation water in cotton irrigation using real-time crop evapotranspiration based on the FAO-56 Penman-Monteith (FAO-56 PM).

Material and Methods

Study Area

Field trials were conducted in the Experimental Station of Dicle University, Agricultural Faculty in Diyarbakır, Turkey, during the 2016 and 2017 growing season. The study area is located at the Research Station of Faculty of Agriculture in Dicle University, Diyarbakır, Turkey (37°54'11"N; 40°13′48"E). The soils of the experimental site had flat sloppy and ABC profiles with a heavy texture (Clay content is about 65%). The soil texture, pH, organic matter and electrical conductivity (EC) were clay, 7.7, 1.7% and 0.48 $dS m^{-1}$, respectively. The soils contained higher lime (11%) and potassium (561 ppm K); however, had lower organic matter and phosphorus (8 ppm P). There was no salinity or alkalinity, and there were no drainage problems.

The climate is continental and the study area receives approximately 480 mm yr^{1} of precipitation. However, the amount of precipitation was quite low as well as 46.5 mm for the growing season (about 180 days) of cotton. The annual average, minimum and maximum, temperatures during the growing season for the study area were 13.8, 0.9 and 42.3ºC, respectively [24].

Field Trials and Treatments

Split plots design was used in randomized blocks with three replications in this study, including three drip irrigation systems in the main plots (I_1: SDI; I_2: SSDI (30 cm); and I_3: SSDI (40 cm)) and three ET_c levels (K_1: 1.25 × ET_c, K_2: 1.0 x ET_c and K_3 = 0.75 × ET_c) for different irrigation water levels. The treatments in the experiment are provided in Table 1.

The area of one of the plots in the field experiment was 33.60 m^2 (4.20 m x 8.00 m). Each one lateral line served for two cotton rows, thus the spacing of two laterals was 1.40 m considering cotton row of 70 cm.

A 16-mm diameter polyethylene (PE) pipe (lateral pipe) with in-line drippers at each 0.40 m, the average discharge of pressure compensated drippers was 2.2 L h^{-1} at the 0.1 MPa because of the soil conditions.

Estimation of Crop Evapotranspiration and Irrigation Scheduling

For the estimation of crop evapotranspiration based on the FAO-56 PM method, the required climatological data were used from the automatic climatological station near the experimental site. Irrigation scheduling was performed at a frequency of 5 days [25] based on ET_c levels. The crop coefficient (K_c) approach was used for the crop ET_c, and the equation given below (1) was used to calculate crop ET_c [13].

$$ET_c = K_c \times ET_o \quad (1)$$

...where ET_c is the estimation of crop evapotranspiration based on FAO-56 PM (mm d^{-1}), K_c is the crop coefficient for cotton and ET_o is the reference crop evapotranspiration (mm d^{-1}).

The daily reference ET_o was calculated in a spreadsheet program using the FAO-56 PM method. K_c values concerning the crop development stages (initial stage, crop development stage, boll development stage (mid-season), and maturity stage (last season) of cotton in the study area were derived/computed from the publication of FAO-56 [13] considering using the long-term climatological data in the study area (last 30 years) [26]. Thus, the K_c values were considered to be 0.33, 0.33-1.27, 1.27, and 1.27-0.68 for the initial (0-30 days after sowing (DAS)) development stage (31-80 DAS), boll development (81-131 DAS), and maturity stage (131 DAS<) for cotton, respectively (Fig. 1).

The volume of water was calculated [3] as the following:

$$I = A \times ET_c \times K \times P_c \quad (2)$$

...where I is the amount of irrigation water applied to the experimental plot (liters, L), A is the plot area (m^2), ET_c is the estimated crop evapotranspiration (mm), K is

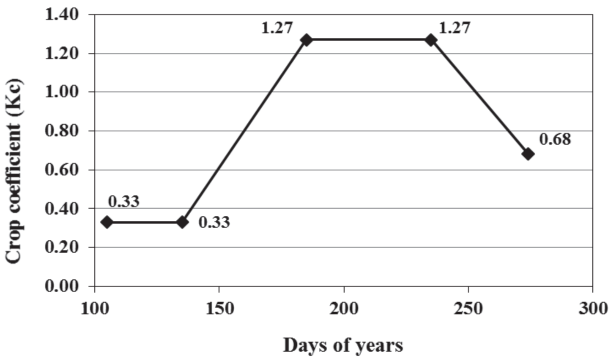

Fig. 1. Crop coefficient (Kc) used in the calculation of irrigation water according to the FAO-56 PM in the study area for cotton [26].

the different rates of ET_c according to the treatments, and P_c is the canopy cover (%). Canopy cover was used to calculate the amount of water applied in this study in case the whole soil surface should not be irrigated/ wetted depending on the development of canopy cover. This was considerably important at the beginning of the growing season [3].

The percentage of crop canopy cover was computed before each irrigation cycle by measuring using a simple wooden device (70 cm × 100 cm) divided into 100 equal sections. The crop canopy coverage, thus, calculated by measuring the average crop width in a row and dividing that value by the crop bed width (row space). Thus, the development of plant canopy as numerical value was calculated by dividing canopy wide to plant row space [27]. The crop canopy cover values, P, of 35% were used until the value exceeded 35%. When the Pc exceeded 35%, the actual measured values were taken into account for each treatment and the other irrigation cycles [3].

The first irrigation was performed to bring to the field capacity a level of soil depth of 60 cm for all the treatments/plots; thus, the same amount of water was applied to all the plots. Then, the treatments (different amounts of irrigation water) based on FAO-56 PM were applied considering an irrigation interval of 5 days. Irrigation continued according to treatments until the beginning of September when approximately 10% of bolls on the plants were fully open.

Measurement of the Soil Moisture and Actual Evapotranspiration

Soil moisture level was measured before and after each irrigation cycle using soil moisture sensors (Decagon, Procheck) for each treatment and considering soil depths of 30, 60 and 90 cm. In addition, the gravimetric method was used in order to check soil moisture sensors from time to time.

To determine the actual crop evapotranspiration in the field plots, the water balance equation was used considering a soil depth of 90 cm [13].

Table 1. Experimental treatments according to the split plots in randomized blocks.

Main plots (Different drip irrigation systems)	Sub-plots (Different amount of irrigation water)
I_1 : Surface drip irrigation	K_1: I = 1.25x ETc
I_2: Subsurface drip irrigation (depth of 30 cm)	K_2: I = 1.0xETc
I_3: Subsurface drip irrigation (depth of 40 cm)	K_3: I = 0.75xETc

$$P + I = ET_a + R + D + C \pm S \quad (3)$$

...where P is the precipitation (mm), I is the amount of irrigation water applied(mm), ET_a is the actual crop evapotranspiration (mm), R is the runoff (mm), D is deep percolation (mm), C is capillary rise (mm), and S is the soil moisture change (mm).

In this equation, the precipitation data was provided from an automatic climatic station near the study area. The precipitation occurred only at the beginning of growing season and there were no more than 10 mm for each precipitation event. There was some deep percolation in the treatment of 1.25xET_c in 2017. In addition, there was not runoff. The capillary rise was negligible because there was not any water table in the soil profile.

Agricultural Applications

Cotton seeds (*Gossypium hirsutum* cv. ST 468) were sown with a spacing of 20 cm × 70 cm on May 11 and 9, 2016 and 2017, respectively. All fertilizers were applied according to the previous studies' results in the study region [3]. The total amounts of nitrogen (N) and phosphorus (P) were 130 N kg ha^{-1} and 80 P_2O_5 kg ha^{-1}, respectively [28]. One-fifth of the N and P was applied to the experimental plots before cotton seed sowing [29]. Application of the rest of the fertilizers was applied by fertigation. Fertigation was implemented at the first irrigation and continued throughout the boll formation stage at each of the two irrigation cycles [25]. The fertilizer used at the fertigation application was a mix of N, P, and potassium at 19-5-5. Fertigation was applied using a fertilizer by-pass tank employing the pressure difference method [11, 25].

The seed cotton harvested by hand in the central four rows of each subplot two times during the cropping seasons: the first harvest was made at about 80% of the opened bolls, and the second harvest was made for the rest of opened bolls at the beginning of September and end of September, respectively. Thus, the size of the sowing area was 4.20 m × 8.00 m (33.60 m^2). The harvesting area is 15.6 m^2 (2.8 m × 6.00 m). The obtained yields from the harvesting area were converted to the unit land area (ha) for all the calculations and evaluations.

Statistical Evaluation and Analysis

The yield and other data were analyzed through the analysis of variance (ANOVA) using the SPSS software (Version 16.0.0). In the event that the results obtained from statistical analysis were statistically significant, a Duncan's multiple range test was applied to determine and to evaluate the differences among the means of treatments [30].

Results and Discussion

Seed Cotton Yields Under The Different Drip Irrigation Systems

Seed cotton yield obtained from each treatment according to the experimental years are given in Table 2. The yields obtained from the experiment ranged from 2520 to 5214 kg ha^{-1} depending on the experimental years and the treatments.

It was observed that during 2016, no statistical difference were found on yields for both drip irrigation systems and the interaction of drip irrigation systems together with different amounts of irrigation levels based on ET_c. However, SSDI in the lateral depth of 40 cm resulted in considerably more yield (Tables 2 and 3). Considering the different amount of irrigation levels based on ET_c, the seed cotton yields were significantly different ($p \leq 0.01$).

In 2017, there were significant differences between drip irrigation systems ($p \leq 0.05$) and the amount of irrigation water applied ($p \leq 0.01$) on seed cotton yield. No significant effect on the interaction was found between different amounts of irrigation water applied and different drip irrigation systems, as it occurred in 2016.

Seed cotton yields, based on both the amount of irrigation water and drip irrigation systems, are provided separately in Table 3 because there was no significant interaction between the treatments. In each of the two experimental years, the seed cotton yields increased as long as there was an increase in the amount of irrigation water, regardless of the type of drip irrigation systems. However, SSDI, especially in the depth of 40 cm, resulted in the highest yield considering all the experimental years.

The main reasons for increasing the seed cotton yield by means of increasing irrigation water for all the drip irrigation systems in this study could be that the plants in hot and dry areas use more water to both cool off and produce more biomass [19]. Increasing irrigation water for all the drip irrigation systems were the increase in the number of good opened bolls and

Table 2. Seed cotton yield (kg ha^{-1}) and amount of irrigation water applied (mm) according to the experimental years and the treatments.

Main plots	Subplots	Seed-cotton yield (kg ha^{-1}) Years 2016	Seed-cotton yield (kg ha^{-1}) Years 2017	Average yield (kg ha^{-1})	Amount of irrigation water applied (mm) Years 2016	Amount of irrigation water applied (mm) Years 2017	Average irrigation water (mm)	WP_{Irr} (kg m^{-3})
I_1	K_1	4139	4624	4382	606.2	675.9	641.1	0.68
	K_2	4191	3972	4082	458.1	517.6	487.9	0.84
	K_3	2558	2520	2539	310.2	303.1	306.7	0.83
I_2	K_1	4286	5214	4750	604.6	676	640.3	0.74
	K_2	3862	4197	4030	540.2	522.6	531.4	0.76
	K_3	2741	3016	2879	337.8	364.1	351.0	0.82
I_3	K_1	4332	5184	4758	661.5	685.8	673.7	0.71
	K_2	4268	4687	4478	543.9	558.7	551.3	0.81
	K_3	3819	3646	3733	363.2	375.6	369.4	1.01

Coefficient of variation (CV): 12.5% in 2016 and 11.1% in 2017

the total number of bolls produced per plant [3, 9, 31]. Concerning the highest seed cotton yield provided by SSDI, the evaporation from the soil is decreased by decreasing top soil moisture content because the drip laterals are under the soil surface [14, 19, 32]. Thus, the loss of irrigation water due to evaporation was insignificant and the plants used more water and it provided increasing seed cotton yield. The volume of wetted soil in SSDI might be, thus, bigger (spherical) than in SDI (hemi-spherical). The available water and soil volume for crop root development could be also bigger, whereas the wetted radius was smaller in SDI than in SSDI [14] and (Fig. 2).

The scheduling of irrigation at 1.25×ET_c with a 40-cm SSDI recorded a significantly higher seed cotton yield in both 2016 and 2017 (Table 2). Azevedo et al. [33] reported that irrigation with 120% of that crop evapotranspiration under sprinkler irrigation produced the maximum seed cotton yield. Moreover, Shruti and Aladakatti [34] determined a significantly higher seed-cotton yield (4024 kg ha^{-1}) in drip irrigation at 1.0 × ET_c. The SSDI, regardless of the amount of irrigation water, resulted in an increase of 18% and 11% over SSDI-30 cm and SDI, respectively (Fig. 3). Kalfountzos et al. [7] and Roopashree et al. [9] also found similar results.

The reason that the maximum yield was obtained in the SSDI system (40 cm) might be attributed to the controlled and/or preferable quantity of water applied directly to the root zone in quantities, which move toward the use of plant consumption by means of SSDI. In addition, a higher irrigation coefficient (K_1 and K_2) caused more amount of irrigation water applied and this increased also canopy cover. Thus, the yield was obtained much more higher depending on increasing canopy cover (Fig. 4). However, the evaporation losses from the soil surface on the SDI were much more than SSDI [8, 19, 22]. Thus, the use of SSDI on cotton increased dramatically, especially in areas with water shortages [7, 15, 17, 18, 22]. In addition, the main reason of that the installation depth of emitter and lateral line for 0.40 m was more appropriate could be that cotton plant roots would grow through relatively dry soil to find moisture in the soil at deeper soil depths.

Table 3. The separately effects of the different drip irrigation systems and different amount of irrigation water on seed-cotton yield (kg ha^{-1}).

Drip irrigation systems	2016	2017	Ave.	Relative yield level (%)	Irr. levels	2016	2017	Ave.	Relative yield (%)
I_1	3629 b*	3705 b	3667 b	84.8	K_1	4252 a	5007 a	4630	100
I_2	3630 b	4142 ab	3886 ab	89.8	K_2	4107 a	4285 b	4196	90.6
I_3	4140 a	4506 a	4323a	100	K_3	3039 b	3061 c	3050	65.8

I_1: Surface drip irrigation (SDI), I_2: Subsurface drip irrigation (SSDI-30 cm), I_3: Subsurface drip irrigation (SSDI-40 cm), K_1: 1.25xETc, K_2: 1.00xETc. K_3: 0.75xETc

*: The same letter groups are not the statistically significant according to the Duncan's multiple comparison test.

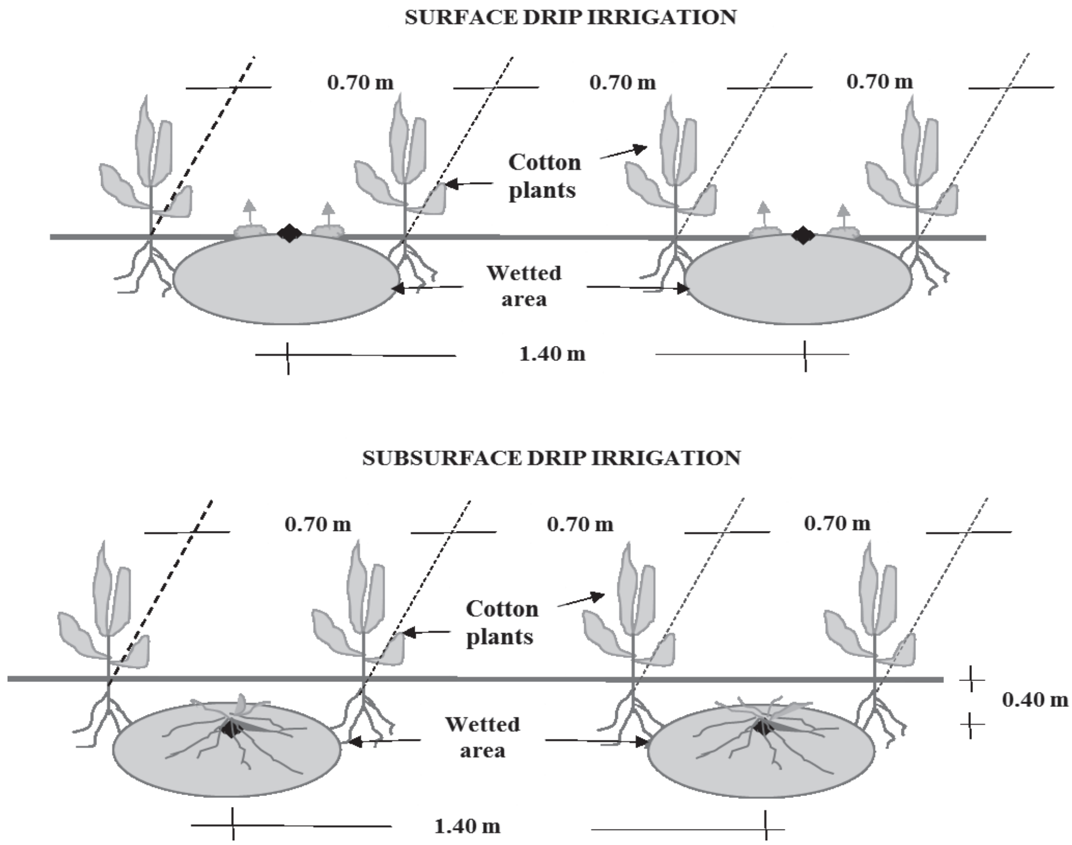

Fig. 2. Shematic layout of laterals and drippers in surface and subsurface drip irrigation and soil moisture distribution depending on drip lateral spaces and depth of subsurface drip irrigation.

This system was, thus, more effective in meeting the maximum evapotranspiration demands of cotton and in pushing salt to the edge of the bed.

Irrigation Water Use and Crop Evapotranspiration

The amounts of irrigation water applied according to the treatments in the experiment varied from 310.2 mm to 661.5 mm in 2016 and from 303.1 mm to 685.8 mm in 2017 (Table 2). The number of irrigation in 2016 was 17 and/or 18 based on the irrigation intervals of 5 days, and depending on the treatments. Considering the calculation of the amount of irrigation water for each treatment and its components, the amount of irrigation water applied was different as dependent on the coefficients of Etc, the development of canopy cover, and the physiological maturity date of crops.

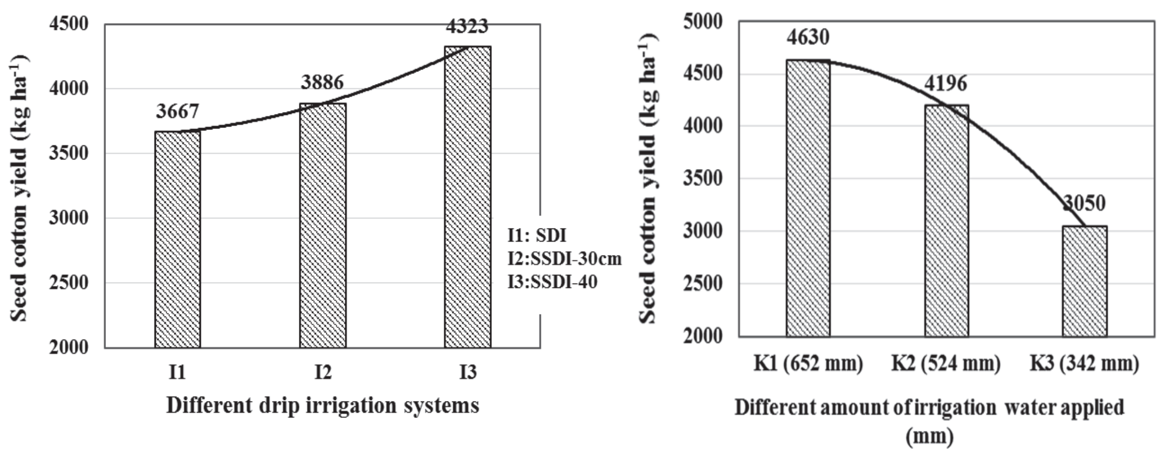

Fig. 3. The effects of the different drip irrigation systems and different amount of irrigation water on seed- cotton yield. (SDI: Surface drip irrigation, SSDI: Sub-surface drip irrigation).

In general, SSDI-40 cm received relatively more irrigation water because the development of canopy cover in SSDI-40 cm was rapid compared to the other treatments, and the calculation of irrigation water was also dependent on the canopy cover (Equation 2). Because the plant canopy factor used for all treatments was the percentage area covered by plant canopy (foliage). The canopy cover gradually expanded and in the following days or crop development stages, canopy cover rapidly increased [27]. The higher irrigation coefficient (K_1 and K_2) resulted in more amount of irrigation water and this increased canopy cover.

On the other hand, according to the previous studies, the number of bolls and cotton production decreased as long as the irrigation water decreased (stress conditions) [3, 5, 35]. Thus, it was also reported that seed cotton yield were positively affected by increased irrigation amounts. Deficit irrigation resulted in 27-29% in biomass, 16-28 % in seed yield depending on different cotton varieties [31].

Considering the average seed-cotton yields, there was a linear relationships between seed-cotton yield and irrigation water for SDI: $y = 987 + 5.6\ x$, $R^2 = 0.90^{**}$, $P \leq 0.01$; for SSDI-30 cm: $y = 608.8 + 6.45\ x$, $R^2 = 0.99^{**}$, $P \leq 0.01$; and for SSDI-40 cm: $y = 2502.8 + 3.42\ x$, $R^2 = 0.98^{**}$, $P \leq 0.01$. Where y is seed cotton yield (kg ha^{-1} and x is amount of irrigation water (mm).

The reference evapotranspiration (ET_o) according to the experimental years for the growing season of cotton was computed as 627.7 mm and 622.5 mm in 2016 and 2017, respectively. The values of ET_o in the experimental years were quite close to each other. The actual measured ET_a was calculated using the water budget equation (Equation 3). The actual ET_a ranged from 349.4 to 697.1 mm in 2017 and from 312.6 to 701.1 mm in 2017 depending on the treatments, respectively. The most important input for the determination of the actual ET_a was the amount of irrigation water applied because there was no significant precipitation during the growing season. However, the precipitation of 44.8 and 19.4 mm occurred at the beginning of the growing season in 2016 and 2017, respectively. In another study, the average ETc during the growing season for drip irrigated cotton was 526 mm in Northwestern China. Thus, the fluctuation in daily crop evapotranspiration was attributed to variation in cotton leaves [36]. Evett *et al.* [37] compared the SDI and SSDI systems for the corn crop, and the insignificant differences occurred on the soil heat flux between SDI and SSDI. The net radiation on the SDI increased as much as the leaf area index of 4.2 compared to that of the SSDI; however sensible heat was smaller. There were differences in ETa between SDI and SSDI for only during the partial development of the crop canopy. Thus, there was almost no difference in ETa under the canopy cover were 100%. In this study, the crop ETa on SDI was lower than that on SSDI because crop development and canopy cover in SSDI were much more than those in SDI.

The amount of irrigation water applied increased as long as increasing rates of estimated crop ET_c based on FAO-56 PM. Thus, the actual ET_c increased even if SSDI systems were used. The main reason for the increases in the evapotranspiration could be attributed to the climatic conditions during the experiment in the study area because the maximum temperatures (40.5°C) and wind speed (4.4 m $sec.^{-1}$) were significantly high and the average relative humidity (20.7%) in summer was quite low [24]. In particular, the evaporation from the soil surface was much higher at the stage of the crop canopy, which had not covered the entire soil surface, as well as the stage of vegetative development [Fig. 4]. It might be stated that this could restrict the utilization of crop root per unit water.

Regarding water use, the horizontal movement of water in the SDI was more than that in the SSDI because the irrigation water in SDI was applied directly to the soil surface and the soil texture was heavy clay (clay content is about 65%). In particular, the wetted area in the period between sowing and before the canopy cover of 100% could be exposed to the sun radiation in SDI; thus, this circumstance could increase evaporation from the soil (Fig. 4). Hence, the efficient use of water could be decreased by crops in SDI [38]. On the other hand, it was reported that the evaporation loss from the soil could be decreased by using SSDI [8, 15, 23].

Another finding in this study was that irrigation water productivity (IWP) increased as long as a decreased amount of irrigation water was applied (Table 2). Similar results were found by Keten [39]. This might be attributed to a much higher response of the crop to the water since the study area has a very high temperature and a very low relative humidity during the growing season.

Considering the drip irrigation systems, IWP for SDI, SSDI-30 cm, and SSDI-40 were 0.78, 0.77, and 0.84 kg m^{-3}, respectively. Thus, the highest IWP was obtained from the treatment of SSDI-40 cm (Table 2). Similarly, various studies on IWP showed that SSDI resulted in the highest IWP for cotton [6, 8, 40].

Regarding the actual measured crop evapotranspiration, evaporation from the soil is especially dependent on the content of water on the soil surface and the rate of canopy cover [41]. Thus, canopy cover is significantly important for crop evapotranspiration and calculating the amount of irrigation water applied for the drip irrigation methods. For this, evaporation from the soil decreases as long as the canopy cover of the crop and/or vegetative development increases (Fig. 4).

Evaporation from the soil after the irrigation event is high; however, it quickly decreases as long as the soil surface dries after the first wetted period of the soil (Fig. 4). Thus, crop evapotranspiration, under the condition wherein part of the soil surface is covered by plant canopy, is lower than under the condition wherein the whole soil surface is covered by plant canopy [13,

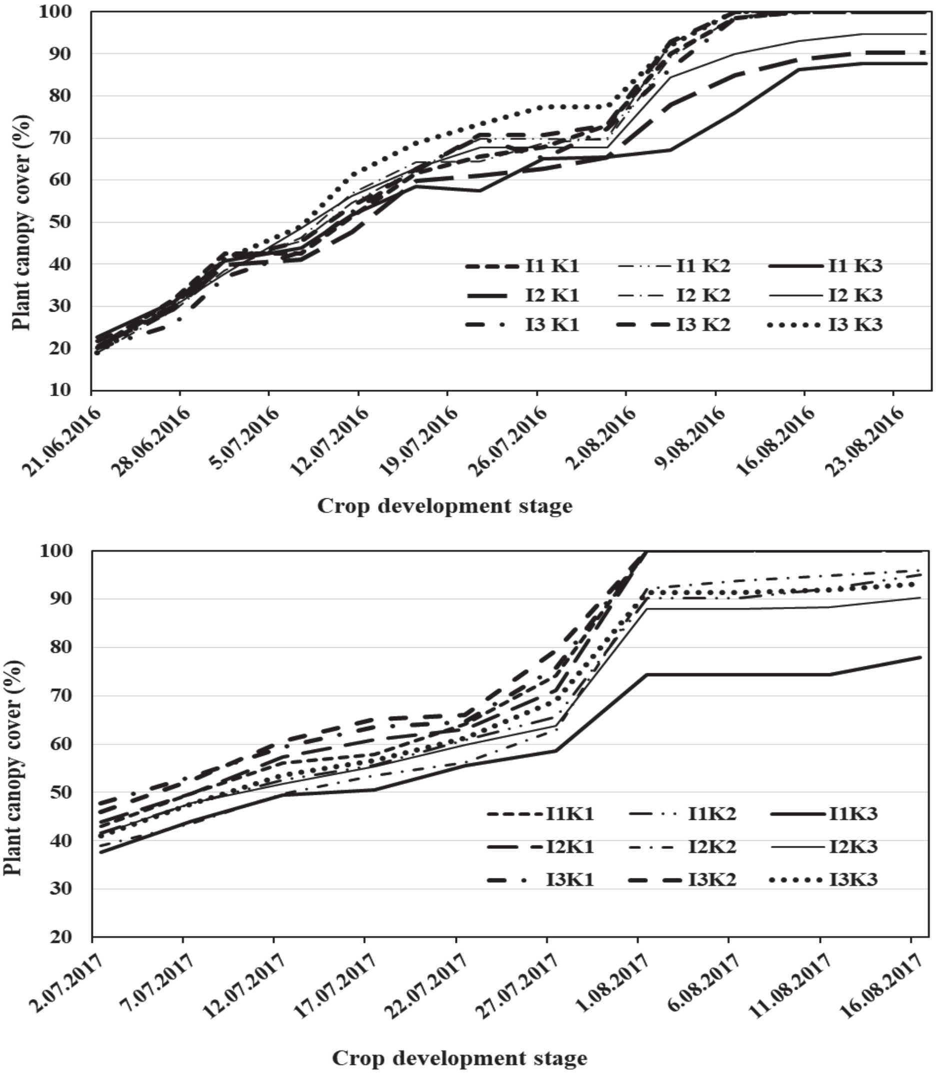

Fig. 4. Development of canopy cover as percentage according to the treatments (surface and subsurface drip irrigation, and different amount of irrigation water) and experimental years. (I_1: Surface drip irrigation (SDI), I_2: Subsurface drip irrigation (SSDI-30 cm), I_3: Subsurface drip irrigation (SSDI-40 cm), K_1: 1.25xETc, K_2: 1.00xETc. K_3: 0.75xETc.

14, 42]. However, crop evapotranspiration could be decreased by surface and subsurface drip irrigation against surface irrigation (border and furrow) was mainly due to the significant reduction in evaporation [43]

Total Water Use and Net Income For Cultivated Cotton Region

In this part of the article, some projections on total water use, water productivity and economic incomes was made using the regression equations obtained from the research results for the cultivated cotton area. For furrow irrigation, the results of the previous research [3] in the same study region was based on for the calculations. Accordingly, the sub-surface drip irrigation in the depth of 40 cm instead of it in the depth of 30 cm was preferred because of tillage problems and some damage risk in the dripper lines in 30 cm.

The calculations given in Table 4 were realized based on the following equations, furrow irrigation: $y = -431.1+6.1x - 0.0021x^2$ [3], SDI: $y = 987 + 5.6x$ and SSDI-40 cm: $y = 2502.8 + 3.42x$. The amount of irrigation water was computed using the regression equations for the almost same seed cotton yield obtained by drip irrigation methods and the optimum yield in furrow irrigation. Accordingly the other estimated calculations and comparison were realized.

According to the evaluations given in Table 4, surface and sub-surface drip irrigation saved about 37 and 42% compared to furrow irrigation, respectively. Sub-surface drip irrigation saved also water of 9% compared to surface drip irrigation. This difference is very important and quite high compared to furrow irrigation. Some previous studies have been also reported that drip irrigation have already provided significant water savings compared to surface irrigation [3, 8, 44, 45]. In addition, Rao et al. [46] reported similar result in our

Table 4. Total water use and total net incomes based on total cotton cultivated area and water economic productivity according to the projection using irrigation water-yield relatioships in the study.

Irrigation systems	Irr. water (m^3 ha^{-1})	Cotton cultivated area* (ha)	Seed-cotton yield (kg ha^{-1})	Total production (mill. Tonnes)	Irr. water used (bill. m^3)	Irr. water productivity (kg m^{-3})	Water economic productivity (WEP) ($ m^{-3})	Net incomes per land area ($ ha^{-1})	Total net income based on land (mill. $)	Total net income based on WEP (mill. $)
	1	2	3	4 (2x3)	5 (1x2)	6 (3/1)	7 (8/1)	8	9 (2x8)	10 (5x7)
Furrow**	9500	293000	3469	1.016	2.78	0.37	0.07	652	191	195
Surface drip (30 cm)	6000	293000	4347	1.273	1.76	0.72	0.13	781	229	229
Subsurface drip (40 cm)	5500	293000	4383	1.284	1.61	0.80	0.20	1105	324	322

*: Total cotton cultivated area in the study region [4].
**: The data are obtained and adapted from the Cetin and Bilgel [3]. This study was carried out in the same study region.

study that drip irrigation significantly increased seed cotton yield by 33.5% and saved 30% irrigation water compared to furrow irrigation at 1.0 x ETc for cotton. In another study, drip irrigation provided more yield of 24% in seed cotton yield at 100% ETc compared to furrow irrigation. [47]. Net income based on unit area in surface and subsurface irrigation was higher 20 and 69% than it in furrow irrigation, respectively (Table 4). Therefore, this result is also valid for the total income in the study region. Irrigation water productivity in furrow irrigation was very low compared to surface and subsurface drip irrigation. The main reason for this was to use much more irrigation water in furrow irrigation and lower yield was obtained. Considering the total income based on the water economic productivity in furrow irrigation was higher than it in the surface drip. Although this seems to be inconsistent with other previous calculation results, this occurred due to the use of more irrigation water in furrow irrigation.

The results of this study will be important for irrigation management, irrigation water saving, water productivity (kg m^{-3}), water economic productivity ($ m^{-3}) and net income per unit area ($ ha^{-1}) in case of use of different irrigation methods and/or systems. Thus, these comparisons will be useful in terms of policy making on irrigation management for decision makers [48, 49]. Probably, it will not be possible to irrigate all cotton cultivated areas using drip irrigation systems. However, these data based on these scientific results can be considered alternatively in case of drought and water insufficiency and all these can be also used to compensate and/or support the famers in case of the income and production losses.

As a result, it has been determined that the use of drip irrigation systems (especially subsurface drip) is significantly important considering possible water shortage, decreasing water resources, farmers, irrigation schemes, regional and national incomes. However, it should not be paid insufficient attention on the necessary engineering approaches for the irrigation systems, appropriate irrigation management and operation taking into account the soil, crop and climate characteristics in the irrigated area. In this case, all advantages of drip irrigation systems can be realized.

Conclusions

It was concluded that the SSDI method at $1.0 \times ET_c$ was proven to be optimum and resulted in recording higher seed-cotton yield and water saving in comparison to the SDI method. SSDI resulted in much more seed cotton yield compared to SDI in every case. Thus, there were statistically significant ($p \leq 0.01$) seed cotton yield differences, as much as 18% (657 kg ha^{-1}), between SSDI (the lateral depth of 40 cm, which is recommendable) (4323 kg ha^{-1}) and SDI (3667 kg ha^{-1}). The seasonal actual evapotranspiration and amount of irrigation water in SSDI were 589 and

552 mm, respectively. According to the projections and comparing the previous study in the same study region [3], surface and sub-surface drip irrigation saved about 37 and 42% compared to furrow irrigation, respectively. However, net income based on unit area in surface and subsurface irrigation was higher 20 and 69% than it in furrow irrigation, respectively. The use of 30 cm at the lateral depth for SSDI has created some soil plough problems in terms of damaging the system; thus, this lateral depth should not be used for SSDI construction for cotton irrigation. Irrigation scheduling based on real crop evapotranspiration was more appropriate for water saving and increasing water productivity.

The use of drip irrigation systems (especially subsurface drip) is significantly important considering possible water shortage, decreasing water resources, farmers, irrigation schemes, regional and national incomes.

On the other hand, the wetted percentage area and/or canopy cover is one of the most important criteria in irrigation water calculation for drip irrigation systems. It could be recommended to be as much as 40% at the beginning of the irrigation season for arid regions, as in the study area, which had very low relative humidity (10-15%) and very high temperatures (up to 45^{o}C). In addition, the percentage of canopy cover used to calculate the amount of water applied should be set from the first irrigation until the canopy cover exceeds 40%, after which it should be set to the measured value until the last irrigation. However, the value of the canopy cover used to calculate the amount of water applied might be considered to be 80% (0.80) during the maturity stage, that is, from the opening stage of the first bolls to the last irrigation (approximately 2-3 weeks).

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Conflict of Interest

The authors declare no conflict of interest.

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