Determination of Irrigation Scheduling of Drip Irrigated Tomato Using Pan-Evaporation in Harran Plain

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Abstract: This study was conducted to determine the amount of irrigation water and two irrigation intervals on the yield and growth of tomato irrigated by drip method. The amount of irrigation water applied was based on cumulative evaporation from a screened class-A pan. The irrigation treatments consisted of two different irrigation intervals (I_1 = 4 and I_2 = 8 days), and three pan coefficients (kcp_1= 1.00, kcp_2 = 0.80, kcp_3 = 0.60). The seasonal irrigation water varied from 465 to 920 mm; the seasonal ET ranged from 495 to 1150 mm; and yield of tomato varied from 53.1 to 112.5 ton ha^{-1} based on treatments used. According to the results, it was concluded that tomato could be irrigated at 4-day irrigation intervals and the irrigation water amount might be computed by 0.80 of class-A-pan cumulative evaporation. A significant reduction in growth parameters (plant height, canopy diameter and stem diameter), dry biomass and leaf relative water content (LRWC) was observed based on reductions in water use and irrigation water applications.
Keywords: Tomato, Drip irrigation, Yield, Class-A pan evaporation, Irrigation interval

Harran Ovası Koşullarında Buharlaşma Kabından Faydalanılarak Damla Sulama Sistemiyle Sulanan Domates Bitkisinde Sulama Programının Belirlenmesi

Özet: Bu çalışma, damla sulama sistemiyle sulanan domates bitkisinde iki farklı sulama aralığı ve sulama suyu miktarının verim ve gelişim faktörlerine etkisini belirlemek amacıyla yürütülmüştür. Sulama suyu miktarının belirlenmesinde buharlaşma kabı kullanılmıştır. Çalışmada iki sulama aralığı (I_1=4 ve I_2= 8 gün) ve açık su yüzeyi buharlaşmasına dayandırılan üç su düzeyi (kcp_1 = 1.00, kcp_2 = 0.80 ve kcp_3 = 0.60) uygulanmıştır. Konulara ilşkin ortalama mevsimlik sulama suyu, bitki su tüketimi ve verim sırasıyla 465-920 mm, 495-1150 mm ve 53.1-112.5 ton ha^{-1} değerleri arasında değişmiştir. Araştırma sonuçları, Harran ovası koşullarında domates bitkisinin 4 gün aralıklarla ve buharlaşma kabı katasyısının 0.80'i alınarak sulanabilineceğini göstermiştir. Konulara verilen sulama suyu ve bitki su tüketimine bağlı olarak bitki büyüme parametrelerinde (bitki boyu, taç genişliği ve gövde çapı), kuru madde miktarı ve nisbi yaprak su içeriğinde önemli değişimler gözlenmiştir.
Anahtar kelimeler: Domates, damla sulama, verim, A sınıfı buharlaşma kabı, Sulama aralığı

1. Introduction

Water is one of the most important inputs essential for the tomato production in the Mediterranean Region. There has been an increasing interest for scheduling deficit irrigation in order to conserve water and maintain crop productivity in arid and semi-arid regions. Most farmers in Harran Plain use traditional surface irrigation methods; this often results in both waste of water and loss of nutrients.

Efficient use of irrigation water is becoming increasingly important in arid and semi-arid conditions with limited water resources. Furrow irrigation, which is one of the irrigation methods, is most widely used in Harran Plain and is characterized by low irrigation efficiencies and high labor costs. On the other hand, drip irrigation has greater irrigation water efficiency over other methods in arid and semi-arid regions characterized by high evaporation rates. It has also the potential to increase yields of crops even with reduced irrigation water applications (Dawood and Hamad, 1985; Yohannes and Tadesse, 1998).

When environmental factors are otherwise favourable, vegetable growth is often suppressed and yields reduced if supplemental water is inadequate or too infrequent during low rainfall months; vegetable crops therefore have critical periods of growth when irrigation is a necessity for optimal yield and quality (Nagel 1995; Hardeman et al., 1999). However, water is a limited and expensive commodity in many production areas. This is particularly important for the regions where farmers were applied the irrigation water by surface irrigation methods. Water shortages frequently occur at critical times. Therefore, vegetable producers need to be both more efficient in their use of irrigation and utilise other means to improve water use efficiency (Grimes et al., 1976).

Tan (1995) states that drip irrigation reduces evaporation and deep percolation, controls soil water content more precisely and eliminates the effects of wind. Two distinct features of drip irrigation are (1) high frequency of irrigation and (2) localized water application to only part of the crop's potential root zone. The studies in the USA showed that drip irrigation increased yield of tomato and water use efficiency by 19% to 20%, respectively as compared to furrow irrigation (Pruitt et al., 1989). Grimes et al. (1976) stated advantages of drip irrigated fresh marker tomatoes over furrow irrigated ones in terms of higher water use efficiency, fruit quality, and yield.

The objective of this study was to determine irrigation scheduling of drip irrigated tomato via class-A-pan in Harran Plain conditions and also to establish relationships among growth parameters, water applications and water use efficiencies.

2. Materials and Methods

2.1. Plant Culture and Treatments

This experiment was carried out on a clay loam soil during the growing seasons of 1999 and 2000, at a farm located 30 km SE of the city of Sanliurfa in Harran plain. The long term weather records for Şanlıurfa show that average air temperature, and annual precipitation are 19.6 °C and 350 mm, respectively. Average relative humidity is around 48% during the summer months. The observed average maximum and minimum temperatures during the experimental period were 40.2 °C and 16.6 °C, respectively. The average daily pan evaporation during the experiment was 14.8 mm. Readings for field capacity, permanent wilting point, dry bulk density, pH, and EC of the soil at the site for 0-90 cm soil depth were 33.75%, 21.40%, 1.14 g/cm^3, 7.15, and 1.17 dS/m respectively. The irrigation water quality used in the experiment was good (EC = 0.52 dS/m , and pH = 6.8). Irrigation water was provided from a deep well.

Fertilizer applications were based on soil analysis recommendations. All treatment received the same amounts of total N (150 kg ha^{-1}), P (100 kg ha^{-1}) and K (200 kg ha^{-1}) fertiliser. All of the P, K and 40% of the N fertiliser were applied prior to planting and thoroughly mixed into the soil. The remaining 60% of N was added at weekly intervals through the drip irrigation system starting three weeks after transplanting until one week before the first harvest.

2.2. Irrigation Treatments

Seeds of tomato (cv. Falcon) were germinated in fine sand in the last week of March in both years. After germination, at the first true leaf stage (20 days), seedlings were transplanted into a plastic tube containing a mixture of turf and soil. Similar sized seedlings were selected for each treatment. When the fifth true leaves appeared, similar sized seedlings were selected again and transplanted into the field. After transplanting, irrigation was applied without considering irrigation scheduling treatment for two weeks to promote root system establishment without water stress.

In this study, two different irrigation intervals (I_1 = 4 and I_2 = 8 days) and three different pan coefficients (Kcp_1 = 1.0, Kcp_2 = 0.80, Kcp_3 = 0.60) were tested. A randomised split-block design was used and data were analyzed using the Tarist computer program (Anonymous, 1995). Irrigation intervals were in the main plot while pan coefficients were in the sub-plots. Means were separated by Duncan's multiple range test ($P<0.05$).

The amount of irrigation water was calculated based on Kanber (1984). To do so, the following equation was used:

$$I = A * Epan * Kcp * P \qquad (1)$$

Where; I = amount of irrigation water (L), A = area (m^2), Epan = cumulative class-A-pan evaporation (mm), Kcp = plant-A pan coefficient, P = percentage of soil cover.

P was determined as a ratio of plant canopy width to inter-row spacing. Each plot had a separate flow meter to monitor water input. There were 6 rows in each plot. The observations and data collection were done from the central rows. Drip irrigated plots were separated by 2 m space to minimize water movement between treatments. For drip irrigation methods, plants were planted in rows with an inter-plant spacing of 0.60 m and an inter-row spacing of 0.80 m. The length of the drip tube was 10 m. The drip irrigation tubes with single lateral per row was placed on the soil surface. Spacing of the drippers with a constant discharge of 4.0 L/h at 100 kPa operating pressure for irrigation systems was 60 cm.

Plant measurements and observations were started one month after planting, and continued till the end of the final harvest. In order to determine total dry matter above the ground level, two plants in each plot were cut at the ground level at 30-day intervals till last harvest. Plant samples were dried at 70°C for 48 hours to obtain a constant weight. Measurements of plant height, canopy diameter, and stem diameter from ten randomly selected plants in each plot were also taken 30-day intervals till last harvest. Yield components determined were fruit weight and fruit size. Soluble solids concentration (SSC) in fruit samples were also determined using a hand reflectometer (Çevik et al., 1996).

Evapotranspiration (ET) was estimated according to the water balance approach (James, 1993). Hence, soil moisture content at a depth of 90 cm was determined gravimetrically:

$$ET = I + P - D_r - R_f \pm \Delta_s \qquad (2)$$

Where ET = evapotranspiration (mm), P = effective rainfall during the growth period (mm), I = irrigation water applied during the growth period (mm), D_r = amount of drainage water (mm), R_f = amount of runoff (mm), Δ_s = change in the soil moisture content determined by gravimetric sampling (mm).

Even though deep percolation and runoff could not measured, it is unlikely they were significant, since soil moisture was increased up to field capacity. Total water use efficiency (TWUE) was calculated as the ratio of tomato yield to water use. Irrigation water use efficiency (IWUE) was computed as the ratio of tomato yield to applied irrigation water.

In order to evaluate the effects of water stress on plant yield reduction through the relative ET (ET_a/ET_m), Doorenbos and Kassam (1988) expressed the crop yield response to water as:

$$\left(1-\frac{Y_a}{Y_m}\right)=k_y\left(1-\frac{ET_a}{ET_m}\right) \qquad (3)$$

Where Y_a = actual harvested yield, Y_m = maximum harvested yield, k_y = yield response factor, ET_a= actual evapotranspiration, ET_m = maximum evapotranspiration, $(1-Y_a/Y_m)$ = relative yield decrease, and $(1-ET_a/ET_m)$ = relative evapotranspiration deficit.

2.3. Leaf Relative Water Content

Leaf relative water content (LRWC) was calculated based on the methods from Yamasaki and Dillenburg (1999). The LRWC analysis was done periodically with 30 day intervals after planting till harvest. Four leaves of four randomly chosen plants per treatment were always collected from mid section of plant in order to minimize age effects; individual leaves were removed and weighed to obtain fresh mass (FM). To determine the turgid mass (TM), leaves were floated in distilled water inside a closed petri dish. During the imbibition period, leaf samples were weighed periodically, after gently wiping the water from the leaf surface with tissue paper. At the end of the imbibition period, leaf samples were placed in a pre-heated oven at 80°C for 48 h, in order to obtain dry mass (DM). All mass measurements were made using an analytical balance, with precision of 0.0001 g. The values of FM, TM and DM were used to calculate the LRWC using the equation:

$$LRWC (\%) = [(FM-DM)/(TM-DM)]*100 \qquad (4)$$

3. Results and Discussion

The drip-irrigated plots received irrigation water varying from a low of 465 mm in water-stressed plots (I_2Kcp_3) to a high of 920 mm in non-stressed plots (I_1Kcp_1). Seasonal water use (ET) of tomato varied from a low of 495 mm to a high of 1150 mm based on water stress levels. Balçın and Güleç (1999) reported that seasonal water use and irrigation application of tomato irrigated by surface irrigation were 659 and 487 mm, respectively, in Tokat region. Çevik et al. (1996) found that irrigation application of daily irrigated tomato by drip system was 875 mm in Harran plain conditions. Aliyu (1987) mentioned that seasonal ET and irrigation amount for furrow irrigated tomato in an arid region were 1278 mm and 1011 mm, respectively. The yield, amount of applied irrigation water, water use, TWUE, IWUE data are summarized in Table 1. Irrigation intervals (II), irrigation levels (Kcp) and interactions between II and Kcp were found significant at

$p<0.05$ level. The highest yield, averaging 112.5 ton ha^{-1}, was measured with 4- day irrigation intervals in I_1Kcp_1 treatment, followed by I_1Kcp_2 with 98.5 ton ha^{-1}. There was no significant difference in yield between the I_1Kcp_1 and I_1Kcp_2 in the growing season of 1999. The lowest yield was obtained from I_2Kcp_3 with 60.2 and 53.1 ton ha^{-1} for the years of 1999 and 2000, respectively. From the results it can be seen that as the amount of irrigation water decreased, tomato yields also decreased.

The highest IWUE and TWUE, averaging 0.157 and 0.125 ton ha^{-1} mm^{-1}, respectively, were obtained from I_1Kcp_3 treatment. In general, IWUE and TWUE decreased with increasing water applications and water use. Furthermore, the 4-day irrigation intervals had higher IWUE and TWUE values than those for 8-day irrigation intervals in both years. The reason why 4-day irrigation interval treatments had higher WUE than 8-day irrigation intervals was mainly due to increased yield in 4-day irrigation plots.

Table 1. Effects Of Irrigation Levels On Applied Water (I, mm), Water Use (ET, mm), Yield (ton ha^{-1}), IWUE (ton ha^{-1} mm^{-1}) and TWUE (ton ha^{-1} mm^{-1}) In Tomato.

	1999					2000				
Tr.	I	ET	Yield	IWUE	TWUE	I	ET	Yield	IWUE	TWUE
I_1Kcp_1	915	1108	99.5 a*	0.108 e	0.089 d	920	1150	112.5 a*	0.122 c	0.097 d
I_1Kcp_2	710	813	96.7 a	0.136 b	0.118 b	725	862	98.5 b	0.135 b	0.114 b
I_1Kcp_3	458	560	70.1 d	0.153 a	0.125 a	460	581	72.5 d	0.157 a	0.124 a
I_2Kcp_1	895	955	90.1 b	0.100 e	0.094 d	905	990	85.8 c	0.094 e	0.086 e
I_2Kcp_2	694	778	86.3 c	0.124 d	0.110 c	700	749	68.2 e	0.097 e	0.091 d
I_2Kcp_3	465	500	60.2 e	0.129 c	0.120 b	470	495	53.1 f	0.112 d	0.107 c

*Within each column, means followed by the same letter indicates no significant difference between treatments by Duncan's multiple range test at $P<0.05$.

Significant linear relationships were found between the tomato yield and applied irrigation water as shown in Figure 1. The relationship was defined as $y = 0.0688\ I + 36.409$ ($R^2 = 0.78$) and $y = 0.0835\ I + 23.595$ ($R^2 = 0.61$) for 1999 and 2000 growing seasons, respectively. There was also a good relationship between the yield of tomato and the water use as shown in Figure 2. The relationship between the yield and ET for 1999 and 2000 were $y = 0.0488\ ET + 47.407$ ($R^2 = 0.75$) and $y = 0.0785\ ET + 18.584$ ($R^2 = 0.82$), respectively. These results (a good correlation among yield, ET and applied irrigation water) were in agreements with other studies. For example, Ertek and Kanber (2001) in cotton under Çukurova region, Çevik et al. (1996) in vegetables in Harran plain and Ramalan and Nwokeocha (2000) in tomato in Nigeria reported a good correlation among ET, irrigation water and yield.

In order to evaluate the sensivity of tomato to soil water deficit, yield response factor, ky, was shown in Figure 3 for whole growing season for both years. The calculated yield response factor for total growing period, ky, was 0.84. This result implies that tomato is a moderate water sensitivity to water deficit. According to this result, it can be said that one unit decrease in water use causes 0.84 unit low yield. According to Doorenbos and Pruitt (1992), yield response factor of tomato is 1.05. However, our result look likes lower than this value. It can be explained by changes in climate, soil and other agricultural practices applied in a specific region.

Soil moisture profile variations during the growing season for drip-irrigated tomato are shown in Figure 4. Soil water storage within the 90 cm depth decreased gradually towards the end of the season in I_1Kcp_3, I_2Kcp_2 and I_2Kcp_3 treatments. However, soil moisture profile variation for I_1Kcp_1 and I_1Kcp_2 were similar to each other. Soil water remained higher in the full irrigation treatment (I_1Kcp_1) and light stress treatment (I_1Kcp_2) than the other treatments considered. As the amount of applied irrigation water decreased, soil water storage also decreased. Heavy stress treatment (I_2Kcp_3) resulted in soil water contents below permanent wilting point during the most of the growing season. Allen et al. (1998) reported that not more than 60% of the available water of clay soils should be allowed to be depleted in the root zone for maintaining optimum productivity.

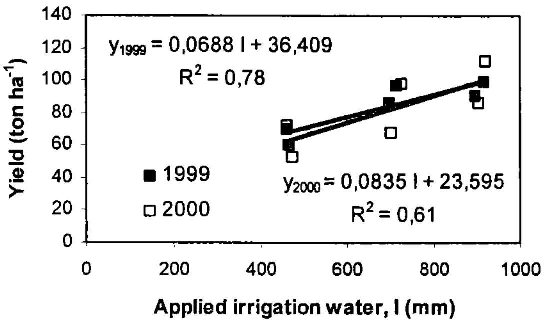

Figure 1. Relationship Between Applied Irrigation Water and Yield Of Drip Irrigated Tomato.

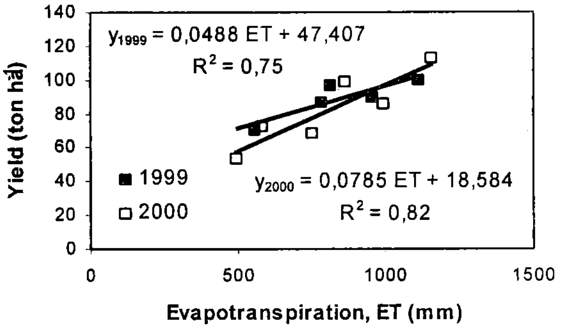

Figure 2. Relationship Between Evapotranspiration and Yield Of Dirp Irrigated Tomato.

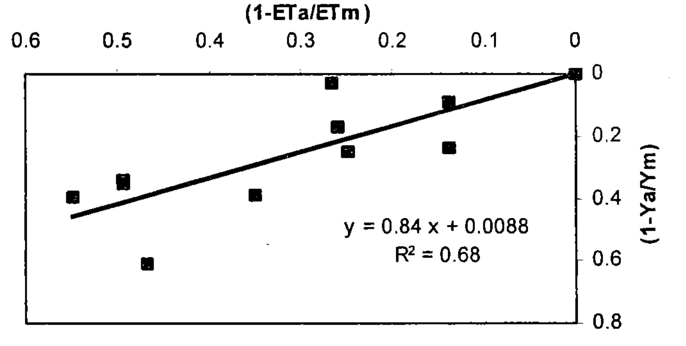

Figure 3. Crop Yield Response Of Drip Irrigated Tomato For Total Growing Period.

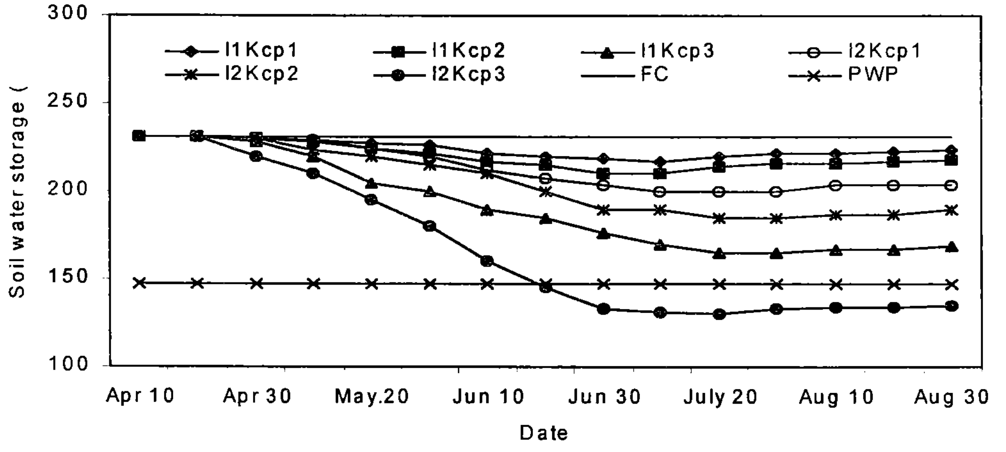

Figure 4. Average Soil Water Storage Variations During the Growing Season For Drip Irrigated Tomato In Harran Plain.

There was a significant change between growth parameters and irrigation treatments (Table 2). The highest plant height, canopy diameter and stem diameter were found in I_1Kcp_1 treatment in both years as 77.5 cm, 61.6 cm and 1.21 cm, respectively. Growth parameters increased with increasing ET as with tomato yield. The lowest growth parameters were obtained from the least irrigation application treatment (I_2Kcp_3) in both years. The effects of higher irrigation interval (8 days) were more severe on biometric parameters compared to 4-day irrigation intervals at the same Kcp values. The average plant height, canopy and stem diameter of I_2Kcp_3 were reduced by 18%, 32% and 30 %, respectively, compared to I_1Kcp_1 treatment. In general, plant vegetative growth parameters were decreased with increasing water deficit levels (Table 2). These results are in agreement with other studies like Alvino et al. (1989) in bell pepper and Bodge et al. (1989) in tomato.

Table 2. Average Plant Height (cm), Canopy Diameter (cm) and Plant Stem Diameter (cm) For Tomato Grown In Different Irrigation Levels.

Irrigation treatments	1999			2000		
	Plant height	Canopy diameter	Stem diameter	Plant height	Canopy diameter	Stem diameter
I_1Kcp_1	75.4 a*	59.2 a	1.15 a	77.5 a	61.6 a	1.21 a
I_1Kcp_2	74.2 a	58.3 a	1.03 ab	76.1 a	60.3 a	1.17 ab
I_1Kcp_3	69.2 b	51.4 b	0.94 bc	71.6 bc	53.2 b	0.95 c
I_2Kcp_1	70.1 b	53.2 b	0.99 bc	73.4 b	55.4 b	1.12 bc
I_2Kcp_2	68.3 b	47.5 c	0.90 c	69.1 c	46.1 c	0.92 c
I_2Kcp_3	62.4 c	40.3 d	0.80 d	63.0 d	41.2 d	0.81 d

*Within each column, means followed by the same letter indicates no significant difference between treatments by Duncan's multiple range test at $P<0.05$.

Dry matter yields and LRWC values increased with increasing ET and water applications (Table 3). The I_1Kcp_1 treatment resulted in higher dry matter (95.2 g plant^{-1}) and LRWC (95.2%) compared with other irrigation treatments. The reductions in dry matter with water-deficit treatments (especially in I_2Kcp_3) were due to the lessened plant growth parameters (reduced leaf area, plant height, canopy and stem diameters). There were an average of 22.5% difference between well-watered (I_1Kcp_1) and water stressed treatment (I_2Kcp_3) in term of dry matter productions (Table 3). The LRWC decreased with increasing water deficit levels. For example; while the LRWC value was 94.1% with I_1Kcp_1, it reduced to 78.5% and 71.2% with I_1Kcp_3 and I_2Kcp_3 treatments, respectively (Table 3). The decline in LRWC and dry matter productions with water deficit treatment compared to well-watered treatment were expected since soil-moisture content in the root zone at water stressed treatments was lower compared to well-watered treatment. Decreases in plant growth parameters, dry matter productions and LRWC with increasing water stress are in broad agreement with other studies. For example, Çevik et al. (1996) in vegetable plants and Yazar et al. (1991) in soybean plant reported that water-deficit reduced growth parameters. Kadam (1993) concluded that water deficit could reduce plant growth and dry matter production in tomato. Hedge (1987) in radish and Srinivas et al. (1989) in watermelon concluded that the decrease in LRWC with water stress was due to diminishing of the soil moisture in the root zone and hence, reduced transpiration rate.

Table 3. Average LRWC (%) and Dry Matter Content (g plant^{-1}) For Tomato Grown In Different Irrigation Levels.

Irrigation treatments	1999		2000	
	LRWC	Dry matter	LRWC	Dry matter
I_1Kcp_1	94.1 a*	172.5 a	95.2 a	185.2 a
I_1Kcp_2	93.1 a	169.8 ab	93.8 ab	182.7 a
I_1Kcp_3	78.5 c	154.9 c	79.2 c	165.3 c
I_2Kcp_1	90.1 b	167.9 b	91.5 b	177.3 b
I_2Kcp_2	80.3 c	147.5 d	78.3 c	150.2 d
I_2Kcp_3	71.2 d	133.4 e	70.5 d	139.7 e

*Within each column, means followed by the same letter indicates no significant difference between treatments by Duncan's multiple range test at $P<0.05$.

The fruit quality (fruit diameter, fruit weight and SSC) was also affected by irrigation treatments statistically at both years. But, there was no statistical difference between I_1Kcp_1 and

I_1Kcp_2 treatments in terms of fruit quality. The average highest fruit weight and fruit size were obtained from I_1Kcp_1 treatment in both years as 110 g $fruit^{-1}$ and 51.5 mm, respectively. On the other hand, the lowest fruit weight and fruit size were in I_2Kcp_3 with and average of 84 g $fruit^{-1}$ and 37 mm, respectively. The SSC was significantly increased by water-deficit (Table 4). The SSC of I_2Kcp_3 increased by 15% compared to well-watered (I_1Kcp_1) treatments. Table 4 shows that the water-deficit can improve significantly fruit quality in terms of SSC of tomato, but this advantage is accompanied with depression of yield. Our results can be comparable with other studies. Mitchell et al. (1991) in tomato, Çevik et al. (1996) in vegetable crops and Tan (1995) in tomato reported that water deficit reduced fruit weight, size and SSC.

In conclusion, the drip irrigated tomato with 4-day interval at Kcp_1 = 1.00 resulted in the highest yield among the treatments studied. However, usage of I_1Kcp2 can be recommended in tomato production in Harran plain without important yield reductions but saving an important water use efficiencies. The yield response factor for tomato was found as 0.84 for whole growing season. The average applied irrigation water, water use, yield, IWUE and TWUE of I_1Kcp_2 were 718 mm, 838 mm, 97 ton ha^{-1}, 0.135 ton ha^{-1} mm^{-1} and 0.116 ton ha^{-1} mm^{-1}, respectively. It has been found that there was a linear correlation among ET, irrigation water application, growth parameters and dry biomass productions in tomato.

Table 4. Average Fruit Diameter (mm), Fruit Weight (g $fruit^{-1}$), and SSC For Tomato Grown In Different Irrigation Levels

Irrigation treatments	1999			2000		
	Fruit weight	Fruit size	SSC	Fruit weight	Fruit size	SSC
I_1Kcp_1	105.7 a*	51.2 a	3.78 e	112.3 a	52.2 a	3.80 c
I_1Kcp_2	103.0 a	50.0 a	3.91 d	110.5 ab	51.7 ab	4.06 b
I_1Kcp_3	92.3 b	44.5 c	4.03 c	93.5 c	45.5 c	4.10 b
I_2Kcp_1	95.3 b	47.6 b	3.80 e	98.7 b	49.8 b	3.85 c
I_2Kcp_2	88.4 c	41.2 d	4.05 b	89.3 d	42.1 d	4.12 b
I_2Kcp_3	83.4 d	36.5 e	4.32 a	84.2 e	37.3 e	4.48 a

*Within each column, means followed by the same letter indicates no significant difference between treatments by Duncan's multiple range test at $P<0.05$.

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