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Irrigation Scheduling of Drip-Irrigated Tomatoes Using Class A Pan Evaporation

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Abstract: This study was carried out to investigate the irrigation schedule of drip-irrigated tomatoes (*Lycopersicon esculentum* cv. Dual Large, F 1) using Class A pan evaporation. Tomatoes plants were grown in a clay soil in the experimental fields of the Research Institute of Rural Services in Eskişehir between 1998 and 2000. Irrigation water was applied as a certain ratio of Class A pan evaporation (k_{pc} = 0.50, 0.75, 1.00, and 1.25) with different irrigation intervals (2, 4, and 6 days). Significant differences in fruit yields were obtained between the treatments, except for in 1998. Maximum marketable fruit yield was found at the treatment level of 1.00 of k_{pc} and 4-day irrigation intervals. For this treatment, fruit yield ranged from 116.6 to 176.3 t ha^{-1} depending on the climatological and soil conditions according to the experimental years. Hence, ground variety tomatoes grown in the field under Eskişehir conditions should be irrigated at 4-day intervals and the irrigation water should be determined using k_{pc} at 1.00 in combination with cumulative evaporation from a Class A pan. For this program, average irrigation water applied, evapotranspiration, and water use efficiency (WUE) were determined to be 602 mm and 710 mm, and 23.8 kg m^{-3}, respectively.

Key Words: irrigation, scheduling, tomatoes, drip, evaporation.

Damla Yöntemiyle Sulanan Domateste A Sınıfı Buharlaşma Kabından Yararlanarak Sulama Zamanının Planlanması

Özet: Bu çalışma, damla yöntemi ile sulanan domateste, A sınıfı buharlaşma kabından yararlanarak uygun sulama programının belirlenmesi amacıyla, 1998-2000 yılları arasında, Köy Hizmetleri Eskişehir Araştırma Enstitüsünün killi topraklara sahip deneme tarlalarında yürütülmüştür. Deneme konuları, 2, 4 ve 6 gün aralıklarla, A Sınıfı kaptan olan toplam buharlaşmanın 0.50, 0.75, 1.00 ve 1.25 katı kadar (k_{pc}) sulama suyu uygulamasıdır. 1998 yılı dışında, meyve verimi açısından deneme konuları arasında önemli düzeyde farklılık bulunmuştur. En yüksek pazarlanabilir meyve verimi 4 gün sulama aralığı ve k_{pc} = 1.00 katsayısının uygulandığı deneme konusunda elde edilmiştir. Bu konudaki meyve verimi, iklim ve toprak koşullarındaki değişime bağlı olarak, yıllara göre 116.6-176.3 t ha^{-1} arasında değişmiştir. Böylece, Eskişehir koşulları için, açık tarla domatesinde en uygun sulama programı 4 günlük sulama aralığındaki A sınıfı buharlaşma kabınndan olan birikimli buharlaşmanın tamamı (k_{pc}=1.00) net sulama suyu olarak uygulanmalıdır. Önerilen bu konuda, mevsimlik ortalama sulama suyu ihtiyacı 602 mm, bitki su tüketimi 710 mm ve su kullanım randımanı ise 23.8 kg m^{-3} olmuştur.

Anahtar Sözcükler: sulama, damla, domates, buharlaşma.

Introduction

Irrigation is one of the most important inputs for agricultural production. Limited water resources and increasing water demand for industrial and urban settlements have caused decreases in the quantity and quality of agricultural water use. On the other hand, the use of irrigation methods or systems that require low labor and energy inguts has become more popular in recent years. These conditions are readily satisfied by means of drip (micro) irrigation systems. Water applied by a drip system enters into the soil through small holes placed directly on the soil surface. The possibility of applying water at very slow rates offers the drip irrigation system the means to deliver water to the soil in small and frequent quantities at a relatively low cost compared to other pressurized systems. Therefore, water stress in the root zone does not generally occur, and plants use irrigation water more efficiently than in other irrigation methods (Bresler, 1978; Keller and Bliesner, 1990; Yıldırım, 1993; Hargreaves and Merkley, 1998). In addition, economic and environmental reasons, such as increasing irrigation costs and decreasing sources of irrigation, have encouraged farmers to use the drip irrigation method, especially for valuable crops (Özekici and Bozkurt, 1999).

The total vegetable area in the Eskişehir region is 6,194 ha and 30% of this area is allocated for tomatoes production (Anonymous, 1997). Farmers in this region have utilized the drip irrigation method in order to irrigate tomatoes since they can efficiently fertilize by means of fertigation, thus saving time and labor, and at the same time increase yield and quality.

Some researchers have shown that higher tomatoes yields are obtained by drip irrigation compared to other irrigation methods. Tekinel et al. (1989) compared drip irrigation and conventional irrigation methods for tomatoes in the Çukurova region and obtained the highest yield and water use efficiency (WUE) with drip irrigation. Jadhaw et al. (1990) tested drip and furrow methods for tomatoes. Tomatoes yields were 48 t ha^{-1} for drip irrigation systems with pressure-compensating emitters and 32 t ha^{-1} when furrow irrigation was used. The benefit to cost ratios were 5.15 and 2.96, respectively, for the drip and furrow methods. The drip system showed a 31% saving in irrigation water. The water saved was available to irrigate a further 0.4 ha. Branthome et al. (1993) irrigated tomatoes using drip irrigation at 0.7, 1.0 or 1.3 times maximum evapotranspiration (ETm). Total yield and fruit weight were highest at 1.0 of ETm, but most of the quality components such as acidity and color were best at 0.7 ETm. Kadam (1993) compared the effects of furrow, sprinkler and drip irrigation methods on the growth of tomatoes. The plant leaf area index was highest under drip irrigation, and these plants reached 50% flowering stage sooner than plants irrigated with other irrigation systems. Drip irrigation also resulted in the highest fruit yields. Tan (1995) compared tomatoes grown on a sandy loamy soil that were either irrigated by a drip or sprinkler system or not irrigated at all. Both drip and sprinkler methods increased the marketable fruit yield in 3 of 4 years. In general, drip irrigation resulted in higher fruit yields than did sprinkler irrigation. Locassio and Smajstrla (1996) carried out research on tomatoes grown on fine sandy soil with black polyethylene mulch and irrigated by drip irrigation. Water was applied at 0, 0.25, 0.50, 0.75 or 1.0 times pan evaporation. Total marketable yields were highest at 1.0 pan (87.0 t ha-1) and 0.75 pan, (79.3 t ha-1) compared with 30.7 t ha^{-1} for controls. Total water use was higher with the 0.75 pan schedule. Çevik et al. (1997) carried out research on the irrigation program of tomatoes irrigated by a drip system on the Harran Plain. The highest tomatoes yield of 132.7 t ha^{-1} was obtained by applied irrigation water at 0.30, 0.90, 1.20 and 1.20 times pan evaporation for planted-flowering, flowering-fruit formation, fruit maturity-first harvesting and first harvesting-last harvesting stages, respectively. The irrigation water requirement of tomatoes according to this program was 1229 mm. According to research results presented by Balçın and Güleç (1998) for the Tokat region, there were no significant differences between coefficients of k_{pc} (0.75, 1.00 and 1.25) on bush tomatoes irrigated by the furrow method. They recommended 7-day intervals at 0.75 times pan evaporation. For this irrigation program, the yield obtained and irrigation water applied were 92.7 t ha^{-1} and 487 mm, respectively.

According to a preliminary survey carried out by us on irrigation practices for tomatoes in the Eskişehir region, data and practices on applying irrigation water quantity and time for drip irrigation under farm conditions were insufficient, and no reliable results or applications were found. Therefore, this study was carried out to determine irrigation scheduling and the effects of irrigation water quantities on fruit yield and the quality of drip-irrigated tomatoes using Class A pan evaporation.

Materials and Methods

Experimental Site

This study was conducted by the Research Station of the Rural Services Research Institute in Eskişehir. The experimental site is situated latitude 39°46'N and longitude 30°31'E. The altitude is 781 m. The experimental site has typical terrestrial climatological properties. According to the long-term data, the annual average temperature, precipitation, relative humidity, wind speed and evaporation are 10.7 °C, 374 mm, 68%,

Table 1. Some soil properties of the experimental site.

Soil layers (cm)	Texture	Field capacity (g g^{-1})	Wilting point (g g^{-1})	Bulk density (g cm^{-3})	pH	ECx10^{-3} (dS m^{-1})	Lime (%)	Infiltration rate (mm h^{-1})
0-30	C	0.32	0.21	1.10	8.1	1.09	16-37	9
30-60	C	0.33	0.21	1.34	8.1	1.20	17-29	
60-90	C	0.34	0.22	1.26	8.2	1.00	21-37	
90-120	C	0.34	0.21	1.20	8.2	0.88	22-37	

2.0 m s^{-1}, and 1001 mm, respectively. The soils in the area have a clay texture and are classified as being alluvial. Some of the soil's properties are presented in Table 1.

Irrigation Treatments

The research was conducted in randomized blocks that had two main factors with three replications. The first and second main factors were irrigation intervals and coefficients of Class A pan evaporation (k_{pc}). Irrigation treatments are given in Table 2. According to the experimental design, 12 different irrigation treatments were applied.

The plant rows spacing and plant spacing were 1.00 and 0.50 m., respectively. Each plot had 5 plant rows and the length of each plot was 8 m. The two rows placed on the border of the plot and 0.50 m at the end and beginning of the plot were excluded from evaluation. Thus, the planted and harvested area were 8 x 5 m and 6 x 3 m, respectively.

Irrigation System

All calculations for system design were completed according to the soil and plant properties before the system was installed on the field. The lateral lines had on-line compensating emitters and the discharge rates of the emitters were 3.2 L h^{-1} at the operating pressure of 1 atm. The emitter spacing was chosen as 0.50 m due to soil characteristics (Papazafiriou, 1980).

Table 2. Irrigation treatments

I. Factor (Irrigation intervals)	II. Factor (Coefficients of Class A pan evaporation)
A: 2 days	a: 0.50
B: 4 days	b: 0.75
C: 6 days	c: 1.00
	d: 1.25

The drip system consisted of PE laterals 16 mm in diameter laid out along each tomatoes row at 1.00 m spacing. Each plot had a PE manifold pipeline 32 mm in diameter. The irrigation water, which was pumped from a deep well, was conveyed by means of PE pipes 50 mm in diameter into the manifolds along the border of the plots. In addition, the control unit of the system had a vortex sand separator, sand media filters, a fertilizer tank, screen-mesh filters (120 mesh), and pressure gauges.

Determining Irrigation Water Applied and Evapotranspiration

The amount of irrigation water applied during the irrigation treatments was determined by Class A pan evaporation using the equation given below.

$$I = A\, E_p\, k_{pc}\, P \qquad (1)$$

Where I equals amount of irrigation water (L), A equals plot area (m^2), E_p equals cumulative evaporation amount for considering irrigation intervals (mm), k_{pc} equals coefficient (including pan coefficient k_p, crop coefficient k_c, and application efficiency E_a), and P equals wetted area (%). Wetted area was determined to be 90% by field tests done at the beginning of the study by the methods described by Keller and Bliesner (1990).

The drip system was placed on the plots immediately following planting. The amount of first irrigation water for all the plots was based on the moisture deficit that would be needed to bring a 0-90 cm layer of soil to field capacity and it was applied by means of the system. Subsequent irrigations were applied considering irrigation intervals and coefficients of k_{pc}.

Soil moisture was monitored by means of a neutron probe placed at one point in each plot of all the irrigation treatments including replications considering 30 cm layers in the depth of 0-120 cm of the soil. The water balance equation was used in order to determine evapotranspiration (James, 1988).

The amount of irrigation water applied was measured by flow meter, while rainfall and evaporation data were obtained from the records of the climatological station near the experimental site. Runoff and capillary additive were ignored.

WUE kg m^{-3} was considered as fresh fruit weight (kg) obtained per unit volume of irrigation water applied (m^{-3}) (James, 1988).

Agricultural Applications

Tomatoes (*Lycopercion esculentum* cv. Dual Large, F1) seeds of a freshly consumed bush variety was sown in a greenhouse at the end of March. Young tomatoes plants were transferred into plastic tubes at the end of April. Afterwards, the plants were planted in plots in the middle of May. A total of 180 kg N ha^{-1} and 120 kg P_2O_5 ha^{-1} fertilizer were applied as recommended by Sefa and Oruç (1990). Half of the phosphorus and approximately one-third of the nitrogen were applied into the soil before planting. The remaining fertilizer, which contained nitrogen, phosphorus, potash and some minor elements, was applied by fertigation 3 or 4 times. The harvest began at the beginning of August and finished at the beginning of October.

Statistical Evaluation

For statistical analysis, randomized blocks with three replications were used to evaluate the effects of treatments on the yield and some yield components. Duncan's multiple test, an acceptable tool for the comparison of discrete data, was used to compare different irrigation programs. In addition, regression analysis for the irrigation levels was performed (Yurtsever, 1984).

Results and Discussion

Irrigation Water Applied and Marketable Fruit Yields

The results of irrigation water amounts applied and marketable fruit yields obtained in the experimental years (from 1998 to 2000) and irrigation treatments are shown in Table 3. The results of statistical analysis on marketable fruit yields are shown in Table 4. There were no significant differences between either irrigation intervals or irrigation water amounts (coefficients of k_{pc}) in 1998. The fruit yields ranged from 127.0 t ha^{-1} (2 days and 1.00 of k_{pc}) through 162.8 t ha^{-1} (4 days and 0.50 of k_{pc}).

In 1999, it was found that there were significant differences ($P = 0.05$) between irrigation water amounts. However, irrigation intervals had no significant effect on fruit yield. The highest fruit yield was 176.3 t ha^{-1} at the treatment Bc (4 days and 1.00 of k_{pc}) and the lowest fruit yield (147.8 t ha-1) was obtained from the highest

Table 3. The marketable fruit yields according to irrigation treatments and the experimental years.

Treatments	1998		1999		2000	
	Irrigation water (mm)	Fruit yield (t ha^{-1})	Irrigation water (mm)	Fruit yield (t ha^{-1})	Irrigation water (mm)	Fruit yield (t ha^{-1})
Aa (2 x 0.50)	291	156.2	312	161.2	376	49.3
Ab (2 x 0.75)	410	144.1	441	169.3	533	90.8
Ac (2 x 1.00)	563	127.0	584	165.4	680	114.1
Ad (2 x 1.25)	695	135.1	724	164.1	832	115.5
Ba (4 x 0.50)	286	162.8	311	160.0	374	55.7
Bb (4 x 0.75)	423	137.7	448	169.9	525	86.4
Bc (4 x 1.00)	557	131.5	577	176.3	673	116.6
Bd (4 x 1.25)	698	131.5	715	174.2	827	115.1
Ca (6 x 0.50)	271	129.2	307	147.8	375	55.5
Cb (6 x 0.75)	406	141.6	449	168.2	526	83.9
Cc (6 x 1.00)	541	139.4	586	170.1	678	99.2
Cd (6 x 1.25)	670	131.9	722	161.3	830	124.5
Average	-	139.0	-	165.6	-	92.2

Table 4. Marketable fruit yields according to the irrigation intervals and the coefficients of k_{pc}.

Irrigation interval (days)	Marketable fruit yield (t ha^{-1})			Coefficients of k_{pc}	Marketable fruit yield (t ha^{-1})		
	1998	1999	2000		1998	1999	2000
2 (A)	140.6	164.7	92.4	0.50 (a)	149.4	156.3 b	53.5 c
4 (B)	140.8	170.1	93.5	0.75 (b)	141.1	169.1 a	87.0 b
6 (C)	135.5	161.8	90.7	1.00 (c)	132.6	170.6 a	109.9 a
				1.25 (d)	132.8	166.5 a	118.4 a

irrigation interval (6 days) and the lowest k_{pc} (0.50) [Ca]. Consequently, marketable fruit yield for Bc was 16% higher than that of Ca.

As for the statistical evaluation in 1999, it was determined that were significant differences (P = 0.01) between fruit yields considering only irrigation water amounts in 2000. There were no significant effects regarding irrigation intervals and the interaction between irrigation intervals and irrigation water amounts. Therefore, yields according to irrigation intervals and irrigation water amounts were tabulated separately (Table 4). According to the results in 2000, the highest and lowest yields were 124.5 and 49.3 t ha^{-1} at the treatments of Cd (6 days and 1.25) and Aa (2 days and 0.50), respectively.

The results, which were tabulated separately according to the irrigation intervals and irrigation water amounts (Table 4), show that the highest yields were encountered for 4-day irrigation intervals and 1.00 of k_{pc} both in 1999 and 2000 (except for the yields in 1998).

On the other hand, Branthome et al. (1993) found that tomatoes yield and fruit weight were highest at 1.0 times that of maximum evapotranspiration. According to a study carried out by Locassio and Smajstrla (1996) total marketable tomatoes yields were highest at 1.0 pan (87 t ha-1) and 0.75 pan (79.3 t ha-1). The results obtained by these researchers were similar to our findings in terms of the highest marketable yields of tomatoes irrigated by drip for k_{pc} of 1.00. It may be attributed to the similar soil and climatological conditions of this research region. Furthermore, Çevik et al. (1997) studied different coefficients of k_{pc} for the growth stages of tomatoes on the Harran Plain. The highest yield was obtained at 1.20 of k_{pc} for maturity and harvesting stages. The reasons for this difference may be higher temperature, lower relative humidity, cracking soils, clay types and soil structure on the Harran Plain compared to the Eskişehir region. Balçın and Güleç (1998) stated that there were no significant differences between coefficients of k_{pc} (0.75, 1.00 and 1.25) on bush tomatoes irrigated by the furrow method for the Tokat region. Therefore, they recommended 7-day intervals at 0.75 times pan evaporation. Contrary data found from the Harran Plain can be attributed to higher relative humidity and more precipitation in the Tokat region.

As a result, in order to obtain a maximum tomatoes yield for bush varieties grown in fields for the Eskişehir region, the amount of irrigation water should be at 1.0 times pan evaporation.

In discussing the differences in fruit yields between the experimental years, the arithmetic average yields for all treatments were 139.0, 165.6 and 92.2 t ha^{-1} in 1998, 1999 and 2000, respectively (Table 3). On the other hand, the average fruit yield of tomatoes in the Eskişehir region according to the data given by the Ministry of Agriculture is 54.8 t ha^{-1} (Uysal, 2001)*. The fruit yields obtained from this study were higher than the average yield in this region. Due to the fact that the nature of drip irrigation, which applies irrigation water slowly and frequently, soil water content in a portion of the plant root zone remains fairly constant compared to other methods. Therefore, the plants more efficiently use fertilizers and water. Some studies carried out in different regions have proved that higher yields are obtained by drip irrigation compared to other irrigation methods. Tekinel et al. (1989), Jadhaw et al. (1990), and Tan (1995) have shown that drip irrigation resulted in higher fruit yields compared to furrow or sprinkler irrigation.

* Personal communication

On the other hand, fruit yields obtained in 2000 were considerably 33.6 and 44% less than the yields in 1998 and 1999, respectively. When irrigation treatments were considered, these fruit yield differences might be attributed to high temperatures of up to 40.4 °C during the pollination period.

Evapotranspiration and Water-Yield Relations

The results of evapotranspiration obtained according to the treatments and experimental years are given in Table 5. The values varied between 454 and 871 mm in 1998, 405 and 807 mm in 1999, and 424 and 946 mm in 2000 due to variations in rainfall and evaporation during the growing period in the experimental years. The average value of three years was 710 mm for the considered treatment (Bc, 4-day intervals and k_{pc} of 1.00). Evapotranspiration increased as long as irrigation water increased.

The curves showing the relationship between marketable fruit yields, evapotranspiration, marketable fruit yield and irrigation water applied are presented in the Figure 1. Regression analysis showed that there were statistically significant quadratic relations (P = 0.01 in 1999 and 2000) between marketable fruit yield and evapotranspiration in both 1999 and 2000 (Fig. 1). Similar results were obtained for the relationship between marketable fruit yield and irrigation water quantity. The results in 1998 were not evaluated by means of regression because it was found that there were

Table 5. Evapotranspiration results according to the treatment and the experimental years

Treatments	Seasonal evapotranspiration (mm)			WUEs (kg m^{-3})		
	1998	1999	2000	1998	1999	2000
Aa (2 x 0.50)	476	421	424	53.7	51.6	13.0
Ab (2 x 0.75)	591	542	643	35.1	38.3	17.1
Ac (2 x 1.00)	745	652	759	22.6	28.3	16.8
Ad (2 x 1.25)	867	806	946	19.4	22.7	13.9
Ba (4 x 0.50)	482	418	432	56.9	51.4	14.9
Bb (4 x 0.75)	604	532	583	32.3	37.9	16.5
Bc (4 x 1.00)	732	666	731	23.6	30.5	17.3
Bd (4 x 1.25)	871	807	858	18.8	24.3	13.9
Ca (6 x 0.50)	454	405	473	47.7	48.2	14.8
Cb (6 x 0.75)	577	546	585	34.9	37.4	16.0
Cc (6 x 1.00)	714	667	799	25.8	29.0	14.6
Cd (6 x 1.25)	837	802	877	19.7	22.3	15.0

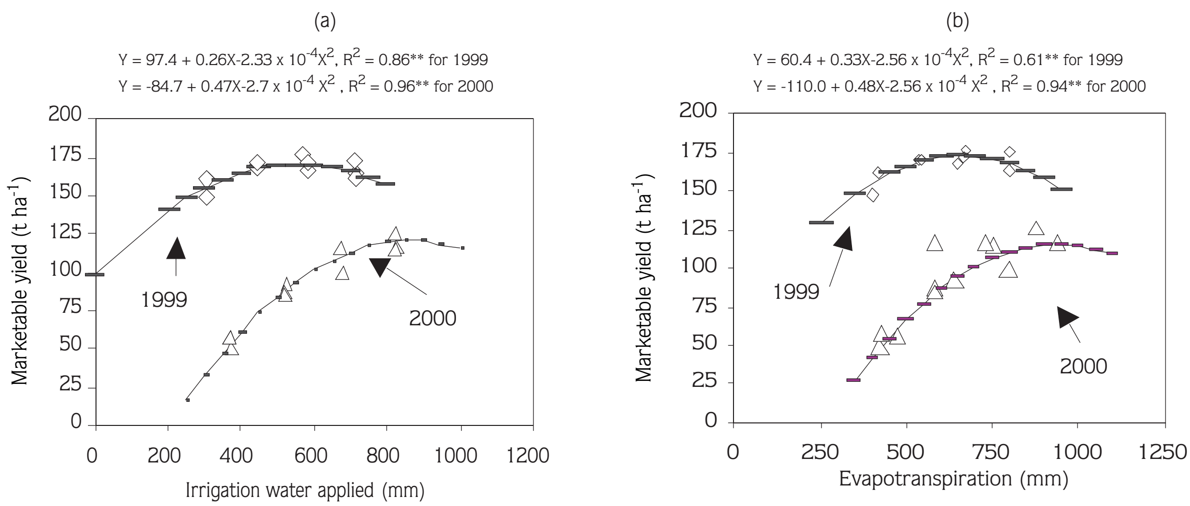

Figure 1. Marketable tomatoes yield versus irrigation water applied (a) and evapotranspiration (b) in 1999 and 2000

no significant effects of the treatments on marketable fruit yields. As is known, the relationship between yield and evapotranspiration or irrigation water depends on the quantity of water applied, and irrigation programs, as well as soil and climatological factors. Hence, it would be either a linear or quadratic curve. Our research results show that the marketable fruit yield of tomatoes did not increase at irrigation levels with values greater than 1.00.

On the other hand, according to the Jensen-pan evaporation method (Kanber et al., 1999), the average constant value of k_{pc} was calculated as 0.95 using actual evapotranspiration and cumulative evaporation for vegetation duration for k_{pc} of 1.00 recommended for an appropriate irrigation program.

Water Use Efficiency (WUE)

WUEs calculated for all treatments are given in Table 5. The values of WUE ranged from 13.0 to 56.9 kg m^{-3} depending on the treatments and experimental years. The WUEs were higher at low coefficients of k_{pc} compared with high coefficients. These results proved that tomatoes plants use irrigation water more efficiently at low levels of irrigation. There were significant differences between WUEs according to the years. As mentioned above, this might be attributed to differences in the amount of irrigation water or fruit yield obtained due to climatological and soil conditions. The lower yields in 2000 resulted in lower WUEs. However, WUEs do not only depend on the amount of irrigation water applied but also on the amount of fertilizers and application methods, protection for diseases and insects and other agricultural practices such as hoeing.

Conclusion

In this study, firstly, the drip irrigation method increased considerably marketable tomatoes yields compared to yields under average farming conditions. Essentially, appropriate irrigation scheduling for tomatoes irrigated by a drip system can be based on Pan evaporation. Considering the results of this study, there were significant differences for the marketable fruit yield of tomatoes according to the coefficients of k_{pc}, i.e. amount of irrigation water applied. The highest fruit yields were obtained from the treatment of 4-day irrigation intervals and a k_{pc} value of 1.00.

The results clearly show that ground variety tomatoes grown in the field under Eskişehir conditions should be irrigated every 4 days, and the quantity of irrigation water should be determined by employing k_{pc} at 1.00 using cumulative evaporation occurring from a Class A pan. Consequently, irrigation water requirements and evapotranspiration for this irrigation program were 602 and 710 mm on average, respectively.

On the other hand, the wetted area is an important parameter for drip irrigation systems since the percentage of wetted area determines directly the amount of irrigation water. Therefore, it should be accurately measured or calculated for each system and soil conditions.

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