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Evapotranspiration and crop coefficients of drip-irrigated apricot trees under semiarid climatic conditions

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Abstract

This study was conducted to determine the evapotranspiration and the most suitable crop coefficients of drip-irrigated Salak apricot (*Prunus armeniaca,* L., cv. Salak). Application of irrigation water (I) was based on cumulative class A pan evaporation (Epan) within the irrigation intervals. Actual evapotranspiration (ETc) of apricot was calculated according to the water balance method. ETc was determined as 596 mm during the experimental period (May–September). Reference evapotranspiration (ETo) was calculated with FAO Penman-Monteith equation. There were also significant relationships among I, Epan, ETc and ETo ($p<0.001$- 0.05). Crop coefficients (Kc) ranged from 0.56 to 0.96 (0.89 for May, 0.96 for June, 0.95 for July and August and 0.56 for September). Kc values calculated on the basis of the water balance over a 5-month-period led to a saving of 19.4% water, since the coefficients were slightly below those presented in the FAO 24. Thus, using the relationship between ETc and Epan or Kc values obtained from present study is recommended for irrigation scheduling of Salak apricot.

Key words: Crop coefficients, evapotranspiration, class A pan evaporation, Salak apricot, irrigation scheduling, Igdir Plain.

Introduction

Evapotranspiration (ET) is an important parameter for determining the irrigation requirements of fruit trees, especially in semiarid environments [1]. Evapotranspiration is not easy to measure. Specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters are required to determine evapotranspiration [2].

The general procedure for estimating ET is to first estimate reference ET (ETo). Then the evapotranspiration for different cover types (ETc) is obtained by multiplying ETo with an empirical crop coefficient (Kc). In this procedure, the accuracy of the ETc estimation is dependent upon the derivation of the proper crop coefficient (Kc) as well as the calculation of ETo [3].

A large number of empirical or semi-empirical equations have been developed for assessing crop or reference crop evapotranspiration (ETo) from meteorological data. The FAO Penman-Monteith (FAO PM) method is recommended as the sole method for determining ETo. The FAO PM has been selected as the standard method for estimating ETo because it closely approximates short grass and alfalfa Eto at the locations evaluated. The FAO PM method is physically based and explicitly incorporates both physiological and aerodynamic properties [4].

In some locations, however, there are insufficient weather data to calculate ETo, so Class "A" pan evaporation (Epan) data provide an alternative method to determine ETo. The Epan data are multiplied by a pan coefficient (Kpan) to estimate ETo [5]. More importantly, pan evaporation measurements are widely used in agricultural meteorology due to their simplicity, low cost and proven ease of application for irrigation scheduling and evapotranspiration estimation [6-8].

The aim of this study was to determine the evapotranspiration of drip-irrigated Salak apricot during vegetative growth and to calculate local crop coefficients in an attempt to save water.

Material and Methods

The experiment was carried out from 2004 to 2008 in an apricot plot located at the Soil and Water Resources Research Station, Igdir, Turkey. The Igdir Plain is located in the Eastern Anatolia region (44°49' to 45°31' E; 39°38' to 40°03' N; altitude 850 m). The region has a semi-arid climate. The climatic variables observed at the meteorological station in experimental area and Igdir synoptic meteorological station for 2008 are given in Table 1.

The soil at the experimental site is clay loam with 34% clay, 40% silt and 26% sand. The average field capacity is 31.4%, the permanent wilting point 17.1%, the dry bulk density 1.27 g cm^{-3} and the pH 8.04 at 0-120 cm soil depth. Suitable water (with C_2S_1 quality) for irrigation was obtained from a deep well in the experimental area.

The studied plant material was Salak apricot cultivar trees (*Prunus armeniaca,* L., cv. Salak) grafted on Zerdali rootstocks. The trees were planted in 2001, spaced 8 m × 8 m apart. The plot was drip irrigated by using a double-drip irrigation line for each row, with emitter that had a 6.8 l h^{-1} flow rate. Emitters were placed

Table 1. Climatic data of the experimental area in the growing season of 2008.

Climatic parameters	Months				
	May	June	July	August	September
Mean temperature (ºC)	17.1	23.0	25.8	25.6	21.0
Mean relative humidity (%)	43.7	36.9	42.9	44.9	50.1
Mean wind speed at 2 m height (m s^{-1})	1.2	1.3	1.2	0.9	0.8
Mean sunshine (h d^{-1})	7.2	10.0	10.3	6.7	7.4
Mean evaporation (mm d^{-1})	3.8	4.7	6.6	6.1	4.0
Total precipitation (mm)	32.3	10.8	1.0	10.4	-

at 0.5 m intervals along lateral lines.Trees received the same fertilization treatments by using fertigation techniques. The amount of fertilizer was 0.44 kg urea, and 0.11 kg H_3PO_4 applied to each tree each year. A routine pesticide program was maintained. No weeds were allowed to grow within the orchard, resulting in a clean orchard floor for the duration of the experiment.

Treatments consisted of the application of six different water regimes: five of which (S1, S2, S3, S4 and S5) were based on adjustment coefficients of Class A pan evaporation (0.50, 0.75, 1.00, 1.25, and 1.50). The other treatment (S6) was regulated deficit irrigation treatment that was irrigated by applying 100% of Class A pan evaporation until harvest, but not irrigated after harvest in all the years of the study. The experiment was conducted using a randomized complete block design with six irrigation treatments (S1 to S6) and three replications.

Previous results of this study showed that there was not a statistically significant difference among the treatments in terms of yield per tree and the S1 treatment gave the highest yield per unit crown volume and unit trunk cross sectional area in 2008 [9]. So, in this study, the amount of irrigation water applied to the S1 treatment was considered to be sufficient to meet the crop water requirement. Therefore, in this study, the amount of water applied to the S1 treatment in 2008, in which normal fruit yield was taken and trees reached their full size, was taken into consideration for plant water consumption and crop coefficients.

The amount of irrigation water applied (I, mm) to the S1 treatment was determined by Class A pan evaporation using the equation given below:

$$I = 0.50 \bullet Pc \bullet Epan \quad (1)$$

where I equals the amount of irrigation water (mm), 0.50 equals coefficient (including crop coefficient, Kc; pan coefficient, Kpan; application efficiency, Ea; and uniformity coefficient, Eu), Pc equals the ratio of the tree crown width to the the tree row spacing (Pc was accepted as 1.0 in 2008), and Epan equals cumulative evaporation amount measured during the preceding week (mm), The evaporation was measured from a Class A pan in the Meteorological Station of Soil and Water Resources Research Institute. The experimental plots were approximately far of 100 m from the meteorological station.

The amount of the first irrigation water for all the plots was based on the moisture deficit that would be needed to bring a 0 to 120 cm layer of soil to field capacity, and it was applied by means of the system when available water at a 120 cm depth soil profile was at 50%. Experimental treatments were initiated one week after the first irrigation application, which was in the third week of May, and were continued by mid of September.

Soil water contents were determined monthly by gravimetric sampling method at 30 cm increments down to 120 cm in the profile. Rainfall was measured by both a manual rain gauge and an automatic rain gauge connected to a datalogger (Campbell Scientific, Inc. 21X) at the meteorological station in the experimental area. The amount of irrigation water applied to each plot was measured by a water meter.

ETc was calculated for the period from the beginning of May up to the end of September. ETc was calculated for the S1 treatment via water balance equation [10]:

$$ETc = P + I - D - R \pm \Delta S \quad (2)$$

where P is the precipitation, I is the applied irrigation water, D is the drainage, R is the runoff, and ΔS is the change in soil water content in that interval. All terms are expressed in mm of water in the crop root zone.

Since there was no runoff during irrigation and the water table was at a depth of more than 3 m, capillary flow to the root zone and runoff were assumed to be negligible in the calculation of ET. On the basis of a number of soil water content measurements, drainage below 120 cm was considered to be negligible. Thus, the above equation was simplified as:

$$ETc = P + I \pm \Delta S \quad (3)$$

The FAO Penman-Monteith (FAO P-M) method was used to estimate the reference crop evapotraspiration. A study previously carried out in the experimental area have demonstrated that the ETo monthly estimated by FAO PM method was in good agreement with ETo calculated using the FAO Pan Evaporation (FAO PE) method ($ETo_{(FAO\ PM)} = 0.992\ ETo_{(FAO\ PE)}$; $R^2 = 0.934$) [11].

The FAO Penman-Monteith equation [2] is as follows:

$$ETo = \frac{0.408\,\Delta(Rn - G) + \gamma(\frac{900}{T + 273})U}{\Delta + \gamma(1 + 0.34U_2)} \quad (4)$$

where ETo is reference crop evapotranspiration (mm day^{-1}), T is mean daily air temperature at the 2 m height (ºC), Rn is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), U_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), (e_s - e_a) is vapor pressure deficit (kPa), Δ is slope of the evaporation vapor pressure curve (kPa °C^{-1}), and γ is psychometric constant (kPa °C^{-1}).

The various values in this equation were computed on a daily basis, and the ET_o was estimated as per the procedure outlined in FAO 56 [2].

The crop coefficient (Kc) is the ratio of ETc to ETo and is estimated with the following equation [2, 12].

$$Kc = ETc / ETo \quad (5)$$

Results and Discussion

Pan evaporation and the irrigation water amounts during the irrigation season are shown in Fig. 1. During the irrigation season, in which a total 636.1 mm of pan evaporation occurred, treatments with 7-day intervals were irrigated 17 times.

A total 115 mm of water was applied prior to the scheduled irrigations. Soil water deficit in all plots was replenished to field

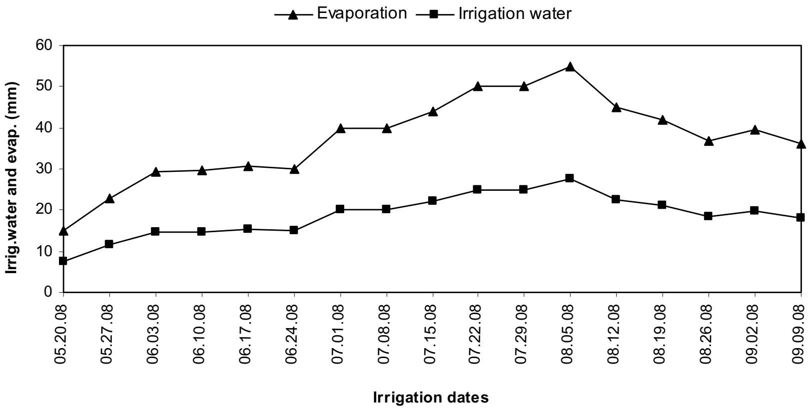

Figure 1. Pan evaporations measured and amounts of irrigation water applied to the S1 treatment during the irrigation season.

capacity in 0-120 cm soil depth and then scheduled irrigation, based on 7 days of cumulative evaporation, was initiated. The total amount of irrigation water applied during the irrigation season for the S1 treatment was 433.2 mm. Thus, the ratio of total irrigation water to total pan evaporation was calculated as 0.68 (433.2/636.1). In the same way, Abrisqueta *et al.* [13] stated that the ratio of total irrigation water to total pan evaporation was 0.76. There was little rainfall (32.7 mm) during the irrigation period. Fig. 2a shows that there was a significant relationship between cumulative I and cumulative Epan during the irrigation season (I = 0.499 Epan + 100.73). The relationship was statistically significant at the level $P < 0.001$. The intercept value (100.73) is a result of 115 mm of irrigation water applied before programmed irrigations.

ETc and ETo values determined by the soil water balance and the FAO Penman-Monteith methods are given in Fig. 2b. ETc was determined as 596 mm during the experimental period (May–September) and varied from 1.85 to 5.21 mm day^{-1}. ETc reached its maximum in July and then decreased until the end of experimental period. Also, Abrisqueta *et al.* [13] and Mounzer *et al.* [1] stated that maximum ETc value was 3.5 mm day^{-1} and 5.5 mm day^{-1} for apricot, respectively. Evapotranspiration was determined as 645 mm during vegetative period [9].

ETo values varied from 3.29 to 5.46 mm day^{-1}. ETo was determined as 679.6 mm during the experimental period. More importantly, ETo was higher than than ETc. Fig. 3a shows the relationship between ETc and ETo during the irrigation season. There was a significant quadratic correlation between ETc and ETo ($ETc = -0.0173(ETo)^2 + 6.0834(ETo) - 375.21$). The relationship was statistically significant at the level $P < 0.01$.

In conjunction with the development of ETc equations, it is also valuable to compare crop ET with evaporation from a class A evaporation pan. Therefore, the relationship between ETc and Epan was determined. Fig. 3b shows the relationship between ETc and Epan for the S1 treatment. There was a significant quadratic correlation between ETc and Epan ($ETc = -0.007(Epan)^2 + 2.6211(Epan) - 98.599$; $P < 0.05$). This is in agreement with other studies, showing a close relationship between plant water consumption and pan evaporation. For example, Parmele and Mc Guinness [14], Phene and Campbell [15] and Howell *et al.* [16] revealed that Class A pan evaporation measurements with adequate coefficients provided reasonable estimates of daily ETc when soil water was not restricting plant growth [6].

Consequently, based on this study, irrigation could be scheduled according to the relationship between ETc and Epan. Furthermore, relatively lower irrigation coefficients could be chosen in the early and late growing periods to save significant amounts of water.

The values of monthly Kc derived from ETc and ETo are shown in Table 2. Kc values ranged from 0.56 to 0.96. These values were found to be 0.43 and 0.78 by Abrisqueta *et al.* [13]. Maximum values of Kc were in June – August period. The Kc values observed in this study were generally lower than those given in the FAO 24 [12] and were found in agreement with FAO 56 [2]. However, Kc value in May was higher than that of FAO 24 due to 115 mm of irrigation water applied before programmed irrigations.

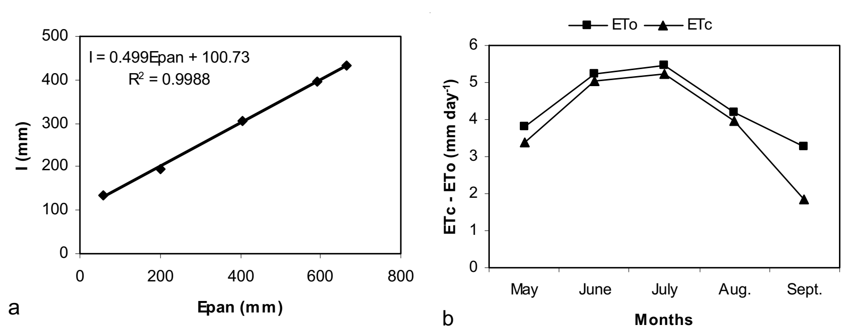

Figure 2. The relationship between cumulative I and cumulative Epan (a) and ETc and ETo values as daily average during the experimental period (b).

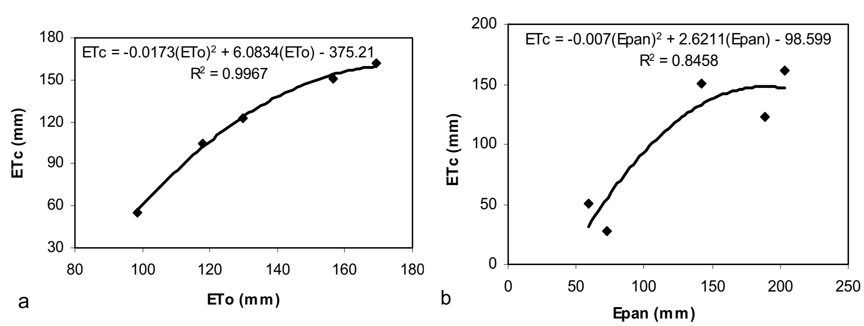

Figure 3. Relationships between ETc and ETo (a), and Epan (b) during the experimental period.

Table 2. Kc values obtained from this study, and given in FAO 24 and FAO 56.

Kc values	Months				
	May	June	July	August	September
Present study	0.89	0.96	0.95	0.95	0.56
FAO 24	0.80	1.05	1.15	1.15	1.10
FAO 56	0.83	0.96	0.96	0.95	0.65

Conclusions

The ratio of total irrigation water to total pan evaporation was 0.68, which is sufficient to meet fully the needs of the crop (100% of the ETc). There was a significant correlations among I, Epan, ETc and ETo. Kc values ranged from 0.56 to 0.96 and were generally lower than those given in the FAO 24. The crop coefficients, calculated on the basis of a water balance kept for 5 months, may save up to 19.4% irrigation water with respect to FAO recommendations. Consequently, irrigation could be scheduled according to the relationship between ETc and Epan or Kc values obtained from the present study for apricot.

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