Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi
1. Uluslararası Tarımsal Yapılar ve Sulama Kongresi Özel Sayısı:140-150, 2018
ISSN 1304-9984, *Araştırma Makalesi*

Comparison of Measured and Estimated Evapotranspiration of Pomegranate Grown Under Mediterranean Conditions

Cihan KARACA[1*] Köksal AYDINŞAKİR[2] Nazmi DİNÇ[2]
Dursun BÜYÜKTAŞ[1] Ruhi BAŞTUĞ[1] Begüm POLAT[1]

[1]Department of Farm Structures and Irrigation, Faculty of Agriculture, Akdeniz University, Antalya
[2]Batı Akdeniz Agricultural Research Institute, Antalya,
*Corresponding Author: cihankaraca@akdeniz.edu.tr

Geliş tarihi: 31/07/2018 Yayına kabul tarihi: 20/11/2018

Abstract: Due to the climatic changes and the decreasing water resources, it is very important to determine the correct crop water requirement and schedule an appropriate irrigation. FAO methodology based on reference evapotranspiration (ET_o) and crop coefficients (k_c) is widely used all over the world to determine crop water requirement. For many of the economically important plants, the k_c coefficients have been determined. In contrast, many equations have been developed at different levels of detail to determine ET_o. For this reason, it is essential to choose the most suitable ET_o equation for a region and a plant. The aim of this study is to determine the crop water requirement (ET_c) of the pomegranate using eleven different ET_o equations (ASCE-StPM, FAO-56PM, 1972-KPen, 1948-Pen, FAO-24Pn, Prs-Tylr, 1957-Makk, 1961-Turc, FAO-24Rd, FAO-24BC and 1985-Harg) based on climatic data and to compare them with the measured crop evapotranspiration (ET_c) value. To determine the best estimation equation of ET_o, some performance criteria were used including coefficient of determination (R^2), root mean square error (RMSE), relative error (RE), mean bias error (MBE), the Willmott index of agreement (d). According to the obtained results of the study, it was determined that the combination based and temperature based methods overestimated the crop water use. The best results were obtained using radiation-based equations. Makkink model (1957-Makk) was the best ET_o equation for pomegranate grown in the Antalya region.

Key words: Antalya, Referance Evapotranspiration, Crop Water Requirement, Crop Water Use

Akdeniz Koşullarında Yetiştirilen Nar'da (Punica granatum) Ölçülen ve Tahmin edilen Evapotranspirasyon Değerlerinin Karşılaştırılması

Özet: Değişen iklim ve azalan su kaynakları nedeniyle, bitkinin gereksinim duyduğu su miktarını doğru belirleyerek uygun bir sulama programı hazırlamak çok önem arz etmektedir. Bitki su ihtiyacını belirlemek için referans evapotranspirasyon (ET_o) ve ürün katsayılarına (k_c) dayalı FAO metodolojisi tüm dünyada yaygın olarak kullanılmaktadır. Ekonomik açıdan önemli bitkilerin çoğunda, k_c katsayıları belirlenmiştir. Buna karşı ET_o'yu belirlemek için farklı seviye ve düzeylerde çok sayıda eşitlik bulunmaktadır. Belirli bir bölgede yetişen bir bitki için bu eşitlikler arasından en uygun eşitliği seçmek çok önemlidir. Bu çalışmanın amacı, iklimsel verilere dayanan on bir farklı ET_o denklemi (ASCE-StPM, FAO-56PM, 1972-KPen, 1948-Pen, FAO-24Pn, Prs-Tylr, 1957, Makk, 1961-Turc, FAO-24Rd, FAO-24BC ve 1985-Harg) kullanarak narın su ihtiyacının (ET_c) belirlemek ve bunları ölçülen değerle karşılaştırmaktır. En iyi ET_o tahmin eşitliğini belirlemek için, determinasyon katsayısı (R^2), tahminin standart hataları (RMSE), göreli hata (RE), ortalama taraflı hata (MBE) ve Willmott indeksini (d) içeren performans kriterleri kullanılmıştır. Araştırmadan elde edilen sonuçlara göre, kombinasyona dayalı ve sıcaklığa dayalı eşitliklerin, bitki su tüketimi değerlerini gereğinden fazla tahmin ettiği belirlenmiştir. En iyi sonuçlar radyasyona dayalı eşitlikler kullanılarak elde edilmiştir Antalya bölgesinde yetişen nar için en iyi ET_o denkleminin Makkink eşitliği (1957-Makk) olduğu belirlenmiştir.

Anahtar kelimeler: Antalya, Kıyas bitki su tüketimi, Sulama suyu ihtiyacı, Bitki su tüketimi

Introduction

Pomegranates have been cultivated in the Mediterranean region for at least 5,000 years. Turkey is one of the important producers and exporters in the world (Kurt and Şahin, 2013). The total pomegranate production of Turkey was 465 200 tons in 2016 which corresponds to 13% of world pomegranate production (Dinc et al., 2018). Turkey’s pomegranate production area from 2004 to 2017 increased by 4.6 times approximately and reached 29 767 ha. Correspondingly, the amount of production has increased about 7 times and reached to 502 606 tons (TUİK, 2018). Pomegranate is one of the most important crops in Antalya province where Mediterranean climate is prevailing. About 33% of the pomegranate exports (33 Million USD) took place in the province of Antalya (AKİB, 2018; BAİB, 2018).

Although pomegranate is a drought-resistant crop (Aseri et al., 2008; Parvizi et al., 2016), it is very important to make a proper irrigation program. The most important step for a proper irrigation program is to determine the crop water requirement (Karaca et al., 2017a, 2017b). Lysimeters are the most reliable and accurate method to determine crop evapotranspiration. However, the most important disadvantage of this method is that it is difficult, expensive and time-consuming (Irmak et al., 2003; Karaca et al., 2017b). That's why, the FAO methodology has been developed in order to make it easier for the growers to determine the ET value using the climate data (Allen et al., 1998). For this purpose, determination of crop evapotranspiration (ET_c) is a two-step approach that quantifies the atmospheric demand through the calculation of the reference evapotranspiration (ET_o) and characterizes the crop growth through a crop coefficient (k_c). The product of these two parameters provides an estimation of the crop evapotranspiration ($ET_c = ET_o \times k_c$) (Gavilán and Castillo-Llanque, 2009).

Numerous methods have been developed at different levels of detail, requiring different data for the calculation of the reference evapotranspiration values. Because of the large number of ET_o equations, these equations have been categorized into five groups based on temperature, radiation, mass transfer, pan evaporation and combination (Karaca et al., 2017c; Pandey et al., 2016; Tabari et al., 2013). Some of those equations need only a single climatic parameter, while others need many climatic parameters (Karaca et al., 2017c). Some of the equations were developed for specific climatic conditions while some of them were applied universally.

The potential usage of these equations depends on availability of necessary meteorological parameters for calculating ET_o in different climate conditions (Farzanpour et al., 2018). The correct determination of the ET_o value is very important in terms of optimum irrigation. Therefore, the effects of irrigation water on yield and quality of pomegranate under the Mediterranean climate conditions were pointed out by many researchers (Ayars et al., 2017; Dinc et al., 2018; Galindo et al., 2018; Intrigliolo et al., 2011). From previous studies, it was reported that yield (Dinc et al., 2018; Mellisho et al., 2012; Parvizi et al., 2014; Tavousi et al., 2015), fruit diameter (Mellisho et al., 2012) and number of fruit (Galindo et al., 2014; Mellisho et al., 2012) decreases as a result of inadequate irrigation applications. Similarly, unlike Dinc et al. (2018), fruit weight was decreased with deficit irrigation application (Intrigliolo et al., 2012; Mellisho et al., 2012; Parvizi et al., 2014). Additionally, it was underlined that the water deficit did not affect the total soluble solid (TSS, ^{o}Brix) total acidity (TA, % citric acid), and colour parameters such as L^*, a^*, b^* and H^* (Dinc et al., 2018; Mellisho et al., 2012). Although pomegranate is known tolerant to drought, Pourghayoumi et al. (2017) put forward that metabolites contents and activities of antioxidant enzymes are changed significantly during severe water stress and recovery. As pointed out by Xie et al. (2015), water stress increased concentration of $NH_3^-NH_4^+$, arginine and proline in leaves.

Because water stress affects many factors, it is very important to determine ET_o and ET_c correctly. From previous studies

(Bhagat and Patil, 2014; Bhagat and Popale, 2016; Jedhe et al., 2014; Meshram et al., 2010), it was reported that Penman Monteith (PM) model was the most widely used model to determine pomegranate evapotranspiration. Meshram et al. (2011b) selected six most commonly used reference crop evapotranspiration models (FAO-56 Penman-Monteith, FAO-24 Modified Penman, Hargreaves Samani, FAO-24 Pan Evaporation, Blaney Criddle, and FAO Radiation) for testing their validity under the Indian step climatic conditions. According to this study, the most accurate result was obtained from the FAO Radiation model, followed by modified Penman method, Blanney Criddle, pan evaporation, Hargreaves-Samani and Penman Monteith. In another study (Meshram et al., 2011a), five different ET_o equations were compared with PM model. It was reported that Hargreaves-Samani model gave the least value of root mean square error.

A comparative study of different evapotranspiration models for the pomegranate grown in the Mediterranean climatic conditions is not available in the literature. Therefore, the aim of this study is to compare eleven equations developed for estimating crop evapotranspiration with the measured data obtained from Dinç et al. (2017) and to find out the best equation representing evapotranspiration of pomegaranate under the Mediterranean climatic conditions.

Materials and Methods

Measured crop evapotranspiration values was obtained in the research conducted by Dinç et al. (2017) between 2013 and 2015 years at Batı Akdeniz Agricultural Research Institute (BATEM) in Antalya, Turkey. The research area is located at 36°56′N latitude, 30°53′E longitude, and an altitude of 28 m above sea level. The climatic data (daily maximum, average, and minimum temperature, relative humidity, average wind speed and average actual sunshine duration) was taken from the meterology station located at a distance of 150 m from the study area. Since there was no sensor to measure the solar radiation in the region, the solar radiation values were calculated using the FAO-56 procedure (Allen et al., 1998) (Equation 1).

$$R_s = k_{Rs}\sqrt{(T_{max} - T_{min})}\, R_a \qquad (1)$$

where k_{Rs} is adjustment coefficient (0.19); T_{max} is maximum air temperature (°C); T_{min} is minimum air temperature (°C), and R_a is extraterrestrial radiation (MJ m^{-2} d^{-1}).

Hicaznar variety (*Punica granatum L.*, var. Hicaz) was used as plant material in this study where the performances of different ET_o equations were tested. The experimental plots were irrigated with drip irrigation system. The details of the experimental procedure can be found in Dinç et al. (2017).

FAO-56 procedure (Allen et al., 1998) was used (Equation 2) to compute crop evapotranspiration using climatic data.

$$ET_c = ET_o x k_c \qquad (2)$$

where ET_c is crop evapotranspiration (mm); ET_o is reference evapotranspiration (mm), and k_c is crop coefficient.

Crop coefficient of the pomegranate plant depending on growing periods were obtained from GTHB (2017) and was shown in Figure 1.

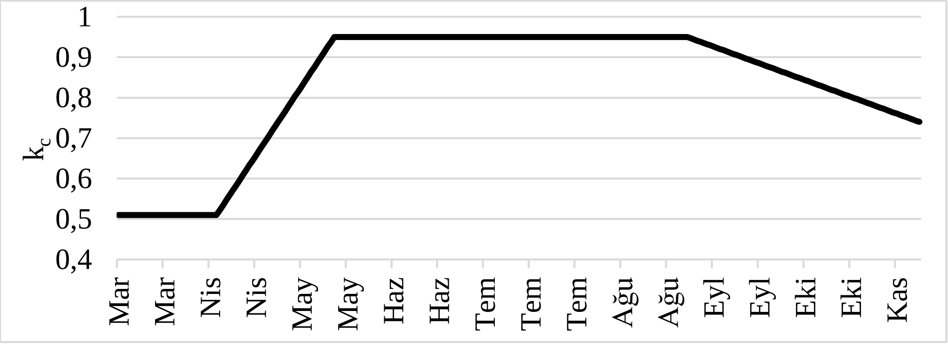

Figure 1. Crop coefficient curve for pomegranate in Antalya (GTHB, 2017).

Daily ET_o values computed using REF-ET software (Allen, 2015) with different equations (Eq 3 through 14) were multiplied by crop coefficients to determine daily ET_c values. Monthly ET_c values were obtained by adding daily ET_c values. These monthly ET_c values were compared with the measured (actual) ET_c values reported by Dinç et al. (2017).

Combination Based Equation	The Standardized ASCE Penman-Monteith Equation (ASCE-StPM)		$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T_a+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$	(3)
	The FAO-56 Penman-Monteith Equation (FAO-56PM)		$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$	(4)
	Kimberly Penman-72 (1972-KPen)		$ET_o = \frac{1}{\lambda}\frac{\Delta}{\Delta + \gamma}(R_n - G) + \frac{1}{\lambda}\frac{\gamma}{\Delta + \gamma} 6.43W_f(e_s - e_a)$	(5)
	Penman 1948 (1948-Pen)		$\lambda E = \frac{\Delta}{\Delta + \gamma}(R_n - G) + K_w \frac{\gamma}{\Delta + \gamma}(a_w + b_w u_2)(e_s - e_a)$	(6)
	FAO-24 Penman (FAO-24Pn)		$ET_o = \frac{\Delta}{\Delta + \gamma}(R_n - G) + \frac{\gamma}{\Delta + \gamma} 2.7W_f(e_s - e_a)$	(7)
Temperature Based Equation	Blaney and Criddle (1950) (FAO-24BC)		$ET_o = a + b[p(0.46T_a + 813)]$	(8)
	Hargreaves and Samani (1985) (1985-Harg)		$ET_o = 0.0023Ra(T_a + 17.8)(T_{max} - T_{min})^{0.424}$	(9)
Radiation Based Equation	Makkink (1957) (1957-Makk)		$ET_o = 0.61\frac{\Delta}{\Delta + \gamma}\frac{R_s}{2.45} - 0.12$	(10)
	Priestley and Taylor (1972) (Prs-Tylr)		$ET_o = 1.26\frac{\Delta}{\Delta + \gamma}\frac{(R_n - G)}{\lambda}$	(11)
	Turc (1961) (1961-Turc)	$RH \geq \%50$	$ET_o = 0.013\frac{T_a}{T_a + 15}\frac{(23.88R_s) + 50}{\lambda}$	(12)
		$RH < \%50$	$ET_o = \left(1 + \frac{50 - RH}{70}\right)0.013\frac{T_a}{T_a + 15}\frac{(23.88R_s) + 50}{\lambda}$	(13)
	FAO-24-Radiation (Doorenboos and Pruitt, 1977)		$ET_o = 0.408a\left(\frac{\Delta}{\Delta + \gamma}\right)R_s - 0.3$	(14)

Where ET_o is reference evapotranspiration (mm day^{-1}); Δ is the slope of the saturation vapor pressure-temperature curve (kPa $^oC^{-1}$); R_n is the net radiation (MJ m^{-2} day^{-1}); G is the soil heat flux (MJ m^{-2} day^{-1}); γ is the psychometric constant (kPa $^oC^{-1}$); e_s is the saturation vapor pressure (kPa); e_a is the actual vapor pressure (kPa); T_a is the average daily air temperature (^{o}C); u_2 is the mean daily wind speed at height of 2 m (m s^{-1}); W_f is wind function (m s^{-1}); a_w and b_w are coefficients of wind function; R_s is the solar radiation (MJ m^{-2} day^{-1}); λ is latent heat of vaporization (MJ kg^{-1}); a and b are correction factors for FAO-24 Blaney-Criddle; a is correction factors for FAO-24 Radiation; R_a is extraterrestrial radiation (MJ m^{-2} day^{-1}); p is daily percentage of annual sunshine hours for Blaney-Criddle; T_{max} is the maximum daily air temperature (^{o}C) and T_{min} is the minimum daily air temperature (^{o}C).

Criteria such as coefficient of determination (R^2), root mean square error (RMSE), relative error (RE), mean bias error (MBE), and the Willmott index of agreement (d) were used to determine the performance of the equations. These criteria are defined as in Eq. 15, 16, 17, 18 and 19. The most accurate result is obtained when RMSE, RE and MBE are equal to 0 and d and R^2 equal to 1.

$$R^2 = \frac{\left[\sum_{i=1}^{n}(X_i - \ddot{X})\left(Y_i - \hat{Y}\right)\right]^2}{\sum_{i=1}^{n}(X_i - \ddot{X})^2 \sum_{i=1}^{n}\left(Y_i - \hat{Y}\right)^2} \tag{15}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{n}} \tag{16}$$

$$RE = \frac{RMSE}{\bar{\hat{Y}}} \tag{17}$$

$$MBE = \frac{\sum_{i=1}^{n}(X_i - Y_i)}{n} \tag{18}$$

$$d = 1 - \frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{\sum_{i=n}^{n}\left(\left(X_i - \hat{Y}_i\right) + \left(Y_i - \hat{Y}_i\right)\right)^2} \tag{19}$$

Where n is number of observations, X_i is estimated ET_c, Y_i is measured ET_c and $\ddot{X}$ is mean value of estimated ET_c, $\hat{Y}$ is mean value of measured ET_c.

Results and Discussion

The measured ET_c values reported by Dinç et al. (2017) and the estimated ET_c values computed using 11 different ET_o equations (ASCE-StPM, FAO-56PM, 1972-KPen, 1948-Pen, FAO-24Pn, Prs-Tylr, 1957-Makk, 1961-Turc, FAO-24Rd, FAO-24BC and 1985-Harg) are presented in Table 1. Seasonal ET_c values reported by Dinç et al. (2017) ranged from 698.70 to 756.60 mm. The highest monthly ET_c was found to be in July in 2013 and 2014 while it was in August in 2015. The lowest monthly ET_c values were determined in November in all of the three experimental years.

Evapotranspiration of pomegranate were reported to vary from 171.0 to 557.0 mm by Bhantana and Lazarovitch (2010) in Negev, Israel; from 200 to 600 mm by (Khattab et al., 2011) in Egypt; and from 645 to 932 mm by (Ayars et al., 2017) in California, USA. Results obtained in this study and obtained from already published studies for similar climatic conditions are close to each other. The differences between reported evepotranspiration values can be attributed to the climatic conditions as well as the varieties.

In 2013, 2014 and 2015, seasonal estimated ET_c values varied from 931.6 to 1407.6 for combination methods, from 626.4 to 1255.3 for radiation based and 887.7 to 1286.6 for temperature based methods. The ET_c values calculated by the combination equations were very high compared to the measured ET_c values. On the other hand, combination equations in previous studies were widely used to estimte the ET_c value of the pomegranate (Bhagat and Patil, 2014; Jedhe et al., 2014; Mellisho et al., 2012; Noitsakis et al., 2016; Parvizi et al., 2014). In addition, some researchers (Mellisho et al., 2012; Meshram et al., 2011a, 2011b; Noitsakis et al., 2016) used climate based equations to estimate the value of ET_c of pomegranate.

The closest estimated ET_c to the measured ET_c was obtained in 2014 using radiation-based methods. The use of radiation-based equations to compute ET_c was proposed in a study in Antalya by Karaca et al. (2017a). Similarly, Meshram et al. (2011b) reported that the equations based on radiation are the best method to determine the pomegranate ET_c. They also reported that the combination based Penman monteith equation gave poor performance.

The results regarding criteria to evaluate the equations are given in Table 2. After examining Table 2, the best equation to estimate ET_c in each equation group is given in Figure 1.

Table 1. Comparison of monthly measured and estimated evapotranspiration (ET_c) based on various ET_0 methods for pomegranate plant (mm)

Year (Yıl)	Month (Ay)	Measured	Combination based methods					Radiation based methods				Temp. based meth.	
		Dinç et. al. 2017	ASCE-StPM	FAO-56PM	1972-KPen	1948-Pen	FAO-24Pn	FAO-24Rd	Prs-Tylr	1957-Makk	1961-Turc	FAO-24BC	1985-Harg
2013	March	41.5	29.4	29.8	32.6	33.4	38.1	32.9	26.5	23.1	27.3	29.6	29.1
	April	67.7	78.2	79.0	83.3	84.1	100.5	92.4	71.3	61.3	72.7	84.1	71.7
	May	80.8	148.8	150.3	154.5	161.1	194.8	173.8	146.1	116.7	139.4	164.6	138.1
	June	87.8	182.7	184.3	188.9	198.0	238.6	209.2	174.7	137.5	167.0	205.0	158.0
	July	151.4	221.4	223.3	229.6	229.5	264.5	238.5	180.8	146.1	191.2	247.4	173.0
	August	139.2	205.9	208.6	214.0	210.9	246.1	220.9	163.0	134.8	175.6	237.9	172.4
	September	79.5	156.0	158.7	169.1	157.7	183.2	161.6	108.9	98.8	127.2	174.8	118.5
	October	77.6	105.7	108.1	123.2	105.0	117.4	103.7	52.2	62.2	84.2	116.8	74.1
	November	31.1	22.0	23.0	25.4	20.4	24.4	22.3	11.7	15.0	19.5	26.4	18.2
	Seasonal	**756.6**	**1150.1**	**1165.1**	**1220.6**	**1200.1**	**1407.6**	**1255.3**	**935.2**	**795.5**	**1004.1**	**1286.6**	**953.1**
2014	March	43.5	37.0	37.4	42.9	40.9	45.3	38.1	27.6	25.2	30.3	36.3	32.4
	April	75.0	56.9	57.6	59.3	65.5	76.4	66.2	61.4	49.0	58.3	60.1	64.3
	May	70.5	109.9	111.0	111.5	123.4	144.8	122.9	117.3	88.9	106.5	117.6	120.4
	June	64.7	177.8	179.0	185.2	187.3	217.8	183.3	145.4	113.8	144.5	195.5	162.7
	July	138.3	157.4	159.2	158.8	168.1	194.7	159.6	148.0	108.6	134.8	173.6	159.1
	August	133.9	157.5	159.9	160.5	164.0	191.3	156.0	138.5	103.9	129.4	175.4	154.8
	September	63.7	124.0	126.3	133.3	127.9	142.5	110.5	89.9	72.5	94.3	128.4	104.7
	October	78.0	89.3	91.7	99.8	89.4	97.0	78.4	52.6	51.0	70.6	95.0	71.2
	November	31.1	21.8	22.7	24.9	20.5	24.1	20.0	10.9	13.5	17.7	24.2	18.1
	Seasonal	**698.7**	**931.6**	**944.8**	**976.2**	**987**	**1133.9**	**935.0**	**791.6**	**626.4**	**786.4**	**1006.1**	**887.7**
2015	March	39.4	31.5	31.8	36.1	34.7	37.6	30.5	24.1	20.7	25.3	28.6	26.6
	April	66.0	77.0	77.4	87.7	85.5	93.9	79.8	59.0	50.1	62.1	74.7	65.1
	May	82.6	128.3	129.3	133.3	140.6	165.6	140.5	118.4	93.1	115.2	138.6	127.3
	June	94.4	153.1	154.2	157.0	166.1	193.5	161.1	137.1	105.1	129.8	167.1	148.0
	July	109.6	186.3	187.8	189.7	193.4	221.1	189.6	151.1	117.5	154.0	209.0	173.3
	August	119.6	172.8	174.9	177.1	178.4	198.7	163.3	130.7	102.1	135.3	187.4	152.7
	September	95.7	115.0	117.6	120.4	121.2	140.8	117.1	98.4	79.5	102.6	133.3	115.7
	October	80.0	85.2	87.9	93.8	84.5	97.0	78.3	54.3	51.9	68.3	94.7	72.8
	November	33.2	30.2	31.1	34.7	28.2	31.1	23.8	10.0	14.4	20.8	30.5	19.5
	Seasonal	**720.5**	**979.4**	**992.0**	**1029.8**	**1032.6**	**1179.3**	**984**	**783.1**	**634.4**	**813.4**	**1063.9**	**901**

Table 2. Criteria used to evaluate the performance of the equations.

	Equation	R^2	RMSE	RE	MBE	d
Combination	ASCE-StPM	0.72	48.79	0.61	-32.79	0.82
	FAO-56PM	0.73	50.05	0.62	-34.30	0.81
	1972-KPen	0.71	53.83	0.67	-38.92	0.79
	1948-Pen	0.71	54.87	0.68	-38.66	0.79
	FAO-24Pn	0.70	75.52	0.94	-57.21	0.67
Radiation	Prs-Tylr	0.68	34.85	0.43	-12.37	0.90
	1957-Makk	0.69	23.02	0.29	4.43	0.95
	1961-Turc	0.72	33.17	0.41	-15.86	0.90
	FAO-24Rd	0.69	55.42	0.69	-36.98	0.79
Temperature	FAO-24BC	0.73	61.65	0.77	-43.74	0.75
	1985-Harg	0.72	37.31	0.46	-20.96	0.88

R^2: coefficient of determination, RMSE: root mean square error, RE: relative error, MBE: mean bias error, and d: the Willmott index of agreement.

When the MBE value was evaluated, all equations except 1957-Makk overestimated the value of ET_c (Table 2). When the equations based on the combination were examined, the highest values of R^2, d and the lowest values of RMSE, RE, and MBE were determined in the ASCE-StPM and FAO56 equations. The FAO-24Pn method with the lowest R^2 and d and the highest RMSE, RE, and MBE was the equation estimated the lowest ET_c value. This was caused by the fact that Penman equation overestimates in humid regions (Kashyap and Panda, 2001). 1957-Makk was the most accurate estimation equation among radiation based equations. However, FAO-24Rd equation was the worst-performing equation among radiation-based equations. It was found that the performance of the 1985-Harg equation was higher than that of the FAO-24BC equations among temperature-based equations. It was reported that the 1985-Harg equation was used to determine the ET_c value of a large number of plants, including pomegranate, in the Model Guidelines for River Basin Management Planning in Armenia (USAID, 2008). For this reason, the 1985-Harg equation can be used in regions such as Antalya where only temperature data is available.

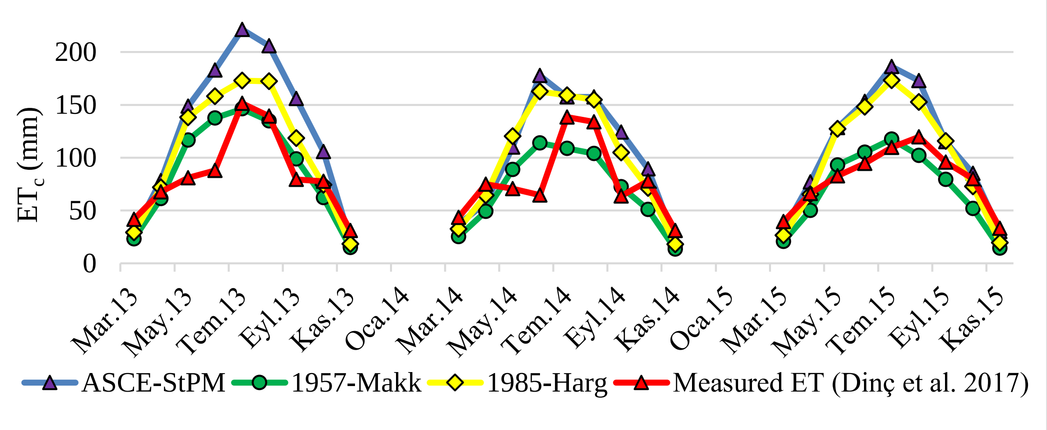

Figure 1. Comparing measured and the best equation estimating ET_c for each equation group.

When Table 2 and Figure 1 were evaluated, it is shown that ASCE-StPM and 1985-Harg equations estimated the ET_c values considerably higher than measured values in all years. It was determined that

1957-Makkink was the best equation in all growing periods

Conclusions

In this study, the daily ET_o value was estimated with 11 different equations (ASCE-StPM, FAO-56PM, 1972-KPen, 1948-Pen, FAO-24Pn, Prs-Tylr, 1957-Makk, 1961-Turc, FAO-24Rd, FAO-24BC and 1985-Harg) for three growing seasons and then the ET_c value was determined by multiplying these values by the region specific k_c value. Montly values were calculated by adding daily values and compared with measured ET_c values.

In almost all previous studies, it was reported that the equations based on the combination method were used for the irrigation programming of the pomegranate. However, it was determined that these equations overestimated the ET_c value in the Antalya region where the Mediterranean climate is prevailing. It was determined that the equations based on the temperature also overestimated the measured ET_c values. However, in areas where only temperature data is available, 1985-Harg equation can be used. The best estimate of ET_c within three growing periods was obtained with radiation-based equations. Since 1957-Makk ET_0 equation gave the closest estimated results to the measured evapotranspiration for pomegranate grown in the Antalya region where Mediterranean climate is prevailing, it is suggested for crop evapotranspiration estimations.

References

AKİB, 2018. 2016/2017 Ocak-Aralik Dönemi, Yaş Meyve Ve Sebze Sektörü Türkiye Geneli Değerlendirme Raporu.

Allen, R.G., 2015. REF-ET: Reference Evapotranspıratıon Calculatıon Software for FAO and ASCE Standardized Equations, University of Idaho.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration: Guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56. FAO, Roma.

Aseri, G.K., Jain, N., Panwar, J., Rao, A. V., Meghwal, P.R., 2008. Biofertilizers improve plant growth, fruit yield, nutrition, metabolism and rhizosphere enzyme activities of Pomegranate (Punica granatum L.) in Indian Thar Desert. Scientia Horticulturae 117, 130–135. doi:10.1016/j.scienta.2008.03.014

Ayars, J.E., Phene, C.J., Phene, R.C., Gao, S., Wang, D., Day, K.R., Makus, D.J., 2017. Determining pomegranate water and nitrogen requirements with drip irrigation. Agricultural Water Management 187, 11–23. doi:10.1016/j.agwat.2017.03.007

BAİB, 2018. Ürün Grubu Bazında İhracat Raporu [WWW Document]. Bati Akdeniz İhracatçılar Birliği Genel Sekreterliği. URL http://www.baib.org.tr/tr/oi_istmalgr.asp (accessed 4.18.18).

Bhagat, A., Patil, M., 2014. Water excess/deficit studies at different seasons (bahars) of pomegranate (Punica granatum L.) cultivation. International Journal of Agricultural Engineering 7, 323–327.

Bhagat, A.D., Popale, P.G., 2016. Water requirement of pomegranate (Punica granatumL.) orchards for season August-March (Mrig bahar). International Journal of Agricultural Engineering 9, 130–139. doi:10.15740/HAS/IJAE/9.2/130-139

Bhantana, P., Lazarovitch, N., 2010. Evapotranspiration, crop coefficient and growth of two young pomegranate (Punica granatum L.) varieties under salt stress. Agricultural Water Management 97, 715–722. doi:10.1016/j.agwat.2009.12.016

Blaney, H.F., Criddle, W.D., 1950. Determining Water Requeriments in Irrigated Areas from Climatological and Irrigation Data. Soil Conservation Service. US Department of Agriculture technical, p 48.

Dinc, N., Aydinsakir, K., Isik, M., Bastug, R., Ari, N., Sahin, A., Buyuktas, D., 2018. Assessment of different irrigation strategies on yield and quality characteristics of drip irrigated pomegranate under mediterranean conditions. Irrigation Science 36, 87–96. doi:10.1007/s00271-017-0565-5

Dinç, N., Işik, M., Ari, N., Alican, M., Şahin, A., Baştuğ, R., 2017. Antalya Koşullarinda Damla Sulama Yöntemi Ile Sulanan Narin Sulama Programinin Oluşturulmasi, Proje Sonuç Raporu- Bati Akdeniz Tarimsal Araştirma Enstitüsü Müdürlüğü.

Doorenboos, J., Pruitt, W.O., 1977. Guidelines for Predicting Crop Water Requirements, Irrigation and Drainage Paper 24. Land and Water Development Division FAO Rome 24, 144.

Farzanpour, H., Shiri, J., Sadraddini, A.A., Trajkovic, S., 2018. Global comparison of 20 reference evapotranspiration equations in a semi-arid region of Iran. Hydrology Research 49.

Galindo, A., Calín-Sánchez, Á., Collado-González, J., Ondoño, S., Hernández, F., Torrecillas, A., Carbonell-Barrachina, Á.A., 2014. Phytochemical and quality attributes of pomegranate fruits for juice consumption as affected by ripening stage and deficit irrigation. Journal of the Science of Food and Agriculture 94, 2259–2265. doi:10.1002/jsfa.6551

Galindo, A., Collado-González, J., Griñán, I., Corell, M., Centeno, A., Martín-Palomo, M.J., Girón, I.F., Rodríguez, P., Cruz, Z.N., Memmi, H., Carbonell-Barrachina, A.A., Hernández, F., Torrecillas, A., Moriana, A., López-Pérez, D., 2018. Deficit irrigation and emerging fruit crops as a strategy to save water in Mediterranean semiarid agrosystems. Agricultural Water Management 202, 311–324. doi:10.1016/j.agwat.2017.08.015

Gavilán, P., Castillo-Llanque, F., 2009. Estimating reference evapotranspiration with atmometers in a semiarid environment. Agricultural Water Management 96, 465–472. doi:10.1016/j.agwat.2008.09.011

GTHB, 2017. Türkiyede'de Sulanan Bitkilerin Bitki Su Tüketimleri, T.C Gıda Tarım ve Hayvancılık Bakanlığı.

Hargreaves, G.., Samani, Z.., 1985. Reference Crop Evapotranspiration from Temperature. Applied Engineering in Agriculture 1, 96–99. doi:10.13031/2013.26773

Intrigliolo, D.S., García, J., Lozoya, A., Bonet, L., Nicolás, E., Alarcón, J.J., Bartual, J., 2012. Regulated deficit irrigation in pomegranate (Punica granatum) trees. Yield and its components. Options Méditerranéennes. Séries A: Mediterranean Seminars 103, 101–106.

Intrigliolo, D.S., Nicolas, E., Bonet, L., Ferrer, P., Alarcón, J.J., Bartual, J., 2011. Water relations of field grown Pomegranate trees (Punica granatum) under different drip irrigation regimes. Agricultural Water Management 98, 691–696. doi:10.1016/j.agwat.2010.11.006

Irmak, S., Irmak, A., Allen, R.G., Jones, J.W., 2003. Solar and Net Radiation-Based Equations to Estimate Reference Evapotranspiration in Humid Climates. Journal of Irrigation and Drainage Engineering 129, 336–347. doi:10.1061/(ASCE)0733-9437(2003)129:5(336)

Jedhe, S.H., Jadhav, S.B., Mandale, V.P., 2014. Weekly water balance of pomegranate in Parbhani district. Asian Journal of Environmental Science 9, 103–105. doi:10.15740/HAS/AJES/9.2/103-105

Karaca, C., Büyüktaş, D., Baştuğ, R., Aydinşakir, K., Büyüktaş, K., 2017a. Comparing Eight Different ETo Equations with Penman-Monteith for Antalya, Turkey. 2nd International Conference On Advances in Natural and Applied Sciences, Antalya, TURKEY 189.

Karaca, C., Tekelioğlu, B., Büyüktaş, D., 2017b. Sürdürülebilir Tarımsal Üretim için Toprak Nem Sensörlerinin Etkin Kullanımı. Academia Journal of Engineering and Applied Sciences 2, 33–41.

Karaca, C., Tekelioğlu, B., Büyüktaş, D., Baştuğ, R., 2017c. Kıyas Bitki Su Tüketiminin Hesaplanmasında Kullanılan Eşitliklerin Değerlendirilmesi. Akademia Mühendislik ve Fen Bilimleri Dergisi 144–161.

Kashyap, P.S., Panda, R.K., 2001. Evaluation of Evapotranspiration Estimation Methods and Development of Crop-Coefficients for Potato Crop in a Sub-Humid Region. Agricultural Water Management 50, 9–25. doi:10.1016/S0378-3774(01)00102-0

Khattab, M.M., Shaban, A.E., El-Shrief, A.H., Mohamed, A.S.E.-D., 2011. Growth and Productivity of Pomegranate Trees under Different Irrigation Levels I: Vegetative Growth and Fruiting. Journal of Horticultural Science & Ornamental Plants 3, 194–198.

Kurt, H., Şahin, G., 2013. Bir Ziraat Coğrafyasi Çalişmasi: Türkiye’de Nar (Punica granatum L.) Tarimi. Marmara Coğrafya Dergisi 27, 551–574.

Makkink, G.F., 1957. Testing the Penman Formula by Means of Lysimeters. Journal Inst. Water Engineering 11, 277–288.

Mellisho, C.D., Egea, I., Galindo, A., Rodríguez, P., Rodríguez, J., Conejero, W., Romojaro, F., 2012. Pomegranate (Punica granatum L.) fruit response to different deficit irrigation conditions. Agricultural Water Management 114, 30–36. doi:10.1016/J.AGWAT.2012.06.010

Meshram, D.T., Gorantiwar, S.D., Jadhav, V.T., Chandra, R., 2011a. Evaluation of ET Models to Study Water Requirement of Pomegranate (Punica Granatum L.) For Satara District of Maharashtra. Indian Journal of Soil Conservation 39, 142–148.

Meshram, D.T., Gorantiwar, S.D., Silva, Jaime A. Teixeira Jadhav, V.T., Chandra, R., 2010. Water Management in Pomegranate. Fruit, Vegetable and Cereal Science and Biotechnology 4, 106–112.

Meshram, D.T., Mittal, H.K., Purohit, R.C., Gorantiwar, S.D., 2011b. Water Requirement of Pomegranate (Punica granatum L.) for Solapur District of Maharashtra State. Acta Hortic. 890, 311–322.

Noitsakis, B., Chouzouri, A., Papa, L., Patakas, A., 2016. Pomegranate physiological responses to partial root drying under field conditions. Emirates Journal of Food and Agriculture 28, 410–414. doi:10.9755/ejfa.2016-04-343

Pandey, P.K., Dabral, P.P., Pandey, V., 2016. Evaluation of reference evapotranspiration methods for the northeastern region of India. International Soil and Water Conservation Research 4, 52–63. doi:10.1016/j.iswcr.2016.02.003

Parvizi, H., Sepaskhah, A.R., Ahmadi, S.H., 2016. Physiological and growth responses of pomegranate tree (Punica granatum (L.) cv. Rabab) under partial root zone drying and deficit irrigation regimes. Agricultural Water Management 163, 146–158. doi:10.1016/j.agwat.2015.09.019

Parvizi, H., Sepaskhah, A.R., Ahmadi, S.H., 2014. Effect of drip irrigation and fertilizer regimes on fruit yields and water productivity of a pomegranate (Punica granatum (L.) cv. Rabab) orchard. Agricultural Water Management 146, 45–56. doi:10.1016/J.AGWAT.2014.07.005

Pourghayoumi, M., Rahemi, M., Bakhshi, D., Aalami, A., Kamgar-Haghighi, A.A., 2017. Responses of pomegranate cultivars to severe water stress and recovery: changes on antioxidant enzyme activities, gene expression patterns and water stress responsive metabolites. Physiology and Molecular Biology of Plants 23, 321–330. doi:10.1007/s12298-017-0435-x

Priestley, C., Taylor, R., 1972. On the Assessment of Surface Heat Flux and Evaporation Using Large-Scale Parameters. Monthly Weather Review 100, 81–92. doi:10.1175/1520-0493(1972)100<0081:OTAOSH>2.3.CO;2

Tabari, H., Grismer, M.E., Trajkovic, S.,

2013. Comparative Analysis of 31 Reference Evapotranspiration Methods Under Humid Conditions. Irrigation Science 31, 107–117. doi:10.1007/s00271-011-0295-z

Tavousi, M., Kaveh, F., Alizadeh, A., Babazadeh, H., Tehranifar, A., 2015. Effects of Drought and Salinity on Yield and Water Use Efficiency in Pomegranate Tree. J. Mater. Environ. Sci. 6, 1975–1980.

TUİK, 2018. Bitkisel Üretim İstatistikleri. Türkiye İstatistik Kurumu. URL https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr (accessed 4.18.18).

Turc, L., 1961. Estimation of İrrigation Water Requirements, Potential Evapotranspiration: A Simple Climatic Formula Evolved Up to Date. Annals of Agronomy 2, 13–49.

USAID, 2008. Model Guidelines for River Basin Management Planning in Armenia. United States Agency for International Development Armenia Mission 221.

Xie, S., Lu, X., Zhao, X., Nie, Q., 2015. Effect of Water Stress on Vegetative Growth and Nitrogen Metabolism of Pomegranate Seedling. Acta Horticulturae 1089, 63–69.