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Determination of Crop Evapotranspiration and Single Crop Coefficients of Maize Using by a Weighing Lysimeter in Mediterranean Region in Turkey

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ABSTRACT

Today, accurate irrigation approaches are of great importance due to climate change and a decrease in water resources. FAO methodology based on reference evapotranspiration (ET_0) and crop coefficients (K_c) are commonly used worldwide to determine crop water requirements (ET_c). K_c values of different plants for different areas can be taken from FAO-56 and FAO-24. However, crop coefficients must be determined or calibrated for every relevant region because the climate conditions in the field and surrounding conditions may not be similar to the standard conditions. For this purpose, what crop evapotranspiration and crop coefficients would be in the case of timely (first crop) and late sowing (second crop) of maize were investigated in this study in Adana where the Mediterranean climate characteristics are prevalent during 2012 and 2013 years. A weighing lysimeter was used to obtain ET_c and K_c of maize. ET_0 was calculated using the FAO-56 Penman-Monteith (PM56) method. The results showed that the duration of initial, development, mid-season, and end-season growth stages for first crop maize was 22, 26, 43, and 37 days totaling 128 days, and for second crop maize, it was 14, 24, 42, and 38 days totaling 118 days. The ET_c value of the second crop maize was 14% higher than that value of the first crop maize. The mean K_c values were 0.74, 0.92, 1.63, and 0.42 at the initial, development, mid-season, and end-season growth stages for the first crop maize, whereas they were determined as 0.46, 0.89, 1.68, and 0.92, respectively for the second crop maize.

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Türkiye'de Akdeniz Bölgesinde Tartılı Lizimetre Kullanılarak Mısır Su Tüketiminin ve Bitki Katsayılarının Belirlenmesi

ÖZET

Günümüzde, iklim değişikliği ve su kaynaklarının azalması sorunları nedeniyle doğru sulama yaklaşımları büyük önem taşımaktadır. Kıyas bitki su tüketimi (ET_0) ve bitki katsayılarına (K_c) dayalı FAO metodolojisi, bitki su gereksinimlerini (ET_c) belirlemek için dünya genelinde yaygın olarak kullanılmaktadır. Farklı bölgeler için farklı bitkilerin K_c değerleri FAO-56 ve FAO-24'ten alınabilir. Ancak, tarladaki iklim koşulları ile çevre koşulları standart şartlara benzemeyebileceği için her bölge için bitki katsayılarının belirlenmesi ya da kalibre edilmesi gerekir. Bu amaçla, 2012 ve 2013 yıllarında Akdeniz iklimi özelliklerinin hakim olduğu Adana'da yapılan bu çalışmada, zamanında (ilk ürün) ve geç ekilen (ikinci ürün) mısırın bitki su tüketimi ve bitki katsayıları belirlenmiştir. Mısır ET_c ve K_c'sini elde etmek için tartılı lizimetre kullanılmıştır. ET_0, FAO-56 Penman-Monteith (PM56) yöntemi kullanılarak hesaplanmıştır. Birinci ürün mısırda başlangıç, gelişme, mevsim ortası ve mevsim sonu büyüme dönemleri sırasıyla 22, 26, 43 ve 37 gün, toplamda 128 gün; ikinci ürün mısırda ise, 14, 24, 42 ve 38 gün ve toplamda 118 gün olarak gerçekleşmiştir. İkinci ürün mısırın ET_c değeri, birinci ürün mısırın ET_c değerinden %14

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daha yüksek bulunmuştur. Başlangıç, gelişme, mevsim ortası ve mevsim sonu büyüme dönemlerinde birinci ürün mısır için ortalama K_c değerleri 0.74, 0.92, 1.63 ve 0.42 iken, ikinci ürün için bu değerler sırasıyla 0.46, 0.89, 1.68 ve 0.92 olarak belirlenmiştir.

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INTRODUCTION

Knowledge of crop evapotranspiration is important for preparing suitable irrigation scheduling and obtaining high-level agricultural production (Ünlü et al., 2010). Crop evapotranspiration must be accurately determined in field conditions. However, it is difficult because evapotranspiration depends on surrounding conditions, climate parameters, plant properties, and water management (Shahrokhnia and Sepaskhah, 2013).

There are several methods in use to determine ET_c directly and indirectly. ET_c can be directly measured using water budget methods (lysimeter and field plots, etc), micro-climatological methods (aerodynamic, BREB, Eddy Co-variance, etc), physiological methods (canopy chamber, and sap flow measurement, etc). The indirect methods use the mathematical models based on the meteorological parameters for estimating crop ET_c (Kanber et al., 2007). Lysimeters are the most accurate and most reliable to measure crop evapotranspiration but are expensive and intrusive to install and operate, and difficult as well as time-consuming. Therefore, the using of the indirect methods to determine ET_0 and K_c are the most practical approaches for estimating ET_c (Allen et al., 1998). ET_0 is usually estimated from weather data. The PM56 equation, which gives results similar to the data measured by lysimeter, is being accepted by FAO as a standard method for predicting ET_0 in all climatic conditions. (Allen et al., 1998).

K_c is an important parameter for determining ET_c (Kjaersgaard et al. 2008; Piccini et al., 2009). There are two types of crop coefficients. These are the single and dual crop coefficients. The single crop coefficient is experimentally determined as the ratio of ET_c to ET_0 (Doorenbos and Kassam, 1984). K_c changes during the growing period because of the variations in the percentage of cover of vegetation (Reddy, 2015). While the plant grows, evapotranspiration changes during the growth period because of the changing of ground cover of plant, crop height, and leaf area. Phenological stages are generally divided into four phases during the growth period of the plant. These are initial, crop development, mid-season, and end-(late) season (Allen et al., 1998).

The crop coefficients (K_c) are available in the literature (Allen et al., 1998). For example, K_c, ET_c values of different plants for different regions can be found in FAO-56 and FAO-24. However, K_c should be calibrated since the climate in the field conditions differs from the standard conditions (Shahrokhnia and Sepaskah, 2013; Reddy, 2015). For this reason, many researchers have been studying to determine local K_c and to compare them against to values given in FAO publications.

To date, a lot of studies have been conducted in different locations of the world on the determination of K_c, ET_c of plants (Vaughan, et al., 2007; Lopez-Urea et al., 2009; Ünlü et al., 2010; Mehta and Pandey, 2015). Various crops, from perennial crops to annual crops, were studied in various places. In Bangladesh, Islam and Hossain (2010) determined the crop coefficients of hybrid maize as 0.38, 0.87, 1.36, and 0.75 for initial, development, mid- and end-season stages, respectively. In the same study, observed crop coefficient values differed in somewhat from those suggested by FAO. Shahrokhnia and Sepaskhah (2013) used the weighing lysimeter for determining K_c and ET_c of maize under Fars-Iran conditions. According to results, the single crop coefficients were 0.48, 1.40, 0.31 for the initial, mid-season, and end-season stages, respectively. Based on the review of the research conducted over the years, one can conclude that the measured K_c values for initial and mid-season stages differed from the values suggested by FAO. Piccinni et al. (2009) have determined the crop coefficients (K_c) and evapotranspiration (ET_c) of maize using the weighing lysimeters at the high plains of Texas. The results showed that seasonal ET_c of maize changed from 441 to 641 mm. Measured K_c values ranged between 0.2 and 1.2. In a study used lysimeter by Tyagi et al. (2003), the estimated values of K_c for maize by the Penman–Monteith method at the four crop growth stages; namely, initial, crop development, mid-season and maturity, were 0.55, 1.00, 1.23 and 0.64, respectively. In another study used lysimeter by Abedinpour (2015), the K_c values for the initial, crop development, mid-season, and late stages were 0.40–

0.60, 0.70–0.80, 1.1–1.21, and 0.50–0.65, respectively, whereas the values reported for maize by FAO are 0.3, 1.2, 0.3–0.6 for the initial, mid-season and late stage, respectively.

When it comes to Turkey, maize is the crop with the largest cultivation area after wheat and barley. Adana is the second province with the highest maize production as of 2019 with a share of 15%. In the region, maize is produced as the main crop and second crop (Anonymous, 2020). Thus, it is essential to schedule irrigation appropriately in maize, which is such an important product in the region. In line with this purpose, in this study performed in the Çukurova region in Turkey, it is aimed to determine the ET_c and K_c of first crop and second crop maize using a large-scale continuous weighing lysimeter and to compare them against the values obtained by modified-FAO equations.

MATERIAL and METHOD

The experiment was performed at the Research Field of the Çukurova University, Adana, Turkey. According to the long-term mean climate parameters of the meteorology station between 1970 and 2018, annual precipitation was 668.7 mm, most of it occurs throughout the winter season; relative humidity (RH_{long}) was 66%; air temperature (T_{long}) was 19.3 °C; wind speed (u_{long}) was 1.4 m s^{-1}; daily evaporation (e_{long}) was 4.2 mm; and daily sunshine (SS_{long}) was 7.4 h (MGM, 2019).

During the study, all the climatic data were obtained by the climate station constituted in the experimental field. The trial was conducted in 2012 and 2013. Averaged meteorological parameters for those years were: annual precipitation (P_{2012} and P_{2013}) of 1073 and 413 mm; average temperature (T_{2012} and T_{2013}) of 19.5 and 19 °C; mean humidity (RH_{2012} and RH_{2013}) of 63.9 and 63.2%; wind speed (u_{2012} and u_{2013}) of 0.7 and 0.81 m s^{-1}; daily evaporation (e_{2012} and e_{2013}), 4.1 mm for both years; and daily sunshine (SS_{2012} and SS_{2013}) of 8.7 and 9.6 h, respectively for growing seasons. The monthly mean climatic values during the experimental years were given in Table 1.

Table 1. Monthly mean climate data during the growing periods in the trial years
Çizelge 1. Deneme yıllarında mısır büyüme dönemlerinde aylık ortalama iklim verileri

Years(Yıl)		April	May	June	July	August	September	October
2012	T (⁰C)	18.0	21.2	26.1	28.9	29.6	27.4	22.7
	VPD (kPa)	0.79	0.80	1.47	1.68	1.48	1.08	0.64
	RH (%)	62.1	68.5	65.2	63.1	59.6	59.2	60.9
	Rn ($MJ.m^{-2}.d^{-1}$)	10.4	11.7	15.3	15.0	13.6	10.5	5.9
	P (mm)	18.0	80.8	7.8	4.2	0.0	0.0	71.2
	u_2 ($m.s^{-1}$)	1.0	1.1	0.6	0.4	0.5	0.5	0.4
	I (mm)			160.6	142.7			
2013	T (⁰C)			24.9	27.4	27.7	24.5	19.1
	VPD (kPa)			1.06	1.13	1.21	1.14	1.05
	RH (%)			66.3	69.1	67.4	62.9	52.6
	Rn ($MJ.m^{-2}.d^{-1}$)			15.2	15.8	14.1	10.5	6.5
	P (mm)			0.6	0.0	18.6	40.8	56.8
	u_2 ($m.s^{-1}$)			1.3	1.1	0.5	0.4	0.5
	I (mm)				111.3	218.7		

Note: T: Temperature (Sıcaklık), VPD: Saturation vapor pressure deficit (doygun buhar basıncı açığı), RH: Relative humidity (Oransal nem), Rn: Net radiation (Net radyasyon), P: Precipitation (Yağış), u_2: Wind speed at 2 m height (2 m yükseklikteki rüzgar hızı), I:Irrigation (Sulama)

The soil of the experimental area is cataloged as Palexerollic Chromoxerert. The soil texture in the experimental area is clay and the soil have poor organic matter. There is no salinity and drainage problem (Ünlü, 2000). For 210 cm depth, average field capacity, and permanent wilting point were 36.6% and 18.7%, respectively. The average bulk density of soil was about 1.22 $g.cm^{-3}$. All the physical and chemical soil characteristics were determined by the routine laboratory and field methods given by USSL (1954), Hizalan and Ünal (1966), Güzel (1982). The soil placed in the lysimeter was taken from the same land (Ünlü et al., 2010).

Weighing lysimeter

To measure crop evapotranspiration, a precision weighing lysimeter was used in the study. The dimensions of the lysimeter were (2x2x2.5) m. Its accuracy was 0.025 mm, and it was located in the 1.2 ha field covered by irrigated maize and the upwind fetch distance was 110 m. A neutron probe was placed inside the tank in the lysimeter to the continual measurement of soil water content in the soil profile (Howell et al., 1985). In the bottom of the tank, there was a washed pea pebble layer and a sand layer above of its. A free drainage system was placed into the gravel layer, and the vacuum drainage system was established between the soil and sand. The weighing equipment was programmed to take and record weight readings every 5 seconds for calculating hourly and daily evapotranspiration. The weight data registered on the visor were stored in a data logger (Ünlü et al., 2010). Successive weighing data, irrigation, and drainage water amounts were used to determine the crop evapotranspiration in the lysimeter.

Crop evapotranspiration measurements

Dekalb 6630 maize cultivar were planted on the 118th day of the year (DOY) of 2012 with 0.7 m row distance and 0.18 m spacing as the first crop and on the 169th DOY of 2013 with the same distance and spacing as the second crop after wheat. The maize cultivar was planted by hand in the lysimeter and its surrounding area of 6 m. It was planted in the other parts of the field with the pneumatic sowing machine, simultaneously. Rows were directed from north to south. Around the lysimeter, 8 to 10 labeled areas which were 1 m^2 each one, were selected for observations of the variation between lysimeter and field conditions during the seasons. Some observations on the growth of maize were given in Table 2. The fertilizer doses of 20 kg da^{-1} pure nitrogen, and 10 kg da^{-1} phosphor, P_2O_5 were applied to maize by a drip irrigation system.

Table 2. Field observations for first and second crops maize
Çizelge 2. Birinci ve ikinci ürün mısır için yapılan tarla gözlemleri

	First Crop Maize *(Birinci Ürün Mısır)*	Second Crop Maize *(İkinci Ürün Mısır)*
Variety *(Çeşit)*	Dekalb 6630	Dekalb 6630
Sowing *(Ekim)*	28/04/2012	19/06/2013
Emergence *(Çıkış)*	04/05/2012	24/06/2013
First Irrigation *(İlk Sulama)*	05/06/2012	23/07/2013
Last Irrigation *(Son Sulama)*	02/08/2012	02/09/2013
Harvest *(Hasat)*	02/09/2012	14/10/2013

The experimental area including the lysimeter was irrigated by a drip irrigation system. Irrigation applications for first crop maize started on 5th June of 2012 when the maximum allowable depletion (MAD) in the 90 cm soil depth was 50%. Sequential irrigations were applied every week. Class A Pan method and percentage of wetted area were used to calculate irrigation water amounts (Equation 1).

$$I=e_{pan}\times k_{cp}\times p_w \quad (1)$$

where, I, irrigation, mm; e_{pan}, pan evaporation, mm; k_{cp}, crop-pan coefficient, (k_{cp} was taken as 0.70 for all irrigation season). p_w, wetted percent of the irrigated area which was used as 0.60 for all irrigation events. During the growing season, 9 irrigations were applied and 34 mm irrigation water was given for first crop maize on the average.

Irrigations for second crop maize started on 23rd July of 2013 when MAD was 50%. At the first irrigation, soil moisture level before irrigation was filled to the field capacity. Other applications were repeated almost weekly. The water amount for irrigations was computed according to Equation 1. K_{cp} and P_w were kept the same as those in 2012. For second crop maize, 7 irrigations were applied and an averaging of 47 mm of water was applied at each irrigation. Irrigations were ended when maize tassel and grains in the cob almost for a month (more than one month for second crop maize) before harvest. The mature cobs were hand- harvested on the same day.

Since the soil water content during the growing season was higher than the critical soil water content, the measured evapotranspiration was considered to be crop evapotranspiration of maize (Doorenbos and Pruitt, 1984; Allen et al., 1998).

Evapotranspiration of both in the lysimeter and in the field were determined using the water balance method (Equation 2).

$$ET_c = I+P-D_p\pm\Delta SW \quad (2)$$

where ET_c is the daily crop evapotranspiration (mm), I is the irrigation (mm), P is the precipitation (mm), D_p is the deep percolation (mm), and ΔSW is the change of the soil water content (mm). Deep percolation was volumetrically measured in the lysimeter and using the irrigation water amount, soil water content before irrigation, and field capacity of the soil depth of the 210 cm in the field (Kanber et al., 1992). Change of the soil water content was determined by the differences in the weights of the tank in the lysimeter and measurements of the soil water content were determined by using the neutron method in the field.

Reference evapotranspiration (ET0)

ET_0 was computed by the PM56 equation (Equation 3) because it is being accepted as the most correct method (Allen et al., 1998).

$$ETo = \frac{0.408\Delta(Rn-G)+\gamma(900/(T+273))\,u_2(e_s-e_a)}{\Delta+\gamma(1+0.34u_2)} \quad (3)$$

where ET_0 is the reference evapotranspiration (mm day^{-1}), R_n is the net solar radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux (MJ m^{-2} day^{-1}), Δ is the slope of the saturation vapor pressure-temperature function (kPa C^{-1}), γ is the psychometric constant (kPa C^{-1}), T is the daily average of air temperature at the 2 m above of the ground (°C), u_2 is the wind speed at height 2 m from the ground (m s^{-1}), es is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), and (e_s-e_a) is the saturation vapor pressure deficit of the air (kPa). The calculation procedure of the equation and other climatic parameters were presented by Allen et al. (1998), Allen et al. (2005), and Zotarelli et al. (2013).

Determination of crop coefficients (Kc)

The single crop coefficients were determined for the first crop maize and the second crop maize according to FAO (Allen et al., 1998). Therefore, the measured ET_c by lysimeter was divided by the ET_0 estimated by the FAO Penman-Monteith Equation as seen below (Equation 4).

$$K_{c-single} = \frac{ETc}{ETo} \quad (4)$$

Then, the crop growth was divided into initial, developmental, mid-season, and late-season stages. The length of the growth stages of maize was determined according to the percentage of groundcover and other growing parameters such as date of germination, maturity, change of leaves color and etc (Doorenbos and Pruitt, 1984; Allen et al., 1998).

The experimental coefficients of K_c values were compared with K_c estimated by FAO approaches. The single crop coefficients for a large number of crops were given for average conditions in sub-humid climate regimes with RH_{min}≈ 45%, and u_2≈2 m s^{-1} (Allen et al., 1998). FAO has also presented correction equations (Equation 5-7) for crop coefficients for other areas having climates where RH_{min} differs from 45% or where u_2 larger or smaller than 2 m s^{-1} during the mid- and late growth stages and different soil characteristic and infiltration or irrigations bigger than or equal to 40 mm depths for initial growth stage.

$$K_{c-ini} = K_{c-ini(Fig\,29)} + \frac{(I-10)}{(40-10)}\left[K_{c-ini(Fig\,30)} - K_{c-ini(Fig\,29)}\right] \quad (5)$$

$$K_{c-mid} = K_{c-mid(tab)} + \left[0.04(u_2-2) - 0.004(RH_{min}-45)\right]\left(\frac{h}{3}\right)^{0.3} \quad (6)$$

$$K_{c-end} = K_{c-end(tab)} + \left[0.04(u_2-2) - 0.004(RH_{min}-45)\right]\left(\frac{h}{3}\right)^{0.3} \quad (7)$$

where, K_{c-ini} , K_{c-mid} and K_{c-end} are the corrected K_c values, K_{c-ini} (Fig 29), K_{c-ini} (Fig 30), $K_{c-mid(tab)}$ and $K_{c-end(tab)}$ are the values mentioned in the FAO figures and table (Allen et al. 1998), I, average irrigation or infiltration depth (mm), RH_{min} is the minimum relative humidity (%), u_2 is the wind speed at the 2 m height (m s^{-1}) and h is the crop height (m).

RESULTS and DISCUSSION

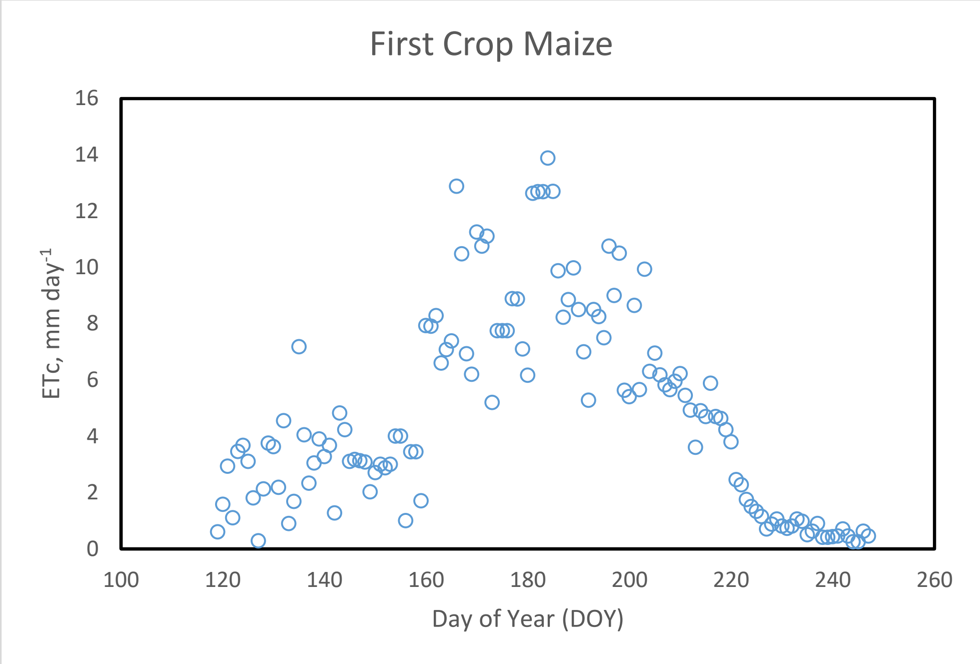
Reference Evapotranspiration (ET0)

The daily ET_0 was calculated using the PM56 method. The daily ET_0 for the first crop maize during the 2012 growing season changed from 1.2 to 6.2 mm day^{-1}, and daily mean ET_0 was 4.8 mm day^{-1}, while total ET_0 was 610.6 mm. Daily ET_0 for second crop maize during the 2013 growing season, varied from 1.9 to 9.2 mm day^{-1}, and daily mean ET_0 was 4.6 mm day^{-1}, while total ET_0 was 547 mm. During the growing season of second crop maize, maximum and minimum ET_0 values were higher than those of the growing season of the first crop maize. This may be the result of the later planting date, and growth stages of the second crop maize coincided with warmer periods. Besides, total ET_0 in the second crop maize was a little lower than that in the growing season of first crop maize. On the other hand, the total rainfall was 133 and 56.5 mm in the growing seasons of the first and second crop maize, respectively. In addition to this, 128 days of the growing season of first crop maize was longer than 118 days of the growing season of the second crop maize.

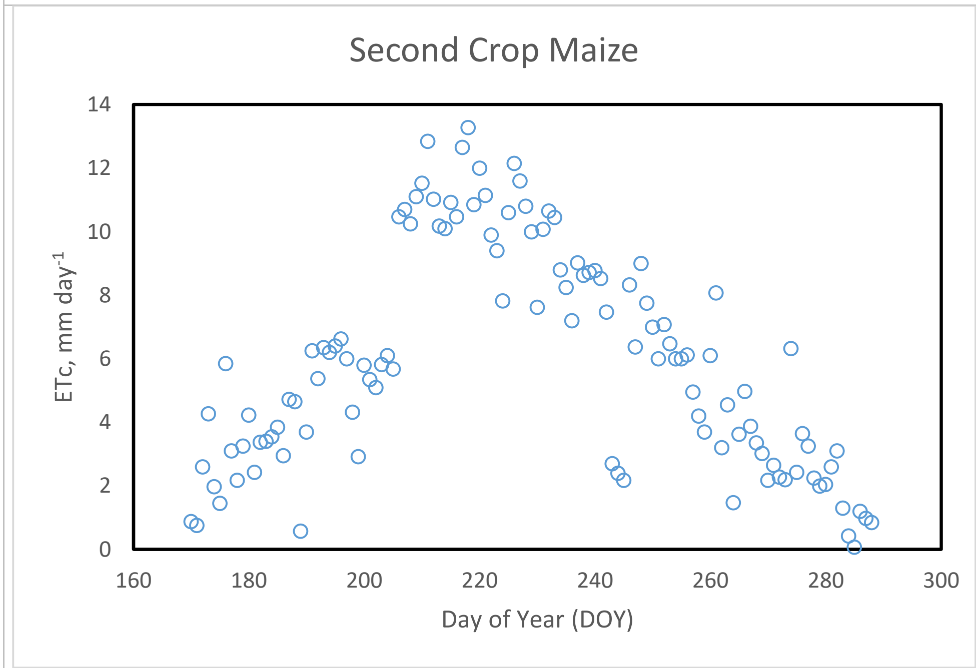
Crop Evapotranspiration (ETc)

The daily first crop maize ET_c reached its maximum value after 65 days from the planting (Figure 1a). Afterward, the maize ET_c started to decrease until harvest. The maximum maize ET_c rate was 13.9 mm per day. The daily second crop maize ET_c reached its maximum value (13.3 mm per day) after 49 days from planting (Figure 1b). The maximum maize ET_c observed in this study was practically the same with that obtained in Texas High Plains (Howell et al. 1997, 1998; Music and Dusek 1980), where the maximum ET_c ranged from 13 to 14 mm per day. In the other study, the maximum maize ET_c has been reported as 12 mm per day by Piccinni et al. (2009).

The total measured ET_c of first and second crop maize during the growing seasons was 618 and 715 mm, respectively. The second crop maize ET_c was 14 % higher than that of the first crop. This may be due to the fact that the seeds were planted in the summer months when the air temperature was too high resulting in high soil evaporation and transpiration. Tolk et al. (1998) reported ET_c values between the range of 328 and 617 mm and Howell et al. (2008) reported these values between the ranged of 418 and 671 mm. These values changed between 670 and 790 mm and 741 and 802 mm as reported by Musick and Dusek (1980) and Howell et al. (1997). Compared to the ET_c values reported by others, ET_c values in this study were slightly higher or lower showing a general agreement.



(a)



(b)

Figure 1. Daily evapotranspiration values of first crop (a) and second crop (b) maize from lysimeter measurements

Şekil 1. Birinci ürün (a) ve ikinci ürün (b) mısır için lizimetreden elde edilen günlük bitki su tüketimleri

Mazie crop ET_c in each growth stage was given in Table 3. The crops ET_c of growth stages for the FAO approach were estimated using the product of the FAO K_c and the ET_0 values. FAO methodologies predicted seasonal ET_c values 26% and 42% lower than the measured lysimeter for first crop maize and second crop maize, respectively. Reductions in the FAO-ET_c values in the first and second crop maize plants occurred at different rates in the growth stages. The highest reduction rates of 61% and 24% were obtained for the first crop for the initial and mid-season growth stages, respectively. For the second crop maize, the highest reduction was calculated for development and late growth stages with 40% and 69%, respectively. Similarly, in a study with maize and wheat performed by Shahrokhnia and Sepaskhah (2013), The measured K_c values for the initial and mid-season stages differed from the FAO values. Also, the FAO approach for the single crop coefficient method showed better predictions on a daily scale whereas the dual crop coefficient method was more accurate on a seasonal basis in the same study performed by Shahrokhnia and Sepaskhah (2013). Similar results to our study were reported by Malek and Sepaskhah (1981), Liu and Luo (2010). According to Malek and Sepaskhah (1981), the reason for the differences between the measured ET_c values and the FAO-Predicted ET_c values at places in the semi-arid regions such as the Çukurova region was related to the impact of the advection. In addition to this, when the ground was fully covered by the plant canopy, latent and sensible heat is absorbed more by crop canopy, causing in higher crop evapotranspiration (ET_c) and crop coefficient (K_c). Besides, the reason for the differences ET_c values during both seasons between timely (first crop) and late sowing (second crop) maize may be due to the fluctuation of the weather parameters such as temperature, radiation, precipitation, humidity, wind speed. (Liu and Luo, 2010; Shahrokhnia and Sepaskhah, 2013).

Maize grain yields were about 600 kg da^{-1} for the first crop maize and 617 kg da^{-1} for the second crop maize with total crop water use efficiencies of 0.97 and 0.86 kg da^{-1} mm^{-1}, respectively. Irrigation water use efficiencies for the first and second crop maize were slightly higher than those of the total crop water use efficiencies with 1.98 and 1.87 kg da mm^{-1}.

Table 3. ET_c values of first and second crop maize in the different growth stages
Çizelge 3. Birinci ve ikinci ürün mısırın farklı gelişme dönemlerindeki ET_c değerleri

Maize *(Mısır)*	Growth Stages *(Gelişme Dönemleri)*	Measured ET_c (mm) *(Ölçülmüş ET_c (mm))*	FAO-Single ET_c (mm) *(FAO Tahmini ET_c (mm))*
First Crop Maize *(Birinci Ürün Mısır)*	Initial *(Başlangıç)*	61	24
	Development *(Gelişme)*	116	100
	Mid-season *(Mevsim Ortası)*	365	270
	End-season *(Mevsim Sonu)*	76	69
	Seasonal *(Mevsimsel)*	618	457
Second Crop Maize *(İkinci Ürün Mısır)*	Initial *(Başlangıç)*	40	26
	Development *(Gelişme)*	129	102
	Mid-season *(Mevsim Ortası)*	407	246
	End-season *(Mevsim Sonu)*	139	43
	Seasonal *(Mevsimsel)*	715	417

Single Crop Coefficient (Kc)

The duration of initial, development, mid- and end-season growth stages for first crop maize was 22, 26, 43, and 37 days totaling 128 days, and for second crop maize, it was 14, 24, 42 and 38 days with a total of 118 days, (Figure 2). At the early stages of growth (initial and development stages) the single crop coefficients for the second crop maize were reduced by 18% compared to the first crop maize. This may be a result of the fact that the second crop was planted in the summer months when the temperature was higher. However, at the last two growth stages, the mid and last seasons, the single crop coefficients were similar for both first and second crop maize.

In Table 4, the measured K_c and FAO single K_c of maize in each growth stage have been presented. The crop coefficients for first and second crop maize were determined according to FAO-56 paper (Allen et al., 1998), and then corrected using Equation 5-7. The mean K_c values of first crop maize were 0.74, 0.92, 1.63, and 0.42, whereas they were measured as 0.46, 0.89, 1.68, and 0.92 at the initial, development, mid- and end-growth stages, respectively for second crop maize.

The average seasonal measured K_c value for the second crop maize was 6% higher than the measured K_c value for the first crop maize. This may be a result of the fact that the ET_c values in the different growth stages were higher, whereas ET_0 values were smaller than those expected in the second crop maize. Similarly, measured the K_c values were 28% higher in the first crop maize and 30% higher in the second crop maize than those predicted by the FAO method.

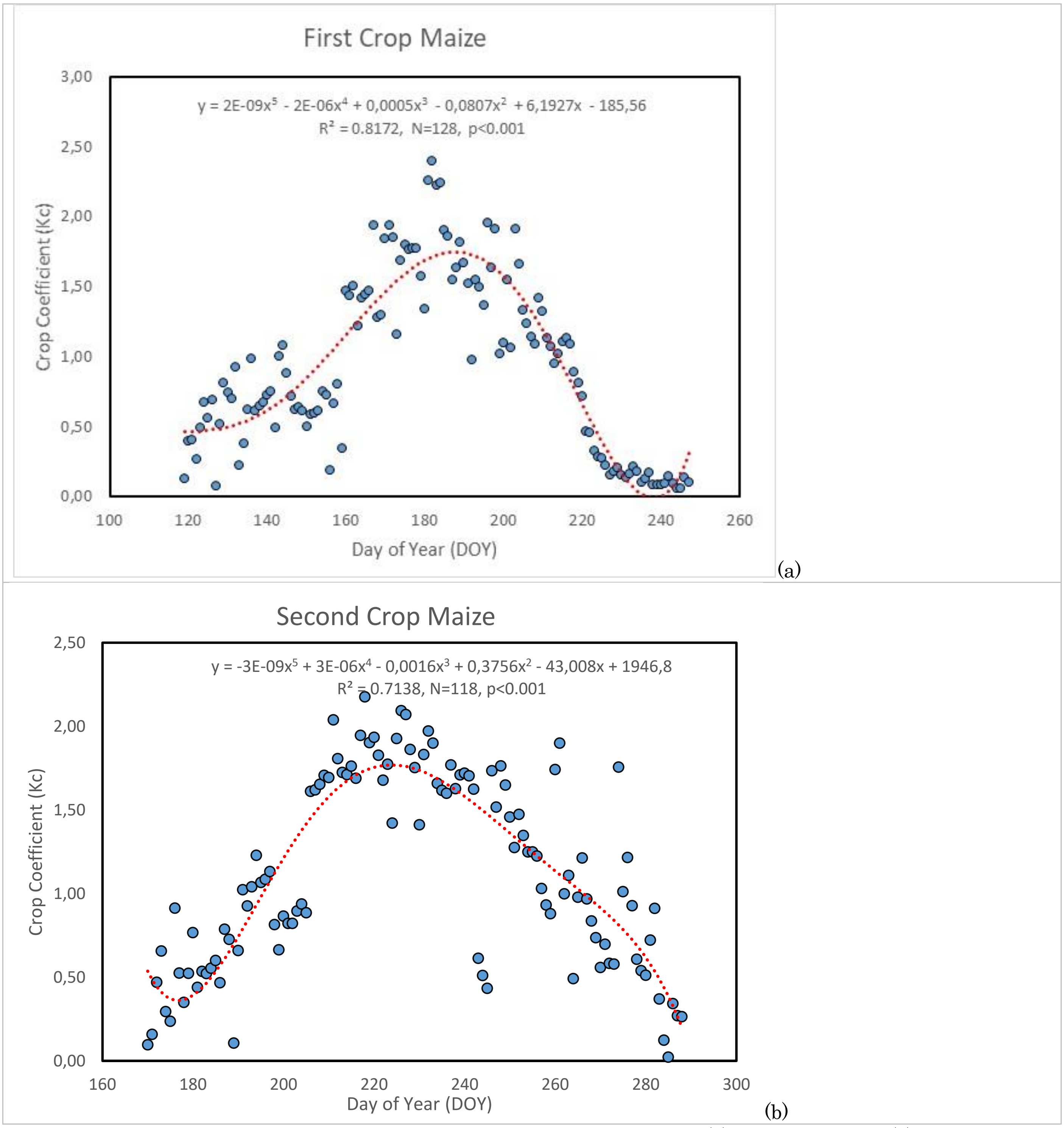


Figure 2. Polynomial relationship between daily K_c and DOY for first crop (a) and second crop (b) maize
Şekil 2. Birinci ürün (a) ve ikinci ürün (b) mısır için günlük K_c ve DOY arasındaki ilişki

On the other hand, no difference was found between the average seasonal K_c values (0.66 and 0.69) predicted by the FAO method for the first and second crop maize. The greatest K_c reductions were observed in initial and development growth stages with an average of 32% for first crop maize and 28% for second crop maize. This can result from the fact that the $K_{c\text{-}ini}$ and $K_{c\text{-}dev}$ values were significantly influenced by irrigation strategies. Many researchers found varying results regarding maize K_c values. For example, the mean K_c values of maize were 0.48, 1.40, and 0.31 at the initial, mid- and end-season stages, respectively in a study by Shahrokhnia and Sepaskhah (2013). The average, maximum, and minimum K_c values were 0.92, 1.33 and 0.42 in another study by Kang et al. (2003). In a study performed by Mirzaei etc. (2011), the Kc values during the growing season was 0.59, 1.19 and 0.85 for initial, mid and end stage respectively. The K_c value estimated by field water balance method in the initial stage was greater than FAO method but K_c values in the mid end seasons were lesser than FAO method over the growth season. In another study performed by Abedinpour (2015), the measured K_c values were different up to some extent from the FAO reported values and according to the Abedinpour the cause of this might be that FAO K_c values are generalized ones and recommended for a wide range of climatic conditions. Other causes might be that different maize varieties have different crop water use and evapotranspiration patterns. Therefore, determination of K_c for crops in different regions and climates is important to improve irrigation water management.

Table 4. K_c of first and second crop maize for the different growth stages
Çizelge 4. Birinci ve ikinci ürün mısırın farklı gelişme dönemlerindeki K_c değerleri

Sowing Time *(Ekim Zamanı)*	Growth Stages *(Gelişme Dönemleri)*	Measured K_c *(Ölçülmüş K_c)*	FAO-Single K_c *(FAO Tahmini K_c)*
First Crop Maize *(Birinci Ürün Mısır)*	Initial *(Başlangıç)*	0.74	0.37
	Development *(Gelişme)*	0.92	0.77
	Mid-Season *(Mevsim Ortası)*	1.63	1.16
	End-Season *(Mevsim Sonu)*	0.42	0.36
Second Crop Maize *(İkinci Ürün Mısır)*	Initial *(Başlangıç)*	0.46	0.37
	Development *(Gelişme)*	0.89	0.87
	Mid-Season *(Mevsim Ortası)*	1.68	1.17
	End-Season *(Mevsim Sonu)*	0.92	0.35

The relationship between K_c and DOY was fitted to a fifth-order polynomial equation for first crop maize and second crop maize with a similar significant correlation coefficient R^2=0.82 and R^2=0.71 (Figure 2). Other studies presented a second degree- up to fifth-order polynomial (Kuo et al. 2006; Shahrokhnia and Sepaskhah, 2013). The maximum measured Kc occurred at 63 days after planting in the first crop maize, whereas in the second crop maize maximum Kc was measured at 48 days after planting. Because of second crop maize was planted during the summer months, its maximum K_c value was reached 15 days before than that in the first crop maize. The results in the study on timing for the maximum K_c value to occur were similar to the result of Reddy (2015) who measured the maximum K_c at 68 days after planting. Other results reported by Shahrokhnia and Sepaskhah (2013) and Kuo et al. (2006) were different reporting timing those values like 76 and 78 days after planting. The daily maize crop coefficients can be calculated by the best-fitted a fifth-order polynomial equation shown in Fig. 2 (a) and (b), Equation 8, and 9.

$$K_c = 2E\text{-}09(DOY)^5 - 2E\text{-}06(DOY)^4 + 0.0005(DOY)^3 - 0.0807(DOY)^2 + 6.1927(DOY) - 185.56 \quad (8)$$

($R^2 = 0.8172$, $N = 128$, $p<0.001$)

$$K_c = -3E\text{-}09(DOY)^5 + 3E\text{-}06(DOY)^4 - 0.0016(DOY)^3 + 0.3756(DOY)^2 - 43.008(DOY) + 1946.8 \quad (9)$$

($R^2 = 0.7138$, $N = 118$, $p<0.001$)

CONCLUSION

In this study, the greatest differences between the measured K_c and FAO-predicted K_c occurred at the initial growing stage for first crop maize, whereas it occurred at the end-season growing stage for second crop maize. This should be considered in using FAO Kc values in Çukurova region conditions. In this study, FAO methodologies predicted K_c values 28% and 30% lower than the measured K_c values for first crop maize and second crop maize, respectively. Generally, the underestimation of FAO single K_c, especially for arid and semi-arid regions, was showed by other similar studies. (Miranda et al., 2006; Ko et al., 2009; Mirzaei et al., 2011; Abedinpour, 2015). As a result, it can be said that the real K_c values may not be the same as the FAO values for locations in the whole world. Therefore, it is recommended to perform a local calibration of K_c for each plant for each region in future studies. Additionally, the K_c values obtained by this study performed in the Çukurova region can be used for effective water management of maize cultivated in a region that a similar climate prevails.

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Statement of Conflict of Interest

The authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

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