Received: 3 August 2020 | Revised: 10 April 2021 | Accepted: 13 April 2021

DOI: 10.1002/ird.2607

RESEARCH ARTICLE

WILEY

Determining evapotranspiration and crop coefficients of young and mature pomegranate trees under drip irrigation*

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[Correction added on 17 May 2021 after first online publication: This updated version of the article has additional affiliations inserted into the author byline and list. Affiliations 3 and 4 have been included at the request of author Hossein Azadi.]

Funding information
Iran National Science Foundation (INSF)

Abstract

In spite of the importance of increasing water shortages in most pomegranate production regions, there is not sufficient information about the water requirement and crop coefficients (K_c) of pomegranate trees under various conditions (e.g., plant cultivar and age and irrigation system). The aim of this study was to measure evapotranspiration during three growing seasons (2013, 2015, and 2016) and to determine K_c of young and mature pomegranate (*Punica granatum* L.) trees under drip irrigation in Iran. The soil water balance approach was applied to determine crop evapotranspiration (ET_c) using soil water content measured during the growing seasons. The ratio of measured ET_c to reference evapotranspiration calculated according to the Penman–Monteith equation provided the K_c values. According to the findings, from bud burst to peak season, daily K_c values for young pomegranate trees ranged from 0.18 to 0.70, 0.22 to 0.89, and 0.23 to 0.95 in 2013, 2015, and 2016, respectively. For mature pomegranate trees, these values varied between 0.26 to 1.15, 0.21 to 1.25, and 0.30 to 1.08 in 2013, 2015, and 2016, respectively. From bud burst to peak season, the total ET_c for young pomegranate trees was 711, 905, and 934 mm and for mature pomegranate trees 1,172, 1,086, and 1,138 in 2013, 2015, and 2016, respectively. The results of this study are applicable to accurate water allocation, precision irrigation scheduling, and design of irrigation systems in pomegranate orchards.

KEYWORDS

drip irrigation, *Punica granatum* L, soil water content, water balance

Résumé

Malgré l'importance des pénuries d'eau croissantes dans les régions les plus productives de grenadiers, il n'y a pas suffisamment d'informations sur les

* Détermination des coefficients d'évapotranspiration et de culture des grenadiers jeunes et matures sous irrigation goutte à goutte

besoins en eau et les coefficients de culture des grenadiers dans diverses conditions (par exemple, cultivar de la plante et âge et système d'irrigation). Le but de cette étude était de mesurer l'évapotranspiration au cours de trois saisons de croissance (2013, 2015 et 2016) et de déterminer les coefficients de culture (Kc) de grenadiers jeunes et matures (*Punica granatum* L.) sous irrigation goutte à goutte en Iran. L'approche du bilan hydrique du sol a été appliquée pour déterminer l'évapotranspiration des cultures en utilisant la teneur en eau du sol mesurée pendant les saisons de croissance. Le rapport entre l'évapotranspiration mesurée des cultures et l'évapotranspiration de référence calculé selon l'équation de Penman-Monteith a fourni les valeurs des coefficients de culture. Selon les résultats, du débourrement à la haute saison, les valeurs quotidiennes de Kc pour les jeunes grenadiers variaient de 0,18 à 0,70, de 0,22 à 0,89 et de 0,23 à 0,95 en 2013, 2015 et 2016, respectivement. Pour les grenadiers matures, ces valeurs variaient entre 0,26 à 1,15, 0,21 à 1,25 et 0,30 à 1,08 en 2013, 2015 et 2016, respectivement. Du débourrement à la haute saison, l'ETc totale pour les jeunes grenadiers était de 711, 905 et 934 mm et pour les grenadiers matures était de 1,172, 1,086 et 1,138 en 2013, 2015 et 2016, respectivement. Les résultats de cette étude sont applicables à l'allocation précise de l'eau, à la planification précise de l'irrigation et à la conception de systèmes d'irrigation dans les vergers de grenadiers.

MOTS CLÉS

bilan hydrique, irrigation goutte à goutte, *Punica granatum* L, teneur en eau du sol

1 | INTRODUCTION

The pomegranate (*Punica granatum* L.) tree is cultivated in all continents, it can be grown in arid regions, and has beneficial properties for human health. Leading producers in the European and world market include Iran, India, or Turkey. Chile, Peru, Argentina, South Africa, and Australia are also on the list of pomegranate producers. The total area under pomegranate cultivation in the world is more than 302,000 ha, of which more than 76% is located in five countries (India, Iran, China, Turkey, and the USA). Some countries have less extensive plantings (Spain, Egypt, and Israel) with an area of between 16,000 and 24,000 ha (Melgarejo-Sánchez *et al.*, 2015). Pomegranate is considered a minor crop; however, the fruit is used to obtain different products of nutritional, pharmaceutical, or cosmetic interest. Pomegranate juice contains substances with antibacterial, antiviral, anticancer, and anti-inflammatory activity (Melgarejo-Sánchez *et al.*, 2015).

Iran is one of the main producers of pomegranate in the world; there are approximately 65,000 ha under production in its different parts; and it ranks high in the world for several pomegranate cultivars, quality, cultivated area, production, and export (Iranian Ministry of Agriculture, 2018). Markazi province is one of the largest producers, with a cultivated area of 8,104 ha and a production of 96,700 t year^{-1} in Iran. In Markazi province, Saveh is a centre of pomegranate production.

Pomegranate is characterized as being drought tolerant, but few studies have quantified the actual water requirement (Volschenk, 2020). However, irrigation scheduling (i.e., irrigation amount and interval) highly affects the quantity and quality of pomegranate in arid and semi-arid regions (Dinc *et al.*, 2018). Nothing has been published about the pomegranate water requirement and crop coefficients (K_c) in the *Food and Agriculture Organization (FAO) Irrigation and Drainage Paper No. 56* (Allen *et al.*, 1998). ET_c, K_c, and growth of two young pomegranate varieties were determined by Bhantana & Lazarovitch (2010). Ayars *et al.* (2017) in California obtained a total water requirement of approximately 952 mm and a maximum daily water use of 10.5 mm for a 6-year-old tree in a developing pomegranate orchard. Meshram *et al.* (2011) estimated the maximum K_c to be 1.18 and daily water use 5.3 mm day^{-1} for a 5-year-old tree under drip irrigation. Some researchers (Intrigliolo *et al.*, 2011a; Intrigliolo *et al.*, 2011b; Laribi *et al.*, 2013) have adjusted the K_c values obtained in Bhantana & Lazarovitch (2010) and calculated ET_c

accordingly. Parvizi *et al.* (2014) investigated the effect of different irrigation and fertilizer regimes on yield of 9-year-old pomegranate trees in Fars province in Iran. The K_c values were calculated from 10-day average values reported by Farshi *et al.* (1995) and Ashraf & Majeed (2006). Volschenk (2020) recently reviewed all international research on water use and irrigation management of pomegranate trees and reported that the results from one study cannot merely be transferred to another area where conditions (e.g., irrigation system, soil and water management, and cultivar types) may not be the same. This review strongly suggests that further research is required to determine water use (transpiration and evapotranspiration) of a range of young to mature pomegranate orchards for different irrigation systems and cultivars in different areas throughout the world.

In recent years, reduction in ground water resources and severe droughts have destroyed many of the pomegranate orchards, particularly in arid regions like Iran. Considering the lack of alternative water resources, the optimal and precious use of existing water by modern irrigation systems and new strategies like deficit irrigation is necessary. In the past years, surface irrigation was used by the orchard owners in Iran, and traditional irrigation was the principal irrigation method. However, deep percolation and evaporation losses were too significant. Kumar *et al.* (2012, 2013) indicated that water use of pomegranate orchards in arid Punjab regions decreased by using micro-irrigation (drip) systems. Moreover, the quality of pomegranate fruit, water productivity, and farmers' income were improved. Due to the paramount importance of increasing water shortage in Iran, drip irrigation has been widely adopted in many orchards, and farmers are eager to save water by changing their irrigation systems. Before designing modern irrigation systems and applying irrigation scheduling and new irrigation strategies, we need basic information regarding pomegranate water requirement. Therefore, this study was conducted to determine the water requirement of fully irrigated young and mature pomegranate orchards during three growing seasons using high-frequency drip irrigation.

2 | MATERIALS AND METHODS

The experiment was performed at a farm with different orchards and an area of 70 ha located 12 km west of Saveh (Iran) in Aghdarreh village (34°57′32″ N, 50°14′38″ E and an altitude of 1,230 m) in 2013, 2015, and 2016. The plant materials were own-rooted and single-trunk young (3 years old in 2013) and mature (15 years old in 2013) pomegranate trees of the cultivar "Malas-e-Saveh." Tree spacing followed a pattern of 1.5 m × 4.5 m and 2.5–2.8 m × 3.5–4 m for young and mature trees, respectively. In the study area, the pomegranate growing season usually begins in April and ends in early November. In the case of deciduous crops, the days after bud burst play a major role in changes in ET_c (Shani & Ben-Gal, 2005). Therefore, in all the studied years (2013, 2015, and 2016), the water requirement was measured from May to early November. The dimensions to calculate tree crown volume were measured three times between bud burst and maturity (May 30, July 30, and September 25) in all studied years. Tree crown volume (±SD) was calculated according to Hutchinson (1977) and was 3.8 ± 0.45 m^3, 4.9 ± 0.6 m^3, and 6.2 ± 0.73 m^3 in 2013, 2015, and 2016, respectively, for young trees. Tree crown volume for mature trees remained about 15.1 (±1.6) m^3 during the experimental period. The experimental orchards were representative of most pomegranate orchards in Saveh with regard to variety, age, and canopy size. Two treatments, including young and mature pomegranate trees, were evaluated in this study. The design of the experiment was completely randomized with four replications, each replication consisting of three adjacent tree rows, each with five trees (60 trees for each treatment). Measurements were taken on the central tree of the central row (experimental tree) of each replication, which were similar in appearance, while the other trees served as border trees.

The soil texture was loam (20.9% clay, 46.5% silt, and 32.6% sand) with a volumetric field capacity (FC) and permanent wilting point (PWP) of 24.5% and 9.6%, respectively. Analytical soil data showed a low salinity (electrical conductivity of the saturated soil water extract was 1.1 dS m^{-1}), high lime content (30% calcium carbonate), very low organic matter content (0.7%), low cationic exchange capacity (5.8 cmol kg^{-1}), and low available potassium and phosphorus levels (data not shown). Irrigation water electrical conductivity was 1.93 dS m^{-1}, and the concentrations of Cl^-, CO_3^{2-}, HCO_3^-, Na^+, K^+, Mg^{2+}, and Ca^{2+} were 8.6, 2.3, 3.4, 9.9, 0.1, 7.0, and 4.8 mEq L^{-1}, respectively. Also, total suspended solids, total dissolved solids, alkalinity, and total hardness were 10.9, 1,120, 287, and 592 mg L^{-1}, respectively, and sodium adsorption ratio was 4.07.

No significant pest or disease outburst during the growing seasons was observed, and no pesticides were applied. Fertilization practices were those usually used by the grower, and no weeds were allowed to develop within the orchard. A total of 70 kg manure, containing 50% cow manure and 50% sheep manure, were applied on both sides of the tree rows in the middle of April. Also, for each tree, 30 g of macro-NPK (nitrogen, phosphorus, and potassium) fertilizer and 7 cm^3 of liquid organic humisol fertilizer were injected into the drip irrigation system once in late May.

Micrometeorological data, including air temperature, solar radiation, relative humidity, rainfall, and wind speed 2 m above the soil surface, were collected by an automatic weather station located 5 km from the experimental site. Reference crop evapotranspiration (ET_0) in mm day^{-1} was calculated according to the FAO Penman–Monteith method (Allen *et al.*, 1998).

Young pomegranate trees were irrigated with a single dripper line (three drippers per tree spaced 15 cm apart) positioned 10 cm from the tree stem. Mature trees were irrigated using double-line drip (three drippers on each side of the tree, spaced 20 cm apart) with lines positioned 20 cm from the tree stem. Drippers had a delivery rate of 4 L $hour^{-1}$. Soil surface wetted area (A_w), percentage of wetted area (P_w), and the ratio of A_w to tree spacing were measured for both young and mature pomegranate trees (Sharifinia *et al.*, 2019). In the study area, Sharifinia *et al.* (2019) investigated the dimensions of the wetted bulb for the loam soil as a representative soil texture, with an emitter discharge of 4 and 8 L $hour^{-1}$ and single- and double-dripper lines, in 2011 and 2012. For this purpose, several experiments were installed, and after 24 hours from the end of irrigation, wetted bulb and P_w were measured in the horizontal and vertical directions by digging a trench under the installation location of the drippers and measuring soil water content. Electronic in-line water meters (SS/AMAS/F_2, ABB Inc.) were used to measure the water supplied to each experimental unit. Recorded irrigation volumes were converted to millimetres on the basis of the measured soil surface wetted area.

ET_c (mm) data for each experimental tree were measured on the basis of recording soil water content depletion (Hayashi *et al.*, 2010). Daily soil water balance was used for calculating ET_c (mm) for each experimental tree in the drip area (Equation 1):

$$ET_c = I + R - Dr + \Delta\theta D, \tag{1}$$

where I is irrigation (mm), R is the effective rainfall (mm), Dr is the drainage (mm) assumed equal to zero, and $\Delta\theta$ is the change in stored root-zone water to an effective root depth (D in mm). Effective rainfall was calculated according to Allen *et al.* (1998). The conversion of the ET_c calculated for the drip area where volumetric water content was measured to ET_c for the full surface area ($ET_{c\_full\ surface\ area}$) was done on the basis of P_w (Equation 2):

$$ET_{c\_full\ surface\ area} = \frac{ET_c}{P_w} \tag{2}$$

The ratio of $ET_{c\_full\ surface\ area}$ to ET_0 provided the K_c values during the growing seasons (Allen *et al.*, 1998) (Equation 3):

$$K_c = \frac{ET_{c\_full\ surface\ area}}{ET_0} \tag{3}$$

A time domain reflectometry (TDR) device (6050X3K1B Mini Trase, Soilmoisture Equipment Corp.) and burial 20-cm-length model 6005L2 probes were used to determine volumetric soil water content. According to the trenches drilled near the young and mature trees, the effective root depth was 40 and 60 cm, respectively. Root distribution may differ depending on cultivar and soil properties. Several studies showed that the pomegranate tree root system is shallow, with most of it being less than 60 cm deep and very rarely below 90 cm in large, mature trees or strong, wide shrubs (Hiwale *et al.*, 2011; Marathe *et al.*, 2016). However, root systems extended to 1.2 m depth in stony soil for the cultivar “Wonderful” in South Africa (Volschenk & Mulidzi, 2019).

For the experimental tree of each replication, TDR probes were horizontally buried at 5 and 25 cm in radial distance relative to the trees (at both sides of the tree) at depths of 10, 20, 40, and 50 cm for young trees and at 10 and 40 cm in radial distance relative to the trees and across the tree rows (at both sides of the tree) at depths of 10, 20, 40, 60, and 70 cm for mature trees. Twelve and sixteen upper probes were used to measure the volumetric soil water content amount hourly for young and mature trees, respectively. The profile volumetric water content for the young and mature trees, (θ_{young_tree} and θ_{mature_tree}), was calculated by considering the weighted average of the recorded volumetric soil water content amount (Equations 4 and 5). θ_{10}, θ_{20}, θ_{40}, and θ_{60} are the volumetric soil water content at depths of 10, 20, 40, and 60 cm.

$$\theta_{young\_tree} = \frac{10(\theta_{10}) + 10(\theta_{20}) + 20(\theta_{40})}{40} \tag{4}$$

$$\theta_{mature\_tree} = \frac{10(\theta_{10}) + 10(\theta_{20}) + 20(\theta_{40}) + 20(\theta_{60})}{60} \tag{5}$$

On the basis of the profile volumetric water content, soil water content deficit from FC, the irrigation times, irrigation amounts, and frequency were calculated, and the orchard was automatically irrigated considering a maximum allowable depletion (MAD) of 4% for plant total available water (i.e., FC-PWP). Maintaining the soil water content close to FC and no drought stress condition for the pomegranate trees were very important, and therefore a small value for MAD was considered (2.4 and 3.6 mm for the studied soil).

The lower probes, that is, the probes installed at 50 cm depth for young trees and at 70 cm depth for mature trees, were used to monitor and prevent water transport to below the effective root zone and to validate the method used for measuring ET_c in this study (Equation 1). Soil water content at 50 cm depth for young trees and 70 cm depth for mature trees was recorded hourly in April and during the experiment period (May to early November) in 2013, and temporal variations were recorded. The recorded data were used to assess if drainage occurred, and if it did occur, irrigation volumes applied were adjusted to prevent drainage.

3 | RESULTS AND DISCUSSION

3.1 | Meteorology of experiment site

Average daily air temperatures and relative humidity from May to early November during the experimental years are presented in Figure 1. In 2013, 2015, and 2016, average daily air temperature and relative humidity ranged for the respective periods from 8.1 to 33.1°C and 8% to 73.7%, 8.7 to 32.1°C and 8.3% to 85%, and 6.7 to 34.4°C and 9.8% to 75.9%.

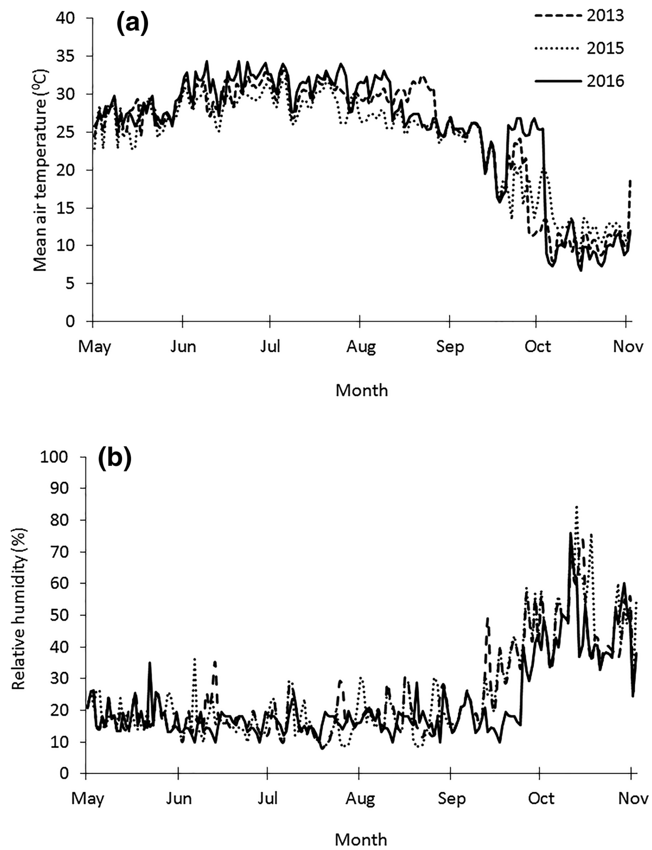

FIGURE 1 Daily mean air temperature and relative humidity measured from May until early November at Aghdarreh village near Saveh, Iran, during 2013, 2015, and 2016

3.2 | Reference evapotranspiration

ET_0, ET_c, and K_c of young and mature pomegranate trees for 2013, 2015, and 2016 (from May to early November) are presented in Figure 2 and Figure 3, respectively. The total amount of ET_0 and ET_c and effective rainfall are shown in Table 1.

The daily ET_0 from May to early November changed from 2.9 to 11.3 mm day^{-1}, 3.0 to 11.9 mm day^{-1}, and 2.9 to 11.6 mm day^{-1} in 2013, 2015, and 2016, respectively. The total ET_0 for the respective period was higher in 2013 than in 2015 and 2016. Between 2013 and 2015, there was approximately a 3.4% and 1.7% difference in the average daily and seasonal total ET_0, respectively. Comparison of ET_0 data for 2013 and 2016 showed a difference of around 1.9% and 0.3% in the average daily and seasonal total ET_0, respectively. Also, this evaluation for 2015 and 2016 indicated a difference of about 1.4% and 1.3% in the daily and total ET_0, respectively. The effective rainfall amounts for the respective periods in the experimental years were low (Table 1). Most of the yearly effective rainfall occurred after November, which agrees with the long-term climate data of Saveh.

3.3 | Crop evapotranspiration

The daily ET_c measured from bud burst to peak season for young pomegranate trees changed from 0.7 to 7.1 mm day^{-1}, 0.8 to 8.7 mm day^{-1}, and 0.8 to 9.1 mm day^{-1} in 2013, 2015, and 2016, respectively (Figure 2). In mature pomegranate trees (Figure 3), variability of ET_c in all experimental years was quite similar, especially the maximum value of ET_c. The daily ET_c changed from 1.1 to 11.8 mm day^{-1}, 0.8 to 11.2 mm day^{-1}, and 1.0 to 11.4 mm day^{-1} in 2013, 2015, and 2016, respectively.

In young pomegranate trees, ET_c increased each year (Table 1) as the plants grew larger, and the daily ET_c increased to around 8.7–9.1 mm day^{-1} when the pomegranate trees were 6 years old in the last year of the experiment. This is slightly lower than what was reported by Ayars *et al.* (2017) for the cultivar Wonderful (approximately 10–10.5 mm day^{-1}) in California. The daily peak

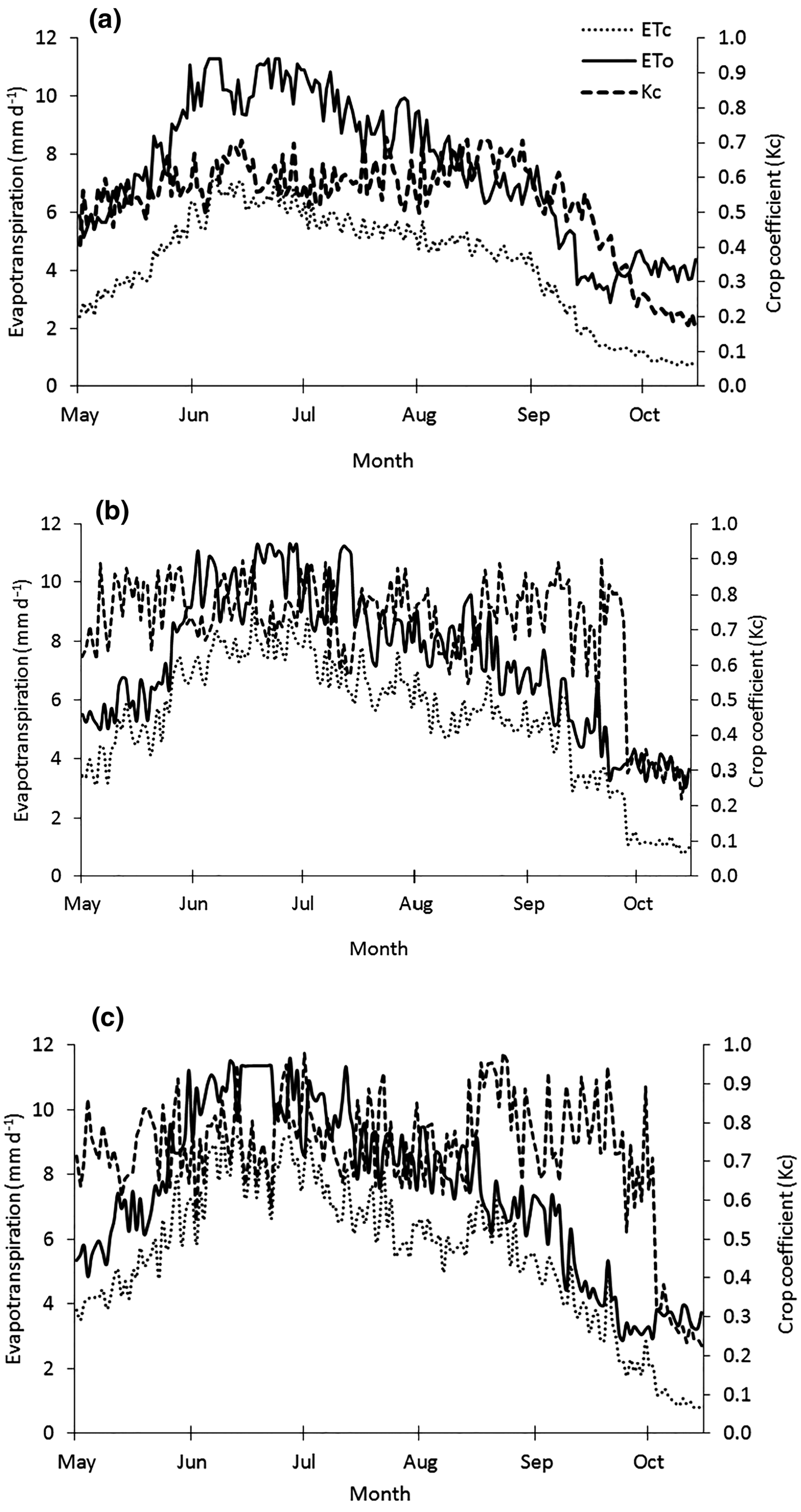

FIGURE 2 Daily reference evapotranspiration (ET_0), crop evapotranspiration (ET_c), and crop coefficients (K_c) for young Malas-e-Saveh pomegranate trees at Aghdarreh village near Saveh, Iran, for the period from May until early November during 2013 (a), 2015 (b), and 2016 (c)

ET_c of 8.7 mm day^{-1} for 5-year-old Malas-e-Saveh trees measured in 2015 was higher than what was reported by Meshram *et al.* (2011) for the cultivar "Mrig Bahar" in India (5.3 mm day^{-1}).

For 3-year-old Malas-e-Saveh trees, the total amount of ET_c for a period of about five and a half months (Table 1) was considerably more (c. 47%) than the annual ET_c for cv. Wonderful trees (483 mm) of similar age in California (Ayars *et al.*, 2017). However, for 5-year-old and 6-year-old trees, the total ET_c for the shorter period in Iran and annual period in California was comparable. The total ET_c for the Malas-e-Saveh trees (Table 1)

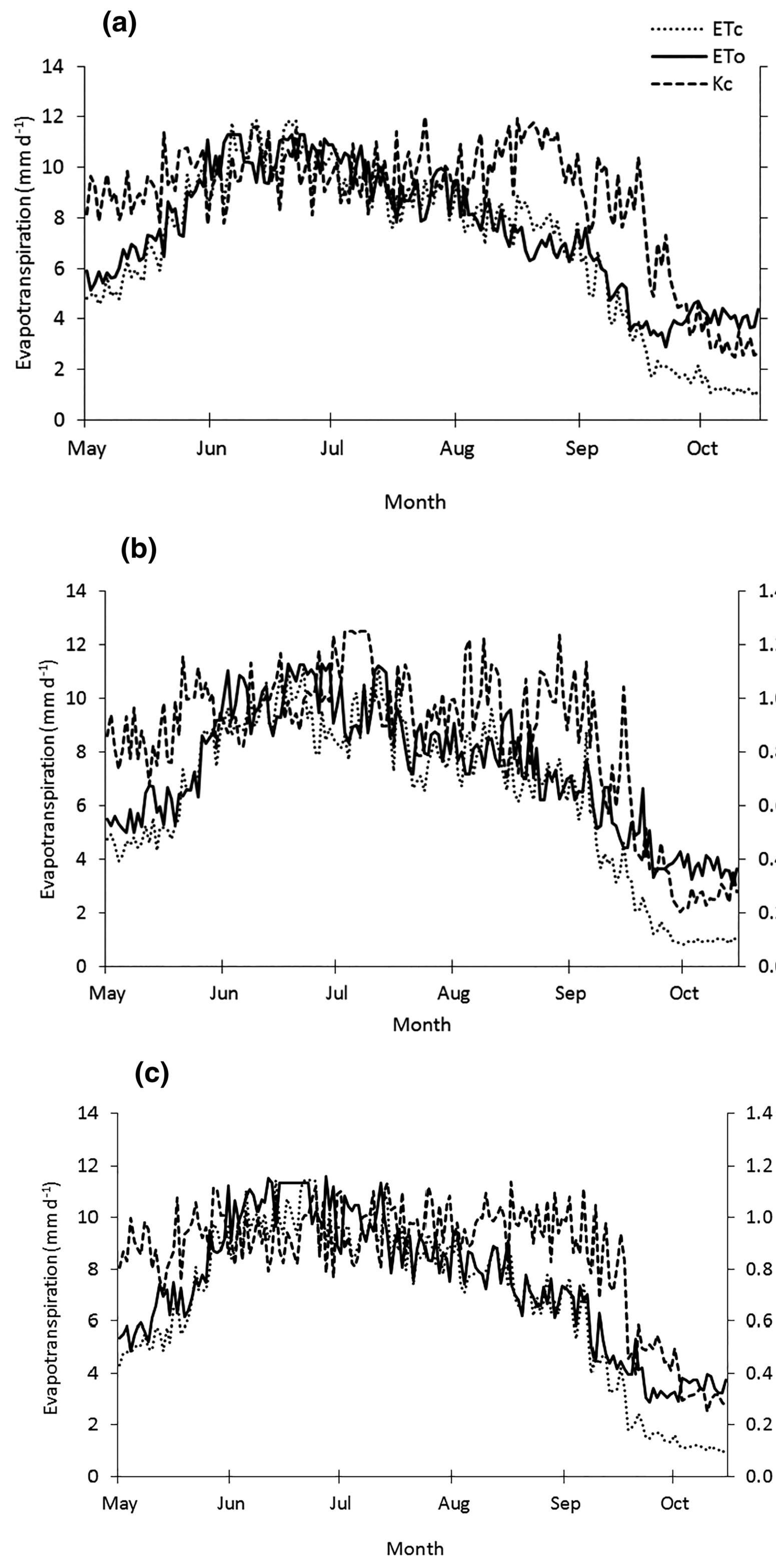

FIGURE 3 Daily reference evapotranspiration (ET_0), crop evapotranspiration (ET_c), and crop coefficients (K_c) for mature Malas-e-Saveh pomegranate trees at Aghdarreh village near Saveh, Iran, for the period from May until early November during 2013 (a), 2015 (b), and 2016 (c)

differed by less than 2% from the 912 and 953 mm annual ET_c measured for cv. Wonderful trees of these respective ages (Ayars *et al.*, 2017). The annual ET_0 for 2013 and 2015 were 1,693 and 1705 mm, respectively, in Iran (Aghdarreh site), which is more than that reported by Ayars *et al.* (2017) for the California site, which was 1,397 mm for 2013 and 1,379 mm for 2015.

Variability of ET_c of mature pomegranate trees in all experimental years was quite similar, especially in terms of maximum value of ET_c (Figure 2). The seasonal total

TABLE 1 Seasonal total reference evapotranspiration (ET_0) and means ± SD of crop evapotranspiration (ET_c) for pomegranate (cv. Malas-e-Saveh) as well as effective rainfall measured for 3 years at Aghdarreh village near Saveh, Iran

		ET_c (mm)		
Year	ET_0 (mm)	Young[a]	Mature[b]	Effective rainfall (mm)
2013	1262[c]	711±23[c]	1,172 ± 36	12.4
2015	1,241	905 ± 31	1,086 ± 45	9.5
2016	1,258	934 ± 29	1,138 ± 29	5.8

[a]Age 3, 5, and 6 years in 2013, 2015, and 2016, respectively.
[b]Age 15, 17, and 18 years in 2013, 2015, and 2016, respectively.
[c]ET_c, ET_0, and effective rainfall measured from May 22 to November 3.

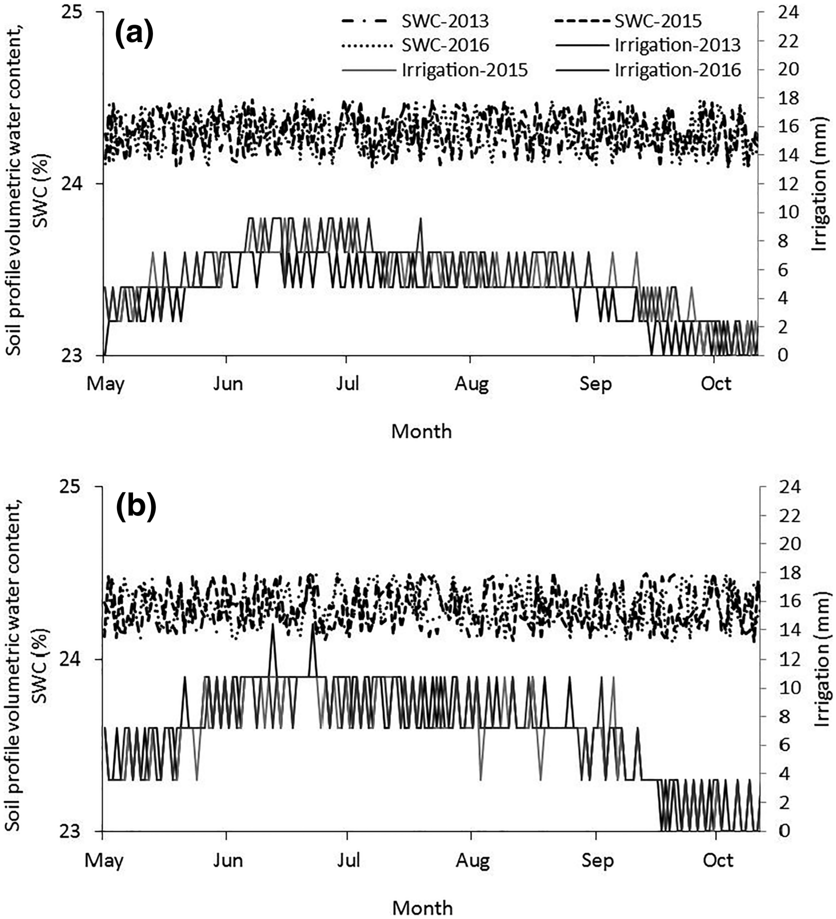

FIGURE 4 Daily soil profile volumetric water content (SWC) and irrigation amounts for young (a) and mature (b) Malas-e-Saveh trees at Aghdarreh village near Saveh, Iran, for the period from May until early November during 2013, 2015, and 2016

amount of ET_c for the mature trees in the experimental years was considerably similar (Table 1). The seasonal total ET_c was higher in 2013 than in 2015 and 2016. The values of the average daily and seasonal total ET_c in 2013 were 13.0% and 8.0% higher than those in 2015 and 4.0% and 3.0% higher than those in 2016, respectively. These values in 2015 were 8.0% and 5.0% less than those in 2016, respectively.

The seasonal total ET_c values for mature Malas-e-Saveh pomegranate trees were considerably higher than those measured for the young trees in this study (Table 1). Similarly, the seasonal total ET_c for Malas-e-Saveh trees was significantly higher than what was reported by Ayars *et al.* (2017) in California for 6-year-old pomegranate trees.

3.4 | Soil profile water content and deep drainage

The temporal variations of daily soil profile volumetric water content and irrigation amounts for the young and mature trees are presented in Figure 4. The measured data showed that the volumetric soil water content was maintained in a range of 24.0%–24.5% for the young and mature trees during the experiment period, which is so close to FC for this loam soil and confirmed no drought stress condition for the pomegranate trees.

For determining water transport to below the root depth, it is essential to monitor soil water content variation below the crop root zone. The temporal variations of average daily volumetric soil water content at a depth of 50 cm for the young trees and a depth of 70 cm for the mature trees are presented in Figure 5. The measured data showed that the soil water content was maintained in a range of 23.3%–25.7% and 23.8%–25.2%, respectively, for the young and mature trees in April and during the experiment period in 2013, which is in a close range to FC for this loam soil.

There are two spikes in temporal variation of soil water content at a depth of 50 cm for the young trees and a depth of 70 cm for the mature trees in April 2013 (Figure 5). They occurred when the irrigation system was not well scheduled and excess water was applied. These spikes in soil water content measurement validated the sensitivity of the sensors to soil water content changes. Measured data showed that maximum variations of volumetric soil water content are 2.4% and 1.4% at a depth of 50 cm for the young trees and a depth of 70 cm for the mature trees, respectively. The measurement accuracy of the TDR device in recording soil water content is +/−2%, which warranted that water losses by drainage did not occur. Daily SD of hourly volumetric soil water content during April to early November varied between 0.56% to 0.88% and 0.25% to 0.49% at a depth of 50 cm for the young trees and a depth of 70 cm for the mature trees, respectively. The lack of drainage was due to criteria of irrigation on the basis of measured effective root-zone soil water content depletion, refilling it to FC, and using high-frequency irrigation with drip irrigation based on the accurate determination of the hourly crop water use. High-frequency irrigation and supplying crop water with small applications of water reduced the potential for deep percolation with drip irrigation.

3.5 | Crop coefficients

The daily K_c values for young Malas-e-Saveh pomegranate trees changed from 0.18 to 0.70, 0.22 to 0.89, and 0.23

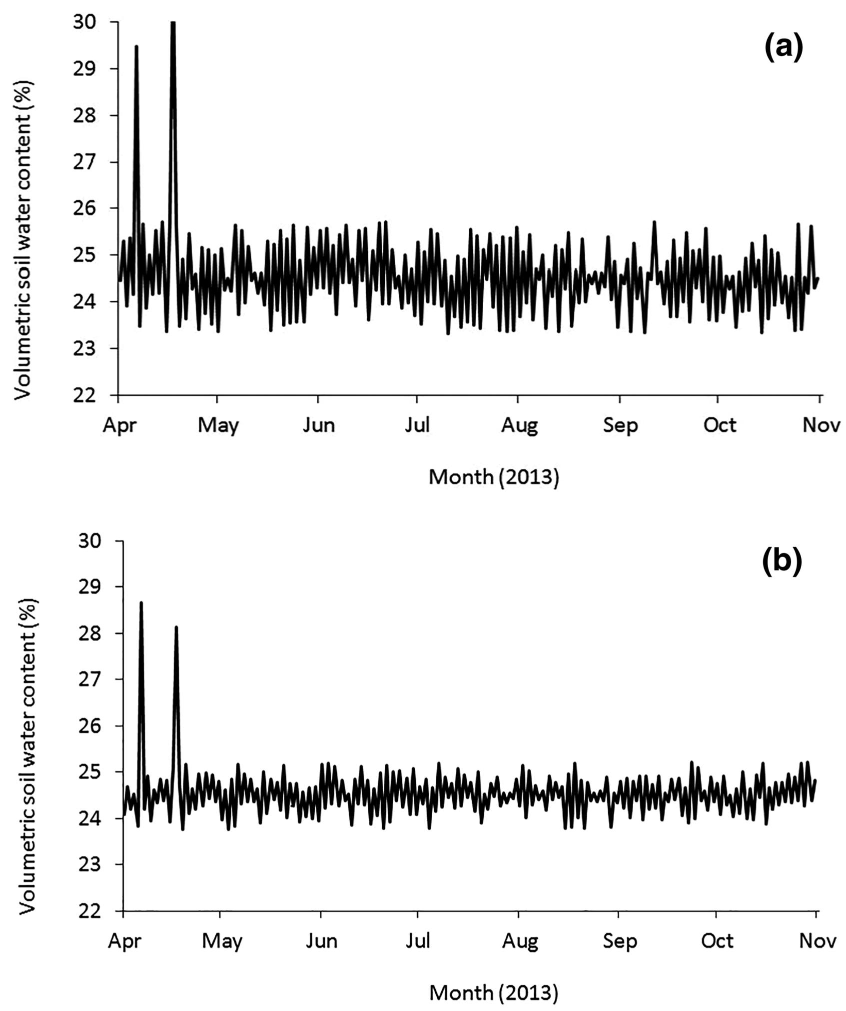

FIGURE 5 Average daily soil water content (%) for young and mature Malas-e-Saveh trees monitored at 50 cm (a) and 70 cm (b) depths, respectively, at Aghdarreh village near Saveh, Iran, in 2013

to 0.95 from bud burst to peak season in 2013, 2015, and 2016, respectively (Figure 2). The measured K_c values in this study for young Malas-e-Saveh pomegranate trees were lower than the maximum K_c (1–1.2) reported by Ayars *et al.* (2017) for 6-year-old cv. Wonderful pomegranate trees. In comparison, K_c values estimated by Meshram *et al.* (2011) for 5-year-old cv. Mrig Bahar pomegranate trees increased from 0.15 to 1.20 from new leaf initiation to crop maturity.

The daily values of K_c for mature Malas-e-Saveh pomegranate trees from bud burst to peak season ranged from 0.26 to 1.15, 0.21 to 1.25, and 0.30 to 1.08 in 2013, 2015, and 2016, respectively (Figure 3). The measured K_c values in this study (Figure 3) were higher than those employed by Parvizi *et al.* (2014), which varied from 0.39 to 0.71 for 9-year-old cv. Rabab pomegranate trees. In their study, K_c values were calculated from 10-day average values reported by Farshi *et al.* (1995) and Ashraf & Majeed (2006) and then were transformed into daily values using a fifth-degree polynomial equation. Also, the values of K_c were higher than those obtained by Intrigliolo *et al.* (2013), which varied from 0.38 to 0.64 for 9- to 11 year-old pomegranate trees. The K_c values employed by them were based on the values reported by Bhantana & Lazarovitch (2010) for 1-year-old pomegranate trees.

As shown in Figure 2, the maximum values of ET_0 and ET_c for the young trees occurred in July. However, the maximum values of K_c occurred in August and September after the warmest month (July) of the year. This is similar to the trend reported and interpreted by Ayars *et al.* (2017). High K_c values towards the end of the season are the result of crop water use remaining high in August and September, while the ET_0 decreased from peak values in July.

The maximum ET_0 and ET_c for mature trees occurred in July and the maximum values of K_c in August and September (Figure 3). There was a moderate conformity between ET_0 and ET_c values from June to September, while it was not observed in May and October.

The 10-day average K_c values were calculated as ratio of the ET_c and ET_0 in 2013, 2015, and 2016 and averaged for the mature trees for the three studied years (Table 2). The 10-day average values of K_c (Table 2) are applicable and valuable for calculating crop water requirements and promote the optimal use of water by modern irrigation systems and new strategies like deficit irrigation. It definitely helps engineers to design irrigation systems more accurately and water managers to allocate water according to real crop water requirements and therefore save scarce and valuable water resources.

TABLE 2 Ten-day average values of crop coefficients (K_c) for young and mature Malas-e-Saveh pomegranate trees under drip irrigation at Aghdarreh village near Saveh, Iran, for the period from May until early November during 2013, 2015, and 2016

	Young trees			Mature trees			
Decade no.	**2013**	**2015**	**2016**	**2013**	**2015**	**2016**	**Average**
1[a]	0.46	0.68	0.75	0.85	0.89	0.87	0.87
2	0.55	0.87	0.71	0.87	0.84	0.82	0.84
3	0.56	0.80	0.79	1.00	1.01	1.01	1.01
4	0.57	0.78	0.69	0.96	0.90	0.94	0.93
5	0.63	0.88	0.81	1.04	0.98	0.93	0.98
6	0.60	0.74	0.70	0.99	0.90	0.95	0.95
7	0.58	0.80	0.84	0.96	0.89	0.94	0.93
8	0.58	0.66	0.71	0.96	1.07	1.00	1.01
9	0.63	0.85	0.79	1.03	0.89	0.98	0.97
10	0.58	0.70	0.71	0.96	0.95	0.96	0.96
11	0.62	0.69	0.74	1.02	0.99	1.00	1.00
12	0.68	0.72	0.92	1.12	0.91	1.01	1.01
13	0.61	0.79	0.74	1.00	1.02	1.01	1.01
14	0.53	0.71	0.79	0.86	0.94	0.89	0.90
15	0.44	0.62	0.74	0.62	0.6	0.48	0.57
16	0.27	0.32	0.64	0.38	0.24	0.42	0.35
17[b]	0.21	0.24	0.25	0.30	0.27	0.30	0.29

[a]Second decade in May.
[b]Third decade in October.

4 | CONCLUSION

There are limited data about pomegranate tree water requirements and K_c, and more research is required to determine water use of a range of young to mature pomegranate orchards for different irrigation systems and cultivars in different areas throughout the world. Therefore, in this study, K_c and ET_c of young and mature Malas-e-Saveh pomegranate trees in 2013, 2015, and 2016 were measured and analysed.

According to the results of 3-year study, for young pomegranate trees the mean values of daily K_c and evapotranspiration ranged from 0.23 to 0.77 mm day^{-1} and 0.7 to 8.3 mm day^{-1}, respectively. For mature pomegranate trees, these values varied from 0.29 to 1.01 mm day^{-1} and 1.0 to 11.4 mm day^{-1}, respectively. The values of K_c of pomegranate obtained in this study were different from the values reported for other regions of the world, mainly due to differences in cultivars and meteorological conditions. The findings of this paper could be used for precision irrigation scheduling and design of irrigation systems for pomegranate orchards. These findings are crucial to enhance water use efficiency in pomegranate production regions suffering from water scarcity. Moreover, separation of transpiration and soil evaporation for accurate estimation of pomegranate water use is recommended for various cultivars, irrigation systems and strategies, and climates for future studies.

ACKNOWLEDGEMENTS

This research was funded by the Iran National Science Foundation (INSF) under the project no. 91042454.

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How to cite this article: Noory, H., Abbasnejad, M., Ebrahimian, H. & Azadi, H. (2021) Determining evapotranspiration and crop coefficients of young and mature pomegranate trees under drip irrigation. *Irrigation and Drainage*, 70(5), 1073–1084. Available from: https://doi.org/10.1002/ird.2607