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Species factor and evapotranspiration for an Ash (*Fraxinus rotundifolia*) and Cypress (*Cupressus arizonica*) in an arid region

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Abstract

The determination of crop coefficients (species factor) and evapotranspiration are important for estimating irrigation water requirements in order to have better irrigation scheduling and water management. The aim of this study was to determine the species factor and evapotranspiration for a reference crop of grass (*Lolium perenne*) and for two typical landscape crops of Ash (*Fraxinus rotundifolia*) and Cypress (*Cupressus arizonica*) using field drainage lysimeters in an arid region of Isfahan in central part of Iran. The potential evapotranspiration was estimated using nine different common methods. Among these methods, the FAO-Radiation, Turc-Radiation-Grass and FAO-Blaney-Criddle methods showed very close agreement with the lysimeter data. The Penman-Monteith 56 and FAO-Corrected-Penman methods showed moderate agreement with the lysimeter data. The Hargreaves, Priestley-Taylor, Makkink 1957 and Penman-Kimberley did not show close agreement with the lysimeter data. The adjustment factors were suggested to overlap the estimated values to the lysimetric values. The values of the species factor for Ash for four different growth stages (first-stage, crop-development, reproductive stage and late-season) were 0.24, 0.56, 0.73 and 0.37, respectively. The values of the species factor for Cypress for the above four different growth stages were 0.32, 0.44, 0.58 and 0.34.

Key words: Crop water requirement; lysimeter; Ash; Cypress.

Introduction

The determination of crop coefficients (species factor) and consequently the potential evapotranspiration (ET) is important for irrigation scheduling and management in order to reduce irrigation water losses such as deep percolation and runoff. Estimate of landscape water needs are important for at least three reasons: (1) Water conservation: due to lack of suitable available water for irrigation. Efficient use of water in urban landscapes contributes substantially to the conservation of water resources. (2) Economic: water costs continue to increase. By applying only the amount of water needed by landscape, and avoiding excess use, the cost can be reduced. (3) Landscape: the potential for plant injury caused by water deficits or excess can be minimized by identifying and meeting plant needs (Costello et al., 2000). The irrigation water requirement varies widely from crop to crop and also for different stages of growth of individual crops. Therefore, the estimation of crop water requirement considering the cropping pattern is the main goal of many researches and has attracted the attention of water resource planners and engineers. Estimates of crop evapotranspiration have

Table 1. The mean daily climatic parameters for the study area (e. g. 1975-2005)

Month	Temperature (°C)		Humidity (%)		Precipitation (mm)	Sunshine hours
	Max.	Min.	Max.	Min.		
March	18.75	4.38	51.18	20.45	0.06	10.28
April	23.95	10.36	57.43	24.1	0.16	8.88
May	26.93	13.56	53.71	18.45	0.15	9.5
June	34.17	19.25	39.07	17.47	0	12.32
July	37.52	23.6	38.35	14.55	0	11
August	35.65	20.95	40.94	14.29	0	11.34
September	31.88	15.77	45.03	13.79	0	10.67
October	25.62	10.07	45.65	15.06	0	9.73
November	15.76	4.79	71.71	35.48	1.09	6.39

practical application in irrigation scheduling, the modeling of crop yield in relation to crop water use, and in irrigation project planning and management (Wright, 1982). Determination of crop coefficient under local climatic condition is the base to improve planning and efficient irrigation management in many field crops (Gouranga et al., 2007). Many researchers have studied crop coefficients and potential evapotranspiration for different crops. For example Benli et al. (2006) have studied evapotranspiration and crop coefficients of alfalfa for four crop growth stages using a weighing lysimeter. Doorenbos and Pruitt (1977a, b) and Allen et al. (1998) suggested crop coefficient values for a number of agriculture crops grown under different climatic conditions.

An important parameter, which needs to be determined for estimating the crop water requirement, is the reference crop evapotranspiration (ET_o). Reference crop evapotranspiration is often defined as the evapotranspiration of a broad expanse of 10-15 cm tall, cool season grass not limited by soil water content (Doorenbos and Pruitt, 1977a, b). ET_o is used to estimate the crop evapotranspiration (ET_c). The ET_c is computed by multiplying the ET_o with a crop coefficient (K_c) to account for differences between the grass and crop ET (Benli et al., 2006).

There are several methods for calculation of ET_o from climatic data and there is no universal consensus on the suitability of any given methods for a given climate (Smith et al., 1996). These methods need to be calibrated before their application for actual field conditions (DehghaniSanij et al., 2004). The methods to calculate ET_o varies from simple empirical relationships to complex methods such as Penman combination method (Penman, 1948). Jensen et al. (1990) ranked the Penman-Monteith 56 (PM) method at the top for estimating daily and monthly reference ET_o in their lysimeteric evaluation of 19 different methods applied in 11 climatologic conditions. The PM method is currently recommended by the United Nation Food and Agriculture Organization (FAO) and by World Meteorological Organization (WMO), although the determination of weather and vegetation input data is often difficult and expensive for many applications (Allen et al.,1998; Kashyap and Panda, 2001). It is difficult to estimate irrigation water requirements and species factors for landscape plant species. For the landscape area as compared to the common agricultural fields, the vegetation density is higher and more variety exists. The plants or shrubs or trees are different and they are close to each other which cause higher transpiration. Costello et al. (2000) presented a guide for estimating irrigation water needs for landscape plants. They estimated species factor based on water use studies for different landscape plant species and then calculated landscape coefficients using three factors of species (crop coefficient), density and microclimate as follow: $K_L = k_s * k_d * k_{mc}$ (1) where: K_L = landscape coefficient, k_s = species factor (range from 0.1 to 0.9), k_d = density factor, k_{mc} = microclimate factor. Zehtabian and Farshi (1999) determined the irrigation water requirements of some local landscape crops in Iran using climatic data and plant characteristics as guides. They used long term climatic data (27 years), Penman-Monteith formula and plant characteristic to

Table 2. The soil characteristics for the experimenttal field

Characteristic	Soil depth	
	0–30 cm	30–60 cm
Sand content (%)	2	2
Silt content (%)	27	23
Clay content (%)	71	75
Soil texture	Clay	Clay
pH	6.7	7.1
Electrical conductivity (dS m^{-1})	3.15	3.50
Ca (mg kg^{-1})	108.6	155.8
Mg (mg kg^{-1})	25.4	24.5
Na (mg kg^{-1})	178.7	218.4
Sodium adsorption ratio	5.9	6.1
K (mg kg^{-1})	488.5	458.9
P (mg kg^{-1})	11.7	12.0
Total nitrogen (%)	0.07	0.05
Organic mater (%)	1.8	0.9
Bulk density (mgm^{-3})	1.58	-
Particle density (mgm^{-3})	2.69	-

determine the irrigation water requirements. The landscape crops were Ash (*Fraxinus rotundifolia*), Elm (*ulmus carpinifolia*), Shiraz Cypress (*Cupressus sempervirens var. fastigiata*), Arizona Cypress (*Cupressus arizonica*) and Varnish tree (*Koelreuteria paniculata*). They estimated the species factor to range between 0.4 and 0.6 based on the characteristics of leaf stomata and other crop genetics. The maximum evapotranspiration for 10 days irrigation interval for landscape crops of deciduous tree and evergreen tree ranged between 25 – 35 mm.

In the central part of Iran, due to shortage of irrigation water and also high use of Ash and Cypress as landscape crops, it is necessary to determine the species factor for these crops. The objective of this study was to use field lysimeters to determine the species factor of landscape crops of Ash and Cypress and to evaluate the common methods of estimating ET_o for these crops for the central part of Iran.

Materials and methods

Experimental layout and data collection

Isfahan is located in central part of Iran at 31° 29´ - 33° 1´N latitude and 51° 31´ to 53° 12´E longitude with arid climatic conditions with an annual rainfall of 134 mm. Table 1 shows some of the mean daily climatic data for the period of study for the area. To achieve the objective of the study nine lysimeters were installed at Mahmoud-Abad Research Station near Isfahan at 32° 47´N latitude and 51° 35´E longitude in 2004 and data were collected during the year of 2005. Each lysimeter was 1.5m×1m×1.2m and had a drain pipe at the bottom (Fig. 1). Nine lysimeters were used to determine the potential evapotranspiration at different crop growth stages for the Ash, Cypress and grass (*Lolium perenne*), using three replications for each crop. Ash and Cypress are landscape plant species commonly used in Iran and they are irrigated by surface, sprinkler and trickle irrigation methods. For example in Isfahan, central part of Iran, the irrigation interval of about 2-3 weeks are applied for Ash and Cypress using surface irrigation method based on about 50% soil moisture depletion from the plant root zone. Grass (*Lolium perenne*) was used as the reference crop for measuring the ET_o. Each grass lysimeter was surrounded by similar plant to a distance of 20 meters

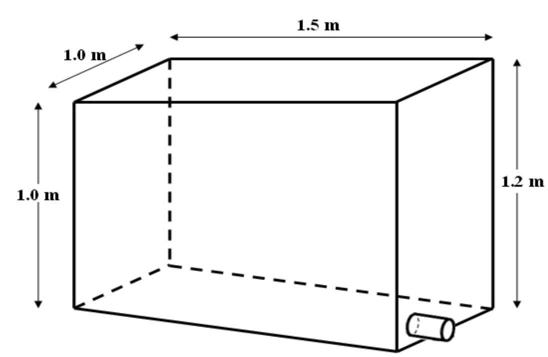

Fig 1. Schematic of the lysimeter used to collect field data

from the lysimeter. Each Ash and Cypress lysimeter was surrounded by similar plant to a distance of 30m×50m. The trees were spaced 2 meters. Ash and Cypress crops were planted on December 2004 and grass was planted on September 2004. The plants used in lysimeter were delivered from nursery, aged three years, height about 2 meters and had average root depth of 30-40 cm. For grass, the planting date was on September and the green coverage was about 100% at the beginning of the March and the average root depth was about 30 cm during the growing period.

Table 3. The volume balance components for the grass lysimeters

Month	Mean irrigation (mm)	Precipitation (mm)	Mean drainage (mm)	Mean evapotran-spiration (mm)
March	95	1.86	12.86	84
April	180	4.8	17.8	167
May	250	4.65	25.65	229
June	312	0	26	286
July	345	0	31	314
Agust	325	0	34	291
September	240	0	24	216
October	175	0	16	159
November	40	32.7	10.7	62

Table 2 shows the soil characteristics for the experimental field. Soil moisture at field capacity (FC) was 55.3% and soil moisture at permanent wilting point (PWP) was 29%. The soil moistures are based on volume. These values were determined in the laboratory using field obtained soil samples. In each irrigation, 10% more water was applied to allow for drainage. The lysimeters were irrigated by surface irrigation method and a water flow meter was used to apply the required amount of irrigation water to each lysimeter. Irrigations started when 30% of the available root zone soil moisture was depleted. Also, the trees surrounded the lysimeters were irrigated similarly by surface irrigation. The grass was irrigated using sprinkler irrigation.

Nearly one day after each irrigation, the drainage outflow from each lysimeter was measured volumetrically at a short distance from the lysimeter in a drainage box by opening the drainage valve located at the end of drainage pipe. To assure that all drainage water will be removed from the soil profile, the drainage water was collected one day after each irrigation. It should be noted that after the measurement of the drainage outflow, the drainage valve was closed until the next outflow measurement of the next irrigation. Over the period of study the rainfall was not noticeable (Table 1). If rain occurred it influenced the soil moisture status and irrigation time. If deep drainage occurred after a rainfall event, the drainage outflow was measured similar to measurement for irrigation event. The mass-balance method was used to calculate ET_o as follow: $ET_o = P_n + I - R_o - \Delta D_e - D_r$ (2) where: ET_o = evapotranspiration (mm), P_n = precipitation (mm), I = irrigation (mm), R_o = net runoff (mm), ΔD_e = the change in soil water storage (mm), D_r = drainage (mm). The climatic data from the nearby weather station was used to estimate P_n, the value of I was calculated based on 30% reduction of soil moisture from field capacity, R_o was equal to zero because of no surface runoff from lysimeter, the ΔD_e was equal to the change in soil water storage and the D_r was calculated based on lysimeter outflow data.

The following equation was used to calculate irrigation:

$$I = d(\theta_{FC} - \theta_{pwp})MAD \quad (3)$$

where: d = soil depth, θ_{FC} = volumetric soil moisture at field capacity, θ_{PWP} = volumetric soil moisture at wilting point, MAD = maximum allowable depletion which was equal to 30%. The soil samples were taken at different time periods (almost daily at the peak period) until the soil moisture reaches the limits for irrigation.

Daily meteorological data, including maximum air temperature, minimum air temperature, average air temperature, maximum relative humidity, minimum relative humidity, sunshine hours and wind speed at a height of 2m were collected from the Isfahan University of Technology Weather Station, located near the research station. Then, the data were used to estimate evapotranspiration by different methods. The values of mean monthly irrigations, rain, mean drainage and mean ET_o for the grass lysimetr are given in Table 3. It should be noted that the results given in this paper are based on one year period of measurements.

Methods of computing potential evapotranpiration

The nine common methods that were used to estimate potential evapotranspiration are shown in Table 4. Details about the above methods are given bellow:

1) FAO-Penman equation (Doorenboss and Pruitt ,1975, 1977a, b):

$$ET_0 = c\left[\left(\frac{\Delta}{\Delta+\gamma}\right)(R_n) + \left(\frac{\gamma}{\Delta+\gamma}\right)(2.7)(W_f)(e_z^0 - e_z)\right] \quad (4)$$

where: ET_o = reference evapotranspiration (mm day^{-1}), $(e_z^0 - e_z)$ = vapor pressure deficit at height z (kPa), γ = psychometric constant (kPa ºC^{-1}), Δ = slope

Table 4. Different methods for estimating potential evapotranspiration

	Classification	Method	Reference crop
1	Combination based	Penman-Monteith 56 (PM)	Grass
2	Combination based	Penman-Kimberley (PK)	Grass
3	Combination based	FAO-Corrected-Penman (PF)	Grass
4	Radiation based	Turc-Radiation Grass (TR)	Grass
5	Radiation based	Hargreaves (HG)	Grass
6	Radiation based	FAO-Radiation (FR)	Grass
7	Radiation based	Makkink 1957 (MA)	Grass
8	Temperature based	Priestley-Taylor (PT)	Grass
9	Temperature based	FAO-Blaney-Criddle (BC)	Grass

vapor pressure curve (kPa °C^{-1}), R_n = net radiation (MJ m^{-2} per day), W_f = the wind function, c = adjustment factor which is equal to 1.

2) Penman-Kimberly-1982 (Wright, 1982):

$$ET_0 = \frac{1}{\lambda}\left[\left(\frac{\Delta}{\Delta+\gamma}\right)(R_n - G) + \left(\frac{\gamma}{\Delta+\gamma}\right)(6.43)(W_f)(e_z^0 - e_z)\right] \quad (5)$$

where: G = soil heat flux density (MJ m^{-2} day^{-1}), λ = latent heat of vaporization (MJ kg^{-1}).

3) FAO Penman-Monteith 56 (Allen et al. 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (6)$$

where: u_2 = wind speed at 2 m height (m s^{-1}), (e_s - e_a) = saturation vapor pressure deficit (kPa).

4) Turc-Radiation (Turc, 1961):

$$ET_o = a_T (0.013) \frac{T_{mean}}{T_{mean} + 15} \left(\frac{23.8856 R_s + 50}{\lambda}\right) \quad (7)$$

where: T_{maen} = mean daily air temperature (°C), R_s = solar radiation (MJ m^{-2} d^{-1}), a_T = 1.0 for $RH_{mean} \geq 50\%$ and $a_T = 1+(50-RH_{mean})/70$ for $RH_{mean} < 50\%$.

5) Priestley and Taylor (Priestley and Taylor, 1972):

$$ET_{\circ} = \frac{1}{\lambda} \alpha \frac{\Delta}{\Delta + \gamma} (R_n - G) \quad (8)$$

where: α is a constant ($\alpha = 1.26$).

6) Hargreaves (Hargreaves and Samani, 1982, 1985):

$$ET_o = \frac{1}{\lambda} (0.0023) R_A TD^{1/2} (T + 17.8) \quad (9)$$

where: R_A = extraterrestrial solar radiation received on earth's surface (MJ m^{-2} d^{-1}), TD = difference of mean maximum and mean minimum air temperatures (ºC), T = mean daily air temperature at 2 m height (°C).

7) Blaney-Criddle method (Blaney and Criddle, 1950, 1962; Doorenboss and Pruitt, 1977a, b):

$$ET_o = a + bf \quad (10)$$

$$a = 0.0043\ RH_{min} - n / N - 1.41 \quad (11)$$

$$b = 0.82 - 0.41 \times 10^{-2} RH_{min} + 1.07 \times n/N + 0.066 \times U_d - 0.60 \times 10^{-2} RH_{min} \times n/N - 0.60 \times 103 RH_{min} \times U_d \quad (12)$$

$$f = p(0.46\ T + 8.13) \quad (13)$$

where: RH_{min} = minimum relative humidity (%), n = actual daily sunshine hours (h), N = maximum possible daily sunshine hours (h), p = monthly percentage of daytime hours, U_d = daytime wind speed (m s^{-1}).

8) Makkink (1957):

$$ET_{\circ} = 0.61 \frac{\Delta}{\Delta + \gamma} \frac{R_s}{2.45} - 0.12 \quad (14)$$

9) FAO-Radiation (Doorenboss and Pruitt, 1977a, b):

$$ET_o = b\left[\frac{\Delta}{\Delta + \gamma} \frac{R_s}{\lambda}\right] - 0.3 \quad (15)$$

$$b = 1.066 - 0.13 \times 10^{-2} RH + 0.045 U_d - 0.20 \times 10^{-3} RH U_d - 0.315 \times 10^{-4} RH^2 - 0.11 \times 10^{2} U_d^2 \quad (16)$$

where: RH = mean relative humidity (%).

For more information about the methods presented in Table 4 the reader can refer to references such as

Table 5. The comparison of lysimeter with different methods for estimating potential evapotranspiration

Method	Evapotranspiration	
	Mean (mm/month)	Total (mm)
Lysimeter	201.3	1811.4
Penman-Monteith 56	245.4	2208.7
Penman-Kimberley	295.8	2662.1
FAO-Corrected-Penman	245.5	2209.8
Turc-Radiation Grass	167.7	1509.4
Hargreaves	144.9	1303.8
FAO-Radiation	234.3	2108.4
Makkink 1957	118.8	1069.6
Priestley-Taylor	123	1107
FAO-Blaney-Criddle	236.5	2128.9

The values are based on nine months measurements

FAO Irrigation and Drainage Paper No. 24 (Doorenbos and Pruitt 1977a, b ; Jensen et al 1990).
In this study, to calculate ET_o the calibration method was not used, but instead, the best method among the nine methods mentioned above was selected and the comparison were made between the measured lysimeter data and the prediction of the best method.
The following equation was used to calculate the crop coefficient (K_c), which is the ratio of crop evapotranspiration (ET_c, measured by lysimeter) to grass reference evapotranspiration (ET_o, measured by lysimeter):

$$K_c = \frac{ET_c}{ET_0} \quad (17)$$

Data analyses

The values of mean monthly measured ET_o and the total values of ET_o for lysimeter data and the predicted values from each of the nine methods are presented in Table 5.
The method suggested by Jacovides and Kontoyiannis (1995) and Jacovides (1997) were used for statistical analyses. The following equations were used to compute the regression coefficients (r), root mean square error (RMSE), mean bias error (MBE) and t-statistic test (t).

$$r = \frac{\sum_{i=1}^{n}(x-\bar{x})(y-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x-\bar{x})^2\sum_{i=1}^{n}(y-\bar{y})^2}} \quad (18)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}} \quad (19)$$

$$MBE = \sum_{i=1}^{n}\frac{d_i}{n} \quad (20)$$

$$t = \sqrt{\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}} \quad (21)$$

where: x = the measurement value, $\bar{x}$ = the mean measurement value, y = the predicted value, $\bar{y}$ = the mean predict value, d_i = difference between ith predicted and ith measured values, n = number of data pairs i.

Results and discussion

Monthly ET_o

The monthly evapotranspiration was computed based on water-balance data collected from lysimeters using Eq. 2. The computed ET_o values from the lysimeter data for *Lolium perenne* grass which is the reference crop from March to November are compared to the ET_o values computed from nine different methods as shown in Fig. 2. This figure shows the ET_o increases from March to July and then starts to decrease and reaches the lowest value on November. Both lysimeter and different methods of computing ET_o show similar trend. For the nine months period (March-November), the PM, PK, PF, FR and BC methods overestimate the ET_o and HG, PT, MA and TR methods underestimate the ET_o (Fig.2). The study by DehghaniSanij et al. (2004) for an semi-arid region in Iran also showed similar results which indicate that PF, FR, PK and BC methods overestimate the ET_o and HG method underestimate the ET_o for the reference crop of grass.

The ET_o values of lysimeter for *Lolium perenne* grass is 84 mm per month for March, 314 mm per month for July and 62 mm per month for November. The mean monthly lysimeter ET_o values for nine months from March to November for the *Lolium perenne* grass is 201 mm and the total ET_o is 1811 mm (Table 5). The other methods show different values for which the comparison is given below.

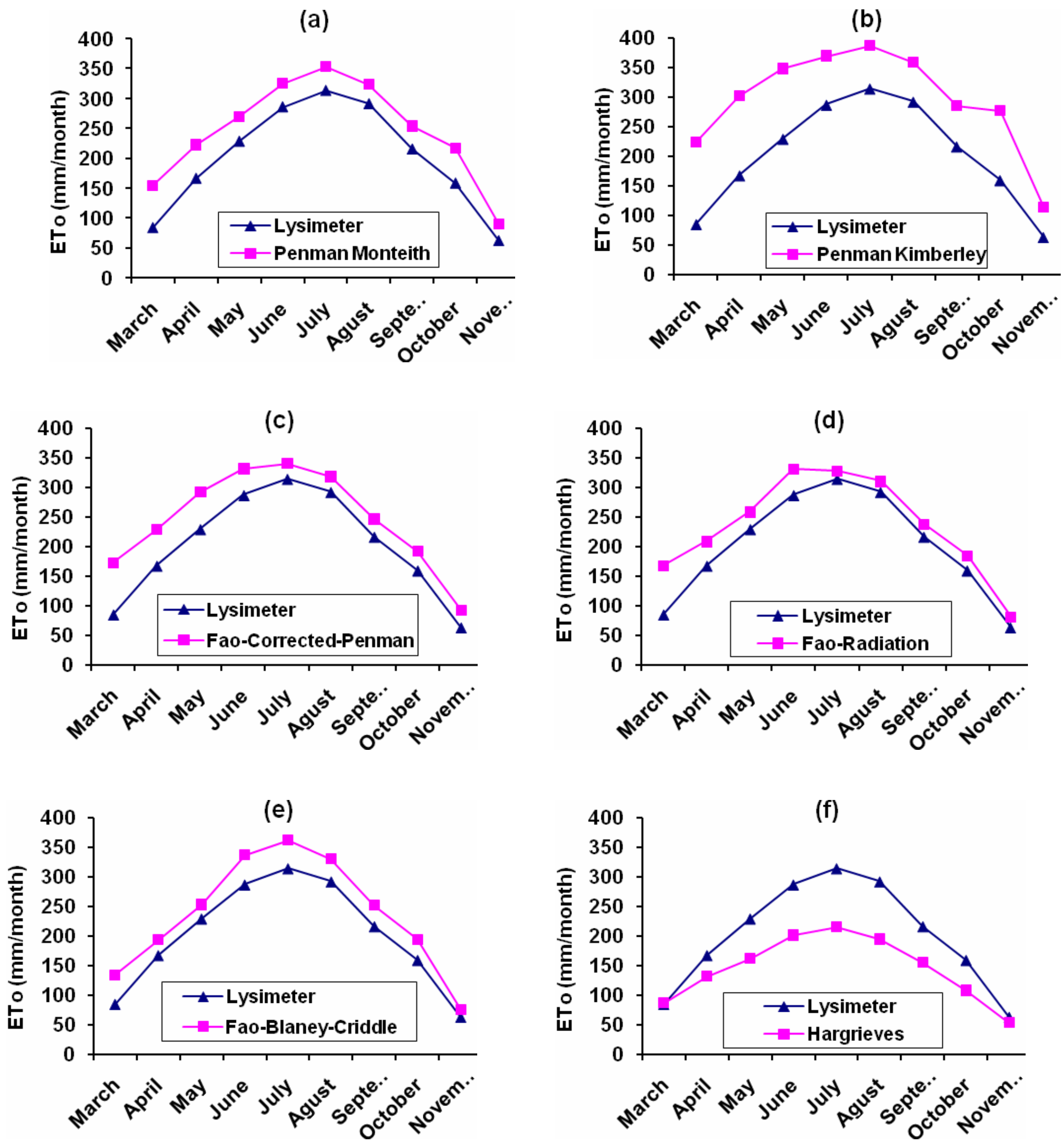

Fig 2. Comparison of monthly measured and computed evapotranspiration using different methods

Statistical comparison of ET_o values

The RMSE, MBE and t-test statistical methods were used to compare the lysimeter ET_o values with the ET_o values computed by nine different methods. The results of these comparisons for the above parameters are shown in Table 6. The methods in Table 6 are ranked according to RMSE. Based on RMSE and MBE valus presented in Table 6, the BC, FR and TR methods estimate the lysimeter ET_o values most closely. The PM and PF methods showed reasonable agreement with the lysimeter values and the HG, PT, MA and PK methods did not show close agreement with the lysimeter values. The negative sign of the MBE indicates that the computed ET_o is lower than the ET_o measured by the lysimeter and the positive MBE shows over estimation of the lysimeter ET_o values, while the absolute value is an indicator of method performance (Table 6). The FAO-Blaney-Criddle method showed the best monthly estimation of the ET_o as compared to the lysimeter ET_o. This method had almost the lowest RMSE and MBE values as shown in Table 6. The Penman-Kimberley method showed the worst monthly estimation of the ET_o as compared to the lysimeter ET_o. This method had the highest RMSE and MBE values as shown in Table 6. The PM method did not show good agreement with the lysimeter data. The measurements of some parameters such as solar radiation and resistances can improve the prediction of the Penman-Monteith 56 method (Ventura et al., 1999).

In this article, according to the Jacovides (1997), the performance of each method is based on the t-values. Lower t-values show better performance of the method which means the differences between the measurement and the estimates are less. According to the t-values shown in Table 6, the FR and TR methods show the best estimations.

Based on data presented in Table 7, the goodness of fit between the monthly measured evapotranspiration (ET_o) of the grass grown in the lysimeter and the evapotranspiration values estimated by the combination method and radiation and temperature method are shown in Figs. 3a and 3b, respectively. The slope near to unity indicates a parallelism of the measured and the calculated ET_0 curves, while the low intercept of the regression equation indicates proportionality between the two, whatever the value of the slope. Table 7 shows that only the BC and PM results are close enough to the measured data. The PF and FR methods ranked in middle and the PK, TR,

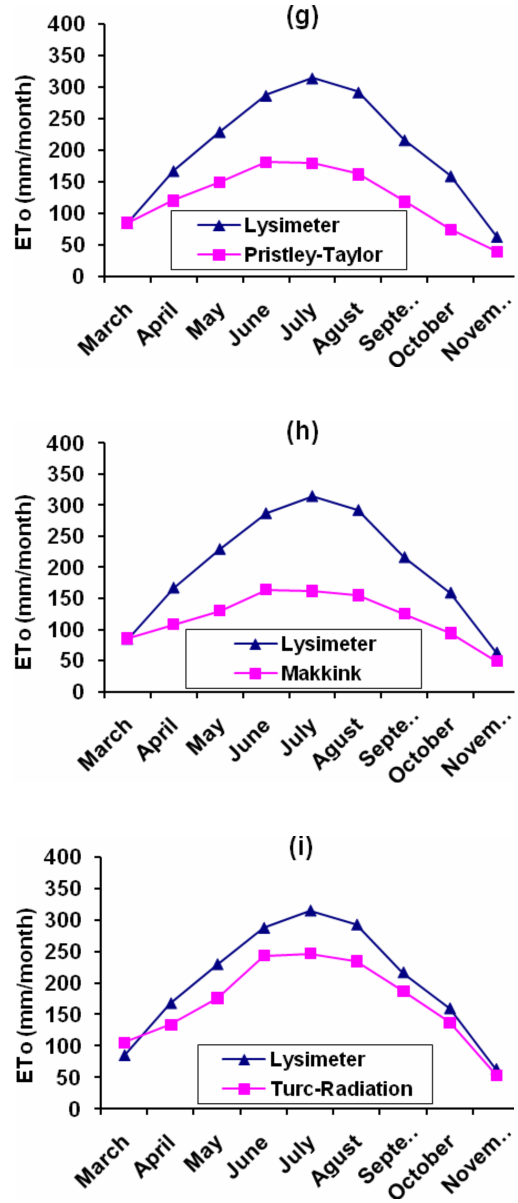

Fig 2 continued. Comparison of monthly measured and computed evapotranspiration using different methods

HG, PT and MA methods ranked in the lower category for estimating the ET_o values. The results show that the constant values of the above equations have high influence on prediction of equations. For example, although, all the penman equations are driven from

Table 6. Ranking of different methods for estimating evapotranspiration

	Method	RMSE	MBE	t-value
1	FAO-Blaney-Criddle (BC)	37.7	35.27	7.95
2	FAO-Radiation (FR)	39.0	33.0	4.73
3	Turc-Radiation Grass (TR)	41.8	-33.55	4.02
4	Penman-Monteith 56(PM)	46.4	44.14	9.12
5	FAO-Corrected-Penman (PF)	49.2	44.26	6.17
6	Hargreaves (HG)	65.5	-56.4	5.06
7	Priestley-Taylor (PT)	89.1	-78.26	5.50
8	Makkink 1957 (MA)	95.9	-82.41	5.03
9	Penman-Kimberley (PK)	99.9	94.52	8.73

RMSE: root mean square error; MBE: mean bias error; t-value. Lower t-values show better performance

one equation, but their results are significantly different. Based on Fig. 3a, the PM and PF methods show good results but the PK method does not show good results for the study area. The constant parameters of the equations such as the wind factor is responsible for this. Also, as shown in Fig. 3b, even the MA and FR methods are similar but the difference in their constants caused the FR method be placed in a better rank. This shows that the constant parameters of the equations have important influence on their predictions. Therefore, the calibration of the constants of the equations for the study area results in better prediction by the equations. The above results show that for the period (March-November), the PM, PK, PF, FR and BC methods overestimated the ET_o and HG, PT, MA and TR methods underestimated the ET_o. For the PM, PK, PF, FR and BC methods the adjustment factors can be used to nearly overlap the prediction of any of the above methods to the lysimetric measurement because as shown in Figs. 3a and 3b the lines of relationship between ET_o measured and ET_o predicted are nearly parallel. The adjustment factors for the above five methods are 0.84, 0.7, 0.84, 0.87 and 0.86, respectively. By multiplying these values to the predicted value, the lysimetric value can be reached. For the HG, PT, MA and TR methods, the adjustment factors can not be used because as shown in Fig. 3b the lines of relationship between ET_o measured and ET_o predicted are not parallel.

Species factor

The results of lysimetric measurements for reference crop (ET_0), Ash and cypress crops are shown in Fig. 4 which shows that the evapotranspiration of reference crop is higher than the Ash and Cypress crops for the study period. The graphs of monthly species factor (nine values for each crop) for ash and Cypress are given in Fig. 5. These data have been transformed into four values for each crop (the first-stage, development-stage, reproductive stage and late-season crop coefficients). Based on FAO suggestions these four stages were defined (Allen et al, 1998). The beginning and end of each grow stage was based on the overlapping of the species factor curve to the curve suggested by the FAO method. Also it is important to know the duration of each stage. For example, for Ash, the duration of the first-stage was 35 days, the duration of the crop-development stage was 45 days, the duration of the reproductive stage was 60 days and the duration of the last-stage was 90 days approximately. The coefficients for winter months were not measured because of low evapotranspiration during the winter months.

The crop coefficients for Ash for different growth stages including first-stage, crop-development, reproductive stage and late-season are 0.24, 0.56, 0.73 and 0.37, respectively (Fig. 5a). During the first-stage of crop growth for Ash (0–35 days after planting), crop coefficient value was low (0.24 on average) because the leaf area was small, the transpiration rate was low, and water losses by evaporation occurred mostly on the fraction of soil surface wetted by irrigation. The second crop growth stage started on day of 36 after planting which was nearly the start of rapid increase in crop coefficient. During the development stage, days of 80 to 140, the highest value of Kc (above 0.77) was observed. Because, at this period, the root length, the leaf area index and the air temperature were highest. During the late-season, days of 140 to 240, the value of crop coefficient decreased nearly linearly and reached to 0.23 in November. At this month the mean average air temperature was 10 °C.

As shown in Fig. 5b, the species factor for Cypress for different growth stages including first-stage, crop-development, reproductive stage and late-season are 0.32, 0.44, 0.58 and 0.34, respectively. During the first-stage of crop growth for Cypress (0–60 days after planting), crop coefficient value was low (0.32 on average) because the leaf area was small, the transpiration rate was low, and water losses by evaporation occurred mostly on the fraction of soil surface wetted by irrigation. At this crop growth stage, the crop coefficient of Cypress is higher as

Table 7. The regression analysis of measured and estimated evapotranspiration by various methods

	Method	Slope of the regression line	Intercept of the regression line	R^2
1	FAO-Blaney-Criddle (BC)	1.06	21.89	0.98
2	Penman-Monteith 56(PM)	0.93	56.84	0.97
3	FAO-Corrected-Penman (PF)	0.89	64	0.94
4	FAO-Radiation (FR)	0.89	53.18	0.94
5	Penman-Kimberley (PK)	0.88	116.9	0.86
6	Turc-Radiation Grass (TR)	0.72	20.89	0.96
7	Hargreaves (HG)	0.60	23.03	0.98
8	Priestley-Taylor (PT)	0.52	18.08	0.89
9	Makkink 1957 (MA)	0.41	34.43	0.94

Number of observations, n = 9

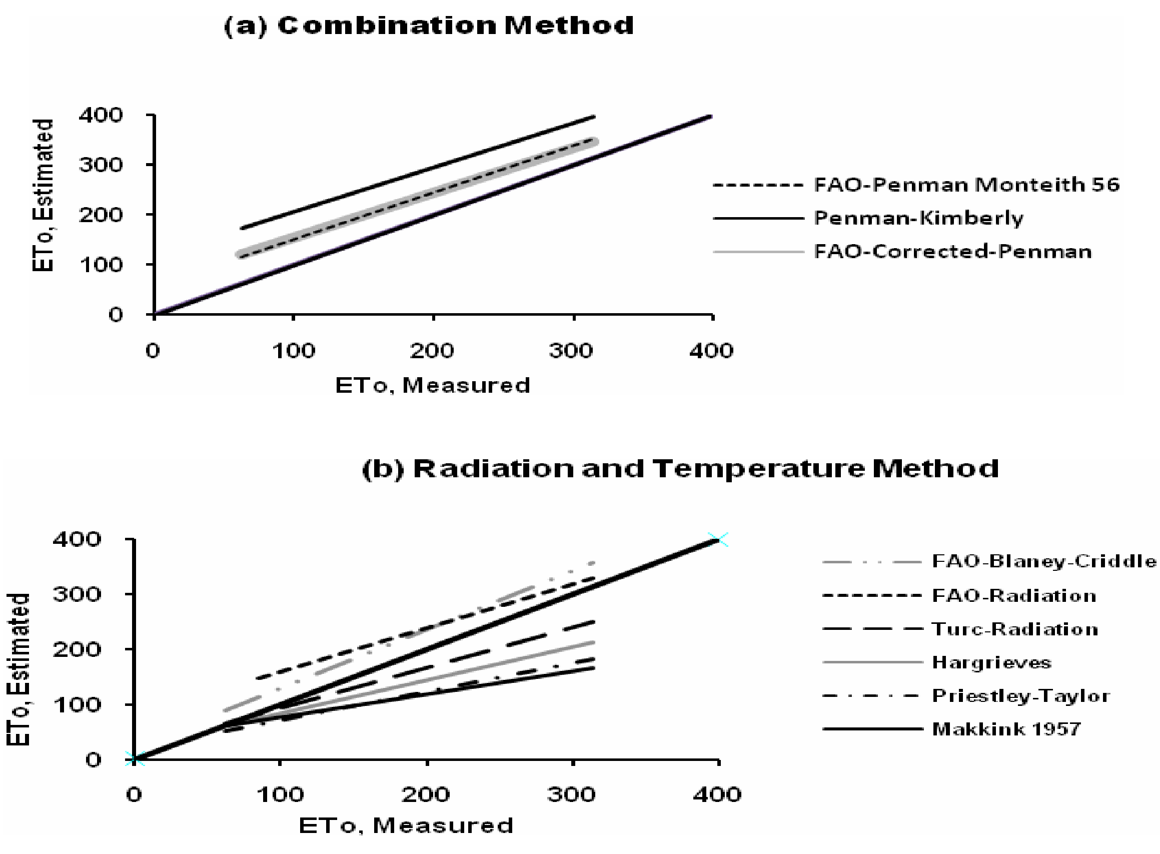

Fig 3. Comparison of measured and estimated evapotranspiration for combination methods (**a**) and radiation and temperature methods (**b**).

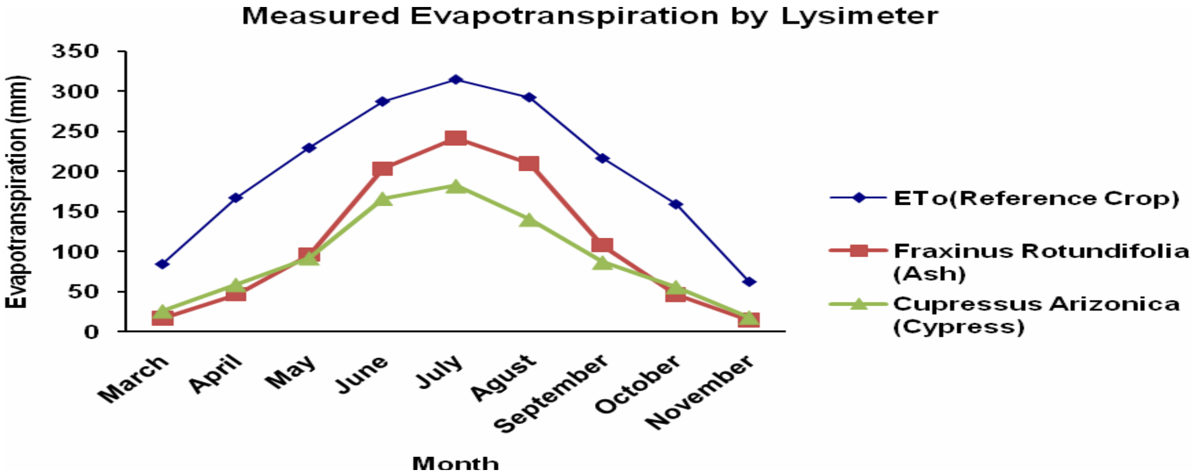

Fig 4. The measured evapotranspiration by lysimeter for refrence crop, Ash and cypress

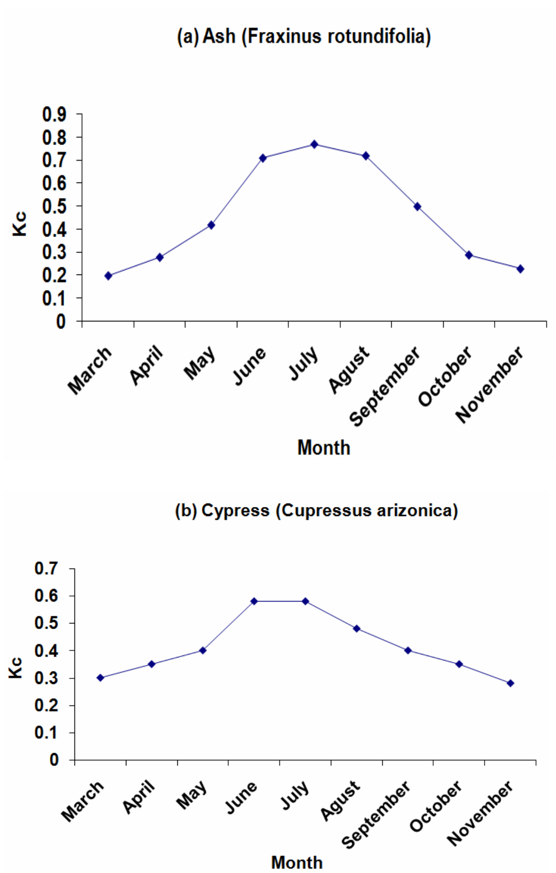

Fig 5. The lysimeter monthly species factor for *Fraxinus rotundifolia* (**a**) and *Cupressus arizonica* (**b**).

compared to the Ash, because the leaf area index of Cypress was greater (almost 40%). The second crop growth stage started on day of 61 after planting which was nearly the start of rapid increase in crop coefficient. During the development stage, days of 95 to 120, the highest value of Kc (above 0.58) was observed. Because, at this period, the root length, the leaf area index and the air temperature were highest. During the late-season, days of 120 to 240, the value of crop coefficient decreased nearly linearly and reached to 0.28 in November. The observed variability in crop coefficients for the two crops studied is related to variability in factors such as variety, root-stock, plant age, management system and micrometeorological conditions

Conclusion

For the study area which is an arid region, the measured evapotranspiration using lysimeter were compared with the computed evapotranspiration from nine common methods of estimating evapotrans - piration for two landscape plant species and a reference crop. The results showed that the BC, FR and TR methods estimate the lysimeter ET_o values most closely. The PM and PF methods showed reasonable agreement with the lysimeter values and the HG, PT, MA and PK methods did not show close agreement with the lysimeter values. For the PM, PK, PF, FR and BC methods the adjustment factors can be used to nearly overlap the prediction of any of the above methods to the lysimetric measurement. The crop coefficients, as compared to the reference crop, for two landscape plant species of Ash and Cypress were determined for different crop growth stages.

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