تحقیقات منابع آب ایران
Iran-Water Resources Research

سال یکم، شماره ۲، تابستان ۱۳۸۴
Volume 1, No. 2, Summer 2005 (IR-WRR)
1-6

# Evaluation and Calibration of Three Evapotranspiration Equations in a Semi-Arid Region

*H. R. Fooladmand[1], A. R. Sepaskhah[2]*

**Abstract**

This paper evaluates three different methods for estimation of reference crop evapotranspiration ($ET_o$) in Bajgah area, Fars province, in Iran. Monthly values of $ET_o$ were estimated with Penman-FAO, Penman-Monteith and Hargreaves equations using the mean monthly weather data from 1986-2002 (17 years). The Penman-Monteith and Hargreaves equations were calibrated based on Penman-FAO method which was recognized as the most appropriate equation for $ET_o$ estimation, according to the previous studies. This study showed that the results of Penman-Monteith and Hargreaves equations are similar to but somehow they underestimate $ET_o$ compared with Penman-FAO method. To calibrate the Penman-Monteith and Hargreaves equations, a linear regression was used. The results of calibration for Penman-Monteith equation showed the variation of the slope of the line and $ET_0$ the calibration coefficient ($C_H$) of the Hargreaves equation for each month. annual $ET_o$ estimated.

***Keywords:*** Reference crop, Potential evapotranspiration, Penman-FAO, Penman-Monteith, Hargreaves

1-Marvdasht Islamic Azad University, Marvdasht, Email:hrfoolad@yahoo.com
2-Professor, Department of Irrigation, Shiraz University, Shiraz, Email: sepas@shirazu.ac.ir

# ارزیابی و واسنجی سه معادله تبخیر تعرق در منطقه ای نیمه خشک

**حمید رضا فولادمند[1] و علیرضا سپاسخواه[2]**

**چکیده**

در این مقاله سه روش مختلف برای تخمین تبخیر تعرق بالقوه سطوح گیاهی ($ET_0$) در منطقه باجگاه ( استان فارس, ایران) ارزیابی می شود. با استفاده از میانگین داده های هواشناسی در سال‌های ۲۰۰۲- ۱۹۸۶ در (۱۷ سال) , مقادیر ماهانه $ET_0$ با معادله‌های پن من – فائو , پن من – مانتیث و هارگریوز تخمین زده شد. معادله‌های پن من – مانتیث و هارگریوز بر اساس روش پن‌من- فائو که در مطالعات قبلی مناسب ترین معادله برای تخمین $ET_0$ شناخته شده واسنجی گردید.

بررسی‌ها نشان داد که نتایج معادله های پن من – مانتیث و هارگریوز تا اندازه‌ای به هم شبیه‌اند. ولی میزان $ET_0$ را برای همه سال‌ها کمتر از روش پن من – فائو تخمین می زنند. برای واسنجی معادله‌های پن من – مانتیث و هارگریوز رابطه رگرسیون خطی به کار برده شد. همچنین در واسنجی معادله هارگریوز، تغییرات شیب خط برای مقادیر مختلف $ET_0$ در دو روش محاسبه کویر ضرایب واسنجی شده معادله هارگریوز ($C_H$) برای ماه‌های مختلف بدست آمد. همچنین $ET_0$ سالانه بدست آمد.

***کلمات کلیدی:*** تبخیر تعرق بالقوه، سطوح گیاهی مرجع، پن‌من- فائو , پن من – مانتیث , هارگریوز

۱- هیئت علمی دانشگاه آزاد واحد مرودشت
۲- استاد بخش آبیاری دانشگاه شیراز – شیراز

## Introduction

In semi-arid regions, water use in irrigated agriculture is very important for different aspects of water resources management. In most conditions, irrigation water use is calculated based on crop potential evapotranspiration. Crop potential evapotranspiration ($ET_c$) is estimated as follows:

$$ET_c = K_c ET_o \qquad (1)$$

Where $K_c$ is the crop coefficient and $ET_o$ is reference crop potential evapotranspiration. Thus, most irrigation engineers use $ET_o$ to estimate different crop water requirements (Martinez-Cob and Tejero-Juste, 2004). Therefore, using historical $ET_o$ for irrigation scheduling and system design is very common. Historical $ET_o$ is simply long-term average value. Because of the consistency of climate in the most regions, variability in $ET_o$ from year to year (or each months of year during several years) is assumed to be small, and thus differences between a historical value based on many years of data and actual values for any given year would be small. The main advantages of using historical $ET_o$ are convenient and the ability to predict the irrigation requirements throughout the growing season (Hanson et al., 1999).

Although several equations have been proposed to estimate $ET_o$, there is no universal consensus on the suitability of any given equation for a given climate, and they require rigorous local calibration (Dehghani-Sanij et al., 2004). The most common methods are Penman-FAO (Doorenbos and Pruitt, 1977) and Penman-Monteith (Allen et al.,1998). To calculate $ET_o$ by these methods, minimum and maximum air temperature, minimum and maximum relative humidity, sunshine and wind speed data, must be available. Hargreaves equation is another method that only needs minimum and maximum air temperature data (Hargreaves and Samani, 1985). The Hargreaves equation tends to overestimate $ET_o$ in humid regions and underestimate $ET_o$ in very dry regions (Xu and Singh, 2002). So, it is essential to calibrate each equation locally.

Some investigators tried to determine the best method of $ET_o$ estimation in the Bajgah area, Fars province, in Iran. Malek (1982) showed that the Penman-FAO equation gives a good estimation of $ET_o$ in this area. Sepaskhah (1999) showed that Penman-FAO equation is more appropriate than Penman-Monteith for the Bajgah area. Furthermore, Sepaskhah and Fooladmand (2004) showed that the Penman-FAO equation is the most appropriate method for estimating $ET_o$ in the Bajgah area. This is optained by using water balance model for microcatchment water harvesting systems for rainfed vineyard. Furthermore, Zand-Parsa et al. (1996) calculated $ET_o$ based on Penman-FAO method for most synoptic meteorological stations in Iran. They showed that type III Pearson and Normal distributions are the most appropriate distributions for all stations in Iran. Later, Zand-Parsa and Sepaskhah (1996) introduced a simple method for calculating $ET_o$ based on type III Pearson and Normal distributions for different probabilities of occurrence.

The purpose of this study is to evaluate the different methods of estimation for reference crop evapotranspiration ($ET_o$) in the Bajgah area, Fars province, I. R. of Iran, and calibrating the Penman-Monteith and Hargreaves equations based on Penman-FAO equation in monthly bases.

## Materials and Methods

Fars province is located in the southern part of I. R. of Iran, at 50°30´ to 55°38´ longitude and 27°3´ to 31°42´ N latitude, with an arable land area of 1.32 million $km^2$. The mean annual precipitation for the province ranges from 50 to 1000 mm (Sadeghi et al., 2002). The Bajgah area is located 16 km north of Shiraz (center portion of Fars province) at 52°46´ longitude, 29°50´ N latitude. Bajgah elevation is 1810 m above the mean sea level and its mean annual rainfall is approximately 420 mm (Fooladmand and Sepaskhah, 2004). The climate of this region is semi-arid as reported by Malek (1984). Also, Malek (1984) showed that the most weather data in the Bajgah area is homogeneous.

Because of the lack of measured $ET_o$ data in Bajgah area, calibration of Penman-Monteith and Hargreaves equations based on Penman-FAO equation is required. This is done using water balance model for microcachment water harvesting systems for rainfed vineyard. For this purpose the mean monthly weather data of the Bajgah area during 1986-2002 (17 years) were used for estimation of $ET_o$ with Penman-FAO, Penman-Monteith and Hargreaves equations. The mean monthly weather data of the study area are shown in Table 1. The Penman-FAO (Doorenbos and Pruitt, 1977) equation is as follows:

$$ET_o = C \times \left[0.408 \times W \times R_n + (1-W) \times f_u \times (e_s - e_a)\right] \qquad (2)$$

where $ET_o$ is the reference crop potential evapotranspiration (mm $d^{-1}$), C is the coefficient that depends on the wind speed at 2 m height ($U_2$), maximum relative humidity ($RH_{max}$) and solar radiation ($R_s$), W is the coefficient related to the temperature, $R_n$ is the net radiation (MJ $m^{-2}$ $d^{-1}$), $f_u$ is the wind function, and $e_s$, $e_a$ are the saturation and actual vapor pressures (mbar), respectively. More details are reported by

Doorenbos and Pruitt (1977). The Penman- Monteith (Allen et al.,1998) equation is as follows:

$$ET_o = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \frac{900}{T_m + 273} \times U_2 \times (e_s - e_a)}{\Delta + \gamma \times (1 + 0.34 \times U_2)} \quad (3)$$

where $ET_o$ is the reference crop potential evapotranspiration (mm per day), $R_n$ is the net radiation (MJ $m^{-2}$ $d^{-1}$), G is the soil heat flux density (MJ $m^{-2}$ $d^{-1}$), T is the air temperature at 2 m height ($^oC$), $U_2$ is the wind speed at 2 m height (m $s^{-1}$), and $e_s$ and $e_a$ are the saturation and actual vapor pressures (kPa), Δ is the slope of vapor pressure curve (kPa $^oC^{-1}$) and γ is the psychrometric constant (kPa $^oC^{-1}$). More details are reported by Allen et al. (1998). Also, solar radiation ($R_s$) was computed using the following equation which was derived for the Bajgah area by Malek (1979):

$$R_s = (0.31 + 0.55\frac{n}{N})R_a \quad (4)$$

where $R_s$ is the solar radiation (MJ $m^{-2}$ $d^{-1}$), $R_a$ is the extraterrestrial radiation (MJ $m^{-2}$ $d^{-1}$), n is the actual duration of sunshine (hour). and N is the maximum possible duration of sunshine or daylight hours (hour). The Hargreaves (Hargreaves and Samani, 1985) equation is as follows:

$$ET_o = 0.408 \times 0.0023 \times (T_{mean} + 17.8) \times (T_{max} - T_{min})^{0.5} \times R_a \quad (5)$$

**Table 1- The mean monthly weather data in the Bajgah area (1986-2002).**

| Month | $T_{min}$ ($^oC$) | $T_{max}$ ($^oC$) | $RH_{min}$ (%) | $RH_{max}$ (%) | n (hour) | u (m $s^{-1}$) |
|---|---|---|---|---|---|---|
| January | -3.63 | 10.70 | 32.48 | 87.91 | 5.72 | 1.10 |
| February | -3.55 | 10.54 | 29.92 | 86.28 | 6.61 | 1.82 |
| March | -0.01 | 13.98 | 25.81 | 84.21 | 6.79 | 1.66 |
| April | 3.32 | 18.50 | 24.79 | 81.23 | 7.83 | 1.60 |
| May | 7.04 | 24.32 | 20.68 | 78.80 | 9.31 | 1.45 |
| June | 9.83 | 30.59 | 17.76 | 69.19 | 11.16 | 1.28 |
| July | 13.41 | 33.53 | 19.67 | 64.13 | 10.65 | 1.16 |
| August | 13.92 | 33.31 | 20.80 | 65.76 | 10.30 | 1.07 |
| September | 9.65 | 31.15 | 20.54 | 70.79 | 10.22 | 1.05 |
| October | 4.55 | 26.07 | 21.33 | 76.33 | 9.06 | 0.99 |
| November | 0.43 | 19.83 | 24.73 | 81.27 | 7.84 | 0.98 |
| December | -2.05 | 13.64 | 30.55 | 84.42 | 5.98 | 1.08 |

where $ET_o$ is the reference crop potential evapotranspiration (mm per day), $T_{mean}$, $T_{max}$ and $T_{min}$ are the mean, maximum and minimum air temperatures ($^oC$), respectively, and $R_a$ has been previously defined. Also, 0.408 is for converting MJ $m^{-2}$ $d^{-1}$ to mm per day (Allen et al.,1998).

## Results and Discussion

The monthly $ET_o$ rates (mm per day) were calculated with Penman-FAO, Penman-Monteith and Hargreaves equations by using 17 years data (1986-2002). The values of mean monthly $ET_o$ obtained by different methods are shown in Figure 1. The results indicated that the Penman-Monteith and Hargreaves equations tend to underestimate the monthly $ET_o$ for all months compared with the Penman-FAO method. But their results are similar to some extent. Table 2 shows the frequency and percentage of monthly $ET_o$ rates (mm per day) calculated with different methods. The results indicated that the most frequent estimated values of monthly $ET_o$ rate through 204 months (17 years) occurred between 3-4, 6-7 and 1-2 mm per day for Penman-FAO, Penman-Monteith and Hargreaves equations, respectively. Also, this Table shows that the monthly $ET_o$ rates estimated with Penman-Monteith and Hargreaves equations are lower than 9 mm per day, but the ones estimated with Penman-FAO equation are less than 13 mm per day during 1986-2002.

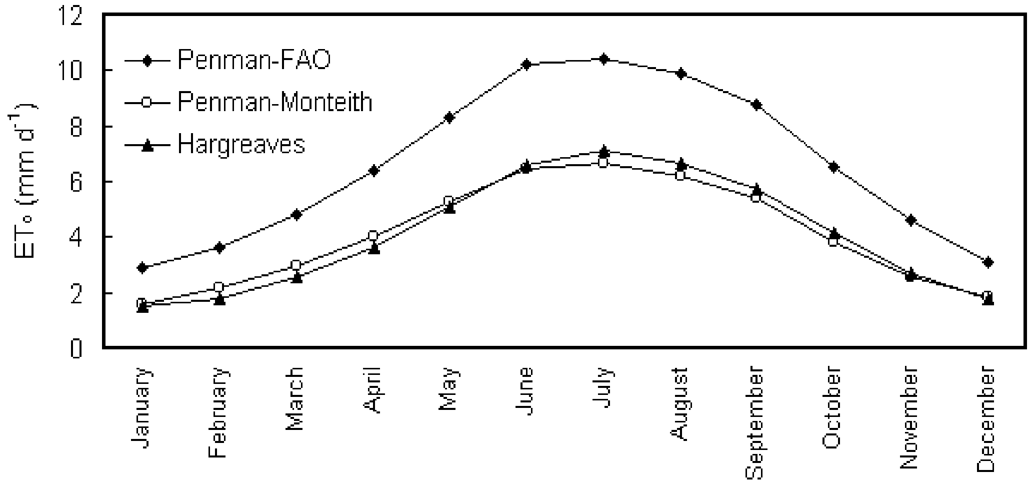


**Fig. 1- The estimation of mean monthly $ET_o$ rate for different methods.**

**Table 2- The frequency and percentage of different values of $ET_o$ with different methods.**

| | Penman- FAO | | Penman- Monteith | | Hargreaves | |
|---|---|---|---|---|---|---|
| $ET_o$ (mm $d^{-1}$) | Frequency | Cumulative percentage | Frequency | Cumulative percentage | Frequency | Cumulative percentage |
| 1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 2 | 1 | 0.5 | 38 | 18.6 | 47 | 23.0 |
| 3 | 15 | 7.8 | 39 | 37.7 | 37 | 41.2 |
| 4 | 35 | 25.0 | 31 | 52.9 | 21 | 51.5 |
| 5 | 28 | 38.7 | 19 | 62.3 | 21 | 61.8 |
| 6 | 9 | 43.1 | 31 | 77.5 | 26 | 74.5 |
| 7 | 29 | 57.4 | 43 | 98.5 | 37 | 92.6 |
| 8 | 10 | 62.3 | 3 | 100.0 | 15 | 100.0 |
| 9 | 19 | 71.6 | 0 | 100.0 | 0 | 100.0 |
| 10 | 25 | 83.8 | 0 | 100.0 | 0 | 100.0 |
| 11 | 31 | 99.0 | 0 | 100.0 | 0 | 100.0 |
| 12 | 2 | 100.0 | 0 | 100.0 | 0 | 100.0 |

The ratios of monthly $ET_o$ for different methods were calculated for each month of all years as $S = Y / X$ or $Y = S X$, *where* $S$ is the slope of the regression line between the monthly $ET_o$ of the correlated methods (the regression lines are forced through the origin).

To calibrate the Penman-Monteith equation based on Penman-FAO equation for the Bajgah area, Y was considered as $ET_o$ rate obtained by Penman-FAO and X was considered as $ET_o$ rate obtained by Penman-Monteith. The monthly and annual average slope of calibration line is shown in Table 3. The results showed that the values of S varied between 1.562 for July to 1.836 for January. So, for using the Penman-Monteith equation for the Bajgah area, these coefficients for different months should be applied, separately, or the average calibration coefficient equal to 1.603 should be applied for all months in a year. Also, Dehghani-Sanij et al. (2004) showed that the Penman-Monteith equation is the best method for monthly $ET_o$ estimation for Karaj (a semi-arid region in I. R. of Iran with mean annual rainfall of 240 mm). They estimated annual $ET_o$ based on Penman-FAO and Penman-Monteith equations for Karaj (west of Tehran) in 1993 equal to 1641 and 1435 mm, respectively, and 1726 and 1491 mm for 1994, respectively. The ratio of annual $ET_o$ of Penman-FAO to Penman-Monteith equation for these years is therefore estimated to be equal to 1.144 and 1.158, respectively. Therefore, similar results were obtained in Karaj for annual $ET_o$ compared with monthly and annual $ET_o$ in the Bajgah area.

**Table 3- The ratio between monthly $ET_o$ of Penman-FAO to Penman-Monteith equation.**

| Month | S | n | $R^2$ |
|---|---|---|---|
| January | 1.836 | 17 | 0.843 |
| February | 1.643 | 17 | 0.712 |
| March | 1.618 | 17 | 0.933 |
| April | 1.590 | 17 | 0.952 |
| May | 1.575 | 17 | 0.953 |
| June | 1.580 | 17 | 0.849 |
| July | 1.562 | 17 | 0.762 |
| August | 1.587 | 17 | 0.988 |
| September | 1.627 | 17 | 0.787 |
| October | 1.707 | 17 | 0.977 |
| November | 1.802 | 17 | 0.655 |
| December | 1.824 | 17 | 0.920 |
| **All months** | **1.603** | **204** | **0.973** |

To calibrate the Hargreaves equation based on Penman-FAO equation for the Bajgah area, similar analysis was used. The results for each month of the year and for all months are shown in Table 4. The results showed that the values of S for Hargreaves equation varied between 1.466 for July to 2.003 for February. So, for using the Hargreaves equation in the Bajgah area, these coefficients for different months should be applied, separately, or an average calibration coefficient equal to 1.562 should be applied for all months of a year. If the value of S for each month of year multiplied by the value of 0.0023, the calibration coefficient ($C_H$) of the Hargreaves equation for each month is obtained. The values of $C_H$ varied between 0.0034 for July and August to 0.0046 for February, and the average value of $C_H$ is 0.0036 for all months of year. So, for using the Hargreaves equation in the Bajgah area, the new $C_H$ values for each month should be applied instead of 0.0023. These results showed that the calibration coefficient ($C_H$) of the Hargreaves equation for each month, to some extent, is higher than 0.0023 which resulted in a lower estimation of monthly $ET_o$ compared with Penman-FAO equation. Martinez-Cob and Tejero-Juste (2004) showed that the calibration coefficient ($C_H$) of the Hargreaves equation is 0.0023 (no changes to common situation) for windy locations (monthly mean wind speeds above 2 per Sec. are frequent), and 0.0020 for non-windy locations (monthly mean wind speeds below 2 m $s^{-1}$ are frequent) under the semi-arid conditions of the middle Ebro River Valley (NE Spain), based on Penman-Monteith equation.

The values of $C_H$ were determined for different months in the Bajgah area based on the Penman-Monteith equation (Table 5). The results showed that the $C_H$ values varied between 0.0021 for August and October to 0.0028 for February, and its average value for all months of year is 0.0022.

**Table 4- The ratio between monthly $ET_o$ of Penman-FAO to Hargreaves equation and the modified coefficient of Hargreaves equation, $C_H$.**

| Month | S | $C_H$ | n | $R^2$ |
|---|---|---|---|---|
| January | 1.906 | 0.0044 | 17 | 0.618 |
| February | 2.003 | 0.0046 | 17 | 0.572 |
| March | 1.873 | 0.0043 | 17 | 0.932 |
| April | 1.749 | 0.0040 | 17 | 0.575 |
| May | 1.637 | 0.0038 | 17 | 0.689 |
| June | 1.544 | 0.0036 | 17 | 0.638 |
| July | 1.466 | 0.0034 | 17 | 0.974 |
| August | 1.482 | 0.0034 | 17 | 0.962 |
| September | 1.522 | 0.0035 | 17 | 0.950 |
| October | 1.568 | 0.0036 | 17 | 0.766 |
| November | 1.692 | 0.0039 | 17 | 0.575 |
| December | 1.778 | 0.0041 | 17 | 0.590 |
| **All months** | **1.562** | **0.0036** | **204** | **0.949** |

**Table 5- The ratio between monthly $ET_o$ of Penman-Monteith to Hargreaves equation and the modified coefficient of Hargreaves equation, $C_H$.**

| Month | S | $C_H$ | n | $R^2$ |
|---|---|---|---|---|
| January | 1.035 | 0.0024 | 17 | 0.882 |
| February | 1.198 | 0.0028 | 17 | 0.739 |
| March | 1.158 | 0.0027 | 17 | 0.927 |
| April | 1.100 | 0.0025 | 17 | 0.641 |
| May | 1.040 | 0.0024 | 17 | 0.822 |
| June | 0.978 | 0.0022 | 17 | 0.856 |
| July | 0.939 | 0.0022 | 17 | 0.984 |
| August | 0.934 | 0.0021 | 17 | 0.985 |
| September | 0.935 | 0.0022 | 17 | 0.963 |
| October | 0.918 | 0.0021 | 17 | 0.587 |
| November | 0.938 | 0.0022 | 17 | 0.954 |
| December | 0.993 | 0.0023 | 17 | 0.859 |
| **All months** | **0.973** | **0.0022** | **204** | **0.961** |

By considering the mean monthly wind speeds in the Bajgah area (Table 1), it is known that this area is non-windy throughout the year. So, according to the results that obtained by Martinez-Cob and Tejero-Juste (2004), the $C_H$ value of 0.0020 should be used instead of 0.0023, while it was obtained as 0.0022 instead of 0.0023 for all months of the year in the Bajgah area. But, according to the Penman-FAO equation, the $C_H$ value should be 0.0036 instead of 0.0023 in the Bajgah area in Hargreaves equation. Also, Dehghani-Sanij et al. (2004) obtained annual $ET_o$ for Karaj in years 1993 and 1994 based on Hargreaves equations equal to 1255 and 1316 mm, respectively. Accordingly, the ratios of annual $ET_o$ of Penman-FAO to Hargreaves equations for these years were 1.308 and 1.312, respectively, and the ratios of annual $ET_o$ of Penman-Monteith to Hargreaves equations for these years were 1.143 and

1.133, respectively. Therefore, the values of $C_H$ were equation, and 0.0026 for 1993 and 1994 based on Penman-Monteith equation. The results indicated that $C_H$ value in the Bajgah area is greater than that for Karaj based on Penman-FAO equation, but its value based on the Penman-Monteith equation in the Bajgah area is less than that for Karaj.

## Conclusions

By considering the Penman-FAO equation as base method for estimation of monthly $ET_o$, the Penman-Monteith and Hargreaves equations were calibrated in the Bajgah area for each month of year ,separately, by using 17 years of weather data. The results showed that the Penman-Monteith and Hargreaves equations tend to underestimate $ET_o$ compared with Penman-FAO method for all years of data, but the amounts of $ET_o$ for Penman-Monteith and Hargreaves equations are close to each other to some extent. The results of calibrating Penman-Monteith equation showed that the values of S (ratio of $ET_o$ for Penman-FAO to that for Penman-Monteith) varied between 1.562 for July to 1.836 for January, and 1.603 for all months of the year. Also, the results of calibrating Hargreaves equation showed that its coefficient ($C_H$ = 0.0023) should be adjusted for the study area for each month. The adjusted coefficient varied between 0.0034 for July and August to 0.0046 for February, and 0.0036 for all months of the year.

## References

Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. (1998), "Crop evapotranspiration". *Irrigation and Drainage* Paper No. 56, FAO, United Nations, Rome, Italy. 310p.

Dehghani-Sanij, H., T. Yamamoto, and V. Rasiah. (2004), "Assessment of evapotranspiration estimation models for use in semi-arid environments". *Agric. Water Manage*. 64, pp. 91-106.

Doorenbos, J., and W. O. Pruitt. (1977), "Crop water requirements". *Irrigation and Drainage* Paper No. 24, FAO, United Nations, Rome, Italy. 144p.

Fooladmand, H. R., and A. R. Sepaskhah. (2004), "Economic analysis for the production of four grape cultivars using microcatchment water harvesting systems in Iran". *J. Arid Environ*. 58, pp. 525-533.

Hanson, B., L. Schwankl, and A. Fulton. (1999), "Scheduling Irrigation: When and How Much Water to Apply". *Department of Land, Air and Water Resources*, University of California, Davis. 202p.

0.0030 for 1993 and 1994 based on Penman-FAO

Hargreaves, G. L., and Z. A. Samani. (1985), "Reference crop evapotranspiration from temperature". *Appl. Engin. Agric*. 1(2), pp. 96-99.

Malek, E. (1979), "Determination of the constants for the global radiation equation at Bajgah, Iran". *Agric. Meteorol*. 20, pp. 233-235.

Malek, E. (1982), "Methods of evaluating water balance and determining climatic type: an example for Bajgah". Iran. J. *Agric. Sci*. 12, pp. 57-72 (in Farsi).

Malek, E. (1984), "Agroclimatic characteristics of the Bajgah area, Fars Province of Iran". *Iran Agric. Res*. 3, pp. 65-74.

Martinez-Cob, A., and M. Tejero-Juste. (2004), "A wind-based qualitative calibration of the Hargreaves $ET_o$ estimation equation in semiarid regions". *Agric. Water Manage*. 64, pp. 251-264.

Sadeghi, A. R., A. A. Kamgar-Haghighi, A. R. Sepaskhah, D. Khalili, and Sh. Zand-Parsa. (2002), "Regional classification for dryland agriculture in southern Iran". *J. Arid Environ*. 50, pp. 333-341.

Sepaskhah, A. R (1999), "A review on methods for calculating crop evapotranspiration". Proceeding of the 7th International Seminar on Irrigation and Evaporation Reduction, Shahid Bahonar University, Kerman, I. R. of Iran, pp.1-10 (in Farsi).

Sepaskhah, A. R., and H. R. Fooladmand. (2004), "A computer model for design of microcatchment water harvesting systems for rain-fed vineyard". *Agric. Water Manage*. 64, pp. 213-232.

Xu, C. Y., and V. P. Singh. (2002), "Cross comparison of empirical equations for calculating potential evapotranspiration with data from Switzerland". *Water Res. Manage*. 16, pp.197-219.

Zand-Parsa, Sh., and A. R. Sepaskhah. (1996), "Introducing a simple methodology for frequency analysis of reference crop potential evapotranspiration in Iran". Proceeding of the 6th International Seminar on Irrigation and Evaporation Reduction, Shahid Bahonar University, Kerman, I. R. of Iran, pp. 38-55 (in Farsi).

Zand-Parsa, Sh., A. R. Sepaskhah, and T. Honar. (1996), "Selection of the appropriate distribution function for frequency analysis of reference crop potential evapotranspiration in Iran". Proceeding of the 6th International Seminar on Irrigation and Evaporation Reduction, Shahid Bahonar University, Kerman, I. R. of Iran, pp. 134-139 (in Farsi).

Submitted: April 14, 2004
Accepted: October 2, 2004