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PJBS

ISSN 1028-8880

Pakistan
Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 10 (3): 462-469, 2007
ISSN 1028-8880

Evaluation of Evapotranspiration Estimation Methods for Sweet Cherry Trees (*Prunus avium*) in Sub-humid Climate

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Abstract: This study was carried out in the summer of 2001 in a 3 year old and in the summer of 2002 in a 4 year old sweet cherry trees (*Prunus avium*, variety Z-900) on Mazzard rootstocks in Bayramic-Canakkale which is located in the west part of Turkey. Micro-sprinkler irrigation was selected as the irrigation method. The trees were subjected to four micro-sprinkler irrigation treatments (T-1, T-2, T-3 and T-4). The water applied in treatment T-3 was considered sufficient to satisfy fully needs of the crop (100% of ET_c) and to allow good rooting and tree growth. The water balance relationship was used in estimating ET_c. A total of 4 climatological methods were selected for estimating reference crop evapotranspiration on a daily basis. Some of these methods are based on combination theory and others are empirical methods based primarily on solar radiation, temperature ans relative humidity. An attempt was made in the current study to develop regional relationship between the evapotranspiration measured and that estimated by the climatological methods, such as FAO-Penman, Penman-Monteith, FAO-Radiation and FAO-Blaney-Criddle. Performance of the climatological methods in estimating the ET_0 values as compared to the measured values was evaluated on the basis of root mean square error (RMSE). In 2001, the Penman-Monteith equation gave the best results followed by FAO-Penman, FAO-Radiation and FAO-Blaney-Criddle. In 2002, the Penman-Monteith and FAO-Blaney-Criddle equations gave same results.

Key words: Sweet cherry, micro sprinkler, reference ET, crop ET

INTRODUCTION

Evapotranspiration (ET) is one of the major components of the hydrological cycle and its accurate estimation is of paramount importance for many studies such as hydrologic water balance, irrigation system design and management, crop yield simulation and water resources planning and management. Water use efficiency can be improved by proper irrigation scheduling, which is essentially governed by crop evapotranspiration. A common practice for estimating ET from a well-watered agricultural crop is to first estimate reference crop ET, i.e., grass reference ET (ET_0) or alfalfa reference ET (ET_r), from a standard surface and to then apply an appropriate empirical crop coefficient, which accounts for the difference between the standard and crop ET (Kumar *et al*., 2002).

Evapotranspiration is not easy to measure. Specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters are required to determine evapotranspiration. The methods are often expensive, demanding in terms of accuracy of measurements and can only be fully exploited by well-trained research personnel. Although the methods are inappropriate for routine measurements, they remain important for the evaluation of ET estimates obtained by more indirect methods (Allen *et al*., 1994). Indirect methods based on climatological data are used for ET_0 estimation. These methods vary from empirical relationships to complex methods based on physical processes such as the Penman (1948) combination method. The combination approach links evaporation dynamics with the flux of net radiation and aerodynamic transport characteristics of a natural surface based on the observations that latent heat transfer in plant stems is influenced not only by these abiotic factors, Monteith (1965) introduced a surface conductance term that accounted for the response of leaf stomata to its hydrologic environment. This modified form of the Penman equation is widely known as the Penman-Monteith evapotranspiration model.

Allen *et al*. (1994) recommended using a modified Penman-Monteith equation for estimating ET_0. The modified Penman-Monteith equation, which was first presented by Allen *et al*. (1989), has received widespread acceptance internationally for estimating ET_0. This equation is currently recommended by the United Nations Food and Agriculture Organizations (FAO) and by World

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Meteorological Organization (WMO). However many different methods for estimating ET_0 have been developed, most of which are complex and require a significant number of weather parameters (Doorenbos and Pruitt, 1977). But later studies also showed lesser differences between estimated and measured ET_0 with the Penman-Monteith equation than with others (Choisnel *et al.*, 1992; Hussein, 1999; Ventura *et al.*, 1999).

Crop ET is computed by multiplying the ET_0 with a crop coefficient (k_c) to account for differences between the grass and crop ET. Due to variation in crop canopy and climatic conditions, ET_c differs with the crop irrigation, planning and decision making on a regional scale is performed on the basis estimated crop ET, which in turn depends on the crop coefficient. The crop coefficient represents crop specific water use and is essential for accurate estimation of irrigation requirement of different crops in the command area (CSSRI, 2000; Kashyap and Panda, 2001).

The aim of this study is to compare the actual ET values with ET values calculated by different prediction methods and to define the method which gives the most accurate results of ET for sub-humid climatic region.

MATERIALS AND METHODS

Experimental site and meteorological data: This study was carried out in the summer of 2001 in a 3 year old and in the summer of 2002 in a 4 year old sweet cherry trees (*Prunus avium*, variety Z-900) on Mazzard rootstocks in Bayramic-Canakkale which is located in the west part of Turkey. The co-ordinates of research area are as follows: latitude 39° 48' N, longitude 26° 37' E and altitude 70 m above sea level.

The local climate is temperate, summers are hot and dry and winters are mild and rainy. According to long term meteorological data which were taken from State Meteorological Station, located 1 km away from the orchard, annual mean rainfall, temperature and relative humidity are 624.3 mm, 14.0°C and 69%, respectively (Anonymous, 1992). Although sub-humid climate prevails in the region according to mean rainfall amount (from 600 to 700 mm of annual precipitation) (Jensen *et al.*, 1980), rainfall amounts are extremely low in the summer period. Meteorological data used for ET measurements for June-October 2001 and May-September 2002 was monitored by Metos early warning system and forecasting station which is located in research area. Some meteorological data as average values were given in Table 1 for irrigation season. Daily meteorological conditions during the irrigation season, May to October, were also given in Fig. 1 and 2 for 2001 and 2002. Data

Table 1: Meteorological data for 2001, 2002 and long-term averages

Years	Months	Mean temperature (°C)	Mean humidity (%)	Mean wind speed (m sec^{-1})	Precipitation (mm)
2001*	May	17.6	70.4	0.6	52.2
	June	22.7	54.8	0.5	14.2
	July	26.8	55.1	0.6	0.6
	Aug.	26.2	61.2	0.8	17.2
	Sept.	24.0	54.2	0.3	12.7
	Oct.	17.3	67.9	0.6	3.0
2002*	May	17.4	69.5	0.5	49.0
	June	23.3	61.0	0.1	2.4
	July	26.6	60.9	0.0	2.8
	Aug.	24.9	65.5	0.0	8.2
	Sept.	20.8	74.7	0.0	36.4
	Oct.	15.7	82.8	0.0	35.2
Long-term averages**	May	17.3	66.0	1.0	38.2
	June	21.9	57.0	1.1	24.3
	July	24.3	54.0	1.4	8.6
	Aug.	23.6	56.0	1.4	8.3
	Sept.	19.8	62.0	1.2	24.1
	Oct.	14.7	72.0	13.0	35.8

* 2001-2002 Metos Early Warning System and Forecasting Station Records
**1970-2000 Bayramic State Meteorological Station Records

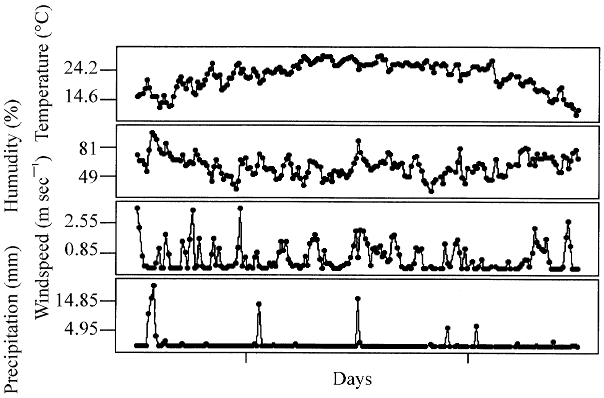

Fig. 1: Daily meteorological conditions during the irrigation season, May to October 2001, in Bayramic, Canakkale

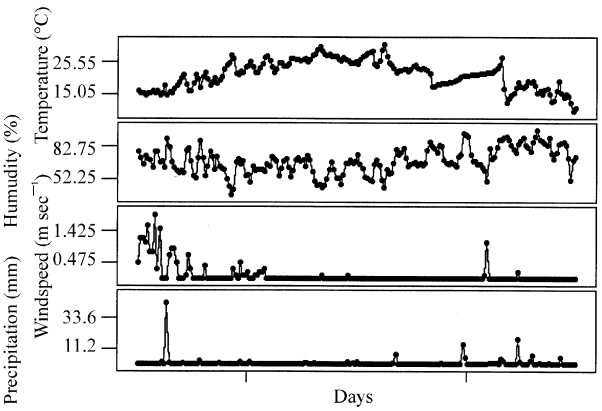

Fig. 2: Daily meteorological conditions during the irrigation season, May to October 2002, in Bayramic, Canakkale

about daily maximum and minimum temperature, relative humidity, rainfall, wind speed and solar radiation were used in calculating ET. Other parameters needed for calculation were measured and estimated from meteorological data.

Field layout and experimental design: Soil texture characterization was carried out from 12 profiles. Samples were taken with an auger at 0.30 m intervals and with maximum depth to 0.90 m. The granulometric composition was determined for each sample (Clay, <0.002 mm; Silt, 0.002-0.05 mm; Sand, 0.05-2 mm), as were the d_{50} parameter, the mean granulometrics and the mean d_{50} for each profile and the mean values for each depth (Liu and Evet, 1984). No vertical variability in the texture could be observed. The samples were analyzed for soil texture, field capacity, wilting point, bulk density, total salt content, pH and productivity level of the soil samples were found according to methods given by Hansen *et al.* (1980). Soils in research area have clayey loam texture. The main soil properties were given in Table 2.

The trial was carried out with three replications in random blocks. However, replications have been distributed to the random blocks in such a way that following same range in three blocks not to disturb the existing irrigation system. The trees were planted in 1998, spaced 6×6 m apart. Each plot contained three plant rows and 39 trees, each block consists of 156 trees and total number of trees is 468 on the trial plot. In order to prevent the water in any one plot from affecting its neighboring plots, the two rows on the outer edges of each plot were left untouched and only the one middle row was monitored. The alleyway was kept under grass with an herbicide stripe (3 m broad) along the tree rows. The experimental plots were fertilized with mineral nitrogen (1.5 kg/tree $(NH_4)_2SO_4$), potassium (1.2 kg/tree K_2SO_4), MAP (1.6 kg da^{-1}) and magnesium (7 kg da^{-1}) in two experimental years. A routine pesticide program was maintained.

Table 2: Physical and chemical properties of soils

Soil Depth (cm)	0-30	30-60	60-90
Field capacity (%)	26.83	28.42	30.59
Wilting point (%)	19.14	20.51	20.09
Bulk density (g cm 3)	1.61	1.7	1.68
Clay (%)	35.81	38.14	38.18
Loam (%)	20.82	23.08	23.1
Sand (%)	43.37	38.78	38.72
Texture class	CL	CL	CL
pH	6.48	7.03	7.65
Total salt (%)	0.083	0.1	0.083
Lime (%)	0.74	0.89	6.7
Organic matter (%)	1.1	0.84	0.2
Phosphorus (kg da 1)	0.9	0.21	0.22
Potassium (kg da 1)	56.91	44.71	46.07

Plant material studied was sweet cherry trees (*Prunus avium*, variety Z-900) on 3-4 years old Mazzard rootstocks. Mazzard rootstock produces a vigorous tree with very good anchorage and best compatible with sweet cherries. Z-900 grafted on Mazzard rootstock is large, firm, juicy, sweet variety with bordeaux color and is adaptable to grow in different altitudes and different climates.

Irrigation water amount and irrigation scheduling: Micro-sprinkler irrigation was selected as the irrigation method. The laterals with the micro-sprinklers are laid along the rows of the trees, one line at each row; with one micro-sprinkler per tree. Sprinkler are operated under 1.4 bar pressure head and discharge of each is 35.8 L h^{-1} and sprinklers wetted diameter is 4.2 m. To determine the applied irrigation water along a lateral, water measurement devices were used for each lateral.

The trees were subjected to four micro-sprinkler irrigation treatments (T-1, T-2, T-3 and T-4). T-1 and T-2 treatments were programmed using two reduction percentages of the US Weather Bureau Class A pan evaporation. The water applied in treatment T-3 was considered sufficient to satisfy fully needs of the crop (100% of ET_c) and to allow good rooting and tree growth.

The total amount of irrigation water (TIW) applied in treatment T-2 was calculated from (Allen *et al.* 2000);

$$\mathrm{TIW} = \frac{K_p.K_c.K_l}{E_a.E_u} E_{pan}$$

where K_p is the pan coefficient (0.70; Doorenbos and Pruitt 1977), K_c the crop coefficient (0.85; Allen *et al.*, 2000), K_l the shade coefficient (0.97; Wermeiren and Jobling, 1986) taking into account that the estimated mean shade surface provided by the tree canopies was 85% of the total surface of the orchard, E_a water application efficiency (0.85; Armoni, 1986; Burt and Styles, 1994), E_u the coefficient of uniformity of emitters (0.9).

T-3 treatment which is applied water amount in farm was selected as the control. In this treatment, full of evaporated amount from Class A pan (100 % of E_{pan}) was applied to the trees. The difference at 25% level between T-2 and T-3 treatments was considered as deficit amount and T-1 treatment was defined according to this difference. To determine the impact of excessive water application on cherry trees, another treatment (T-4) with the same amount of difference was selected and applied to the trees. Thus, irrigation treatments were as follows:

$$\mathrm{TIW}_{(T\text{-}1)} = 0.50\ E_{pan}$$
$$\mathrm{TIW}_{(T\text{-}2)} = 0.75\ E_{pan}$$
$$\mathrm{TIW}_{(T\text{-}3)} = 1.00\ E_{pan}$$
$$\mathrm{TIW}_{(T\text{-}4)} = 1.25\ E_{pan}$$

The amount of irrigation water to be applied during a particular week was calculated from the weekly evaporation values measured in the Class A pan during the preceding week. Irrigation water was supplied weekly.

Calculation of crop evapotranspiration (Et_{crop}): Measurements of soil water content were initiated immediately after the completion of the flowering period with the ratio of 70% and ended with first frost appearance. The soil water content was measured every 7 days from 25 June 2001 to 29 October 2001 and from 27 May 2002 to 29 September 2002 (i.e., during the irrigation season) on 2 trees root zone. Elisea (2002) reported that the young cherry trees irrigated with micro-sprinklers shows that the bulk of the root system is located at 40-50 cm soil depth. Since the trees are young, efficient root depth was taken as 0.90 m. The soil water content was determined by gravimetrical method and soil samples were taken at 0.30 m intervals and with a maximum depth of 0.90 m. For each treatment, samples were taken from the points which are 0.50, 1.0, 2.0 and 3.0 m far from stem under tree crown. As it is reported by Abrisqueta *et al.* (2001); the three-dimensional aspect of water flow in the soil-plant-atmosphere system means that it is essential to determine the areas and volumes of soil in which water moves or is stored. It is customary to relate the water balance to the plantation spacing (Sharples *et al.*, 1985), down to a depth slightly below that reached by the roots.

The water balance in the soil is estimated by means of the mass conservation equation by James (1988);

$$ET_c = I + P \pm \Delta S - D - R$$

where ET_c is the evapotranspiration (mm), I is the applied irrigation water amount (mm), P is the precipitation (mm) and ΔS is soil water content variation in crop root depth (mm/90 cm), D is drainage below the root zone and R is the runoff. Since the clayey loam soil characteristics are fully dominant in the field and lower sprinkling velocity of sprinkler (I_{sp}= 5.81 mm h^{-1}) than soil infiltration (I_s= 8.00 mm h^{-1}), runoff and drainage (deep percolation) were assumed to be negligible.

Calculation of reference crop evapotranspiration (ET_0): Reference evapotranspiration was calculated by four methods for all months where sufficient data available (Table 3).

Table 3: Different types of evapotranspiration estimated methods used for the study

No.	Classification	Method	Reference crop
1	Combination based	FAO-Penman	Alfalfa
2	Combination based	Penman-Monteith	Grass
3	Radiation based	FAO-Radiation	Grass
4	Temperature based	FAO-Blaney-Criddle	Grass

Doorenbos and Pruitt (1975, 1977) presented a modified equation for estimating reference ET for grass. The major modifications consisted of a more sensitive wind function than that used by Penman (1948), an adjusted factor c that is based on local climatic conditions and the assumption that soil heat flux (G)=0 for daily periods. Thus the form of FAO-Penman became

$$ET_o = c\left[\left(\frac{\Delta}{\Delta+\gamma}\right)(Rn) + (\frac{\gamma}{\Delta+\gamma})(2.7)(Wf)(e_z{}^0 - e_{z)}\right]$$

where c the adjustment factor and W_f= 1+0.864 x u_z.

When the value of c is set to 1.0 it is called FAO-Penman and when the value of c calculated using the following equation:

$$c = 0.68 + 0.0028RH_{max} + 0.018R_s - 0.068U_d + 0.013\frac{U_d}{U_n} + 0.0097U_d\frac{U_d}{U_n} + 0.43.10^{-4}RH_{max}R_sU_d$$

Studies in the Sahel (Monteith, 1991) and in other arid regions (Jensen *et al.*, 1980) have shown the Penman-Monteith equation to be the most reliable of the commonly used reference evapo-transpiration equations in arid and semi-arid environments. The form of the Penman-Monteith equation for reference evapotranspiration (Allen *et al.*, 1994) requires values of temperature, humidity, sunshine and wind speed. Penman-Monteith method (Allen *et al.*, 1994).

$$ET_o = \frac{0.408\Delta(Rn-G)}{\Delta+\gamma(1+rc/ra)} + \frac{86.4}{\lambda}\frac{1}{\Delta+\gamma(1+rc/ra)}\frac{\varsigma c_p}{ra}(ea-ed)$$

where Rn is the net radiation (MJm^{-2} day^{-1}), G is the soil heat flux (0 MJ m^{-2} day^{-1}), *ea–ed* is the vapour pressure deficit (kPa), ¢ is the slope of the vapour pressure curve (kPa °C^{-1}), Á is the psychrometric constant (kPa °C^{-1}), rc is the canopy resistance (70 sm^{-1}), ra is the aerodynamic resistance (sm^{-1}), Ú is the atmospheric density (kg m^{-3}), *c*p is the specific heat of moist air (1.013 kJ kg^{-1} °C^{-1}), Ï is the latent heat of evaporation (MJ kg^{-1}).

Doorenboss and Pruitt (1975, 1977) reported an equation, which is called FAO-Radiation method and is given as:

$$ET_o = c(\frac{\Delta}{\Delta+\gamma}\frac{Rs}{\lambda})$$

Where c is an adjustment factor which depends of mean humidity and daytime wind (Fervert *et al.*, 1983), Δ is the slope of vapour pressure curve (kPa °C^{-1}), γ is the psychrometric constant (kPa °C^{-1}), Rs is the mean solar radiation (MJ m^{-2} day$^{-1)}$, λ is the latent heat of evaporation (MJ kg^{-1}).

Doorenboss and Pruitt (1977) presented the most fundamental revision of the Blaney-Criddle method, which is given as

$$ET_o = \{a + b[P(0.46T + 8.13)]\ \}(1 + 0.1E/1000)$$

where P is the mean daily percentage of annual daytime hours (%), T is the mean air temperature (°C), a, b are empirical factors (dimensionless), E is the altitude of the station (m). a and b estimated from equations produced by (Allen and Pruitt, 1986) and (Fervert *et al.*, 1983), respectively, using long-term average values of minimum relative humidity, sunshine fraction and daytime wind speed.

It has been suggested (Smith *et al.*, 1996) that where full climate data are not available, the Penman-Monteith equation can be used with long-term monthly average values of wind speed and estimates of mean daily vapour pressure, assuming dew point temperature equal to mean monthly minimum air temperature. As both wind speed and sunshine duration data are frequently missing for the chosen stations, the performance of the Penman-Monteith equation, using mean monthly values for both sunshine and wind, was tested. In order to maintain independence, the long-term monthly average values were taken from a published source (FAO, 1984) rather than the original data set.

Calculation of crop coefficient Kc: Crop evapotranspiration (ET$_{crop}$) refers to evapotranspiration of a disease-free crop, grown in very large fields, not short of water and fertiliser (Doorenbos and Pruitt, 1977). Estimation of ET$_{crop}$ is essential for computing the soil water balance and irrigation scheduling. ET$_{crop}$ is governed by weather and crop condition. Mathematically, ET$_{crop}$ can be expressed as

$$ET_{crop} = Kc.ETo$$

Where, K_c is the crop coefficient which varies for different crops and their growth stages and ET_0 is the reference crop evapotranspiration. Most of the current demand models are non-spatial models which uses point data of ET_0 and the K_c values from available literature (Doorenbos and Pruitt, 1977).

Comparison of methods: The results from each evapotranspiration calculation method were compared to those from the crop evapotranspiration (ET$_{crop}$) for which the latter could be calculated. The Root Mean Square Error (RMSE) criterion was used to compare the daily values of ET_0 estimated by various climatological methods. The RMSE provides a good measure of how closely two independent data sets match (Ventura *et al.*, 1999). The RMSE values were calculated as

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(ET_{o(measured)} - ET_{o(estimated)})^2}$$

Where, n is number of observations.

RESULTS AND DISCUSSION

The annual amount of irrigation water applied is shown in Table 4 in which the amounts of irrigation water applied were ranged from 346.0 to 846.7 mm and from 313.3 to 783.3 mm for 2001 and 2002, respectively.

The soil water content was firstly measured on 25 June in 2001 and 27 May for 2002 to determine the crop water requirement. Daily measurements of the evaporation from the Class A pan were started at 26 June for first experimental year and 28 May for second year. Total evaporation from Class A pan were 689.9 and 626.6 mm for 2001 and 2002, respectively. According to those values, measured evapotranspiration at applied irrigation levels were realized as 365.0-839.0 and 447.0-866.0 mm for first and second year, respectively (Table 5). The average value of both years was found as

Table 4: Amount of water applied for each irrigation treatments and rainfall in two years (mm)

Year	T-1	T-2	T-3	T-4	Rainfall* (mm/ season)
2001	346.0	518.8	691.6	846.7	33.30
2002	313.3	470.0	626.6	783.3	66.00

*Total precipitation during the observation of soil moisture

Table 5: Monthly and seasonal evapotranspiration (ET_c mm)

3 years old sweet cherry tree, 2001

Treatment	June[a]	July	August	September	October[b]	Seasonal
T-1	21	81	128	79	56	365
T-2	26	131	156	103	79	495
T-3	38	151	217	136	107	649
T-4	25	198	264	184	168	839

4 years old sweet cherry tree, 2002

Treatment	May[c]	June	July	August	September[d]	Seasonal
T-1	12	134	136	87	78	447
T-2	21	177	161	124	92	575
T-3	19	221	227	164	86	717
T-4	13	259	290	185	119	866

[a] June 2001: ET_c values in between 25-30 June, [b] October 2001: ET_c values in between 01-29 October, [c] May 2002: ET_c values in between 27-31 May, [d] September 2002: ET_c values in between 01-29 September

Table 6: Ranking of ET_0 estimation methods on the basis of root mean square error(RMSE) for 2001 and 2002

Estimation Methods	Coefficient of Determination (R^2)				RMSE (mm per day)			
	T1	T2	T3	T4	T1	T2	T3	T4
2001								
Penman-monteith	0.43	0.79	0.50	0.41	0.06	0.03	0.04	0.08
FAO-penman	0.41	0.77	0.48	0.39	0.22	0.16	0.10	0.09
Blaney-criddle	0.33	0.68	0.39	0.29	0.08	0.04	0.07	0.16
FAO-radiation	0.42	0.77	0.48	0.39	0.11	0.07	0.05	0.05
2002								
Penman-monteith	0.52	0.59	0.84	0.79	0.09	0.50	0.05	0.12
FAO-penman	0.51	0.56	0.81	0.79	0.26	0.21	0.13	0.17
Blaney-criddle	0.57	0.67	0.89	0.83	0.09	0.05	0.05	0.13
FAO-radiation	0.54	0.63	0.86	0.80	0.18	0.13	0.06	0.06

535.0 and 406.0 mm for T-2 and T-1 treatments, respectively. Monthly ET_c has reached a maximum in August, July and September in 2001 and in July, June and August in 2002, respectively.

The relationships between referens evapotranspiration values (ET_0) and ET values estimated by four different methods were investigated in the study. In this context, the results of RMSE are presented in Table 6 for 2001 and 2002. The lowest values of RMSE were observed at Penman-Monteith method (Table 6). In addition, the coefficient of determination (R^2), which expresses the proportion of the total variation in the values of estimated variable can be explained by a linear relationship with the values of the measured variable, was also used as a criterion for relative performance of the estimation method (Fig. 3 and 4). The values of R^2 are listed in Table 6.

In 2001, the coefficient of determination (R2) and RMSE were found as 0.79 and 0.03 mm/day in the Penman-Monteith method for T-2 treatment, respectively. On the contrary, in 2002, coefficient of determination (R^2) and RMSE were found as 0.84 and 0.05 mm/day in the Penman-Monteith method for T-3 treatment, respectively. The value of the coefficient of determination (R^2) was the highest and the RMSE was the least in this case. The reason for the best performance is that this method uses data of maximum number of weather variables to estimate daily ET_0.

Though, Penman-Monteith method is considered as the most rational and elaborate approach, it requires a large number of climatological data. Often such data are very scanty forcing the user to choose some other alternative empirical methods for reliable estimation of ET_0. Another reason to find an alternative method is that the Penman type equations, having calibrated wind functions, often fail in locations with a different climate than where they were calibrated (Ventura *et al.*, 1999).

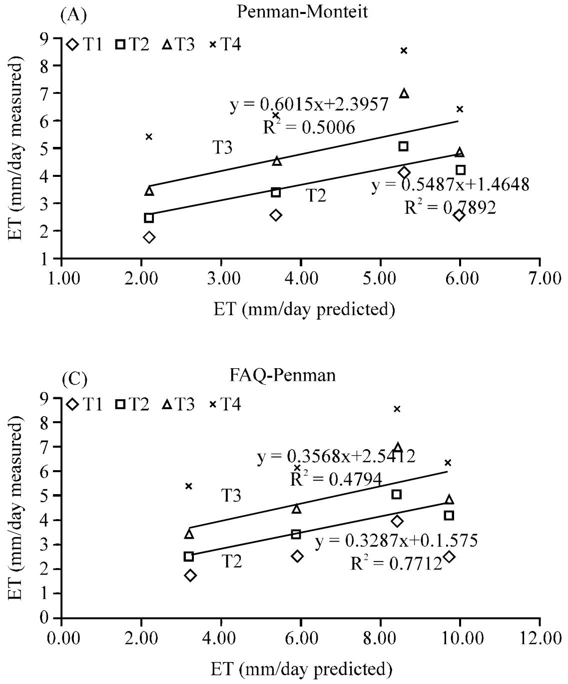

Fig. 3: Comparison of measured daily ET_0 with that estimated by different methods: (2001), (a) Penman-Monteith (b) Blaney-Criddle (c) Fao-Penman (d) Fao-Radiation

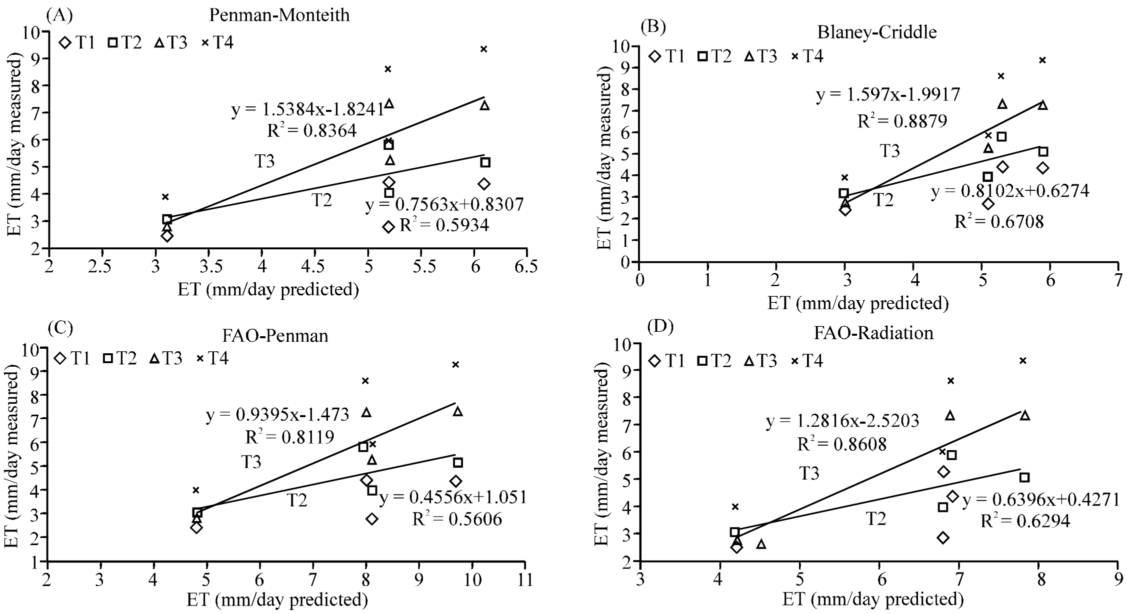

Fig. 4: Comparison of measured daily ET_0 (2002) with that estimated by different methods: (a) Penman-Monteith (b) Blaney-Criddle (c) Fao-Penman (d) Fao-Radiation

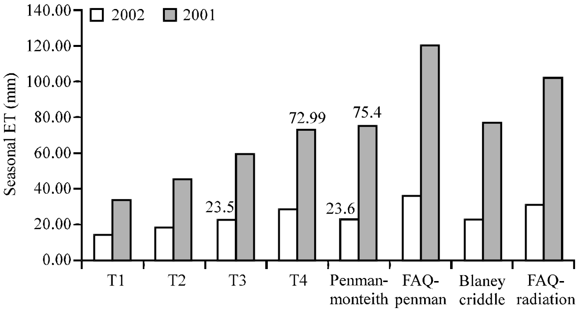

Fig. 5: Comparison of seasonal ET_0 estimated by different methods with respect to measured ET for 2001 and 2002

Comparison of seasonal ET_0 estimated by different methods with respect to that measured is given in Fig. 5. Results of all the tests mentioned above indicated that the Penman-Monteith method were close to measured ET_0, particularly T-3 and T-4 treatments in all years.

From the results of the study it is inferred that Penman-Monteith method is most ideal for estimation of ET_0. Results of all the tests mentioned above indicated that the Penman-Monteith method is the best followed by the Blaney-Criddle method though FAO-Penman also gave reasonably good estimation of seasonal ET_0 value.

The following conclusions were drawn from the results of the study.

- Comparison measured data revealed that the Penman-Monteith gives the best estimate of daily reference evapotranspiration in a sub-humid climatic region.
- The alternative methods to the Penman-Monteith, for estimation of reference evapotranspiration, are Blaney Criddle, FAO-Penman and FAO-Radiation in that order.

REFERENCES

Abrisqueta, J.M., A.J. Ruiz and A. Franco, 2001. Water balance of apricot trees. Agric. Water Manag., 50: 211-227.

Allen, R.G. and W.O. Pruitt, 1986. Rational use of the FAO Blaney-Criddle formula. J. Irrig. and Drain. Eng. ASCE, 112: 139-155.

Allen, R.G., M.E. Jensen, J.L. Wright and R.D. Burman, 1989. Operational estimates of reference evapotranspiration. Agron. J., 81: 650-662.

Allen, R.G., M. Smith and L.S. Pereira, 1994. An update for the calculation of reference evapotranspiration. ICID Bull., 43: 35-92.

Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. Crop evapotranspiration-guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, Rome, Italy, pp: 299.

Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 2000. Crop Evapotranspiration. FAO Irrigation and Drainage Paper No. 56, FAO, Rome, pp: 300.

Anonymous, 1992. Meteoroloji bulteni. Devlet Meteoroloji Isleri Genel Mudurlugu, Bapbakanlik Basimevi, Ankara, (In Turkish).

Armoni, S., 1986. Micro-Sprinkler Irrigation. Text Book, Dan Sprinklers Kibbutz DAN, Israel.

Burt, M.C. and M.S. Styles, 1994. Drip and micro irrigation for trees, vines and row crops. Irrigation Training and Research Center. Californis Polytechnic State University, San Louis Obispo, Californis, pp: 261.

Choisnel, E., O. de Villele and F. Lacroze, 1992. Une approche uniformisée du calcul de l'évapotranspiration potentielle pour l'ensemble des pays de la Communauté Européenne Centre Commun de Recherche, Commission des Communautés Européennes, EUR14223.

CSSRI, 2000. Evapotranspiration estimation and crop coefficients. Technical Report of Central Soil Salinity Research Institute, Karnal, India.

Doorenbos, J. and W.O. Pruitt, 1975. Guidelines for predicting crop water requirement: FAO Irrig. Drain. Paper No. 24 FAO, Rome, Italy, pp: 179.

Doorenbos, J. and W.O. Pruitt, 1977. Crop water requirement: Food and Agriculture Organization of the United Nations. FAO Irrigation and Drainage Paper 24, Rome, (revised), pp: 144.

Elisea N.R., 2002. Tree water use, irrigation scheduling and water management systems in sweet cherry. Northwest Cherry Research Review, Oregon Sweet Cherry Commission and Washington Tree Fruit Research Commission. The Dalles, Oregon.

FAO., 1984. Agroclimatological data for Africa. FAO Plant Production and Protection Series. No 22. Rome: Food and Agriculture Organisation of the United Nations. Vol. 2.

Fervert, D.K., R.W. Hill and B.C. Beraaten, 1983. Estimation of FAO evapotranspiration coefficients. J. Irrig. Drainage Eng., 109: 265-269.

Hansen, V.E., O.W. Israelsen and G.E. Stringham, 1980. Irrigation principles and practices. The 4th Edn. John Wiley and Sons, USA., pp: 417.

Hussein, S.A., 1999. Grass ET estimating using Penman-type equations in central Sudan. J. Irrig. Drain. Eng., ASCE., 125: 324-329.

James, L.G., 1988. Principles of farm irrigation system design. New York, pp: 543.

Jensen, M.E., R.D. Burman and R.G. Allen, 1980. Evapotranspiration and irrigation water requirements. ASCE Manuals and Reports on Engineering Practice No. 70, pp: 332.

Kashyap, P.S. and R.K. Panda, 2001. Evaluation of evapotranspiration methods and development of crop-coefficients for potato crop in a sub-humid region. Agric. Water Manag., 50: 9-25.

Kumar, M., N.S. Raghuwanshi, R. Singh, W.W. Wallender and W.O. Pruitt, 2002. Estimating evapotranspiration using artificial neural network. J. Irrig. Drin. Eng., 128: 224-233.

Liu, C. and J.B. Evet, 1984. Soil properties: Testing, Measurement and Evaluation. Prentice-Hall, Englewood Cliffs, NJ.

Monteith, J.L., 1965. The state and movement of water in living organisms. In: Proceedings of the 19th Symposium of Society for Experimental Biology, Swansea, Cambridge University Press, Cambridge, pp: 205-234.

Monteith, J.L., 1991. Weather and Water in the Sudano-sahelian Zone. In: Soil water balance in the Sudano-Sahelian zone UK: M.V.K. Sivakumar, J.S. Wallace, C. Renark and C. Giroux (Eds.). IAHS Press (IAHS Publication No. 199), pp: 11-31.

Penman, H.L., 1948. Natural evaporation from openwater bare soil and grass. Proc. R. Soc. LondonA, 193: 120-146.

Sharples, R.A., D.E. Rolston, J.W. Biggar and H.I. Nightingale, 1985. Evaporation and soil water balances of young trickle-irrigation almond trees. In: Proceedings of the 3rd International Drip/Trickle Irrigation Congress, Fresno, CA, November 1985, 2: 792-797.

Smith, M., R.G. Allen and L. Pereira, 1996. Revised FAO Methodology for Crop Water Requirements. Proc., Evapotranspiration and Irrigation Scheduling Conf., Camp, C.R., E.J. Sadler and R.E. Yoder (Eds.). American Society of Agricultural Engineering, St. Joseph, Mich., pp: 116-123.

Ventura, F., D. Spano, P. Duce and R.L. Snyder, 1999. An evaluation of common evapotranspiration equations. Irrig. Sci., 18: 163-170.

Wermeiren, L. and G.A. Jobling, 1986. Localized Irrigation. FAO Irrigation and Drainage Paper No. 36, FAO, Rome, pp: 203.