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Evaluation of pan coefficient for reference crop evapotranspiration for Igdir region of Turkey

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Abstract

Pan coefficient (K_{pan}) is the important factor to convert from pan evaporation (E_{pan}) to reference evapotranspiration (ET_o). There are several methods to estimate K_{pan}, but their performance in different environments is diverse. In this study, approaches proposed by Cuenca (1989), Snyder (1992), Orang (1998), Allen and Pruitt (1991), Raghuwanshi and Wallender (1998), and Pereira *et al.* (1995) were evaluated by comparing them with the FAO 56 Penman-Monteith (FAO-PM) method. For this study, weather data sets collected during the growing seasons of 2004 and 2008 in the Igdir region of Turkey were used. The monthly analysis showed that the Allen and Pruitt (1991) equation provided the best agreement with the FAO 24. The weekly, 10-day and monthly analysis indicated that the Snyder (1992) equation showed better agreement than other K_{pan} equations with the FAO-PM method, followed by equations of Cuenca (1989), Allen and Pruitt (1991) and Orang (1998). The results suggested that, under the Igdir conditions, the ET_o data from these four equations using weekly or more long-term averages of daily meteorological data could easily be used for irrigation scheduling.

Key words: Pan evaporation, K_{pan} equations, reference crop evapotranspiration, FAO Penman-Monteith method.

Introduction

Evapotranspiration is not easy to measure because of the difficulties in quantifying atmospheric evaporative demand and plant transpiration. The general procedure for estimating ET is to first estimate reference ET (ET_o). Then the ET for different cover types is obtained by multiplying ET_o with an empirical crop coefficient (Kc) [1]. The expression can be given as follows [2]:

$$ET = ETo \cdot Kc \qquad (1)$$

In some locations, Class A pan evaporation (E_{pan}) data provide an alternative method to determining ET_o, because there are insufficient weather data to calculate ET_o [3]. Several equations and methods have been developed using class A pan data to estimate ET_o [2,4-5]. Doorenbos and Pruitt [2] reported a high correlation between E_{pan} and ET_o when evaporation pans are properly maintained. The E_{pan} data are multiplied by a pan coefficient (K_{pan}), which is a function of the fetch of a uniform surface around the pan, daily wind run, and daily mean relative humidity, to estimate ET_o [2,3].

$$ETo = Epan \cdot Kpan \qquad (2)$$

Doorenbos and Pruitt [2] did not provide equations to estimate K_{pan} values, although they reported the K_{pan} values for evaporation pans surrounded by green vegetation and by fallow soils [3]. Since then, several equations have been developed for estimating K_{pan} values for pans surrounded by green vegetation by fallow soils[3,6-13].

Several studies were conducted on the performance of a few K_{pan} coefficient models using the FAO-PM estimates as a reference model and made a detailed comparison between K_{pan} values in the FAO-24 table and the K_{pan} values calculated with several K_{pan} equations [1,14-18]. However, the results of these studies were not consistent with the performance of K_{pan} equations due to probably variability of leading environmental controls across sites. These findings clearly indicate a variability of K_{pan} over different regions because of the particular combination of environmental variables such as daily wind run, fetch of upwind of low vegetation, and relative humidity. Therefore, a coefficient or model derived for one region may need validation before being used in another region [1].

Since the location is important for converting E_{pan} to ET_o, this study was conducted to determine which method used to estimate K_{pan} is best for the estimation of ET_o values for the Igdir region of Turkey, which has a semi-arid climate.

Materials and Methods

Study area and data: This study was conducted in 2004 and 2008 at the Soil and Water Resources Research Station, Igdir, Turkey. The Igdir region is located between 39°38' and 40°03' N latitude and 44°49' and 45°31' E longitude, with an elevation of 850 m above sea level in Eastern Anatolia. The region has a semi-arid climate with an average annual temperature of 12.1°C, an average relative humidity of 55%, average sunshine of 6.41 h day^{-1}, and average annual rainfall of 255.7 mm [19].

Daily temperature and relative humidity data from 2004 to 2008 were obtained from automatic meteorological station located at the Soil and Water Resources Research Station. Daily wind speed and sunshine data were obtained from Igdir Synoptic Meteorological Station, which is 2000 m away from the experimental area. Because Allen *et al.* [20] stated that missing data can be taken from the closest station. The automatic meteorological station uses a datalogger (Campbell Scientific, Inc. CR 21 X) to record hourly values of air temperature and relative humidity at 2 m height above ground surface and the soil temperature (5, 10, 20, 50, and 100 cm below bare soil surface). The automatic meteorological station where the pan was located was in an agricultural area having orchards.

Daily pan evaporation data from 2004 and 2008 were obtained from a Class-A pan evaporimeter. The pan was located on a bare field in the automatic weather station. The Class-A pan evaporimeter (USWB) is surrounded by dry fallow land. The distance or fetch of fallow soil around the pan was 100 m. The pan was unscreened and deployed in accordance with the criteria in the FAO 24 [2].

Pan evaporation measurements were made at 8 a.m. each day. Daily air temperature and relative humidity data were obtained from 24 hourly weather data recorded immediately before pan evaporation was measured. These data were used to calculate grass reference crop evapotranspiration (ET_o) each day. Since daily pan evaporation values were measured from 1 April 2004 to 1 November 2004 and from 1 June 2008 to 1 November 2008, ET_o was also calculated daily for the same periods.

Methodology

***K_{pan}* derivation equations:** The following six approaches were considered to determine ET_o from Class A pan evaporation (E_{pan}) data.

1. Cuenca: The relationship proposed by Frevert *et al.* [16] as a function of daily mean relative humidity, wind speed, and upwind fetch distance was modified by Cuenca [7] and is given as follows [13-17].

$$Kpan = 0.475 - 2.4 \times 10^{-4} \cdot U_2 + 5.16 \times 10^{-3} \cdot H + 1.18 \times 10^{-3} \cdot F - 1.63 \times 10^{-5} \cdot H^2 - 1.013 \times 10^{-6} \cdot F^2 - 8.3 \times 10^{-9} \cdot H \cdot U_2 - 1.03 \times 10^{-8} \cdot H^2 \cdot F \quad (3)$$

2. Snyder: The following relationship [17] for K_{pan} values was suggested by Snyder [8] who reported that the K_{pan} relationship proposed by Cuenca [7] was too complex and gave unsatisfactory results for some climatic conditions compared with the original coefficients published by Doorenbos and Pruitt [2].

$$Kpan = 0.482 + 2.4 \times 10^{-1} \cdot \ln(F) - 3.76 \times 10^{-4} \cdot U_2 + 4.5 \times 10^{-3} \cdot H \quad (4)$$

3. Orang: Orang [9] proposed the following equation [13] for K_{pan} using interpolation between fetch distances and based on the data used to develop FAO 24 K_{pan} values [2] and adopting linear regression techniques similar to Snyder [8].

$$Kpan = 0.51206 - 3.21 \times 10^{-4} \cdot U_2 + 2.889 \times 10^{-3} \cdot H + 3.18861 \times 10^{-2} \cdot \ln(F) - 1.07 \times 10^{-4} \cdot H \cdot \ln(F) \quad (5)$$

In equations (3) through (5) U_2 is daily mean wind speed measured at 2 m height (km day^{-1}), H is daily mean relative humidity (%), and F is upwind fetch distance of low-growing vegetation (m) [17].

4. Allen and Pruitt: The Allen and Pruitt [10] equation to calculate K_{pan} values for evaporation pans surrounded by low-growing vegetation is a regression equation derived from FAO Irrigation and Drainage Paper No. 24 [2] and is expressed as:

$$Kpan = 0.108 - 2.86 \times 10^{-2} \cdot U_2 + 4.22 \times 10^{-2} \cdot \ln(F) + 1.434 \times 10^{-1} \cdot \ln(H) - 6.31 \times 10^{-4} \cdot \ln(F)^2 \cdot \ln(H) \quad (6)$$

where U_2 is daily mean wind speed m s^{-1}, F is fetch distance of low-growing vegetation (m), and RH is daily mean relative humidity (%) [20].

5. Raghuwanshi and Wallender: Raghuwanshi and Wallender [11] introduced the following equation for K_{pan} using the indicator regression approach. In this method, wind run and relative humidity (as the categorical) and quantitative fetch length data were used rather than the average or particular values within a range [17].

$$Kpan = 0.5944 + 2.42 \times 10^{-2} \cdot \ln(F) - 5.83 \times 10^{-2} \cdot U_1 - 1.333 \times 10^{-1} \cdot U_2 - 2.083 \times 10^{-1} \cdot U_3 + 8.12 \times 10^{-2} \cdot H_1 + 1.344 \times 10^{-1} \cdot H_2 \quad (7)$$

where F is fetch distance of low-growing vegetation (m), and U_1, U_2 and U_3 are wind run categories of 175-425, 425-700, and > 700 km day^{-1}, respectively, and were assigned values of 1 or 0 depending upon their presence. A 0 value for these variables represented a wind run of < 175 km day^{-1}. Similarly, H_1 and H_2 are relative humidity categories of 40-70% and ≥70%, respectively. Again, the value of 1 or 0 was assigned depending on the presence of the relative humidity category, and a 0 value for these variables represented a relative humidity of ≤ 40%.

6. Pereira et al.: The following relationship for K_{pan} based on temperature and the psychometric constant developed byPereira *et al* [12].

$$Kpan = 0.85 \cdot \frac{(\Delta + \gamma)}{[\Delta + \gamma \cdot (1 + 0.33 \cdot U_2)]} \quad (8)$$

where Δ is slope of the saturation vapor pressure curve (kPa °C^{-1}), and γ is psychometric constant (i.e., 0.0642 kPa °C^{-1}) [17].

ET_o equation

FAO-56 Penman-Monteith (FAO - PM): The FAO-56 Penman-Monteith (FAO - PM) equation is considered the most precise model to estimate ET_o [1-20]. Furthermore, the FAO - PM Combination equation has been recommended by the Food and Agriculture Organization of the United Nations (FAO) as the standard equation for estimating reference evapotranspiration (ET_o) [21]. In this study, the FAO - PM equation was used to test the accuracy of the ET_o estimated from K_{pan} equations.

$$ETo = \frac{0.408\,\Delta(Rn - G) + \gamma\left(\frac{900}{T + 273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (9)$$

where ET_o is reference crop evapotranspiration (mm day^{-1}), T is mean daily air temperature at the 2 m height (°C), Rn is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), U_2 is wind speed at 2 m height (ms^{-1}), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), (e_s - e_a) is vapor pressure deficit (kPa), Δ is slope of the evaporation vapor pressure curve (kPa °C^{-1}), and γ is psychometric constant (kPa °C^{-1}). The various values in this equation were computed on a daily basis, and the ET_o was estimated per the procedure outlined in FAO 56 [20].

Evaluation standards

In this study, the root-mean-squared error (RMSE), the Wilmott agreement index (d), and the linear regression (slope and determination coefficient) were used as statistical criteria. RMSE, in mm day-1, and (d) were calculated by the following equations:

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (Pi - Oi)^2 \right]^{0.5} \quad (10)$$

$$d = 1 - \left[\frac{\sum_{i=1}^{N} (Pi - Oi)^2}{\sum_{i=1}^{N} \left(|Pi - \overline{O}| + |Oi - \overline{O}| \right)^2} \right], \qquad 0 \le d \le 1 \quad (11)$$

where Pi is modeled values of different methods, Oi is calculated ET_o using the FAO PM, and Ô is mean value of calculated ET_o using FAO - PM and N number of observations. A (d) value of 1 means a perfect agreement, whereas a (d) value of (0) means a poor agreement [22]. If an equation performs perfectly, it will have RMSE = 0.0, R^2 = 1.0, d = 1, and a slope of (b) = 1.0 [3].

Results and Discussion

Comparison of K_{pan} values: Two-year daily average air temperature, relative humidity, wind speed, and E_{pan} values are given in Fig. 1. Daily K_{pan} values were calculated from daily weather data using equations 3-8 and are given in Fig. 2. The monthly mean K_{pan} values obtained from daily K_{pan} values were compared with FAO 24 K_{pan} [2] and are given in Table 1.

The Snyder [8] equation (Eq. 4) gave the highest K_{pan} values, followed by the Allen and Pruitt [10] (Eq. 6) and Cuenca [7] (Eq. 3) equations. Monthly K_{pan} values were nearly the same for Eq. 3 and Eq. 6. Xing *et al.* [1] also reported that the Snyder [8] equation gave higher K_{pan} values than the Cuenca [7] equation. The Pereira *et al.* [12] equation (Eq. 8) produced the lowest values of K_{pan}. These results agree with those reported by Abdel-Wahed and Snyder[3]. Gundekar *et al.* [17] also indicated that Pereira *et al.* [12] equation showed poor ability to predict the K_{pan}. It is clear from Table 1 that Allen and Pruitt's [10] method (Eq. 6) gave the best agreement to the FAO 24 [2]. Allen and Pruitt's [10] method was followed by the Cuenca [7] and Snyder [8] methods. Similarly, Snyder *et al.* [13] reported that the Allen and Pruitt [10], Cuenca [7], Snyder [8], and Orang [9] equations provide good estimates of the K_{pan} values in Allen and Pruitt [10].

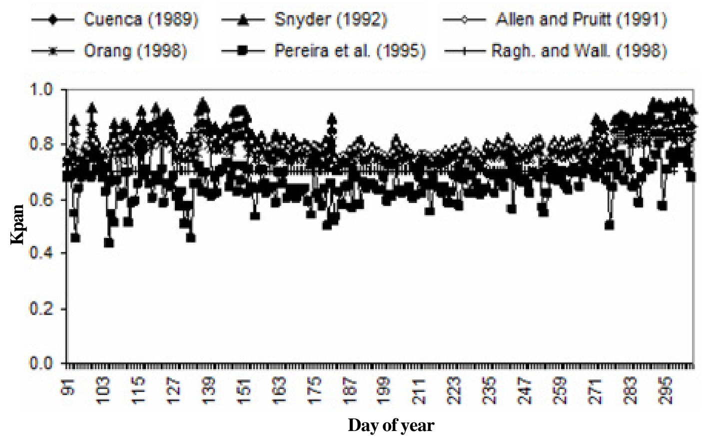

Figure 2. Calculated daily K_{pan} values using equations (3) to (8).

Table 1. Monthly mean K_{pan} coefficients obtained from equations (3) to (8) and FAO 24 [2].

Months	Pan Coefficients (K_{pan})						
	FAO 24	Eq.3	Eq.4	Eq.5	Eq.6	Eq.7	Eq.8
April	0.80	0.79	0.82	0.77	0.79	0.74	0.64
May	0.82	0.83	0.86	0.79	0.82	0.77	0.65
June	0.80	0.78	0.80	0.76	0.79	0.71	0.63
July	0.78	0.76	0.76	0.74	0.77	0.71	0.63
August	0.79	0.76	0.77	0.74	0.77	0.71	0.64
September	0.79	0.78	0.80	0.76	0.79	0.71	0.67
October	0.83	0.85	0.89	0.81	0.84	0.80	0.70
Mean	0.80	0.79	0.81	0.77	0.80	0.73	0.65
b	-	0.992	1.019	0.959	0.994	0.918	0.816
R^2	-	0.808	0.637	0.870	0.910	0.700	0.397
RMSE	-	0.014	0.030	0.034	0.008	0.068	0.149
d	-	0.910	0.771	0.608	0.957	0.369	0.176

Comparison of daily, weekly, 10-day, and monthly ET_o: The K_{pan} values computed by Eqs. 3-8 were used to estimate daily

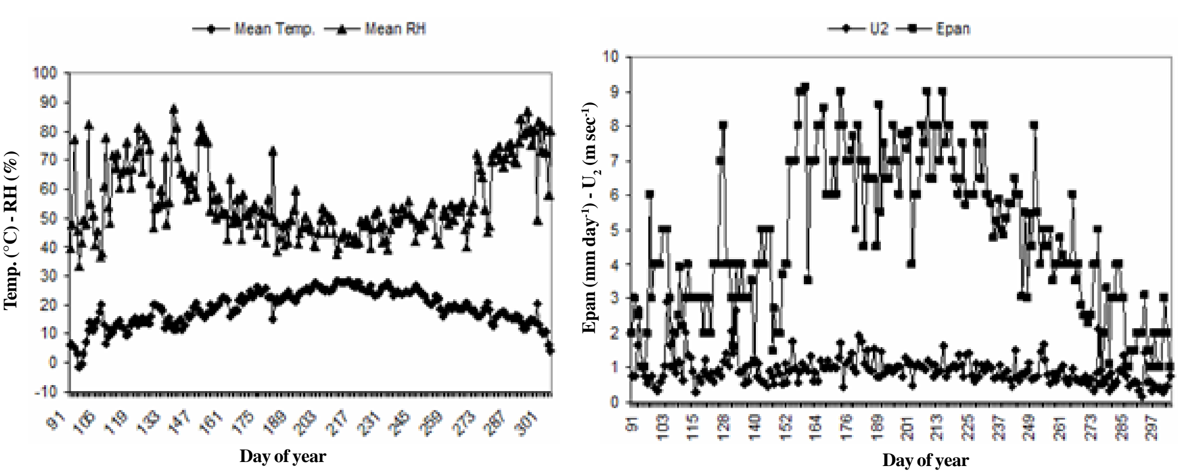

Figure 1. The mean daily meteorological values measured in 2004 and 2008.

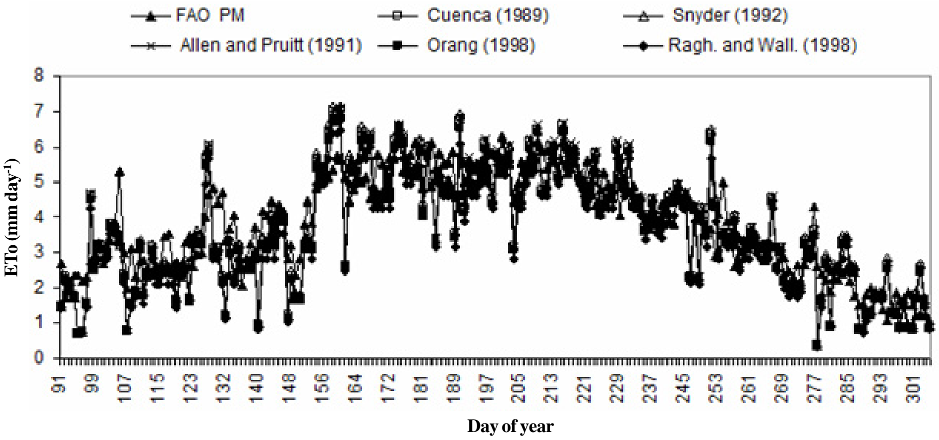

Figure 3. Daily values of ET_o calculated by FAO- PM and using equations (3) to (8).

$ET_{o(pan)}$ using Eq. 2. Daily values of $ET_{o(pan)}$ are plotted in Fig. 3. Later, $ET_{o(pan)}$ values were compared with ET_o computed by FAO-PM. The resulting $ET_{o(pan)}$ data for Eqs. (3-8) were plotted against the ET_o data by forcing through the origin of the regression line. The following equation was obtained:

$$ETo(pan) = b \cdot ETo \quad (12)$$

The weekly, 10-day, and monthly mean $ET_{o(pan)}$ values were obtained from daily $ET_{o(pan)}$ values. Daily, weekly, 10-day, and monthly $ET_{o(pan)}$ values were evaluated using statistical criteria previously established (b, R^2, RMSE, and d), and results are given in Table 2. Table 2 shows that $ET_{o(pan)}$ values obtained from Eqs. (3-8)(except for Eq. 4) were slightly lower than FAO- PM ET_o. Similar findings were reported by Xing *et al.* [1] and Gundekar *et al.* [17].

The daily analysis showed that the Allen and Pruitt [10] equation provided the best agreement with the FAO-PM method, and Eqs. (3) to (7) showed nearly the same performance. However, Eqs. (5) and (7) produced lower $ET_{o(pan)}$ values than Eqs. (3), (4), and (6). The Pereira [12] equation gave the worst performance. Daily $ET_{o(pan)}$ values cannot be used for irrigation scheduling due to high RMSE values, because RMSE values of more than 0.5 mm day^{-1} are not sufficiently accurate for irrigation applications [17].

The weekly, 10-day, and monthly analysis showed that the Snyder [8] equation provided closer agreement with the FAO-PM method, followed by the Cuenca [7], Allen and Pruitt [10], and Orang [9] equations, whereas other equations consistently underestimated ET_o. The performance of Raghuwanshi and Wallender [11] approach with the b value lower than those of other methods was also acceptable for estimating the ET_o.

In fact, Snyder [8], and Cuenca [7] equations showed a better performance than Allen and Pruitt [10] equation, although Allen and Pruitt [10] equation gave a relationship of 1:1 with FAO- PM. Also, Gundekar *et al.* [17] reported that Snyder's [8] method gave the best agreement to the FAO-PM method. However, they determined that the sequential performance was observed as follows: Snyder[8] > Raghuwanshi and Wallender [11] > Orang [9] > Cuenca [7]. Similarly, Trajkovic and Kolakovic [18] reported that the Snyder ET_o equation consistently provides better results compared to FAO-24 pan equation, although required measurements of only one weather parameter pan evaporation. Table 2 shows that Eqs. (3-6) can easily be used for weekly, 10-day, and monthly irrigation planning due to low RMSE and high (b), R^2, and (d) values. These findings are in accordance with suggestions of Doorenbos and Pruitt [2] and Allen *et al.* [20]. They stated that notwithstanding the difference between pan-evaporation and the evapotranspiration of cropped surfaces, the use of pans to predict ET_o for periods of 10 days or longer may be warranted.

Conclusions

The equations for the estimation of K_{pan} presented by Cuenca [7], Snyder [8], Orang [9], Allen and Pruitt [10], Raghuwanshi and Wallender [11], and Pereira *et al.* [12] were evaluated for estimating ET_o by comparing them with the FAO 56 Penman-Monteith (FAO-PM) method for the Igdir region of Turkey, which has a semi-arid climate.

The monthly mean K_{pan} values were compared with FAO 24 K_{pan} [2]. Method of Allen and Pruitt [10] (Eq. 6) gave the best agreement to the FAO 24 [2], followed by the Cuenca [7] and Snyder [8] methods. While equations 3 to 7 (except for Eq. 4) slightly underestimated the ET_o compared to the FAO-PM method, the Eq. (8) has produced very low values. The Snyder [8] equation generally gave the best agreement to the FAO-PM, followed by the Cuenca [7], Allen and Pruitt [10], Orang [9] and Raghuwanshi and Wallender [11] approaches.

Table 2. Statistical test for comparison of estimated daily mean, weekly mean, 10-day mean and monthly mean ET_o using Eqs. (3) to (8) and the FAO-PM method.

Eqs. compared with FAO -PM method	Daily				Weekly				10-day				Monthly			
	(b)	(R^2)	RMSE	(d)	(b)	(R^2)	RMSE	(d)	(b)	(R^2)	RMSE	(d)	(b)	(R^2)	RMSE	(d)
Eq. (3)	0.989	0.679	0.946	0.894	0.993	0.895	0.460	0.969	0.990	0.930	0.358	0.980	0.995	0.958	0.271	0.988
Eq. (4)	1.004	0.664	0.965	0.889	1.008	0.896	0.455	0.969	1.006	0.932	0.346	0.981	1.011	0.963	0.255	0.989
Eq. (5)	0.959	0.683	0.931	0.895	0.962	0.894	0.477	0.966	0.960	0.928	0.388	0.976	0.964	0.956	0.305	0.984
Eq. (6)	0.996	0.683	0.954	0.894	0.999	0.893	0.475	0.968	0.997	0.927	0.371	0.979	1.001	0.954	0.286	0.987
Eq. (7)	0.912	0.689	0.924	0.891	0.915	0.902	0.532	0.955	0.913	0.932	0.475	0.962	0.916	0.961	0.407	0.971
Eq. (8)	0.815	0.631	1.133	0.831	0.819	0.865	0.850	0.884	0.817	0.907	0.811	0.888	0.821	0.944	0.756	0.898

The results suggested that the Snyder [8], Cuenca [7], Allen and Pruitt [10], and Orang [9] approaches could be used to estimate ET_o through Class-A pan data with fewer concerns compared to the other evaluated methods. Under Igdir conditions, the weekly or more long-term averages of ET_o data from these four equations using daily meteorological data could be easily used for irrigation scheduling.

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