Reference Crop Evapotranspiration from Temperature

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ABSTRACT

MEASURED lysimeter evapotranspiration of Alta fescue grass (a cool season grass) is taken as an index of reference crop evapotranspiration (ETo). An equation is presented that estimates ETo from measured values of daily or mean values of maximum and minimum temperature. This equation is compared with various other methods for estimating ETo.

The equation was developed using eight years of daily lysimeter data from Davis, California and used to estimate values of ETo for other locations. Comparisons with other methods with measured cool season grass evapotranspiration at Aspendale, Australia; Lompoc, California; and Seabrook, New Jersey; with lysimeter data from Damin, Haiti; and with the modified Penman for various locations in Bangladesh indicated that the method usually does not require local calibration and that the estimated values are probably as reliable and useable as those from the other estimating methods used for comparison.

Considering the scarcity of complete and reliable climatic data for estimating crop water requirements in developing countries, this proposed method can do much to improve irrigation planning design and scheduling in the developing countries.

INTRODUCTION

In many parts of the world, the area of fertile lands that could be made more productive by irrigation far exceeds developed and developable water supplies. It is, therefore, important to manage available irrigation water supplies as efficiently as possible. There are several factors, that when properly managed, can result in significant improvements in the use of agricultural water. These include:

1. Better land preparation.
2. Water measurement particularly at the farm level.
3. Monitoring soil moisture status within the crop root zone.
4. Conversion from surface to drip or sprinkle whenever conditions of soils, topography and economics indicate clear advantages.
5. Improved estimates of crop water requirements based upon weather and climatic data.

This paper deals with the last of these five items. There are a number of good procedures for estimating the potential evapotranspiration of a reference crop or reference crop evapotranspiration, ETo. Evapotranspiration from other crops can be estimated from ETo and established crop coefficients [Doorenbos and Pruitt,(1977)]. Any computational procedure for estimating ETo should provide consistent and reliable results and require a minimum of data and computation. Some of the currently used estimating methods require data inputs that are not widely available.

A procedure based on almost universally available data is presented here and is recommended for general use. This procedure requires little or no local calibration and uses only measurements of maximum and minimum temperature.

LIMITATIONS OF ETo ESTIMATES

All equations for estimating ETo are to some degree empirical. Many have been derived and/or calibrated from evapotranspiration measured with lysimeters or soil moisture depletions by a particular reference crop. Numerous reference crops have been used but the most common ones are grass or alfalfa. Grasses vary widely in their water use, and different varieties of alfalfa have different water use characteristics. There is an urgent need for standardization of reference crops.

The FAO version of the Penman equation for estimating ETo as given by Doorenbos and Pruitt (1977) and Doorenbos and Kassam (1979) is widely proposed for use in developing countries. In many developing countries, data may be incomplete and estimates or data from other locations used to facilitate computation. For example, mean relative humidity is often used to estimate the vapor pressure deficit value required in the Penman equation. In different countries, and sometimes in the same country, published values of mean relative humidity are determined by averaging at various times of measurement. [See Her Majesty's Stationery Office (1978)]. Some of the published values of mean relative humidity are fairly comparable and other published values may by significantly different. Climatic data for estimating ETo may be taken from airports, arid, hilly locations or from other irrigated areas very dissimilar to the areas for which ETo computations are needed. Comparable estimates of ETo require closely comparable sites for reasonable data transfer.

McVicker (1982) calibrated 12 methods for estimating ETo and then compared their performances for two locations (Davis, California and Logan, Utah). The best six methods, ranked in order of the smaller root mean square errors, are Hargreaves, Jensen-Haise, Stephens and Stewart, Makkink, Turc and Grassi. All of these computations are based on mean air temperature and incoming solar radiation, RS. The equations did not vary significantly in their performance after calibration. All six performed better than the Penman combination

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equation. This probably resulted from poor calibration of the aerodynamic term in the Penman equation.

Shih (1984) evaluated the data requirements for evapotranspiration estimates. Evapotranspiration estimated from nine climatic variables was compared with calculated values using the two variables of air temperature and solar radiation. He concluded that the two variables provide satisfactory estimates for southern Florida. Coefficients of determination (R^2) were found to be almost as good with the two variables as with all of the nine variables.

Salih and Sendil (1984) compared several methods for estimating ETo and evaluated them using ET data from alfalfa at two sites in the Al-Hassa region of Saudi Arabia. At one site a lysimeter was used and at the other a field plot technique. After statistical evaluation of the results they ranked Jensen-Haise and the Class A Pan methods in first place, Hargreaves methods consistently next and then Penman and Modified Penman.

The study by McVicker (1982), the data and analysis presented by Jensen (1974) the comparisons made by Shih (1984), and those by Salih and Sendil (1984) indicated that the two climatic variables of mean air temperature and global solar radiation can be used to provide satisfactory estimates of ETo at most locations. It seems that adding climatic measurements or estimated values relating to climate may either slightly improve the estimates or somewhat decrease their reliability. However, temperature and radiation alone do not always adequately compensate for the influence of advective energy. Some judgement or local calibration may be desirable when winds provide significant cooling or heating of the reference area. Attempts to date at finding a generalized method for estimating the effect of advective energy on ETo have not been very successful.

Equations requiring global radiation and mean air temperature produce satisfactory ETo estimates for most conditions where irrigation is required when they are calibrated to a satisfactory reference crop and if the temperature and radiation measurements are reliable and are from a representative site. Unfortunately, radiation measurements are often unavailable and some radiometers may be poorly calibrated.

A NEW METHOD

The Hargreaves original equation (1975, 1982) for ETo based upon radiation and temperature can be written:

$$ETo = 0.0135 \times RS\ (T^{\circ}C + 17.8) \quad \ldots\ldots\ldots\ldots [1]$$

in which ETo and solar radiation, RS, are in the same units of equivalent water evaporation (usually mm per unit of time) and T°C is mean temperature in degrees Centigrade. Equation [1] was calibrated based on eight years of Alta fescue grass lysimeter evapotranspiration from Davis, California.

Various equations have been developed for estimating the value of RS indirectly from measurements of sunshine hours and tables or calculations of extraterrestrial radiation. Hargreaves and Samani (1982), give an equation for determining RS from extraterrestril radiation, RA, and the measured temperature range. The equation is:

$$RS = K_{RS} \times RA \times TD^{0.50} \quad \ldots\ldots\ldots\ldots [2]$$

in which RS and RA are in the same units, K_{RS} is a calibration coefficient and TD is mean maximum minus mean minimum temperature. Combining equations [1] and [2] results in:

$$ETo = K_{ET} \times RA \times TD^{0.50}\ (T\,C^{\circ} + 17.8) \quad \ldots\ldots [3]$$

TD varies depending on proximity to the ocean or to mountains or to changes in relative humidity and advection that moderate or accentuate the daily temperature range in particular locations. Equation [1] overestimates ETo for coastal (low advection) conditions and underestimates ETo for highly advective conditions. However, use of a single constant value for K_{ET} appears to approximately compensate for differences in advection or in vapor transfer effect.

CALIBRATION OF THE NEW ETo METHOD

Eight years of data for Alta fescue grass evapotranspiration from the $29 m^2$ weighing lysimeters at Davis, California were used to calibrate the values of K_{ET} in equation [3] giving:

$$ETo = 0.00023 \times RA \times TD^{0.50}\ (T^{\circ}C + 17.8) \quad \ldots\ldots [4]$$

in which ETo and RA are in the same units of equivalent water evaporation and TD is in °C.

Mean monthly climatic data and ET from a carefully managed 3.0 m^2 lysimeter at Damien, Haiti and Class A and Colorado pan evaporation were available. Using measured climatological data for the site, values of ETo were estimated by various other computational methods (Table 1), and ratios of lysimeter ET to estimated ETo and standard deviations of the monthly ratios (in percent of the mean values) were determined. The pan coefficients were obtained from those given by Doorenbos and Pruitt (1977). The results are given in Table 1.

Equation 4 required only maximum and minimum temperature data. The pan evaporation methods require measured pan evaporation, wind and relative humidity. Equation [1] uses mean air temperature and solar radiation. The SCS Blaney-Criddle method required only mean temperature. The three FAO methods use temperature, solar radiation or sunshine hours, wind and relative humidity. Equation [4] produced estimates that correlate as well with the measure lysimeter ET as any of the procedures shown in Table 1 and use a minimum of measured data.

The average ratio of lysimeter ET to estimated ETo for the four methods from Doorenbos and Pruitt (1977) is 0.94. This is the same ratio as from Equation [1] and [4].

Karim and Akhand (1982) calculated the potential

TABLE 1. MONTHLY AVERAGE RATIOS OF LYSIMETER Et TO ETo ESTIMATED BY VARIOUS METHODS AND STANDARD DEVIATIONS OF RATIOS FOR DATA FROM DAMIEN, HAITI.

Method	ET/ETo	Std. dev. %
Equation [4]	0.94	3.6
Pan evaporation (KP = 0.85)	0.84	5.0
Equation [1]	0.94	5.7
S.C.S. Blaney-Criddle [Borrelli et al. (1981)]	0.79	6.7
FAO Penman [Doorenbos and Pruitt (1977)]	0.91	7.5
FAO Radiation [Doorenbos and Pruitt]	1.02	7.5
Colorado Pan (KP = 1.05) [Doorenbos and Pruitt]	0.87	8.1
FAO Blaney-Criddle [Doorenbos and Pruitt]	0.96	11.0
Average	0.91	6.9

TABLE 2. MONTHLY AVERAGE RATIOS OF ESTIMATED VALUES OF ETo USING HARGREAVES (EQUATION [4]) AND PENMAN METHOD AND STANDARD DEVIATION OF RATIOS AS PERCENTAGES OF MEAN RATIO.

Station	ETo(Hargreaves) / ETo(Penman)	Std% / Mean
Barisal	1.05	7.8
Bogra	1.03	7.3
Chittagong	0.94	15.4
Cox's Bazar	0.84	8.6
Comilla	1.01	11.3
Dacca	0.94	10.5
Narayanganj	0.93	11.5
Dinajpur	1.10	8.6
Faridpur	0.98	14.1
Jessore	1.05	11.2
Khulna	1.05	7.4
Satkhira	1.14	17.5
Mymensingh	1.07	8.2
Noakhali	0.92	11.9
Rangpur	1.11	9.3
Sylhet	1.09	5.7
Average	1.02	10.4

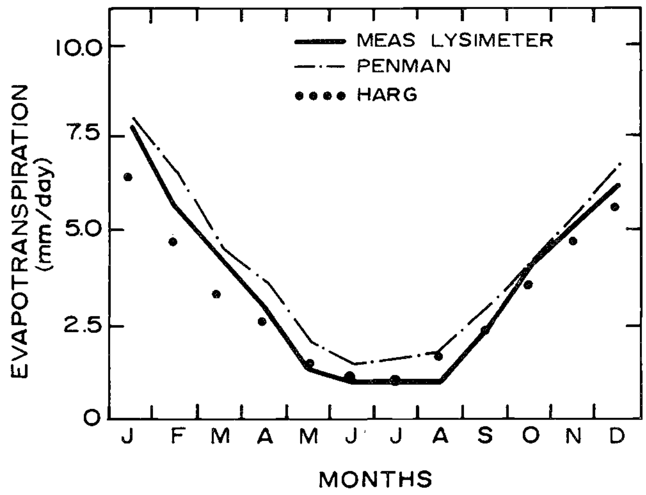

Fig. 1—Measured and estimated potential evapotranspiration at Aspendale, Australia. (Fig. 7.1, Jensen, 1974).

evapotranspiration for 16 stations in Bangladesh, using the FAO modified Penman equation given by Doorenbos and Pruitt (1977). The climatological data (average monthly values of maximum and minimum temperature) reported by Karim and Akhand (1982) were used to calculate the reference crop evapotranspiration by equation [4]. Table 2 shows the ratios and standard deviations for the 16 stations. The average ratio of [ET (Harg)/ET (Penman)] was equal to 1.02 with an average standard deviation equal to 10.4% of the mean.

Jensen (1974) has presented figures comparing different methods of estimating potential evapotranspiration with measured lysimeter data. Maximum and minimum temperature data from these stations were obtained and equation [4] was used to calculate the reference crop evapotranspiration for these stations. Estimation of ETo by modified method was not possible due to unavailability of the climatological data. Fig. 1, 2 and 3 compare measured lysimeter data with estimated values from equation [4] and the modified Penman method [Jensen (1974)].

The comparisons show that equation [4] can be used with reasonable accuracy to estimate the reference crop evapotranspiration. Considering the paucity of the climatological data in most parts of the world and the lack of knowledge and facilities to use more sophisticated methods in estimating ETo, the temperature method is recommended as a superior method for estimating the reference crop evapotranspiration.

SUMMARY AND CONCLUSIONS

A method for estimating reference crop evapotranspiration, ETo from measured temperature alone is presented and compared with other methods of estimating ETo and with actual measured data. The estimated values of ETo from equation [4] presented herein compared favorably with those of other methods or lysimeter data, providing a better fit of the measured data in nearly all cases.

Considering the problems associated with the availability and reliability of climatological data in the world and the possible errors in the more sophisticated methods for estimating crop water requirements, the temperature method herein presented is recommended as the most simple and practical method for estimating reference crop evapotranspiration. This method is recommended for further evaluation and for possible acceptance for world-wide use.

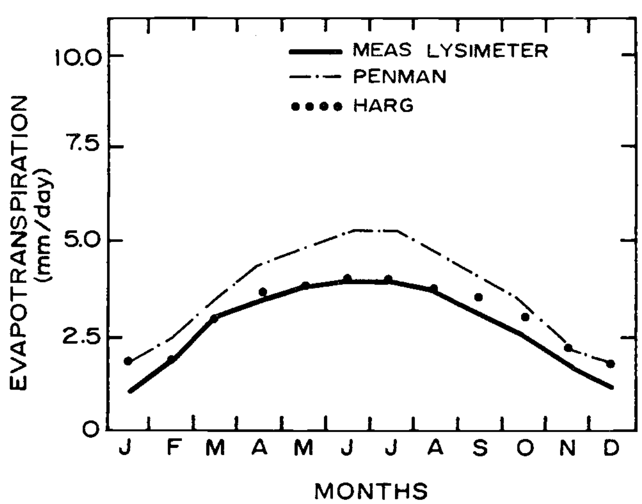

Fig. 2—Measured and estimated potential evapotranspiration at Lompoc, California. (Fig.7.31, Jensen. 1974).

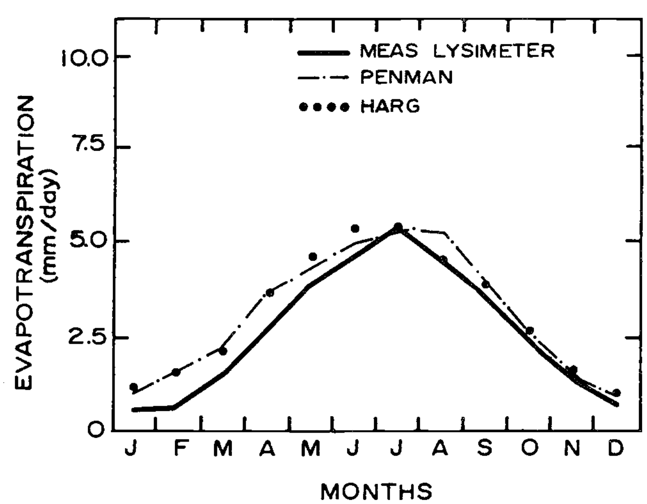

Fig. 3—Measured and estimated potential evapotranspiration at Seabrook, New Jersey. (Fig. 7.41, Jensen, 1974).

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