ADAPTATION OF THE THORNTHWAITE SCHEME FOR ESTIMATING DAILY REFERENCE EVAPOTRANSPIRATION

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1. Introduction

The Food and Agriculture Organization (FAO) released the Irrigation and Drainage Paper 56 (ALLEN et al., 1998) recommending that the reference evapotranspiration (ETo) be computed solely based on the parameterizations proposed by ALLEN et al. (1989) for the Penman-Monteith equation. Even though such proposal has been tested positively in many climates, the need for many input variables, seldom available in remote areas of developing regions, limits its widespread use. An alternative is the use of regional weather stations providing the necessary inputs. However, such rarely available stations require qualified personnel for operation and maintenance of the very sensitive instruments, and calibration is not a common practice, even in research centers. Large measurements errors are possible as the instruments age.

Empirical methods are the next alternative and the Thornthwaite scheme is a choice since it requires only temperature as input. However, the Thornthwaite approach has been found to underestimate under arid conditions (PELTON et al., 1960; STANHILL, 1961; PRUITT, 1964; HASHEMI & HABIBIAN, 1979; MALEK, 1987) and to overestimate in the equatorial humid climate of the Amazon region (CAMARGO et al., 1999). Up to now, the only adjustment of the Thornthwaite scheme was proposed by CAMARGO et al. (1999) using an “effective” temperature instead of the original average temperature. Their proposal was based on monthly averages and totals, and it was tested against the Penman-Monteith FAO-56 ETo estimatives.

The objective here is to test such modification of the Thornthwaite scheme against daily lysimetric measurements on two constrasting environments (the dry climate of Davis, CA, and the humid summer and the dry fall - winter of Piracicaba, SP, Brazil). A further correction based on the daily photoperiod is proposed for the effective temperature.

2. Material and methods

The potential evapotranspiration (reference evapotranspiration, mm/month) for a standard month of 30 days, each day with 12 hours of photoperiod, was computed as a function of the month average temperature (T, ^{o}C) by the scheme proposed by THORNTHWAITE (1948) as:

$$\mathbf{ET_M} = 16\,(10\,\frac{\mathbf{T}}{\mathbf{I}})^{\mathbf{a}} \qquad 0\ ^{\mathbf{o}}\mathbf{C} \le \mathbf{T} \le 26\ ^{\mathbf{o}}\mathbf{C}$$

where **I** is a thermal index imposed by the local normal climatic temperature regime (Tn, ^{o}C); and the exponent **a** is a function of **I**, both computed by

$$\mathbf{I} = \sum_{\mathbf{n}=1}^{12} (0.2\ \mathbf{Tn})^{1.514} \qquad \mathbf{Tn} > 0\ ^{\mathbf{o}}\mathbf{C}$$

$$\mathbf{a} = 6.75\,10^{-7}\,\mathbf{I}^3 - 7.71\,10^{-5}\,\mathbf{I}^2 + 1.7912\ 10^{-2}\ \mathbf{I} + 0.49239$$

For temperature above 26 ^{o}C, instead of the original table of THORNTHWAITE (1948), WILLMOTT et al. (1985) represented ET_M by the following equation

$$\mathbf{ET_M} = -415.85 + 32.24\ \mathbf{T} - 0.43\ \mathbf{T}^2;\ \ \mathbf{T} > 26\ ^{\mathbf{o}}\mathbf{C}$$

In order to convert the estimates from a standard monthly (ET_M, mm/mo) to a daily (ET_D, mm/d) time scale the folowing correction factor (C) was used $\mathbf{C} = \frac{\mathbf{N}}{360}$

where **N** is the photoperiod (in hours) for a given day.

CAMARGO et al. (1999) found that the performance of the Thornthwaite approach in a month time scale improved if an “effective” temperature (Tef) is used instead of the recommended average temperature (Tavg = 0.5 [Tmax + Tmin]). The effective temperature was computed empirically as a function of the average temperature and of the daily amplitude (A = Tmax - Tmin), as

$$\mathbf{Tef} = \mathbf{k}\ (\mathbf{Tavg} + \mathbf{A}) = \frac{\mathbf{k}}{2}\,(3\ \mathbf{Tmax} - \mathbf{Tmin})$$

with k = 0.72 as the statistically best value for estimating ET_M. Different values were tested here with k = 0.69 giving the best estimatives for ETo.

However, any two days with the same Tef but with very different photoperiods (N) are likely to have different evapotranspiration rates. It is proposed here to correct Tef with the day-night ratio N/(24 – N), or

$$\mathbf{Tef^*} = \mathbf{Tef}\ \ \frac{\mathbf{N}}{24 - \mathbf{N}},$$

with the following restrictions: Tavg ≤ Tef* ≤ Tmax.

Daily reference evapotranspiration was obtained from 1960 to 1963 at UC Davis, CA, USA (38^{o} 32’N; 121^{o} 46’W; 19m a.m.s.l.) with a weighing lysimeter in a field of perennial ryegrass with an average height of 0.1 m, and irrigated weekly (PRUITT, 1964). Days with strong advection and those with restricted ET were discarded based on the 0.5 < ET/Rn+ < 0.9 criteria, where Rn+ is the summation of the positive values of measured net radiation.

Another data set came from measurements at Piracicaba, SP, Brazil (22^{o} 47’S; 47^{o} 30’W; 546 m a.m.s.l.) during 1996. ET was obtained from a weighing lysimeter in a field of irrigated *Paspalum notatum* L. grass. The grass was mowed close to the 0.12 m of a reference surface defined by Allen et al. (1998). The same ET/Rn+ criteria was used here.

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Regression analysis was performed to test the goodness of the fit between estimated (X) versus measured ET (Y). The standard error of the estimatives (see, ± mm/d) and coefficient of determination (r^2) statistics were also used.

3. Results and Discussion

To visualize the improvement obtained with the new proposal for the Thornthwaite scheme a comparison with the original approach is presented. As expected, for the arid conditions of Davis, CA, the degree of underestimation using Tavg as input was very large (Lys = 1.6657 Thorn; see = ± 1.04 mm/d; r^2 = 0.5298; n = 306) confirmed previous reports (Figure 1). However, when an "effective" daily temperature (Tef) was used instead of the original daily average temperature, the estimatives improved substantially with most of points spreading around the line of perfect fit (Lys = 1.0036 Thorn; see = ± 1.13 mm/d; r^2 = 0.4489; n = 306). Taking into account the different photoperiods during the year, the corrected effective temperature (Tef*) gave a slight overprediction (Figure 2) but with less spread of the points and with a decrease in the standard error of the estimatives (Lys = 0.9362 Thorn; see = ± 0.90 mm/d; r^2 = 0.6497; n = 306).

For the sake of comparison, the Thornthwaite scheme with Tef* gave an almost identical relationship as that obtained with the same data set using the Penman-Monteith FAO-56 estimatives (Lys = 0.94 PM56; see = ± 0.64 mm/d; r^2 = 0.8238; n = 306).

For the data set from Piracicaba, SP, Brazil, the original Thornthwaite scheme (Tavg) resulted also in underprediction of 25%, on average, or Lys = 1.2475 Thorn; see = ± 1.22 mm/d; r^2 = 0.3889; n = 127. Using the "effective" daily temperature (Tef) resulted in a substantial improvement of the estimatives with the points spreading around the 1:1 line, giving the following statistics: Lys = 1.0179 Thorn; see = ± 0.91 mm/d; r^2 = 0.4021; n = 127. When the photoperiodic effective temperature (Tef*) was used it resulted in almost identical overprediction observed for Davis, CA, i.e., Lys = 0.9555 Thorn; see = ± 0.87 mm/d; r^2 = 0.4514; n = 127.

For this data set, the Penman-Monteith FAO-56 gave the following relationships: Lys = 0.9904 PM-56; see = ± 0.51 mm/d; r^2 = 0.8145; n = 127.

4. References

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