

CALCULATION OF REFERENCE CROP EVAPOTRANSPIRATION USING THE PENMAN-MONTEITH METHOD

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ABSTRACT

The rational designing of irrigation systems requires the calculation of the evapotranspiration in the best possible way. Reference crop evapotranspiration (ET_r) is the rate at which water, if available, would be removed from the soil and plant surface of a specific crop, arbitrarily called a reference crop. A large number of more or less empirical methods have been developed over the last years by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. Relationships were often subject to rigorous local calibrations and proved to have limited global validity. Testing the accuracy of the methods under a new set of conditions is laborious, time-consuming and costly, and yet evapotranspiration data are frequently needed at short notice for project planning or irrigation scheduling design. The analysis of the performance of the various calculation methods reveals the need for formulating a standard method for the computation of ET_r . The Penman-Monteith method is recommended as the sole standard method. It is a method with strong likelihood of correctly predicting ET_r in a wide range of locations and climates and has provision for application in data-short situations. The use of other reference ET methods is no longer encouraged. Because of the required calculating procedure when the Penman-Monteith method is used, is very complex and calls for a lot of calculations we present in this paper, a computer system of estimating ET_r using this method. The system facilitates irrigation network designers in calculating reference crop evapotranspiration. It is simple in use, do not demand special informatics knowledge, and it is approachable to a wide range of researchers. System's architecture includes a user-friendly interface for the data input, a computational module and the output subsystem, where the user is given a detailed table of results. The computer system provides a quick and accurate solution to the problem of estimating ET_r . In addition, it could be incorporated as subroutine of integrated software dealing with hydraulic calculations.

1 INTRODUCTION

Reference crop evapotranspiration, ET_r , is "the rate at which water, if available, would be removed from the soil and plant surface of a specific crop, arbitrarily called a reference crop" as described by Jensen et al. (1990). The reference crop is typically grass or alfalfa under well-watered conditions. The height of the grass reference should be at least 8 and no more than 15 cm as shown by Doorenbos and Pruitt (1977). Three general approaches to estimating ET_r were considered: temperature methods, radiation methods and combination methods. The

temperature methods, Thornthwaite (1948); Blaney- Criddle (1950), (1962); Hargreaves - Samani (1982), (1985), are empirical equations that rely on air temperature as a surrogate for the amount of energy that is available to the reference crop for evapotranspiration. However, there is no direct, unique relationship between temperature and energy. The temperature methods remain empirical and require local calibration in order to achieve satisfactory results. A possible exception is the Hargreaves - Samani (1985) method which has shown reasonable ET_r results with a global validity. According to the Radiation Methods, Makkink (1957); Jensen - Haise (1963); Turc (1963); Priestley-Taylor (1972), the ET_r process is controlled by available energy and the ability of evaporated water to be transferred from the surface. The transfer process is a function of the wind speed and the amount of water vapour in the air closest to the surface. The radiation methods show good results in humid climates where the aerodynamic term is relatively small, but performance in arid conditions is erratic and tends to underestimate evapotranspiration. The combination methods, Doorenbos and Pruitt (1977); Penman-Monteith (1981), (1985), are based on the original Penman (1948) combination equation that consists of two terms: the radiation term and the temperature term. The combination methods require more data than the previous methods including net radiation, air temperature, wind speed and relative humidity. The combination type of equations give the best results for a variety of vegetated surfaces and climates; and their application is suitable for those locations where measured data on temperature, wind and sunshine duration or radiation are available. The original combination Penman equation predicted evaporation losses from an open water surface. This method was further developed by many researchers and extended to cropped surfaces by introducing resistance factors. The Penman-Monteith method is recommended as the sole standard method. It is a method with strong likelihood of correctly predicting ET_r in a wide range of locations and climates and has provision for application in data - short situations. Because of the required calculating procedure when the Penman - Monteith combination method is used, is very complex and calls for a lot of calculations we present in this paper, a computer system of estimating ET_r using this method. The system facilitates irrigation network designers in calculating ET_r . System's architecture includes a user friendly interface for the data input, a computational module and the output subsystem, where the user is given a detailed table of results. The computer system provides a quick and accurate solution to the problem of estimating ET_r . In addition, it could be incorporated as subroutine of integrated software dealing with hydraulic calculations.

2 THE PENMAN - MONTEITH COMBINATION METHOD

The Penman-Monteith (1981) form of the combination equation is:

$$ET_r = \frac{10^3}{\rho_w} \left[\frac{\Delta}{\gamma' + \Delta} \frac{(R_n - G)}{\lambda} + \frac{\gamma}{\gamma' + \Delta} D F(u) \right] \text{ mmd}^{-1} \quad (1)$$

where: Δ is the slope saturated vapour pressure-temperature curve at mean air temperature [$\text{hPa } ^\circ\text{C}^{-1}$]; R_n is the net solar radiation [$\text{MJm}^{-2}\text{d}^{-1}$]; G is the soil heat flux [$\text{MJm}^{-2}\text{d}^{-1}$]; λ is the latent heat of evaporation [MJ kg^{-1}]; $\rho_w = 1000 \text{ kgm}^{-3}$, is the density of water; γ and γ' are respectively the Penman's and the Penman - Monteith psychrometric constant [$\text{hPa } ^\circ\text{C}^{-1}$]; D represents the slope of the saturation vapour pressure temperature relationship [hPa]; and $F(u)$ is the wind related function [$\text{kg hPa}^{-1}\text{m}^{-2}\text{d}^{-1}$].

2.1 The slope of saturation vapour pressure curve (Δ)

It is calculated from the equation provided by Tetens (1930) and Murray (1967):

$$\Delta = \frac{4098}{[T_a + 237.3]^2} 6.108 \exp \left[\frac{17.27 T_a}{T_a + 237.3} \right] \text{ hPa } ^\circ\text{C}^{-1} \quad (2)$$

where: T_a is the daily mean air temperature [$^\circ\text{C}$].

2.2 The latent heat of vaporization (λ)

It is computed by:

$$\lambda = 2.501 - 0.002361 T_s \quad \text{MJ kg}^{-1} \quad (3)$$

where T_s is the daily mean temperature of the water surface (or the water saturated soil surface) [$^\circ\text{C}$].

2.3 The Penman's psychrometric constant (γ)

It is calculated from the equation provided by Brunt (Brunt 1952):

$$\gamma = \frac{c_p p}{\varepsilon \lambda} \quad \text{hPa } ^\circ\text{C}^{-1} \quad (4)$$

p is the atmospheric pressure [kPa]; λ is latent heat of vaporization [MJ kg⁻¹]; c_p is the specific heat at constant pressure [MJ kg⁻¹ °C⁻¹]; and $\varepsilon = 0.622$ is the ratio molecular weight of water vapour/dry air = 0.622.

The specific heat at constant pressure is the amount of energy required to increase the temperature of a unit mass of air by one degree at constant pressure. Its value depends on the composition of the air, i.e., on its humidity. For average atmospheric conditions a value $c_p = 1.01325 \cdot 10^{-3} \text{ MJ kg}^{-1} \text{ } ^\circ\text{C}^{-1}$ can be used. The atmospheric pressure at height z in is computed by:

$$p = 1013.25 \left(1 - 2.256 \cdot (10^{-5}) z \right)^{5.256} \quad (5)$$

Therefore the Penman's psychrometric constant (γ) becomes:

$$\gamma = \frac{\left(1 - \frac{0.0065}{273 + T_a} h \right)^{5.2586}}{1.5156 - 0.0014307 T_s} \quad \text{hPa } ^\circ\text{C}^{-1} \quad (6)$$

where h is the altitude of the area [m]; T_a and T_s are as above described.

2.4 The Penman - Monteith psychrometric constant (γ')

It is calculated from the equation (Monteith, 1981):

$$\gamma' = \gamma \cdot \left(1 + \frac{r_s}{r_a} \right) \quad \text{hPa } ^\circ\text{C}^{-1} \quad (7)$$

where: r_s is the surface resistance which describes the resistance of vapour flow through stomata openings, total leaf area and soil surface [sm^{-1}]; and r_a is the aerodynamic resistance which describes the resistance from the vegetation upward and involves friction from air flowing over vegetative surfaces [sm^{-1}].

The surface resistance, r_s , is calculated from the equation:

$$r_s = \frac{r_l}{\text{LAI}_{\text{active}}} \quad (8)$$

LAI, a dimensionless quantity, is the leaf area (upper side only) per unit area of soil below it; and r_l is the bulk stomatal resistance of the well-illuminated leaf [sm^{-1}]. A general equation for $\text{LAI}_{\text{active}}$ is: $\text{LAI}_{\text{active}} = 0.5 \text{ LAI}$. For clipped grass a general equation for LAI is:

$$\text{LAI} = 1.5 \ln(h_c) - 1.4 \quad (9)$$

where h_c is the crop height [cm].

The stomatal resistance, r_l , of a single leaf has a value of about 100 sm^{-1} under well-watered conditions.

Therefore the surface resistance, r_s [sm^{-1}], for the grass reference surface becomes:

$$r_s = \frac{100}{0.5 (1.5 \ln(h_c) - 1.4)} \text{ sm}^{-1} \quad (10)$$

The aerodynamic resistance, r_a , is determined by :

$$r_a = \frac{\ln \left[\frac{z_u - d}{z_{om}} \right] \ln \left[\frac{z_p - d}{z_{ov}} \right]}{k^2 u_z} \text{ sm}^{-1} \quad (11)$$

where r_a is the aerodynamic resistance [sm^{-1}]; z_u is the height of wind measurements [m]; z_p is the height of humidity measurements [m]; d is the zero plane displacement height [m]; z_{om} is the roughness length governing momentum transfer [m]; z_{ov} is the roughness length governing transfer of heat and vapour [m]; k is the von Karman's constant, 0.41 [-]; and u_z is the wind speed at height z [ms^{-1}].

For a wide range of crops the zero plane displacement height, d [m], and the roughness length governing momentum transfer, z_{om} [m], can be estimated from the crop height h [m] by the following equations: $d = 2/3 h_c$ and $z_{om} = 0.123 h_c$. The roughness length governing transfer of heat and vapour, z_{ov} [m], can be approximated by $z_{ov} = 0.1 z_{om}$. Assuming a standardized height for wind speed, temperature and humidity at 2.00 m ($z_u = z_p = 2 \text{ m}$), the aerodynamic resistance r_a [sm^{-1}] for the grass reference surface becomes:

$$r_a = \frac{\ln \left[\frac{2.00 - 2/3(h_c)}{0.123(h_c)} \right] \ln \left[\frac{2.00 - 2/3(h_c)}{0.0123(h_c)} \right]}{0.41^2 u_2} \text{ sm}^{-1} \quad (12)$$

where h_c is the crop height [m]; and u_2 is the wind speed [ms^{-1}] at height 2.00 m.

Wind speed is measured at many different heights above the ground surface. The Penman-Monteith equation requires wind speed at a height of 2.00 m. It can be adjusted to a height of 2.00 m by:

$$u_2 = u_z \left(\frac{2}{z} \right)^{0.2} \text{ ms}^{-1} \quad (13)$$

where u_2 and u_z is the wind speed corresponded at height of 2.00 m and z m, [ms^{-1}]; and z is the height of wind measurement [m].

2.5 The vapour pressure deficit (D)

It is expressed as the difference between the mean saturation water vapour pressure (e_0) and the mean actual vapour pressure (e_d). From Tetens (1930), saturated air vapour pressure as a function of temperature can be computed by:

$$D = e_0(T_a) - e_d(T_a) \text{ hPa} \quad (14)$$

The mean saturation water vapour pressure is calculated from the equation provided by Tetens (1930):

$$e_0(T_a) = 6.108 \exp \left[\frac{17.27 T_a}{T_a + 237.3} \right] \text{ hPa} \quad (15)$$

The mean actual vapour pressure is calculated using saturation vapour pressure and the mean relative humidity:

$$e_d(T_a) = \frac{\text{RH}_{\text{mean}} e_0(T_a)}{100} \text{ hPa} \quad (16)$$

Therefore the vapour pressure deficit, D, becomes:

$$D = 6.108 \exp \left[\frac{17.27 T_a}{T_a + 237.3} \right] \left(1 - \frac{\text{RH}_{\text{mean}}}{100} \right) \quad (17)$$

where RH_{mean} is the relative humidity [-] ; and T_a is the daily mean air temperature [$^{\circ}\text{C}$]. Relative humidity is the ratio between the amount of water the ambient air actually holds and the amount it could hold at the same temperature. It is dimensionless and is commonly given as a percentage. The variation of the relative humidity is the result of the fact that the saturation vapour pressure is determined by the air temperature. As the temperature changes during the day, the relative humidity also changes substantially.

2.6 Wind related function (F(u))

It is produced from:

$$F(u) = \frac{\varepsilon \rho_a}{p r_a} \text{ kg hPa}^{-1} \text{ m}^{-2} \text{ s}^{-1} = 86400 \frac{\varepsilon \rho_a}{p r_a} \text{ kg hPa}^{-1} \text{ m}^{-2} \text{ d}^{-1} \quad (18)$$

where: $\rho_a = \frac{0.348 \cdot p}{T_a + 273}$ is the atmospheric density [Kg m^{-3}]; and ε , p and r_a are as above described. Therefore $F(u)$ becomes:

$$F(u) = \frac{97.783}{T_a + 273} u_2 \text{ kg hPa}^{-1} \text{ m}^{-2} \text{ d}^{-1} \quad (19)$$

2.7 Net Radiation (R_n)

Net Radiation is the difference between incoming and outgoing solar radiation. It can be measured, but such data are seldom available. Instead, it is calculated from solar radiation on sunshine hours, temperature, and humidity data as shown by Koutsoyiannis and Xanthopoulos (1997), Papazafiriou (1999) and Theocharis (2009). The value of R_n , as shown by Theocharis (2009), is calculated as follows :

The net radiation is the algebraic sum of the net shortwave radiation (R_{ns}) and net longwave radiation (R_{nl}). As R_{nl} constitutes a loss, this relationship is:

$$R_n = R_{ns} - R_{nl} \text{ MJm}^{-2} \text{ d}^{-1} \quad (20)$$

Net shortwave radiation (R_{ns}), can be calculated by correcting the incoming solar radiation for surface albedo (α) of the crop surface by:

$$R_{ns} = (1 - \alpha) R_s \text{ MJm}^{-2} \text{ d}^{-1} \quad (21)$$

where: $\alpha = 0.05$ for water surface; $\alpha = 0.15$ for bare soil surfaces; and $\alpha = 0.23$ for green vegetated surfaces.

Solar radiation (R_s), is calculated using the amount of radiation received at the top of the atmosphere (R_a). This value is calculated as shown by Duffie and Beckman (1980), (1991) by:

$$R_a = 3.6 \frac{2 I_s d_r}{15} \left(\omega_s \sin \varphi \sin \delta + \frac{180}{\pi} \sin \omega_s \cos \varphi \cos \delta \right) \text{ MJm}^{-2} \text{ d}^{-1} \quad (22)$$

where: $I_s = 1.367 \text{ kWm}^{-2}$ is the solar constant; d_r is the relative distance from the sun to the earth [-]; φ is the station latitude [degrees]; δ is the declination of the sun [degrees]; ω_s is the sunset hour angle [degrees]; The values of d_r , δ and ω_s are calculated respectively from:

$$d_r = 1 + 0.034 \cos \left(\frac{360}{365} J - 2.86479 \right)^0 \quad (23)$$

$$\delta = 23.45^{\circ} \sin \left(\frac{360}{365} (284 + J) \right)^{\circ} \quad (24)$$

and

$$\omega_s = \arccos(-\tan \phi \tan \delta) \quad (25)$$

In the above relations, J is the Julian day of the year considered given from:

$$J = 30,5M - 14,6 \text{ (integer)} \quad (26)$$

where: M = 1, 2, 3, ..., 12 is the number of the month considered.

After that solar radiation (R_s), is obtained with the Angstrom formulation:

$$R_s = \left(0.25 + 0.50 \frac{n}{N} \right) R_a \text{ MJm}^{-2}\text{d}^{-1} \quad (27)$$

where: n and N are correspondently the actual and the maximum possible sunshine hours [hd^{-1}]; and

$$N = \frac{2}{15} \omega_s \text{ hd}^{-1} \quad (28)$$

Net longwave radiation (R_{nl}), can be determined from available temperature, the vapour pressure and the n/N ratio data by the equation:

$$R_{nl} = \varepsilon_n f_L \sigma (T_a + 273)^4 \text{ MJm}^{-2}\text{d}^{-1} \quad (29)$$

where: $\sigma = 4.903(10^{-9})$ is the Stefan-Boltzmann constant [$\text{MJ K}^{-4} \text{ m}^{-2} \text{ day}^{-1}$]; ε_n is the net emissivity factor which is calculated by $\varepsilon_n = 0.34 - 0.044 \sqrt{e_d}$ where e_d is expressed in hpa;

and f_L is the cloudiness adjustment factor which is calculated by $f_L = 0.1 + 0.9 \frac{n}{N}$.

Therefore R_{nl} can be determined by:

$$R_{nl} = \sigma (T_a + 273)^4 \left[0.34 - 0.044 \sqrt{e_d} \right] \left[0.1 + 0.9 \frac{n}{N} \right] \text{ MJm}^{-2}\text{d}^{-1} \quad (30)$$

2.8 Soil Heat Flux (G)

Soil heat flux is calculated from the relation provided by Jensen et al. (1990):

$$G = c_s d_s \frac{|T_{n+1} - T_{n-1}|}{\Delta t} \text{ or } G = 2 c_s d_s \frac{|T_n - T_{n-1}|}{\Delta t} \text{ MJ m}^{-2}\text{d}^{-1} \quad (31)$$

where: T_{n+1} , T_n and T_{n-1} are respectively the mean temperature on next month n+1, month considered n, and on previous month n-1 [$^{\circ}\text{C}$]; c_s is the soil heat capacity = $2.1 \text{ MJ m}^{-3} \text{ }^{\circ}\text{C}^{-1}$; Δt is the length period [d]; d_s is the estimated effective soil depth. $d_s = 0,18 \text{ m}$ for daily

temperature fluctuations; and $d_s = 0,03$ m for monthly temperature fluctuations (Jensen et. al. 1990).

Therefore G can be determined by: $G = 0,38 \left| T_d - T_{d-1} \right| \text{ MJ m}^{-2}\text{d}^{-1}$ for daily temperature fluctuations and by: $G = 0,14 \left| T_n - T_{n-1} \right|$ or $G = 0,07 \left| T_{n+1} - T_{n-1} \right| \text{ MJ m}^{-2}\text{d}^{-1}$ for monthly temperature fluctuations.

Note: The soil heat flux is generally very small and it is assumed to be $G = 0.01R_n$ during the day and $G = 0.02R_n$ during the night.

3 THE FAO PENMAN - MONTEITH COMBINATION METHOD

The panel of experts, Pereira and Smith (1989), Smith et. al. (1991), and Allen et. al. (1994a, 1994b), recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters. By assuming a latent heat of vaporization $\lambda = 2.45 \text{ MJ kg}^{-1}$, a wind related function $F(u) = \frac{90}{T_a + 273} u_2 \text{ kg hPa}^{-1}\text{m}^{-2}\text{d}^{-1}$ and defining the reference crop as a

hypothetical crop with an assumed height $h_c = 0.12$ m, having a surface resistance $r_s = 70 \text{ sm}^{-1}$, and an albedo $\alpha = 0.23$, the FAO56 Penman-Monteith method was developed. According to the FAO56-PM method the reference crop evapotranspiration, ET_r , is produced from:

$$ET_r = \frac{10^3}{\rho_w} \left[\frac{0.408 \Delta (R_n - G) + \gamma D \frac{90}{T_a + 273} u_2}{\Delta + \gamma (1 + 0.34 u_2)} \right] \text{ mmd}^{-1} \quad (32)$$

4 ESTIMATING OF REFERENCE CROP EVAPOTRANSPIRATION ACCORDING TO THE PM COMBINATION METHOD USING PERSONAL COMPUTER

The required calculating procedure when the Penman - Monteith method is used, is very complex and calls for a lot of calculations. For this reason, we found necessary to develop a simple computer system that enables researchers and students to easily calculate reference crop evapotranspiration. This program, being accessible by those who need it, could be embedded as subroutine in larger computer systems dealing with hydraulic calculations.

4.1 Organising the Input Parameters

The first step is to organise the data for the problem on the spreadsheet. In Figure 1, the input parameters for the altitude of the area, h [m], the height of wind speed measurement, z [m], the wind speed corresponded at height z , u_z [m/s], the number of the month considered, M , the station latitude, ϕ [degrees], the daily mean air temperature, T_a in $^{\circ}\text{C}$, the daily mean temperature of the soil (or water) surface, T_s [$^{\circ}\text{C}$], the actual possible sunshine hours, n [h/d], the crop height, h_c [m], and the mean relative humidity, Rh_{mean} [%], were entered in cells e15, i15, m15, e18, i18, m18, e21, i21, m21 and e24 respectively.

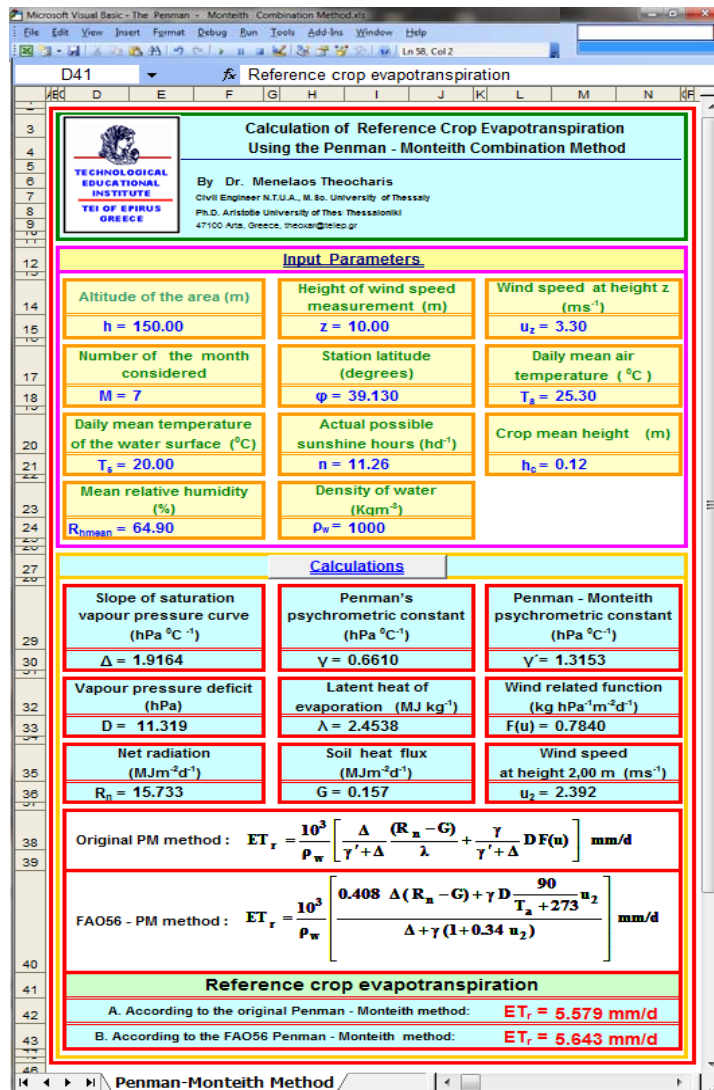


Figure 1. Spreadsheet of data and calculations of ET_r using the Penman – Monteith combination method.

4.2 Solving the Problem

In order to solve the problem the following macro command is created:

Sub Crop_Evapotranspiration_Using_the_Penman_Monteith_Combination_Method()

'Macro recorded in 20/4/2011 by M. Theocharis

Range("f3") = "Estimating Reference Crop Evapotranspiration "

Range("f4") = "Using the Penman - Monteith Combination Method"

```
Range("h12") = "Input Parameters "  
h = Range("e15").Value  
z = Range("i15").Value  
uz = Range("m15").Value  
M = Range("e18").Value  
φ = Range("i18").Value  
Ta = Range("m18").Value  
Ts = Range("e21").Value  
n = Range("i21").Value  
hc = Range("m21").Value  
Rhmean = Range("e24").Value  
pw = Range("i24").Value  
Δ1 = (4098 / (Ta + 237.3) ^ 2 * 6.108 * Exp(17.27 * Ta / (Ta + 237.3)))  
Range("e30") = Δ1  
λ = 2.501 - 0.002361 * Ts  
Range("i33") = λ  
γ = ((1 - 0.0065 * h / (273 + Ta)) ^ 5.256) / (1.5156 - 0.0014307 * Ts)  
Range("i30") = γ  
LAI = 1.5 * Log(100 * hc) / Log(Exp(1)) - 1.4  
Rs1 = 100 / (0.5 * LAI)  
Ra1 = (Log((2 - (2/3) * hc) / (0.123 * hc)) / Log(Exp(1))) * (Log((2 - (2/3) * hc) / (0.0123 * hc)) /  
    Log(Exp(1))) / ((0.41 ^ 2) * uz * (2/z) ^ 0.2)  
γ' = γ * (1 + Rs1 / Ra1)  
Range("m30") = γ'  
e0 = 6.108 * Exp(17.27 * Ta / (Ta + 237.3))  
ed = e0 * Rhmean / 100  
D = e0 - ed  
Range("e33") = D  
u2 = (uz * (2/z) ^ 0.2)  
Range("m36") = u2  
Fu = 97.783 * u2 / (Ta + 273)  
Range("m33") = Fu  
J = Int(30.5 * M - 14.6)  
dr = 1 + 0.034 * Cos((4 * Atn(1) / 180) * (360 * Int(30.5 * M - 14.6) / 365 - 2.86479))  
δ = 23.45 * Sin((4 * Atn(1) / 180) * (360 * (284 + Int(30.5 * M - 14.6)) / 365))  
cosωs = -Tan(4 * Atn(1) * φ / 180) * Tan(4 * Atn(1) * δ / 180)  
ωs = (180 / (4 * Atn(1))) * (Atn(-cosωs / Sqr(-cosωs * cosωs + 1)) + 2 * Atn(1))  
Ra = 1/15 * (3.6 * 2 * 1.367 * dr) * (ωs * Sin(4 * Atn(1) * φ / 180) * Sin(4 * Atn(1) * δ / 180) + (180 /  
    (4 * Atn(1))) * Sin(4 * Atn(1) * ωs / 180) * Cos(4 * Atn(1) * φ / 180) * Cos(4 * Atn(1) * δ / 180))  
N = (2/15) * ωs  
Rs = (0.25 + 0.5 * n / N) * Ra  
Rns = (1 - 0.23) * Rs  
Rnl = 4.903 * 10 ^ -9 * ((Ta + 273) ^ 4) * (0.34 - 0.0442719 * ed ^ 0.5) * (0.1 + 0.9 * n / N)  
Rn = Rns - Rnl
```

```

Range("e36") = Rn
G = 0.01 * Rn
Range("i36") = G
ETr = 10^3 / rho_w * ((Delta * (Rn - G) / ((gamma' + Delta) * lambda)) + gamma * D * Fu / (gamma' + Delta))
Range("m42") = Round(ETr, 3) & " mm/d"
ETrFAO56 = (0.408 * Delta * (Rn - G) + gamma * D * 90 * (u_z * (2/z)^0.2) / (T_a + 273)) / (Delta + gamma * (1 + 0.34 * u_2))
Range("m43") = Round(ETrFAO56, 3) & " mm/d"
End Sub

```

After that the **“Solutions”** button is clicked and the solution of the problem results:

A. According to the original Penman-Monteith combination method; and B. According to the FAO56 - PM method. The described procedure is shown in Figure 1.

5 APPLICATION

Below the reference crop evapotranspiration in Arta, Greece semi mountainous area for the month July is estimated, using the above described computer system, Figure 1. For the input parameters: $h = 150.00$ m; $z = 10.00$ m; $u_z = 3.30$ ms^{-1} ; $M = 7$; $\phi = 39.13^\circ$; $T_a = 25.30$ $^\circ\text{C}$; $T_s = 20.00$ $^\circ\text{C}$; $n = 11.26$ hd^{-1} ; $h_c = 0.12$ m; and $Rh_{\text{mean}} = 64.90$ %; it emerges that: $\Delta = 1.916$ $\text{hPa } ^\circ\text{C}^{-1}$; $\gamma = 0.661$ $\text{hPa } ^\circ\text{C}^{-1}$; $\gamma' = 1,315$ $\text{hPa } ^\circ\text{C}^{-1}$; $D = 11.323$ hPa ; $\lambda = 2.454$ MJ kg^{-1} ; $f(u) = 0,784$ $\text{kg hPa}^{-1}\text{m}^{-2}\text{d}^{-1}$; $R_n = 15.733$ $\text{MJ m}^{-2}\text{d}^{-1}$; $G = 0.157$ $\text{MJ m}^{-2}\text{d}^{-1}$; $u_2 = 2,392$ ms^{-1} . Finally the reference crop evapotranspiration is calculated A. According to the original Penman - Monteith method: $ET_r = 5.579$ mm d^{-1} ; and B. According to the FAO56 Penman - Monteith method: $ET_r = 5.643$ mm d^{-1} . It is concluded that the results of the proposed FAO56 - PM simplified form are identical with the results of the original Penman-Monteith combination method. Consequently, this FAO56 - PM simplified form can be equally used for the original PM method.

6 CONCLUSIONS

Solving problems of estimating reference crop evapotranspiration is of prime importance for the study of irrigation networks.

The Penman-Monteith method is recommended as the sole standard method.

The required calculating procedure when the Penman - Monteith combination method, or the FAO56 – PM, is used is very complex and calls for a lot of calculations. For this reason we have developed in this paper, a computer system of estimating ET_r using this method.

The computer system is simple in use, does not demand special informatics knowledge and is approachable to a wide range of researchers. In addition, it could be incorporated as subroutine of integrated software dealing with irrigation calculations.

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