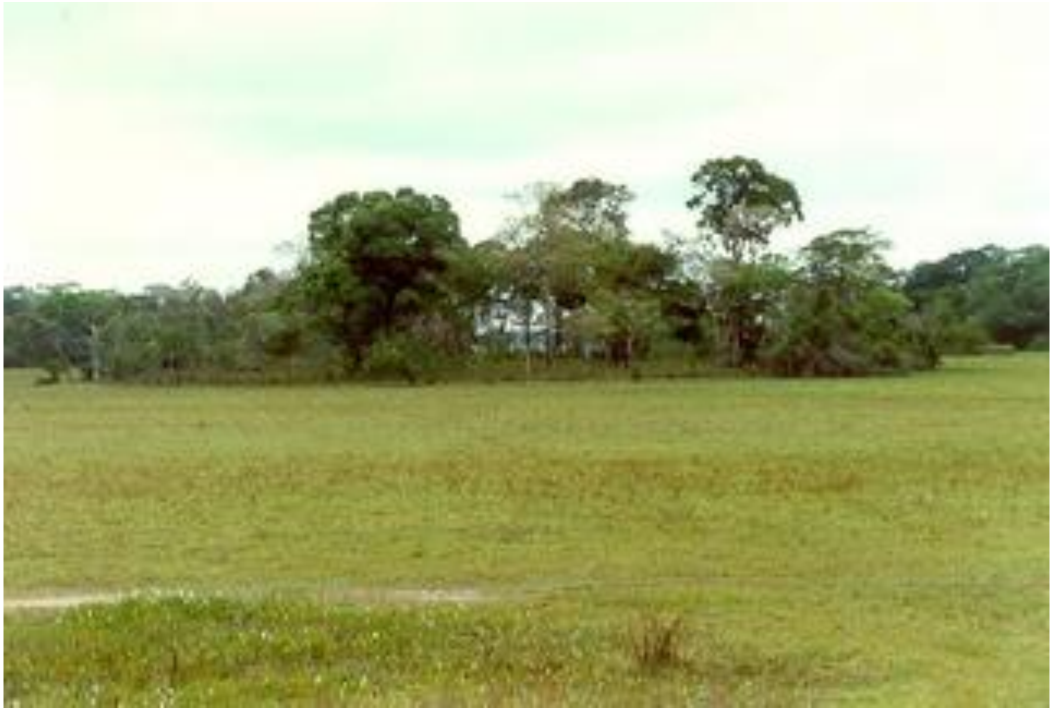

Fig. 1 Vegetated earthmounds and surrounding grasslands, Pantanal of Mato Grosso, Brazil.

HOW TO CALCULATE ONLINE REFERENCE CROP EVAPOTRANSPIRATION BY THE PENMAN-MONTEITH METHOD?

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ABSTRACT. In this article we show how to calculate online reference crop potential evapotranspiration by the Penman-Monteith method. The latter is a combination method based on a modification of the classical evaporation method developed by Penman in the 1940s. The Penman-Monteith method has been endorsed by the United Nations Food and Agriculture Organization (FAO) for general use in the calculation of reference crop potential evapotranspiration. The online calculator **ONLINE_PENMAN_MONTEITH** was developed in 2020 by the **Visualab** at San Diego State University.

1. INTRODUCTION

The calculation of reference crop evapotranspiration is a preeminent analytical tool used in the design of irrigation projects. The FAO Penman-Monteith method has been recommended as the method of choice for calculating reference crop evapotranspiration (ETo) (**Irrigation and Drainage Paper 56 - Chapter 2, FAO, 1998**). In this article we present an **online calculator** for the Penman-Monteith method. This calculator was developed in 2020 by the **Visualab**, a computational laboratory of the Department of Civil, Environmental, and Construction Engineering, San Diego State University, San Diego, California.

2. PENMAN-MONTEITH METHOD

The Penman-Monteith method is a modification of the Penman (1948) method. The original Penman method is a combination method to calculate evaporation (**Ponce, 2014a: Combination Methods**) in which the total evaporation rate is calculated by weighing the evaporation rate due to net radiation and the evaporation rate due to mass transfer, as follows :

$$E = \frac{\Delta E_n + \gamma E_a}{\Delta + \gamma} \qquad (1)$$

in which E = total evaporation rate; E_n = evaporation rate due to net radiation; E_a = evaporation rate due to mass transfer; Δ = saturation vapor pressure gradient, a function of air temperature; and γ = psychrometric constant, which may be shown to vary slightly with temperature. The mass-transfer evaporation rate E_a is calculated with an empirical mass-transfer formula (**Ponce, 2014a: Mass-Transfer Approach**).

In the Penman-Monteith method, the mass-transfer evaporation rate E_a is calculated based on physical principles. The original form of the Penman-Monteith equation, in dimensionally consistent units, is the following (**Ponce, 2014b)**:

$$\rho\lambda E = \frac{\Delta H + [\, \rho_a \, c_p \, (e_s - e_a) \, / \, r_a \,]}{\Delta + \gamma^*} \qquad (2)$$

in which

- $\rho \lambda E$ = total evaporative energy flux, in cal/(cm^2-s);
- ρ = density of water, in gr/cm^3;
- λ = heat of vaporization, in cal/gr;
- E = evaporation rate, in cm/s;
- Δ = saturation vapor pressure gradient, in mb/°C;
- H = energy flux supplied externally, by net radiation, in cal/(cm^2-s);
- ρ_a = density of moist air, in gr/cm^3;
- c_p = specific heat of moist air, in cal/(gr-°C);
- $(e_s - e_a)$ = vapor pressure deficit, in mb;
- r_a = external (aerodynamic) resistance, in s/cm; and
- γ^* = modified psychrometric constant, in mb/°C, equal to:

$$\gamma^* = \gamma \left(1 + \frac{r_s}{r_a} \right) \qquad (3)$$

in which:

- γ = psychrometric constant, in mb/°C, which varies slightly with temperature (**Ponce, 2014c**), and
- r_s = internal (stomatal or surface) resistance, in s/cm.

The quantity r_a^{-1} is the external conductance, in cm^3 of air per cm^2 of surface per second (cm/s).

In evaporation rate units, Eq. 2 is expressed as follows:

$$E = \frac{\Delta E_n + [\rho_a c_p (e_s - e_a) / (r_a \rho \lambda)]}{\Delta + \gamma^*} \qquad (4)$$

in which

- E = total evaporation rate, in cm/s;
- E_n = evaporation rate due to net radiation, in cm/s;
- ρ = density of water, in gr/cm^3;
- λ = heat of vaporization, in cal/gr;

  and

- Δ, γ^*, ρ_a, c_p, $(e_s - e_a)$, and r_a are in the same units as in Eq. 2.

Equation 4 is the equation of the Penman-Monteith method used in the online calculator presented here.

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3. USE OF THE ONLINE CALCULATOR

We run the calculator **ONLINE_PENMAN_MONTEITH** with the following input data:

- Month [Select one]: April
- Air temperature T_a (C°): 20
- Net radiation Q_n (cal cm^{-2} d^{-1}): 550
- Relative humidity ϕ (%): 70
- Wind velocity v_2 (km d^{-1}): 200
- Atmospheric pressure p_a (mb): 1013.25

Output from the calculator is shown below.

The reference crop potential evapotranspiration for the month of April is: 19.32 cm. **ANSWER.**

online_penman_monteith: Potential evapotranspiration by the Penman-Monteith method

Formulas

$$(e_s - e_a) \cong (e_o - e_a) = e_o[1 + (\phi/100)]$$

$$E_n = Q_n/(\varrho\lambda)$$

$$E_a = 86400[(\varrho_a c_p)/(\varrho\lambda\gamma)](e_s - e_a)(r_s + r_a)^{-1}$$

$$\Delta = (0.00815\ T_a + 0.8912)^7$$

$$\gamma * = \gamma\ [1 + (r_s/r_a)]$$

$$E = (\Delta\ E_n + \gamma *\ E_a)\ /\ (\Delta + \gamma *)$$

INPUT DATA:

[Description] [Sample input]

Month: January

Air temperature T_a (°C): 20

Net radiation Q_n (cal cm^{-2} d^{-1}): 550

Relative humidity ϕ (%): 70

Wind velocity v_2 (km d^{-1}): 200

Atmospheric pressure p (mb): 1013.25

[Leave blank to specify sea-level atmospheric pressure]

ECHO OF INPUT:

Month: April

OUTPUT:

- ♦ Internal resistance r_s = 0.694 s cm^{-1}.
- ♦ External resistance r_a = 0.899 s cm^{-1}.
- ♦ Daily reference crop PET = 0.644 cm d^{-1}.
- ♦ Monthly reference crop PET = 19.32 cm.

Calculate Reset

Your request was processed at 04:10:01 pm on March 5th, 2024 [240305 16:10:01].

Thank you for running online_penman_monteith. Please call again. [200803]

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