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Evaluation of Water Needs of Plants Estimation Basing on Meteorological Measurements

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1. Introduction

Increasing the efficient use of water for irrigation is introduction to the practice of accurate methods of determining the needs of aquatic plants. Deadline for irrigation of plants can be determined by plant criteria [8, 9], soil [10] or climate [13]. The criterion is climate based on the assumption that the consumption of water by plants is determined mainly the course of weather and crop development phase [12, 15]. The development of theoretical about the impact of climatic conditions on pairing introduced in 1948 Thornthwaite. Doorenbos and Pruitt [4] provide a definition of potential evapotranspiration *(ETP)* as the pairing with a large green, completely shading the soil surface canopy grass (height 8–15 cm), without encountering the difficulties in collecting water. So presented a definition not only allows to calculate the *ETP* on the basis of physical parameters, but it can also be measured in the lysimeters [5] or by ewaporometrs [18]. Is now becoming increasingly popular use of the term reference evapotranspiration (ET_0). Defines the reference evapotranspiration ability of the atmosphere to cause evaporation of water from the surface covered plants regardless of their type and level of soil moisture. Factors affecting the height of the meteorological conditions ET_0: radiation solar, air temperature, humidity and lack speed wind [11]. Currently, the world over as the main criteria are adopted irrigation forecasting, meteorological data on the basis of which is calculated evapotranspiration [3, 14, 17].Water needs of specific species of plants (evapotranspiration indicator – ET_W) gardening and agricultural areas are determined by multiplying the values of evapotranspiration potential or by specific reference to a particular species product and its development phase coefficient k [2] by the formula (Fig. 1).

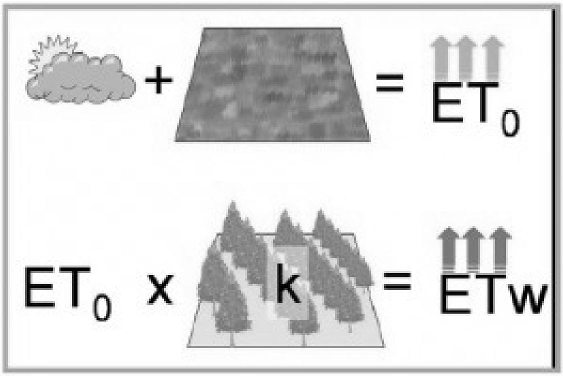

Fig. 1. Evapotranspiration indicator
Rys. 1. Wskaźnik ewotranspiracji

Hence, a lot of models to determine evapotranspiration [2, 6, 7, 11]. Organization of the United Nations Food and Agriculture Organization (FAO), recommended for the determination of reference evapotranspiration Penman-Monteith model [1, 16]. This model requires a complete meteorological data, which hinders its widespread use. The development of electronics has allowed the introduction to the practice of meteorological stations, which automatically determine the value of ET_0. Unfortunately, due to the relatively high price of these devices are not yet widely used. Therefore it is important that in our climatic conditions to verify the models allowing the estimation of evapotranspiration with limited access to meteorological data. Model developed by Hargrevesa [7] is a significant simplification of Penman model. His appointment is needed only measurements of maximum and minimum air temperatures and the data on solar radiation reaching the Earth's atmosphere (*Ra*). Ra is constant for a particular time and place on earth, because these values do not measure – data read from the tables. To determine ET_0 are required only on measurements of daily maximum and minimum air temperature (T_{max} and T_{min}). Based on measurements of T_{max} and T_{min} is calculated in average air temperature. The daily radiation reaching the earth is estimated based on the value of *Ra*, and the difference between maximum and minimum daily air temperature.

The aim of the study was to assess the possibility of estimating ET_0 based on a simple mathematical model Hargrevesa, taking into account only the basic meteorological measurements for the standard, according to FAO, Penman-Monteith model.

2. Materials and methods

Meteorological measurements were carried out using two automatic weather stations in the period April–September 2011 (Tab. 1).

Table 1. Location of the meteorological stations
Tabela 1. Lokalizacja stacji meterologicznych

Location Lokalizacja	Longitude Długość geograficzna	Latitude Szerokość geograficzna	Height above sea level Wysokość nad poziomem morza [m]
Ivanka pri Dunaji	48° 20’	17° 20’	133
Warszaw	52° 20’	21° 00’	107

To determine the reference evapotranspiration, the following calculation modelsFirst FAO 56 Penman-Monteiha – ET_0 (*PM*) – requires a complete meteorological data (1)

$$ET_O = \frac{0.408 \cdot \Delta \cdot (R_N - G) + \gamma \cdot \dfrac{900}{T+273} \cdot u_2 \cdot (e_S - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)} \tag{1}$$

R_N – rays (radiation) [MJ m^{-2} day^{-1}],
G – the soil heat flux density [MJ m^{-2} day^{-1}],
T – the average daily temperature measured at a height of 2 m [°C],
u_2 – wind speed at a height of 2 m [m s^{-1}],
e_s – saturated vapor pressure [kPa],

e_a – current vapor pressure [kPa],
$(e_s - e_a)$ – water vapor pressure deficit [kPa],
D – slope saturated vapor pressure [kPa °C^{-1}],
g – constant psychrometers [kPa °C^{-1}].

ET_0 value for each day automatically determined the meteorological stations.
Hargreaves Model (H)

$$ET_O = HC \cdot Ra \cdot (T_{\max} - T_{\min})^{HE} \cdot \left(\frac{T_{\max} - T_{\min}}{2} + HT \right) \tag{2}$$

HC – author's empirical coefficient = 0.0023,
Ra – radiation above the atmosphere (mm day^{-1}),
T_{max} – maximum temperature (°C),
T_{min} – minimum temperature (°C),
HE – author of the empirical coefficient = 0.5,
HT – author of the empirical coefficient = 17.8.

3. Results and discussion

Automatic weather stations perform measurements with a predetermined frequency is usually every 10 to 60 minutes. On the basis of individual measurements for each of the periods determined parameters are the minimum, maximum and average. Automatic stations so determine the daily average temperature of several measurements from 144, when we measured every 10 minutes, and 24, when we do it in 1 hour. In the absence of virtually automatic station is not possible to observe with such a high frequency. In determining the model developed by Hargreaves ET_0 average daily temperature is calculated based on the average only two measurements – the maximum and minimum. The values obtained are deposited on the vertical axis of the graph (normal value). If the observations are normally distributed, it received points should form approximately a straight line (Fig. 2).

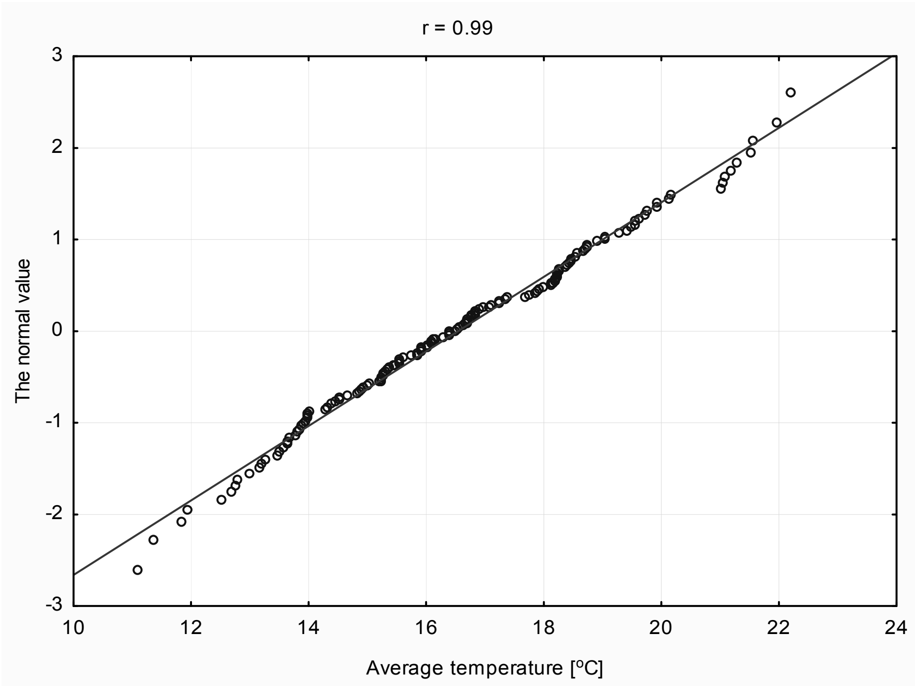

Fig. 2. The relationship between daily average temperatures and normal value
Rys. 2. Zależność pomiędzy średnimi temperaturami dobowymi a wartością normalną

Comparison of monthly average temperature (for the test run period) determined on the basis of daily averages also showed a high consistency of results (Tab. 2).

The analysis confirmed the high usefulness of determining the average daily temperature on the basis of the designation of the average of the maximum and minimum air temperature. To determine the average daily temperature of just maximum-minimum thermometer, and the measurement can be carried out only once a day.

Correlation analysis demonstrated a high level of dependence between the values of ET_0 designated by the reference and calculated on the basis of a simplified model (Fig. 3). ET_0 values obtained from the model of the *PM* and *H* significantly differed among themselves. ET_0 levels determined by the formula by the formula Hargreaves are higher than the set reference model (Fig. 3 and 4).

Table 2 Average monthly air temperatures
Tabela 2 Średnie miesięczne temperatury powietrza

Month Miesiąc	T average T średnia [ºC]	$(T_{max}+T_{min})/2$ [ºC]	Difference Różnica [ºC]
V	14,6	13,7	0,9
VI	17,6	16,6	1,0
VII	19,5	18,2	1,3
VIII	19,2	17,8	1,4
IX	14,7	13,2	1,5

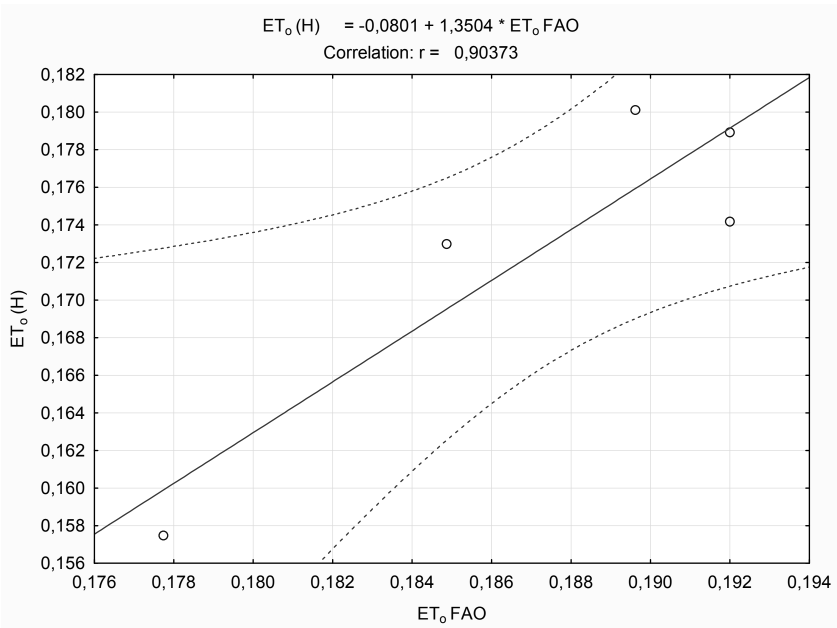

Fig. 3. Correlation between (ET_0) worked out according to FAO's Penman-Monteith formula and the simplified models of Hargreaves ET_0 *(H)*
Rys. 3. Korelacja pomiędzy ewapotranspiracją referencyjną wyznaczoną wg wzoru FAO Penmana-Monteitha a modelem Hargreavesa ET_0 (*H*).

We conclude that the Hargreaves model is relatively simple, and using a spreadsheet should not be difficult to compute. It can be used in individual farms or even in local websites. Still open is the issue whether the standard model by FAO in our climatic conditions correctly describes the reference evapotranspiration. Terms of Polish and Slovak regions in comparison with which to determine the water needs of plants is used Penman-Monteith model are characterized by relatively high humidity and high frequency periods of rainfall. Data obtained on the basis of the calculation model should be verified with measurements lysimeters, and as necessary to carry out correction of simplified models they contain empirical coefficients.

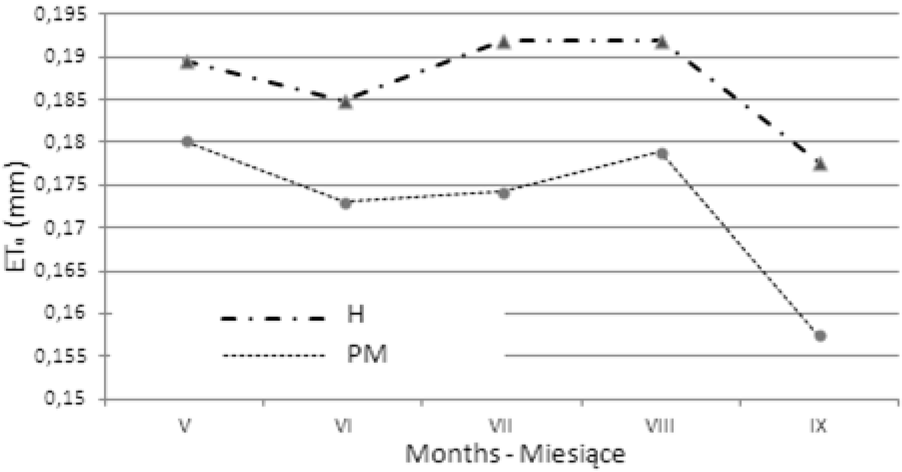

Fig. 4. Average monthly values of ET_0 determined with various models: FAO's Penman-Monteith formula and the simplified models of Hargreaves ET_0 (*H*)
Rys. 4. Średnie dla poszczególnych miesięcy wartości ET_0 wyznaczane za pomocą różnych modeli matematycznych, FAO Penmana-Monteitha ET_0 (*PM*) i Hargreavesa ET_0 (*H*)

4. Conclusions

1. On the basis of the assessment can be concluded that the Polish climatic conditions and Slovakia in the case of limited availability of meteorological data to determine the reference evapotranspiration calculation model can be used Hargreaves.
2. Introduction to the practice of Penman-Monteith model requires prior verification of the coefficients used there.

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Ocena szacowania potrzeb wodnych roślin na podstawie pomiarów meteorologicznych

Streszczenie

Na podstawie pomiarów zarejestrowanych przez dwie automatyczne stacje meteorologiczne, położone w Polsce i na Słowacji została obliczona ewapotranspiracja (ET_0) według wzoru opracowanego przez Hargreavesa. Uzyskane wyniki porównano ze wzorem odniesienia zalecanego przez FAO, która przyjęła wzór Penmana-Monteitha (PM).Wysoka korelacja pomiędzy modelem odniesienia a wzorem uproszczonym Hergreavesa została pokazana. Różnice dotyczą poziomu ewapotranspiracji opracowanych na podstawie wzorów. Model Hargreaves daje wyższą wartość w porównaniu z formułą PM.

W celu zastosowania modelu Penmana-Monteitha w praktyce potrzebne jest wiele parametrów meteorologicznych które są wymagane. Brak dostępu do szczegółowych danych meteorologicznych jest poważnym ograniczeniem. Metoda Hergreavesa może być używana, ale wymaga ona dalszych badań w zarówno w naszych jak i zagranicznych warunkach weryfikacji o czynniki empiryczne.