https://doi.org/10.17221/25/2025-SWR

Alternative solution for determining the irrigation water quantity: ET_{Gauge}

Ismail Tas[1], Fatih Cem Kuzucu[2]*

[1]*Department of Agricultural Structures and Irrigation, Agriculture Faculty, Canakkale Onsekiz Mart University, Canakkale, Turkey*
[2]*Department of Horticulture Crops, Agriculture Faculty, Canakkale Onsekiz Mart University, Canakkale, Turkey*

**Corresponding author: tas_ismail@yahoo.com*

Citation: Tas I., Kuzucu F.C. (2025): Alternative solution for determining the irrigation water quantity: ET_{Gauge}. Soil & Water Res., 20: 219–233.

Abstract: Measuring the reference evapotranspiration (ET_0) is difficult and costly. Some regions can have variable microclimates and these can often be quite far from climate stations. Therefore, it is optimal to use local measurements rather than a regionally calculated ET_0. In this respect, one piece of equipment that provides cheap and reliable measurement results is ET_{Gauge} equipment. In this study, ET_0 values measured with ET_{Gauge} equipment were compared with daily and monthly ET_0 values calculated by five different commonly used empirical methods ($Thornthwaite_{Adj}$, Blaney-Criddle, Penman-Monteith = PM, Jensen-Haise and ASCE standardised Penman-Monteith = ASCE SZ PM). During the measurement period, daily ET_0 values measured with ET_{Gauge} varied between 0–10 mm/day and the average was determined as 4.5 ± 2.7 mm/day in the study area. In the calculations made with the empirical models, the change in $Thornthwaite_{Adj}$ is 1.3–6.6 mm/day with an average of 3.8 ± 1.6 mm/day, the change in Blaney-Criddle is 1.8–7.2 mm per day with an average of 5.1 ± 1.4, the change in PM is 1.2–10.5 mm/day with an average of 5.8 ± 2.7 mm/day, the change in Jensen-Haise was 5.8 ± 2.7 mm/day with an average of 5.5 ± 2.7 mm/day, and the change in ASCE SZ PM was calculated as 1.0–10.1 mm/day with an average of 5.4 ± 2.5 mm/day. Considering the obtained results, the ET_{Gauge} equipment can be used safely in creating irrigation programmes.

Keywords: ASCE Standardised Penman-Monteith; Blaney-Criddle; FAO Penman Monteith; Jensen-Haise; Thornthwaite

Climate change has increased the frequency and severity of extreme weather events whose events are forecasted even more in the future. Increasing temperatures will increase both the evaporation and transpiration. Agriculture is the greatest water use sector in both developed and developing countries. Therefore, irrigation water requirements of plants should be well-defined for the more efficient use of water resources. Therefore, reference evapotranspiration (ET_0) values should accurately be measured/determined for each region. Providing plant water requirements at the appropriate time and quantity will only be possible through systems designed, built and operated with the right data. The ET values of the plants grown or planned to be produced in the region where the construction will take place is among one of the most important components of planning and design works of irrigation structures (Tas & Kirnak 2011; Kypris et al. 2023).

Supported by Scientific Research Projects Department of Canakkale Onsekiz Mart University (Project number: FBA-2018-2653).

https://doi.org/10.17221/25/2025-SWR

ET is used as a critical parameter in various disciplines such as agronomy, agriculture, forestry, plant sciences, hydrological sciences, earth and atmospheric sciences, as well as climate and water sciences. Evapotranspiration has significant effects on several on-going processes in plants, the soil and water. Evapotranspiration is a combined process of water transfer from earth's surface into the atmosphere. It covers evaporation from soil surfaces and transpiration from plant surfaces (Irmak 2017). ET is a highly significant parameter for the efficient use of water resources especially in arid and semi-arid regions. Improper irrigation not only results in the waste of water but also has negative effects on soil and water resources (salination, erosion and environmental pollution). Such a case then negatively affects the sustainable use of these resources. Additionally, improper irrigation practices can also facilitate the development and progress of important diseases.

Factors affecting evapotranspiration can be grouped into three categories: climate parameters, plant characteristics and management-environmental issues. Climate parameters include the solar radiation, temperature, relative humidity and wind. Plant characteristics include the plant species, radiation reflection coefficient, leaf area index, plant height and root depth. Management and environmental considerations include the planting-sowing distance, plant orientation and soil properties (Zhang et al. 2009; Carlos et al. 2013; Bhatt & Hossain 2019).

ET is not an easily-measured parameter. Besides various physical parameters that need to be accurately measured with special instruments, lysimeters are also needed in ET measurements. The use of a lysimeter is an expensive method that requires intensive labour, and it is necessary to carry out the procedures by trained research personnel who are experts in the subject in order for the measurements to be made correctly and for the system to be fully operational. Although lysimeter measurements are not suitable for ordinary use, they still continue to be an important parameter used in the comparison of evapotranspiration values estimated by indirect methods (Allen et al. 1998; Thornthwaite 1948; Kobak & Tas 2021).

Irrigation-based agricultural production is the sector that uses the most water among the water-using sectors in the world. Therefore, water user farmers need to manage their water resources effectively. This requires incorporating irrigation planning techniques into standard management practices. Irrigation planning requires farm managers to make decisions on a daily basis for the crop production system. A key element of an irrigation planning programme is the availability of climate data. However, in many places, not all the necessary datasets of meteorological variables are available (Kypris et al. 2023). In the study, evapotranspiration values measured from ET_{Gauge} were compared with evapotranspiration values calculated monthly by the $Thornthwaite_{Adj}$, Blaney-Criddle, PM, Jensen-Haise and ASCE SZ PM methods. Additionally, unlike other studies, the usability of ET_{Gauge} equipment in marine-influenced areas was examined. With the comparison results, the usability of ET_{Gauge} in determining the amount of irrigation water was evaluated.

MATERIAL AND METHODS

Research site and climate

The province of Çanakkale is located in the Marmora Region in northwest Turkey (Figure 1). The ET_{Gauge} equipment was placed into an observation park of the Çanakkale Provincial Directorate of Meteorology. The observation park is located at 40°8'29.01''N latitude and 26°23'58.42''E longitude. The station has an altitude of 2 m and the northeast-southwest axis totally faces the Dardanelles. It is about 30 m from the shore.

Although the climate of Çanakkale province shows a transitional nature due to its geographical location, it mostly shows the characteristics of a Mediterranean climate. The long-term (1929–2018) averages for some climate parameters of the research site are provided in Table 1. The hottest month is July (25.1 °C), followed by August (24.9 °C). The coldest month is January (6.2 °C), followed by February (6.6 °C). The majority of the annual precipitation falls in the winter months. The highest amount of precipitation falls in December with 106.7 mm, followed by January with 91.7 mm. The highest average wind speed was measured as 4.7 m/s in February, followed by January with 4.5 m/s. In terms of the relative humidity, the highest value was measured as 80.3% in December, followed by January with 80.0%. Considering the average sunshine duration, July has the highest value with 11.8 hours, followed by August with 11.2 hours.

Some climate parameters of the experimental year 2019 are provided in Table 2. The hottest month was August with an average value of 27.5 °C. The coldest month was February with an average value of 7.1 °C. While the highest precipitation was measured as 92.9 mm in January, it was followed by April

https://doi.org/10.17221/25/2025-SWR

Figure 1. Map of the study area

and May with 86.6 mm. The highest average wind speed was measured as 4.1 m/s in February. In terms of the average relative humidity, the highest value was measured as 76.1% in January. Considering the average sunshine duration, the greatest value was measured as 11.4 hours in July, followed by August with 11.1 hours. Considering the number of rainy days, the greatest values were seen in January (19 days) and February (13 days) and the lowest values were seen in September (2 days), July and August (3 days).

ET_{Gauge} and measurements

The ET_{Gauge} (also called as ET_{Gauge} and an atmometer) is a practical piece of equipment in which a ceramic cup is placed on a 7.6 cm diameter pipe (used as a water reservoir) used to determine the reference evapotranspiration. The ceramic structure is covered with a green fabric. The water absorbed from the reservoir is evaporated by the ceramic structure. There is a glass structure in front of the pipe, which has a water reservoir, showing the amount of water in it.

Table 1. Long-term climate data for the study area (1929–2018)

Months	Temperature average (°C)			Sunshine duration (h)	Wind speed (m/s)	Total precipitation (mm)	Temperature extreme (°C)		Relative humidity (%)
	T_{avr}	T_{max}	T_{min}				T_{max}	T_{min}	
1	6.2	9.5	3.1	3.5	4.5	91.7	20	–11	80.0
2	6.6	10.2	3.3	4.3	4.7	72.1	21.3	–11.5	78.5
3	8.3	12.4	4.7	5.4	4.3	66.1	27.3	–8.5	77.0
4	12.6	17.2	8.3	7.3	3.8	44.7	30.8	–1.6	75.0
5	17.5	22.6	12.7	9.5	3.4	30.1	39	2.3	73.2
6	22.3	27.7	16.5	11.1	3.3	23.8	36.8	6.6	67.6
7	25.1	30.7	19.2	11.8	3.8	10.9	39	11.2	62.9
8	24.9	30.6	19.5	11.2	4.0	6.3	39.1	9.4	63.3
9	20.9	26.3	15.9	8.9	3.7	23.4	35.8	5.9	68.0
10	16.1	20.7	12.1	6.4	3.7	53.6	31.7	0.4	74.3
11	11.9	15.9	8.4	4.4	3.9	87.3	26.2	–7	78.7
12	8.3	11.6	5.2	3.2	4.4	106.7	22.6	–10.5	80.3
Average/ annual	15.1	19.6	10.7	87.0	4.0	616.7	39.1	–11.5	73.2

https://doi.org/10.17221/25/2025-SWR

Table 2. Climate data for the study year (2019)

Months	Temperature (°C)			Sunshine duration (h)	Wind speed (m/s)	Relative humidity (%)	Total precipitation (mm)	No. of rainy days
	T_{avr}	T_{max}	T_{min}					
1	7.7	10.3	5.1	1.8	1.8	76.1	92.9	19
2	7.1	10.5	4.0	4.8	4.1	73.0	68.4	13
3	10.8	15.3	6.9	6.9	3.9	69.3	64.5	1
4	13.1	17.8	9.2	7.5	3.1	68.9	86.6	9
5	19.6	24.7	15.0	7.8	3.1	64.7	86.6	9
6	25.8	31.5	20.2	10.4	2.9	56.4	56.8	7
7	26.7	32.8	21.0	11.4	3.1	52.2	19.6	3
8	27.5	33.4	22.6	11.1	3.8	52.6	10.5	3
9	23.4	29.3	18.5	9.4	3.3	52.4	1.0	2
10	19.4	24.5	14.7	7.4	2.7	67.5	34.8	4
11	17.5	21.6	13.6	3.7	3.0	71.4	18.8	9
12	11.1	14.5	7.8	1.8	3.2	71.8	47.2	10
Average/ annual	17.5	22.2	13.2	7.1	3.4	64.7	587.7	7.4

The ET_{Gauge} equipment installed in the observation and measurement station of the Çanakkale Provincial Directorate of Meteorology was mounted on a 1.5 m long 10 × 10 m wooden platform (Figure 2). The equipment was so established as to refer to the grass plant in accordance with the principles specified in the user's manual and the necessary arrangements were made accordingly. Measurements were taken at 9:00 am every day for about 5 months.

Figure 2. ET_{Gauge} equipment used in this study

Methods

ET_0 calculations were made with the use of the empirical methods listed below. The climate parameters used in the calculations were obtained from the meteorological station where the ET_{Gauge} equipment was installed. In other words, observations and measurements were made at the same point.

Thornthwaite method. The equation developed by Thornthwaite (1948) can basically calculate the monthly potential evapotranspiration by using the latitude of a region and the monthly average air temperature. The Thornthwaite equation was modified by Trajkovic (2005) to calculate the daily ET_0 using the Paliç, Belgrade and Nis station data (Thornthwaite 1948; Trajkovic 2005).

$$ET_{0Th,i} = \frac{16 N_i}{360}\left(\frac{10\,T_i}{\sum_{i=1}^{12}(0.2T_i)^{1.514}}\right)^{0.016\sum_{i=1}^{12}(0.2\,T_i)^{1.514}+0.5} \quad (1)$$

where:

ET_{0Th} – reference evapotranspiration estimated by the Thornthwaite equation (mm/day);

N_i – maximum possible duration of sunshine (h/day);

T_i – mean air temperature in the i-th month (°C);

i – 1, 2, ... 12.

https://doi.org/10.17221/25/2025-SWR

$$\text{cET} = 0.88\ \text{ET}_{0\text{Th},i} + 0.565 \tag{2}$$

where:

cET – ET_0 estimated by the calibrated Thornthwaite method.

Blaney-Criddle method. Since temperature is a meteorological parameter that can be measured easily and simply, it is the most basic climate element used in plant water consumption calculations. This method, which is a basic method used in plant water consumption calculations, was developed by Blaney and Criddle in 1950 (Allen et al. 1998; Cuenca 1989). The equation and its components are given below.

$$\text{PET} = p\left(\left(0.46 \times T\right) + 8\right) \tag{3}$$

where:

PET – estimated reference evapotranspiration by the Blaney-Criddle equation (mm/day);

T – average monthly temperature (°C);

p – mean daily percentage of the annual daytime hours.

Penman Monteith method. It is the Penman Monteith equation quoted from Allen et al. (1998) and is shown below:

$$\lambda\text{ET} = \frac{\Delta(R_n - G) + P_a C_p \dfrac{(e_s - e_a)}{r_a}\ u_2(e_s - e_a)}{\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right)} \tag{4}$$

where:

λET – reference evapotranspiration (mm/month);

Δ – slope of the saturation vapor pressure-temperature curve (kPa/°C);

R_n – net radiation at crop surface (MJ/m^2 day);

G – soil heat flux density (MJ/m^2 day);

P_a – air density for a given air pressure (kg/m^3);

C_p – specific heat of air (MJ kg/°C);

u_2 – wind speed at 2 m height (m/s);

e_s – saturation vapour pressure (kPa);

e_a – actual vapour pressure (kPa);

$e_s - e_a$ – saturation vapour pressure deficit (kPa);

γ – the psychrometric constant (kPa/°C)

r_s – (bulk) surface resistance;

r_a – aerodynamic resistance;

ASCE standardised Penman Monteith method. The Food and Agriculture Organization of the United Nations (FAO)'s Penman-Monteith method is a combined method that requires data on radiation, air temperature, humidity and wind speed. As a result of a meeting held by experts in May 1990, it was recommended as the only standard method in the definition and calculation of reference evapotranspiration (Allen et al. 2006). The equation for the standardised FAO PM (ASCE SZ PM) method was developed by the American Society of Civil Engineers. The equation is given below:

$$\text{ET}_{\text{sz}} = \frac{0.408\ \Delta(R_n - G) + \gamma \dfrac{C_n}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + C_d\ u_2)} \tag{5}$$

where:

ETsz – standardised reference crop evapotranspiration for short (ET_{os}) or tall (ET_{rs}) surfaces (mm/day for daily time steps or mm/h for hourly time steps);

R_n – calculated net radiation at the crop surface (MJ/m^2·day for daily time steps or MJ/m^2 h for hourly time steps);

G – soil heat flux density at the soil surface (MJ/m^2·day for daily time steps or MJ/m^2·h for hourly time steps);

T – mean daily or hourly air temperature at 1.5 to 2.5 m height (°C);

u_2 – mean daily or hourly wind speed at 2 m height (m/s);

e_s – saturation vapour pressure at 1.5 to 2.5-m height (kPa), calculated for daily time steps as the average of saturation vapour pressure at maximum and minimum air temperature;

e_a – mean actual vapour pressure at 1.5 to 2.5-m height (kPa);

Δ – slope of the saturation vapour pressure-temperature curve (kPa/°C);

γ – psychrometric constant (kPa/°C);

C_n – numerator constant that changes with reference type and calculation time step (K·mm·s^3/Mg·day or K·mm·s^3/Mg·h);

C_d – denominator constant that changes with reference type and calculation time step (s/m);

Units for the 0.408 coefficient are m^2 mm/MJ.

Jensen-Haise method. To estimate the evapotranspiration, researchers developed the following equation as a result of 35 years of observations and measurements on 3 000 soil samples (Jensen & Haise 1963; Lingling et al. 2013; Bağçacı & Şarlak 2019):

https://doi.org/10.17221/25/2025-SWR

$$\mathrm{ET_0} = C_T \frac{(T - T_x) Rs}{\lambda} \quad (6)$$

where:
$\mathrm{ET_0}$ – reference evapotranspiration (mm/month);
C_T – temperature coefficient (°C [(0.025)]);
Rs – monthly mean of the daily global (total) solar radiation (kJ/m^2/day);
T – temperature (°C);
T_x – intercept on the temperature axis (°C [–3]);
γ – latent heat (MJ/kg).

Data comparison. The relationships between the $\mathrm{ET_{Gauge}}$ measurements and the values obtained from $\mathrm{Thornthwaite_{Adj}}$, Blaney-Criddle, PM, ASCE SZ PM and Jensen-Haise methods were assessed through regression (R^2), adjusted regression (R^2_{Adj}), correlation, standard deviation (SD) and other descriptive statistical methods. The correlation shows the strength of the relationship between the variables. On the other hand, the regression reflects the effect of unit change in the independent variable on the dependent variable. Both R^2 and R^2_{Adj} give an idea of how many data points fall on the regression equation line. However, there is a difference between R^2 and R^2_{Adj}. R^2 assumes that each variable explains the change in the dependent variable. R^2_{Adj} refers to the percentage of variation explained by independent variables that only actually affect the dependent variable (Jeremy 2005; Karch 2020). Therefore, the R^2_{Adj} values were also calculated in this study.

RESULTS

Numerous methods have been developed to calculate the $\mathrm{ET_0}$. However, the accuracy depends on the weather or temperature dataset considered in each model. Statistical analyses were performed to verify the differences in the calculation and to evaluate the performance of the estimation methods. Within the scope of the study, the $\mathrm{ET_0}$ values were calculated on a daily and monthly basis using the $\mathrm{Thornthwaite_{Adj}}$, Blaney-Criddle, PM, Jensen-Haise and ASCE SZ PM methods. The change between the $\mathrm{ET_0}$ values calculated on a daily basis by empirical methods and the values measured from $\mathrm{ET_{Gauge}}$ is shown in Figure 3. The results of the descriptive statistics to determine the relationship between the daily measured and empirically calculated values are shown in Table 3. Additionally, the cumulative $\mathrm{ET_0}$ charts created by aggregating the daily $\mathrm{ET_0}$ values are shown in Figure 4. Using this graph, the linear regression relationship and conversion equations between the values measured with the $\mathrm{ET_{Gauge}}$ readings and the calculated values are also shown in Figure 3 and Table 3. The total number of observations and calculations is 153. The minimum value measured by the $\mathrm{ET_{Gauge}}$ is 0 mm/day. The minimum values calculated by the empirical methods are $\mathrm{Thornthwaite_{Adj}}$ 1.3; Blaney-Criddle 1.8; PM 1.2; Jensen-Haise was calculated as 0.5 and ASCE SZ PM was calculated as 1 mm/day. The maximum values obtained from the study are $\mathrm{ET_{Gauge}}$ 10; $\mathrm{Thornthwaite_{Adj}}$ 6.6; Blaney-Criddle 7.2; PM 10.5;

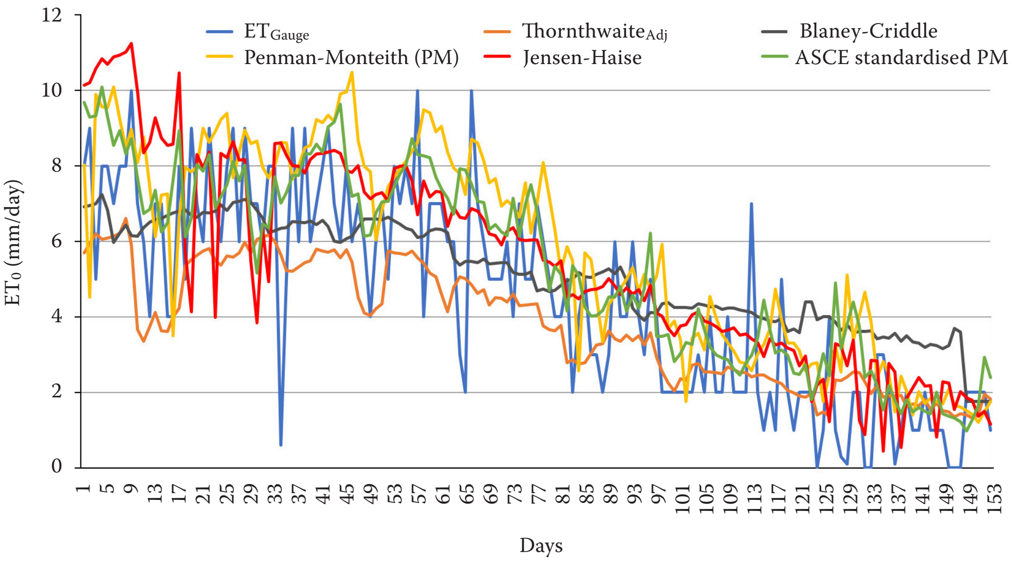

Figure 3. Change in the daily reference evapotranspiration ($\mathrm{ET_0}$) values calculated with the $\mathrm{ET_{Gauge}}$ and equations

https://doi.org/10.17221/25/2025-SWR

Table 3. Statistical results regarding daily evapotranspiration values

Parameters	ET_{Gauge}	Thornth-waite$_{Adj}$	Blaney-Criddle	Penman-Monteith	Jensen-Haise	ASCE standardised Penman-Monteith
N	153	153	153	153	153	153
Min	0.0	1.3	1.8	1.2	0.5	1.0
Max	10.0	6.6	7.2	10.5	11.2	10.1
Average	4.5	3.8	5.1	5.8	5.5	5.4
SD	2.7	1.6	1.4	2.7	2.7	2.5
SEM	0.22	0.13	0.11	0.22	0.22	0.20
Upper 95% mean	5.0	4.0	5.4	6.3	6.0	5.8
Lower 95% mean	4.1	3.5	4.9	5.4	5.1	5.0
R^2		0.9972	0.9851	0.9985	0.9983	0.9984
R^2_{Adj}		0.99716	0.98490	0.99848	0.99828	0.99838
Korelasyon		0.8350	0.7853	0.8122	0.7826	0.8259
Skewness	0.08	0.05	–0.37	–0.15	0.16	–0.10
Kurtosis	–1.15	–1.43	–0.75	–1.42	–0.93	–1.31
Autocorrelation	0.69	0.96	0.96	0.92	0.91	0.94
Equation		$0.8239\ ET_{Gauge} - 13.628$	$1.0933\ ET_{Gauge} - 34.755$	$1.2961\ ET_{Gauge} - 25.011$	$1.18\ ET_{Gauge} + 9.3259$	$1.1791\ ET_{Gauge} - 11.059$

SD – standard deviation; SEM – standard error of the mean; R^2 – regression; R^2_{Adj} – adjusted regression

Jensen-Haise was determined as 11.2 and ASCE SZ PM was determined as 10.1 mm/day. The average values calculated for the measurement period are ET_{Gauge} 4.5; Thornthwaite$_{Adj}$ 3.8; Blaney-Criddle 5.1; PM 5.8; Jensen-Haise was determined as 5.5 and ASCE SZ PM was determined as 5.4 mm per day. While the standard deviation in the measured ET_{Gauge} values was 2.7 mm, the lowest among the calculated

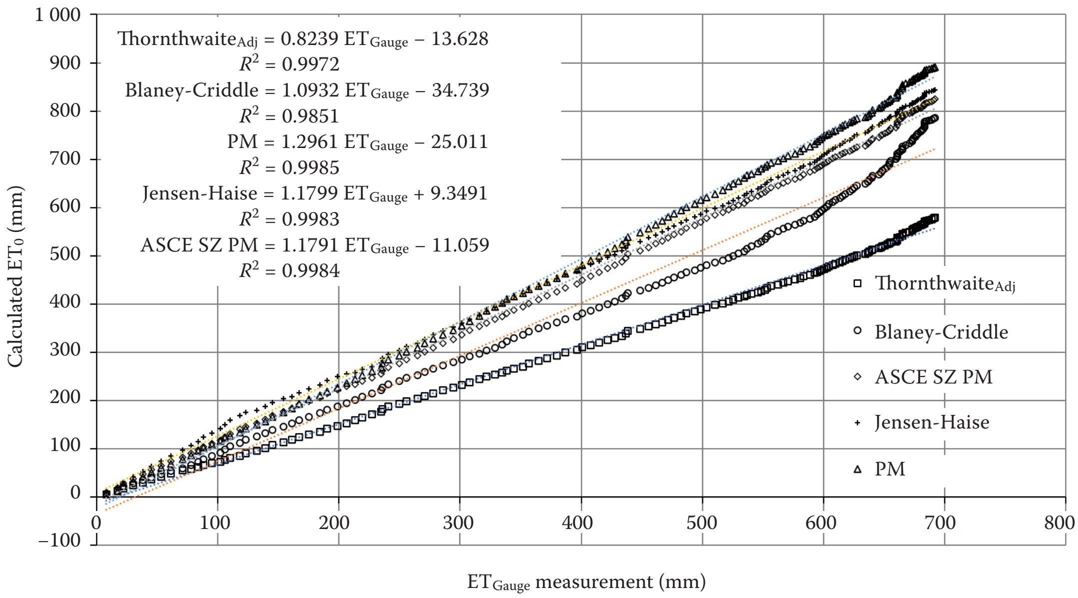

Figure 4. Regression relationship between ET_{Gauge} measurements and calculated using empirical methods at cumulative daily reference evapotranspiration (ET_0) values

PM – Penman-Monteith; ASCE SZ PM – ASCE standardised Penman-Monteith

https://doi.org/10.17221/25/2025-SWR

values was 1.4 mm in Blaney-Criddle and the highest was 2.7 mm in the Jensen-Haise method. While the standard error average values are 0.22 in ET_{Gauge}, the lowest in the empirical methods is 0.11 in the Blaney-Criddle method and the highest is 0.22 in the PM and Jensen-Haise methods. Considering the regression coefficients and adjusted regression coefficients showing the relationship between the ET_{Gauge} and the ETo values calculated by the empirical methods, it was determined that the relationship was over 98%. Considering the correlation coefficients, the lowest was determined as 78.53% in the Blaney-Criddle method, while the highest was calculated as 83.5% in the $Thornthwaite_{Adj}$ method. Considering the skewness in the distribution of the values, the ET_{Gauge}, $Thornthwaite_{Adj}$ and Jensen-Haise values showed a slight skewness to the right, while the PM and ASCE SZ PM methods showed a slight skewness to the left. The Blaney-Criddle method showed the highest skewness (to the left, at 37%). When the distribution kurtosis in the values was examined, it was determined that they showed a flat distribution compared to the normal distribution. Considering the autocorrelation and others calculated in the study, a positive correlation was determined and ET_{Gauge} was calculated as 0.69 in the measurement values. In the empirical methods, the lowest was calculated as 0.91 in the Jensen-Haise method and the highest was 0.96 in the $Thornthwaite_{Adj}$ and Blaney-Criddle methods.

Additionally, the relationships between the methods and their levels are presented in Table 4. The $Thornthwaite_{Adj}$ and ASCE SZ PM method showed the highest correlation with ET_{Gauge}. The highest correlation was determined between the $Thornthwaite_{Adj}$ method and the ASCE SZ PM method (0.93). The $Thornthwaite_{Adj}$ and ASCE SZ PM methods showed the highest correlation with the Blaney-Criddle method. The highest correlation for the PM method was calculated for the $Thornthwaite_{Adj}$ and ASCE SZ PM methods. The highest correlation for the Jensen-Haise method was determined at the ASCE SZ PM method (0.93). The ASCE SZ PM method showed the highest correlation with both the $Thornthwaite_{Adj}$ and Jensen-Haise methods.

The results of the descriptive statistics to determine the relationship between the ET_0 values calculated on a monthly basis by the empirical methods and the values measured from the ET_{Gauge} are shown in Table 5. Additionally, the graph shown in Figure 5 was prepared using the obtained results. The linear regression relationship and conversion equations between the values measured by the ET_{Gauge} readings and the calculated values are also shown in Figure 4 and Table 5. Considering the total 5-month ET_0 values (692.1 mm) measured from the ET_{Gauge}, the ET_0 values calculated only with $Thornthwaite_{Adj}$ (579.7 mm) were calculated to be lower than the measured values (Table 4). In other words, the 5-month total ET_0 value calculated by the Thornthwaite method was determined to be 16.2% lower than the value obtained from the ET_{Gauge} readings. On the other hand, 13.6% calculated by the Blaney-Criddle method; PM 28.9%; The Jensen-Haise method calculated a higher ET_0 by 22% and the ASCE SZ PM method calculated a higher ET_0 by 19.2%. Considering the monthly values, the lowest ET_0 values were measured/calculated in November. The highest values were realised in July and the highest value calculated by the Jensen-Haise method was 264.9 mm/month. The monthly minimum value measured in ET_{Gauge} is 37.5 mm in November. The minimum values calculated in the empirical methods are also in November where $Thornthwaite_{Adj}$ is 54.2; Blaney-Criddle is 97.3; PM is 170.8; Jensen-Haise was calculated as 59.8 and ASCE SZ PM was calculated as 66.3 mm. Although the PM method and ASCE SZ PM equations seem largely the same, there are small differences. These

Table 4. Relationship between the methods and their level

Parameters	ET_{Gauge}	$Thornthwaite_{Adj}$	Blaney-Criddle	Penman-Monteith	Jensen-Haise	ASCE standardised Penman-Monteith
ET_{Gauge}	1.0000	0.8341	0.7873	0.7956	0.7823	0.8258
$Thornthwaite_{Adj}$	0.8341	1.0000	0.8898	0.9183	0.8652	0.9336
Blaney-Criddle	0.7873	0.8898	1.0000	0.8666	0.8750	0.8864
FAO-PM	0.7956	0.9183	0.8666	1.0000	0.8469	0.9072
Jensen-Haise	0.7823	0.8652	0.8750	0.8469	1.0000	0.9313
ASCE SZ PM ET	0.8258	0.9336	0.8864	0.9072	0.9313	1.0000

https://doi.org/10.17221/25/2025-SWR

Table 5. Monthly evapotranspiration values (mm) and statistical results

Parameters	ET_{Gauge}	$Thornthwaite_{Adj}$	Blaney-Criddle	Penman-Monteith	Jensen-Haise	ASCE standardised Penman-Monteith
July	219.0	164.9	208.3	252.6	264.9	240.5
August	200.6	158.0	191.2	256.1	233.1	233.6
September	143.0	118.2	155.2	190.6	169.0	174.1
October	84.0	78.2	127.8	114.1	112.6	103.8
November	37.5	54.2	97.3	70.8	59.8	66.3
Total	692.1	579.7	786.0	891.9	844.4	824.7
Change (%)		16.2	–13.6	–28.9	–22.0	–19.2
Min	37.5	54.2	97.3	70.8	59.8	66.3
Max	219.0	164.9	208.3	263.8	264.9	240.5
Aver	138.4	115.9	157.2	178.4	168.9	164.9
SD	70.1	44.6	41.6	75.7	76.2	70.6
SEM	35.08	22.32	20.82	37.85	38.12	35.28
R^2		0.995	0.9783	0.9984	0.9982	0.9983
R^2_{Adj}		0.9900	0.9966	0.9768	0.9966	0.9994
Correlation		0.9983	0.9975	0.9941	0.9974	0.9976
Skewness	–0.28	–0.20	–0.17	–0.33	–0.17	–0.28
Kurtosis	–2.08	–2.42	–1.88	–2.29	–1.86	–2.42
Autocorrelation	0.46	0.47	0.44	0.47	0.44	0.48
Equation		$0.8588\ ET_{Gauge} - 21.808$	$1.1828\ ET_{Gauge} - 74.824$	$1.3345\ ET_{Gauge} - 88.327$	$0.6952\ ET_{Gauge} + 87.862$	$1.2181\ ET_{Gauge} - 31.589$

SD – standard deviation; SEM – standard error of the mean; R^2 – regression; R^2_{Adj} – adjusted regression

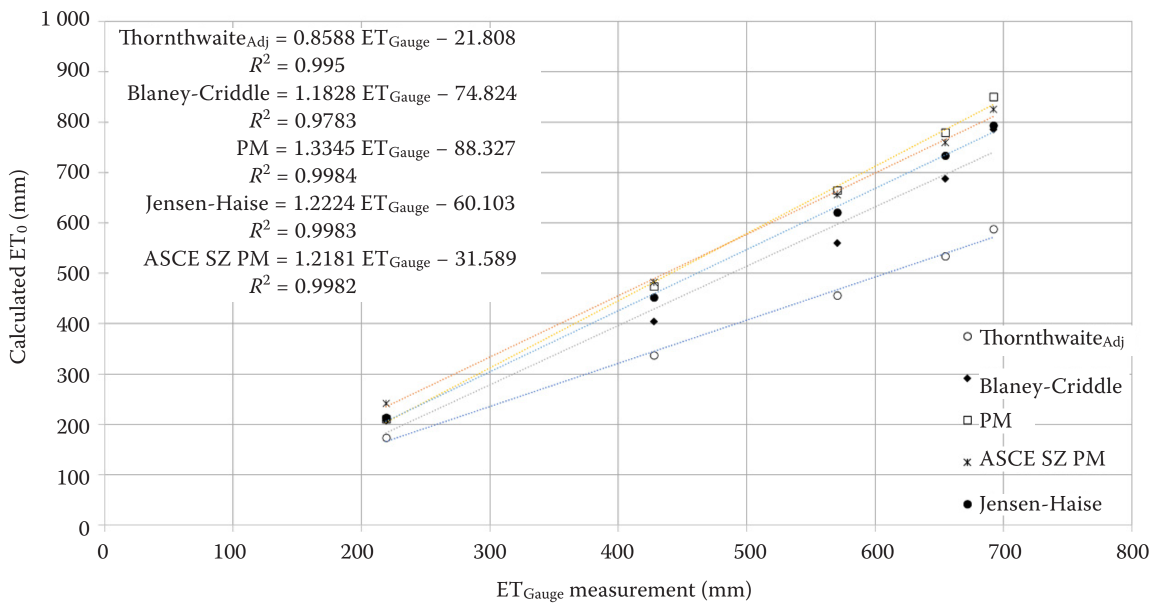

Figure 5. Regression relationship between ET_{Gauge} measurements and calculated using empirical methods at cumulative monthly reference evapotranspiration (ET_0) values

PM – Penman-Monteith; ASCE SZ PM – ASCE standardised Penman-Monteith

https://doi.org/10.17221/25/2025-SWR

differences cause slight changes in the calculation. Generally, in the PM model, the K in parameter in (1) is equal to $1.8576 \times 10^5 \lambda/[(T + 273)\ r_a$. For the PM model (Allen et al. 1998), $K = 900\lambda/(T + 273)\ u_2$ and $\gamma^* = \gamma\ (1 + 0.34u_2)$. For the ASCE SZ PM model (Walter et al. 2002), $K = 1\ 600\ \lambda/(T + 273)\ u_2$ and $\gamma^* = \gamma\ (1 + 0.38u_2)$. For the complete ASCE SZ PM model (Jensen et al. 1990), $K = (700 - 2.8T)\ \lambda/r_a$ and $\gamma^* = \gamma\ (1 + r_s/r_a)$ (Alazba 2004).

The standard error mean values of the monthly ET_0 values in the study are 35.08 in the ET_{Gauge}; 22.32 in $Thornthwaite_{Adj}$; 20.82 in Blaney-Criddle; 37.85 in PM; while Jensen-Haise was determined as 38.12 and ASCE SZ PM was determined as 35.28 mm. Considering the regression coefficients and adjusted regression coefficients showing the relationship between the ET_{Gauge} and ET_0 values calculated by the empirical methods, it was determined that the relationship was over 97%. Considering the monthly values, the correlation value between the measured value and the calculated values was calculated to be over 99%. When the skewness of the monthly values was examined, it was determined that all the values were skewed to the left. The highest skewness was determined as 33% in the PM method. It was calculated as 20% in the least skewed $Thornthwaite_{Adj}$ method. Considering the distribution kurtosis of the values, it was determined that the data showed a flat distribution compared to the normal distribution. Considering the autocorrelation values calculated in the study, a positive correlation was determined. The autocorrelation value of the ET_{Gauge} measurements was calculated to be 0.46. In the empirical methods, the lowest was calculated as 0.44 in the Blaney-Criddle and Jensen-Haise methods, and the highest was calculated as 0.48 in the ASCE SZ PM method.

The differences between the ET_0 values measured from the ET_{Gauge} and the 5-month values calculated by the empirical methods are evaluated on a monthly basis and shown in Table 6. Considering monthly values from ET_{Gauge} measurements, the Thornthwaite method underestimated the depth by 54 mm (24.7%) in July, 44 mm (21.3%) in August, 25 mm (17.3%) in September, and 6 mm (6.9%) in October. However, in November, it was overestimated by 17 mm (45%) compared to ET_{Gauge} measurements.. Especially in the season when irrigation is intense in the region, the ET_0 values calculated with the Thornthwaite method are quite different from the values read from the ET_{Gauge}. Therefore, it will cause incomplete irrigation in July and August, when irrigation is intense. In other words, in July and August, when the irrigation is at its peak, a total of 98 mm less irrigation water will be given to the plant root zone. Similarly, in the Blaney-Criddle method, it was calculated at a lower rate compared to the ET_{Gauge} in July at 11 mm (4.9%) and August at 11 mm (5.4%), when irrigation is at its peak. It was calculated higher in September at 12 mm (8.5%), October at 44 mm (52.2%) and November at 60 mm (160.3%). The PM method calculated July as 34 mm (15.4%) higher, August as 55 mm (26.4%), September as 48 mm (33.3%), October as 30 mm (35.8%) and November as 33 mm (88.3%) higher. The Jensen-Haise method calculated July as 46 mm (20.9%) higher, August as 29 mm (14.1%), September

Table 6. Monthly differences between the evapotranspiration values measured with ET_{Gauge} and the calculated values

Months	$Thornthwaite_{Adj}$	Blaney-Criddle	Penman-Monteith	Jensen-Haise	ASCE standardised Penman-Monteith
	(mm)				
July	–54	–11	34	46	22
August	–44	–11	55	29	31
September	–25	12	48	26	31
October	–6	44	30	29	20
November	17	60	33	22	29
Difference rates (%)					
July	–24.7	–4.9	15.4	20.9	9.8
August	–21.3	–5.4	26.4	14.1	15.1
September	–17.3	8.5	33.3	18.2	21.7
October	–6.9	52.2	35.8	34.1	23.5
November	45.0	160.3	89.3	60.0	77.3

https://doi.org/10.17221/25/2025-SWR

as 26 mm (18.2%), October as 29 mm (34.1%) and November as 22 mm (60%) higher. The ASCE SZ PM method calculated July as 22 mm (9.8%) higher, August as 31 mm (15.1%), September as 31 mm (21.7%), October as 20 mm (23.5%) and November as 29 mm (77.3%) higher. Considering the results obtained, the prediction made by the Blaney-Criddle method in July and August, when the irrigation is intense, seems to be closest to the ET_{Gauge} readings. However, predictions made with this method cause incomplete irrigation, which may cause water stress in the plants. It can be said that the ASCE SZ PM method provides the best fit in terms of preventing water stress and saving irrigation water.

In general, differences are observed in both the daily and monthly values. These differences are due to variations in the methods used. The parameters considered in the evapotranspiration calculation methods are not only different, but each meteorological parameter does not have the same impact (weight) in every equation. Therefore, differences can occur in both the daily and monthly calculated values.

DISCUSSION

Grass-reference evapotranspiration (ET_0) is commonly used in irrigation scheduling. ET_0 can also be estimated with the use of various climate parameters including solar radiation, air temperature, wind speed and relative humidity (Alam & Trooien 2001; Irmak et al. 2005). However, these parameters may not be readily available to use in ET_0 estimations. Therefore, ET_{Gauge} is used as an alternative tool to measure ET_0 rates. The simple and feasible nature of ET_{Gauge} offer an efficient tool to monitor crop water use and irrigation practices (Irmak et al. 2005).

ET_0 is an important agrometeorological index for rational irrigation management. The standard method for the ET_0 prediction recommended by the FAO is based on a complex PM equation and requires many meteorological inputs, making it difficult for farmers to use it in practical terms. There are currently many alternative simplified approaches to determine the ET_0 estimation; most of these are aimed at reducing the number of meteorological inputs required for the calculation. In a study conducted for six different regions of Ukraine, monthly ET_0 values were calculated using the FAO PM method. As a result of the statistical comparison of the obtained ET_0 values, although it varied depending on the regions on a monthly scale, R^2 was calculated in the range of 0.88–0.95, RMSE was in the range of 0.50–0.72 mm, mean absolute error (MAE) was in the range of 0.33–0.59 mm, and mean absolute percentage error (MAPE) was in the range of 8.96 to 24.08%. The FAO PM method, although complex, has been found to be a good method for Ukrainian farmers (Lykhovyd 2022). ASCE SZ PM and FAO PM equations were compared for 15-minute and daily ET_0 forecasts using 15-minute and daily weather data measured between 1997 and 2006 for eleven different stations with humid climatic conditions in the US state of Georgia. When the daytime 15-minute ET_0 values were compared, ASCE SZ calculated the ET_0 5% higher than FAO PM due to the lower surface resistance parameter value of the SZ PM equation. At night, opposite results were obtained. In other words, the calculation made with the ASCE SZ PM method obtained lower results than the FAO PM method. The difference between the day and night results is thought to be largely due to the wind speed. The daily ET0 values in three summer months (June, July and August) were compared with two methods. The total daily ET_0 values calculated hourly by the FAO PM method were found to be 5% lower than those calculated by the ASCE SZ PM method (Manik et al. 2017). In a study conducted in Indonesia, the ET_0 values obtained from the FAO PM method was compared with six different methods (Hargreaves- Samani 1985 (HS), FAO 24 Radiation (24RD), FAO 24 Blaney-Criddle (24BC), FAO 24 Pan Evaporation (24PAN), Linacre (Lin), and Makkink (Mk)) were compared with the calculated daily ET_0 value. The average ET_0 and standard deviation values calculated at the end of the study were 3.533 and 0.774 for FAO PM; 2.851 and 0.485 for 24RD; 4.607 and 1.419 for 24BC; 4.821 and 0.561 for HS; 3.306 and 0.370 for Mk; 4.387 and 0.569 for Lin; and 2.925 and 1.009 for 24Pan, respectively (Djaman et al. 2016). In the research conducted in the Senegal River Delta area, the ET_0 values obtained from the ASCE SZ PM equation were evaluated by six different methods (Trabert, Mahringer, Penman1948, Albrecht, Valiantzas1 and Valiantzas2). All six compared methods showed good agreement (R^2 > 0.64) with the ASCE SZ PM method. Among the compared ET_0 estimates, the values obtained with the Valiantzas2 equation created the best model for the study area [RMSE = 0.45 mm/day and the prediction error was approximately 7.1%] (Reyes-González et al. 2017).

https://doi.org/10.17221/25/2025-SWR

As reported by Blanco and Folegatti, they conducted a study under greenhouse conditions to compare ETo values calculated with the Penman-Monteith equation with a Class-A evaporation pan and reduced pan ET_{Gauge} readings and reported a strong relationship (R^2 = 0.86) between the ET_0 values obtained from the Penman-Monteith equation and the ET_{Gauge} readings (Blanco & Folegatti 2004). In another study carried out, the authors compared the ET_{Gauge} readings and the ET_0 values calculated with the FAO PM equation at two sites in north-central Florida and reported that ET_{Gauge} readings were 27% lower than the FAO PM calculations. It was indicated that most of the days, where the ET_{Gauge} underperformed and were underestimated, occurred on rainy days. It was also indicated that readings in the 3 and 7-day periods reduced the error and the measurements were more accurate (Irmak et al. 2005). In another published study, compared ET_{Gauge} measurements at 19 points in 5 different regions of North Carolina, USA with the daily ET_0 values calculated with ASCE SZ PM equation were conducted. It was determined that the ET_{Gauge} readings across the study area were 21% lower than the calculated daily ET_0 values. The relationships between the ET_{Gauge} readings and the calculated ET_0 values differed for each region and R^2 values were reported as between 0.74–0.82. Gavilán and Castillo-Llanque (2009) compared ET_{Gauge} readings with the ET_0 values estimated with the FAO PM equation in Cordoba, Spain (Gavilán & Castillo-Llanque 2009). It was stated that ET_{Gauge} readings were about 9% lower than the calculated ET_0 values. It was also indicated that there was a strong relationship between the ET_{Gauge} readings and the calculated ET_0 values (R^2 = 0.89). The difference between the ET_{Gauge} readings and the calculated ET_0 values varied between –2.4 and 2.2 mm/day. Lower measurements were reported to occur more frequently on days with high maximum temperatures and low wind speeds. It was indicated that the ET_{Gauge} readings were more accurate under windy conditions and high temperatures, as well as under non-windy conditions and moderate temperatures (Chen & Robinson 2009). In a study conducted in the US state of Arkansas, USA to compare ET_{Gauge} readings in grass-covered (three sites) and alfalfa-covered (three sites) with the ET_0 values calculated by the Penman Monteith equation for both grass and alfalfa, the cumulative ET_0 measured with the ET_{Gauge} was 12.5–21.0% lower than the ET_0 calculated for the grass and 15% lower than the ET_0 calculated for the alfalfa. While the ET_{Gauge} values measured from the alfalfa-covered sites had the strongest relationships (R^2 = 0.68–0.72), The ET_{Gauge} readings from the grass-covered sites had the weakest relationships (R^2 = 0.49-0.68) (Diop et al. 2015). According to the results of another reported study, a study in Bedfordshire, England was conducted to compare ET_{Gauge} measurements with the ET_0 values calculated by the Penman-Monteith method. It was indicated that there was a strong relationship between the ET_{Gauge} measurements and the calculated ET_0 values (R^2 = 0.68–0.90). It was determined that if ET_{Gauge} was used, 15% more water would be applied during the irrigation season as compared to the ET_0 calculated with the Penman-Monteith equation. It was also reported that ET_{Gauge} values could be used for deep rooted plants in humid regions where the irrigation interval was not less than 5–7 days (Knox et al. 2011).

In a study conducted in Manhattan, Kansas, USA to compare ET_0 values measured with ET_{Gage} and ET_0 values calculated with the Penman-Monteith method, it was reported that ET_{Gauge} yielded similar values with the calculated ET_0 values with Penman-Monteith in open fields and microclimates, where the wind speed was > 1 m/s, vapour pressure deficit was > 2 kPa and net radiation was > 5 MJ/m/day (Peterson et al. 2015). In another study carried out, the authors compared the daily ET_0 values obtained with the ET_{Gauge} and the ET_0 values calculated with the ASCE SZ PM equation in Minnesota, USA. During a 3-month period (August 1 – October 28, 2019), the total ET_0 value measured from the ET_{Gauge} was 213.4 mm, while the calculated ET_0 value was 238.8 mm. It was stated that there was a strong relationship between two methods (R^2 = 0.95). It was also indicated that ET_{Gauge} yielded a reasonable estimation of the ET_0 and could be used in irrigation when adjusted with crop coefficients (kc) (Sharma 2020). According to the results of another reported study in the US state of Colorado, the authors compared ET_{Gauge} with the Penman method (a modification of Jensen 1983). They determined the mean of the ET_{Gauge} readings to be 4.5 and the standard deviation to be 1.4. The ET_0 value calculated by the Penman method was determined as 4.4 mm. While the standard deviation of the ET_{Gauge} readings was 1.4 mm, the standard deviation of Penman calculated values was 1.2 mm. The difference between the ET_0 values calculated by the ET_{Gauge} and Penman method was calculated as 3.9% (Broner & Law 1991). In another research paper, conducted on three different corn fields in three different regions in the

https://doi.org/10.17221/25/2025-SWR

South Dakota region of the USA, there was a good correlation between the actual ET_0 value predicted by the METRIC model and the value measured by the ET_{Gauge} (R^2 = 0.87, index of agreement 0.84 and RMSE = 0.65 mm/day). However, the ET_{Gauge} values consistently measured lower than the METRIC values. Daily differences between the two methods increase with higher wind speed values (> 4 m/s) (Reyes-González et al. 2017). In a study conducted in the state of Kansas, USA, the authors compared the ET_0 value calculated from the Penman-Monteith equation with the 3-day cumulative ET_{Gage} readings and reported that there was a good relationship (R^2 = 0.81) in terms of the regression between the calculated ET_0 value and ET_{Gauge} readings (Alam & Trooien 2001). To research the relationships between FAO PM, an atmometer and a Class A pan in the Mediterranean region, a study was conducted during five irrigation seasons in different eastern and western coastal regions of southern Italy. In all the regions, high correlation coefficient values were found when comparing the atmometer's daily forecasts with the PM ET_0. Linear regression models produced intercept coefficients that were not different from zero in any region. When the data from all the regions were pooled together, a unique relationship between the atmometer and PM was identified, yielding a slope coefficient of 1.034. A slope not different from unity was found when compared with high-resolution weighing lysimetry over a full irrigation season. Comparisons with the Class A average weekly ET_0 over two consecutive irrigation seasons showed that the atmometer slightly underestimated the ET_0 relative to the Class A container. Based on experimental evidence, atmometers can be used for reliable ET_0 estimates on both farm and extension levels in Mediterranean conditions when standard meteorological data are not available (Magliulo et al. 2003). According to the results of another reported study, the ET_{Gauge} and FAO PM equation were compared to determine the amount of irrigation water in urban lawn areas. The ET_{Gauge} (4.73 mm per day) underestimated the FAO PM (5.48 mm/day) by an average of 14%. Among microclimates, ET_{Gauge} (3.94 mm/day) gave an average of 22% higher results than FAO PM (3.23 mm/day). Differences in ET_0 estimates between the measurement techniques vary depending on the wind speed, net radiation and vapour pressure deficit. The best relationships between the ET_{Gauge} and FAO PM occurred in an open space and microclimates, with a wind speed of > 1 m/s, a vapour pressure deficit of > 2 kPa, and a net radiation of > 5 MJ/m^2/day. Overall, ET_{Gauge} can provide reliable estimates and benefit practitioners in irrigation management in microclimates (Peterson et al. 2017).

The results obtained from studies conducted under various conditions with ET_{Gauge} show a significant similarity to the results of the current study. The minor differences are believed to arise from the region, climate, environment, and other meteorological conditions where the studies were conducted.

CONCLUSIONS

In the realm of crop production, irrigation is not just essential, but required for emphasis. The key issue is mastering the art of applying the correct amount of water, a task fundamentally linked to the dynamic process of evapotranspiration. Evapotranspiration is difficult to measure and can only be calculated indirectly after a series of procedures, usually using meteorological factors for estimation. However, while these calculations provide reliable results for homogeneous areas, they may cause large deviations/errors in conditions with microclimatic zones. In recent years, many methods and technological tools/equipment have been developed, and new ones are being developed over time. The usability of most of the developed tools and equipment in practice remains limited due to reasons such as the accuracy of measurement values, scientific suitability and especially the complexity of use. The A-class evaporation container method, which is easy to use and has been adopted in practice, also has some limitations (occupying a large area, being greatly affected by adverse weather conditions such as wind, contamination of the water in the container and, accordingly, serious errors in measurements, etc.). Additionally, some of the highly sensitive empirical methods require a large amount of meteorological data. One of the alternative approaches to all these approaches is the use of a modified/improved ET_{Gauge} that reduces the data requirement and complexity associated with ET_0-based irrigation planning. ET_{Gauge} equipment has been increasingly used in the last few decades. In addition to the ease of use of the equipment in question, the important factor that shows that it is more advantageous is that it is designed for irrigation automation. Additionally, ET_{Gauge} is among the cheapest equipment that can be used to measure ET_0 on site.

https://doi.org/10.17221/25/2025-SWR

Considering the results obtained, ET_{Gauge} can be used safely in determining the amount of irrigation water and creating irrigation programmes. At the same time, it is of great benefit to thoroughly research the equipment under different climatic and environmental conditions (especially calibrating with lysimeter results) and compare the equipment with different empirical methods. In addition, irrigation programmes for different plants must be created and tested.

REFERENCES

Alam M., Trooien T.P. (2001): Estimating reference evapotranspiration with an atmometer. Applied Engineering in Agriculture, 17: 153–158.

Alazba A.A. (2004): Comparison of the ASCE standardized and other Penman-Monteith type equations under hyper-arid area. 2004 ASAE/CSAE Annual International Meeting: 042092. Available at https://doi.org/10.13031/2013.16218

Allen R.G., Pereira L.S., Raes D., Smith M. (1998): Crop Evapotranspiration: Guidelines for Computing Crop Water Requirement. FAO Irrigation and Drainage Paper No. 56, Rome, FAO.

Allen R.G., Pruitt W.O., Wright J.L., Howell T.A., Ventura F., Snyder R., Itenfisu D., Steduto P., Berengena J., Yrisarry J.B., Smith M., Pereira L.S., Raes D., Perrier A., Alves I., Walter I., Elliott R. (2006): A recommendation on standardized surface resistance for hourly calculation of reference ET_0 by the FAO56 Penman-Monteith method. Agricultural Water Management, 81: 1–22.

Bağçacı S.C., Şarlak N. (2019): Estimation of potential evapotranspiration in the Karaman Province. Toprak Su Dergisi, Özel Sayı: 1–8. (in Turkish)

Bhatt R., Hossain A. (2019): Concept and consequence of evapotranspiration for sustainable crop production in the era of climate change. In: Advanced Evapotranspiration Methods and Applications. IntechOpen. Available at https://doi.org/10.5772/intechopen.83707

Blanco F.F., Folegatti M.V. (2004): Evaluation of evaporation-measuring equipment for estimating evapotranspiration within a greenhouse. Revista Brasileira de Engenharia Agricola e Ambiental, 8: 184–188.

Broner I., Law R.A.P. (1991): Evaluation of a modified atmometer for estimating reference ET. Irrigation Science, 12: 21–26.

Carlos D.S.S., Francisco A.S.P., Aureo S.O., João F.G.J., Lucas M.V. (2013): Design, installation and calibration of a weighing lysimeter for crop evapotranspiration studies. Water Resource Irrigation Management, 2: 77–85.

Chen F., Robinson P.J. (2009): Estimating reference crop evapotranspiration with ETgages. Journal of Irrigation and Drainage Engineering, 135: 335–342.

Cuenca R.H. (1989): Irrigation System Design: An Engineering Approach. Englewood Cliffs, Prentice Hall.

Diop L., Bodian A., Diallo D. (2015): Use of atmometers to estimate reference evapotranspiration in Arkansas. African Journal of Agricultural Research, 10: 4376–4383.

Djaman K., Tabari H., Balde A.B., Diop L., Futakuchi K., Irmak S. (2016): Analyses, calibration and validation of evapotranspiration models to predict grass-reference evapotranspiration in the Senegal river delta. Journal of Hydrology: Regional Studies, 8: 82–94.

Gavilán F., Castillo-Llanque F. (2009): Estimating reference evapotranspiration with atmometers in a semiarid environment. Agricultural Water Management, 96: 465–472.

Irmak S. (2017): Evapotranspiration basics and estimating actual crop evapotranspiration from reference evapotranspiration and crop-specific coefficients. The Board of Regents of the University of Nebraska on behalf of the University of Nebraska-Lincoln Extension. Available at https://extensionpubs.unl.edu/publication/g1994/na/html/view

Irmak S., Dukes M.D., Jacobs J.M. (2005): Using modified Bellani plate evapotranspiration gauges to estimate short canopy evapotranspiration. Journal of Irrigation and Drainage Engineering, 131: 164–175.

Jensen M.E. (1983): Design and Operation of Farm Irrigation Systems. St. Joseph, American Society of Agricultural Engineers.

Jensen M.E., Haise H.R. (1963): Estimating evapotranspiration from solar radiation. Journal of the Irrigation and Drainage Division-ASCE, 89(IR3): 15–41.

Jensen M.E., Burman R.D., Allen R.G. (eds.) (1990): Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practices No. 70, New York, American Society of Civil Engineers.

Jeremy M. (2005): *R*-squared, adjusted *R*-squared. In: Encyclopedia of Statistics in Behavioral Science. Chichester, John Wiley & Sons, Ltd.

Karch J. (2020): Improving on adjusted *R*-squared. Collabra: Psychology, 6: 45.

Knox J.W., Rodriguez-Diaz J.A., Hess T.M. (2011): Estimating evapotranspiration by using atmometers for irrigation scheduling in a humid environment. Journal of Irrigation and Drainage Engineering, 137: 685–691.

Kobak O., Tas I. (2021): The effect of dynamic irrigation scheduling on yield and morphological properties of second crop silage corn. Journal of Adnan Menderes University Agricultural Faculty, 18: 49–57.

https://doi.org/10.17221/25/2025-SWR

Kypris D., Nikolaou G., Evangelides E., Neocleous D. (2023): Installation and adjustment of a hydraulic evapotranspiration multisensor prototype. AgriEngineering, 5: 876–885.

Lingling Z., Jun X., Chong-Yu X., Zhonggen W., Leszek S. (2013): Evapotranspiration estimation methods in hydrological models. Journal of Geographical Sciences, 23: 359–369.

Lykhovyd P. (2022): Comparing reference evapotranspiration calculated in ETo calculator (Ukraine) mobile app with the estimated by standard FAO-based approach. AgriEngineering, 4: 747–757.

Magliulo V., d'Andria R., Rana G. (2003): Use of the modified atmometer to estimate reference evapotranspiration in Mediterranean environments. Agricultural Water Management, 63: 1–14.

Manik T.K., Sanjaya P., Bustomi R.A. (2017): Comparison of different models in estimating standard evapotranspiration in Lampung Province, Indonesia. International Journal of Environment, Agriculture and Biotechnology, 2: 2309–2318.

Peterson K.W., Bremer D.J., Fry J.D. (2015): Evaluation of atmometers within urban home lawn microclimates. Crop Science, 55: 2359–2367.

Peterson K.W., Bremer D.J., Shonkwiler K.B., Ham J.M. (2017): Measurement of evapotranspiration in turfgrass: A comparison of techniques. Agronomy Journal, 109: 2190–2198.

Reyes-González A., Kjaersgaard J., Trooien T., Hay C., Ahiablame L. (2017): Comparative analysis of METRIC model and atmometer methods for estimating actual evapotranspiration. International Journal of Agronomy, 2017: 3632501.

Sharma V. (2020): Is ETgage an effective tool for irrigation management? University of Minnesota Extension Blog. Available at https://blog-crop-news.extension.umn.edu/2020/01/is-etgage-effective-tool-for-irrigation.html

Tas I., Kirnak H. (2011): Empirical models used in the estimation of crop evapotranspiration in semi arid region of Turkey. Journal of Adnan Menderes University Agricultural Faculty, 8: 57–66.

Thornthwaite C.W. (1948): An approach toward a rational classification of climate. Geographical Review, 38: 55–94.

Trajkovic S. (2005): Temperature-based approaches for estimating reference evapotranspiration. Journal of Irrigation and Drainage Engineering, 131: 316–323.

Walter I.A., Allen R.G., Elliott R., Jensen M.E., Itenfisu D., Mecham B., Howell T.A., Snyder R., Brown R., Echings S., Spofford T., Hattendorf M., Cuenca R.H., Wright J.L. (2002): The ASCE Standardized Reference Evapotranspiration Equation. In: Watershed Management and Operations Management 2000, Fort Collins, Jun 20, 2000: 744.

Zhang X.Y., Chen S.Y., Sun H.Y., Wang Y., Shao L. (2009): Root size, distribution and soil water depletion as affected by cultivars and environmental factors. Field Crops Research, 114: 75–83.

Received: March 11, 2025
Accepted: June 9, 2025
Published online: July 18, 2025