COMPARISON OF CLASS A PAN EVAPORATION WITH ESTIMATED REFERENCE EVAPORATION AND EVAPOTRANSPIRATION

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Abstract

Aquatic plants (macrophytes) can have a large effect on water evaporation, yet they are ignored when determining evaporation from lakes and reservoirs. The aim of the experiment was to determine the effect of a floating leaf macrophyte (*Nuphar lutea*, yellow water lily) on evaporation. The measured evaporation data were also compared with the calculated from the evaporation/evapotranspiration formulas used in the literature (Shuttleworth, FAO56 Penman-Monteith, Hargreaves-Samani and Priestley-Taylor formula). The results showed that the presence of yellow water lily increase Class A pan evaporation. Of the empirical formulas, the FAO-56 Penman-Monteith reference evapotranspiration values were closest to the observed evaporation values.

Keywords: evaporation, class A pan, floating leaf macrophyte

Összefoglalás

A vízi növények nagy hatással lehetnek a víz párolgására, ennek ellenére figyelmen kívül hagyják őket a tavak és víztározók párolgásának meghatározásakor. A kísérletben célul tűztük ki egy úszó levelű hínár (Nuohar lutea, sárga vízitök) párolgásra gyakorolt hatásának meghatározását. A mért párolgás adatokat a szakirodalomban alkalmazott párolgási formulákból számolt párolgásértékekkel is összehasonlítottuk (Shuttleworth, FAO56 Penman-Monteith, Hargreaves-Samani and Priestley-Taylor formula). Az eredmények azt mutatták, hogy a sárga vízitök növeli az A kád párolgását. Az empirikus formulák közül a FAO-56 Penman- Monteith referencia párolgás értékei álltak a legközelebb a mért párolgásértékekhez.

Kulcsszavak: párolgás, párolgásmérő A kád, úszó levelű hínár

Introduction

Evaporation measurement is cumbersome and impractical in many locations in the World. Therefore, solutions are needed that can be used to estimate evaporation without measurement. Originally, the Dalton types of equations were the mainstream formulas used to estimate evaporation. The subsequent amendments improved the accuracy of estimating evaporation (Xiang et al., 2020). Evaporation refers to the evaporation of the soil surface and the open water. In nature, in addition to the evaporation of surfaces, transpiration of plants is also present. The two phenomena (evaporation and transpiration) together were called evapotranspiration.

However, it is important to distinguish between two closely related concepts: potential evapotranspiration and reference crop evapotranspiration (Xiang et al., 2020). Potential evapotranspiration represents "the combined evaporation from the soil surface and transpiration from plants, represents the transport of water from the earth back to the atmosphere, the reverse of precipitation (Thornthwaite, 1948)." It can be estimated, for example, by the Hargareves-

Samani and the Priestley-Taylor formula. The reference crop evapotranspiration defines "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water" (Doorenbos and Pruitt, 1977). A good example to estimate reference crop evapotranspiration is the FAO56 Penman-Monteith formula recommended by FAO as a standardized method.

Aquatic macrophytes play an important role in water and wetlands balance (Said et al., 2018). Macrophytes can be divided depending on the connection with water and air: free floating; floating leaf but rooted; submerged and amphibian plants. Many of them are aggressive species that accelerate evaporation and contributes to the reduction of water resources (Soloviy& Malovanyy, 2019).

Nuphar lutea L. (yellow water lily) is common in the temperate regions of the northern hemisphere. They prefer water depths between 0.6 m and 2.4 m (Heslop-Harrison, 1955), so it also occurs in Hungarian lakes and reservoir, such as Lake Balaton. The floating leaves of yellow water lily shade most of the submerged leaves hereby limiting light penetration and photosynthesis (Schoelynck et al., 2014). Unlike the yellow water lily, other rooted, floating-leaved species like *Potamogeton natans* L. concentrate all leaves at the water surface which maximises their photosynthetic success (Bal et al., 2011). Nevertheless, transpiration of yellow water lily is not negligible, in lakes and reservoirs, where it occurs.

There are few studies in the literature that account impact of floating leaf macrophytes in estimating evaporation. Aim of study was determine the effect of floating leaf macrophyte on open water evaporation. A further aim is to determine which formula (hereinafter referred to as E/ET) is the most appropriate to estimate the actual evapotraspiration of yellow water lily. Investigating the effect of macrophyte on evaporation is particularly relevant, as any change in evaporation leads to change in water level and water quality.

Material and method

The location of the study is the experimental area of the Georgikon Campus, Hungarian University of Agriculture and Life Sciences. The Agrometeorological Research Station belongs to the observation network of the Hungarian Meteorological Service. Three different pan treatments were set in the study: Class A pan as control pan (*C*); Class A pan with sediment covered bottom (*S*) and Class A pan planted with yellow waterlily (*YWL*).

The observed daily pan evaporation values (the daily water loss was measured every morning at 7.00 am LMT) were compared to estimate the daily E/ET from the formulas below.

Daily evaporation rate, E_0 (mm day^{-1}) of water bodies was computed by the Shuttleworth formula (Shuttleworth, 1992), which was adapted from the original Penman equation (Penman, 1948):

$$E_0 = \frac{e_s R_n + \gamma * 6{,}43(1 + 0{,}536 * u_2)VPD}{LE(\Delta + \gamma)} \quad (1)$$

where R_n is net radiation (MJ m^{-2} day^{-1}), *m* is the slope of the saturation vapor pressure curve (kPa K^{-1}), u_2 is wind speed (m s^{-1}) at 2 m height, *VPD* is the vapor pressure deficit (kPa), *LE* is the latent heat of vaporization (MJ kg^{-1}), and γ is a psychrometric constant (kPa °C^{-1}).

The evapotranspiration was estimated using Penman- Monteith FAO-56 equation (Allen et al., 1998) for every day (mm day^{-1}) as follows (ET_{PM}):

$$ET_{PM} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} u(e_s - e_a)}{\Delta + \gamma(1 + 0.34u)} \quad (2)$$

where *G* is the soil heat flux density (MJ m^{-2} day^{-1}), T_a is the mean daily air temperature at 2 m height (°C), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), Δ is the slope of the vapor pressure curve (kPa °C^{-1}) and 0.408 is a conversion factor from MJ m^{-2} day^{-1} to equivalent evaporation in mm day^{-1}.

Hargreaves and Samani (1985) developed a simplified equation requiring only temperature, day of year and latitude for calculating evapotranspiration (ET_{HS}):

$$ET_{HS} = 0.00135\, K_T (T_a + 17.78)(T_{max} - T_{min})^{0.5} R_a \quad (3)$$

where, T_{max} is the daily maximum air temperature at 2 m height (°C), T_{min} is the daily minimum air temperature at 2 m height (°C), R_a is extraterrestrial radiation in millimetres per day and can be obtained from tables (Samani, 2000). Because *KT* (empirical coefficient) assumes a value of 0.17, the 0.0135*KT* constant can be replaced by 0.0023 (Hargreaves and Samani, 1985).

The Priestley-Taylor equation (Priestley and Taylor, 1972), (ET_{PT}) is given by

$$ET_{PT} = \alpha \frac{R_n - G}{\Delta - \gamma} \quad (4)$$

where α are parameter:

$$\alpha = 1 + \frac{r_H^{-1}}{\Delta + \gamma^*}\left[\gamma r_c + (\Delta + \gamma)\Delta^{-1} \rho C_p \frac{VPD}{R_n - G}\right] \quad (5)$$

where *rH* and *rc* are the aerodynamic and bulk surface resistances, respectively, ρ is the atmospheric density, C_p is the specific heat of moist air and γ^* is a modified psychrometric constant (Monteith and Unsworth, 1990).

Alltests were carried out with Microsoft Excel (paired-type t-test) and SPSS Statistics version 17.0 software (repeated measure ANOVA).

Results and discussion

The presence of sediment had no significant effect on daily mean evaporation, although it increased evaporation by 6.1% compared to the *C* (Figure 1). Yellow waterlily further increased daily mean evaporation by 10.6% compared to the *C* and 4.8% compared to the *S*. A significant difference was found between *C* and *YWL* ($p<0.001$). According to Waheeb Youssef and Khodzinskaya (2019), some floating aquatic plants such as water lily, can reduce the evaporation of water reservoirs. The reason for the decrease in evaporation is that the aquatic plant preventing the connection between the air and the boundary layer of water. In a previous study, Snyder & Boyd (1987) also came to this conclusion. However, these authors did not consider the process of transpiration (Jiménez-Rodríguez et al., 2019). In contrast to the former, several have reported that the presence of aquatic plants increases evaporation (Brezny et al., 1973; Anda et al., 2018; Jiménez-Rodríguez et al., 2019).

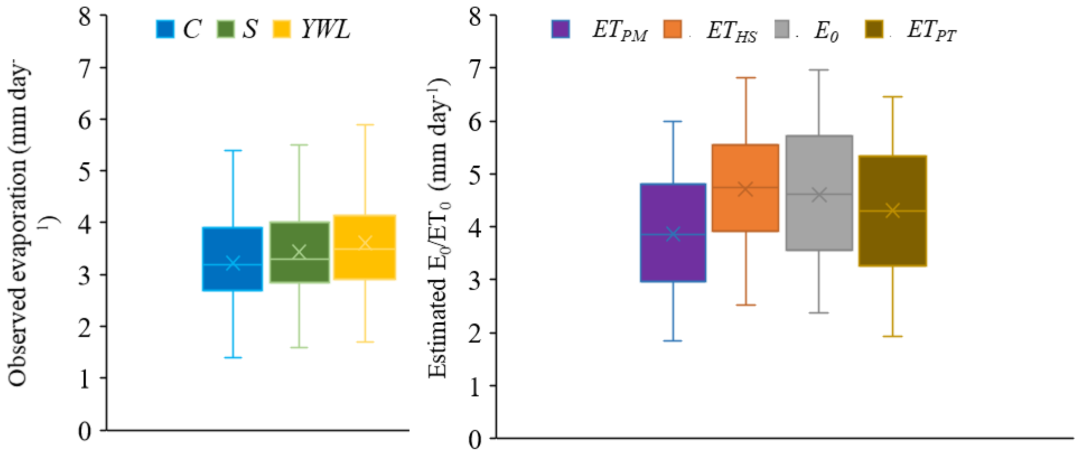

Figure 1. a) Daily mean pan evaporation (mm day^{-1}) of treated Class A pans: control pan (C), Class A pan with sediment cover bottom (S) and Class A pan with yellow water lily (YWL). b) Estimated daily mean evaporation (Shuttleworth formula, E_0) and evapotranspiration (ET_{PM} - FAO56 Penman- Monteith formula, ET_{HS} - Hargreaves-Samani formula and ET_{PT} - Priestley-Taylor formula)

The estimated *E/ET* was 16.6 – 31.4% higher than the E_p of *C* in 2020 growing season. In the case of *S*, there were low differences between the measured E_p and estimated *E/ET* (11.2-27.0%). E_p of *YWL* was closest to the estimated *E/ET* values, the estimated values were 6.7-23.3% higher than the measured rates. Irrespective of the Class A pan treatment, the ET_{PM} deviated the least from the measured E_p.

Irrespective of the pan treatments, there was a deviation in measured E_p rates and estimated *E/ET* values (Figure 2). The estimated *E/ET* values represent a different correlation (R^2 ranged from 0.437 and 0.5765, regardless of pan treatment). The highest R^2 value was for ET_{PM} for all pan treatments (*C*: 0.5765, *S*: 0.5395, *YWL*: 0.5386). Consistent with this, RMSE values were lowest for ET_{PM} regardless of pan treatment (*C*: 0.59 mm day^{-1}, *S*: 0.63 mm day^{-1}, *YWL*: 0.67 mm day^{-1}). Of the pan treatments, *C* was the highest R^2 values for all four estimated *E/ET* (R^2=0.5235-0.5765). Comparing the pan treatments, the lowest R^2 value was for ET_{PM}, ET_{HS} and ET_{PT} for *YWL* (0.5386, 0.437 and 0.4663, respectively). For E_0, R^2 was lowest for *S* (0.4957). RMSE values for all estimated *E/ET* were highest for *YWL* pan treatment (see Figure 2).

Tukey post-hoc comparisons revealed no significant difference between the E_p rate of *YWL* and ET_{PM} rate (p=0.510) (Table 1.). Therefore, of the formulas examined the Penman-Monteith assumption may be most suitable in a lake's estimation of evaporation when composed of floating leaf macrophytes (e.g. yellow water lily). Anda et al. (2018) concluded that estimated E_0 rates overestimated the measured E_p rates, when the Class A pan contained submerged macrophytes and sediments. Furthermore, similar to the results of current study, the ET_{PM} rate was closest to the measured E_p rate of submerged macrophyte in Class A pan.

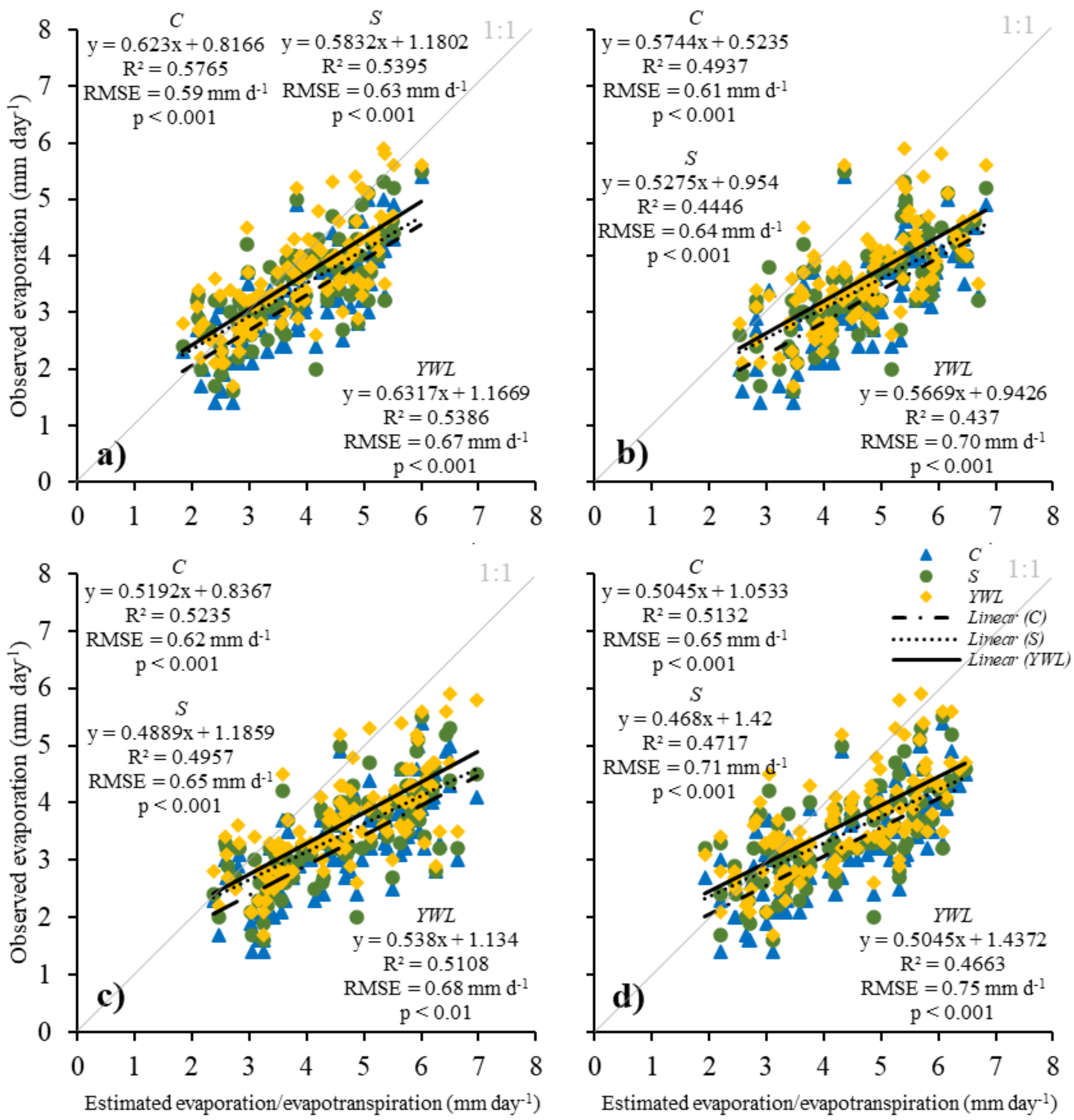

Figure 2. Relationship between the daily measured Class A pan evaporations (observed evaporation in different pan treatments) and daily reference evaporations and daily reference evapotranspirations computed by the FAO56 Penman- Monteith formula (a), Hargreaves-Samani formula (b), Shuttleworth formula (c) and Priestley-Taylor formula (d). C, S, and YWL denotes control, sediment covered, and yellow water lily implemented Class A pans, respectively.

Table 1 Effect on the observed evaporation (control pan - C, Class A pan with sediment cover bottom - S and Class A pan with yellow water lily - YWL) and estimated evaporation/evapotranspiration rates (E_0 - Shuttleworth formula, ET_{PM} - FAO56 Penman- Monteith formula, ET_{HS} - Hargreaves-Samani formula and ET_{PT} - Priestley-Taylor formula)

(I) treatment	(J) formula	Mean Difference (I-J)	Sig.	95% Confidence Interval Lower Bound	Upper Bound
C	ET_{HS}	-1.480*	**0.000**	-1.892	-1.068
	ET_{PM}	-0.642*	**0.000**	-1.054	-0.231
	ET_{PT}	-1.082*	**0.000**	-1.494	-0.671
	E_0	-1.378*	**0.000**	-1.789	-0.966
S	ET_{HS}	-1.270*	**0.000**	-1.682	-0.859
	ET_{PM}	-0.433*	**0.032**	-0.844	-0.021
	ET_{PT}	-0.873*	**0.000**	-1.284	-0.461
	E_0	-1.168*	**0.000**	-1.580	-0.757
YWL	ET_{HS}	-1.096*	**0.000**	-1.508	-0.685
	ET_{PM}	-0.258	0.510	-0.670	0.153
	ET_{PT}	-0.699*	**0.000**	-1.110	-0.287
	E_0	-0.994*	**0.000**	-1.405	-0.582

Based on observed means.
The error term is Mean Square(Error) = 1.017.
The error term is Mean Square(Error) = 1.065.
The error term is Mean Square(Error) = 1.327.
*. The mean difference is significant at the 0.05 level.

Conclusion

The change in E_p of a standard Class A pan with a sediment-covered bottom and with a floating leaf macrophytes (yellow water lily) was observed at Keszthely, in 2020 growing seasons. For *S* and *YWL* pan treatments increased E_p with a larger increment when floating leaf macrophytes were used but a smaller increment when sediment was used compared to *C*. Estimated ET_{PT}, ET_{HS} and E_0 rates overestimated the measured E_p rates during this study for all three pan treatments, therefore we do not propose the use of them to estimate evaporation of lake or reservoir with floating leaf macrophytes. However, ET_{PM} may be considered appropriate for estimating a lakes and reservoirs evaporation with floating leaf plants.

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