19. Gumpensteiner Lysimetertagung 2021, 31 – 36
ISBN: 978-3-902849-83-0

Evaluation of evapotranspiration methods by means of weighing lysimeter data in Argentina

Adán M.G. Faraminán[1,2*], Facundo Carmona[1,2], Raúl Rivas[1,3], Florencia Degano[1,3] and Paula Olivera Rodriguez[1,2]

Summary

The Instituto de Hidrología de Llanuras -Argentina has been studying evapotranspiration (*ET*) using lysimeters since 2010 with the aim of validating different methods. This work presents the study about direct measurements of actual *ET* by means of a weighing lysimeter in an Argiudol soil from Pampa Plains, Argentina. The information generated was used to evaluate the Penman-Monteith (FAO-56). The methods were tested under different soil moisture conditions. Estimated *ET* values showed a good correlation with actual *ET* when soil moisture was high, moreover greater differences were showed when the soil moisture tends to lower values (<30%). However, the correlation improved significantly when the methods were corrected with evaporative fraction. This study provides necessary information for the validation of local-regional models applied in Argentinian plains, where *ET* is a term of great importance.

Keywords: agrometeorological station, evaporative fraction, soil moisture, surface energy balance

Introduction

The evapotranspiration (*ET*) can be obtained indirectly from information logged in surface energy balance stations or on a regional scale with the use of satellite or reanalysis data. In order to have reliability of the models used, it is important to validate the information generated with direct measures of evapotranspiration. Actually, lysimeters are the most accurate instruments for estimating changes in soil water content. However, in Argentina there are few agrometeorological stations that have these instruments (Lazzari et al. 1984, Andriulo et al. 2004, Requena et al. 2010, Olmedo & Vallone 2011, Caprile et al. 2016).

Against this background, the Instituto de Hidrología de Llanuras "Dr. Eduardo Ussunof" decided to create two prototypes of weighing lysimeters for monitoring soil water storage. The first was installed in 2010 and its weighing system was manual by means of a hydraulic scale. The second was installed in 2017, and unlike the previous one, this lysimeter had a load cell that recorded the its weight every hour (Faramiñán et al. 2021).

The information generated by these instruments allowed to validate methods at different spatial scales. For example, Degano et al. (2017) validated MOD16 product with lysimetric information. Recently, Olivera Rodriguez et al. (2020) published a new methodology for calculating the water footprint in soybean crops with weighing lysimeter data as complementary information.

The aforementioned works base their methodology on remote sensing, using a regional scale. In order to generate information useful for validate remote sensing data, this work aims to analyze the performance of plot models. Thus, actual evapotranspiration (*ETa*) values were correlated with the Penman-Montieth/FAO 56 method (ET_0). *ETa* values were calculated daily and hourly from data measured by the two weighing lysimeters

[1] Instituto de Hidrologia de Llanuras „Dr. Eduardo Usunoff" (IHLLA), Gral. Pinto 399, Tandil, 7000, Argentina, [2] Consejo Nacional de Investigaciones Cientificas y Técnicas (CONICET), [3] Comisión de Investigaciones Cientificas de la Provincia de Buenos Aires (CICPBA)

* Ansprechpartner: Adan M.G. Faraminán, email: adanfaraminian@ihlla.org.ar

and ET_0 was calculated on the same time scale based in the information from a surface energy balance station. This last method was corrected applying a stress factor based on soil moisture data (ET_0xEF).

Materials and Methods

The study was realized in Tandil, Argentina (37° 19' 07" S., 59° 04' 44" W.). The area has a humid-subhumid temperate climate, with a mean annual rainfall (1970-2010) of 925 mm (Aliaga et al. 2017). The soil corresponds to a Typical Argiudol and has an agricultural and livestock aptitude. Three species predominate in the vegetation cover (*Dactylis glomerata, Festuca Arundinacea* y *Lolium multiflorum*). The period of study was from 2011 to 2014.

Figure 1 shows the weighing lysimeters design. The instruments construction was based on the guidelines of Aboukhaled et al. (1982). *Figure 1a*) shows the manual weighing lysimeter and sensors installed inside the tank. It was built by filling the tank with the soil of the place respecting the profile horizons. A second weighing lysimeter was set up with a load cell, which measure the tank weight every hour, and the soil moisture sensors were installed outside the tank. This lysimeter was designed so that the soil inside the tank does not suffer disturbances in the installation (Faramiñán et al. 2021). Both lysimeters are on the same plot.

The *ETa* is calculated from the lysimeters as follows,

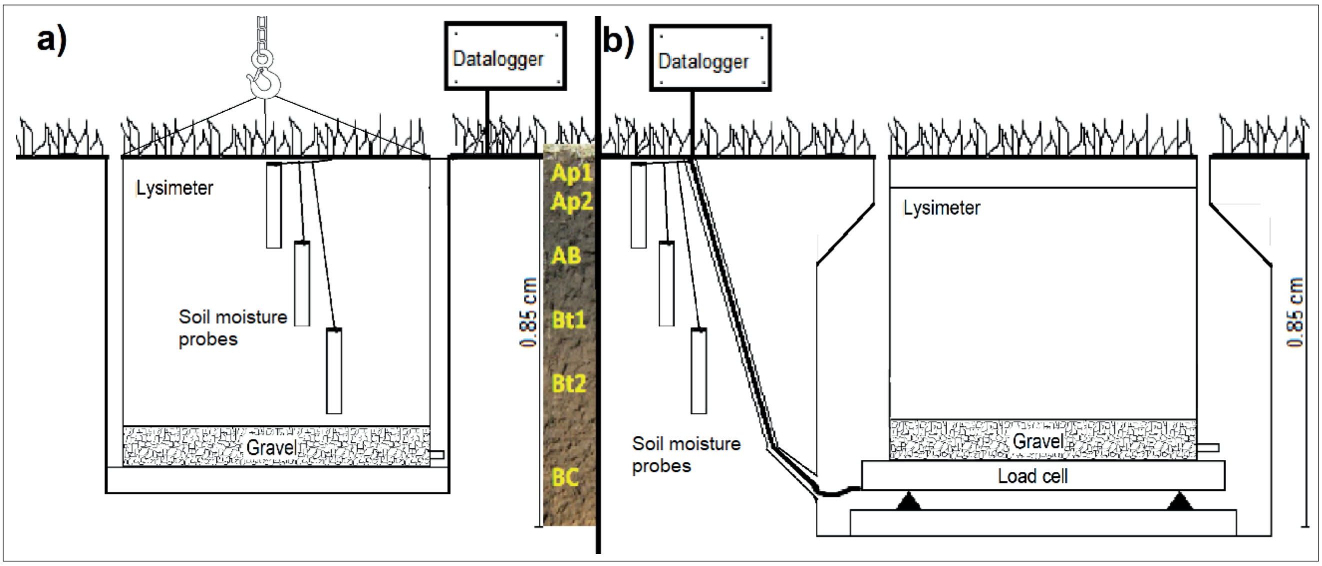
$$ETa = \frac{1}{\rho_w A_{lys}} \frac{\Delta w}{\Delta t} \qquad (1)$$

where *ETa* is the actual evapotranspiration [mm day^{-1} or mm hour^{-1}], ρ_w is the water density, *w* is the weight lysimeter measurement, $\Delta w/\Delta t$ is the change of water in the lysimeter and A_{Lys} is the effective area of evaporating foliage. In this work A_{Lys} is equivalent to 15% more than the lysimeter physical area (0.27 m^2).

On the other hand, the Penman-Montieth method was calculated following the FAO-56 manual (Allen et al. 1998),

$$ET_0 = \frac{C_1\,\Delta\left(Rn - G\right) + \gamma \dfrac{C_2}{T + C_3} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + C_4\,u_2\right)} \qquad (2)$$

Figure 1. Weighing lysimeters diagrams and CSM used in the test. In a) the manual lysimeter and a profile soil image. In b) the automatic lysimeter.



where ET_0 is the reference evapotranspiration rate, T is the mean air temperature [°C], u_2 is the wind speed [m s^{-1}], Rn is the net radiation flux into the soil, G is the sensible heat flux [MJ m^{-2} day^{-1}], e_s is the mean saturation vapour pressure, e_a is the mean ambient vapour pressure [kPa], γ is the psychromatic constant [kPa/°C] and Δ is the saturation pressure at atmospheric temperature slope. The constants *C1, C2, C3* and *C4* were used to obtain the ET_0 in [mm day^{-1}] or [mm hour^{-1}].

To obtain actual values of *ET* it is necessary to multiply the Eq. 2 by a factor that containing soil-vegetation information. For this reason, in this work the Evaporative Fraction (*EF*) was used as a correction factor. The *EF* has a strong link with water soil available, which is the limiting factor of latent heat flux (Nutini et al. 2014). This flux is associated directly with *ET*.

Figure 2 shows the behavior between the ETa/ET_0 ratio and the *EF*. A range of values of this relationship presents a linear behavior and, considering the soil moisture, it can be expressed as follows,

$$EF_L = \frac{SM_i - SM_{\min}}{SM_{\max} - SM_{\min}} \tag{3}$$

where SM is the soil moisture measurement by means of capacitive probes.

However, it is observed in *Figure 2* that this relationship is not completely linear (Gentine et al. 2007). Thus, a new equation was proposed for a better fit,

$$EF = \frac{1}{1 + \exp\left[0.5 - \dfrac{SM_i - SM_{\min}}{SM_{\max} - SM_{\min}}\right] \times 10} \tag{4}$$

Finally, in order to observe the performance of ET_0 and ET_0 multiplied for *EF* (ET_0xEF) against *ETa*, the follows metrics were used,

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(ETa^i - ET^i_{\text{mod}})^2} \tag{5}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|ETa - ET_{\text{mod}}\right| \tag{6}$$

$$NSE = 1 - \frac{\sum_{i=1}^{N}(ETa^i - ET^i_{\text{mod}})^2}{\sum_{i=1}^{N}(ETa^i - ET^i_{mean})^2} \tag{7}$$

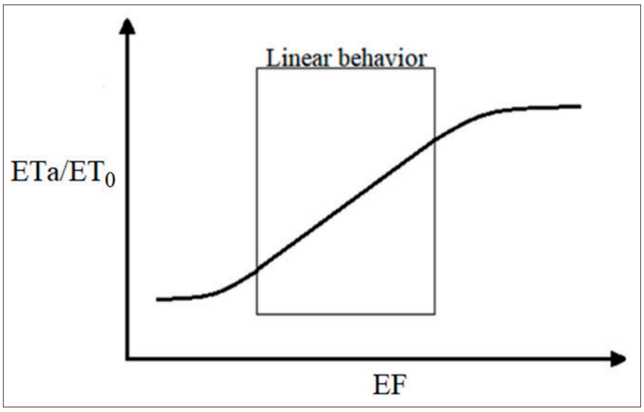


Figure 2. Relationship between ETa /ET_0 and *EF*. The square represents the value range with linear behavior.

where ET_{mod} is ET_0 or ET_0xEF, ET_{mean} is the mean value of *ETa*, *N* is the number of measurements, *RMSE* is the root mean square error, *MAE* is mean absolute error and *NSE* is Nash-Sutcliffe model efficiency coefficient. The *NSE* efficiency factor is useful and effective in hydrological studies (McCuen et al. 2006, Ritter and Muñoz-Carpena 2013).

Results and Discussion

Figure 3 shows the relationships between ET_0 and *ETa*, and ET_0xEF with *ETa*. The overestimation of ET_0 respect to *ETa* was observed on a daily scale (*Figure 3a*). However, applying the *EF* as a soil-vegetation factor, a considerable improvement in the relationship was obtained (*Figure 3c*). The same can be seen on an hourly scale (*Figures 3b, 3d*).

Table 1 shows the statistics relationships of *Figure 3*. Considering *EF* as a correction factor improved the results. In one hand, the *RMSE* was reduced by 57% on a daily scale, while on an hourly scale by 47%. On the other hand, *NSE* values close to 1 indicate that the estimated or predicted values are correct. In our case, the *NSE* indicates a better performance in ET_0xEF than in *ET0*.

In the two time scales, it was observed that the models overestimated when the soil humidity values were lower than 0.15 m^3 m^{-3}, due to the high atmospheric demand of water vapor which exceeds the rate that the vegetation or the soil can provide. In some cases, the estimated values of ET_0 were 4 times higher than the *ETa*.

These results show the need for a correction factor that contains information about the vegetation or the soil that allows to obtain actual ET values. Many authors have approached the subject from different perspectives. For example, Pereira 2004, used the decoupling factor multiplied by the Preatsley-Taylor method. This factor is mainly defined by the aerodynamic vegetation resistance. Other authors relate the correction

Table 1. Statistical indices of the relationship between estimated (ET_0 and ET_0xFE) and observed (*ETa*) data.

Model	Units	R2	RMSE	MAE	NSE
ET_0	mm day^{-1}	0.72	1.12	0.77	0.07
	mm $hour^{-1}$	0.50	0.15	0.11	-0.51
ET_0xEF	mm day^{-1}	0.83	0.48	0.35	0.83
	mm $hour^{-1}$	0.73	0.08	0.07	0.49

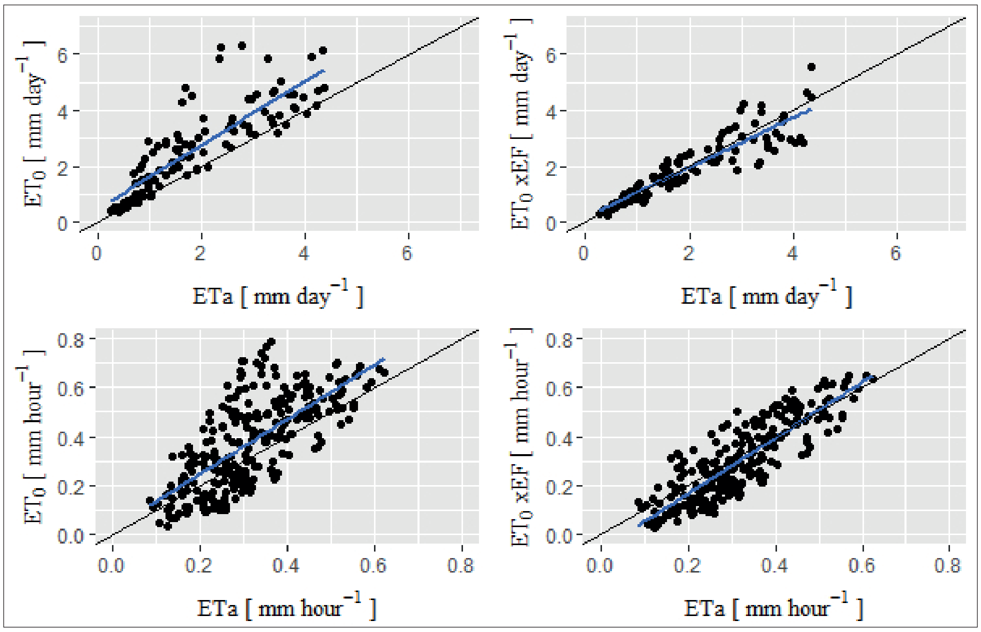


Figure 3. Correlation graphs between ET_0 - ET_0xEF and *ETa* for daily (a and b) and hourly scales (c and d). The blue line is the trend and the black line is the line 1:1.

factor with the sensitive and latent heat flux (Gentine et al. 2007). However, there are few studies that consider soil moisture as a correction factor. Besides, as it can be observed in this work, precise information is obtained on the water storage changes in the unsaturated zone if the factor is adjusted with the relationship between the *ETa* and ET_0 values.

Conclusions

In this work, the Penman-Montieth model (FAO56) was evaluated by means of a weighing lysimeters. Hourly and daily data from a meteorological station located in the city of Tandil, Argentina, were used. The ET_0 model overestimates the *ETa* values obtained by the lysimeters, for this reason the evaporative fraction is proposed as a correction factor. Considering this factor, it was observed that the model improved significantly, with a reduction in RMSE values to 50% approximately, while the *NSE* values indicated a better performance. This technique can be extrapolated to monitor actual evapotranspiration at a larger spatial scale through a set of sampling sites. With the results of this work, it is expected to contribute to scientific knowledge about the evapotranspiration process, to the development of scientific-technical applications and decision-making in the management of water resources in plains areas of Argentina.

Literature

Aboukhaled A., Alfaro A., Smith M. (1982) Lysimeters. Irrigation and Drainage Paper, 39, 68.

Aliaga V., Ferrelli F., Piccolo M.C. (2017) Regionalization of climate over the Argentine Pampas. International journal of climatology, 37 (S1), 1237-1247. https://doi.org/10.1002/joc.5079

Allen R.G., Pereira L.S., Raes D., Smith M. (1998) Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome, 300(9), D05109.

Andriulo A., Hang S., Sasal M.C., Nassetta M., Portela S.I., Cañas A. (2004) Efecto del tipo de suelo sobre el transporte de solutos en lisímetro. II. Atrazina. In XIX Congreso Argentino de la Ciencia del Suelo. Actas: p (Vol. 418).

Caprile A.C., Aparicio V.C., Portela S.I., Sasal M.C., Andriulo A.E. (2017) Drenaje y transporte vertical de herbicidas en dos molisoles de la pampa ondulada Argentina. Ciencia del suelo, 35(1), 147-159.

Carmona F., Rivas R., Ocampo D., Schirmbeck J., Holzman M. (2011) Sensores para la medición y validación de variables hidrológicas a escalas local y regional a partir del balance de energía. Aqua-LAC. 3 (1), 26 - 36.

Degano M.F. (2017) Evaluación del producto de evapotranspiración global MOD16 con medidas in situ en la región de la Pampa Húmeda, Argentina. Doctoral dissertation, Universidad de Valencia.

Faramiñán A.M.G, Carmona F., Rivas R., Degano M.F., Olivera Rodriguez P. (2021) Monitoreo de la evapotranspiración real horaria por medio del balance energético y un lisímetro de pesada. Boletín Geológico y Minero. Madrid, España. In press.

Gentine P., Entekhabi D., Chehbouni A., Boulet G., Duchemin B. (2007) Analysis of evaporative fraction diurnal behaviour. Agricultural and forest meteorology, 143(1-2), 13-29. ISSN 0168-1923, https://doi.org/10.1016/j.agrformet.2006.11.002.

Lázzari M., Laurent G., Victoria R. (1984) Uso del nitrogeno del fertilizante por el cultivo de trigo en la region semiarida pampeana, argentina. In Proceedings of the Regional Workshop on Nuclear Techniques in Crop Production (Piracicaba, 1984)(CERRI, CC, ATHIÉ, D., Eds), Comissäo Interamericana de Energia Nuclear and Centro de Energia Nuclear na Agricultura, Piracicaba (pp. 173-181).

McCuen R.H., Knight Z., Cutter A.G. (2006) Evaluation of the Nash-Sutcliffe Efficiency Index. Journal of Hydrologic Engineering, 11, 597-602. https://doi.org/10.1061/(ASCE)1084-0699(2006)11:6(597).

Nolz R., Cepuder P., Eitzinger J. (2016) Comparison of lysimeter based and calculated ASCE reference evapotranspiration in a subhumid climate. Theoretical and Applied Climatology, 124, 315-324. https://doi.org/10.1007/s00704-015-1417-y

Nutini F., Boschetti M., Candiani G., Bocchi S., Brivio P.A. (2014) Evaporative fraction as an indicator of moisture condition and water stress status in semi-arid rangeland ecosystems. Remote Sensing, 6(7), 6300-6323.

Olmedo G., Vallone R. (2011) Diseño y construcción de un lisímetro de pesada para la medición de evapotranspiración real en vid en Mendoza, Argentina. In Simposio Argentino de Viticultura y Enología. 9-11 noviembre 2011. Mendoza. Argentina.

Pereira A.R. (2004) The Priestley–Taylor parameter and the decoupling factor for estimating reference evapotranspiration. Agricultural and Forest Meteorology 125, 305–313. https://doi.org/10.1016/j.agrformet.2004.04.002

Requena A., Nordenströn G., Castillo E. (2010) Coeficientes de cultivo de manzano en período de formación, obtenidos en lisímetros de drenaje. EEA INTA Alto Valle, 1, 1-7.

Ritter A., Muñoz-Carpena R. (2013) Performance evaluation of hydrological models: Statistical significance for reducing subjectivity in goodness-of-fit assessments. Journal of the Hydrology. 480, 33–45. https://doi.org/10.1016/j.jhydrol.2012.12.004

Rodriguez P.O., Holzman M.E., Degano M.F., Faramiñán A.M.G., Rivas R.E., Bayala M.I. (2020) Spatial variability of the green water footprint using a medium-resolution remote sensing technique: The case of soybean production in the Southeast Argentine Pampas. Science of The Total Environment, 142963. ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.142963.