# CHAPTER 1

# LOW-COST CLASS A EVAPOTRANSPIRATION PAN FOR REFERENCE EVAPOTRANSPIRATION ESTIMATION IN PROTECTED AND FIELD ENVIRONMENTS: A PRACTICAL APPROACH

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**ABSTRACT:** Currently, there are various methods for determining the Class A pan coefficient (Kp) in estimating reference evapotranspiration (ETo), which is of utmost importance for water management in agriculture. This study aimed to estimate ETo inside and outside agricultural greenhouses using a low-cost constructed Class A pan (TCA-c) method. To estimate ETo, it is necessary to establish the Kp, as ETo is the product of ECA multiplied by Kp. This study employed the calibration method, comparing ETo determined by Penman-Monteith (EToPM) with Class A pan evaporation (ECA) to determine Kp. EToPM served as the standard for correlations with reference evapotranspiration using the TCA-c method inside and outside an agricultural greenhouse, avoiding the installation of a "Class A" pan inside the greenhouse. The experiment was conducted at UFF's Gragoatá campus in Niterói - RJ. Four TCA-c pans were installed (three inside and one outside an agricultural greenhouse) and managed for one year. Principal Component Analyses (PCA) revealed significant differences in ETo throughout the seasons. Adjusted Kps were established for all pans. It was observed that ETo inside the greenhouse was lower than that estimated outside. It is recommended to install the TCA-c pan inside the greenhouse for ETo estimation, utilizing different Kps throughout the seasons.

**KEYWORDS:** Reference evapotranspiration; Pan coefficient; Class A Pan.

# INTRODUCTION

Brazil is the second-largest producer of crops in protected environments in Latin America, with an approximate area of 30,000 hectares in 2019, trailing only Mexico, which had 41,000 hectares. This type of production is entirely conducted under irrigation. What is observed throughout the country is a complete absence of soil moisture monitoring instruments to determine the necessary irrigation for the crops. This irrigation requirement should be calculated based on the evapotranspiration rate removed from the system. Evapotranspiration is a complex process involving the evaporation of water from the soil and vegetated surfaces, as well as plant transpiration. To measure evapotranspiration, various techniques and instruments can be employed, utilizing both direct and indirect methods. One way to assess the accuracy of reference evapotranspiration (ETo) estimation methods is by comparing them with the Penman-Monteith method, which has been recommended by the FAO as the standard method for ETo estimation (Allen et al., 1998).

There is currently a trend towards the use of automated meteorological stations that assist in determining reference evapotranspiration, thereby reducing errors in the water depth to be applied to crops. When programmed, these stations can employ the Penman-Monteith method to calculate ETo. However, most farmers use alternative methods and lack access to such equipment, preventing them from determining ETo using the standard method. Therefore, correction equations in relation to the Penman-Monteith method (the FAO standard method) are desirable to minimize errors in ETo calculation.

Reference evapotranspiration can be estimated through various methods, and the Class A Pan method has been one of the most widely employed methods worldwide, owing to its simplicity, relatively low cost, and its ability to provide daily estimates of evapotranspiration. However, its use within greenhouses remains a subject of controversy. Research results regarding which Class A Pan Coefficient (Kp) should be used inside the greenhouse are inconclusive. Furthermore, some producers consider it unfeasible to allocate approximately 10 $m^2$ of unproductive space for the Class A pan container inside the greenhouse.

Vetiver grass (*Vetiveria zizanioides* L. Nash) is used by part of Asia, mainly India, to make handicraft products, manufacture perfumes, medicines, and insect repellent (Gomes et al., 2020). It has been widely used in several countries because it has a deep and abundant root system, and because it is very resistant to climatic variations and tolerates contaminants (Ucker & Almeida, 2013). Vetiver grass is easy to adapt and is used in sediment control, phytoremediation, affluent treatment, and slope stabilization (Medeiros et al, 2020).

## MATERIALS AND METHODS

The study was conducted at the UFF Gragoatá campus. Two automated weather stations of the brand/model E5000 by IRRIPLUS® were installed: one in an outdoor area with Paspalum maritimum vegetative cover, having a 10-meter border, and the other inside an Agricultural Greenhouse (AG). In these areas, four TCA-c pans were also installed (one outdoors and three inside the AG). The meteorological data required for reference evapotranspiration (ETo) calculation (global radiation, air temperature, relative humidity, and wind speed) were collected from the aforementioned stations. The equation used for calculating reference ETo using the Penman-Monteith Method was as follows the Equation 1:

$$ETo\ (PM) = 0.409(Rn - G) + (900 / (T + 273)) * W * (es - e) / (1 + 0.34 * V) \quad (Eq.\ 1)$$

Where:

- ETo (PM) = reference evapotranspiration using the PM method, in millimeters per day (mm $d^{-1}$).
- Rn = net radiation, MJ $m^{-2}$ $d^{-1}$; G = soil heat flux, MJ $m^{-2}$ $d^{-1}$;
- T = mean air temperature, °C;
- W = mean wind speed at 2m height, m $s^{-1}$;
- (es - e) = vapor pressure deficit, kPa;
- and 900 = conversion factor.

The development and construction of the low-cost evapotranspiration pan followed all dimensions and installation protocols recommended by USWB/USA and FAO. The difference is that it was manufactured by adapting a 200-liter iron drum, cut to a height of 25.4 cm (10”) and an internal diameter of 120.6 mm. These TCA-c pans were painted in light gray, and wooden slats (from discarded pallets) were made to the prescribed measurements. A mechanism with graduated rulers in millimeters was installed on the internal walls of the TCA-c pans for reading purposes. Water levels inside the pans fluctuated between 5-7.5 mm from the edge of the pans.

Daily readings from the pans were obtained at the same time during the period from 01/09/2021 to 01/09/2022 (one year), and hourly data from the weather stations (EMs) were collected. The evaporation from the Class A pans (ECA) was measured by calculating the difference between daily readings. The Class A Pan Coefficient (Kp) was established based on the season and the reference ETo determined by the EMs.

The collected data were assessed for normality, subjected to multiple comparisons (Tukey, 0.05 significance level), and analyzed using Principal Component Analysis (PCA) and clustering techniques with R software.

## RESULTS AND DISCUSSION

Table 1 presents the average values of meteorological data provided by the weather stations installed inside and outside the agricultural greenhouse. In Table 2, the Class A Pan Coefficients (Kp) are shown, based on the correlation between Penman-Monteith reference evapotranspiration (EToPM) and Class A Pan evaporation (ECA), for both the protected environment and field conditions, across the four seasons of the year.

| Seasons | T In | UR In | W In | R In | T Out | UR Out | W Out | R Out | P Out |
|---|---|---|---|---|---|---|---|---|---|
| | ºC | % | m s-¹ | MJ | ºC | % | m s-¹ | MJ | mm |
| Spring | 24.24 | 81.85 | 0 | 3.93 | 23.58 | 81.03 | 0.48 | 16.84 | 5.11 |
| Summer | 27.93 | 78.74 | 0 | 4.61 | 26.46 | 77.09 | 0.35 | 20.17 | 4.23 |
| Fall | 24.24 | 81.76 | 0 | 2.39 | 23.32 | 83.46 | 0.13 | 13.28 | 3.08 |
| Winter | 22.59 | 82.08 | 0 | 2.25 | 22.17 | 85.56 | 0.21 | 12.92 | 1.46 |

T: Average Temperature; UR: Average Relative Humidity; W: Average Wind Speed; R: Average Solar Radiation; P: Average Precipitation; In: Inside; Out: Outside.

Table 1. Weather data collected from weather stations inside and outside the greenhouse.

| Seasons | ECA In | EToPM In | Kp In | ECA Out | EToPM Out | Kp Out |
|---|---|---|---|---|---|---|
| | -----mm----- | | | -----mm----- | | |
| Spring | 1.93 b | 1.14 b | 0.62 | 5.45 a | 3.42 b | 0.89 |
| Summer | 2.61 a | 1.28 a | 0.55 | 5.68 a | 4.31 a | 0.96 |
| Fall | 1.75 b | 0.80 c | 0.60 | 3.98 b | 2.41 c | 0.82 |
| Winter | 1.59 b | 0.79 c | 0.60 | 3.49 b | 2.30 c | 0.81 |
| CV (%) | 56.79 | 27.45 | 78.15 | 61.97 | 36.21 | 106.65 |

ECA: Evapotranspiration of the class A pan; EToPM: Penman-Monteith Evapotranspiration; Kp: Pan coefficient; In: Inside; Out: Outside. Consecutive means with the same letters in the column do not differ by Tukey's test at 5%.

Table 2. Evapotranspiration of the class-A pan and Penman-Monteith and Pan coefficients inside and outside the greenhouse.

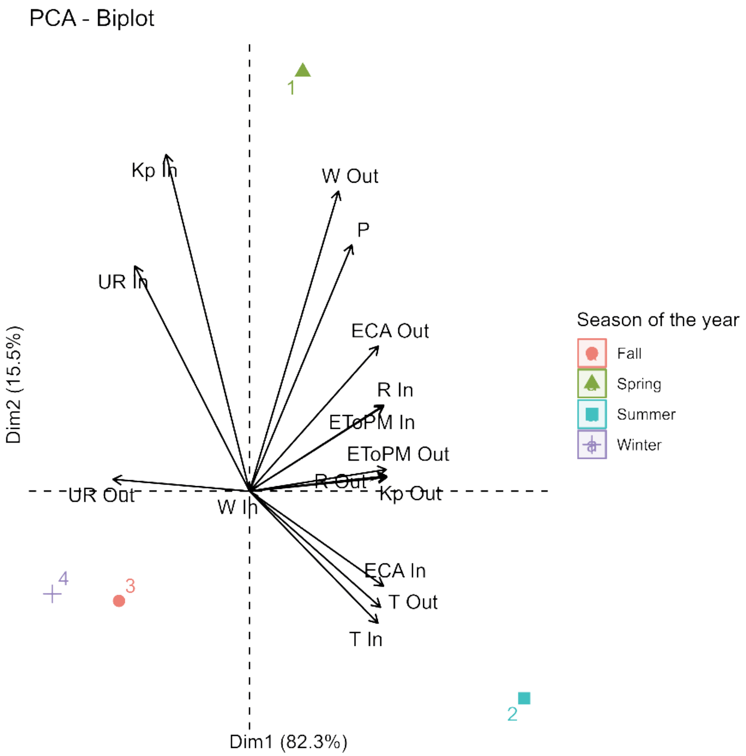
The protected environment condition exhibited a lower Kp, with evaporation ranging from 54 to 64% less, resulting in an evapotranspiration 65 to 70% lower across the analyzed seasons. Kp variations in the protected environment ranged from 0.55 to 0.62, while in the field, they varied from 0.81 to 0.96. There was greater data variability in field conditions. These same trends were also observed by Cunha (2011) when determining TCA pan Kps using different methods: Doorenbos and Pruitt (1977), Cuenca (1989), Snyder (1992), Pereira et al. (1995), Allen et al. (1998), and the correlation between Penman-Monteith reference evapotranspiration (EToPM) and Class A Pan evaporation (ECA) in both protected and field environments in the Botucatu-SP region.

The author concluded that, in a protected environment, the methods of Allen et al. (1998) and Snyder (1992) are the most recommended for dry months, while the correlations between EToPM and ECA and Cuenca (1989) are suitable for rainy months. In field conditions, the methods of Allen et al. (1998) and the correlations between EToPM and ECA are suitable for dry months, and Allen et al. (1998) and Cuenca (1989) for rainy months. The Allen et al. (1998) method proved to be the most efficient, regardless of the environment or the analyzed months.

The plastic covering used in the experimental agricultural greenhouse, combined with the use of a 70% shade net, significantly alters the radiation balance compared to the external environment. This is due to the attenuation (absorption and reflection) of incident solar radiation, resulting in a reduction of the internal radiation balance and, consequently, affecting evapotranspiration (Sentelhas, 2001). The difference between internal and external evapotranspiration varies with meteorological conditions. In this study, it was observed that daily radiations in the external environment were, on average, 76.6% higher than internal radiations throughout the year. Autumn/winter showed the highest radiation variations (82.0 and 82.6%), due to the variation in solar incidence within the greenhouse, which was oriented southeast/northwest.

The proximity of a forest to the east contributed to this difference, impacting the average data of the three internal TCA pans distributed longitudinally in the greenhouse. This resulted in varying amounts of radiation received, leading to differences in pan evaporation.

Figure 1 displays the Principal Component Analysis in a biplot graph. Inside the AG, a positive relationship between air humidity and Kpin was observed. The pan evaporation values closely align with the EMs' evapotranspiration values, which increases Kp values under high humidity conditions. In the external environment, the opposite phenomenon occurs. High air humidity within the AG hinders evaporation due to the lower energy differential between the two environments.



ECA: Evaporation of the class A pan; EToPM: Penman-Monteith Evapotranspiration; Kp: Pan coefficient; T: Average Temperature; UR: Average Relative Humidity; W: Average Wind Speed; R: Average Solar Radiation; P: Average Precipitation; In: Inside; Out: Outside. 1: spring; 2: summer, 3: fall, and 4: winter.

Figure 1. Principal Component Analysis (PCA) of the parameters across different seasons of the year.

The wind speed and precipitation only impact the external environment since these meteorological phenomena are not present inside the agricultural greenhouse. It was observed that these parameters had a greater impact on the spring during the study period. This is because, in addition to magnitude, the direction of the coefficients of the original variables exhibited higher absolute values.

In summer, the internal temperature in the AG is negatively related to KpIn because the internal Class A Pans evaporate more water, necessitating larger corrections in the calculation of evapotranspiration.

The parameter most strongly related to Kpout is solar radiation, as it is the primary energy source for the planet and can transform liquid water into vapor. Thus, the evapotranspiration process is determined by the amount of energy available to vaporize water. In the case of WSout, ECAout closely approximates the values of EToPM.

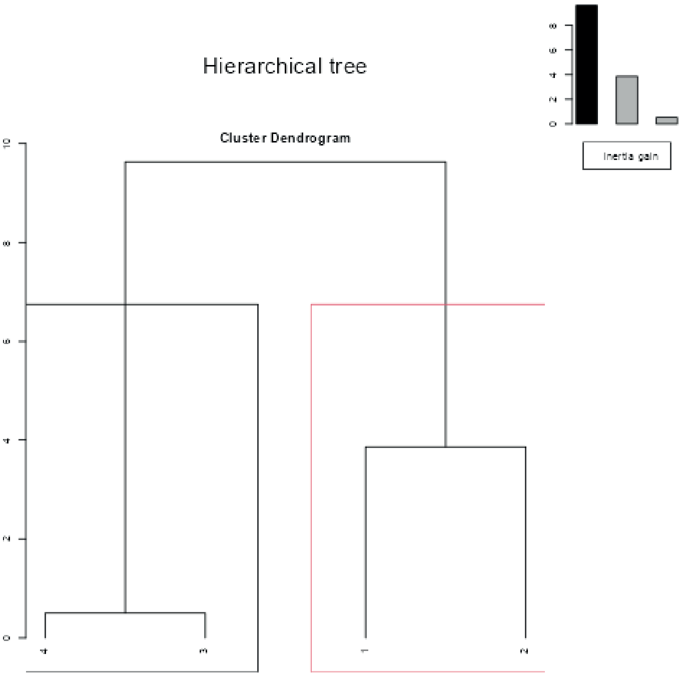


Figure 2: Cluster analysis in which 1 represents spring, 2 summer, 3 autumn, and 4 winter.

Cluster analysis hierarchically separated the seasons into two groups: fall/winter and spring/summer (Fig. 2). Thus, it is evident that a single Kp value cannot be used in both protected and open environments, as there are various variations in climatological parameters throughout the year.

Lopes Filho (2000) estimated ETo inside an AG and estimated the evaporation occurring in three types of Class A Pans (TCAUSWB, Mini metallic pan, and Mini plastic pan). ETo was estimated using the PenmanMonteith-FAO method based on meteorological data also collected from an automatic weather station installed inside the AG. The Kp values ranged from 0.25 to 0.93 for TCAUSWB, 0.23 to 0.85 for the mini metallic pan, and 0.30 to 0.95 for the mini plastic pan.

A variety of machine learning (ML) algorithms, such as random forest (Lu et al., 2018), artificial neural networks (Goyal et al., 2014), support vector machines (Kisi, 2015), among others, have been extensively utilized to predict TCAc. These ML methods offer robust, nonparametric models that don’t require extensive knowledge of internal variables, allowing them to handle complex, nonlinear functions and diverse data more effectively than traditional models (Wang et al., 2023). Compared to traditional statistical models, ML models are known for their superior predictive performance, adaptability across various scenarios, and flexibility in using different input variables (Schmidt et al., 2020).

This research will continue to establish the TCAc coefficient more accurately, incorporating other measurement equipment such as TCAUSWB, atmometer, and automatic reading Class A Pan with pressure transducer.

## CONCLUSION

The results obtained and the experimental conditions lead to the following conclusions: A single Kp value cannot be used for both protected and open environments due to variations in climatological parameters throughout the year. The protected environment exhibits a lower Kp compared to the external environment. Kp variations in the protected environment ranged from 0.55 to 0.62, while in the field, they varied from 0.81 to 0.96. Field conditions exhibited greater data variability. Evapotranspiration in the external environment is greater than in the protected environment. To more accurately account for microclimatic variations in the protected environment, it is recommended to use a longer series of data for Kp calculation, allowing for monthly and seasonal analysis, depending on the agricultural crop.

## REFERENCES

ALLEN, R. G.; PEREIRA, L. S.; RAES, D.; SMITH, M. Crop evapotranspiration: guidelines for computing crop water requirements. Roma: FAO, 1998. 300 p. (Irrigation and Drainage, n.56).

CUENCA, R. H. Irrigation system design: an engineering approach. New Jersey: Prentice-Hall, Englewood Cliffis. 1989. 133 p. DOORENBOS, J.; PRUITT, W. O. Crop water requirements. Rome: FAO, 1977. 179 p. (FAO. Irrigation and Drainage Paper, 24).

GOYAL, M. K.; BHARTI, B.; QUILTY, J.; ADAMOWSKI, J.; PANDEY, A. (2014). Modeling of daily pan evaporation in sub tropical climates using ANN, LS-SVR, Fuzzy Logic, and ANFIS. Expert systems with applications, v.41, n.11, p.5267-5276, 2014.

KISI, O. Pan evaporation modeling using least square support vector machine, multivariate adaptive regression splines and M5 model tree. Journal of Hydrology, v.528, p.312-320, 2015.

LOPES FILHO, R. P. Utilização de diferentes tanques evaporimétricos em ambiente protegido. Lavras: UFLA. 2000.79p.: il.

LU, X.; JU, Y.; WU, L.; Fan, J.; Zhang, F.; Li, Z. Daily pan evaporation modeling from local and cross-station data using three tree-based machine learning models. Journal of Hydrology, v.566, p.668-684, 2018.

PEREIRA, A. R.; VILLA NOVA, N.; PEREIRA, A. S.; BARBIERI, V. A model for the class A pan coefficient. Agricultural and Forest Meteorology, Amsterdam, v. 76, n. 2, p. 75-82, 1995.

SCHIMDT, L.; HEBE, F.; ATTINGER, S.; KUMAR, R. Challenges in applying machine learning models for hydrological inference: acase study for flooding events across Germany. Water resources research, v.56, p.5, e2019WR025924, 2020.

SENTELHAS, P. C.; FOLEGATTI, M. V. Class-A pan coefficients (Kp) to estimate daily reference evapotranspiration (ETo). Revista Brasileira de Engenharia Agrícola e Ambiental, Campina Grande, v. 7, n. 10, p. 111-115, 2003.

SNYDER, R. L. Equation for evaporation pan to evapotranspiration conversion. Journal of Irrigation and Drainage Enginnering of ASCE, New York, v. 118, n. 6, p. 977-980, 1992.

WANG, H.; SUN, F.; LIU, F.; WANG, T.; LIU, W.; FENG, Y. Reconstruction of the pan evaporation based on meteorological factors with machine learning method over China, Agricultural Water Management, v. 287, 108416, 2023.