Alternative Solution to Estimate Cucumber Crop Evapotranspiration in Shade Nets for the Valle de Culiacán, Mexico

López-Avendaño, Jesús E.[1]**; Rodríguez, Julio C.**[2]**; Estrada-Acosta, Mitzi D.**[1]**; Amarillas-Bueno, Luis A.**[1]**; Martínez-Gallardo, José A.**[1]**; Cuadras-Gaxiola, Jesús A.**[1]**; Carrillo-Arredondo, Roberto R.**[1]**; Román-Román, Leonardo**[3]**; López-Inzunza, Hugo de J.**[1*]

[1] Universidad Autónoma de Sinaloa. Facultad de Agronomía, Carretera Culiacán-Eldorado, km 17.5, Apartado Postal 25, C.P. 80000. Culiacán, Sinaloa, México.

[2] Universidad de Sonora. Departamento de Agricultura y Ganadería, Carretera Hermosillo-Bahía Kino, km 20.5, C.P. 83000. Hermosillo, Sonora, México.

[3] Instituto Tecnológico Superior de Eldorado-Tecnológico Nacional de México. Avenida Tecnológico S/N Col. Rubén Jaramillo, C.P. 80450, Eldorado, Sinaloa, México.

* Correspondence: hugolopez.fa@uas.edu.mx

ABSTRACT

Objective: This work aimed to estimate the evapotranspiration of cucumber crop grown in a shade house in Valle de Culiacán, México.

Design/methodology/approach: The FAO56 method was used with a variation of the FAO Penman-Monteith equation, and a non-conventional evaporimeter to measure evaporation inside the shade house. Using the estimated reference evapotranspiration and the measured evaporation, pan coefficients were calculated, and a mathematical model was proposed to calculate this coefficient based on the meteorological parameters: air temperature, relative humidity, and net solar radiation.

Results: The estimated crop evapotranspiration was 417.6 mm. The linear regression between the reference evapotranspiration estimated with FAO56 and calculated with evaporation and adjusted evaporimeter pan coefficient yielded excellent statistical estimators ($R^2>0.9$).

Findings/conclusions: The analysis of the evaporimeter pan coefficient's dependence on meteorological parameters indicates a strong dependence on air temperature, net solar radiation, and vapor pressure deficit, but not on relative humidity.

Keywords: *Cucumis sativus*; evaporimeter pan coefficient; FAO56; protected agriculture; reference evapotranspiration.

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INTRODUCTION

The global increase in food demand pressures production systems to increase crop yields despite water resource limitations. Therefore, there is growing interest in more sustainable practices and optimized operations for agricultural systems that allow efficient use of water resources (Ghiat *et al.*, 2021). However, crop water consumption is affected by meteorological conditions that are impossible to control in open-field conditions. For this reason, the use of agricultural production systems under protected conditions (greenhouse, shade house or netting, and polytunnel or macrotunnel) has increased (Villagrán *et al.*, 2020).

For the period 2019-2022, in the central agricultural region of Sinaloa, which includes the municipalities of Culiacán and Navolato, the area covered with shade nets is 4,593 ha, representing 61.6% of the state total. Regarding cucumber crops (*Cucumis sativus* L.) grown under shade nets, Sinaloa has 1,388 ha established (42.3% of the national total), of which 917 ha (66.1%) are located in the central region of the state (SIAP, 2024). On the other hand, the average net water applied to cucumber crops is 77.8 cm (agricultural cycles 2021-2022 and 2022-2023) in the central region of the state, corresponding to irrigation district 010 Culiacán-Humaya (CONAGUA, 2024).

In this regard, it should be noted that there is a lack of studies analyzing the applicability of evapotranspiration models in closed agricultural systems, and that provide methods and guidelines to improve the estimation of crop water requirements for producers or technicians in charge of irrigation management in shade-net production systems. Therefore, the objective of this study was to estimate the evapotranspiration of cucumber crops in shade nets using the FAO56 methodology, with a variation of the FAO Penman-Monteith equation and the calibration of a non-conventional evaporimeter pan that is easily accessible for producers and field technicians.

MATERIALS AND METHODS

The research was conducted in a shade-net production system located at the facilities of the Faculty of Agronomy of the Autonomous University of Sinaloa, geographically situated in northwestern Mexico, with central coordinates of 24° 37' 24.23" N and 107° 26' 38.43" W. This area is characterized by a warm semi-arid climate (Bsh, Köppen classification) with an average monthly temperature of 24.6 °C, recording maximum temperatures of 43 °C and a minimum of 0.6 °C. The average annual precipitation is 705 mm, with a rainy season from July to September. The total growing cycle of the crop was 118 days, with 28 days in the seedling stage and 90 days after transplant (DAT). The study took place from February 29 to May 28, 2024 (DAT). The area used for the study was 280 m^2, and the shade net allows 75-80% of net solar radiation to pass through. The soil is clayey, containing 69% clay, 16% silt, and 15% sand. The soil bulk density is 1.23 g cm^{-3}, with an organic matter content of 0.8%. The soil's hydrodynamic characterization shows a field capacity moisture content of 46.7 cm^3 cm^{-3} and a permanent wilting point of 35.1 cm^3 cm^{-3}.

In this study, Persian cucumber variety was established. Four beds were constructed, with a separation of 1.5 m between them, each 20 m long and 0.6 m wide. The spacing between plants was 0.3 m, and irrigation was done by drip using emitters with a flow rate of 1 L h^{-1}, spaced 0.3 m apart. The bed was covered with silver-colored plastic mulch.

To measure the meteorological variables required by the FAO56 methodology (Allen *et al.*, 1998), a station with sensors was used to measure air temperature, relative humidity, net solar radiation, soil heat flux, precipitation, and barometric pressure. Given the low or negligible wind speed conditions inside the shade net, the reference evapotranspiration (ET_0) was calculated using Equation (1) established by FAO Penman-Monteith, adjusted for the internal conditions of a greenhouse as used by Liu *et al.* (2020).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{628}{T+273}(e_a - e_s)}{\Delta + 1.24\gamma} \quad \text{(Equation 1)}$$

Where ET_0 is the reference evapotranspiration (mm d^{-1}), R_n is the net solar radiation (MJ m^{-2} d^{-1}), G is the soil heat flux (MJ m^{-2} d^{-1}), T is the mean air temperature (°C), $(e_a - e_s)$ is the vapor pressure deficit (kPa), Δ is the slope of the vapor pressure curve (kPa °C^{-1}), and γ is the psychrometric constant (kPa °C^{-1}).

To measure evaporation inside the shade net, four non-conventional evaporimeters (mini-evaporimeters) were installed. These consisted of a 4-inch nominal diameter PVC cap, with an effective inner diameter of 100.8 mm and a height of 35 mm, in white color. The evaporimeters were placed on the aisles of the shade net between the cultivation beds, on a wooden structure, at a height of 13 cm above the soil level. The initial water level was 30 mm, leaving 5 mm of freeboard in the container, which was reached by adding 239 ml of water. The water in the mini-evaporimeter was changed every third day, adding the initial 239 ml. Evaporation was determined by weight, considering a measured water density of 0.979 g cm^{-3}, which represents 7.8 g mm^{-1} of evaporated water. Daily weight measurements were taken for each container, and the average of the four mini-evaporimeters was calculated to determine the weight difference, applying Equation (2).

$$E = \frac{P_i - P_{i-1}}{7.8} \quad \text{(Equation 2)}$$

Where E is the daily evaporation (mm), P_i is the weight of the container on the current day (g), and P_{i-1} is the weight of the container with water from the previous day (g). Considering Equation (3), where K_p is the evaporimeter pan coefficient.

$$ET_0 = E \cdot K_p \quad \text{(Equation 3)}$$

Allen *et al.* (1998) suggests that the values of K_p depend on the type of evaporimeter pan used, and that if evaporation values are measured with an alternative pan, the values of K_p should be determined by relating the evaporation to the reference evapotranspiration (ET_0) estimated with FAO56. This is achieved using Equation (4).

$$K_p = \frac{ET_0}{E} \quad \text{(Equation 4)}$$

To calculate the water requirement for cucumbers, a single Kc model was used, applying the Kc values proposed by Allen *et al.* (1998) (Table 1).

Table 1. Crop Coefficients (Kc) used.

	Ini	Med	Fin
Kc	0.60	1.15	0.75

To obtain the mathematical model representing the behavior of K_p as a function of meteorological parameters, multiple linear regression was applied. Meanwhile, to evaluate the individual dependence of K_p on meteorological parameters, simple linear regression was used. For statistical analysis, Pearson's correlation coefficient (R), the coefficient of determination (R^2), Willmott's concordance index (d), and the root mean square error (RMSE) were employed.

RESULTS AND DISCUSSION

ET_0 ranged from 1.9 to 6 mm d^{-1}, with a total estimated at 405.3 mm. In contrast, the ETc was 417.6 mm accumulated, with a maximum and minimum of 6.4 mm d^{-1} and 1.5 mm d^{-1}, respectively, resulting in a ratio (ETc/ET_0) of 1.03. Meanwhile, the total evaporation measured with the mini-evaporimeters was 615.4 mm, yielding a ratio (ET_0/E) of 0.66. The maximum recorded evaporation was 7.6 mm d^{-1} and the minimum was 5.9 mm d^{-1}, respectively (Figure 1).

The estimated ETc in this study represents 53.7% of the net water application considered for this crop in the Valle de Culiacán irrigation area (CONAGUA, 2024). Ike *et al.* (2019) obtained an ETc for cucumber in hydroponics of 289.2 mm, considering a 110-day growing cycle in Nigeria, with an ETc/ET_0 ratio of 0.91, given that the prevailing meteorological conditions, cultivation conditions, and crop development periods in both areas are completely different. On the other hand, Yaghi *et al.* (2013) estimated the ETc

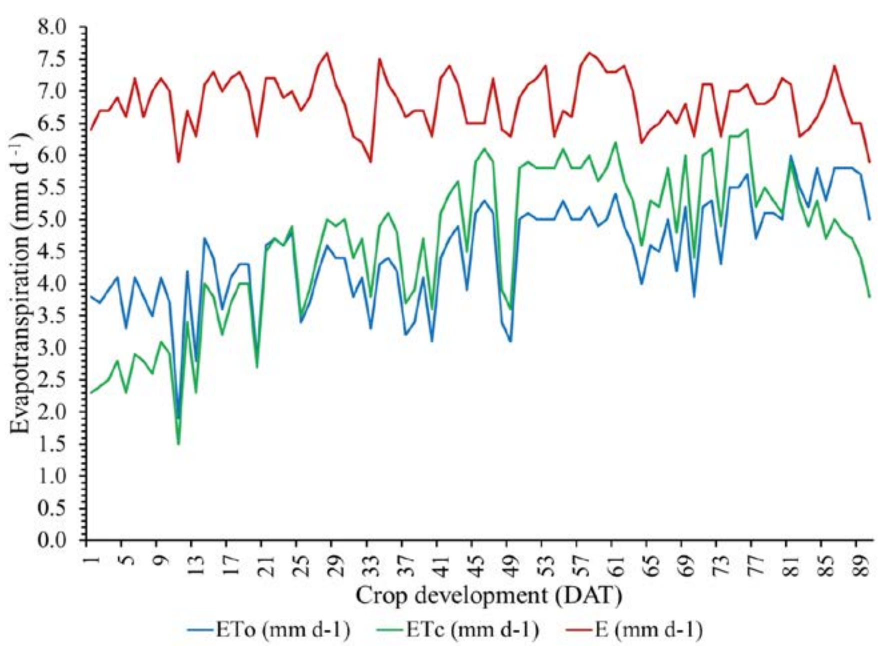

Figure 1. Behavior of evaporation and evapotranspiration during crop development.

for cucumber under open field conditions using furrow irrigation and drip irrigation with and without plastic mulching, reporting values of 673.2 mm, 243.9 mm, and 288.2 mm, respectively. The growing cycle considered was 92 days under prevailing meteorological conditions in Syria. These researchers reported an ETc/ET_0 ratio of 0.37 for drip irrigation with plastic mulching, 0.44 for drip irrigation without plastic mulching, and 1.02 for furrow irrigation; while the ET_0/E ratio was 0.74, higher than that reported in this study.

Based on the ET_0 estimated with the FAO56 methodology and the evaporation measured with the non-conventional evaporimeter, the K_p values were estimated according to Equation 4 in this study. Subsequently, considering that K_p results from the interaction with different meteorological variables, a multiple linear regression was performed, using K_p as the dependent variable and the interaction of air temperature, relative humidity, and net solar radiation. This yielded an excellent correlation with a coefficient of determination (R^2) of 0.97, an error of 0.018, and a Willmott concordance index of 0.99 (Figure 2).

Other studies have explored the possibility of using non-conventional evaporimeters with different pan diameters. For example, Sujitha *et al.* (2020) used pan with diameters of 60 and 20 cm to measure evaporation inside a greenhouse, obtaining acceptable correlation coefficients when comparing the ET_0 obtained with the Class A evaporimeter pan. In a statistical analysis of the daily ET_0 estimation, excellent results were achieved in the RMSE, R^2, R, and d indicators (Figure 3).

In an individual dependence analysis of K_p with respect to T, HR, Rn, and DPV, a good correlation was found between K_p and Rn ($R^2=0.68$) and T ($R^2=0.68$), moderate with respect to DPV ($R^2=0.53$), and low with respect to HR ($R^2<0.1$). This contrasts with what Antensay (2020) reported when analyzing the dependence of the Class A evaporimeter pan coefficient on meteorological parameters in open fields (T, HR, Rn, and DPV), where the correlation was very low with $R^2<0.1$.

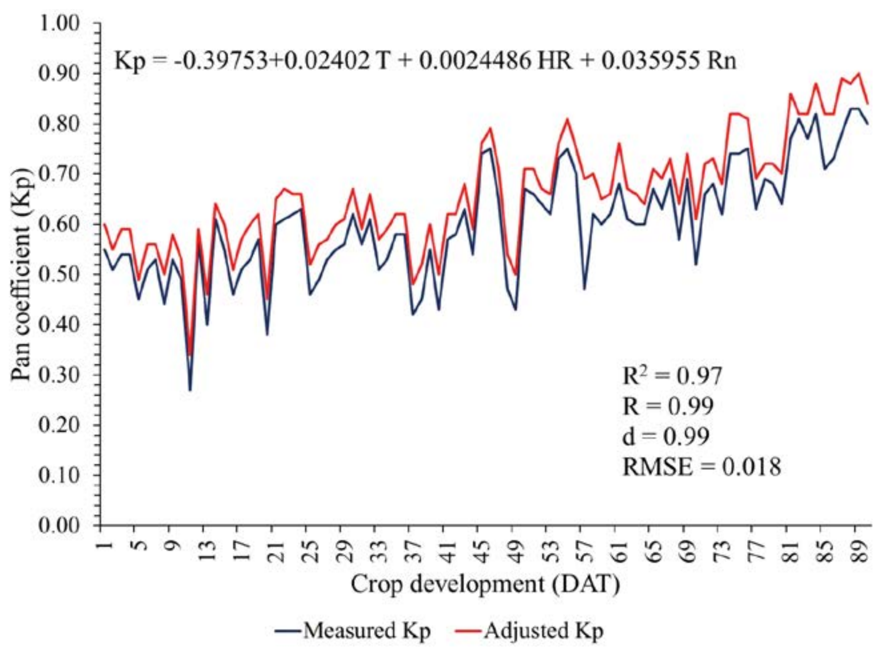

Figure 2. Evolution of the evaporimeter pan coefficient (K_p) during Crop Development.

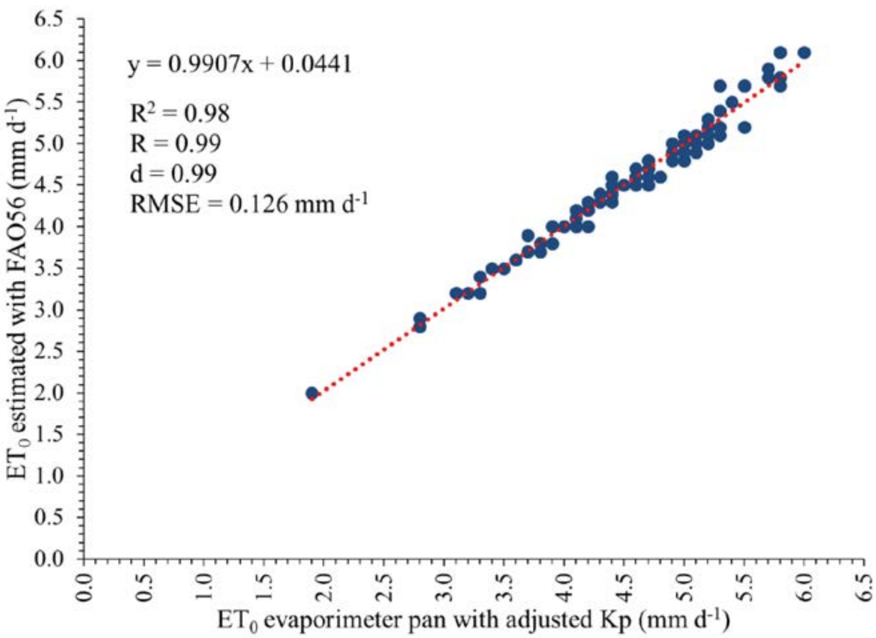

Figure 3. Statistical analysis of ET_0 estimated with FAO56 and evaporimeter pan.

CONCLUSIONS

The evapotranspiration of cucumber crops under shade netting in the Valle de Culiacán, Mexico, was estimated using the FAO56 methodology with a variation of the FAO Penman-Monteith equation for reference evapotranspiration in protected agriculture conditions. The total water consumed by the crop was 417.6 mm. Additionally, the use of a low-cost, accessible, and easy-to-operate unconventional evaporimeter pan is proposed for local agricultural producers, requiring minimal meteorological data. To estimate the reference evapotranspiration, a mathematical model is suggested to calculate the evaporimeter pan coefficient simply and with good, statistically validated precision. Further validation of this methodology under different protected agriculture conditions and for various crops is recommended.

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