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Estimation of rice evapotranspiration using a microlysimeter technique and comparison with FAO Penman-Monteith and Pan evaporation methods under Moroccan conditions

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Abstract – This paper reviews field measurements of evapotranspiration from paddy rice fields (ET) in an experimental station in the Gharb region of Morocco, during the summer seasons in 1995 and 1996. The results showed that the seasonal average water consumption of rice was 6.7 mm·day⁻¹ with a maximum value of 8.3 mm·day⁻¹ during the panicle enlargement stage (R2). The average daily ET for 1996 was compared with US Class ‘A’ open pan evaporation (Ep) and with reference evapotranspiration (ET0) calculated using a validated FAO Penman-Monteith equation. Both methods gave good estimates of ET with a correlation coefficient of 0.78 (P < 0.001, slope = 1.06) with Ep and 0.79 with ET0 (P < 0.001, slope = 1.3). The derived mean crop coefficients were 1.06 and 1.3, respectively, for the average of the two years. The cumulated ET over the growing season was nearly equal to the cumulated Ep, and greater by about 20% of cumulated ET0. This superiority might be attributed to an advective energy transferred from areas surrounding the rice zone activated by wind speed.

1. INTRODUCTION

The water requirement of rice is very high because it is a semi-aquatic culture which requires more water than other crops. It grows under submerged conditions. The main reason for flooding a rice field is that most rice varieties maintain better growth and produce higher grain yields when grown in a flooded soil than when grown in a nonflooded soil [5]. This type of irrigation does not help save water and may cause abundant water loss [27]. Rice water requirement ranges between 750 and 2500 mm, with an average value of 1250 mm [17].

Estimation of evapotranspiration (ET) is an important factor in irrigation management for efficient water use. In fact,
good estimates of rice ET provide a basic tool for computing water balance and predicting water availability and requirements [10, 22]. The evapotranspiration depends upon the evaporative demand of the atmosphere and on the transport processes of heat and water from soils and plants through the sublayers which are next to the evaporative surfaces, and through plant canopies to the outer atmosphere [13]. This phenomenon is controlled by physiological functions of rice under submerged conditions [14]. World-wide estimates of rice ET range between 450 and 700 mm·season⁻¹, depending on the climate and growing season [8]. In South and Southeast Asia, ET varies from 4.4 to 14.3 mm·day⁻¹ [33]. For most areas in Asia, rice ET varies from 4 to 9 mm·day⁻¹ [36].

Many empirical [21, 33, 37], micrometeorological [23], combined and hydrologic methods [3, 10, 14, 27, 34] have been used to estimate rice ET. Different linear relations between rice ET and US class ‘A’ pan evaporation were reported for different geographical regions and seasons [9, 16, 28, 32, 33]. The advantage of using pan evaporation data for estimating ET is that long-term data are available [24]. Generally, ET from wetland rice fields was equal to or greater than class ‘A’ open pan evaporation [33]. Combined equations that include both the radiation balance and aerodynamic approach include the greatest number of variables that influence ET. These equations have higher predictive abilities than other empirical approaches such as the radiation or temperature-based methods [11]. The FAO Penman-Monteith method has been recommended as the main method for defining the grass reference ET₀ and for determining crop coefficients because of its good approximation of accurate lysimeter observations and its more sound physical basis and incorporation of plant physiological and aerodynamic parameters [1, 2, 11, 29]. Direct measurement methods, such as lysimetry, are the most accurate for measuring evapotranspiration from flooded rice. However, large weighing lysimeter methods are expensive and time-consuming. An inexpensive, simple, sensitive, accurate and practical technique has been used to measure ET from a paddy field using a microlysimeter tool [34]. This apparatus was designed and tested to measure rice transpiration and evapotranspiration in a wetland field on an hourly and daily scale.

To estimate rice ET for regional planning, the crop coefficient (KC), or the ratio of ET to grass reference evapotranspiration is needed, and has to be derived empirically for each crop based on lysimeter data and local climatic conditions [7]. Rice has the highest (KC) among all agricultural crops, ranging between 1.05 and 1.2 over the total growing period [8]. As suggested by many authors, the values of this parameter seem to be constant (1.1–1.2) during all phenological stages for different crops, except at the beginning of the vegetative period, when the crop is not completely covering the soil, and during the maturity stage when the leaves are drying up [12]. Crop coefficients based on the Penman-Monteith method were considered adequate for rice irrigation management purposes [27].

In Morocco, as in several areas where wetland rice is grown, paddy rice is used during summer (June to October). The water requirement of the rice is supplemented only by irrigation and the crop consumption varies between 1700 and 2500 mm a season. Cultivation of rice under submerged conditions is currently facing several problems due to water management constraints and to the flooded method of irrigation that does not help save water. Intensifying rice cropping or increasing its area without proper water management could increase the incidence of water logging, salinity and contamination of underground water by pesticide and nitrogen residues, and also increase water loss [21].

The improvement of water management requires a good quantitative estimate of the major components of the water balance in rice fields, and especially the evapotranspiration. The literature on evapotranspiration in rice is abundant. An extensive review has been carried out [34]. Simple and complex models have been proposed to predict ET. However, such models need to be tested against the experimental values for each site [23]. Given the lack of daily experimental rice ET data for the Moroccan rice region, accurate prediction of rice ET based on the lysimetric method is an important factor in efficient water management and can optimize irrigation by reducing water loss. Therefore, the aim of this study was to estimate rice ET for a crop cycle using a microlysimeter approach. To extrapolate the rice ET for irrigation planning on a regional scale, the crop coefficient and reference ET were determined. Moreover, the FAO Penman-Monteith equation calculated for a grass crop at the weather station and the pan evaporation method were tested against rice ET. Another objective was to appraise the relationship between the standard FAO Penman-Monteith equation and US class ‘A’ pan evaporation, as the estimated data required for the Penman-Monteith equation are not always available in all weather stations.

2. MATERIALS AND METHODS

The study was conducted in the experimental station of the National Institute of Agronomic Research (INRA) in Morocco, during the summer seasons of 1995 and 1996. The experimental site was located in the main rice region (Gharb region) of the country, with a latitude of 34°31’21'', a longitude of 6°21’40” and an altitude of 10.5 m (Fig. 1). The climatic data during the rice-growing season for the two years of the study are given in Figures 3a, b, c and d. These data were taken from a classical meteorological station as described by FAO [6], located at the Technical Center of Sugar Cane (CTCAS), 6 km from the experimental station (Fig. 2). The topography of the region is homogenous, and there is no relief between the experimental station and agrometeorological station. The meteorological station is situated inside a zone of growing sugar cane irrigated by aspersion. It is 25 km from the sea. The wind blows from the sea across the sugar cane fields and passes through the meteorological station (Fig. 2). So the station has a specific microclimate with high relative humidity in the morning and low in the evening (Tab. I). Batchelor and Roberts [3] reported that when humidity data are taken in a reference setting, early in the morning, RH approaches 100% even in a semi-arid region, because the measurements are taken inside an irrigated region. This was our case. The wind speed is measured at 2 m above the ground level with an anemometer and expressed in meters per second (m·s⁻¹). The winds in that region are moderate to strong with a maximum
value of 7 m·s⁻¹ for the minimum wind speed and a maximum of 4.5 m·s⁻¹ for the minimum values of wind speed.

The FAO Penman Monteith equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed [3]. The weather measurements should be made at 2 m above an extensive surface of green grass shading the ground and not short of water [3]. The meteorological station has a soil covered with short grass and all the weather climatic data are recorded at the 2 m level.

The field layout of the experiment consisted of four replicated plots. The evapotranspiration of the rice was measured using a microlysimeter designed by [34] with slight modifications. The modified apparatus consists of a galvanized iron cylinder with a closed bottom, with a stylet fixed 5 cm from the top to measure the dropping of water into the cylinder.

After land preparation, four microlysimeters were installed after excavating the soil, by putting the cylinder (50 cm) in the soil and leaving it 10 cm above the ground. The same soil was refilled in each lysimeter up to the soil surface. The diameter of the microlysimeter is equal to 20 cm. One hill of a Moroccan variety of rice (Hayat, japonica type) was transplanted into the cylinder to match the planting pattern in the surrounding field. At the beginning of each day, the water level inside the cylinder was adjusted to equal the water level outside the microlysimeter. The level outside the microlysimeter was measured using the slopping gauge [31]. The evapotranspiration was thus equal to the quantity of water added to adjust the water level at the top of the stylet. Readings were taken each day at 8 am, from the 4-leaf stage until physiological maturity of the crop in 1996 and from panicle initiation to physiological maturity in 1995. But with regard to the lack of data relative to the rice ET from the crop establishment, the values of ET during 1995 were derived from those of Ep multiplied by a pan coefficient of 0.8 and by a crop coefficient of 1.10 given by [3].

| Table I. Meteorological Environment in Gharb (CTCAS, latitude = 34°34'; longitude = 6°14'; Alt = 6 m). |
|---------------------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Rh\text{max} (%) | 88.4     | 82.3     | 89.9     | 90.1     | 77.1     | 78.8     | 88.8     | 88.7     |
| Rh\text{min} (%) | 70.6     | 57.5     | 58.8     | 54.2     | 47.7     | 52.0     | 59.1     | 57.1     |
| T\text{max} (°C) | 26.7     | 31.6     | 30.5     | 27.9     | 30.9     | 31.2     | 28.1     | 27.5     |
| T\text{min} (°C) | 15.8     | 18.7     | 18.7     | 15.4     | 18.2     | 19.3     | 17.2     | 15.9     |
| n/N                | 0.6      | 0.7      | 0.7      | 0.7      | 0.7      | 0.7      | 0.7      | 0.6      |
| Wind_{\text{max}} m·s⁻¹ | 4.4     | 4.3      | 3.8      | 3.8      | 2.8      | 3.3      | 2.4      | 1.7      |
| Wind_{\text{min}} m·s⁻¹ | 0.7      | 0.8      | 0.8      | 0.8      | 1.6      | 0.8      | 1.1      | 0.9      |
| Rn, MJ·m⁻²          | 15.6     | 17.2     | 15.3     | 12.7     | 17.4     | 16.9     | 15.7     | 11.3     |
| ET₀, mm·d⁻¹         | 4.7      | 6.2      | 5.3      | 4.6      | 6.3      | 6.2      | 5.0      | 3.8      |
| Ep, mm·d⁻¹          | 5.5      | 7.1      | 5.9      | 5.0      | 7.0      | 7.0      | 5.9      | 4.1      |
during the initial stage for the computation of mean KC throughout the growing season.

The daily values of the pan evaporation and Penman-Monteith methods were compared with those of the microlysimeter in order to test their accuracy in predicting rice evapotranspiration under Moroccan conditions.

The FAO Penman-Monteith equation ($ET_0$) used is given below [2, 29]:

$$ET_0 = \frac{0.408 \Delta R_n + U_2 \gamma (e_a - e_d) + \frac{900}{T + 273}}{\Delta + \gamma (1 + 0.34 U_2)}$$

(1)

where:

$ET_0$ = reference crop evapotranspiration (mm·day$^{-1}$); $R_n$ = net radiation (MJ·m$^{-2}$); $T$ = mean temperature ($^\circ$C); $U_2$ = wind speed at the 2 m level (m·s$^{-1}$); $e_a$ = saturation vapor pressure at mean air temperature (kPa); $ed$ = mean vapor pressure of the air (kPa); $\Delta$ = slope of $e_a$ versus $T$ curve (kPa·$^\circ$C$^{-1}$); $\gamma$ = psychrometer constant (kPa·$^\circ$C$^{-1}$).

Net radiation ($R_n$) was computed as the sum of net short-wave radiation and net long-wave radiation.

$$R_n = 0.77 R_s - 2.45 \times 10^{-9} \left(273 + \frac{T_{\text{max}} + T_{\text{min}}}{2}\right)^4$$

$$\times \left(0.9 \frac{n}{N} + 0.1\right) (0.34 - 0.14 \sqrt{ed})$$

(2)

$Rs$ = solar radiation. It was estimated from measured sunshine hours.

$$Rs = \left(a + b \frac{n}{N}\right) Ra$$

(3)

$Ra$ = extraterrestrial radiation (MJ·m$^{-2}$·day$^{-1}$), $a$ = fraction of extraterrestrial radiation (Ra) on overcast days. For an average climate it is equal to 0.25; $b = 0.50$ for an average climate, $n/N$ = relative sunshine fraction, $n$ = bright sunshine hours per day (h), $N$ = total day length (h), $T_{\text{max}}$ = maximum daily temperature ($^\circ$C), $T_{\text{min}}$ = minimum daily temperature ($^\circ$C).

The pan evaporation data were taken from a class “A” pan surrounded by irrigated grass and about 15 m from a sugar cane crop irrigated by aspersion. Under our conditions, the pan coefficient ($K_p$) is taken to be equal to 0.8 [3].

3. RESULTS AND DISCUSSION

3.1. Rice evapotranspiration measured

The average values of ET per decade from sowing to physiological maturity of rice are presented in Figure 4. For the whole rice growing season, ET was 665 ± 5 mm with a daily average value of 6.7 mm·day$^{-1}$. The mean value of ET thus represented 32–47% of the rice’s water requirement under Moroccan conditions (total water consumption varies between 1700 and 2500 mm). The mean seasonal value of ET obtained was in the range of the major areas of rice in Asia and America. In the Philippines, 7 mm·day$^{-1}$ was an average requirement during the submerged period [37]. In fact, ET falls within the range given by many authors, which varies between 4 and 9 mm·day$^{-1}$ [27, 30, 36]. ET during the growing season was influenced by climatic conditions when computed over each growing phase. For the vegetative, reproductive and ripening stages in 1996, ET was 8.0, 7.2 and 5.5 mm·day$^{-1}$, respectively. The respective data of relative humidity, net radiation and temperatures were RH = 65, 73 and 74%; $R_n = 17, 14.08$ and 11.5 MJ·m$^{-2}$ and $T^\circ$C = 25.4, 22.8 and 20.6 °C. The average values of rice ET measured per decade, during the two years, showed two peaks where ET reached its maximum value. The first one occurred around 36 days after watering (DAW) in July, before the tillering stage where the value of ET was 9.3 mm·day$^{-1}$ (Fig. 4). The $R_n$ and temperatures also reached their maximum values during that period and the relative humidity reached its minimum value (respectively, 17.3 MJ·m$^{-2}$; 26.9 °C; 56.8%) (Figs. 3a, b, c). The field was not yet covered by the rice crop and it was influenced more by climatic conditions. The second peak was shown during the reproductive stage. There was an increase in the mean value of ET during the panicle enlargement (stage R2, [4]), before the heading stage, between the second and the third decade of August (Fig. 4). It reached a mean value of 8.3 mm·day$^{-1}$. However, $R_n$ and temperature were in their decreasing phases (Figs. 3a, b). This tendency of ET might perhaps be explained by the fact that some significant regional advection, activated by strong, hot winds called “Chergui” which usually occur in

![Figure 3. Evolution per decade of (a) temperature, (b) net radiation, (c) relative humidity (%), and (d) pan evaporation, from sowing to physiological maturity during two growing seasons (1996 and 1995).](image-url)
the region during the rice-growing season, supplied energy for evaporation. This wind frequently occurs between July and August in the Gharb region. As reported by some authors, rice ET might be influenced more by climatic conditions than by the crop growing stage \cite{19, 20}, or it appeared to vary more with crop growth stage \cite{13}, or it is dependent on the water status in a paddy field \cite{14}. Some other authors found that the evapotranspiration from flooded-irrigated rice in a semi-arid region was 1.7 times that which could be caused by radiation because of a large-scale advection which was present to a marked degree \cite{9}.

### 3.2. Determination of rice crop coefficient based on \( \text{ET}_0 \) and \( \text{Ep} \)

To eliminate the effect of the meteorological factors, the value of ET was divided by the value of Ep and \( \text{ET}_0 \) to obtain a relative ET or crop coefficient (KC). The ET/Ep (or KCp) and ET/\( \text{ET}_0 \) (or KCp) ratios during the cropping cycle are presented in Figure 5. The results show that the average KCp and KCp for the two years varied over the growing season, with a maximum value reached during the reproductive stage. The maximum values were 1.2 and 1.5, respectively, for KCp and KCp (Fig. 5). The highest values for the two ratios were obtained when the rice was at its full development, during the stage where water was mostly lost by transpiration (panicle development); later on, there was a slight decrease in the ratio values with leaf senescence during the maturity stage. The average KCp and KCp, for all the growing season for the two years were, respectively, 1.06 and 1.3. The values of rice crop coefficients based on the Penman-Monteith model were close to those found by \cite{27} during the reproductive and maturity stages. In fact, it was shown that the values were 1.51 and 1.43, respectively, for the reproductive and grain filling stages. The values of KCp for the two years of the study were lower than KCp and were in the range mentioned by many studies (Fig. 5). Some authors showed that KCp started at 1 after transplanting and reached a peak of 1.1 to 1.3 during maximum tillering and of 1.4 to 1.7 during the panicle initiation \cite{33} or just before or at the heading stage \cite{30}. At maturity, KCp decreased to 0.6–0.9 \cite{30}. The average ratio was about 1.2 in temperate, subtropical and tropical zones \cite{33}, 1.3 (0.9–1.7) in Japan \cite{30} and 1.17 in the central plain of Thailand \cite{26}. The average KCp found under our conditions was around the unit value (1.06). Some authors showed that the average ET from a rice field was lower than the pan evaporation and it ranged between 0.90 and 0.98 \cite{9, 16, 37}.

### 3.3. Rice ET and its relationship with \( \text{ET}_0 \) and \( \text{Ep} \)

Simple linear regression between the values of the microlysimeter (ET) and the values from pan evaporation (Ep) and the FAO Penman-Monteith (\( \text{ET}_0 \)) equation was performed. The results showed that both of the models gave a good relationship with ET, with significantly high correlation coefficients of 0.79 (\( P < 0.001 \), slope = 1.3) for \( \text{ET}_0 \) and 0.78 (\( P < 0.001 \), slope = 1.06) for Ep (Fig. 6). This last result was confirmed by many researchers who showed a significant relationship between ET and Ep \cite{9, 26, 28}. Cumulated ET was about 20% greater than \( \text{ET}_0 \) (6.7 mm·day\(^{-1}\) and 5.3 mm·day\(^{-1}\), respectively, for ET and \( \text{ET}_0 \)) and gave a good approximation of cumulated Ep for both years (6.4 mm·day\(^{-1}\) for Ep). The value of 20% is close to the 18% found by \cite{15}. The underestimation of ET by the Penman-Monteith method may be due to the significant advective energy transferred from areas where sensible heat was generated. This energy might have increased the rice evapotranspiration, because of a big surrounding rice area with a big area of usually dry land in summer (Fig. 1). Previous studies have demonstrated that sensible heat advection can significantly enhance evapotranspiration \cite{35}. Many authors showed that in some irrigated areas the
evapotranspiration of a well-watered crop would consume more energy and transpire more water than that evaporated from free water surfaces, and found that the ET was significantly stronger and higher than the value of the net radiation \[5, 7, 18, 25\]. Some authors showed that ET\(_0\) predicted over a grass crop growth was less sensitive to wind speed than rice ET. The Penman-Monteith equation includes an aerodynamic resistance function which does not vary with wind speed \[27\]. Table II shows that under the same weather conditions, ET was more sensitive to wind speed than ET\(_0\). So ET increased by 20% when the wind speed increased by 30%, while ET\(_0\) did not differ. This result was also confirmed by \[27\], who showed that rice is very sensitive to wind speed. When wind speed increased by 84.5%, rice ET was 63.5% higher when all the other weather parameters were nearly equal \[27\]. Also, \[3\] showed that in a humid and warm climate, the reference ET does not change with wind speed. The meteorological station during 1995 and 1996 was identified in a semi-humid zone with a warm winter and an Emberger coefficient of 120.83. Perhaps that might explain the underestimation of ET by ET\(_0\).

### 3.4. Relationship between ET\(_0\) and Ep

The relationship between ET\(_0\) and Ep was significantly high, with a correlation coefficient of 0.83 \((P < 0.001)\) (Fig. 7). Also, a better agreement between the Penman-Monteith and pan evaporation \((R^2 = 93.7\%)\) methods was shown in Karnal in India \[35\]. This relationship is useful because the climatic data used to perform the Penman-Monteith method are not always available, and in some places only pan evaporation data are available.

### 4. CONCLUSION

The results obtained in this study show that rice crops need more water during the reproductive period, especially during the panicle enlargement stage \((R^2)\) before the heading stage \((\text{between 60 DAW and 78 DAW})\). The quantity needed during that period is increased and can reach 20% more than a daily seasonal ET. The average rice crop coefficients KCo and KCp for that period corresponded to 1.5 and 1.2, respectively. The linear regression performed between rice evapotranspiration and the values of the two other models, FAO Penman-Monteith and pan evaporation, showed a good relationship. However, pan evaporation does not deviate from rice ET as widely as the FAO Penman-Monteith method during all the rice-growing season. Cumulated ET was 20% greater than cumulated ET\(_0\) and cumulated Ep gave a good approximation of the cumulated ET. The underestimation of ET by the FAO Penman-Monteith method may be due to many factors. It might be attributed to an advective energy due to the fact that the rice in the Gharb region is grown in plots surrounded by a big area of dry land, so local advection may cause large variations in evapotranspiration. Also, strong, hot winds called “Chergui” usually occur between July and August with a frequency of about 3 to 5 days a month. Insufficient fetch under these windy conditions may have increased ET. Some authors reported that the FAO Penman-Monteith equation based on 24-hour time steps has no correction for variation in day-night wind speeds \[2\].

The FAO Penman-Monteith equation includes the greatest number of variables that influence ET. It has superior predictive ability than the evaporation-based method \[11\]. This latter is not applicable for daily ET prediction \[11\]. So, in the rice region and under Moroccan climatic conditions, the FAO Penman-Monteith method might be calculated on data collected inside the rice area for better rice ET estimation.

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