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Characterization of rice (*Oryza sativa*) evapotranspiration using micro paddy lysimeter and class “A” pan in tropical environments

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Abstract

The relationship between the measured evapotranspiration (ETm) and evaporation from Class “A” pan (Ep) was determined in irrigated rice field in tropical Malaysia. Evapotranspiration was measured using Marriott tube type micro-paddy lysimeter (MPL) installed in ponded rice fields and the pan evaporation data was obtained using the class “A” pan. The maximum values of Ep and ETm from the study site were 6.0 and 7.3 mm/day, while the maximum estimated ET value was 5.0 mm/day. The measured (ETm) and calculated (Ep) were compared to determine the goodness of fit (R^2). The study showed that the ET rate of rice increases consistently up to the heading stage and then is declined at the ripening stage. A good simple linear model relationship between the ETm and estimated evapotranspiration was also observed. From the model relationships, values of coefficient of determination R^2 obtained are 0.69, 0.73, 0.90 and 0.50 for vegetative, panicle, reproductive and ripening periods, respectively. Mean pan-crop coefficients (KpKc) of 1.1 and 1.2 were obtained from the ratio of measured crop evapotranspiration (ETm) and measured pan evaporation (Ep). Evapotranspiration rates from the study area were in the range of values obtained for the major areas of rice production in Asia. Generally, evapotranspiration is affected by management and natural factors. These factors may influence crop growth and thereby, amount of water use. It may vary between different farms, season and days. The rate of water use is slow at young stage (evaporation) and it increases with crop growth (due to high transpiration). The rate reaches peak during some part of the growth period, then tapers off by harvest time.

Keywords: Crop coefficients, Evapotranspiration, Growth stages, Micro-paddy lysimeter, Water requirements.

Abbreviations: MPL_micropaddy lysimeter; Ep_measured evaporation from Class “A” pan, ETm_measured evapotranspiration, ETe_estimated crop evapotranspiration, ETc_crop evapotranspiration, ETo_reference evapotranspiration, NWMTC_National Water Management Training Centre, K_p_pan coefficient, K_c_crop (rice) coefficient, R_inner radius of the outer Marriott tube (mm), r_outer radius of the inner Marriott bubble tube (mm), ΔH_change in water column height (mm), A_ effective cross sectional area of the lysimeter tank (mm^2).

Introduction

The determination of crop water requirements is the first step used in project planning and design. The operation commonly involves the estimation of the reference crop evapotranspiration or evaluation of crop evapotranspiration. Better estimates of crop evapotranspiration play important role to accurately determine the crop water requirements. Different methods can be used to determine crop evapotranspiration (ET_c), which is an essential element in crop water use (Attarod et al., 2005). The FAO Penman-Monteith method (Allen et al., 1998) is generally considered to be the best approach for estimating crop evapotranspiration. Crop coefficients are used to estimate evapotranspiration of crops multiplied by calculated potential or reference evapotranspiration (ET_o). To determine crop evapotranspiration, crop coefficients must be derived for each crop empirically based on local climatic conditions (Doorenbos and Pruitt, 1977). An estimate of evapotranspiration forms the foundation for the planning and designing of all irrigation projects and efficient water usage, providing a basic tool for computing water balance and predicting water availability and requirement (Humphrey et al., 1994; Pereira et al., 1999). Crop water requirements are directly related to crop evapotranspiration (ET_c) and vary depends on crop grown and its different growth stages. In Malaysia, rice is unique among agronomic crops because it is grown in flooded condition, where ponding waters are maintained at a constant depth of approximately 50–100 mm throughout much of the growing season (JICA, 1998). Growing rice in flooded environments results in higher irrigation inputs when compared to other agronomic crops. Evapotranspiration involves a highly complex set of processes, which are influenced by many factors depends on the local conditions. These conditions range from precipitation and meteorology factors to soil moisture, plant water requirements and the physical nature of the land covered

(Dunn and Mackay 1995). The amount of water available for rice production in Malaysia has recently become critical especially during the dry seasons. Average annual rainfall in Malaysia is approximately 2500 mm. However, this rainfall is distributed unevenly both temporally and spatially, and the distribution is not optimal for the rice growing seasons. To effectively and efficiently use the available water resources for irrigation supply, studies of crop water requirements for paddy crops based on derived crop coefficient and/or field measurement are crucial. To improve water management practice, experimental data based irrigation management model can be applied for estimation of crop water requirements in rice. On the other hand, evapotranspiration is the one of the important components of the water balance equation in paddy fields. It includes the loss of water from both soil and plant surfaces, playing an important role in both rain-fed and irrigated rice. Evapotranspiration depends upon the evaporative demand of the atmosphere. It also depends on the transport processes of heat and water from soils and plants through the sub layers, which are next to the evaporative surfaces, and through plant canopies to the outer atmosphere (Kutilch and Neilson, 1994).

It is mainly affected by climatic factors and, to some extent, is controlled by physiological functions of rice under submerged conditions (Li and Cui, 1996; Peacock et al., 2004; Tsubo et al., 2007). Poor and uneven water distribution are the main problem for improving irrigation efficiency of rice irrigation schemes in Malaysia. The inefficient use of water by either over or under irrigation has been criticized. The Rapid Appraisal Process (RAP) diagnosis in the four large scale rice irrigation schemes in 2007 showed that the average Relative Water Supply (RWS) were less than 2.0 in the off-season and 3.70 in the main season. However, in some irrigation blocks of the scheme the RWS of 6.9 were scored. Therefore, a better estimate of evapotranspiration is essential to determine the crop water demand as well as improving the irrigation delivery performance (Rowshon et al., 2003a, Rowshon et al., 2003b and Rowshon et al., 2009). The water requirement of rice is very high because of its semi-aquatic nature, which requires more water than any other crops. Seasonal water requirement for rice ranges between 750 and 2500 mm, having an average value of 1250 mm (Mikkelson and De Datta, 1991). The worldwide estimate of rice ET ranges between 450 and 700 mm/season, depends on the climate and growing season (Doorenbos and Kassam, 1979). In South and South East Asia, ET varies widely from 4.4 to 14.3 mm/day (Tomar and O'Toole, 1980). However, for the most areas in Asia, ET ranges between 4 to 9 mm/day (WicKham and Sen, 1978).

There are several techniques used in determining evapotranspiration. These techniques include water balance, empirical formulae or micro-meteorological approaches. Field measurements of evapotranspiration are generally not only tedious also expensive and are therefore, restricted to research plots rather than practical uses in the farms by farmers. On the other hand, micro-paddy lysimeter affords simple and reasonably accurate water accounting device. The micro-paddy lysimeter employed in this study is cheaper and has gained more prominence recently. Tomar and O'Toole, (1979) designed and tested a micro-paddy lysimeter for estimating evapotranspiration of wetland rice, in which the measurements were done with pan evaporation. They concluded that the ratio of (ETc/Ep) could be used to compare difference between and within varieties, as well as variations in crop water requirement between seasons. However, the FAO Penman-Monteith method is considered as the international standard for predicting crop water requirement and has extensively been used worldwide by irrigation engineers, agronomists and hydrologists. The climatic data usually require using Penman's combination equation, which is not always available and, often, ET, is approximated as a factor (pan coefficient) multiply by the standard evaporation pan reading.

In this field study, the relationship between micro-paddy lysimeter estimates and class-A pan data was assessed and investigated whether pan data can be used successfully as a surrogate for Penman-Monteith ET. This study was conducted to compare the relationship between measured evapotranspiration (ETm) using micro-paddy lysimeter and Class "A" pan Evaporation (Ep) and to obtain an equivalent factor (KpKc) presenting the combined effects of pan and crop coefficient for initial and mid-season growth stages for ponded rice.

Results and discussions

Rice evapotranspiration and measured evaporation

Table 1. shows the results of evaporation from class 'A' pan and measured ET from micro-paddy lysimeter in rice plots. The value represents the influence of evaporation and evapotranspiration at various rice growth stages (developmental to ripening). The result indicates the mean, maximum and minimum Ep values of 4.4, 6.0 and 2.6 mm/day, respectively. The measured ET is in the range of 2.9 to 7.3 mm/day, while the mean values of 4.8 and 5.6 mm/day were obtained in both plots.

According to Tabbal, et al. (2002) typical evapotranspiration rates of rice fields are 4 - 5 mm/day in the wet season and 6 - 7 mm/day in the dry season, but can be as high as 10–11 mm/day in subtropical regions. During rice growth period, about 30 - 40 % of evapotranspiration is evaporation (Bouman et al., 2005; Simpson et al., 2002). In addition, the total measured Ep from class "A" evaporation pan was 89.90 mm (Table 2). The total measured - paddy lysimeter (ETm) were 101.68 and 118.96 mm from the two plots. Our results showed that ETm values were in the range of values obtained for the other major areas of rice production in Asia. Several authors obtained 4 and 9 mm/day (Sugimoto, 1976; Wickham, 1978; JICA, 1998). Generally, evapotranspiration is affected by management and natural factors. These factors may influence crop growth and thereby, amount of water use. It may vary between different farms, seasons and days. The rate of water use is slow at young stage and consumptive use increases with crop growth. It reaches peak during some part of the growth period, then tapers off by harvest time.

Table 1. Evaporation measured from class “A” pan (E_p) and Evapotranspiration from lysimeter (ET_m).

Time	Class A	Lysimeter in Paddy Plot 1			Lysimeter in Paddy Plot 2		
in	Pan	A1	A2	Average	B1	B2	Average
Days	E_p mm/day	ET_m mm/day	ET_m mm/day	ET_m mm/day	ET_m mm/day	ET_m mm/day	ET_m mm/day
1	5.8	6.0	6.4	6.2	7.4	7.1	7.3
2	5	5.3	5.1	5.2	5.9	5.2	5.6
3	3.3	3.1	3.8	3.5	3.7	3.9	3.8
4	4.9	5.9	5.1	5.5	6.3	6.1	6.2
5	3.8	4.5	4.7	4.6	5.9	5.7	5.8
6	4.4	5.1	4.9	5.0	5.6	5.2	5.4
7	5.1	5.8	5.3	5.6	5.4	5.7	5.6
8	3.3	3.8	3.4	3.6	3.8	3.9	3.9
9	3.4	4.0	4.4	4.2	4.8	5.1	5.0
10	3.5	4.3	4.1	4.2	6.1	5.9	6.0
11	5.3	5.4	5.3	5.4	5.6	6.2	5.9
12	5.5	4.8	4.9	4.9	6.4	6.6	6.5
13	3.3	3.7	4.4	4.1	4.8	4.9	4.9
14	5.1	4.8	5.9	5.4	6.3	6.7	6.5
15	4.7	5.6	5.2	5.4	6.3	5.5	5.9
16	3.5	4.2	3.8	4.0	5.5	4.8	5.2
17	4.9	5.2	5.4	5.3	6.3	6.0	6.2
18	5	5.8	5.3	5.6	7.1	6.0	6.6
19	6	5.1	4.3	4.7	7.4	7.1	7.3
20	5	5.4	5.2	5.3	5.9	5.2	5.6
21	2.6	4.1	3.9	4.0	3.7	3.9	3.8
Min	2.6	2.9	2.9	2.9	3.7	3.9	3.8
Max	6.0	6.7	6.4	6.2	7.4	7.1	7.3
Mean	4.4	4.8	4.7	4.8	5.7	5.5	5.6

Determination of rice crop and pan coefficient based on ET_m and Ep

To eliminate the effect of the meteorological factors, the value of ETm was divided by the value of Ep to obtain a relative evapotranspiration or pan-crop coefficient (KpKc). Pan-crop coefficients of 0.9 to 1.5 were obtained in this study. The ETm/Ep ratio of 1.10 and 1.20 for vegetative and mid- growth stages were recorded from the study and the value increases to 1.80 during last growth stage. The highest values of the ratio for the two stages were obtained when the rice was at its full (panicle) development, when most of the water lost occurred by transpiration. During the maturity stage, the ratio drops slightly.

$$ET_e = K_p \times K_c \times E_p$$

Where; ETe = estimated crop evapotranspiration from Class “A” pan, K_p = pan coefficient, K_c = rice crop coefficient and Ep = measured evaporation from class “A” pan.

Fig 6. Shows higher ET rates for old rice plant at heading stage, which increased consistently up to heading stage and then declined. Also, a maximum rate of ET at tillering stage is followed by constant rate but lowered at ripening stage. Simple linear relationship between the values of (ETm) from plots 1 and 2 represented young rice at vegetative stage and old rice at mid-season stage, respectively.

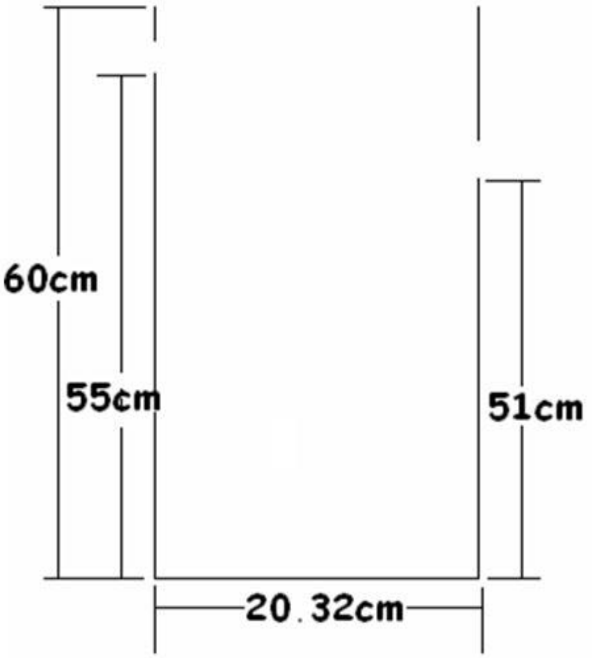


Fig 1. Layout of lysimeter Tank

The values of pan evaporation, Ep were then calculated. Fig 7a, b represent the relationship between (ETm) and (Ep) for young and panicle stages, respectively. The result shows that the model gave a good relationship between ETm and Ep with significantly high co-efficient of determination $ET_m = 0.64E_p + 2.03$ and R^2 = 0.69 for the young rice at vegetative stage. However, the model equation $ET_m = 0.87E_p + 1.79$, R^2 = 0.73 predicted for panicle growth stage indicates a higher significant relationship between measured ET with evaporation. The relationship between the determined (ETe) from class "A" evaporation pan and measured (ETm) using micro-lysimeter was also performed. Fig 8c, d show the linear relationship derived from estimated ETe from pan and measured ETm for rice at its reproductive and late or ripening growth stages. The results shows a significant relationship with a strong co-efficient of determination R^2 = 0.897 and regression model $ET_m = 0.922ET_e + 1.44$ during reproductive stage, however a weak relationship R^2 = 0.50 at ripening or last growth stage was obtained and model equation $ET_m = 0.92ET_e + 2.29$. It may be due to the fact of lower rate evapotranspiration during initial (younger crop) and last growth stages of rice, while higher values are obtained at reproductive stage (mainly due to increased rate of transpiration from larger leaf area). Typical ET values of rice in the tropics are 4 - 5 mm d^{-1} in the wet season and 6 - 7 mm d^{-1} in the dry season (Datta, 1981). For transplanted rice, water use depends on crop growth, the duration of land preparation and the sizes of outflows. Weerasinghe et al. (1988) reported an ET rate of 3 - 4 mm d^{-1} during initial stage and 5 - 7 mm d^{-1} during productive to medium dough stages in Sri Lanka. Several researchers (Evans 1971; Nakagawa 1976; Doorenbos and Pruitt 1977) reported that rice evapotranspiration might be influenced more by climatic conditions than by crop growing stage, or it appears to vary with crop growth and available water in the paddy field.

Material and methods

Study site description

The Kemubu Agricultural Development Authority (KADA) established in 1972. It is a paddy irrigation scheme located in the State of Kelantan on the east coast of Peninsular Malaysia. It covers about 82,900 ha land area with the biggest cultivated paddy field of over 37, 390 ha. The experiment was conducted under the National Water Management Training Centre (NWMTC) Kota Bharu. Two Marriott tube types micro-paddy lysimeter were constructed and installed in two selected plots (75 m × 40 m). It consists of two parts namely the lysimeter tank, where the crop is planted and the marriott system for taking measurements. The lysimeter tank is made of polyvinyl-chloride (PVC) cylinder 60 cm high, 20.32 cm internal diameter and 1.5 cm thick. It has a closed base to avoid water losses due to seepage and two side holes, 51 cm and 55 cm from the base as shown in Fig 1. The lower opening 2 cm in diameter is used to connect marriott tube while the upper opening 2 cm in diameter, is used to drain excess water a result of rain. The tank was used to provide field environment for plant during measurements. The marriott tube on the other hand, is made up of two parts the outer tube and the inner tube (bubble tube). The arrangement of the marriott tube system is presented in Fig 2. The outer tube is made up of a glass cylinder 100 cm long with 4.4 cm internal diameter with both ends open. It serves as a reservoir, such that the depleted water from the tank can be replenished from the water in the tube. The inner tube is an empty cylindrical glass tubing, 0.82 cm outer diameter and 100 cm long. It is inserted into the outer tube and kept in position with the aid of a stop cork and contains no water. The air column in the tube pushes water into the micro-paddy lysimeter tank in response to fall of water level in the tank.

Climatic condition for rice cultivation

The characteristic of climatic features of Malaysia are uniform temperature, high humidity and copious rainfall. Winds are generally light and it is extremely rare to have a full day with completely clear sky. It is also rare to have a stretch of a few days with completely no sunshine except during the northeast monsoon seasons. The potential production of any crop yield is assumed to be determined by the interaction of genotypic characteristics with the solar radiation, temperature, CO_2 level, and day length it experience. Solar radiation provides the energy for the uptake of CO_2 in the photosynthetic process, while temperature determines the crop growth duration and the rates of physiological and morphological processes. Day length can affect the rate of development at certain phases of the crop's life cycle, and to a lesser extent the amount of solar radiation received by the crop. The cloud cover the environment is a potential parameter reducing the photosynthesis and ultimately the overall yield and this may have effect in KADA scheme. Different varieties of rice cultivated respond differently to climatic factors. Rice grown in Malaysia responds to most of the climatic variations. However, there are a number of climatic conditions that are essentially crucial for optimum growth of rice plants or paddy. These conditions are based on temperature, day length or sunshine and rainfall.

Temperature

Rice is a tropical and sub-tropical plant. Therefore, temperature is another climatic factor that significantly influences the development, growth and yield of rice. Rice requires a fairly high temperature between 20°C and 40°C. The optimum temperature of 30°C during day time and 20°C during night time seems to be more favorable for the development and growth of rice crop.

Day length and sunlight

Sunlight is important for the development and growth of the plants. Sunlight is the source of energy for plant life. The yield of rice is influenced by the solar radiation particularly during the last 35 to 45 days of its ripening period. The effect of solar radiation is more profound

Table 2. Comparison of measured and estimated ET from evaporation using class "A"Pan.

Period (day)	Pan Evaporation E_p (mm/day)	Estimated ET_e using Class "A" (mm/day)	Measured ET_m (mm/day)		Ratio = ET_m/E_p	
			Plot 1	Plot 2	Plot 1	Plot 2
1	5.8	5.0	6.2	7.3	1.07	1.26
2	5	4.3	5.2	5.6	1.04	1.12
3	3.3	2.8	3.5	3.8	1.06	1.15
4	4.9	4.2	5.5	6.2	1.12	1.27
5	3.8	3.3	4.6	5.8	1.21	1.53
6	4.4	3.8	5.0	5.4	1.14	1.22
7	5.1	4.4	5.6	5.6	1.10	1.10
8	3.3	2.8	3.6	3.9	1.09	1.18
9	3.4	2.9	4.2	5.0	1.24	1.47
10	3.5	3.0	4.2	6.0	1.20	1.71
11	5.3	4.6	5.4	5.9	1.02	1.11
12	5.5	3.5	4.9	6.5	1.23	1.63
13	3.3	2.8	4.1	4.9	1.24	1.48
14	5.1	4.4	5.4	6.5	1.06	1.27
15	4.7	4.1	5.4	5.9	1.14	1.26
16	3.5	3.0	4.0	5.2	1.14	1.49
17	4.9	4.2	5.3	6.2	1.09	1.27
18	5	4.3	5.6	6.6	1.12	1.32
19	6	3.5	4.7	7.3	1.18	1.83
20	5	4.3	5.3	5.6	1.06	1.12
21	2.6	2.2	4.0	3.8	1.54	1.46
Min	2.6	2.24	3.50	3.80	1.0	0.90
Max	5.8	5.0	6.20	730	1.50	1.50
Mean	4.28	3.69	4.84	5.60	1.10	1.20
Total	89.90	77.54	101.68	118.96	-	-

Where water temperature and nitrogenous nutrients are not limiting factors. Bright sunshine with low temperature during ripening period of the crop helps in the development of carbohydrates in the grains.

Rainfall

Rainfall is the most important weather factor for successful rice cultivation. Understandably, the distribution of rainfall is greatly influenced by the physical features of the terrain, the situation of the mountains or plateau, as well as the geographical locations on the globe. Common indicators associated with climate variability and rice production includes: higher temperature, enhanced $CO_{2,}$ water availability, soil fertility and erosion, pests and diseases, sea-level rise, soil or water salinity climate - intense drought, cyclones, typhoon and heat waves.

Soil condition and rice crop

Agricultural fields in Malaysia are fertile and productive, especially paddy fields. Soil fertility must be sustainable for food productivity and adaptable to environmental changes to maintain food quality both for human and animal health. Paddy soils are naturally heterogeneous and apart from spatial variation, temporal variations such as nutrient status also exist. Complex interrelationships in space and time existing between physical, chemical and biological soil properties have long been recognized (Olson, et al. 1996). Soil properties in paddy field have changed as a result of intensive cropping, use of agrochemicals and monoculture. The recommended rates for fertilizers in Malaysia were set when soil fertility was rather low. Changes in soil texture, organic matter, salinity, subsoil characteristics, and water holding capacity are all factors that can cause changes in yield (Chan, et al. 2006). The process of tilling the soil rapidly incorporates organic

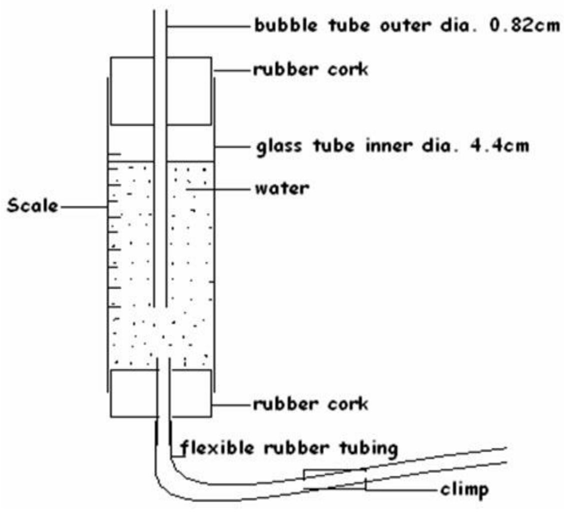
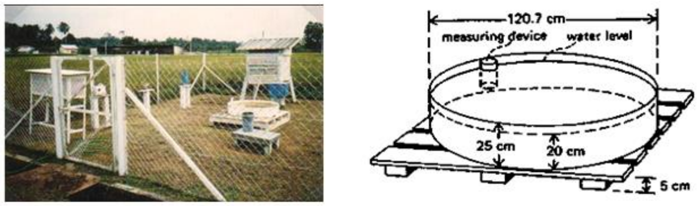


Fig 2. Marriott tube. (Adapted from Tomar and O'Toole 1980).

materials into the soil matrix. Runoff water, drying and wetting have different effects on soil properties and soil microorganisms (Stinner and House 1989). Rice cultivars (MR81) were transplanted in the plots (1 and 2) representing old and young rice crops on 5/5/2008 and 16/6/2008 respectively. Thus they were at different growth stages (initial stage and vegetative stage) at the time of measurements from 26/6/2008 to 17/7/2008. Compound fertilizer (N P K) 30:30:30 kg was applied before transplanting and 21 days after, nitrogenous fertilizer (urea) was applied. The entire growth period for wet paddy and typical crop coefficient (K_c) is presented in Fig 4. The (K_c) is required to determine (ET_c) based on reference crop evapotranspiration (ET_o) (Doorenbos and Pruitt, 1977).



(a) Class "A" Pan evaporation and other units (b) Configuration of Class "A" Evaporation Pan

Fig 3. Weather station at NWMT Khota Bharu (Adapted from MDID, 2009).

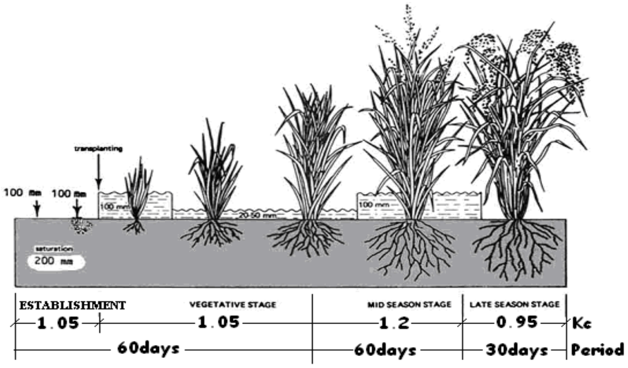


Fig 4. Water level for paddy field at different growth stage (Adapted from Azwan et al., 2010**).**

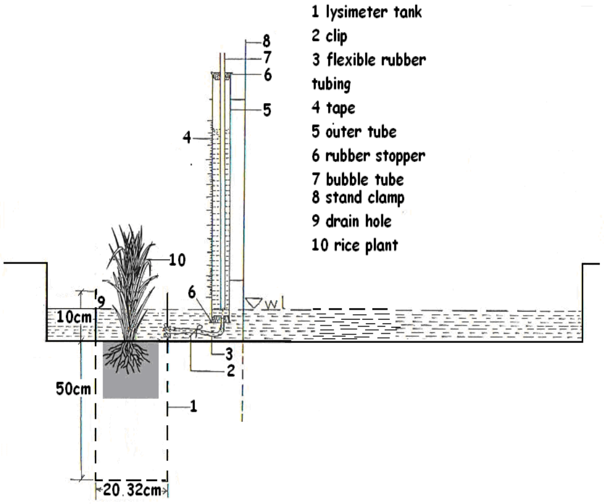


Fig 5. Cross-section micro-paddy lysimeter installed in irrigation plots (Adapted from Tomar and O'Toole 1980).

Class "A" evaporation pan

The most widely used instrument is the US Weather Bureau Class "A" evaporation pan. It is circular in cross-section 120.7 cm in diameter and 25cm deep. The water level is kept at 50 mm below the rim Fig 3. The level is measured daily with the help of hook gauge and the difference between two successive daily readings gives a daily value of evaporation (Doorenbos and Pruitt, 1977). Reference evapotranspiration (ETo), is defined as the potential evapotranspiration of a hypothetical surface of green grass of uniform height, actively growing and adequately watered. It is one of the most important hydrological variables for scheduling irrigation systems, preparing input data to hydrological water-balance models, and calculating actual evapotranspiration for a region and/or a basin (Blaney and Criddle, 1950; Dyck, 1983; Hobbins et al. 2001a; Xu and Li, 2003; Xu and Singh, 2005).

The (ETo) is a measure of the evaporative demand of the atmosphere independent of crop type, crop development and management practices. Only climatic factors affect (ETo). Accordingly, ETo is a climatic parameter and can be computed from meteorological data (Allen et al., 1998). Different types of methods have been attempted to model (ETo)(Xu and Singh, 2005) such as: (1) water budget (Guitjens, 1982), (2) mass-transfer (Harbeck, 1962), (3) combination (Penman, 1948), (4) radiation (Priestley and Taylor, 1972), and (5) temperature-based (Thornthwaite, 1948; Blaney and Criddle, 1950) equations. The Penman–Monteith (P–M) method is recommended by FAO as the sole method to calculate reference evapotranspiration wherever the required input data are available (Allen et al. 1998; Droogers and Allen, 2002).

The FAO method is a physically-based approach that can be used globally without any need for additional adjustments of parameters. Xu et al. (2006b) and Chen et al. (2005) studied the Penman–Monteith (ETo) in the Changjiang basin in detail and found that the spatial pattern and temporal trend of (ET0) agreed with class "A" pan evaporation. To obtain reference crop evapotranspiration (ETo), which is defined as water loss from hypothetical reference grass, measured evaporation from pan must be multiplied with the pan coefficient (Kp), which depends on exposure, wind speed, humidity and distance from homogeneous material (Jensen 1983).

The (Kp) value of 0.85 was obtained from (Doorenbos and Pruitt 1977) for the prevailing condition of the pan

$ET_o = K_p \text{ x } Ep$

Where, ETo = reference crop evapotranspiration (mm/day), Kp= pan coefficient and Ep = measured evaporation from pan (mm/day)

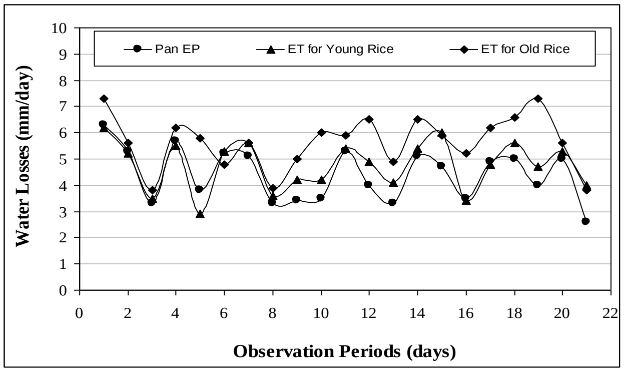
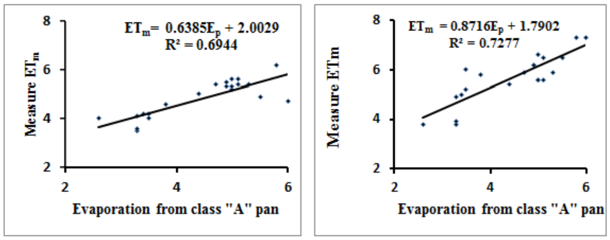


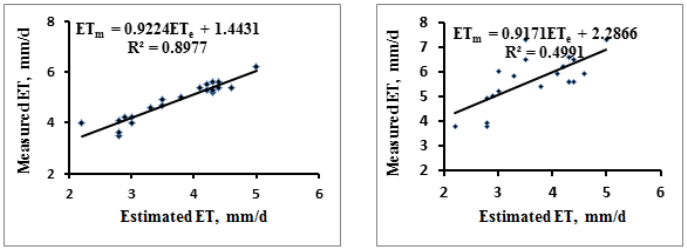
Fig 6. Measured pan evaporation (E_P) and evapotranspiration (ET_m) in Plots 1 and 2.



a. Vegetative stage

b. Panicle stage

Fig 7. a, b. Relationship between the measured ET_m and evaporation from pan $E_{p.}$



c. Reproductive stage

d. Ripening stage

Fig 8. (c), (d). Relationship between the measured ET_m and estimated crop $ET_{e.}$

Micro-paddy lysimeter Installation

After suitable site selection a 25 cm diameter auger was used to excavate the soil to a depth of 50cm. Micro-lysimeter tank was placed into the hole and the excavated soil was then used to refill in and around the tank. The soil in the tank was kept at the same level with the surrounding ground surface. The Marriott tube was then connected to the lower opening of the tank via flexible rubber tubing, having a clip to stop water delivery during refilling of the Marriott reservoir. The connections were all simple but leak proof. Stand clamp was inserted into the soil to give a mechanical support to the Marriott system. One rice hill was uprooted from the field and transplanted in the tank, water was added to a depth of 50 mm, which was the same as water level in the field. The Marriott was adjusted such that the water level in the micro-paddy lysimeter tank was at the same elevation with the lower tip of the inner tube (bubble tube) and clamped in position as shown in Fig 5. The water level at the lower tip end of the bubble tube and the micro-paddy lysimeter tank were at atmospheric pressure so that any change in the water level in the tank due to evapotranspiration causes water to flow from the outer tube into the tank until the levels are equal. Air bubbles enter the outer tube from the bubble tube during this process. Ultimately, water level in the outer tube drops. The drop in water level in the outer Marriott tube can be read with the help of an attached graduated tape. Water lost is obtained from the difference in water level between initial and final readings. The arrangement makes a short duration measurements of 1hr possible. The measurements were taken in the morning 09:00 am local time (GMT +8.0).

Calibration and analysis

The volume of water delivered from Marriott reservoir into the lysimeter tank to maintain a constant level was considered as evapotranspiration (ETm mm/day). This is calculated from the change in height of the water column in the reservoir. $ET = \frac{[\pi R^2 - \pi r^2]}{A} \Delta H$

Where; R = inner radius of the outer Marriott tube (mm), r = outer radius of the inner Marriott bubble tube (mm), ΔH = change in water column height (mm) and A = the effective cross sectional area of the lysimeter tank (mm^2).
Descriptive statistical tools are used to determine the normality of the data and coefficient of determination R^2 was used to establish the model relationship of evaporation rates.

Conclusion

The study used the field experimental data at the KADA rice irrigation scheme in 2008 to determine the crop evapotranspiration for vegetative stage and late growth period and to develop the relationship between measured (ETm) using micro-lysimeter and Class "A" Pan in Malaysia. The value shows the influence of evaporation and evapotranspiration at various rice growth stages. The results indicate the mean, maximum and minimum Ep values of 4.4, 6.0 and 2.6 mm/day, respectively. The measured ET is in the range of 2.9 to 7.3 mm/day, while the mean values of 4.8 and 5.6 mm/day were obtained in both plots. The measured (ETm) and calculated (Ep) were compared to determine the goodness of fit (R^2). The study showed that the ET rate of rice increases consistently until the ripening stage and the declined afterwards. Linear model relationship between the ETm and estimated evapotranspiration exist. The values of coefficient of determination R^2 obtained were 0.69, 0.73, 0.90 and 0.50 for vegetative, panicle, reproductive and ripening periods, respectively. Evapotranspiration is affected by management and natural factors. These factors may influence crop growth and thereby, amount of water use. Rice consumptive water in the study area was in the range of values obtained for other major areas of rice production in Asia.

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