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Effects of crop evapotranspiration estimation techniques and weather parameters on rice crop water requirement

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Abstract

Accurate estimation of crop evapotranspiration is key to determination of crop water requirements as well as water productivity. In this study, Microflex-C sensors were mounted on three sets of lysimeter to measure crop evapotranspiration in the paddy fields of the Tanjung Karang Rice Irrigation Scheme. Evapotranspiration was obtained from water level recorded at 15 minutes interval for the entire irrigation season. The readings were carried out starting from middle of January to end of April 2012. Measured crop evapotranspiration were compared with estimated evapotranspiration from weather data using penman Monteith method. These evapotranspiration values were used to determine the actual crop water requirement of MR219 rice (*Oryza sativa*) variety. The lysimeter and weather data estimates showed that 37% and 48% of the total water supplied was enough to meet the actual crop water requirement. Sensor based Microflex-C readings from the lysimeter measurements reveals that less water was required to meet actual crop water requirement compared to estimated methods. The actual average daily crop evapotranspiration for the growing season were 4.1, 3.9 and 4.0 mm/day for the month of February, March and April, respectively. The average water productivity index was determined using the lysimeter reading and weather data were found to be 10.1kg/ha-mm and 7.8kg/ha-mm respectively.

Keywords: Evapotranspiration, rice irrigation, lysimeter, crop coefficient, microflex-C ultrasonic sensor and telemetry.

Introduction

Evapotranspiration (ET) is the total water loss from both the plant by transpiration and the soil surface by evaporation of a uniformly growing grass covering the surface without short of water supply (Doorenbos and pruitt, 1977). Actual evapotranspiration of plants (ETc) is either equal to or less than Reference Evapotranspiration (ET_O) which occurs under conditions where soil fertility is at its optimum level, plants are free of disease and pests, and soil water status does not limit plant growth in any way. Jensen et al. (1990) provided detailed reviews of the methods commonly used to determine evapotranspiration and estimated crop water requirements. Estimation of crop water requirements is one of the main components used in irrigation planning, design and operation (Rowshon et al., 2013). This involves the estimation of the reference crop evapotranspiration. A good estimate of crop evapotranspiration plays the important role in accurately determining the crop water requirements for appropriate scheduling. Estimation of ETc is an important factor in irrigation management for efficient water use (Rowshon *et al.*, 2006). A good estimated ETc provide basic tool for determining water balance, water availability and crop water requirements (Humphrey et al., 1994; Pereira et al., 1999). Several methods are employed in estimating ET_c which is an essential component in crop water use (Attarod et al., 2005). Many empirical equations were used to compute rice evapotranspiration (Odhiambo and Murty, 1996; Tomar and O'Toole, 1979; Humphrey et al., 1994; Li & Cui, 1996. The FAO Penman-Monteith method is generally considered to be the best approach for estimating ETo and determination of crop coefficient because of its good approximation to accurate lysimeter observations (Maina et al., 2012). Direct measurements of evapotranspiration employ the use of lysimeters which are more accurate in measuring ETc from paddy fields. The device was designed and tested to measure rice transpiration and evaporation on hourly or daily scale basis. ETc is the product of crop coefficients (Kc) and the calculated ETo derived empirically on local climatic conditions (Doorenbos & Pruitt, 1977). Rice is a unique crop because it can be grown on upland as well as under flooded condition where constant depths of water approximately 50–100 mm are maintained throughout much of the growing season (JICA, 1998). Rice grew under flooded environments results in higher irrigation water inputs when compared to other agronomic crops. ETc involves highly complex set of processes which are influenced by many factors which depend on the local conditions. These conditions range from precipitation and climate to soil moisture, crop water requirement and the physical nature of the land cover. Dunn and Mackay (1995) described two possible scenarios for the different effects of ET on crop yields. Deficient evapotranspiration may either prevail throughout the whole growing season or it is confined within a given growth period depending on water allocation and management practices. Water productivity denotes the amount of crop yield or value of product (rice) over water use (evapotranspiration) (Bouman et al., 2007;Rowshon et a*l.*, 2006). Typical evapotranspiration rates of lowland rice fields are 4–5 mm/day in the wet seasons, and 6–7 mm/day in the dry seasons, but can be as high as 10–11 mm/day in subtropical regions (Tabbal et al., 2002). During the crop growth period, about 30–40% of evapotranspiration is evaporation (Bouman et al., 2005; Simpson et al., 1992). Water losses by seepage and percolation account for about 25–50% of all water inputs in heavy soils with shallow groundwater tables of 20–50 cm depth (Cabangon et al., 2004; (Dong et al., 2004). An accurate estimation of actual evapotranspiration is necessary for paddy field water management. Reference evapo-transpiration values, can be calculated by measuring climatic parameters and typical reference crops for actual ET using specialized instruments such as lysimeters (Rashid et al., 2009). The current state of knowledge in estimating ET for irrigation scheduling has shown much information on irrigation scheduling and has been researched over the past three decades; few new fundamental theories to enhance our understanding of water management have been presented. Testing accuracy of the methods under new set of conditions is laborious, time-consuming and costly. It has been stated earlier that lysimeter data is the reliable tool to test the accuracy of a method; climatic fluctuations on one hand and its installation, maintenance and accuracy of measurements are also another highly demanding aspect (Rasul and Mahmood, 1993). Hence the evapotranspiration from a lysimeter has been taken as reference to carry out this comparison. However, the question that needs answer is what are the exact values of ETc for MR219 at Tanjung Karang irrigation scheme? The focus of this paper is to determine the effect of evapotranspiration techniques on Kc for rice cultivar MR219 and rice crop water requirement in Tanjung Karang rice irrigation scheme, Malaysia.

Results and Discussions

The results obtained from the field experiment are displayed as shown in Figures 4 and 5, and estimation of crop water requirements are shown in Tables 1 and 2 below, the average yield for the season was 7tons/ ha. The monthly average of evapotranspiration is presented in fig.1 and the comparison of the weather parameters such as temperatures, humidity, wind and radiation. As shown in fig 2.

ET and Kc

The measured ETc of rice crop was low at early stage but gradually increases as the rice plant grows into development stage. The potential ET is higher than the measured as expected but at some points they became equal especially at the early stage. Normally at the early stage the rice plant was young and there was no canopy, therefore the ponding water surface was exposed to wind and radiations. At this point, evaporation was higher than transpiration from the plant. This was clear from the ET_{O}-PM which maintained moderately (Fig.1) while the measured ETc was low fig. 3. However as the plant transcend into the next stage while water consumption also increased.

From Fig.4, it could be seen that the rice (K_c) was fluctuating steadily at the beginning and later increased as the plant grown older.

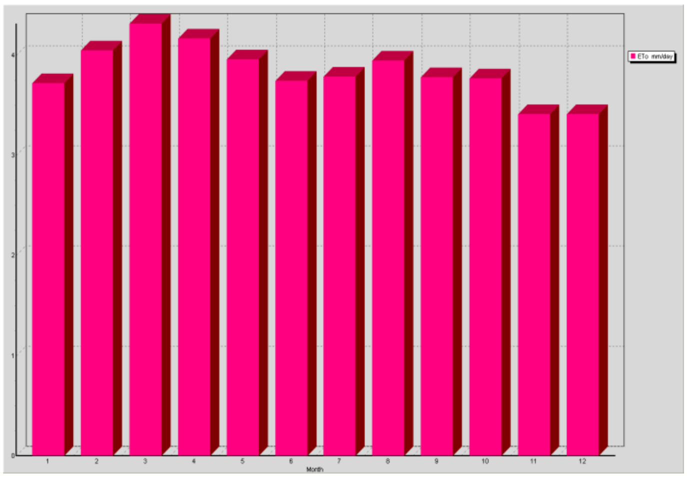

Fig 1. Monthly average Evapotranspiration in Sawah Sempadan.

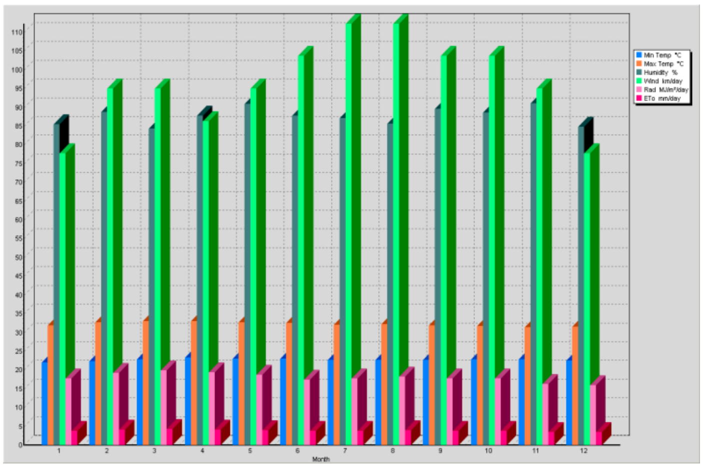

Fig 2. Changes in Evapotranspiration compared to weather parameters in a year.

The average values of Kc were 1.1, 1.3, and 1.2 for February, March and April, respectively. This explains why irrigation should be based on the plants needs. Everyday has a different amount of water needed to meet the crop water requirement due to the variability of the weather parameters fig.2. Again, Fig.4 presents independently the behaviors of the daily temperature, rainfall and the relative humidity and their effects on the crop coefficient on daily basis. Just before the reproductive stage of rice between 50 – 60 days after transplanting, the highest value of Kc was recorded. However during this period, there was not much rainfall but relative humidity was high. Generally in Malaysia, the average daily temperature is almost moderate (fig.1) and can only slightly change but mostly remain constant. The normal daily weather conditions of the research area were usually characterized with high temperature during daytime and cools down after rainfall, likewise high relative humidity. The most important thing to note here was that high crop coefficient recorded was during the reproductive stage (panicle initiation), during this period the rice plant needs much more water than any other stage of growth. It could be deduced that meeting the water needs of rice crop at this stage was critical in order to have good yield. Fig.4 showed the comparison of Kc with the

Table 1 Crop Water Requirement from Weather data Estimation Using P-M Equation

Month	Jan		Feb	March	April	Total
Days	15	16	28	31	30	120
Period	Presat-initail seas.		Mid season		late seas.	n/a
ETo		4.9	4.9	4	4.9	n/a
growth .st (days)		15	28	31	30	104
ETc (mm/day)		5.4	5.4	5.2	5.88	n/a
ETc (mm/period)		81	151.2	161.2	176.4	569.8
SAT (mm)	152	0	0	0	0	152
Total Perc (mm)		49.6	86.8	96.1	93	325.5
RF (mm)		45	95	124	35	1047.3
Effective Rain (mm)		45	95	124	35	299
Irrigation Req. (mm)		85.6	143	133.3	234.4	748.3
Crop water req. (mm)		130.6	238	257.3	269.4	895.3

Table 2 Crop water requirement from Direct Lysimeter measurements of ETc

Month	Jan		Feb	March	April	Total
Days	15	16	28	31	30	120
period	Presat-initial seas.		Mid season		late seas.	n/a
ETc (mm/day)		4.1	4.1	3.9	4	n/a
ETc (mm/period)		65.6	114.8	120.9	120	421.3
SAT (mm)	152	0	0	0	0	152
Total Perc (mm)		41.6	72.8	80.6	78	273
RF (mm)		45	95	124	35	299
Eff. Rain (mm)		45	95	124	35	299
Irrigation Req. (mm)		62.2	92.6	77.5	163	547.3
Crop water req. (mm)		107.2	187.6	201.5	198	694.3

weather parameters where the comparison indicated that increase in water consumption in rice was due to change in crop development, especially just before reproductive stage in rice. It could also be due to the slight changes in the weather parameters such as low rainfall high humidity which were recorded during the same period.

Total crop water requirement for MR219 rice variety

Crop Water requirement refers to the amount of water required to raise successfully a crop until maturity. It comprises of water lost as evaporated from crop field, water transpired or metabolically used by the crop, water lost during water application which was economically unavoidable and the water used for special operations such as land preparation and puddling of soil. The water requirement is usually expressed as the depth of water in mm. Table 1 presents the estimation of rice crop water requirement based on the measured weather data from weather station. While Table 2 presents the estimation of crop water requirements by the direct measurement of the ETc using lysimeters reading. Based on the two approaches, the crop water requirements using ETo was estimated to be 895.3 mm depth of water. Effective rainfall was found to be 299mm; hence making the actual irrigation demand to be 748.3 mm. Furthermore, the crop water requirement calculated as a result of the measured consumptive use of rice plant from lysimeter revealed that only 569.8 mm was needed for the rice crop to mature. This was measured at the field from planting date to harvest. Water depth of 152mm was used for the presaturation; these include water used to soak the land for tillage and amount applied after puddling and transplanting. Thus, another 60mm was applied to maintain field inundation for the remaining period, and thereafter water application was set based on field demand to meet crop water requirement and the losses. Under lysimeter method (Table 2) the total crop water requirement was 694.3mm, effective rainfall same as in Table 1, while Irrigation requirement was 547.3 mm. Other conditions remain the same as in Table 1. Table .3 presents the summary of the irrigation performance indicators, crop water requirements, crop evapotranspiration, water productivity index were some of the indices tested, and it showed that crop water requirement estimated based on weather data was higher as compared to the direct measurement method. The water supply could be saved when using precise information to estimate ETc. The difference in crop water requirement between the two method was due to the over estimating of evapotranspiration using Penman-Monteith method for the study area. This study has important implications for developing stable field water balance model. Some of the issues emerging from this finding relate to crop coefficient

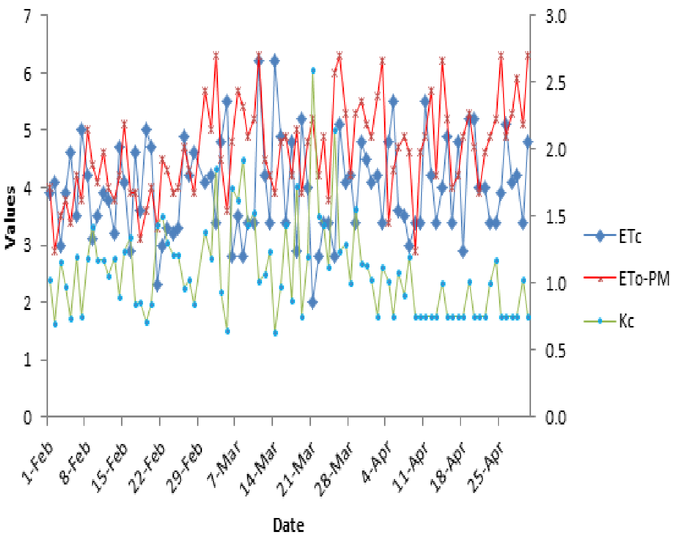

Fig 3. Measured Evapotranspiration (ETc) and potential evapotranspiration (ETo).

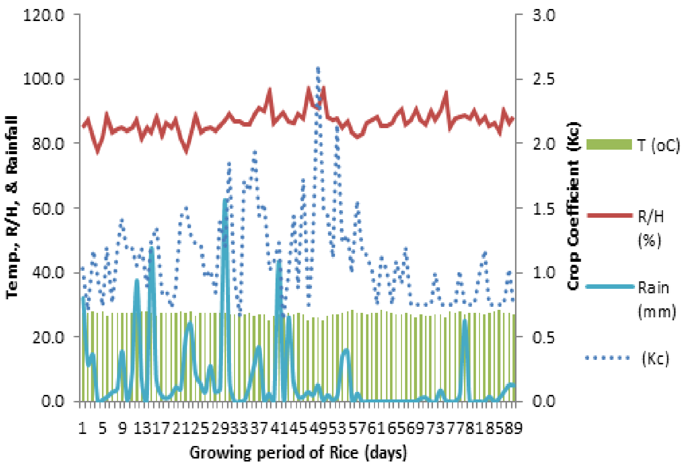

Fig 4. Comparison between Kc, Temperature (^{o}C), Relative Humidity (%) and Rainfall (mm).

for proper scheduling. It was clear that actual ETo for the research area was 4.1, 3.9, and 4.0mm/day for the growing season of rice in the months of February, March and April respectively. which confirmed findings from Bouman et al., (2005), and Rowshon et al., (2013) findings; even though some discrepancies exist but may be due to location and material differences. This study was carried out to ascertain the exact values of the irrigation field model parameters to be used as an input into the new Decision Support System. The Kc of MR219 was determined for the early stage, mid stage and late stage of growth as 1.1, 1.3 and 1.2, respectively. Crop water requirement determined for estimation method from Penman Monteith and lysimeter estimation were 895.3 mm and 694.3 mm, respectively. This is far less than what Rashid et al., (2009) found in their recent studies. Water productivity Index estimates based on the total consumptive water used for weather data and lysimeter reading was 7.9 and 10.1 respectively.

Materials and Methods

Study area

The base station chosen for this study was Sawah Sempadan which is located in the Middle West part of Peninsular Malaysia and sited 100 km north of Kuala Lumpur. Sawah Sempadan is one of the eight irrigation compartments of the Tanjung Karang Irrigation Scheme (fig. 5). The research area; 'Block C' was located at 3^{o}28'09.63465"N 101^{o}13'26.48399"E with average altitude of 6.2m above mean sea level. The soil characteristics were homogeneous across the horizon and mainly mineral and organic soils.

Measurement methods

The equipment used in this study include three sets of one square meter iron lysimeters, one opened bottom and the other closed bottom, and one serves as pan evaporation; all installed within the paddy field. Three sets of ultrasonic sensors were installed for monitoring the water level in the lysimeters (fig. 6a & b). All lysimeters were planted with rice and the pan was for evaporation measurement, both in the paddy field of Sawah Sempadan during the rice active growing season. The sensors recorded the water level in the lysimeter at every 15 minute in mm and these readings continue throughout the rice growing period. Similarly, the weather parameters were concurrently observed using automatic weather station in the same area using watchdog automatic weather station at the same time interval. The methods used for evaluation were the FAO Penman-Monteith equation and lysimeter measurements. Estimated evapotranspiration using weather parameters (ETo) and lysimeter (ETc) were compared and the relationship were analyzed. The relationship was developed based on the above mention methods, with the deployment of high precision sensors which can detect level difference of 1mm, the lysimeters were monitored by Ultrasonic sensor and therefore, higher precision was expected from the readings.

Lysimeters ET measurement using ultrasonic sensor

Ultrasonic sensors were calibrated such that all readings were referring to a particular datum so that the difference between two successive readings can be detected easily. The sensor signals were guided by a PVC pipe to prevent signal interruptions by the leaves of the rice plant. These lysimeters were installed about 40cm below the surface in the same area under the same sensor observations. The percolation was estimated as the difference between the two lysimeter readings; furthermore weather data were simultaneously recorded. The rice plants were planted inside the lysimeter with the same line and intercrop spacing as in the field. The water level inside the lysimeter was also at same level as the field water level. The crop evapotranspiration can be measured by the difference between two successive data reading per interval. The gross total amount of irrigation water was estimated using a flexible off-take gate graduated and calibrated to estimate discharge by the opening size. The gate was only set open when the field water level reaches saturation stage, and rice yield per hectare was also measured and recorded.

Table 3 Irrigation performance indices

Performance Indices	Weather data (mm)	Lysimeter (mm)
Crop water requirement	895.3	694.3
Effective Rainfall	299	299
Schedule Irrigation	8.5	8.5
Actual Irrigation requirement	748.3	547.3
Peak Irrigation Requirement	163	234.4
Average Applied Depth	60	60
Total Evapotranspiration	569.8	421.3
Water Productivity index (kg/ha-mm)	7.8	10.1
Relative water supply (RWS)	1.17	1.22

ETo-PM Estimation Using FAO Penman-Monteith equations

ET_O values were calculated from the weather parameters recorded by automatic weather station system. These parameters include minimum and maximum temperature, relative humidity, sunshine hours and wind speed at 2m height, solar radiation, vapor pressure, and rainfall. Cropwat for windows 8.0 is free software from FAO for estimating potential ET based on ETo-PM (Eq. 1).

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma(\frac{100}{T+273})U_2(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \quad (3.1)$$

Where;
ETo = Reference evapotranspiration [mm/day^{-1}]
R_n = Net radiation at the crop surface [MJm^{-2}day^{-1}]
G = Soil heat flux density [MJm^{-2}day^{-1}]
T = Mean daily air temperature at 2m height [^{o}C]
U_2 = Wind speed at 2m height [ms^{-1}]
e_s = Saturated vapour pressure [kPa]
e_a = Actual vapour pressure [kPa]
e_s-e_a = Saturation vapour pressure deficit [kPa]
Δ = Slope vapour pressure curve [kPa^{o}C^{-1}]
γ = Psychometric constant [kPa^{o}C^{-1}]

Actual crop water requirement from water balance model

The general water balance model was used to calculate total water requirement for a season as follows,

$$WD = IRR + ER - ET - SP - DR + GW \quad (3.2)$$

Where;
ET = Evapotranspiration (mm)
WD = Field pondingor standing water depth (mm)
IR= Irrigation (mm)
EF= Effective rainfall (mm)
SP= Seepage percolation (mm)
DR= Drainage and Runoff (mm)
GW= Ground water influence (mm)

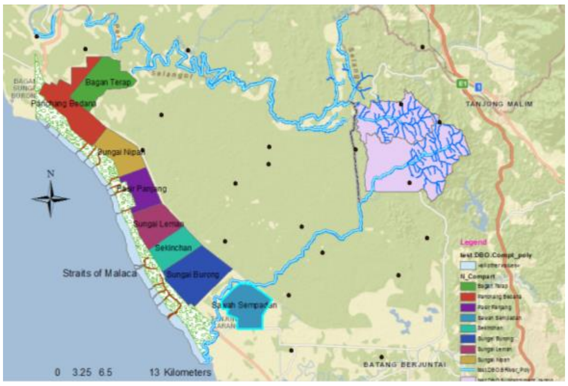

Fig 5. Map of Tanjung karang irrigation scheme showing sewah sempadan compartment.

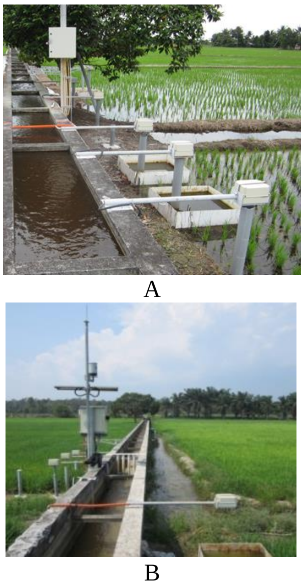

Fig 6. A. Opened bottom and closed bottom Lysimeter. **B.** Wireless Server and rain gauge with Ultrasonic sensors (Microflex-C).

A regulated off-take gate was used to measure the irrigation amount and set the discharge based on field demand. Throughout the growing season, the field water level has been maintained from 3-10cm depth until two weeks before harvesting, when water was drained. Irrigation water was applied based on field water demand. When there was no rainfall and the water level falls below the surface then irrigation water was re-applied at the rate to maintain crop water requirement. The basin system of irrigation for rice in Tanjung Karang was designed for maximum utilization of rainfall; therefore rainwater harvesting was effective. During the season under study, all rainfall was harvested as there was no rainfall that exceeds the drainage height, therefore all was considered effective. Seepage and percolation were measured as a combined term because seepage was considered negligible as a result of inflows from adjacent plots compensates outflow. Percolation was measured by the difference between the two lysimeters (opened and closed bottom). Drainage and runoff happened only when there were heavy storms more than the drainage outlet height (12cm), and when the fields need to be drained prior to harvest. The ground water was not left out by the monitoring well installed at the research plots. Three monitoring wells were constructed, each mounted with a Micro diver sensor to monitor the ground water table fluctuations.

Crop coefficient (Kc)

ETc was calculated from the crop coefficient multiplied by the ETo (Kosa, 2009). The crop coefficient (or crop factor) depends on foliage features, stage of crop development, weather condition and location and it varies widely between crops. It constitutes vital element in computing crop water requirement. In this study Cropwat for Windows Version 8.0 was used to estimates ETo from the weather station data. Kc was estimated from eqn. 3.3 and 3.4.

$$ETc = Kc*ETo \tag{3.3}$$

$$Kc = \frac{ET_c}{ET_o} \tag{3.4}$$

Where;
Kc = Crop Coefficient
ETo = Reference evapotranspiration
ETc = Actual Crop Evapotranspiration

Water productivity index (WPI)

WPI is defined as a ratio of yield output to the crop water consumptive use and it is a concept of partial productivity. In rice production, discrepancies are large in reported values of water productivity of rice (Tuong, 1999). WPI was estimated using eqn 3.5. Relative Water supply indicates the supply adequacy and equity distribution eqn. 3.6.

$$\text{Water Productivity Index (WPI)} = \frac{\text{Yield (kg)}}{\text{Total water consume (m}^3\text{)}} \tag{3.5}$$

Relative water supply (RWS)

This is simply the ratio of supply to demand, the total water supply constitutes irrigation and effective rainfall for period under consideration while the total water demand comprises of evapotranspiration and seepage and percolation losses.

$$\text{Relative water supply} = \frac{IR+ER}{ET+SP} \tag{3.6}$$

Conclusion

This study has important implications for developing stable field water balance model for lowland rice irrigation. Some of the issues emerging from this finding relate to crop coefficient for proper scheduling and using sensors can overcome the problem of oversupply. Precise ET monitoring and measurement is necessary to determine the required amount of water at each crop growth stage. The rainfall distribution pattern in the irrigation scheme should be considered to make better use of effective rainfall with respect to the stage of crop development. Facts have not been established about whether the plant can be sustained by the ground water supply at that point up to maturity without further irrigation, this scope is outside the limit of this study. This study established precise estimation of evapotranspiration which was the only beneficial water loss from the field. The application of ultrasonic sensors to monitor field water depletion proves to be useful. A further study to quantify the contribution of the groundwater to the crop root zone is needed since ground water table came in contact with the root zone during the last stage of rice plant growth at Sawah Sempadan. This could ensure maximum utilization of the residual moisture as well as rainfall harvesting to meet the crop water requirement with less irrigation water supply.

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References

Attarod P, Komori D, Hayashi K, Aoki M (2005) Comparison of the evapotranspiration among a paddy field, cassava plantation and teak plantation in Thailand. 60: 789-792. J Agric Meteorol. 60, 789–792.

Bouman BAM, Lampayan RM, Toung T (2007) Water management in irrigated rice : Coping with water scarcity. (Bill Hardy, Ed.) (p. 59). Los Baños, Philippines: International Rice Research Institue, IRRI.

Bouman BAM, Peng S, Castaneda AR (2005) Yield and water use of irrigated tropical aerobic rice systems. 74:87-105. Agric Water Management. 74, 87–105.

Cabangon RJ, Tuong TP, Castillo EG, Bao LX, Lu G, Wang GH, Cui L, Bouman BAM, Li Y, Chongde Chen JW (2004) Effect of irrigation method and N-fertilizer management on rice yield, water productivity and nutrient-use efficiencies in typical lowland rice conditions in China. 2:195-206. Rice Field Water Environ.2, 195–206.

Dong B, Molden D, Loeve R, Li YH, Chen CD (2004) Farm level practices and water productivity in Zanghe Irrigation System. Rice Field Water Environ. 2, 217–226.

Doorenbos J, Pruitt WO (1977) Guidelines for predicting crop water requirements. Irrig Drain. Paper No. 24, 2nd edition, Food and Agric. Organ. of the United Nations, Rome, Italy, (24), 156.

Humphrey E, Meyer WS, Prathapar SA (1994) Estimation of evapotranspiration from rice in southern New South Wales: a review. Aust J Exp Agric. 34, 1069–1078.

Jensen ME, Burman RD, Allen RG, Jensen ME (1990) Evapotranspiration and irrigation water requirements. p. 332. ASCE, New York.: ASCE Manuals No. 70.

JICA (1998) Japan International Cooperation Agency. The study on modernization of irrigation water management system in the Granary area of peninsular Malaysia. p. Final Report. Japan.

Kosa P (2009) Air temperature and actual evapotranspiration correlation using landsat 5 TM satellite imagery. Kasetsart J. (Nat. Sci.). 611, 605–611.

Li YH and Cui YL (1996) Real-time forecasting of irrigation water requirements of paddy fields. Agricultural Water Management. 31(3):185–193.

Luis S, Pereira AP, Iacovades I (1999) Evapotranspiration: Concepts and future trends. J Irrig Drain Eng. 125, 45–51.

Maina MM, Amin MSM, Aimrun W, Asha TS (2012) Evaluation of different ETo calculation methods: A Case study in Kano state, Nigeria. Philipine Agric Scientist. 95(4), 378–382.

Odhiambo LO and Murty VVN (1996) Modeling water balance components in relation to field layout in lowland paddy fields. II : Model application. Agric Water Manage. 30(2), 185–199.

Rashid MA, Wais K, Khan LR (2009) Etimation Of Water Loss From Irrigated Rice Fields. SAARC Agric. 7(1), 29–42.

Rasul G, Mahmood A (1993) Performance evaluation of different methods for estimation of evapotranspiration in Pakistan's climate, 1–12.

Rowshon MK, Amin MSM, Hassan SMH, Shariff RM, Lee TS (2006) New performance indicators for rice-based irrigation systems. Paddy and Water Environment. 4(2), 71–79.

Rowshon MK, Amin MSM, Mojid M, Yaji M (2013) Estimated evapotranspiration of rice based on pan evaporation as a surrogate to lysimeter measurement. Paddy and Water Environment. 13(4). doi:10.1007/s10333-013-0356-4

Simpson HJ, Herczeg AL, Meyer WS (1992) Stable iso- tope ratios in irrigation water can estimate rice crop evaporation. . 19:377-380. Geophys Res Lett. 19, 377–380.

Tabbal DF, Bouman BAM, Bhuiyan SI, Sibayan EB (2002) On-farm strategies for reducing water input in irrigated rice: case studies in the Philippines. Agric Water Management. 56, 93–112.

Tomar VS and O'Toole J (1979) Evapotranspiration from rice fields. IRRI Res. pap. ser. No. 34, IRRI, Cos Banos, Philippines. (34).