RICE EVAPOTRANSPIRATION ESTIMATION USING SATELLITE DATA

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ABSTRACT

An accurate measurement of evapotranspiration could lead to the development of improved rice irrigation water use efficiency. A study on evapotranspiration was conducted in the Tanjung Karang Rice Irrigation Project. An automatic meteorological station was installed inside the field to collect data for calculation of the crop water requirements using the CROPWAT software. Non-weighing lysimeters were installed to measure the crop evapotranspiration at five different locations. NOAA satellite data was correlated with field data. Results show that the satellite images can provide frequent field information for a large area and also reduce the error of missing data. The observed ET from the lysimeters ranged from 3.2 to 5.8 mm/day, while ET by calculation ranged from 3.2 to 5.7 mm/day. The corresponding ET values from satellite data were 4.0 to 6.5 mm/day. NOAA satellite data can be a convenient source of data for daily monitoring of irrigation water use by crops.

Keywords: paddy, evapotranspiration, remote sensing, lysimeters, Malaysia

INTRODUCTION

Increasing attention is being paid to irrigation water management of paddy fields, both because of its importance in food production and its huge water use. Meeting the physiological and ecological water requirements of rice is a prerequisite for effective irrigation scheduling of paddy fields. Beside the crop water requirements, water losses, which are not beneficial in crop production, can add a huge volume to the total water usage in agriculture. Based on this argument, there could be greater possibility to save water from agriculture, which can be used for other purposes thereafter. There is considerable scope for improving water use efficiency by proper irrigation scheduling which is essentially governed by crop evapotranspiration (ETc). Accurate estimation of crop ET is an important factor in efficient water management. Traditional ET measurements using lysimeters is accurate but time consuming and laborious. There is a need for a more rapid assessment of ET resulting from global environmental changes. The objectives of this work was to compute the evapotranspiration for the Tanjung Karang Irrigation Scheme using remote sensing and to validate the results with field measurements and meteorological computation.

EVAPOTRANSPIRATION BY REMOTE SENSING

Remote sensing can be applied to the management of irrigated agricultural systems either at a local scale or nationally. It has the possibility of offering important water resource related information to policy makers, managers, consultants, researchers and to the general public. Remote sensing, with varying degrees of accuracy, has been able to provide information on land use, irrigated area, crop type, biomass development, crop yield, crop water requirements, crop evapotranspiration, salinity, water logging and river runoff. This information when presented in the context of management can be extremely valuable for planning and evaluation purposes. Remote sensing has several advantages over field measurements. First, measurements derived from remote sensing are objective; they are not based on opinion. Second, the information is collected in a systematic way which allows time series and comparison between schemes. Third, remote sensing covers a wide area such as entire river basins. Ground studies are often confined to a small pilot area because of the expense and logistical constraints. Fourth, information can be aggregated to give a bulk representation, or disaggregated to very fine scales to provide more detailed and explanatory information related to spatial uniformity. Fifth, information can be spatially represented through geographic information system, revealing information that is often not apparent when information is provided in tabular form (Bastiaanssen, 1998).

Evapotranspiration is generally computed not for its own sake but for some other purposes and each method can be assessed for its usefulness in this regard. Traditionally, actual evapotranspiration has been computed as a residual in water balance equations, from estimates of potential evapotranspiration using a soil moisture reduction function or from field measurements by meteorological equipment. Previous work (Bastiaanssen & Molden, 2000), (Vidal & Perrier, 1989) used satellite data to estimate regional actual evapotranspiration. Granger (2000) studied evapotranspiration assessment using NOAA satellite image and AVHHR data with 1.1 km ground resolution, processed the data through radiometric calibration and geo-certified with ERDAS Imagine software. The satellite estimated evapotranspiration was calculated by multiplying potential evapotranspiration and the vegetation and moisture coefficient (VMC). The estimates compared to lysimeter measurements indicated successful estimates of regional evapotranspiration.

The application of surface energy balance algorithm for land (SEBAL) in Idaho indicates substantial promise as an efficient, accurate, and inexpensive procedure to predict the actual evapotranspiration fluxes from irrigated lands throughout a growing season (Droogers & Bastiaanssen, unpublished). Predicted evapotranspiration has been compared to ground measurements of evapotranspiration by lysimeters with good results, with monthly differences averaging +/- 16%, but with seasonal differences of only 4% due to reduction in random error (Allen et al, unpublished). The SEBAL method derives the evaporative fraction from satellite data. This is a measure of energy partitioning and a good indicator of crop stress. Actual evapotranspiration can be easily obtained from the product of the evaporative fraction and the net radiation. The SEBAL remote sensing technique is not restricted to irrigated areas, but can be applied to a broad range of vegetation types. Data requirements are low and restricted to satellite information although some additional ground observations can be used to improve the reliability.

A geographic information system (GIS) is a computer system that can store virtually any information found in paper map. A GIS can display maps on a computer screen, and it can provide detailed information about their features, including roads, buildings, and rivers. Moreover the computer can quickly search and analyze these map features and their attributes in ways not possible in paper maps. A GIS stores the topographic data for all types of map features, representing them as nodes, lines and areas. A GIS also stores the attribute data for all features. This paper reports work done at UPM in the use of remote sensing data for estimating evapotranspiration of rice.

THE STUDY AREA

The area chosen for this study is the Tanjung Karang Rice Irrigation Project (Fig.1). The site is located on a flat coastal plain in the Northwest Selangor Agricultural Development Project (PBLS) at latitude 3^0 35'and longitude 101^0 5' which covers an area of approximately 19,000 hectares extending over a length of 40 km along the coast with a width of 5 km on average. The main irrigation and drainage canals run parallel to the coast. The Bernam River, the water source for the project, meanders northwestward and forms the boundaries between the state of Selangor and Perak.

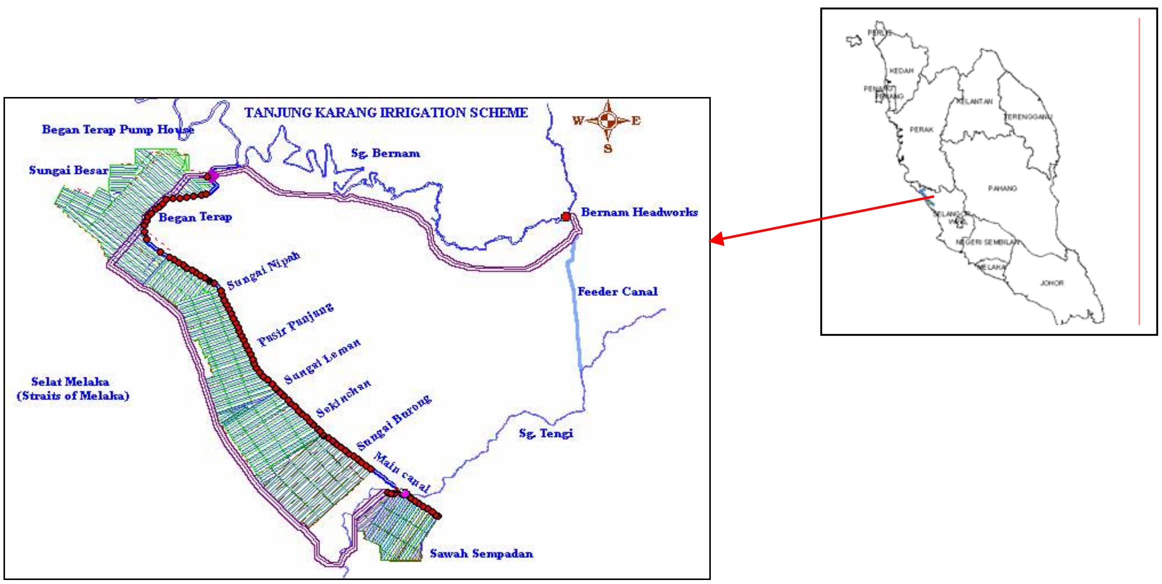


Fig. 1*: Location of the Study Area*

EVAPOTRANSPIRATION ESTIMATION METHOD

The evapotranspiration estimation method described here is based on the calculation of reference evapotranspiration (ET_o), to be multiplied by the crop factor (Kc), resulting in crop evapotranspiration (ETcrop). ET_o is defined as "the rate of evapotranspiration from an extensive surface of 5-15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". ETcrop is defined as "the rate of evapotranspiration from a disease free crop, growing in large fields, under non restricting soil water and fertility conditions and achieving full production potential under the given growing environment". In this study the reference evapotranspiration was calculated using CROPWAT software version 7, (http://www.fao.org/ag/agl/aglw/ cropwat.stm). The method is applied using 10- day running average. All data were collected from the selected study area of the Tanjung Karang Irrigation Scheme. Figure 2 shows a typical result of CROPWAT.

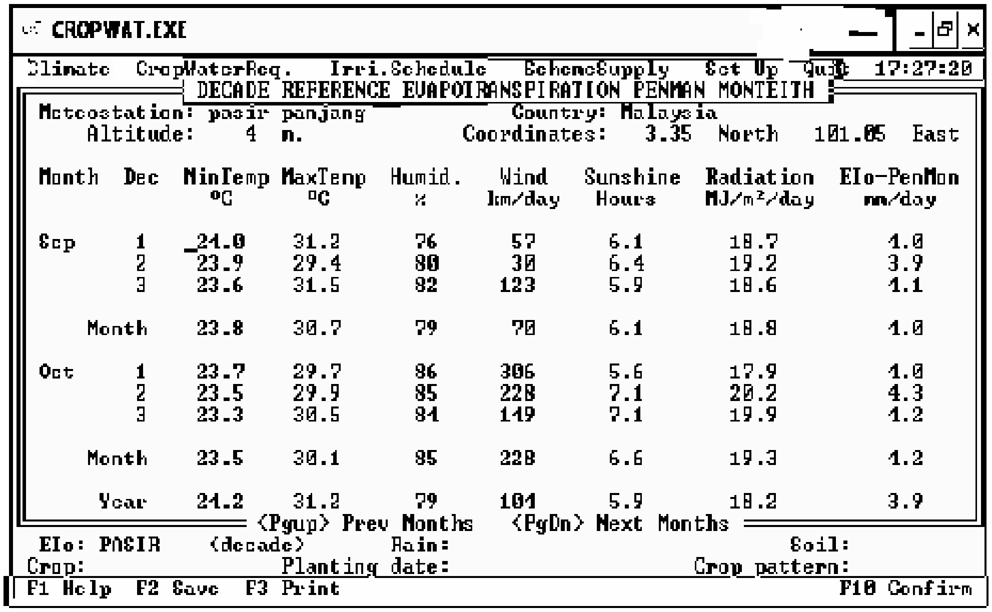


Fig.2: CROPWAT output for calculating ET_0

REMOTE SENSING METHODS

Remote sensing method is attractive to estimate evapotranspiration as they cover large areas and can provide estimates at very high resolutions. Intensive field monitoring is not required, although some ground truth measurements can be helpful in interpreting the satellite images. The methods selected are varying in resolution and degree of physical realism.

SEBAL REMOTE SENSING TECHNIQUE

The Surface Energy Balance Algorithm for Land (SEBAL) developed by Bastiaanssen 1998 is a parameterization of the energy balance and surface fluxes based on spectral satellite measurements (Bastiaanssen, 1998). SEBAL requires visible, near-infrared and thermal infrared input data, which in this case were obtained from the free of charge data provided by NOAA AVHRR (National Oceanographic and Atmospheric Administration - Advanced Very High Resolution Radiometer). Instantaneous net radiation values were computed from incoming solar radiation measured at ground station, and the net radiation estimated from twenty six cloud-free NOAA images via surface albedo, surface emissivity and surface temperature. Surface albedo was computed from the top of the atmosphere broad-band albedo using an atmospheric correction procedure. Surface temperature was extracted from the images using an especial model developed for it. NDVI was calculated from the images using remote sensing software and the surface albedo was then calculated.

LYSIMETER METHOD

Non-weighing lysimeters were fabricated and installed inside the paddy fields to measure the crop evapotranspiration at four randomly selected plots in block C of Sawah Sempadan-Irrigation compartment PBLS. Four other sets of lysimeters were installed in Sungai Burung, Sekinchan, Sungai Leman and Pasir Panjang compartments. The lysimeters, 91cm x 91cm x 61cm, were attached with a casella hook to monitor the daily water level. The lysimeters were inserted into the soil to a depth of 30 cm. Lysimeters were planted with the same rice variety in the scheme which was MR 219. Readings from the lysimeters and calculated ET from weather parameters were compared with the remote sensing derived ET estimates.

DATA COLLECTION AND ANALYSIS

METEOROLOGICAL DATA

The following meteorological data were obtained: location of the scheme (coordinates and elevation), Maximum and minimum temperature, Relative humidity, Wind speed, Sunshine duration or radiation per day, Total rainfall and effective rainfall data, and Pan evaporation. Using meteorological and crop data, the crop water requirements were calculated using the CROPWAT software. The Penman-Montieth equation used in the software is being adopted by FAO as standard evapotranspiration equation to be used all over the world. The crop evapotranspiration, ET_{crop} can be expressed as

$$ET_{crop} = K_C \, ET_o \qquad (1)$$

Where K_C is the crop coefficient and ET_o is the reference crop evapotranspiration. K_C values used were 1.3, 1.09 and 0.9 for the initial stage, the mid season stage and the end of the late season stage, respectively. These values were suggested by FAO (Paper No.56).

SATELLITE DATA

Satellite data was ordered from the Malaysian Center for Remote Sensing (MACRES) for the rice cultivation season. Images were registered, subset to the selected study area and analyzed. The evapotranspiration was calculated using the SEBAL model. The day net radiation is the electromagnetic balance of all incoming and outgoing fluxes reaching and leaving a flat surface for the daylight hours (Bastiaanssen 1995) obtained using the following equation

$$R_{n-day} = (1-\rho_0)\times(K^{\downarrow}) - 110\times\tau_{sw} \quad \text{W/m}^2 \qquad (2)$$

where $K^{\downarrow}$ is the incoming short -wave solar radiation (W/m^2), ρ_0 the surface albedo (-), τ_{sw} is the day single way transmissivity t of the atmosphere (default = 0.7, or from meteorological data if available).

The calculation of evapotranspiration is including the transformation of day net radiation from W/m^2 to mm/day using the following equation

$$ET = R_n 86400\times10^3\left[2.501-(0.002361T)\times10^6\right]^{-1}\ \text{mm/day}\ldots\ldots\ldots\ldots\ldots (3)$$

Using GIS, the data can be manipulated by digitizing the spatial data, entering the non spatial data and associated spatial attributes data, and linking between the spatial and non spatial data

RESULTS AND DISCUSSION

Lysimeter and Calculated ET

The daily evapotranspiration rates from Tanjung Karang irrigation compartments were estimated using different methods. The estimates from lysimeter and calculated ET from weather parameters using CROPWAT software is presented in Figure 3(a-e). The figure shows that the lowest lysimeter measured ET was 3.2 mm/day and highest ET was 5.8 mm/day, and occurred in the 13th week and 8th week after seeding, respectively. The figure also shows that the lowest and highest values for the calculated ET were 3.15 mm/day and 5.72 mm/day respectively.

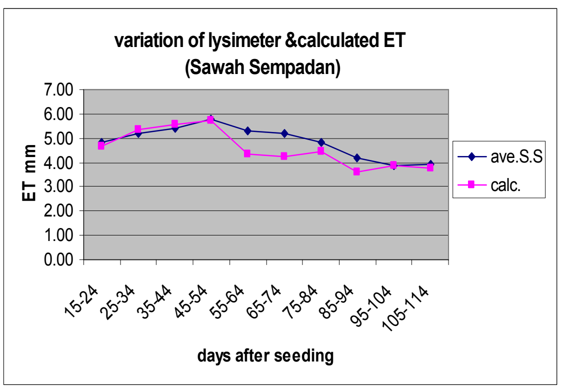


Fig 3a

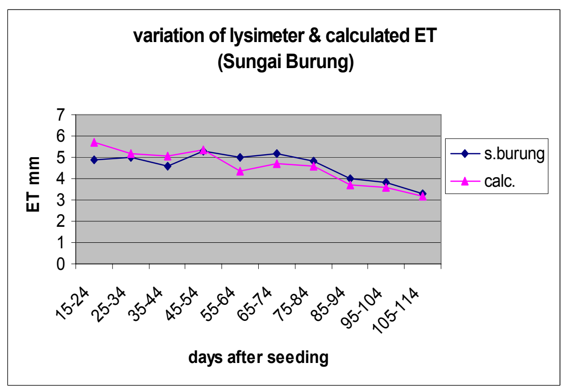


Fig 3b

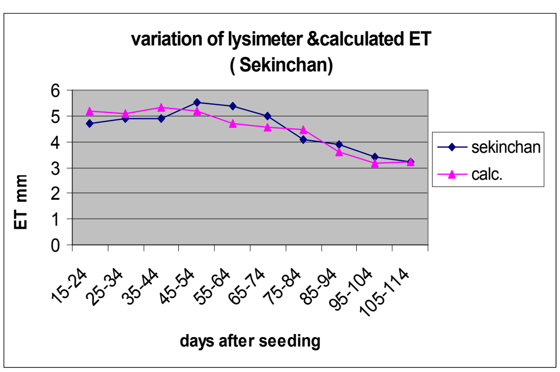


Fig 3c

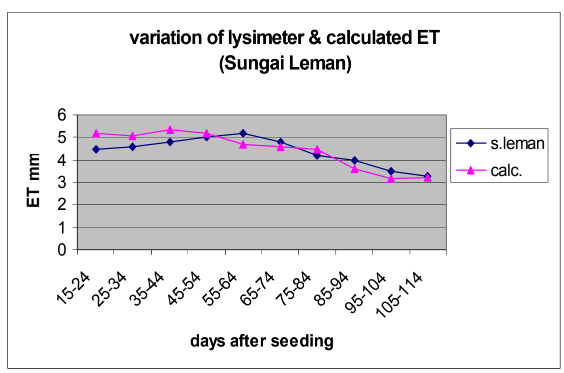


Fig 3d

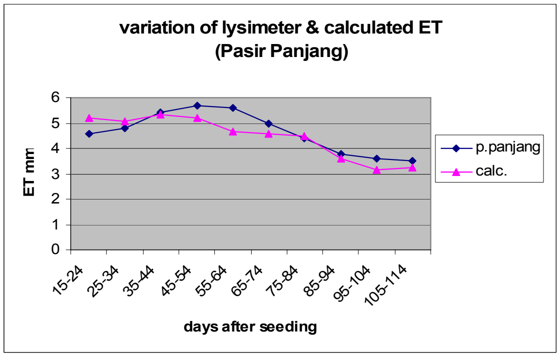


Fig 3e

Fig. 3. ET rate obtained by lysimeter and calculation for 5 locations within the irrigation scheme.

Figure 4(a-e) represents the comparison of measured and calculated ET showing the R^2 values ranging between 70-76%. Sawah Sempadan compartment shows the lowest R^2 because it is a result of average of four points.

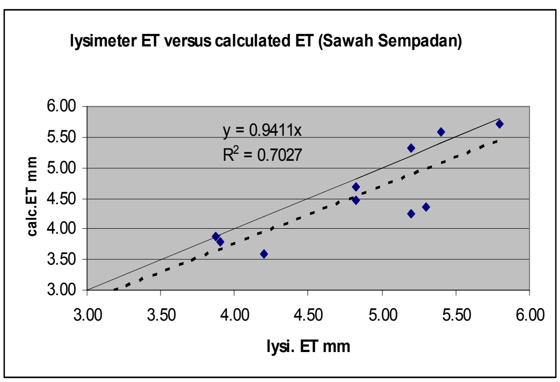


Fig 4a

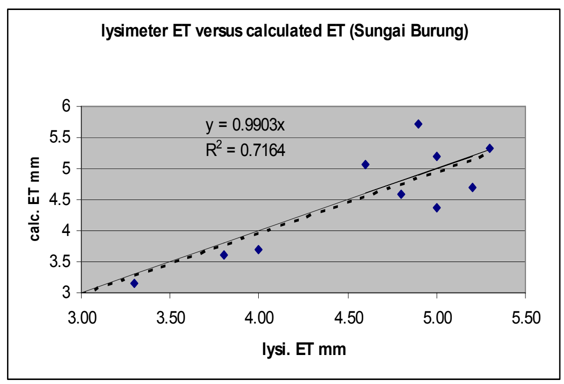
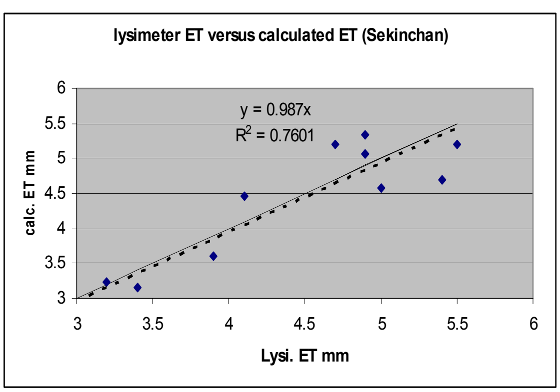


Fig 4b



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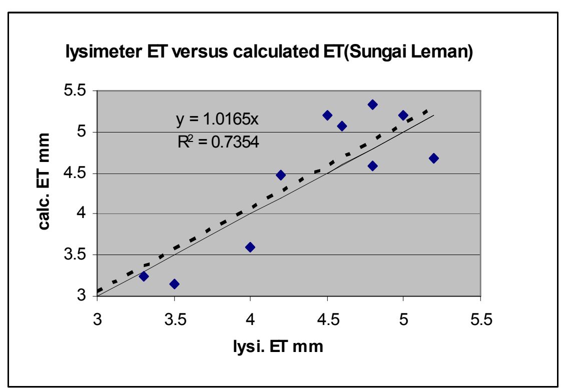

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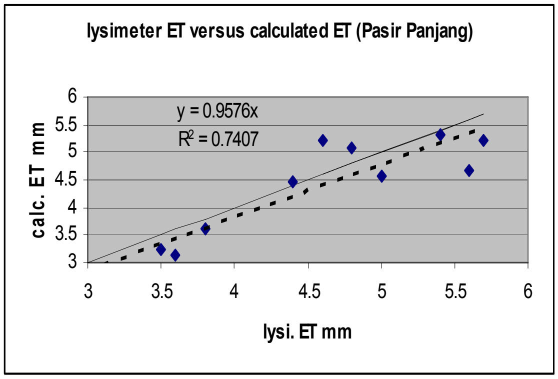

Fig 4e

Fig 4. Comparison of ET obtained by lysimeter and calculation for five locations.

Satellite Derived ET

Surface reflectance, red and near infrared band, was used to calculate the Normalized Difference Vegetation Index values (NDVI). It is defined as the difference between the visible (red) and near infrared (nir) bands, over their sum.

$$NDVI = nir\text{-}red / nir + red$$

The NDVI is representative of plant assimilation condition and of its photosynthetic apparatus capacity and biomass concentration (Groten 1993, Loveland et al 1991). The NDVI values range from -1 to +1 (pixel values 0-255). Calculated NDVI is used to estimate the emissivity values. Figure 5 represents the variations of NDVI between the different compartments obtained from the images. The values in December are low because it was the time of harvesting in the study area.

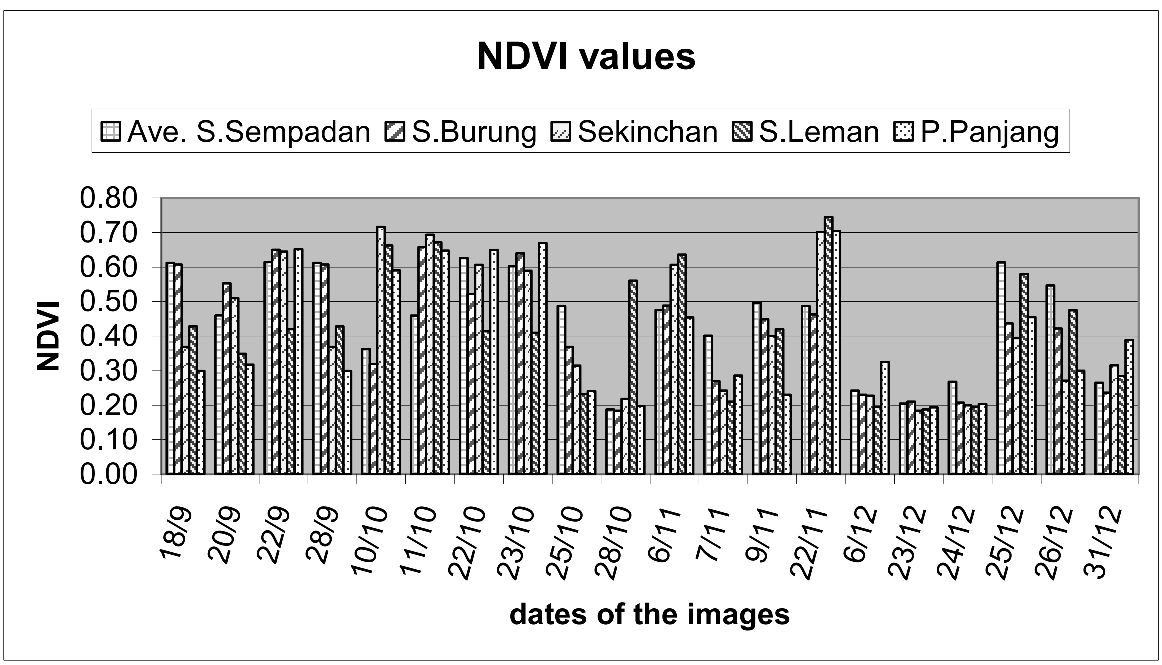

Fig: 5 NDVI values from satellite data

Figure 6 (a-e) shows the ET results obtained from satellite data calculation with the support of solar radiation data from the meteorological station. The images used were cloud free images and they were selected from a set of images taken from MACRES. The ET values from the images ranged between 4.04 mm/day to 6.54 mm/day.

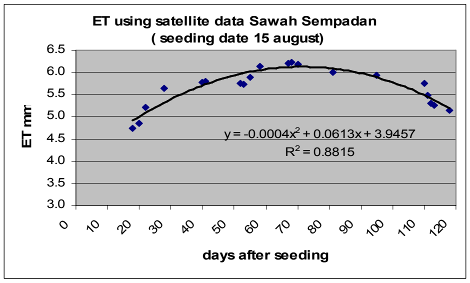

Fig 6a

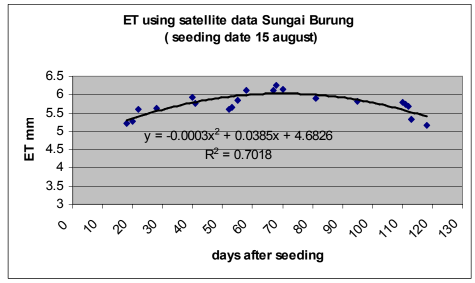

Fig 6b

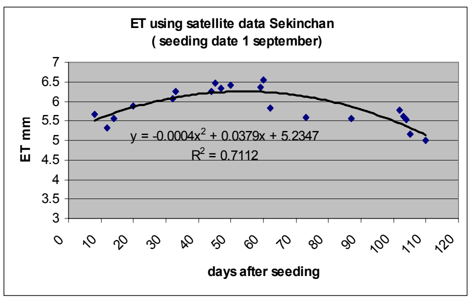

Fig 6c

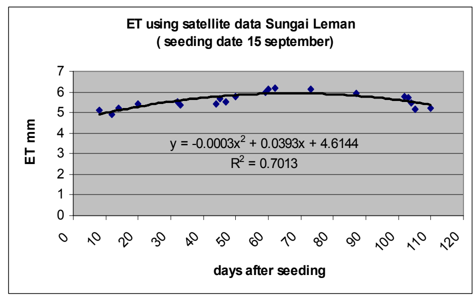

Fig 6d

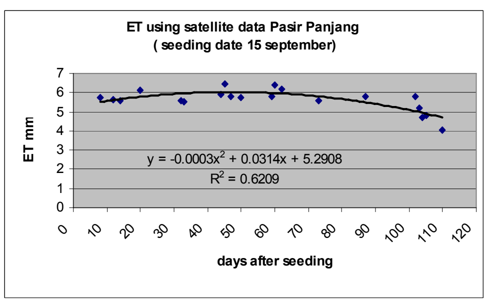

Fig 6e

Fig6. ET rate obtained by satellite data at 5 locations within the irrigation scheme

Twenty cloud free images were used in the study. The results obtained from all methods were compared. Evapotranspiration values from the NOAA data are generally 10% higher than the lysimeter data, but the ETcrop obtained from CROPWAT are generally 14% lower than those measured by lysimeter as shown in Figure 7(a-e).

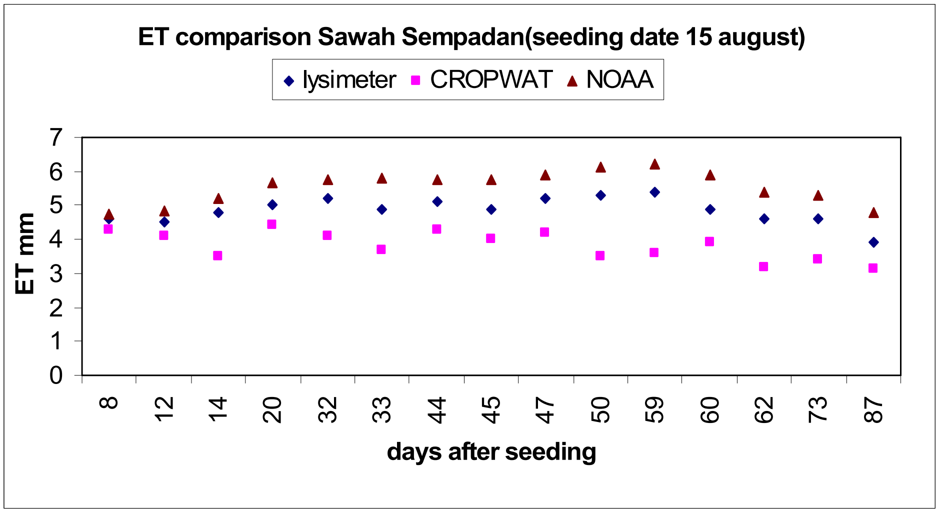

Fig 7a

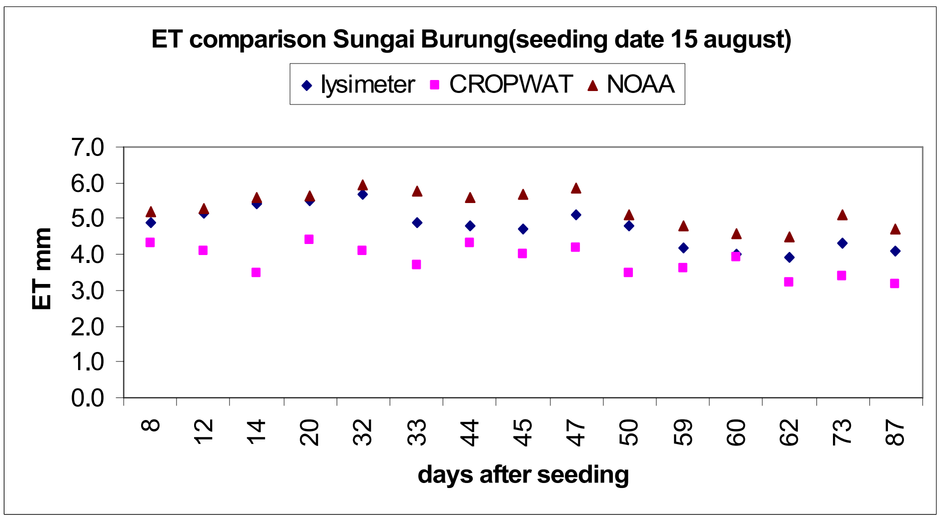

Fig 7b

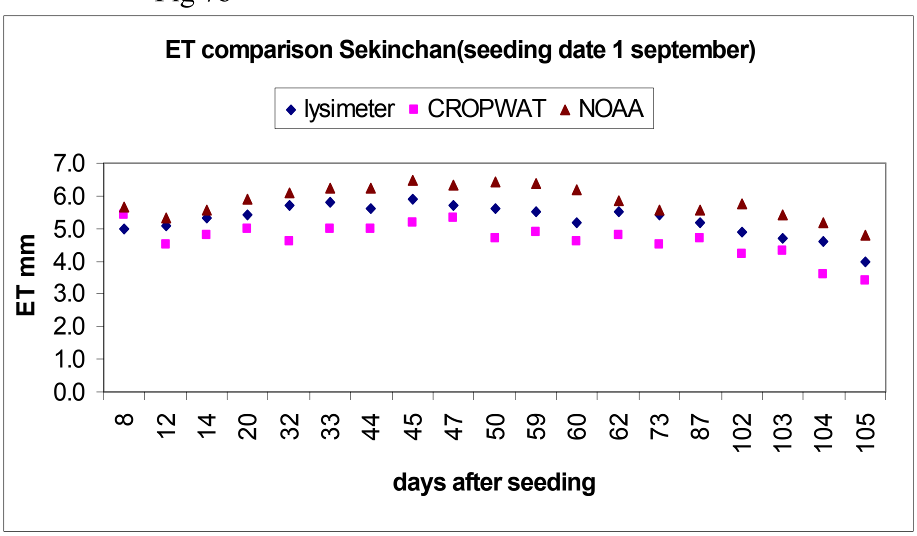

Fig 7c

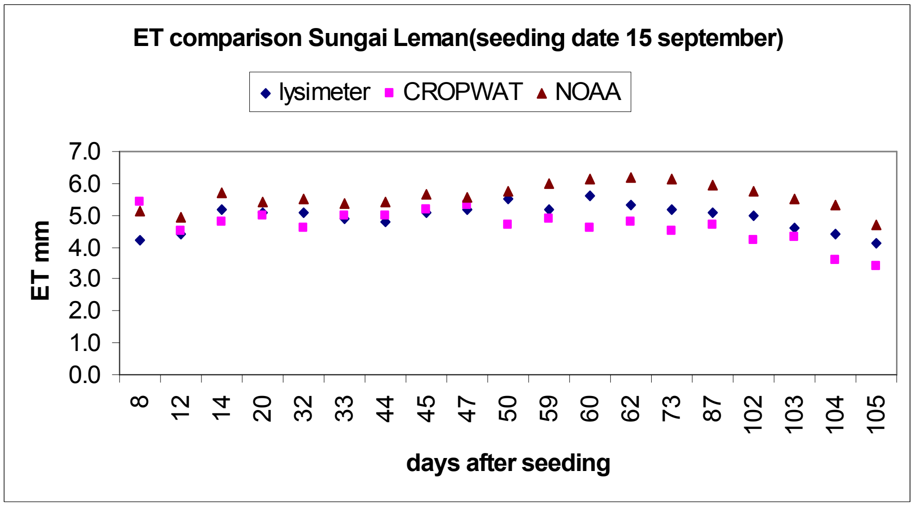

Fig 7d

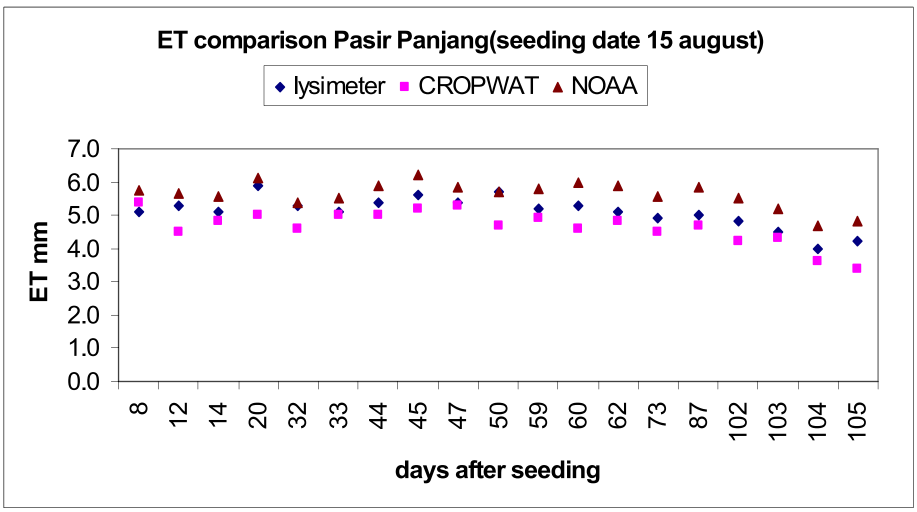

Fig 7e

The application of remote sensing needs highly trained workers and they will require some time to get the necessary skills. Consequently, it will be easy to apply the technique. The use of NOAA data with 1 km resolution is not the ideal for small areas because of its low spatial resolution, but the availability and cost of other data is the limiting factor. NOAA data is available daily even though a cloud free image may not be obtained easily in the humid tropics such as in Malaysia.

CONCLUSION

Estimates of evapotranspiration over the Tanjung Karang irrigation scheme were obtained using satellite-derived data and checked with lysimeters and calculation from weather parameters. Penman-Monteith equation through the use of CROPWAT software was applied to calculate ET. Considering ET obtained by lysimeters as the most accurate, the ET from satellite data overestimates ETcrop by 10%, while CROPWAT underestimates ETcrop by 14%. The availability of advanced very high resolution radiometer AVHRR data from

NOAA on daily basis is a cheaper alternative for evapotranspiration estimation. Satellite images can provide data and information about the paddy fields at any time, hence reduces the cost of taking field data and also reduce the error of missing data. Estimation of evapotranspiration using NOAA data will give good reflection of global changes. However, based on this study a factor of 0.9 needs to be multiplied to the satellite derived ET results.

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