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ESTIMATING EVAPOTRANSPIRATION FROM PADDY (*Oryza Sativa*) FIELD UNDER HUMID TROPICAL CONDITION

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ABSTRACT

Realistic estimate of evapotranspiration (ET) is a major factor in agricultural planning and determining crop production potential of a given region. It varies with crop growth stage. An assessment of water loss as evapotranspiration was conducted using field testing of a simplified, sensitive and accurate microlysimeter for ponded paddy field. A constant water level is maintained in the microlysimeter with a Marriott tube system and water losses from the manometer were measured. Daily variations of ET and deep percolation (DP) were determined in Peninsula Malaysia for main (August to December) and off (January to May) season cropping. Measured evapotranspiration values were compared between season and location. The average ET rates of rice growing areas are in the range of 3.3 – 6.2 and 4.6 – 6.5 mm day^{-1} for main and off season respectively. The relationships between ET and paddy growth period for the entire site had highly significant values with $r^2 > 83$ %, and the DP is between 0.35 and 2.1 mm day^{-1}. The study showed no significant difference in the rate of ET for both seasons and locations. The microlysimeter with the Marriott tube systems measures evapotranspiration on daily or hourly basis and can be fabricated locally.

Keywords: *evapotranspiration, paddy field, Malaysia, microlysimeter, deep percolation*

INTRODUCTION

Worldwide, water for agriculture is becoming increasingly scarce [1]. On a global average, approximately 75% of the water from surface and groundwater sources is consumed by irrigation [2, 3]. Population growth and competition for water resources by many different water users such as industries, municipality, recreation, mining and agriculture, the quantity of water available to be used in irrigated agriculture is decreasing throughout the world [4, 5]. It is estimated that irrigated lowland rice receives some 34 – 43 % of the total world's irrigation water, or 24 – 30 % of the total world's freshwater withdrawals, therefore with increasing water scarcity, the sustainability, food production, and ecosystem services of rice fields are threatened [6]. Malaysia uses more than 75 % of its fresh water withdrawal for rice irrigation with only about 45 % efficiency due to losses from spillage, seepage, deep percolation and evapotranspiration [7]. Rice maturity takes 105 – 125 days after planting (DAP), in the study location MR219 variety is planted and it matures within 110 DAP. This imposes significant challenges in terms of development and evaluation of optimum water management strategies to ensure conservation of water resources for the sustainability of food and fiber production.

Rice receives a large amount of water during land preparation and the growing period, as a result, large irrigation projects are often constructed to meet the water demand. Estimates of rice crop evapotranspiration are important in irrigation planning, irrigation scheduling, and overall crop and irrigation system management in large-scale paddy producing areas. Evapotranspiration (ET) is the process of converting liquid water from soil, water surfaces, and plant tissues to vapour and mixing it with the atmosphere. This process is a primary component of the energy exchange function that determines the production potential of crop species and the distribution of natural vegetation [8]. In rice field it is the total water loss from the land surface to the atmosphere; evaporation leaves the rice field directly from the ponded water layer and transpiration by rice plants withdraws water from the puddled layer. A good estimation of evapotranspiration is vital for proper water management, allowing for improve efficiency of water use, high water productivity and efficient farming activities. According to [9], most of these large-scale paddy schemes have sufficient experience of crop management, but lack engineers who could help with calculation of crop water requirements and so forth.

Evapotranspiration is affected by management and natural factors. These factors may influence crop growth and thereby, amount of water use. It may vary from farm to farm, season to season, and day to day. The rate of water use is slow at young stage. Consumptive use increases with crop growth, it reaches peak during some part of the growth period, then tapers off by harvest time [10]. Typical evapotranspiration rates of rice fields are 4–5 mm d^{-1} in the wet season and 6–7 mm d^{-1} in the dry season, but can be as high as 10–11 mm d^{-1} in subtropical regions [11]. During crop growth period, about 30–40% of evapotranspiration is evaporation [12, 13]. Numerous methods have been developed for evapotranspiration estimation. Some methods need many weather parameters as inputs while others need fewer. When choosing the evapotranspiration calculation technique some of the factors considered are data availability, the intended use, and the time scale required by the problem [14]. Traditional ET measurements using lysimeters is accurate and easy producible. Lysimetry is widely accepted as being an unparalleled standard against which to compare and validate other ET methods and models. The importance of lysimetry is now also recognized in water rights engineering, with lysimeters used to provide basic data on crop water use [15].

Lysimeters can contain monolithic or reconstructed soil and be weighing and non-weighing, with measurements of the soil water balance required for determining ET in non-weighing lysimeters. Percolation is the vertical flow of water to below the root zone. In practice, percolation and seepage flows are not easily separated because of transition flows that cannot be classified as either percolation or seepage. Typical values for percolation vary from 1–5 mm d^{-1} in heavy clay soils to 25–30 mm d^{-1} in sandy and sandy loam soils [16]. The deep percolation (DP) rate is affected by a variety of soil factors: structure, texture, bulk density, mineralogy, organic matter content, and salt type and concentration. . It is further influenced by the water regime in and around the rice field Soil structure is changed by the physical action of puddling. It accounts for about 25 – 50 % and 50 – 85 % of all water inputs in heavy soils with shallow depths and in coarse-textured soils with deep groundwater tables [17, 18, 19, 20]. This study was conducted to estimate evapotranspiration and deep percolation in rice field using non-weighing micro lysimeter in under Humid Tropical Condition, Malaysia.

MATERIALS AND METHODS

The Tanjung Karang rice irrigation scheme (TAKRIS) is a flat plain located on the coastal plain in the Northwest Selangor Fig 1. The scheme is under Agricultural Development Project (PBLS) and covers an approximate area of 19,000 ha. stretching a length of 40km long and 5km. The Bernam River (source) meanders northwestward and forms the boundaries between Selangor and Perak States. This study was conducted at Sawah Sempadan irrigation compartment, of the TAKRIS Malaysia. Sawah Sempadan has a total area of about 2,300 ha. and is divided into 24 blocks (A to X). Each block consists of about 100 lots and the size of each lot is 1.2 ha (200 × 60) m [21].

A total of three experiments was carried out in farmers' fields lot N0 3244**SS1 ($3^0 27' 42''$N; $101^0 12' 55''$E), 3334**SS2 ($3^0 26' 58''$N; $101^0 12' 41.4''$E and 3213**SS3 ($3^0 27' 55.9''$N; $101^0 13' 5''$E), all in Block C, upstream Bernam river close to the main canal. The reference evapotranspiration (ETc) and percolation were measured on site on a daily basis by lysimeter for 80 to 110 days after transplanting (DAT). The data was collected for two (main and off) seasons, August - 2011 and January - 2012 irrigation activities and analyzed using SPSS® version 19.

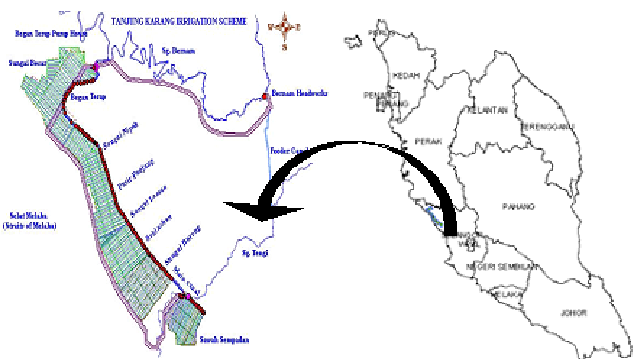
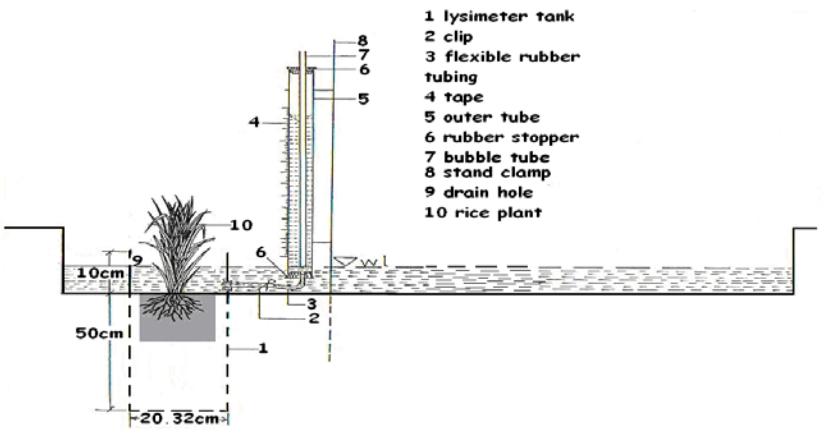


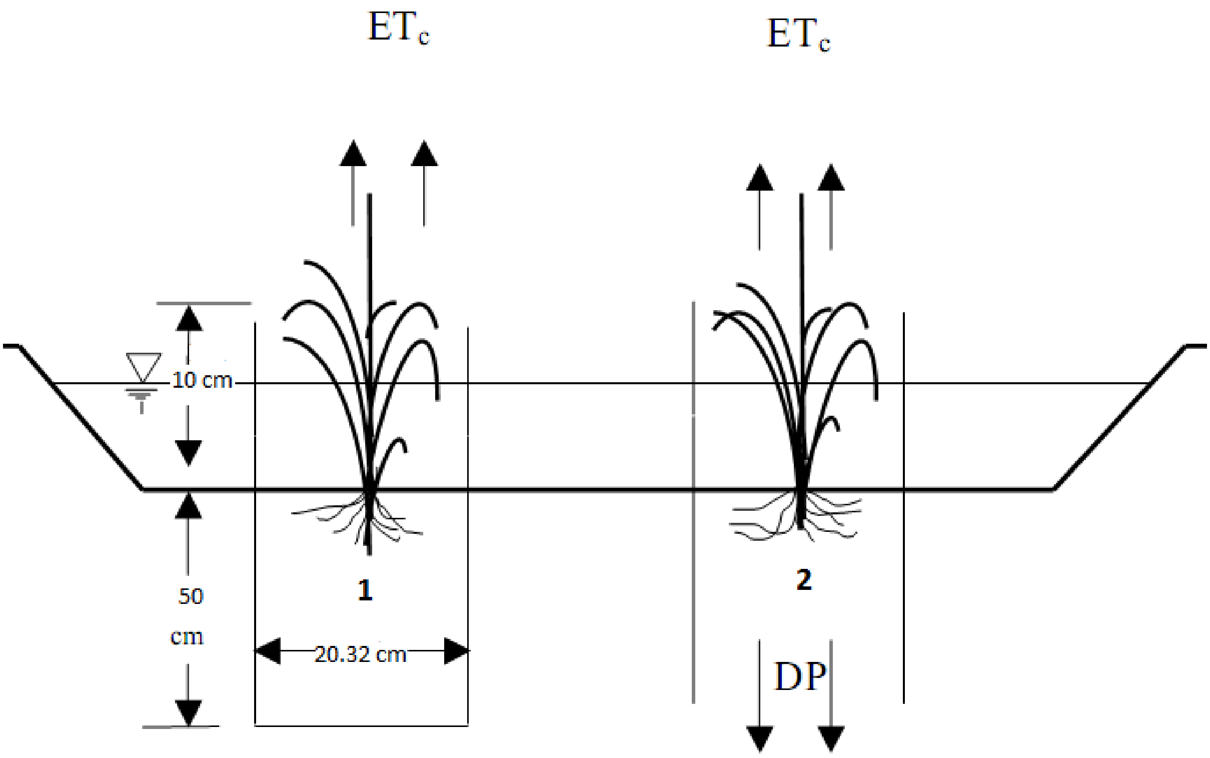
Fig. 1: Location of the Study Area

Lysimeter set – up

Non-weighing lysimeters were fabricated and installed in paddy field at three randomly selected farm lots. Fig. 2 shows the cross section of the designed microlysimetry. It was constructed [8] to measure ET while maintaining the same constant water level in the microlysimeter as in the field.



2a



2b

Fig 2 a, b: Cross-section of installed microlysimeter

It consists of two parts:

- A cylindrical tank made of poly-vinyl-chloride (PVC). Two sets are installed in the field with opened bottom lysimeter to measure losses due to deep percolation and closed water-tight bottom to determine the consumptive water-use Fig 2b. The PVC was 20.32 cm internal diameter (ID), 1.5 cm thick and cut into 60 cm long casing. It had two holes 2 cm diameter on its opposite side at 51 and 55 cm from the base.

- Marriott system consists of glass tubing reservoir 100 cm long and 3.94 cm ID with both ends open. The reservoir replenished the depleted water in the tank and it is attached with a tailor-tape (scale). The inner cylindrical bubble tube 0.83 cm outer diameter (OD) was held straight in the marriott with a stopcock. The upper end of the bubble glass tubing was open to the atmosphere and the lower was adjusted to maintain the desired water level inside the cylinder.

The 60 cm long cylinder casings were buried upright after field preparation in the soil so that 10 cm remained above the ground. One rice hill of rice was transplanted into each lysimeter to minimize field effect and to match the planting pattern in the surrounding field. The PVC tank was set in place beside each marriott system and a clear flexible tubing with a stopcock connected. The change in the volume of water delivered from marriott into the lysimeter tank to maintain the constant water level was considered as evapotranspiration ET (mm d^{-1}). Evapotranspiration and deep percolation was measured daily using equation (1):

$$ET = \frac{[\pi R^2 - \pi r^2]}{A} \Delta H \quad \text{...} \quad (1)$$

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].
Equation 1 was used for both opened and closed bottom lysimeters, however the evapotranspiration from the opened bottom (Fig 2b) also take account for losses due to deep percolation ($ET + DP$). The rate of deep percolation was calculated from equation (2).

$$ET + DP - ET = DP \quad \text{...........................} \quad (2)$$

Water depth on paddy field

Water is required in field during pre-saturation and normal growth period to supplement natural losses from the fields and to satisfy the consumptive use. For water layer be established, during growing period Fig. 3. an average of 10 cm had been used [22]. On paddy fields the pre-saturation and normal growth period involves 14 days and 105 days respectively. As the irrigation season begins, the paddy field is prepared under wet conditions. This wet land preparation consists of soaking, plowing, and puddling i.e., rotavating under shallow submerged conditions. Puddling is done to control weeds, and also to reduce soil permeability. Puddling leads to a complete or partial destruction of soil aggregates and macropore volume, and to increase in micropores volume [23]. After puddling, ponded water in the paddy field will be drained out and rice seedling transplanted or pre-germinated seed is broadcasted onto the wet paddy field. After crop establishment, the soil is usually kept ponded with a 2-10 cm layer of water until 1–2 weeks before harvest [24, 22]. The predesigned standing water depth normally maintained in paddy fields is influenced by farmer’s attitude and available water resources for irrigation [25]. During the crop growth period, water outflows are by overbund runoff, evaporation, seepage, percolation and water also leaves the rice field by transpiration. Of all these outflows, runoff, evaporation, seepage, and percolation are nonproductive and are considered losses from the field. Only transpiration is a productive water flow as it contributes to rice growth and development. During the rice growth period, about 30–40% of evapotranspiration is evaporation [12, 13].

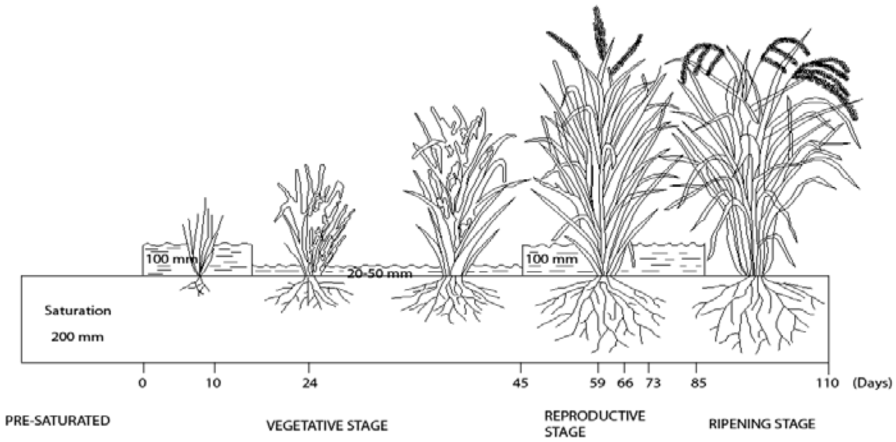


Fig 3: Water level for paddy at different growth stages [22]

RESULTS AND DISCUSSIONS

Tables 1 and 2 showed the mean evapotranspiration and deep percolation rates for August, 2011 and January, 2012 irrigation activities. From the result, ET rates of rice in block C are in the range of 3.3 – 6.2 and 4.6 – 6.5 mm d^{-1} for main and off season and the DP is between 0.35 and 2.1 mm d^{-1} respectively. Little variations are observed from both locations and between seasons. In all the locations evapotranspiration are greater during mid-growth period. The high ETc (higher than 5 mm/day) occurs mainly in February and March, the hottest period in the dry season. On paddy field evaporation (E) take place from the ponded water layer or from the surface of the soil and transpiration (T) is the process by which crop take up water from the soil and release it into the air as vapor. 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 [26]. For transplanted rice water use depends on crop growth, the duration of land preparation and the sizes of outflows. An ET rate of 3 – 4 mm d^{-1} during initial stage and 5 – 7 mm d^{-1} during productive to medium dough stages were reported by [27].

According to [11] for 100-day crop growth duration of a modern short-duration variety, total ET flows are about 400–500 mm in the wet season and 600–700 mm in the dry season. This is typical for MR219 variety which covers 105 days growth period. Percolation (plus seepage) is affected on paddy field, puddling leads to partial destruction of soil aggregates and macropore volume. The highest percolation value was observed in lot**SS3 during off season, in this study ET data was taken for up to 110 days in lot **SS3 beyond harvest period. This lead to high deep percolation value due to the outflows after water is drain from the field 2 weeks before harvest. Percolation in the scheme seems constant through the whole season, except at the end, which averaged 2.1 mm d^{-1}. For irrigated rice typical percolation vary based on soil texture from 1–5 mm per day in heavy clay soils to 25–30 mm d^{-1} in sandy and sandy loam soils. Percolation rates are higher for fields with deep groundwater tables (> 2 m depth) than for fields with shallow groundwater tables (0.5–2 m depth) [28]. In Malaysia, [29] show the average percolation rate of about 0.7 mm $d\text{-}^{1}$ at the KADA irrigation scheme and 0.9 mm d^{-1} was estimated for MUDA area.

The summarized descriptive statistics of evapotranspiration obtained during both main and off seasons are shown in Table 3. It indicates that, in block C average ET range during first, mid and last rice growth stages are 3.6 to 5.6 mm/day, 5.1 to 6.1 mm/day and 3.4 to 5.0 mm/day respectively. However, standard deviation varied from 0.3 to 1.4 mm/day. Generally, the variation in ET was not high due less impact of environmental conditions within the block. In addition, seeding dates for all the farm lots were all within few weeks and this does not affect the difference in ET values.

Table 1: Evapotranspiration and deep percolation for main season Aug to Nov, 2011

Duration (days)	Lot **SS1 ***Mean***		Lot **SS2 ***Mean***		Lot **SS3 ***Mean***	
	ET	DP	ET	DP	ET	DP
Aug 15th – 24th	3.33	1.11	4.27	1.42	3.93	0.78
Aug 25th - Sept 3rd	4.06	0.66	4.50	0.83	4.74	0.76
Sept 4th – 13th	4.68	0.43	5.49	0.81	5.59	0.70
Sept 14th – 23rd	4.81	0.66	5.40	0.57	5.48	0.66
Sept 24th – Oct 3rd	5.75	0.55	5.61	0.72	5.60	0.41
Oct 4th – 13th	5.63	0.42	5.09	0.75	5.71	0.90
Oct 14th - 23rd	6.21	0.48	4.84	0.77	5.08	0.58
Oct 24th – Nov 2nd	5.76	0.79	4.60	1.10	4.69	0.63
Nov 3rd – 12th	5.20	0.91	4.25	1.28	4.42	0.63
Nov13th –22nd	4.0	1.11	3.84	1.73	4.27	0.98

Table 2: Evapotranspiration and deep percolation for off season Jan to April, 2012

Duration (days)	Lot **SS1 ***Mean***		Lot **SS2 ***Mean***		Lot **SS3 ***Mean***	
	ET	DP	ET	DP	ET	DP
Jan 18th - 27th	4.22	0.78	-	-	3.95	0.85
Jan 28th – Feb 6th	4.81	0.80	-	-	4.61	0.73
Feb 7th – 16th	5.79	0.69	-	-	5.67	0.57
Feb 17th – 26th ***Feb 15th – 24th***	6.23	0.68	***4.29***	***0.72***	5.56	0.58
Feb 27th – Mar 7th ***Feb 25th – Mar 5th***	6.3	0.63	***5.17***	***0.78***	5.68	0.35
Mar 8th – 17th ***Mar 6th – 15th***	6.38	0.54	***5.46***	***0.68***	5.63	0.61
Mar 18th – 27th ***Mar 16th – 25th***	6.51	0.49	***5.88***	***0.70***	6.06	0.99
Mar 28th – Apr 6th ***Mar 26th – Apr 4th***	5.87	1.13	***5.68***	***0.79***	5.67	0.57
Apr 7th – 16th ***Apr 5th – 14th***	5.32	1.09	***4.98***	***0.52***	4.84	0.72
Apr 17th – 26th ***Apr 15th – 24th***	4.71	1.02	***3.91***	***0.67***	4.49	1.25
Apr 27th – May 6th ***Apr 25th - May 4th***	-	-	***3.37***	***1.31***	4.15	2.10

Table 3**:** Descriptive statistics of evapotranspiration for main and off season (2011-12) in Sawah Sempadan

Growth stage	Parameter	Farm Lot Identity					
		Lot **SS1		Lot **SS2		Lot **SS3	
		main season	off season	main season	off season	main season	off season
First	Mean	3.6945	4.5155	4.3846	4.384667	4.33335	4.50036
	Median	3.625	4.56	4.392	4.39	4.5565	4.502
	STDEV	1.025914	1.252763	1.356571	1.39371	1.194577	1.322204
Mid	Mean	5.474	6.18	5.171517	5.3956	5.358233	5.637033
	Median	5.545	6.15	4.9775	5.49	5.4165	5.6915
	STDEV	0.876623	0.908858	1.219261	1.015714	1.004099	0.735496
Last	Mean	4.6025	5.014	4.04425	3.463333	4.34635	4.4944
	Median	4.3	5.23	3.8245	3.44	4.099	4.355
	STDEV	0.856676	0.844427	0.690948	0.303801	0.863612	0.733626

Normality test and performance relationship

Several approaches exist to test the normality of data as well as model accuracy, they include graphical methods (visualize the distributions of random variables or differences between an empirical distribution) and a numerical or theoretical distribution (using standard normal distribution). Normality tests determine whether a data set is well-modelled by a normal distribution or not, or it computes the parametric nature of a data. The normality test has been tested using numerical methods of statistics such as skewness and kurtosis. In the normality test results all *p-values* for Shapiro –Wilk (SW) are higher than $\alpha_{0.05}$. Also box plot was used to confirm the normality of the data, thus, Fig. 4 revealed that ET rate in paddy field does not have outliers, and its symmetric box implies that it is normally distributed in all locations.

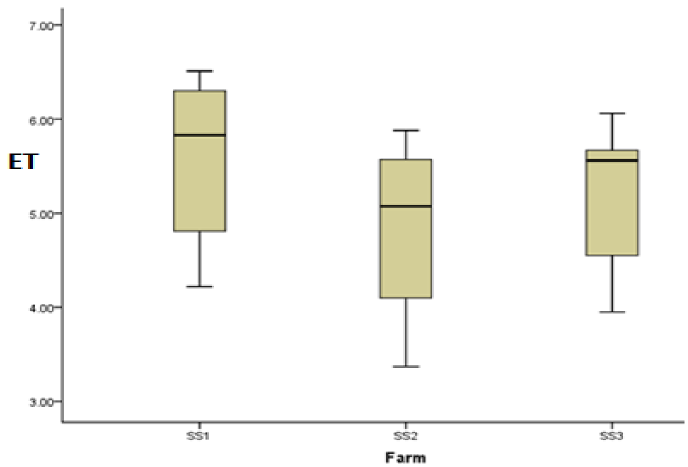


Fig. 4**:** Box Plot for ET distribution between 3 farm lots

The relationship between ET and paddy growth period was determined using coefficient of determination (r^2). The result for the three farm lots (Fig. 5) shows 89, 86 and 83 % in main season and 97, 95 and 89 % in off seasons respectively. Coefficient of determination for the entire site had highly significant relationships. However, values of r^2 in the off season are higher compared to main season irrigation activities; this depicts how ET is influenced due to weather variations during off season.

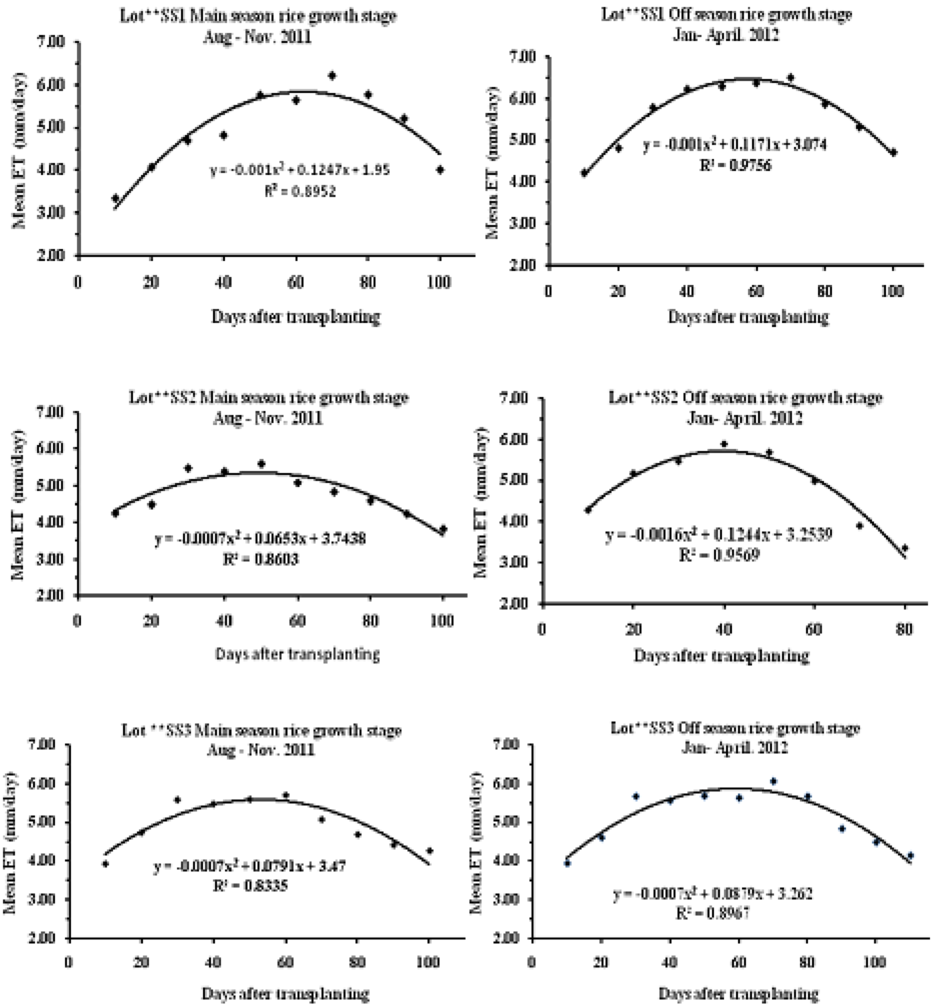


Fig. 5**:** Relationship between ET and paddy growth period for main and off season

CONCLUSIONS

Natural phenomena are generally dynamic not static, evapotranspiration is affected by soil and climatic variables. It varies with to time and location due to changes in soil texture, temperature, humidity, solar radiation, and wind speed. Evapotranspiration at the basin, watershed and regional scale plays an important role in planning and managing water resources. There are many methods for estimating ET. Lysimetry is widely accepted as being an unparalleled standard against which to compare and validate other ET models. Besides it is accurate and easy producible with little skill. Evapotranspiration and deep percolation rates using microlysimeter in Sawah Sempadan paddy field, Malaysia. ET rates of rice in block C are in the range of 3.3 - 6.5 mm d^{-1} for both seasons while DP is between 0.35 and 2.1 mm d^{-1} respectively. Little variations are observed from both locations and between seasons. All the data are normally distributed and relationship between ET and paddy growth period had highly significant relationships (r^2> 83 %). ET is generally influenced by weather variations.

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