DETERMINATION OF WATER REQUIREMENT IN A PADDY FIELD AT SEBERANG PERAK RICE CULTIVATION AREA

(Date received: 23.6.2010/ Date approved: 20.8.2010)

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ABSTRACT

Malaysia experiences water shortages as a result of a combination of drought, urbanisation and pollution. [1]. There are regions of water stress mainly due to low water resources supply, high demands, large agriculture area with consumes a large portion of avaiable water, rapid industrialisation and increasing population and peak irrigation demand during the dry season. The distribution of the rainfall in time and space has resulted in limited availability of water of acceptable quantity for water supplies in some parts of the country [2]. More than 80% of the freshwater resources developed in Asia, are used for irrigation. Of this, more than 90% of the total irrigation water is used for rice production [3]. Water requirement is important in cultivation practices of rice involve water being supplied to the paddy fields before the planting activities begin. This study was carried out to determine the total water requirement needed for 1.82 hectares of paddy field in Seberang Perak rice cultivation area. Water is supply continuously until about 10 days before harvesting. Water is required to bring the fields to saturation, and to establish a layer of water in the fields to facilitate land preparation. There-after water is required to supplement natural losses from the fields and to satisfy the consumptive use by the plant. These two distinct phases of water requirement are termed as pre-saturation and normal growth period. Saturation of water, effective rainfall, evapotranspiration and seepage percolation will be calculated for determination of crop water requirement during the pre-saturation and normal growth periods. Pre-saturation and normal growth period involve 14 days and 105 days respectively. For the establishing of the water layer, an average of 10 cm had been used for the whole growing period. Saturation of water and seepage percolation had been calculated by using the data collected from the study area. Meteorological data from the nearby station had been used for calculation of evapotranspiration and effective rainfall. In this study, the result showed that the total of 775 mm of water needed to be irrigated in 1.82 hectares of paddy plot area. This total water requirement of the paddy field had been calculated for one season of paddy plantation.

Keywords: *Normal Growth Period, Paddy Field, Pre-Saturation Period, Water Requirement*

1.0 INTRODUCTION

Total annual water requirement for agricultural use are exceedingly large especially for rice. Water required by a rice crop in a given period of time need to be considering for normal growth under field conditions. The amount of water required for a given crop depends on state of development of soil, quantity and type of fertiliser given, quality of water used and the climatic conditions. Measurement or estimation of the rate of crop water use is required for determination of irrigation water requirement. The available water for irrigation, however, is becoming increasingly scarce due to decreasing resources and quality, and increased competition from nonagricultural water users [3]. Recently, the demand of water for industrial, municipal, and other use has been increasingly as less water will be available for agriculture.

In developing countries, the growth in water demand for industrial and municipal uses, in absolute terms, is expected to exceed the growth in water demand for agriculture between 1995 and 2020 [4]. As the main source of the irrigation, the decreasing quality of surface water nowadays will retard the normal growth of paddy. Surface water can be exposed to the environmental pollution easily. The dusts and the chemical materials from the factory for instance will directly affecting the quality of the surface water.

Nowdays, groundwater has become an important source of water to meet the increasing requirement for domestic, industrial and agricultural needs [2]. Therefore, groundwater can be other alternative for irrigation of paddy. As an irrigation source, groundwater had been used in Malaysia in several places. In the Meranti Underground Irrigation Scheme, Kelantan, the water source was taken from groundwater. As the first underground irrigation scheme, it successfully prompted many similar schemes in the state.

In this study, the total water requirement for paddy plantation is determined so that the capability of the aquifer to fulfill the paddy field water requirement will be known.

Study Area

The Seberang Perak rice cultivation area is situated in Peninsular Malaysia in the state of Perak. It is located at Mukim Bandar where the specific location of this study is Blok C of Kampung Jejawi at Seberang Perak. Kampung Jejawi is situated to the left of Perak River and close to Teluk Intan, Kg. Gajah and Pasir Salak. This study area is located at latitude of 4°2' to 4° 9' North and longitude of 100° 55' to 101° 00' East where it is under the project of Integrated Agriculture Development Area (IADA), Ministry of Agriculture. This region is characterised by a warm and humid monsoon climate with average rainfall of 2393 mm (2000 to 2008). The type of soil in this region is clay loam. Planting of rice is the main activity among the residents of Kampung Jejawi. The main source of irrigation in the Seberang Perak is from the surface water which is Perak River. The method for planting the rice is by the direct seeding method. The area of this field is 1.82 hectares. The average time taken for pre-saturation is 14 days and the average of standing water depth is 10 cm for the whole season of planting.

2.0 LITERATURE REVIEW

Water Resources for Irrigation of Paddy Field

Lee *et al*., [3] reported that more than 90% of the world's rice is produced and consumed in Asia. More than 80% of the freshwater resources developed in Asia, are used for irrigation. Of this, more than 90% of the total irrigation water is used for rice production. Global rice demand in 2020 is projected to increase by 35% over the 1995 level. With this projected increase, the constraints on water resources will be further aggravated since most of the rice is produced with irrigation.

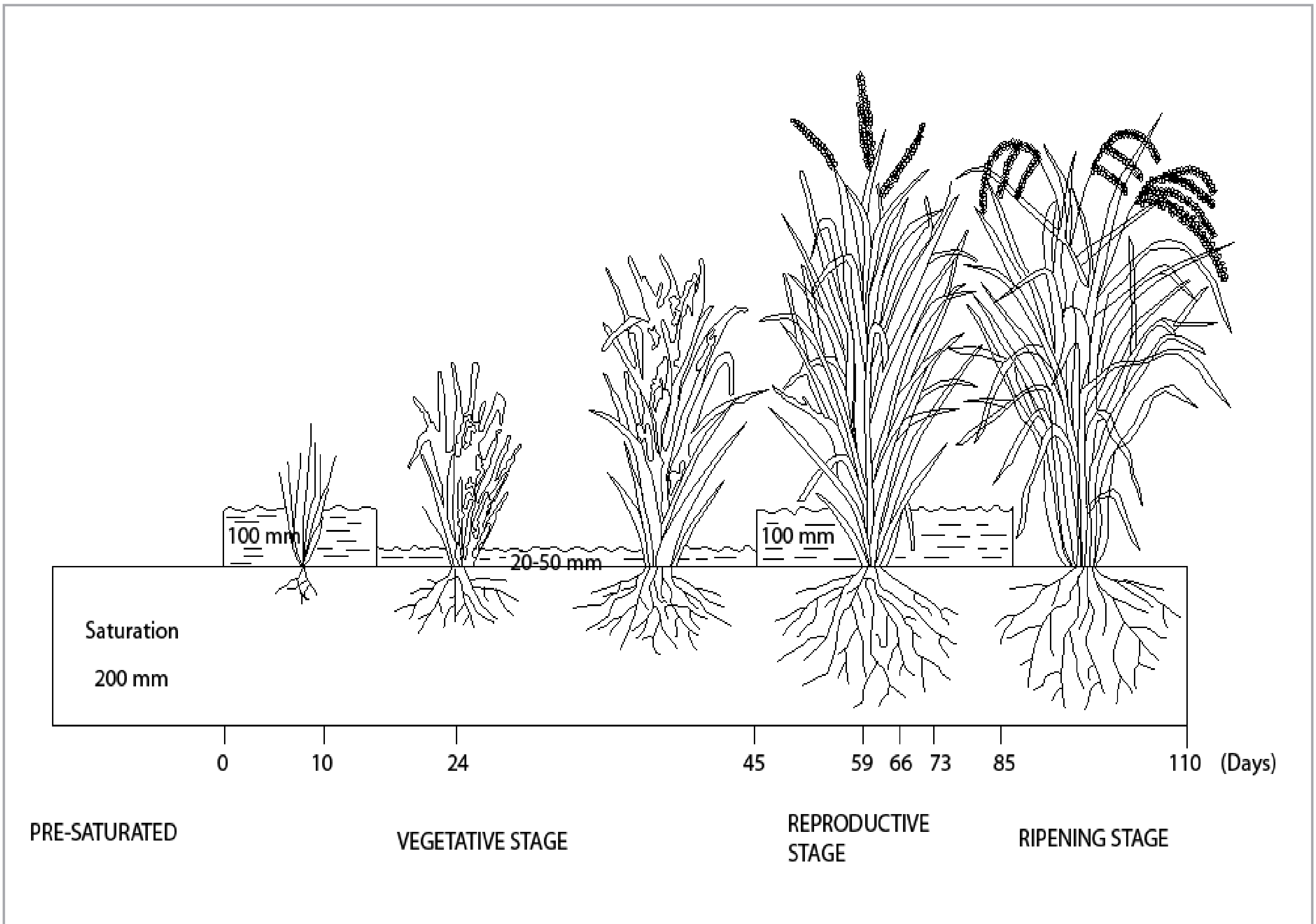

Figure 1: Water Level for Paddy at Different Growth Stages (Source: [8])

Water Requirement (WR) for Rice

The crop water requirement (*WR*) for paddy crops can be defined as the total depth of water needed to meet the water loss of disease free crop, growing in large fields under non-restricted soil conditions and achieving full production through the following processes which are pre-saturation on the field before cultivation, evaporation from field before and after direct seeding, evapotranspiration by paddy during the growth period to maturity, and percolation or infiltration loss [5].

Water Requirement for Pre-saturation Period

Thavaraj [6] indicated that *WR* for pre-saturation alone in Malaysia varied from about 400mm to 500mm, depending on the period required to complete pre-saturation, soil depth to be saturated, water depth to be maintained in the fields and soil porosity. The five factors that influence *WR* in the field during pre-saturation are evaporation from the unsaturated soil; evaporation from the saturated soil surface; infiltration and deep percolation; water required saturating the soil and *WR* for establishing a water layer in the field. To pre-saturate and inundate fields before planting of the crop, more than half of water supplied is being used for pre-saturation and the rice plant does not consume this pre-saturation water at it initial stage of growth. In order to avoid the delaying of planting of the rice during this pre-saturation period, the maximum capacity should be delivered. The *WR* for pre-saturation is theoretically 150 to 200mm, but it can be as high as 650 to 900mm when its duration is long (24 to 48days) [7]. In Malaysia, pre-saturation period will not exceed one month. For standing water depth, an average of 100mm is used for the pre-saturation period as shown in figure 1 below.

Water Requirement at Different Growth Stage of Rice Crop

Rice varieties of the tropics complete their cycle within a general range from 110 to 210 days. The growth of rice plant is divided into three phases which are vegetative, reproductive, and ripening phases. Figure 1 shows the water level at different stages of growth for paddy. In vegetative stage, the activities from transplant to panicle initiation take place. The duration varies from 1½ to 3 months. Vegetative stage includes the tillering. Tillering means that several stems develop on one plant. If the rice is sown directly (broadcast), the two stages combined are called vegetative stage. On mid season or reproductive stage the activities include from panicle initiation to flowering and the duration approximately one month. This stage includes stem elongation, panicle extension and flowering and late tillers may die. Late season or ripening stage contains activities from flowering to full maturity and the duration approximately one month. This stage includes grain growth. Table 1 shows the water requirement for rice cycle which indicate that the water requirement at the stage of vegetative, reduction and spikelet formation is very critical.

The Inflow of Water in the Paddy Field

(i) Effective Rainfall

Effective rainfall is the amount of water available for crop growth from rainfall except surface runoff loss. Effective rainfall during irrigation seasons depends on rainfall amount, rainfall intensity, topography, soil infiltration rate, soil moisture, water management practices and so on. [10]

Table 1: Water Requirement for rice cycle [9]

Day After Planting	Growth Stage	Requirement
30	Vegetative	Very critical
40	Active	Critical
60	Maximum	Critical
70	Initiation	Critical
80	Reduction	Very critical
100	Spikelet Formation	Very critical
115	Ripening	Not Required
130	Harvest	Not Required

Table 2: Water levels during rice cycle for broadcasting system [9]

Stage	Water Level
Rotovation	5cm
1 day before seed broadcasting	Drain all water
7 to 10 days after broadcasting	3 to 5cm
15 to 20 days before harvesting	Drain all water

(ii) Saturation

In the month before sowing or transplanting, water is needed to saturate the root zone. The amount of water needed is depends on the soil type and rooting depth [8]. For soil saturation depth, a Department of Irrigation and Drainage (DID) standard value of 150 mm is applied [3].

(iii) Establishment of Water Layer

A water layer is established after transplanting. By determination of the percolation and seepage losses the amount of water needed for maintaining the water layer has already been taken into account. However the amount of water needed to establish the water layer still has to be considered. Various approaches are being used with respect to the depth of the water layer. Sometimes a water layer of 100mm is established after transplant and maintained throughout the growing season [8]. In other cases the water layer is reduced to 20 to 50 mm during the latter part of the vegetative stage and brought back to 100 mm during the mid-season stage as shown in figure 1. Table 2 shows the water level during rice cycle for broadcasting system.

Water Losses in the Paddy Field

Water is lost through evaporation (*E*) from free surface, transpiration (*T*) from the crop, seepage and percolation of the soil, bund leakages and runoff from the field.

(i) Evapotranspiration (*ET*)

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes [11]. Since it difficult to separate *E* and *T* during crop growth, they are often expressed in one term; evapotranspiration (*ET*). At sowing nearly 100% of *ET* comes from evaporation, while at full crop cover more than 90% of *ET* comes from transpiration [11].

(ii) Seepage and Percolation, S and P

Percolation represent the rate of the vertical movement of water beyond the root zone to the water table, while lateral seepage represents the rate of the movement of subsurface water between fields [12]. Because of seepage and percolation occur simultaneously and are difficult to separate in the field, therefore they are usually considered together. Wickham [13] found that percolation and seepage as the most elusive components in conducting water balance studies due to the difficulty of making accurate measurements. In most cases he found that a clear differentiation is not possible between the two components and they are, therefore, considered together.

By depending upon texture and structure of the soil, depth of water table, depth of field submergence and intensity of puddling, a considerable amount of water in flooded rice is lost as percolation [14]. Kung *et al.*, [15] reported that *WR* of rice in Thailand ranged from 520 to 2549mm out of which 273 to 1275mm was percolation. *WR* values of 750-2500mm were reported by Dastane *et al.*, [16] for India from which about 60% was lost as percolation. In general, percolation rates may range from 1mm per day in well-puddled heavy soils to 20mm per day or more in light textured soils [15].

3.0 METHODOLOGY

Crop Water Requirement

The water required during pre-saturation period can be calculated as in Equation (1) as follows:

$$WR_{ps} = SAT + WD_i + E + SP - EFR \quad (1)$$

Where,

WR_{ps} is water requirement during pre-saturation (mm), *SAT* is saturation water (mm), WD_i is initial depth of flooding (mm), *E* is evaporation rate (mm), *SP* is percolation loss (mm) and *EFR* is effective rainfall (mm).

Water required during the normal irrigation supply period, can be calculated by using the formula like shown in Equation (2) below like suggested by Lee *et al.*, [3]:

$$NIR = ET_j + SP_j + RP_j - WD_j - ERF_j \quad (2)$$

Where,

NIR is net irrigation requirement (mm), ERF_j is effective rainfall (mm), *RP* is required ponding depth (mm), *ET* is crop evapotranspiration (mm), *SP* is seepage and percolation (mm), *WD* is water depth in the field (mm) and *j* is period of water management.

The *RP* and *WD* value is being taken to be equal for this calculation. Therefore, the formula for calculating water requirement for normal growth is like shown in Equation (3) below:

$$NIR = ET_j + SP_j - ERF_j \tag{3}$$

Where,

NIR is net irrigation requirement (mm), ERF_j is effective rainfall (mm), *ET* is crop evapotranspiration (mm), *SP* is seepage and percolation (mm) and *j* is period of water management.

The Inflow of Water into the Paddy Field

(i) Saturation of Water

Saturation of paddy soil which depends on the porosity of the soil and depth of the top soil can be calculated as in Equation (4) below:

$$SAT = n \times D \tag{4}$$

Where,

SAT is saturation (mm), *n* is porosity of the plow layer soil (%) and *D* is depth of the plow layer (mm). There are 7 points of the soil porosity at the plow layer that had been taken for analysing. The depth of the top soil had been determined as 8 cm by analysing the soil resistance result that had been taken by using the soil penetrologger

(ii) Initial Depth of Flooding

For Seberang Perak Irrigation Schemes, an average of 10 cm is being taken as the initial depth of flooding.

(iii) Effective Rainfall

In Seberang Perak irrigation scheme, where water is continuously supplied, excess water is drained whenever it exceeds maximum allowable level of water in the field. Surface runoff in this study area is considered to be zero because of the area of paddy field is flat.

Lee *et al.*, [3] suggested that for weekly calculation, effective rainfall can be calculated as in Equation (5) below:

$$ERF = 0.6 \times RF \text{ if } RF < 50 \text{ mm/week}$$

or

$$ERF = 0.3(RF - 50) + 30 \text{ if } RF > 50 \text{ mm/week} \tag{5}$$

Where,

EFR is effective rainfall (mm/week) and *RF* is rainfall (mm/week). The weekly rainfall is being calculated by using the summation of the rainfall in the whole week. Daily rainfall data for calculation of effective rainfall had been taken from the Hospital Teluk Intan Station.

Water Losses in the Paddy Field

(i) Evaporation Rate (*E*)

In the early stages of crop growth, most water is used through evaporation. Therefore evaporation rate is important to be taken into the water requirement of the pre-saturation period. The value of *E* had been taken from the climatologically data of Hospital Teluk Intan Station.

(ii) Crop Evapotranspiration (*ET*)

The estimation of consumptive use for irrigated crops is determined by the crop coefficient-reference *ET* procedure. Reference *ET* (ET_o) is computed for a hypothetical reference crop according to the FAO paper no. 56 methodology [9] and is then multiplied by an empirical crop coefficient (K_c) to produce an estimate of crop *ET*, as in Equation (6):

$$ET_c = K_c \times ET_o \tag{6}$$

Where,

ET_c is crop evapotranspiration (mm/day), K_c is crop coefficient and ET_o is reference evapotranspiration (mm/day).

Accordingly, the ET_o is calculated using the FAO Penman-Monteith method recommended in FAO paper no. 56, which use all parameters that govern energy exchange and corresponding latent heat flux (evapotranspiration) from uniform expanses of vegetation. Most of the parameters are measured or can be calculated from weather conditions. It requires daily, weekly and monthly meteorological data including air temperature, humidity, sunshine duration and wind speed. The FAO Penman-Monteith equation used for 24 hour calculation of ET_o and using daily or monthly mean data can be simplified as in Equation (7):

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,(900/T) + 273]\,u_2(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)} \tag{7}$$

Where,

ET_o is reference evapotranspiration (mm/day), Δ is slope of saturated vapour pressure per temperature curve (kPa/ ºC), γ is psychrometric constant (kPa/ ºC), u_2 is wind speed at 2m height (m/s), R_n is total net radiation at the crop surface (MJ/m^{2}day), *G* is soil heat flux density (MJ/m^{2}day), *T* is mean daily air temperature at 2m height (ºC), e_s is saturation vapour pressure (kPa) and e_a is actual vapour pressure (kPa).

The meteorological data for computing reference evapotranspiration include maximum and minimum temperature (ºC), maximum and minimum relative humidity (%), wind speed at 2m height (m/s), height above mean sea level altitude (m), solar radiation (MJ/m^2), and latitude. The daily values of all

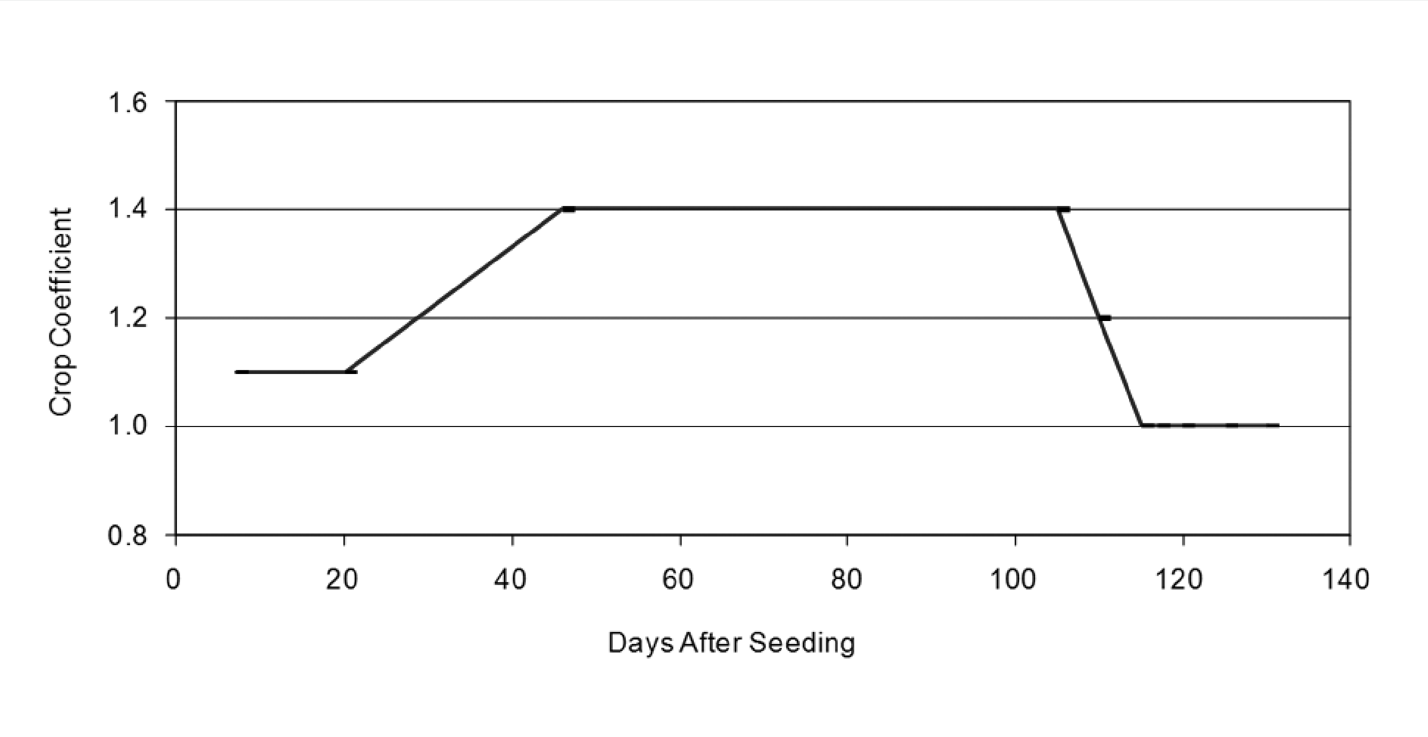

Figure 2: Suggested crop coeffient, K_c values for Rice (MR84) [18]

Table 3: Crop Coefficient, K_c value for rice [18]

Days(after seeding)	7	20	46	105	110	115	117	120	125	130
K_c	1.1	1.1	1.4	1.35	1.2	1	1	1	1	1

components to calculate reference evapotranspiration, were taken from Hospital Teluk Intan (latitude: 4° 02'N; longitude: 101° 01'E) station.

Crop coefficients can be influenced by cultivation, local climatic conditions and seasonal differences in crop growth patterns [17]. The crop coefficient in this study was referred from the result of Chan and Cheong [18]. Chan and Cheong determined crop coefficient values for rice field in Tanjung Karang which are shown in Figure 3 and Table 3. This might be useful for rice in Seberang Perak Irrigation Schemes.

(iii) Seepage and Percolation (S and P)

Seepage and percolation are two movements that often practically inseparable [19]. The deep percolation (*DP*) is the amount of water goes deeper into the soil (below the root zone) vertically. *DP* is influenced by changes in the conditions of rice fields including soil texture and structure, top and subsoil thickness, standing water depth, water and soil temperature and salinity, depth to the groundwater table, and other topographical conditions [19].

Darcy's law was used for estimation of daily percolation rate out of the root zone layer [20] and is given as Equation (8) below:

$$DP = \frac{-K_s \, \Delta h}{\Delta Z} \tag{8}$$

Where,

DP is percolation out of the root zone (mm per day); K_s is the saturated hydraulic conductivity (mm per day; after accounting for puddling effects) and $\Delta h/\Delta z$ the head gradient [21].

For determination of hydraulic conductivity, the formula as shown in Equation (9) below:

$$K_s = \frac{\sum Z}{\frac{Z_1}{K_1} + \frac{Z_2}{K_2}} \tag{9}$$

Where,

K_s is saturated hydraulic conductivity (cm/s), K_1 is hydraulic conductivity at medium 1 (cm/s), K_2 is hydraulic conductivity at medium 2 (cm/s), $\sum Z$ is total thickness of layer (cm), Z_1 is thickness of the layer 1 (cm) and Z_2 is thickness of the layer 2 (cm).

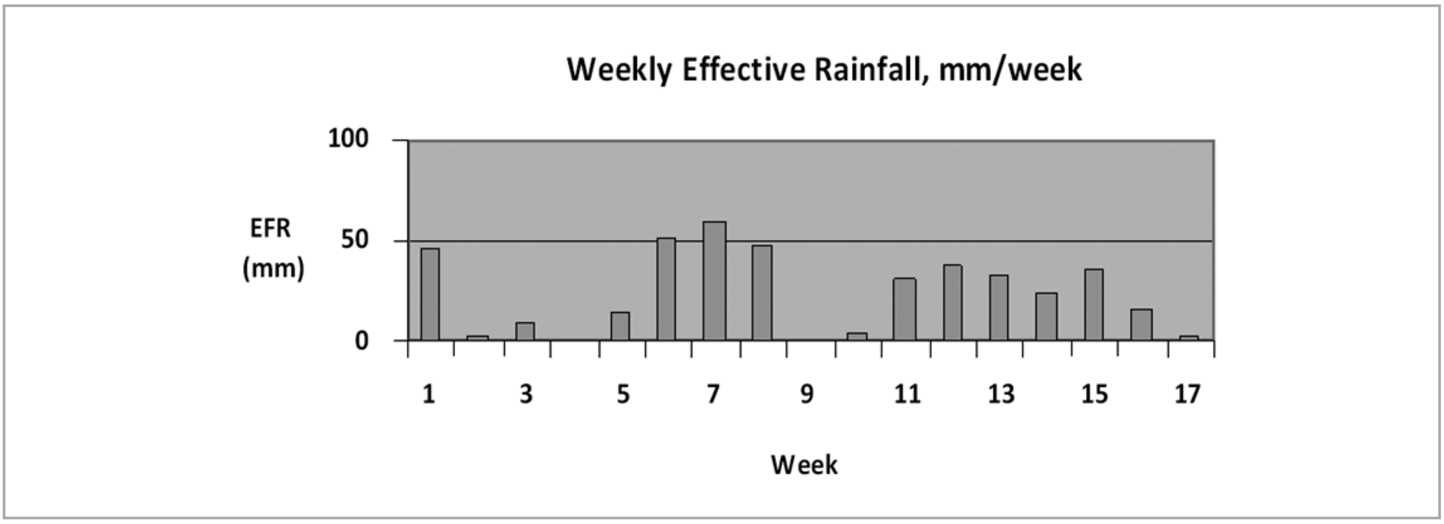

Figure 4: Weekly effective rainfall which depends on different conditions

Site Description

Five soil water pressure sensors were installed at the field of paddy to monitor the pressure of the soil. Proper installation had been done at five different depths which are 5, 20, 40, 65 and 75 cm. Before the installation, the device was soaked in the water for several days to make sure that all the pores in the device are filled with water. Then, the device was coated with the soil to make sure that there will be a contact between the soils and watermark sensor after installation. Data are recorded using the data logger which been connected. Time interval for each measurement is 60 minutes. A longer period of data reading will be able to take by using this data logger.

Climatogical Data Collection

The daily climatologically data that is being used for calculation of water requirement are supplied by the Malaysian Meteorological Department. The lists of daily data are from year of 2000 until year of 2008. Daily data of rainfall, maximum and minimum temperature, 24 hour mean relative humidity, maximum surface wind speed and direction, evaporation, solar radiation and cloud cover had been used.

4.0 RESULTS AND DISCUSSIONS

Determination of Crop Water Requirement

Saturation of water, effective rainfall, evapotranspiration and seepage percolation are the parameters included in the formula of crop *WR* determination. Two components important in the determination of saturation of water are soil porosity and depth of the plow layer. The soil porosity at plow layer is 51.69%. The value of saturation of water is 41 mm. Figure 4 below shows the calculated weekly effective rainfall which depends on different conditions.

The daily calculation of crop evapotranspiration is based on the formula of crop coefficient multiplying by reference evapotranspiration. Table 3 shows the changes value of crop coefficient which depends on the day of growth. The starting value which is 1.1 had been used after seven days of seeding. The results from soil water pressure sensors show that the values of soil moisture are 0 kPa for depth of 5, 20 and 45 cm. This shows that the soil of the field is saturated. As the water requirement in the paddy field needs to be determined so that capability of the aquifer be known, the value of 3mm/day for percolation will be used in this calculation. This recommended value is based on the findings from many fields tests on *SP* conducted by the Ministry of Agriculture, Malaysia and published by the *Asian Development Bank* (ADB) [22] and it is assumed to be constant throughout the growth period.

Total Water Requirement for One Season

The calculation of *WR* is based on the weekly condition where the summation of evaporation (*E*), evapotranspiration (*ET*), and seepage and percolation (*SP*) are needed for the whole week. The weekly value of effective rainfall that had been calculated previously will be used directly in the formula. The saturation value which is 42 mm and 100mm of initial depth of flooding value will be used for calculation of *WR* during pre-saturation for the whole week. While the daily value of evaporation and seepage percolation will be summed respectively for the whole seven days. The duration of pre-saturation period is 2 weeks. Total *WR* of the study area is the summation of the *WR* during pre-saturation and during normal growth of period. Total *WR* is 775 mm/season and the volume of water needed for one season is 13,010 m^3. Table 4 below shows the water requirement during pre-saturation and normal growth period calculated from the formula suggested as in Equation 1.

Flow Rate of Paddy Field

The calculation of flow rate is based on the formula of total *WR* which is 775 mm/season multiplying by the area of paddy field which is 1.82 hectares. The total growth is 119 days where the duration of pre-saturation and normal growth is 14 days and 105 days respectively. The value of flow rate is 1.36 l/sec.

Table 4: Water requirement during pre-saturation and normal growth period

WEEK	PRE-SATURATION	NORMAL GROWTH
1	*140*	*-*
2	*189*	*-*
3	*-*	*41*
4	*-*	*52*
5	*-*	*36*
6	*-*	*3*
7	*-*	*-14*
8	*-*	*2.4*
9	*-*	*50*
10	*-*	*60*
11	*-*	*33*
12	*-*	*21*
13	*-*	*20*
14	*-*	*33*
15	*-*	*11*
16	*-*	*42*
17	*-*	*56*
TOTAL (mm)	*329*	*446*
WR (mm/season)	*775*	

5.0 CONCLUSIONS

The main objective of this study is to determine the *WR* in a paddy field for one season of paddy plantation. This *WR* needs to be determined so that the capability of the aquifer to fulfill the paddy field *WR* will be known. The summation of calculated weekly effective rainfall is 409 mm/season. Besides that, the losses like deep percolation and *ET* also the main parameters in calculating the *WR*. The amount of deep percolation and *ET* in this study area is 357 mm/season and 491 mm/season respectively. From the results, there is a difference between *WR* during pre-saturation and during normal growth where during the pre-saturation period, saturation of water and water level of paddy field need to be considered. *WR* during pre-saturation is 329 mm and during normal growth is 446mm. Overall, *WR* in a paddy field is 775 mm/season where the volume of water required for one season is 1.4 x 104 m^3. This means that the potential of groundwater to be extracted should meet the amount of water needed for the paddy plantation activities. ■

REFERENCES

[1] Salmah, Z. and Rafidah, K., 2000. *River Basin Management in Malaysia*. Workshop on 'The Study on Sustainable Groundwater Resources and Environmental Management For The Langat Basin, Malaysia'.

[2] Nazan, A. M. and Hatta, A. K. M. 1998. *An Overview of Groundwater Resources Potential in Malaysia*. Seminar on Groundwater, The Invisible Resource.

[3] Lee, T. S., M. Aminul Haque, and M. M. M. Najim (2005). *Scheduling the Cropping Calendar in Wet-seeded Rice Schemes in Malaysia*. Agricultural Water Management, 71, pp. 71-84.

[4] Rosegrant, M. W., Ringler, C. and Gerpacio, R. V. (1997). *Water and Land Resources and Global Food Supply*. Washington D. C., International Food Policy Research Institute.

[5] Chong, S. F., Azmi Md. Jafri and C. W Cheong (1987). *Tanjung Karang Evapotranspiration Study*. DID Ministry of Agriculture, Malaysia.

[6] Thavaraj, S. H (1975). *The Necessity of Terminal Facilities for Water Management at the Farm Level. Proceeding of the National seminar on Water Management and Control at Farm Level*, Bulletin No. 139, Drainage and Irrigation Division, Ministry of Agriculture and Rural Development, Malaysia.

[7] Bhuiyan, S. I., Sattar, M. A, and Khan, M. A. K., 1995. *Improving Water use Efficiency in Rice Irrigation through Wet seeding*. Irrigation Sci., 16: pp.1-8

[8] Brouwer, C., Prins, K. and Heibloem, M., 1989. Irrigation Water Management: Irrigation Scheduling. FAO Training Manual No.4. Food and Agriculture Organisation of the United Nations, Rome, Italy.

[9] Teh, S. K., 1998, *Sustainable Rice Production*. Malaysian National Congress of Irrigation and Drainage-Annual Conference held on 13 October 1998. Alor Setar, Kedah, Malaysia.

[10] Yoo, S. H., Choi, J. Y. and Jang, M. W. (2008). *Estimation of Design Water Requirement using FAO Penman-Monteith and Optimal Probability Distribution Function in South*. Agricultural Water Management 95, pp. 845-853. International Rice Research Institute (IRRI), 1977. Annual report for 1997. Los Banos, Philippines.

[11] Allen, R. G., Pereira, L. S., Raes, D. and Smith, M., 1998. Crop Evapotranspiration: Guidelines for Computing Crop Requirements. FAO irrigation and drainage paper no. 56. Food and Agricultural Organisation of the United Nations, Rome, Italy.

[12] Huang, H. C., Liu, C. W., Chen, S. H. and Chen, J. S. (2003). *Analysis of Percolation and Seepage through Paddy Bunds*. Journal of Hydrology 284, pp. 13-25.

[13] Wickham, T. H. 1971. *Water Management in the Humid Tropics: A Farm Level Analysis*. Ph.D. Dissertation, Cornell University, Itacha, N.Y.1971.

[14] Tripathi, R. P., Kushwaha, H. S. and Mishra, R. K., 1986. *Irrigation Requirement of Rice Under Shallow Water Table Conditions*. Agricultural Water Management, 12, pp. 127-136.

[15] Kung, P., and C. Atthayodhin and S. Druthabandhu (1965). *Determining Water Requirement of Rice by Field Measurement in Thailand*. Int. Rice Comm. Newsl. 14: pp. 5-18.

[16] Dastane, N. G., Singh, M., Hukkeri, S. B., and Vamadevan, V.K., 1970. *Review on Work done on Water Requirement of Crops in India*. Navabharat Prakashan, Poona-2.

[17] Kuo, S. -F., Ho, S. S. and Liu, C. -W., 2006. Estimation Irrigation Water Requirements with Derived Crop Coefficients for Upland and Paddy Crops in ChiaNan irrigation Association, Taiwan, Agrc. Water Manag. 82, pp. 433-435

[18] Chan, C. S., and Cheong, A. W. (2001). *Seasonal Water Effects on Crop Evapotraspiration and Rice Yield*. J. Tropical Agriculture and Food Science 29: pp. 77-92.

[19] Wickham, T. H., Singh and V. P., 1978. Water movement through wet soil. In: Soil and Rice, International Rice Research Institute, Los Banos, Philippines. pp. 337-358.

[20] Singh, K. B., Gajri, P. R. and Arora, V. K. (2001). *Modeling the Effects of Soil and Water Management Practices on the Water Balance and Performance of Rice*. Agric. Water Management. 49, pp. 77-95

[21] Chowdary V. M., Rao N. H., Sarma P. B. S. (2003). *A Coupled Soil Water and Nitrogen Balance Model for Flooded Rice Fields in India*. Agriculture, Ecosystems and Environment 103 (2004) pp. 425-441.

[22] ADB, 1992. Northern Terengganu Rural Development Project (Phase II), Malaysia. Interim Report, Vol.1. Asian Development Bank, pp. 1-198.

PROFILES

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