UNIVERSITI PUTRA MALAYSIA

ESTIMATING CONSUMPTIVE WATER USE OF RICE IN LOWLAND PADDY FIELDS OF TANJUNG KARANG, MALAYSIA

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By

ABUBAKAR SADIQ ABDULLAHI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

April 2014

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DEDICATIONS

I dedicate this thesis in the memory of my
Beloved Mother
late Hj. Zainab Abdullahi

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy.

ESTIMATING CONSUMPTIVE WATER USE OF RICE IN LOWLAND PADDY FIELDS OF TANJUNG KARANG, MALAYSIA

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April 2014

Chair: Professor Ir. Desa Ahmad, PhD
Faculty: Engineering

A study was conducted to determine the Consumptive Water Use of rice using micro-lysimeter (in-situ) in Tanjung Karang paddy fields. Two estimation methods for evapotranspiration (ET) using FAO Penman-Monteith and weather ground radar data were evaluated and compared with rice crop ET measurements taken during 2011 and 2012 paddy irrigation seasons. Twenty non-weighing micro-lysimeters (60 cm x 20.3 cm) were installed to measure ET_c and deep percolation (DP).

The study covered eight compartments in the irrigation service areas (ISA) of the Tanjung Karang Rice Irrigation Scheme (TAKRIS). A total of 1900 ET_c data were collected in the study site. Preliminary analysis was done on the field data and no violation of normality and linearity was observed. The results of measured mean ET_c for mid-season (April-August 2011) were between 5.9 mm/day, 7.1 mm/day and 5.1 mm/day for the vegetative, reproductive and maturity stages of paddy growing season, respectively. For the main season (August to February 2011) the mean evapotranspiration obtained were 5.1 mm/day, 6.0 mm/day and 5.1 mm/day for the initial, mid and last stages of the growing season, respectively. In the off season (January to May 2012) the mean evapotranspiration for Sawah Sempadan in block C were 5.4 mm/day, 6.6 mm/day and 5.3 mm/day for the first, mid and last stages of paddy growing season, respectively.
The mean values of ET_{cw} for mid-season 2011 obtained from CROPWAT software were 4.6 mm/day, 4.8 mm/day and 3.6 mm/day for the first, mid and last stages of paddy growing season, respectively. In the wet-season the mean ET_{cw} found were 4.4 mm/day, 5.0 mm/day and 3.9 mm/day for the vegetative, reproductive and

maturity stages of the paddy growing season, while in the off season (2012) ET_{cw} also ranged between 4.4 mm/day, 5.4 mm/day and 4.1 mm/day for the first, mid and the last growth stages of the growing season, respectively. The predicted ET obtained using weather radar data for 21 days (October/November) ranged from 3-6 mm/day, 3.3-6.3 mm/day and 4.2-6.9 mm/d on the three ISA's of TAKRIS. The mean deep percolation was between 1.7-6.3 mm/d during the initial growth stage, 1.6-4.1 mm/d at development stage and 2.5-6.5 mm/d at end growth stage period. The mean values of DP during off season irrigation activity for the three growth stages ranged between 2.0-3.6 mm/d, 1.4-3.5 mm/d and 2.2-4.6 mm/d respectively.

Eight statistics were used for assessing the goodness of fit and spatial cross-validation. The statistical model performance for in-situ rice crop ET and CROPWAT ET obtained are RMSE and MAE with values that ranged from 1.34-2.5 mm/d and (-0.62)-0.00 mm/d. They depict the accuracy between measured and computed ET values. The results of model degree of agreement, uniformity coefficient and simulation efficiency lies between (-0.07)-0.45, (-5.8)-(-0.9) and 0.13-0.21 respectively. The results of model performance for weather radar predicted ET was: MBE (-0.004-1.64 mm/d), RMSE (0.54-1.94 mm/d) and MAE (0.44-1.64). The dimensionless coefficient values are dr=0.03-0.68, E=-29.3-0.23 and U=0.77-0.11 respectively.

The rainfall amount observed by the weather radar for the micro-lysimeter sites showed that higher Z-reflectivity values reflect an increase in rainfall and decrease in evapotranspiration. The FAO CROPWAT under-estimate while the values of ET predicted obtained using weather radar data are closer to ET values measured from the field using micro-lysimeter. More research work is needed in obtaining adequate and accurate radar weather data; and better models to accurately predict ET rates for rice crop.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ANGGARAN AIR TERPAKAI UNTUK TANAMAN PADI DI TANAH SAWAH TANJUNG KARANG, MALAYSIA

Oleh

ABUBAKAR SADIQ ABDULLAHI

April, 2014

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Satu kajian telah dijalankan untuk menganggar air terpakai di tanah sawah Tanjung Karang menggunakan metermikrolisis (in-situ). Dua kaedah anggaran bagi penyejatpeluhan (ET) berdasarkan FAO Penman-Monteith dan data radar cuaca telah dinilai dan dibuat perbandingan dengan pengukuran penyejatpeluhan ET tanaman hasil pengumpulan dalam tempoh musim pengairan padi 2011 dan 2012. Dua puluh metermikrolisis jenis bukan-timbang berukuran (61 cm x 20.3 cm) telah dipasang untuk mengukur ET_c dan penelusan dalam (DP).

Kajian merangkumi lapan ruang dan kawasan perkhidmatan pengairan Tanjung Karang (TAKRIS). Sejumlah 1900 data ETc telah dikumpul dari kawasan kajian. Analisis awal telah dilakukan keatas data dan didapati tiada percanggahan kenormalan dan kelelurusan. Keputusan pengukuran min Etc bagi musim pertengahan (April-Ogos 2011) di kawasan Sekinchan adalah masing-masing 5.9 mm/hari, 7.1 mm/hari dan 5.1 mm/hari bagi peringkat tumbuhan, pengeluran dan kematangan pada musim tanaman padi. Bagi musim utama (Ogos ke Februari 2011) nilai min penyejatpeluhan yang dicapai adalah masing-masing 5.1 mm/hari, 6.0 mm/hari dan 5.1 mm/hari pada peringkat permulaan, pertengahan dan akhir musim penanaman. Di luar musim (Januari ke Mei, 2012) nilai min penyejatpeluhan bagi blok C kawasan Sawah Sempadan adalah masing-masing 5.4 mm/hari, 6.6 mm/hari dan 5.3 mm/hari bagi peringkat permulaan, pertengahan dan akhir musim penanaman padi. Nilai min ETcw bagi pertengahan musim 2011 yang diperolehi dari perisisn CROPWAT ETo di kawasan Sekinchan adalah masing-masing 4.6 mm/hari, 4.8 mm/hari dan 3.6 mm/hari bagi peringkat permulaan, pertengahan dan akhir musim penanaman padi. Dalam waktu musim hujan

min penyejatpeluhan yang diperolehi adalah masing-masing 4.4 mm/hari, 5.0 mm/hari dan 3.9 mm/hari bagi peringkat tumbuhan, pengeluaran dan kematangan di musim tanaman padi manakala di luar musim (2012) ukuran ET masing-masing adalah antara 4.4 mm/hari, 5.4 mm/hari dan 4.1 mm/hari bagi peringkat awal, pertengahan dan akhir musim penanaman. Nilai min DP adalah di antara 1.7-6.3 mm/hari pada peringkat awal tumbuhan,1.6 mm/hari-4.1 mm/hari pada peringkat pertengahan dan 2.5 mm/hari-6.5 mm/hari pada peringkat akhir tumbuhan.. Nilai ramalan ET yang diperolehi menerusi data radar cuaca bagi tempoh 21 hari (Oktober/November) adalah di antara 3-6, 3.3-6.3 dan 4.2-6.9 mm/hari. Nilai min DP ketika aktiviti pengairan di luar musim untuk ketiga peringkat tumbuhan adalah masing-masing antara 2.0 mm/hari-3.6 mm/hari, 1.4 mm/hari-3.5 mm/hari dan 2.2 mm/hari-4.6 mm/hari.

Lapan statistik berbeza untuk penilaian ketepatan keserasian dan pengesahan silang ruang telah digunakan. Prestasi model statistic bagi ET paddy dan ET CROPWAT adalah RMSE dan MAE dengan nilai antara 1.34-2.5 mm/hari dan (-0.62)-0.00 mm/hari.Ini menunjukkan ketepatan antara nilai ET yang diukur dan nilai ET yang diramal. Keputusan darjah persamaan, pekali keseragaman dan kecekapan simulasi masing-masing adalah diantara (-0.07)-0.45, (-5.8)-(-0.9) dan 0.13-0.21. Keputusan prestasi model bagi ramalan ET berdasarkan data radar cuaca adalah :MBE (-0.004-1.64 mm/hari), RMSE (0.54-1.94 mm/hari) dan MAE (0.44-1.64). Nilai pekali takberdimensi masing-masing adalah dr=0.03-0.68, E=-29.3-0.23 dan U=0.77-0.11.

Nilai jumlah hujan yang dicatat oleh radar cuaca bagi lokasi metermikrolisis menunjukkan ketinggian kepantulan-Z dan membawa maksud peningkatan hujan dan penurunan penyejatpeluhan. Dapatan bererti berasaskan penyelidikan ini menunjukkan bahawa pengukuran ET di lokasi menggunakan kaedah Tiub Marriott adalah boleh diharap dan merupakan kaedah paling tepat berbanding kaedah lain (FAO Penman dan data cuaca Radar) yang digunakan dalam kajian aggaran nilai ET. Data FAO CROPWAT kurang lebihi nilai ET sebenar berdasarkan ukuran di ladang menggunakan mikro-lysimeter. Kajian penyelidikan lanjutan adalah diperlukan untuk mendapatkan data cuaca radar yang mencukupi dan tepat agar model lebih baik dapat dihasilkan untuk meramal kadar ET bagi tanaman padi.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AST and D	Academic Staff Training and Development
ATBU	Abubakar Tafawa Balewa University
AVHRR	Advanced Very High Resolution Radiometer
a_{psy}	coefficient of psychrometer
a_s	fraction of extraterrestrial radiation...on an overcast day
a_s+b_s	fraction of extraterrestrial radiation...on a clear day
BRH	Bernam River Headwork
BT	Panchang Bedena
C	Constant (Radar)
c_p	specific heat
c_s	soil heat capacity
CLIMWAT	climatic database
CR	capillary rise
CROPWAT	CropWater decision support tool
CV	Coefficient of Variation
d	degree of agreement
DAT	Days After Transplanting
DOY	Day of Year
DID	Department of Irrigation and Drainage
DP	deep percolation
D_i	Diameter (raindrop)
d_r	degree of agreement (refined)

E	evaporation, Model efficiency
EDF	Empirical Distribution Function
E_{pan}	pan evaporation
e^o	saturation vapour pressure at air temperature T
e_s	saturation vapour pressure for a given time period
e_a	actual vapour pressure
e_s - e_a	saturation vapour pressure deficit
ET	evapotranspiration
ET_o	reference crop evapotranspiration
ET_c	crop evapotranspiration under standard conditions
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural Organization Statistical database
G	soil heat flux
GIS	Geographic Information System
GPS	Geographic Positioning System
H	sensible heat
HRIT	High Resolution Information Transmission
I	Irrigation depth
ISA	Irrigation Service Area
IWMI	International Water Management Institute
JICA	Japan International Cooperation Agency
KADA	Kemubu Agricultural and Development Authority
KETARA	North Terengganu Integrated Agriculture Development Terengganu
K_c	crop coefficient
KS	Kolmogorov Smirnov

MAE	Mean Absolute Error
MBE	Mean Bias Error
MMD	Malaysian Meteorological Department
MODIS	MODerate Resolution Imaging Spectroradiometer
MSL	Mean Surface Level
MTSAT	MultiFunctional Transport Satellite
N	maximum possible sunshine duration, daylight hours
n	actual duration of sunshine
NDVI	Normalized Difference Vegetation Index
n_i	raindrop number
NIR	near infra-red
NIAE	Nigerian Institution of Agricultural Engineering
NSE	Nigerian Society of Engineers
n/N	relative sunshine duration
P	Precipitation, atmospheric Pressure, Average radar returned Power
PP	Pasir Panjang
PB	Panchang Bedena
PBLS	Projek Barat Laut Selangor
PM	Penman-Monteith
PPMC	Pearson Product-Moment Correlation
P_i-M_i	Variation in predicted and measured ET
PVC	Polyvinyl Chloride
r	distance from radar to rainfall

R	specific gas constant, Rain intensity
Ra	extraterrestrial radiation
RADAR	RAdio Detection And Ranging
RAP	Rapid Appraisal Process
RWS	Relative Water Supply
R_l	longwave radiation
R_m	radar measured rainfall intensity
R_n	net radiation
R_{nl}	net longwave radiation
R_{ns}	net solar or shortwave radiation
R_s	solar or shortwave radiation
RS	Remote Sensing
R_{so}	clear-sky solar or clear-sky shortwave radiation
r_a	aerodynamic resistance
r_l	bulk stomatal resistance of well-illuminated leaf
r_s	surface or canopy resistance (bulk)
R_s/R_{so}	relative solar or relative shortwave radiation
RH	relative humidity
RH_{hr}	average hourly relative humidity
RH_{max}	daily maximum relative humidity
RH_{mean}	daily mean relative humidity
RH_{min}	daily minimum relative humidity
RO	surface runoff
RMSE	Root Mean Square Error
RSO	Rectified Skewness Orthomorphic

S_d^2	Variance of the distribution of differences
SEBAL	Surface Energy Balance Algorithm for Land
SF	subsurface flow
SH	Sunshine hour
SAW	Sallalahu Alayhi Wasallam
S - SEBAL	Simplified Surface Energy Balance Index
SWT	Subhanahu WaTa'ala
SK	Sekinchan
SL	Sungai Leman
SN	Sungai Nipah
SS	Sawah Sempadan
SW	Shapiro-Wilk
T	air temperature
TAKRIS	Tanjung Karang Rice Irrigation Scheme
TDR	The Doppler radars
TETFund	Tertiary Education Trust Fund
T_K	air temperature
T_{dew}	dewpoint temperature
T_{max}	daily maximum air temperature
T_{max},K	daily maximum air temperature
T_{mean}	daily mean air temperature
T_{min}	daily minimum air temperature
T_{min},K	daily minimum air temperature

T_{wet}	temperature of wet bulb
t	time
U	Wind speed, Thiel's inequality coefficient
u_2	wind speed at 2 m above ground surface
u_z	wind speed at z m above ground surface
VRT	variable rate technology
WGS	World Geodetic System
WMO	World Meteorological Organization
Z	Radar reflectivity factor
Z_m	radar measured rainfall reflectivity
ΔSW	variation in soil water content
Δt	length of time interval
Δz	effective soil depth
δ	solar declination
ε	ratio molecular weight of water vapour/dry air
η	mean angle of the sun above the horizon
θ	soil water content
ρ_a	mean air density
ρ_w	density of water
σ	Stefan-Boltzmann constant
α	Surface Albedo
γ	Psychrometric Constant
λ	Latent Heat of Vaporization
τ	Day Single-way Transmissivity
Δ	Slope of Saturation Vapor Pressure Curve
γ_{psy}	psychrometric constant of an instrument

CHAPTER 1

INTRODUCTION

1.1 Introduction

Water is one of the critical inputs to agriculture. Water is not only the vital resource for maintaining all our ecosystems and the survival of all forms of life, but it is also the common vector and essential capital for all types of development whether urban or rural. In the present agricultural development, irrigation is the single most important economic activity which provides employment and constitutes a means for livelihood of rural communities. Urgent priorities of irrigation water management around the world today focuses on smallest unit of a field to an entire irrigated valley.

However, most irrigation schemes fall short of the expectations for good water management. This is especially true for water-stressed countries in Africa, the Middle East, Australia, many parts of continental Asia, and island states (Lubis, 1998). Where improved water management practices are combined with good seeds, increased fertilizer and pesticides, and improved production practices, yields can triple and also provides the mechanism for more effectively managing the environmental impacts of irrigation (Clyma, 1983).

Water is expected to be the main issue in the 21 century as it becomes increasingly polluted and scarce. It is now the source of quarrels among neighbours, disputes among sovereign states and confrontation among countries (Weng, 2005). Effective and efficient irrigation begins with a basic understanding of the relationships among soil, water, and plants (Figure 1.1). Water can be supplied to the soil through precipitation, irrigation, or from groundwater. Plants take up soil water (water stored in the soil), and use this for growth and cooling. Transpiration (ET) is an important component of the on-farm hydrologic cycle, with the greatest share devoted to cooling. Water is also lost via evaporation from leaf surfaces and the soil. The combination of transpiration and evaporation is evapotranspiration, or ET.

Evapotranspiration is influenced by several factors, including plant temperature, air temperature, solar radiation, wind speed, relative humidity and soil water availability. The amount of water the plant needs and its consumptive use, is equal to the quantity of water lost through ET. Due to inefficiencies in the delivery of irrigated water through evaporation, runoff, wind drift, and deep percolation losses, the amount of water needed for irrigation is greater than the consumptive use.

1.2 Malaysia Prospects in Irrigation Development

Asia represents the bulk of the irrigation in the world and majority of the countries have achieved self-sufficiency in cereal (rice) production due to rapid increase

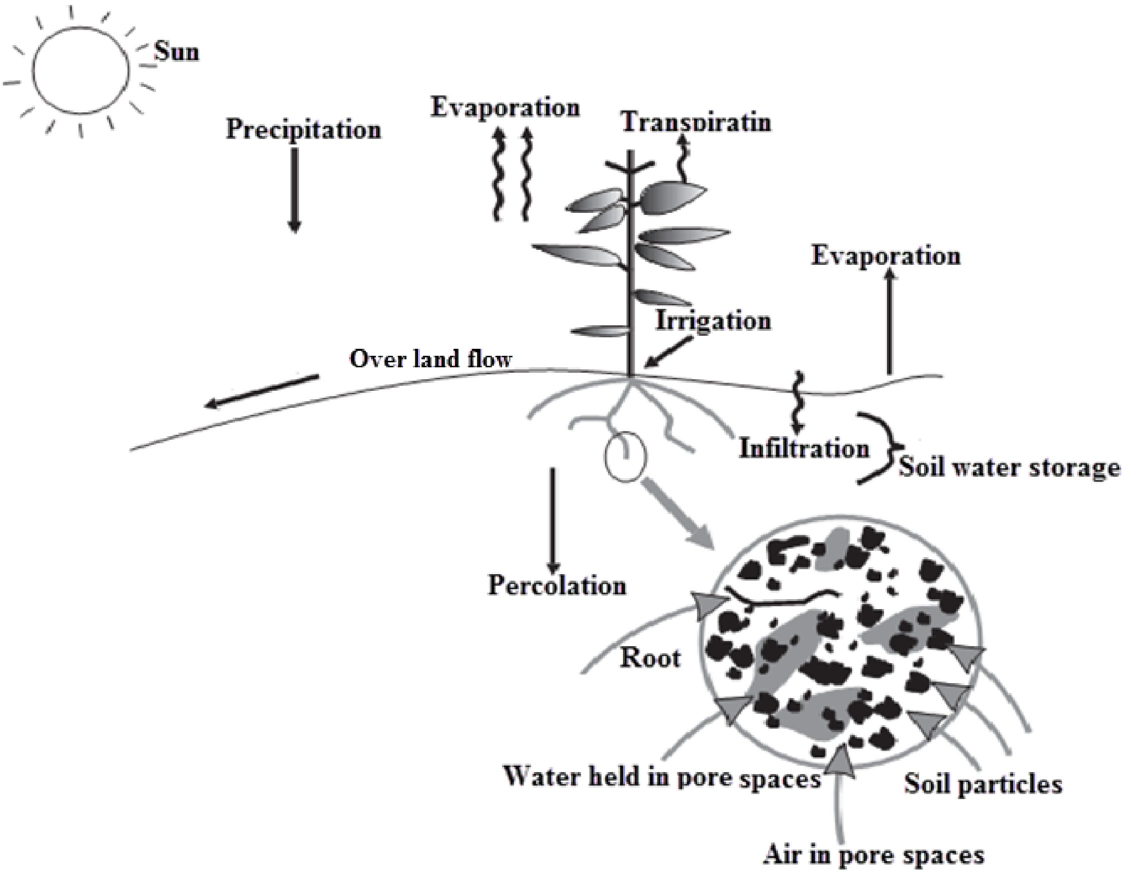

Figure 1.1: A hydrologic Cycle of an Irrigated Farm

in modern irrigation. Malaysia is rich in water resources. It has mean annual precipitation of over 3000 mm / year and average annual precipitation per capita of $50,000\,\mathrm{m}^3$ / year /person (Abdullah, 1999). The average annual water resources on a total land mass of $330,000\,\mathrm{km}^2$ amount to 990 billion m^3. Out of which, 360 billion m^3 (36 %) returns to the atmosphere as evapotranspiration, 566 billion m^3 (57 %) appear as surface runoff and the remaining 64 billion m^3 (7 %) percolate and recharge the groundwater (Toriman et al., 2009; Alam et al., 2011).

Of the total 566 billion m^3 of surface runoff, 147 billion m^3 are found in Peninsular Malaysia, 113 billion m^3 in Sabah and 306 billion m^3 in Sarawak (Toriman and Mokhtar, 2012). The country's vision for water in the twenty-first century is to conserve and maintain a balance between the demands of development and preservation of the environment. It has a long history of irrigation development (Table 1.1) which is related to increase in population density combine with the tradition of rice cultivation in the region. There are currently 924 irrigation schemes,

Table 1.1: Malaysian Land Use 1970-2007 (000 hectares)

Year	Land area	Arable land	Permanent Crops	Medaow and pasture	Forest area	Inland water	Irrigation area (equipped)	Others
1970	32855	920	3510	239	21149	119	262	7037
1980	32855	1000	3800	259	21149	119	320	6647
1990	32855	1700	5248	276	22376	119	342	3255
2000	32855	1820	5785	285	21591	119	365	3374
2007	32855	1800	5785	285	20610	119	365	4375

Source: (FAOSTAT, 2009, 2006)

74 mini-granary (29,500 ha) and 850 non-granary schemes (100,633 ha.). Eight granaries are recognized by the Government in the National Agricultural Policy. They are the main paddy producing areas with land greater than 4,000 hectares. Irrigation schemes existing in the granary areas are: Muda (95,000 ha.), Pulau Pinang (13,000 ha.), Kerian-Sungai Manik (30,058 ha.), Seberang Perak (9,510 ha.), Barat Laut Selangor (19,022 ha.), KETARA (5,100 ha.), Kemasin-Semerak (7,330 ha.) and KADA (31,477 ha.). Non-granary schemes are scattered all over the country and their sizes vary between 50 ha and 200 ha. (Toriman and Mokhtar, 2012; FAO, 1999).

1.3 Problem Statement

In any irrigation scheme, the amount of water conveyed through network of canals and other related structures is based on crop water requirement of the area. Comprehensive water management and planning is essential for better utilization of irrigation water. Measurement of evapotranspiration is necessary to understand crop water use and balance between critical users. Evapotranspiration is a controlling factor in both water cycle and energy transport. It plays an important role in agriculture, meteorology and hydrology.

The growth of non-agricultural water demand is tending towards exceeding the growth of agricultural water demand in future. This is basically due to fast population growth rates, improvement in living standards, expansion of irrigation schemes climate change and global warming (Vita and Crescimanno, 2009). Currently in Malaysia agriculture consumes about 80 % of the total available fresh water (www.icid.org-v malaysia.pdf). Tanjung Karang Rice Irrigation Scheme (TAKRIS) lies in Selangor, the State with the highest population in Malaysia. It has small area compared to other schemes in States like Kedah, Perak and Kelantan, with vast irrigation land and low population. Irrigation sites in Selangor are influenced by both land and water competition. Several factors such as variability in soil condition, unreliable intake of water in the main canal and uneven water distribution to tertiary canals may affect paddy irrigation in the future.

In-situ measurement using micro-lysimeter are both time and labour demanding, it is assumed to measure evapotranspiration directly with good point accuracy. However, in the case of sparse network, the number of micro-lysimeters might not be sufficient to successfully provide spatial variability of evapotranspiration. The previous study by Hassan (2005) used larger lysimeter (91 cm x 91 cm x 61 cm) and SEBAL remote sensing method. In contrast, this study used micro-lysimeter (60 cm x 20.3 cm) to determine the consumptive water use of rice from lowland paddy fields in Malaysia.

In Malaysia, a number of studies on evapotranspiration in rice fields using empirical and remote sensing (RS) data have been documented (Lee et al., 2004; Tukimat et al., 2012; Wahab et al., 2004; Hassan, 2005). However, studies on how to estimate crop evapotranspiration (ET_C) from lowland paddy fields using weather radar data were limited. Malaysia being tropical is well known for cloud coverage and radar can used to measure even a negligible rainfall amount. Also, weather radar is capable of reflecting the spatial pattern of rainfall with high resolution in time and space over a large area and almost in the real-time.

Therefore, applicability and performance of ground radar data to predict ET_C from paddy fields is important for irrigation planners and model users. Understanding ET could help to predict on regional-scale the surface runoff, groundwater and schedule field-scale irrigation. This study will promote the growth of precision farming and application of variable rate technology (VRT) in such a manner as to maximize crop yield.

1.4 Objective of the Study

The overall objective of this study was to predict consumptive water use of rice from lowland paddy fields using weather radar data. The specific objectives were:
i. To determine rice evapotranspiration from paddy fields using mariotte tube micro-lysimeter.
ii. To determine evapotranspiration rates of rice crop using FAO-CROPWAT simulation model.
iii. To measure deep percolation from paddy fields using marriotte tube micro-lysimeter method.
iv. To predict rice evapotranspiration of paddy fields from weather radar data.
v. To make comparisons between three methods of estimating ET of rice crop (Marriott tube micro-lysymeter, FAO-CROPWAT, and radar based weather data).

1.5 Scope of the Study

This study focussed on estimation of rice consumptive water use from paddy fields using three methods namely micro-lysimeter, FAO Penman-Monteith and weather radar data respectively. The field work was limited to some irrigation compartments in the TAKRIS, Selangor Malaysia.
Micro-lysimeters were installed in all the three Irrigation Service Areas (ISA) to represent the upper, middle and downstream of the scheme. In addition deep percolation was measured due to water losses from paddy fields. Finally, variability maps of ET measured and predicted for study area are shown.

1.6 Thesis Organization

This thesis is organized into five chapters. The first chapter gives general introduction on water management on irrigated land, precision farming and aspects of remote sensing and its components. The problem statement, objectives and scope of study are included in the first chapter. All relevant literatures were reviewed and presented in chapter two. Chapter three discuses the materials and methodology used; it also includes the description of the statistical analysis used. The results and discussions are provided in Chapter four. Chapter five gives the conclusion and recommendation for future research work. References and appendices are presented in last part of the thesis.

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