

UNIVERSITI PUTRA MALAYSIA

AQUACROP AND ENSEMBLE GLOBAL CLIMATE MODELS FOR RICE PRODUCTION UNDER CLIMATE CHANGE IMPACT

HOUMA ABDUSSLAM AHMAD ALI

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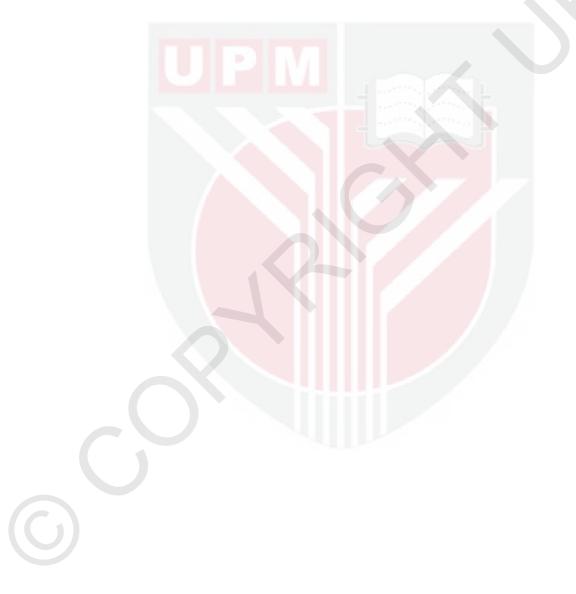
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April 2021

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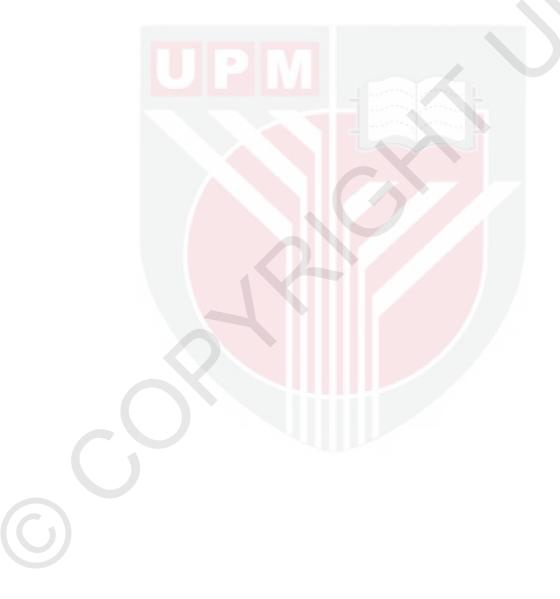
DEDICATION

This thesis is dedicated to:

My mother for her endless love and wishes for her son to achieve this higher dream,

My siblings who have been a source of inspiration and support to me throughout my study, and,

My wife and children who endured hardships all my study years.



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

AQUACROP AND ENSEMBLE GLOBAL CLIMATE MODELS FOR RICE PRODUCTION UNDER CLIMATE CHANGE IMPACT

By

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April 2021

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Lowland paddy rice in Northwest Selangor, particularly in Tanjong Karang Rice Irrigation Scheme (TAKRIS), is the main crop grown during July to October (wet/main season) and January to April (dry/off-season). Climate change is one of the main environmental problems of the current century that directly affects growing conditions of most crops, including rice. This study evaluated the impacts of climate change on rice production in an area within TAKRIS. FAO-AquaCrop model was applied under 18 General Circulation Models (GCMs) with three levels of climate sensitivity (RCP4.5, RCP6.0 and RCP8.5) to assess yield potential of rice.

Future projections of multi-GCMs in the study region have shown that temperature will increase under all emission scenarios, with the largest changes during the dry season. Compared to the baseline period (1976 to 2005), the projected increase in maximum temperature ranges from 0.6 to 1.5° C during the 2020s, 0.5 to 1.7° C during the 2050s and 0.7 to 3.01° C during the 2080s period and that in minimum temperature ranges from 0.7 to 1.7° C during the 2020s, 0.6 to 1.8° C during the 2050s and 0.8 to 3.2° C during the 2080s under RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively. Rainfall projections show average changes of -0.3% during the 2020s, -0.22% during 2050s and -3.25% during the 2080s for the dry season, and 7.6% during 2020s, 6.8% during 2050s and 11% during the 2080s for the wet season under RCP4.5, RCP6.0 and RCP8.5, respectively.

In order to calibrate and validate the AquaCrop model, version 1.6, intensive field investigation was done in a paddy plot at Sawah Sempadan compartment of the TAKRIS during the main and off-seasons of 2017. Data related to developmental stages of plants and yield was measured; historical data were collected from secondary sources. Water balance components were analyzed from the field observations of a paddy field. Irrigation water accounted for 59.6% of the total water input (irrigation and rainfall) during the off season and 76.2% of the total water input during the main season. Rainfall contributed 40.4% and 23.8% of total water input in the corresponding seasons. The grain yield of rice was 5.5 t/ha for the off-season and 5.9 t/ha for the main season. The model was validated with performance indicators of normalized root mean square error (2 < NRMSE < 4), prediction error ($0.75 < P_e < 3$), mean absolute error (120 < MAE < 160), and index of agreement (0.5 < d < 0.8). Satisfactory simulation results were obtained for biomass, (grain) yield and productivity. The average yield is projected to increase by 7.7%, 10.2% and 17.3% from baseline period in the off-season, and 8.6%, 11.5% and 18.4% in the main season under RCP4.5, RCP6.0 and RCP8.5, respectively. Simulation results also reveal that poor weed control measures and water stress conditions will reduce rice yields in the future. Under worst weed control, grain yield is expected to drop by 67% compared to weed-free condition.

Simulation results suggest that crop evapotranspiration (ET_c) is likely to decrease under all climate scenarios during both seasons, the maximum decrease being up to 10% under RCP8.5. Annual effective rainfall is predicted to increase marginally. Therefore, irrigation water requirement is projected to decrease by 3.5% in offseason and 5.5% in main season. Water productivity for continuous flooding shows an increasing trend in both off and main seasons, with the most significant increase under RCP8.5. Water productivity, based on irrigation plus effective rainfall (WP_{Irr+ER}), is predicted to increase by 18%, 20% and 21% in off-season and 16%, 18% and 21% in main season under RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively. Water productivity, based on crop evapotranspiration (WP_{ETc}), is predicted to increase by 22%, 23% and 26% in off-season, and 18%, 19% and 22% in main season under RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively. Thus, AquaCrop simulation revealed a rising trend of potential rice yields and irrigation needs in conjunction with a CO2 fertilization. Suppressing stress on yield under rising temperature has been compensated by the ensuing increased CO₂ fertilization. Moreover, proper weed control and water management practices have augmented yield under changing climate. This study would provide intuitive knowledge for Tanjung Karang Rice Irrigation Scheme for the development of sustainable productive rice yield under different management and environmental conditions.

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

MODEL AQUACROP DAN GABUNGAN MODEL-MODEL IKLIM GLOBAL UNTUK PENGELUARAN PADI DI BAWAH IMPAK PERUBAHAN IKLIM

Oleh

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April 2021

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Sawah Padi di Barat Laut Selangor, umumnya Skim Pengairan Padi Tanjong Karang (TAKRIS), merupakan tanaman utama yang ditanam pada bulan Julai hingga Oktober (musim basah/utama) dan Januari hingga April (musim kering/luar). Perubahan iklim adalah salah satu masalah persekitaran utama abad ini yang secara langsung mempengaruhi tumbesaran kebanyakan tanaman, termasuk padi. Kajian ini menilai kesan perubahan iklim terhadap pengeluaran padi di Kawasan TAKRIS. Model FAO-AquaCrop telah digunakan di bawah 18 Model Peredaran Am (GCM) dengan tiga tahap kepekaan iklim (RCP4.5, RCP6.0 dan RCP8.5) untuk menilai potensi hasil padi.

Unjuran pelbagai-GCM di dalam kajian ini menunjukkan bahawa suhu akan meningkat di bawah semua senario, dengan perubahan terbesar semasa musim luar. Dibandingkan dengan tempoh garis dasar (1976 hingga 2005), kenaikan suhu maksimum yang diunjurkan berada dalam lingkungan antara 0.6 hingga 1.5°C pada tahun 2020-an, 0.5 hingga 1.7°C semasa tahun 2050-an dan 0.7 hingga 3.01°C semasa tahun 2080-an dan suhu minimum antara 0.7 hingga 1.7°C semasa tahun 2020-an, 0.6 hingga 1.8°C semasa tahun 2050-an dan 0.8 hingga 3.2°C semasa tahun 2080-an di bawah senario RCP4.5, RCP6.0 dan RCP8.5 masing-masing. Unjuran hujan menunjukkan purata perubahan –0.3% semasa tahun 2020-an, -0.22% semasa tahun 2020-an, 6.8% semasa tahun 2050-an dan 11% semasa tahun 2080-an untuk musim basah di bawah RCP4.5, RCP6.0 dan RCP8.5 masing-masing.



Bagi menentu-ukur dan pengesahkan model AquaCrop 1.6, penyelidikan secara intensif dilakukan dalam plot padi di petak Sawah Sempadan TAKRIS pada musim utama dan musim luar pada tahun 2017. Data berkaitan dengan peringkat perkembangan tanaman dan hasil diambil kira; data masa lampau dikumpulkan dari sumber sekunder. Komponen-komponen keseimbangan air dianalisis dari pemerhatian di sawah. Air pengairan menyumbang 59.6% dari jumlah input air (pengairan dan hujan) pada musim luar dan 76.2% dari jumlah input air pada musim utama. Hujan menyumbang 40.4% dan 23.8% daripada jumlah input air pada musim yang sama masing-masing. Hasil bijirin beras adalah 5. t/ha untuk musim luar dan 5.9 t/ha untuk musim utama. Model ini disahkan dengan penunjuk prestasi ralat purata punca kuasa dua yang dinormalkan (2 <NRMSE <4), ralat ramalan (0.75 <Pe <3), purata ralat mutlak (120 <MAE <160), dan indeks persetujuan (0.5 <d <0.8). Keputusan simulasi yang memuaskan diperolehi untuk biojisim, (bijirin) hasil dan produktiviti. Purata hasil diunjurkan meningkat sebanyak 7.7%, 10.2% dan 17.3% dari tempoh garis dasar di musim luar, dan 8.6%, 11.5% dan 18.4% pada musim utama di bawah RCP4.5, RCP6.0 dan RCP8.5, masing-masing. Hasil simulasi juga menunjukkan bahawa kawalan rumpai yang tidak teratur dan keadaan tekanan air akan mengurangkan hasil padi pada masa akan hadapan. Di bawah kawalan rumpai yang tidak teratur, hasil bijirin dijangka turun 67% berbanding keadaan bebas rumpai.

Keputusan-kuputusan simulasi mencadangkan bahawa evapotranspirasi tanaman (ETc) cenderung menurun di bawah semua senario iklim bagi kedua-dua musim, penurunan maksimum adalah hingga 10% di bawah RCP8.5. Hujan efektif tahunan diramalkan akan meningkat sedikit. Oleh demikian, keperluan air pengairan diunjurkan menurun sebanyak 3.5% pada musim luar dan 5.5% pada musim utama. Produktiviti air untuk banjir berterusan menunjukkan corak peningkatan pada musim luar dan musim utama, dengan peningkatan yang paling ketara di bawah RCP8.5. Produktiviti air, berdasarkan pengairan dan curahan hujan yang efektif (WPIrr + ER), dijangka meningkat sebanyak 18%, 20% dan 21% pada musim luar dan 16%, 18% dan 21% pada musim utama di bawah RCP4.5, RCP6.0 dan senario RCP8.5, masing-masing. Produktiviti air, berdasarkan evapotranspirasi tanaman (WPETc), dijangka akan meningkat sebanyak 22%, 23% dan 26% pada musim luar, dan 18%, 19% dan 22% pada musim utama di bawah RCP4.5, RCP6.0 dan Senario RCP8.5, masing-masing. Oleh itu, simulasi AquaCrop mendedahkan corak peningkatan terhadap potensi hasil tuaian padi dan keperluan pengairan serentak dengan pembajaan CO₂. Tekanan melampau terhadap hasil kepada suhu yang tinggi akan diredakan melalui pembajaan CO₂ yang dipertingkatkan. Selain itu, amalan kawalan rumpai dan pengurusan air yang baik akan meningkatkan hasil di bawah perubahan iklim. Kajian ini akan memberikan pengetahuan intuitif untuk Skim Pengairan Padi Tanjung Karang untuk pembangunan hasil padi produktif yang lestari dalam keadaan pengurusan dan persekitaran yang berbeza.

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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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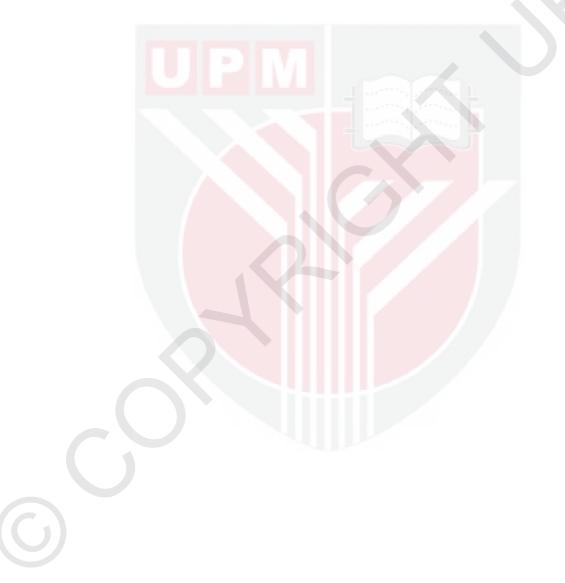
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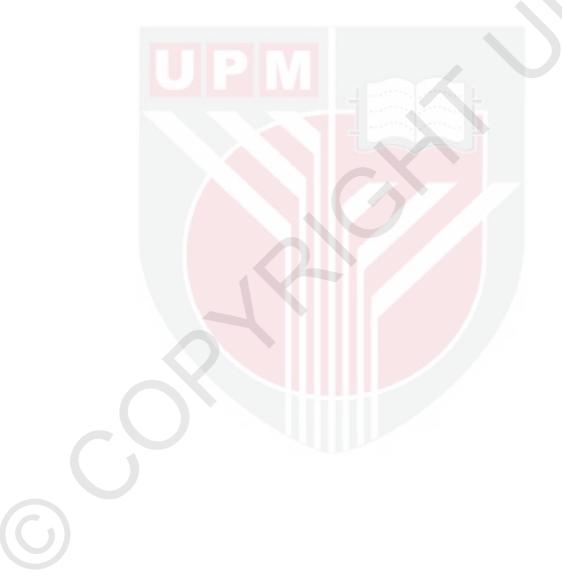
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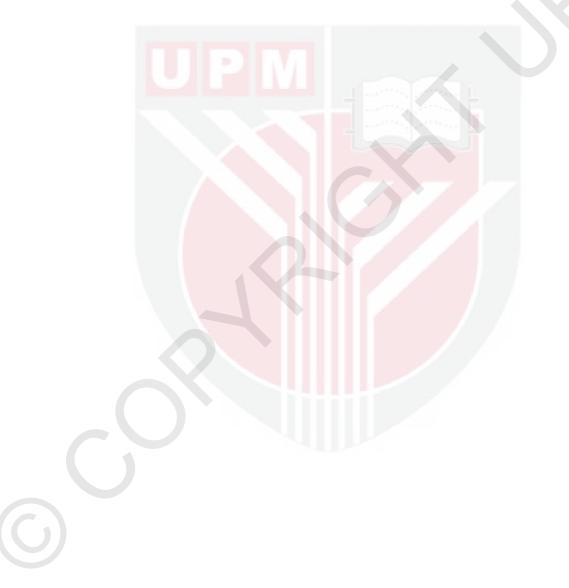
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LIST OF ABBREVIATIONS

AAE	Average Absolute Error
В	Biomass
CC	Canopy Cover
CCo	Initial Canopy Cover
CC _x	Maximum Canopy Cover
CDC	Canopy Decline Coefficient
CGC	Canopy Growth Coefficient
CMIP3	Climate Model Intercomparison Project Phase 3
CMIP5	Climate Model Intercomparison Project Phase 5
CO ₂	Carbon-dioxide
CSDSS	Climate-smart Decision Support System
d-index	Willmott's Index of Agreement
DAS	Days After Sowing
DAT	Day After Transplanting
DID	Department of Irrigation and Drainage
DOA	Department of Agriculture
DR	Drainage Requirement
Dr	Root zone depletion
Е	Soil evaporation
EF	Effective rainfall
ET	Evapotranspiration
ET _a	Actual evapotranspiration
ET _c	Crop evapotranspiration
ETo	Reference crop evapotranspiration

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	ET _x	Maximum evapotranspiration
	FACE	Free-Air CO ₂ Enrichment
	FAO	Food and Agriculture Organization of the United Nations
	FC	Field capacity
	GCM	Global Climate Model
	GDD	Growing Degree Day
	GDP	Gross Domestic Product
	GISS	Goddard Institute for Space Studies for the NASA
	ha	Hectare
	н	Harvest index
	Hlo	Reference harvest index
	IADA	Integrated Agricultural Development Area
	IPCC	Intergovernmental Panel on Climate Change
	Irri	Irrigation
	IRRI	International Rice Research Institute
	IWR	Irrigation Water Requirement
	K _{sat}	Saturated hydraulic conductivity
	Kc	Crop coefficient
	Ks	Water stress coefficient
	LAI	Leaf area index
	MAE	Mean absolute Error
	MARDI	Malaysia Agriculture Research and Development Institute
	mm day ⁻¹	Millimetre per day
	MT	Metric ton
	NAHRIM	National Hydraulic Research Institute of Malaysia
	NIR	Nit Irrigation Water Requirement

NRMSE	Normalized Root Mean Square Error
°C	Degree Celsius
Pe	Prediction error
P _{eff}	Effective rainfall
ppm	Parts per million
Pr	Precipitation
PWP	Permanent wilting point
R ²	Coefficient of determination
RAW	Readily Available Soil-water
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RF	Rainfall
RH	Relative humidity
RMSE	Root mean square error
Sat	Soil Water Content at Saturation
SDSM	Statistical Downscaling Model
SRES	Special Report Emission Scenarios
TAKRIS	Tanjung Karang Rice Irrigation Scheme
TAW	Total available water
Tbase	Base temperature
Tmax	Maximum daily air temperature
Tmean	Mean daily temperalure
Tmin	Minimum daily air temperature
ton ha ⁻¹	Tonnes per hectare
Tr	Crop transpiration
TWD	Total Water Demand

- USDA United States Department of Agriculture
- WL Water level
- WP Water productivity
- WUE Water use efficiency
- Y Maximum yield
- Ya Actual yield



CHAPTER 1

INTRODUCTION

1.1 Background

Climate change has emerged as a global concern over the past 2 to 3 decades. One particular worry is the potentially disastrous consequence for agriculture, food security and water deficit in many parts of the world, particularly developing countries (FAO, 2016; IPCC, 2014c; Mertz et al., 2009; Kotir, 2011). Crop farming is extremely vulnerable to climate change. It has been predicted that climate change will impact negatively on agricultural yield in the 21st century through higher temperatures, more variable rainfall and extreme climate events like floods, cyclones, droughts and rising sea levels (Isik and Devadoss, 2006; IPCC, 2014c; WB, 2010). The susceptibility of agriculture to climate change has led the scientific and policy communities questioning the capacity of farmers to adapt (Reid et al., 2007; Mertz et al., 2009). The United Nations Framework Convention on Climate Change also identified the danger to food production as a major concern (Reid et al., 2007).

Malaysia is one of the countries that are vulnerable to climate change, and current regional climatic trends, with an increase in average surface temperature, are clearly evident (NAHRIM, 2006). The past and present records of Malaysian climate data show clear evidence of climate change that has been voiced globally, having been established in the Intergovernmental Panel on Climate Change (IPCC) assessments report (IPCC, 2014c). Information on considerable fluctuations of temperature has been published recently, showing a very strong correlation between climate change and a significant annual average temperature increase, where record fluctuation is simulated for Malaysia up to 2079 (Malaysian Meteorological Department, 2009). Shahid et al. (2017) reported that rainfall in Peninsular Malaysia will be more variable and river discharge in some basins will increase up to 43% during northeast monsoon season by the end of this century.

The impact of climate change poses serious challenges to the agricultural sector in most countries of the world. Agricultural schemes managed by governmental officials and small farms managed by small holder farmers, both relying on irrigated and rainfed agriculture, are the main sources to achieve self-sufficiency level in food. It is therefore important to adopt strategies to increase crop production. This can be achieved by understanding factors affecting crop yields that are related to production, management and climate. Understanding these factors and their relative contribution to yield increases/decreases is crucial to avoid yield loss and even to ensure increasing yields in the future. Generally, crop production is affected by changes in meteorological variables, such as rising temperatures, change in precipitation amounts and regimes, and increased atmospheric carbon dioxide levels. These effects are positive in some regions and negative in others and vary over time (Parry et al., 2004). There are several ways in which climate change significantly impacts

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crop production and yields. Temperature rise for example, may trigger drought stress to plants in areas suffering from water stress (Tao and Zhang, 2011). This also may change length of crop-growing period resulting in yield reduction. Furthermore, variability in rainfall between and within the seasons (Rowhani et al., 2011), changes in magnitude and occurrence of extreme rainfall events (Moriondo el al., 2011) and irrigation water shortage, prolonged dry spells and drought during growing season (Barron et al., 2003; Laux et al., 2010) may have great impacts in crop production and yields. However, imperfect agricultural management practices, such as improper planting dates, excessive irrigation and low planting density can also hinder crop production and yields from reaching their full potential (Kihara et al., 2015; Laux et al., 2010).

Rice is one of the major crops to feed the world's growing population (Shimono et al., 2010). About 3 billion people consume rice daily. As one of the most common staple foods for humans, rice feeds more people than any other crop (Maclean et al., 2002). It is mostly planted in Asian regions, which make up approximately 90% of total rice farming areas. In Malaysia, rice production is very important because it is the staple diet of people. The total irrigable land in excess of 322,000 hectares is confined under eight large granary schemes for sustaining the nation's self-sufficiency level. Rice production needs to increase to meet future demand of the growing population. Any decline in rice production due to climate change would thus critically impair food security in the country. Therefore, quantifying the effects of climate change on rice farming and assessing the potential of rice farmers to adapt to climate change are urgent research topics.

General Circulation Models (GCMs) are the major sources of climate change data. They provide adequate simulations of the current atmospheric general circulation at the continental scale, such as storm tracks, rain belts and most modes of inter-annual to inter-decadal variability like the Indian Monsoon and El Niño-Southern Oscillation (ENSO) (IPCC. 2013a; Randall et al., 2007). However, they still show significant errors at smaller scales required for regional and national assessments; that is, there is a spatial and temporal scale mismatch between coarse resolution projections of GCM and fine resolution data requirements of impact models. Climate downscaling (e.g., empirical-statistical downscaling) (Benestad et al., 2015; Maraun et al., 2010) and/or dynamical downscaling (Di Luca et al., 2013; Leung et al., 2003) have been used as remedy to provide climate information for many climate impacts studies.

Crop growth models were used as an extensive tool to determine the effect of various climate change scenarios on crop yields for individual countries (Rowhani et al., 2011; Arshad et al., 2017; Pirmoradian and Davatgar, 2019; Lv et al., 2018) and also for geographical regions (Parry et al., 2004; Najafi et al., 2018). AquaCrop is a crop growth model developed by FAO's Land and Water Division to address food security and assess the effect of environment and management on crop production. The model was used in this study to understand the effect of climate change on future rice productivity under different managements of irrigation and field and explore suitable options for achieving the highest possible production capacity per acreage.

1.2 Motivation for the Research

Agriculture plays the most important role in achieving food security as well as for farmer's livelihood in the northwest region of Peninsular Malaysia. Farmers seem worried more about dry spells or droughts and future effects of climate change that affect rice yield. The Asia and Pacific region is more vulnerable to climate change risks compared to other regions of the world because of its dependence on natural resources and agriculture sectors, and densely populated coastal areas (Anbumozhi et al., 2012). There is a clear evidence of climate change impacts on the agricultural sector in this region. In early 2008, China has experienced abnormally cold weather that affected rice production and the disastrous flooding in 2010 has caused heavy losses in rice production in Indonesian (Firdaus et al., 2012). A massive flood in Thailand in October 2011 destroyed approximately 10% of the nation's rice crop (Firdaus et al., 2012). Prior to the projection, the Asia-Pacific region was expected to experience the worst effect of climate change on rice and wheat yields that could threaten food security of 1.6 billion people in South Asia [International Food Policy Research Institute (IFPRI), 2009].

Available studies show that an increase in temperature due to climate change can reduce rice yield in many parts of the world, such as South East Asia, South Asia and Southern Africa (Lobell et al., 2008; Lobell et al., 2011; Lobell and Gourdji, 2012; Van Oort and Zwart, 2018). These studies also affirm that many crops, such as maize, rice and sorghum are susceptible to the negative impact of high temperature (Moron et al., 2015), and the impacts of temperature on crop yield are extremely important (Klink et al., 2014; Lobell et al., 2008; Lobell et al., 2011; Lobell and Gourdji, 2012; Mottaleb et al., 2015; Ramirez et al., 2014). Several studies (e.g., Firdaus et al., 2012; Vaghefi et al., 2016) by exploring the impacts of climate variability on rice production in Malaysia reported that climate variability (i.e., ENSO) can delay the planting seasons and reduce precipitation, leading to lower rice production in Malaysia.

Climate change may affect rice yield in positive or negative ways. Therefore, it is an important issue to investigate how rice productivity performs in response to climate change, and to develop guiding information for farmer's adaptation options. The potential impacts of climate change and climate variability on crop yields at field level can be assessed by crop models. In this study, AquaCrop V1.6 was applied for assessing future rice production potentials in Tanjung Karang Rice Irrigation Scheme (TKRIS) at Selangor, one of the hosts of rice production in Malaysia under several climate change scenarios.

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1.3 Problem Statements

Global temperature will continue to increase over coming decades and is expected to have a strong impact on water resources, water demands of crops, extreme floods and droughts, water quality, salt water intrusion in coastal regions, groundwater recharge and other related processes (IPCC 2014b, Payne, 2018). Mujumdar (2013) stated that the global climate change results in a local modification of water availability, water demands of crops, extreme floods and droughts, water quality, salt water intrusion in coastal regions, groundwater recharge and other related processes. Tangang et al. (2012) reported decreasing trends of wet events in Malaysia. Erratic and spatial variation of rainfall causes uncertainty in water availability for irrigation (NAHRIM 2011, 2014). Drought is well known for declining and varying crop yield drastically. Increased evaporation due to climate change is thought to augment irrigation requirement in Southeast Asia by 15% (Döll et al., 2003). Several recent studies highlighted that climate change causes potential changes in global and regional agricultural water demand for irrigation (Hanjra and Qureshi, 2010; Chung, et al., 2011; Chung and Temba, 2012; Yoo et al., 2012; Tyagi, 2012; NAHRIM, 2012; Chiang and Liu, 2013; Hugh et al., 2013). Yinhong et al. (2009) reported in a comprehensive review that an increase in precipitation will increase crop yield, and crop yield is more sensitive to the precipitation than temperature. Regional climate dynamic downscaling work using the PRECIS regional climate model by Tangang and Juneng (2011) indicated mean surface temperature projections over Peninsular Malaysia and Sabah-Sarawak by 2070-2100 as 3-5°C warmer than the average temperatures of the 1960-1990 period. Tangang et al. (2012) stated that the physical basis and science of climate change at the regional scale are of central importance for adaptation. To date, the number of publications in the area is still a few, and knowledge gaps remain significant. With the temperature raising and precipitation fluctuations, water availability and crop production are likely to decrease in the future. If the irrigated areas are expanded, the total crop production will increase; however, food and environmental quality may degrade. Therefore, rice production systems must be able to respond to challenges posed by the effects of climate change. CO₂ fertilization has positive effects on crop productivity (Lobell and Field 2008). When atmospheric CO_2 concentration increases, plants take up CO_2 via photosynthesis and produce more vegetative matter (Zavala et al. 2008). Doubling the atmospheric CO₂ concentration increases photosynthesis by 30% - 50% in C3 plant species and 10% – 25% in C4 species (Ainsworth and Long, 2005). The IPCC reports suggested that yields may increase by 10% - 25% for C3 crops and by 0% -10% for C4 crops when CO₂ levels reach 550 ppm (Pachauri and Reisinger, 2008). The CO₂ fertilization effect hence could potentially lead to significant increases in crop productivity and offset potential productivity declines resulting from climate change such as higher temperature and altered precipitation patterns (Wolfe 2010). The occurrence of weeds has become a serious problem and they limit the yield and quality of crops (De Datta and Haque, 1982). The rivalry of weeds is one of the main causes of yield loss of lowland rice, and loss varies with the duration of weed infestation of the crop (Azmi et al., 2007).

Climate change is among the most critical problems that mankind faces today. It results a serious impact on agriculture and water resources, which affect food

security. The gap between the current water productivity of irrigated agriculture and future water demand to produce food for growing population by 2050 is ever growing and the impact of climate becomes more evident. There are novel models, tools and approaches to characterize and even recommend potential improvements in irrigation water management at farm scale, but as yet insights on farm level irrigation practices have not considered to translate improvement in water productivity at the irrigation system and basin scale. Modeling studies offer various global projections of the future climate. Projected climate data from Global Climate Models (GCMs) integrated with crop growth models can predict future impacts on agricultural productivity. There is no study yet reported in literature for modeling climate change impacts on rice production in Malaysia. Therefore, this study establishes the assessment of climate change impacts on rice production integrated with the ensemble GCMs climate data from ten/eighteen and AquaCrop model in the Northwest Selangor Rice Irrigation Scheme.

1.4 Aims and Objectives

The primary objective of this study is to assess the impacts of climate change and variability on crop agriculture in Tanjung Karang Irrigation Scheme, TAKRIS. In addition, the determinants of crop productivity and crop water supply were investigated by using appropriate techniques. To achieve the goal, the study was undertaken with the following specific objectives:

- 1. To evaluate AquaCrop model for paddy rice production under climate change impacts in IADA Northwest Selangor.
- 2. To model seasonal water use due to impacts of climate change under different RCP scenarios.
- 3. To predict rice yield under climate change using AquaCrop 6.1 model ensemble with GCMs.
- 4. To develop climate-smart water productivity model for predicting climate change impacts on water productivity of rice.

1.5 Scopes of the Study

The study focused on estimating climate change impacts on crop production and water productivity using the historical and future weather data and crop growth models. The field work was limited to field experiments for both plant and soil in the TAKRIS at Selangor in Malaysia.

The scope of work includes the following tasks:

- Collection of relevant information on planting and production of rice "MR 290" over eight years (2009-2016) for the off-season (January-April) and main season (July-October) in the paddy schemes.
- Collection of recorded meteorological data from different stations within the study area over three decades (1976-2005) for calibration and validation of the crop growth model.
- Downloading and extraction of GCMs data during the future period (2010-2099) from .nc file format to .mat file format using MATLAB (R2016a) Programme.
- Detailed study of/and selection of climate change downscaling techniques and predictor variable suitable for the study purpose.
- Downscaling the climate variables through a specified downscaling domain with coordinates.
- Finding data related to crops, soil and planting management by executing field experiments for both off-season and main season during the year 2017 to calibrate the crop growth model.
- It was also within the scope of the study to utilize AquaCrop model, calibrate and validate it with the aim of using the model to evaluate impacts of climate change on crop production.
- Simulation of future crop production and water productivity for the TAKRIS.

1.6 Limitations on the Scope of Study

Although the study has achieved its objectives as set out, some limitations on the scope of the study are mentioned. The major limitation of the study is that the field investigation was carried out in a specific paddy plot for two seasons in a year only. Therefore, the findings of this study are not generalized to the whole scheme. However, they seek to contribute to the discourse of climate change adaptation and the level of understanding of the impact of climate change on the rice farmers in the scheme. Secondly, soil profiles in the fields were assumed to be uniform. A field soil profile is generally considered one of the main factors affecting the crop-water relationship. Thirdly, the study was conducted using only the simulation outputs from climate models (GCMs) data based on the driving carbon emission scenarios. Finally, the potential effects of other yield-limiting factors, such as pests and diseases, were not considered.

1.7 Outline of the Thesis

The thesis is organized into five chapters. The first chapter gives a general introduction on climate change scenarios and their impacts on agriculture and water resources. The problem statement, objectives and scope of the study are included in the first chapter. All relevant literature was reviewed and presented in chapter two. Chapter three discusses the materials and methods of the study. The results and discussion are provided in chapter four. Chapter five provides the conclusion and recommendation for future research work. References and appendices are presented in the last part of the thesis.

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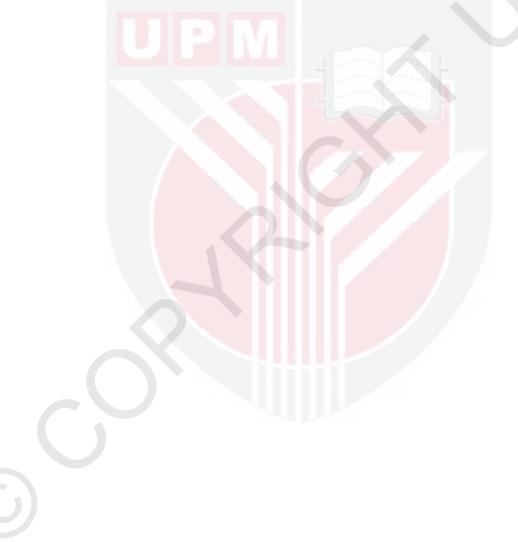
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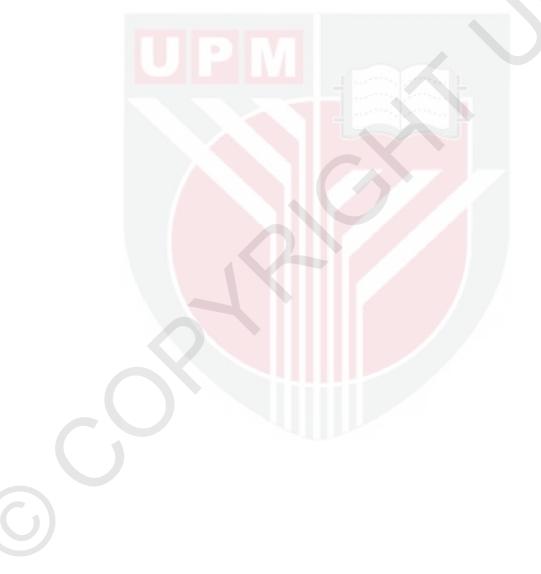


PUBLICATIONS

Houma, A. A., Kamal, M. R., Mojid, M. A., Abdullah, A. F. B., & Wayayok, A. (2021). Climate change impacts on rice yield of a large-scale irrigation scheme in Malaysia. *Agricultural Water Management*, 252, 106908.

Submitted Publications

Abdusslam A Houma, Md Rowshon Kamal, Md Abdul Mojid, Zawawi MAM. Climate Change Impacts on Water Productivity of a Tropical Rice Irrigation System in Malaysia. Q1. *Journal of Cleaner Production*, Under Review.





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