UNIVERSITI PUTRA MALAYSIA

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

HOUMA ABDUSSLAM AHMAD ALI

FK 2021 64

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

By

HOUMA ABDUSSLAM AHMAD ALI

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

April 2021

COPYRIGHT

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

HOUMA ABDUSSLAM AHMAD ALI

April 2021

Chairman : Associate Professor Md Rowshon Kamal, PhD
Faculty : Engineering

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 off-season 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 CO_2 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

HOUMA ABDUSSLAM AHMAD ALI

April 2021

Pengerusi : Profesor Madya Md Rowshon Kamal, PhD
Fakulti : Kejuruteraan

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 2050-an dan –3.25% semasa tahun 2080-an untuk musim kering, dan 7.6% 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 CO_2. Tekanan melampau terhadap hasil kepada suhu yang tinggi akan diredakan melalui pembajaan CO_2 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.

ACKNOWLEDGEMENTS

Completion of this work would not have been possible without the help I received from many supporters. It has been a long exhaustive journey, but a most enlightening one too. I would like to express my respect and gratitude to my supervisor Assoc. Prof. Dr. Md Rowshon Kamal, Department of Biological and Agricultural Engineering, Faculty of Engineering, University of Putra Malaysia, Malaysia for his keen interest, guidance, patience and assistance throughout this research work. I consider myself fortunate to have him as my guide. I am equally grateful to my committee members, Assoc. Prof. Dr. Ahmad Fikri b. Abdullah and Dr. Aimrun Wayayok, without whose extraordinary help I would not have been able to accomplish the task. Sincere appreciation is due to the staff of Integrated Agriculture Development Area (IADA), Barat Laut Selangor for giving me rice datasets from 2000 to 2017. I also thank all the staff of the Department of Biological and Agricultural Engineering for their hospitability and cooperation whenever required during my work.

Finally, I would like to express my deep gratitude towards my mother, siblings, wife, kids and who have continuously provided their moral support and their love, affection and encouragement during my graduate studies. I am highly thankful to all of my friends and surrounding people who assist and encourage me to complete this research.

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:

Md Rowshon Kamal, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ahmad Fikri b. Abdullah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Aimrun Wayayok, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 12 August 2021

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: ____________________________ Date:________________

Name and Matric No: Houma Abdusslam Ahmad Ali, GS45458

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature:	______________________________
Name of Chairman of Supervisory Committee:	Associate Professor Dr. Md Rowshon Kamal

Signature:	______________________________
Name of Member of Supervisory Committee:	Associate Professor Dr. Ahmad Fikri b. Abdullah

Signature:	______________________________
Name of Member of Supervisory Committee:	Dr. Aimrun Wayayok

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix **Page**

LIST OF ABBREVIATIONS

AAE	Average Absolute Error
B	Biomass
CC	Canopy Cover
CC_o	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
D_r	Root zone depletion
E	Soil evaporation
EF	Effective rainfall
ET	Evapotranspiration
ET_a	Actual evapotranspiration
ET_c	Crop evapotranspiration
ET_o	Reference crop evapotranspiration

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
HI	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
K_c	Crop coefficient
K_s	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
P_e	Prediction error
P_{eff}	Effective rainfall
ppm	Parts per million
P_r	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 tempera1ure
Tmin	Minimum daily air temperature
ton ha^{-1}	Tonnes per hectare
T_r	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
Y_a	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 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.

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. CO_2 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 CO_2 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 CO_2 levels reach 550 ppm (Pachauri and Reisinger, 2008). The CO_2 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.

REFERENCES

Ab Rahman, A. K., Abdullah, R., Balu, N., & Shariff, F. M. (2013). The impact of La Niña and El Niño events on crude palm oil prices: An econometric analysis. Oil Palm Industry *Economic Journal*, 13(2), 38–51.

Abdul-Ganiyu, S., Kyei-Baffour, N., Agyare, W. A., & Dogbe, W. (2018). Evaluating the effect of irrigation on paddy rice yield by applying the AquaCrop model in Northern Ghana. In Strategies for Building Resilience against Climate and Ecosystem Changes in Sub-Saharan Africa (pp. 93-116). Springer, Singapore.

Abedinpour, M., Sarangi, A., Rajput, T. B. S., Singh, M., Pathak, H., & Ahmad, T. (2012). Performance evaluation of AquaCrop model for maize crop in a semi-arid environment. *Agricultural Water Management*, 110, 55–66.

Abera, E. A., Getnet, M., & Nigatu, L. (2019). Impacts of Climate Change on Bread Wheat (Triticum aestivum L) Yield in Adet, North Western Ethiopia. *J Pet Environ Biotechnol*, 10, 396.

Abeysingha, N. S., Singh, M., Islam, A., & Sehgal, V. K. (2016). Climate change impacts on irrigated rice and wheat production in Gomti River basin of India: a case study. *SpringerPlus*, 5(1), 1-20.

Abrha, B., Delbecque, N., Raes, D., Tsegay, A., Todorovic, M., Heng, L. E. E., ... & Deckers, S. (2012). Sowing strategies for barley (Hordeum vulgare L.) based on modelled yield response to water with AquaCrop. *Experimental Agriculture*, 48(2), 252.

Acharjee, T. K., Ludwig, F., van Halsema, G., Hellegers, P., & Supit, I. (2017). Future changes in water requirements of Boro rice in the face of climate change in North-West Bangladesh. *Agricultural water management*, 194, 172–183.

Adenan, M. N. H., Ahmad, F., Rahman, S. A. A., Harun, A. R., & Rahim, K. A. (2018). EVALUATION OF AQUACROP MODEL TO PREDICT CROP WATER PRODUCTIVITY FOR PADDY. *Journal of Information*, 3(7), 13-20.

Aggarwal, P. K., Kalra, N., Chander, S., & Pathak, H. (2006). InfoCrop: a dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Model description. *Agricultural systems*, 89(1), 1–25.

Ahmed, I., Ullah, A., ur Rahman, M. H., Ahmad, B., Wajid, S. A., Ahmad, A., & Ahmed, S. (2019). Climate change impacts and adaptation strategies for agronomic crops. In *Climate change and agriculture* (pp. 1-14). IntechOpen.

Ahuja, L. R., & Ma, L. (2002). Parameterization of agricultural system models: Current approaches and future needs. Agricultural System Models in Field Research and Technology Transfer; Lewis Publishers: Boca Raton, FL, USA.

Ainsworth, E. A., & Long, S. P. (2005). What have we learned from 15 years of free- air CO2 enrichment (FACE)? A meta- analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO2. *New phytologist*, 165(2), 351-372.

Ainsworth, E. A., & Rogers, A. (2007). The response of photosynthesis and stomatal conductance to rising [CO2]: mechanisms and environmental interactions. *Plant, cell & environment*, 30(3), 258-270.

Ajetombi, J., & Binuomote, S. (2014). An investigation of the effect of climate change on selected cereal crops yield in Nigeria: A ricardian analysis. *Continental Journal of Agricultural Science*, 8(3), 38–48.

Akobundu, I. O. (1980). Weed science research at the International Institute of Tropical Agriculture and research needs in Africa. *Weed Sci*. 28(439), 445

Alam, M.M., Mohd Ekhwan, T., Siwar, C., and Talib, B. (2011). Rainfall Variation and Changing Pattern of Agricultural Cycle. *American Journal of Environmental Sciences*, 7(1): 82-89.

Al-Amin, A.Q., Siwar, C., (2008). The economic dimensions of climate change: impacts and adaptation practices inMalaysia. Proceedings of the 9th International Review of Business Research Papers in Melbourne, Australia, 2007, *International Business Research Conference*. 2009, pp. 309–321.

Alberto, M. C. R., Wassmann, R., Hirano, T., Miyata, A., Hatano, R., Kumar, A., ... & Amante, M. (2011). Comparisons of energy balance and evapotranspiration between flooded and aerobic rice fields in the Philippines. *Agricultural Water Management*, 98(9), 1417–1430.

Ali, R., and Ali, A. K. (2009). Estimating the Prospective Impacts of Global Warming on Malaysian Agriculture, *Proceeding of 2nd National Conference on Agro-Environment 2009, MARDI*, 24-26 Mar. Malaysia.

Allen Jr, L. H. (1990). Plant responses to rising carbon dioxide and potential interactions with air pollutants. *Journal of Environmental Quality*, 19(1), 15–34.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome, 300(9), D05109.

Amaral, S. S., Costa, M. A. M., Neto, T. G. S., Costa, M. P., Dias, F. F., Anselmo, E., ... & de Carvalho Jr, J. A. (2019). CO2, CO, hydrocarbon gases and PM2. 5 emissions on dry season by deforestation fires in the Brazilian Amazonia. *Environmental Pollution*, 249, 311-320.

Amin, M. A., Abdullahi, G. A., Suryani, D., & Alias, R. (2014). Farmers willingness to pay for crop insurance in north west Selangor Integrated Agricultural Development Area (IADA), Malaysia. *Journal of ISSAAS* (International

Society for Southeast Asian Agricultural Sciences), 20(2), 19-30.

Amin, M. S. M., & Hassan, S. M. H. (2018). Rice evapotranspiration estimation using satellite data.

Anbumozhi, V., Breiling, M., Pathmarajah, S., & Reddy, V. R. (Eds.). (2012). Climate change in Asia and the Pacific: how can countries adapt? SAGE Publications India.

Andarzian, ., Bannayan, M., Steduto, P., Mazraeh, H., Barati, M. E., Barati, M. A., & Rahnama, A. (2011). Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran. *Agricultural Water Management*, 100(1), 1–8.

Anika, N., Farhani, A.C., Fil'aini, R. and Cahyani, D., 2019, November. Water productivity analysis in irrigated central rice production area of SolokRegency, Indonesia. In IOP Conference Series: *Earth and Environmental Science* (Vol. 355, No. 1, p. 012100). IOP Publishing.

Arshad, M., Amjath-Babu, T. S., Krupnik, T. J., Aravindakshan, S., Abbas, A., Kächele, H., & Müller, K. (2017). Climate variability and yield risk in South Asia's rice–wheat systems: emerging evidence from Pakistan. *Paddy and water environment*, 15(2), 249-261.

Ayob, A. H., Zulkefli, M., Mohammud, C. H., Sharma, M. L., Mohd Zain, M., Aminuddin, B. Y., and Ahmad, A. R. (1996, December). Water and nutrient balance study in the KADA paddy irrigation scheme. In *Aciar Proceedings* (pp. 33–44). Australian Centre for International Agricultural.

Azhar, A. H., and Perera, B. J. C. (2011). "Evaluation of reference evapotranspiration estimation methods under Southeast Australian conditions." *J. Irrig. Drain Eng.*, 10.1061/(ASCE)IR.1943-4774.0000297, 268–279.

Azmi, M., Shukor, J. A., & MY, M. N. (2007). Critical period for weedy rice control in direct-seeded rice. *J. Trop. Agric. and Fd. Sc*, 35(2), 333-339.

Babel, M. S., & Wahid, S. M. (2009). Freshwater Under Threat South East Asia: Vulnerability Assessment of Freshwater Resources to Environmental Change: Mekong River Basin. United Nations Environment Programme.

Baker, J. T., and Allen, L. H. Jr. 1993. Effects of CO2 and temperature on rice: A Summary of Five Growing Seasons. *Journal of Agricultural Meteorology*, 48(5), pp.575–582.

Bala, B. K., Alias, E. F., Arshad, F. M., Noh, K. M., & Hadi, A. H. A. (2014). Modelling of food security in Malaysia. *Simulation Modelling Practice and Theory*, 47, 152-164.

Bardossy, A., Duckstein, L., & Bogardi, I. (1995). Fuzzy rule- based classification of atmospheric circulation patterns. *International journal of climatology*, 15(10), 1087-1097.

Barron, J., Rockström, J., Gichuki, F., & Hatibu, N. (2003). Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agricultural and forest meteorology*, 117(1-2), 23-37.

Benestad, R. E., Mezghani, A., & Parding, K. M. (2015). 'esd'-The Empirical-Statistical Downscaling tool & its visualisation capabilities. *Met Report. Norwegian Meteorologi Institute. Oslo. Norwegian Meteorologi Institute*, 55-58.

Bi, E. G., Gachon, P., Vrac, M., & Monette, F. (2017). Which downscaled rainfall data for climate change impact studies in urban areas? Review of current approaches and trends. *Theoretical and Applied Climatology*, 127(3-4), 685-699.

Biello D (2015) Accelerated innovation is the ultimate solution to climate change. *Scientific American.*

Bouman, B. A. M., and Tuong, T. P. (2001). Field water management to save water and increase its productivity in irrigated lowland rice. *Agricultural water management*, 49(1), 11–30.

Bouman, B. A. M., Peng, S., Castaneda, A. R., and Visperas, R. M. (2005). Yield and water use of irrigated tropical aerobic rice systems. *Agricultural Water Management*, 74(2), 87–105.

Brouwer, C., Goffeau, A., & Heibloem, M. (1985). Irrigation water management: training manual no. 1-introduction to irrigation. *Food and Agriculture Organization of the United Nations*, Rome, Italy, 102–103.

Burkart, S., Manderscheid, R., Wittich, K. P., Löpmeier, F. J., & Weigel, H. J. (2011). Elevated CO2 effects on canopy and soil water flux parameters measured using a large chamber in crops grown with free- air CO2 enrichment. *Plant Biology*, 13(2), 258-269.

Cabangon, R. J., Tuong, T. P., & Abdullah, N. B. (2002). Comparing water input and water productivity of transplanted and direct-seeded rice production systems. *Agricultural Water Management*, 57(1), 11–31.

Castro-Llanos, F., Hyman, G., Rubiano, J., Ramirez-Villegas, J., & Achicanoy, H. (2019). Climate change favors rice production at higher elevations in Colombia. *Mitigation and Adaptation Strategies for Global Change*, 24(8), 1401-1430.

Chan, C. S., & Cheong, A. W. (2001). Seasonal weather effects on crop evapotranspiration and rice yield. *Journal of Tropical Agriculture and Food Science*, 29, 77-92.

Chang, C. P., Harr, P. A., & Chen, H. J. (2005). Synoptic disturbances over the equatorial South China Sea and western Maritime Continent during boreal winter. *Monthly Weather Review*, 133(3), 489–503.

Chang, Y., Liu, M., Wang, W., Ma, M., & Fan, Y. (2017). Effects of climate change on winter wheat yield in Wenshui County. *Journal of Arid Land Resources and Environment*, (6), 20.

Chavas, D. R., Izaurralde, R. C., Thomson, A. M., & Gao, X. (2009). Long-term climate change impacts on agricultural productivity in eastern China. *Agricultural and Forest Meteorology*, 149(6–7), 1118–1128.

Chen, C. C., McCarl, B., & Chang, C. C. (2012). Climate change, sea level rise and rice: global market implications. *Climatic change*, 110(3), 543-560.

Chen, J., Brissette, F. P., & Leconte, R. (2011). Uncertainty of downscaling method in quantifying the impact of climate change on hydrology. *Journal of hydrology*, 401(3-4), 190-202.

Chiang, J. L., & Liu, T. M. (2013). Impact of climate change on paddy field irrigation in southern Taiwan. *Paddy and Water Environment*, 11(1), 311-320.

Chinnusamy, C., Kandasamy, O. S., Sathyamoorthy, K., & Chandrasekar, C. N. (2000, February). Critical period of crop weed competition in lowland rice ecosystems. In Proc. *State level seminar on integrated weed management in new millennium, Ratnagiri, Maharastra* (pp. 27-28).

Cho, J., & Oki, T. (2012). Application of temperature, water stress, CO_2 in rice growth models. *Rice*, 5(1), 10.

Chong, L., (2000). Report 3: Assessment of the Impacts of Climate Change on Key Economic Sectors in Malaysia. *National Meteorological Service*.

Choudhury, J.K. and R.K. Thakuria. (1998). Evaluation of herbicides in wet seeded, late Sali (winter) rice (Oryza sativa) in Assam. *Indian J. Agron*., 43 (2): 291–294.

Chowdhury, I. U. A., & Khan, M. A. E. (2015). The impact of climate change on rice yield in Bangladesh: a time series analysis. *Russian Journal of Agricultural and Socio-Economic Sciences*, 40(4).

Chung, SO and Temba, N (2012). Uncertainty of paddy irrigation requirement estimated from climate change projections in the Geumho river basin, Korea. *Paddy Water Environ* 10:175–185.

Chung, SO, Rodri, JA, Guez-di, AZ, Weatherhead, EK and Knox, JW (2011). Climate change impacts on water for irrigating paddy rice in South Korea. *Irrig. and Drain*. 60: 263–273.

Cline, W. R. (2007). Global warming and agriculture: Impact estimates by country. Peterson Institute.

Crane, R. G., & Hewitson, B. C. (1998). Doubled CO2 precipitation changes for the Susquehanna Basin: Down- scaling from the Genesis general circulation model. International Journal of Climatology: A *Journal of the Royal Meteorological Society*, 18(1), 65-76.

Cruz, R. V., Harasawa, H., Lal, M., Wu, S., Anokhin, Y., Punsalmaa, B., ... & Ninh, N. H. (2007). Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability. *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.

De Datta, S. K. and A. Baltazar. (1996). Weed control technology as a component of rice production systems. In: B. Auld and K. U. Kim (eds.) Weed Management in Rice. *FAO Plant Production and Protection Paper No*. 139. pp. 25–52.

De Datta, S. K., & Haque, M. Z. (1982). Weeds, weed problems and weed control in deepwater rice areas. In *Proceedings of the International Deep-water Rice Workshop, International Rice Research Institute held in Manila*, Philippines (pp. 427-442).

Deb, P., Tran, D. A., & Udmale, P. D. (2016). Assessment of the impacts of climate change and brackish irrigation water on rice productivity and evaluation of adaptation measures in Ca Mau province, Vietnam. *Theoretical and Applied Climatology*, 125(3), 641-656.

Deni, S. M., Suhaila, J., Zin, W. Z. W., & Jemain, A. A. (2010). Spatial trends of dry spells over Peninsular Malaysia during monsoon seasons. *Theoretical and applied climatology*, 99(3), 357-371.

Deryng, D., Elliott, J., Folberth, C., Müller, C., Pugh, T. A., Boote, K. J., ... & Khabarov, N. (2016). Regional disparities in the beneficial effects of rising CO 2 concentrations on crop water productivity. *Nature Climate Change*, 6(8), 786–790.

Dessu, S. B., & Melesse, A. M. (2013). Impact and uncertainties of climate change on the hydrology of the Mara River basin, Kenya/Tanzania. *Hydrological Processes*, 27(20), 2973-2986.

Dharmarathna, W. R. S. S., Weerakoon, S. B., Rathnayake, U. R., & Hearth, S. (2012). Variation of Irrigated rice yield under the climate change scenarios. In *SAITM research symposium on Engineering Advancements* (pp. 31-34).

Di Luca, A., de Elía, R., & Laprise, R. (2013). Potential for small scale added value of RCM's downscaled climate change signal. *Climate Dynamics*, 40(3-4), 601-618.

Di Paola, A., Valentini, R., & Santini, M. (2016). An overview of available crop growth and yield models for studies and assessments in agriculture. *Journal of the Science of Food and Agriculture*, 96(3), 709–714.

Diallo, S., & Johnson, D. E. (1997). Les adventices du riz irrigué au Sahel et leur contrôle. *Irrigated rice in the Sahel: prospects for sustainable development. WARDA, Dakar*, 311-323.

Diaz-Nieto, J., & Wilby, R. L. (2005). A comparison of statistical downscaling and climate change factor methods: impacts on low flows in the River Thames, United Kingdom. *Climatic Change*, 69(2), 245-268.

Dibike, Y. B., & Coulibaly, P. (2005). Hydrologic impact of climate change in the Saguenay watershed: comparison of downscaling methods and hydrologic models. *Journal of hydrology*, 307(1-4), 145-163.

Dobermann, A., & Fairhurst, T. (2000). Rice: Nutrient disorders and nutrient management. International Rice Research Institute, Manila, Philippines. *Rice: Nutrient disorders and nutrient management. International Rice Research Institute, Manila, Philippines*.

Döll, P., Kaspar, F., & Lehner, B. (2003). A global hydrological model for deriving water availability indicators: model tuning and validation. *Journal of Hydrology*, 270(1-2), 105-134.

Doorenbos, J., & Kassam, A. H. (1979). Yield response to water. *Irrigation and drainage paper*, (33), 257.

Doorenbos, J., & Pruitt, W. O. (1977). Crop water requirements." *irrigation and Drainage Paper No*. 24,(rev.) FAO. Rome, Italy.

Droogers, P., & Bastiaanssen, W. (2002). Irrigation performance using hydrological and remote sensing modeling. *Journal of Irrigation and Drainage Engineering*, 128(1), 11-18.

Dubey, A. N., Verma, S., Goswami, S. P., & Devedee, A. K. (2018). Effect of Temperature on Different Growth Stages and Physiological Process of Rice crop-a Review. *Bull. Env. Pharmacol. Life Sci*, 7, 129-136.

Easterling, W. E., Aggarwal, P. K., Batima, P., Brander, K. M., Erda, L., Howden, S. M., ... & Tubiello, F. N. (2007). Food, fibre and forest products. *Climate change*, 2007, 273–313.

El-Sharkawy, M. A. (2011). Overview: Early history of crop growth and photosynthesis modeling. *BioSystems*, 103(2), 205–211.

Enyinnia, T. (1992). Chemical weed control in rainfed upland rice in Nigeria. *International Journal of Pest Management*, 38(4), 408-410.

Ercan, A., Bin Mohamad, M. F., & Kavvas, M. L. (2013). The impact of climate change on sea level rise at Peninsular Malaysia and Sabah–Sarawak. *Hydrological Processes*, 27(3), 367–377.

Eum, H. I., Simonovic, S. P., & Kim, Y. O. (2010). Climate change impact assessment using k-nearest neighbor weather generator: case study of the Nakdong River basin in Korea. *Journal of Hydrologic Engineering*, 15(10), 772-785.

FAO (2002) Rice in producing countries. In Nguyen, V. N., Tran, D. V. (Eds.). *FAO rice information*. (pp. 126–128) Rome, Italy: FAO.

FAO (2004). Rice and water: A long and diversified story, Food and Agriculture Organization of the United Nations Viale delle Terme di Caracalla Rome 00100 Italy.

FAO (2006). Rice International commodity profile. Rome: FAO: Food and Agricultural Organization. August 5, 2014. http://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Rice/Documents/Rice_Profile_Dec-06.pdf.

FAO (2012). FAO IRRIGATION AND DRAINAGE PAPER 66" Crop yield response to water"

FAO (2016). The State of Food and Agriculture 2016, Climate Change, Agriculture and Food Security.

FAO (2018). Rice Market Monitor (RMM) April 2018, Volume XXI - Issue No. 1. http://www.fao.org/economic/RMM.

Farooq, M., Kobayashi, N., Wahid, A., Ito, O., & Basra, S. M. (2009). 6 Strategies for Producing More Rice with Less Water. *Advances in Agronomy*, 101(4), 351–388.

Firdaus, R. R., Latiff, I. A., & Borkotoky, P. (2012). The impact of climate change towards Malaysian paddy farmers. *Journal of Development and Agricultural Economics*, 5(2), 57-66.

Fitzgerald, M. A., & Resurreccion, A. P. (2009). Maintaining the yield of edible rice in a warming world. *Functional Plant Biology*, 36(12), 1037-1045.

Flores-Jiménez, D. E., Carbajal, N., Algara-Siller, M., Aguilar-Rivera, N., Álvarez-Fuentes, G., Ávila-Galarza, A., & García, A. R. (2019). Atmospheric dispersion of methane emissions from sugarcane burning in Mexico. *Environmental Pollution*, 250, 922-933.

Foley, D. J., Thenkabail, P. S., Aneece, I. P., Teluguntla, P. G., & Oliphant, A. J. (2019). A meta-analysis of global crop water productivity of three leading world crops (wheat, corn, and rice) in the irrigated areas over three decades. *International Journal of Digital Earth*, 1–37.

Foster, T., Brozović, N., Butler, A. P., Neale, C. M. U., Raes, D., Steduto, P., ... & Hsiao, T. C. (2017). AquaCrop-OS: An open source version of FAO's crop water productivity model. *Agricultural water management*, 181, 18-22.

Fowler, H. J., Blenkinsop, S., & Tebaldi, C. (2007). Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling. International Journal of Climatology: *A Journal of the Royal Meteorological Society*, 27(12), 1547-1578.

Fuhrer, J. (2003). Agroecosystem responses to combinations of elevated CO_2, ozone, and global climate change. *Agriculture, Ecosystems & Environment*, 97(1–3), 1–20.

GAIN REPORT: Grain and Feed Annual (2017), *Malaysia. Report No*. MY7001.

Ghosh, S., & Misra, C. (2010). Assessing hydrological impacts of climate change: Modeling techniques and challenges. *The Open Hydrology Journal*, 4(1).

Ghosh, S., & Mujumdar, P. P. (2007). Nonparametric methods for modeling GCM and scenario uncertainty in drought assessment. *Water Resources Research*, 43(7).

Ghosh, S., & Mujumdar, P. P. (2007). Nonparametric methods for modeling GCM and scenario uncertainty in drought assessment. *Water Resources Research*, 43(7).

Gilanipour, J., & Gholizadeh, B. (2016). Prediction of rice water requirement using FAO-CROPWAT model in North Iran under future climate change.

Gobena, A. K., & Gan, T. Y. (2013). Assessment of trends and possible climate change impacts on summer moisture availability in western Canada based on metrics of the palmer drought severity index. *Journal of Climate*, 26(13), 4583–4595.

Gopinath, K.A., Mina, B.L., Singh, K.P., Nataraja, K.C. (2012). Integrated weed management in direct-seeded rainfed rice (Oryza sativa). *Indian J. Agron*. 57, 245–249

Graham, L. P., Hagemann, S., Jaun, S., & Beniston, M. (2007). On interpreting hydrological change from regional climate models. *Climatic change*, 81(1), 97-122.

Greaves, G. E., & Wang, Y. M. (2016). Assessment of FAO AquaCrop model for simulating maize growth and productivity under deficit irrigation in a tropical environment. Water, 8(12), 557.

Gumel, D. Y., Abdullah, A. M., Sood, A. M., Elhadia, R. E., Jamalani, M. A., & Youssefa, K. A. A. B. (2017). Assessing Paddy Rice Yield Sensitivity to Temperature and Rainfall Variability in Peninsular Malaysia Using DSSAT Model. *International Journal of Applied Environmental Sciences*, 12(8), 1521–1545.

Guo, R., Lin, Z., Mo, X., & Yang, C. (2010). Responses of crop yield and water use efficiency to climate change in the North China Plain. *Agricultural Water Management*, 97(8), 1185-1194.

Gyalistras, D., von Storch, H., Fischlin, A., & Beniston, M. (1994). Linking GCM-simulated climatic changes to ecosystem models: case studies of statistical downscaling in the Alps. *Climate Research*, 167-189.

Hamidon, N., Harun, S., Malek, M. A., Ismail, T., & Alias, N. (2015). Prediction of paddy irrigation requirements by using statistical downscaling and cropwat models: A case study from the Kerian Irrigation Scheme in Malaysia. *Jurnal Teknologi*, 76(1).

Hanjra, M. A., & Qureshi, M. E. (2010). Global water crisis and future food security in an era of climate change. *Food policy*, 35(5), 365-377.

Haque, M. A., Najim, M. M. M., & Lee, T. S. (2014). Modeling irrigation water delivery schedule for rice cultivation in east coast Malaysia.

Hargreaves, G. H., & Samani, Z. A. (1982). Estimating potential evapotranspiration. *Journal of the Irrigation and Drainage Division*, 108(3), 225–230.

Hassam Saad Mohammed Hilmi (2005). Estimation of Ricr Evapotranspiration in Paddy Fields Using Remote Sensing and Field Measurements. *Ph.D Thesis, Universiti Putra Malaysia*.

Heffer P (2013) Assessment of fertilizer use by crop at the global level, 2010–2010/11. *International Fertilizer Industry Association* (IFA), Paris.

Herath, G., Hasanov, A., & Park, J. (2019, August). Impact of climate change on paddy production in Malaysia: empirical analysis at the national and state level experience. *In International Conference on Management Science and Engineering Management* (pp. 656-664). Springer, Cham.

Hertig, E., & Jacobeit, J. (2013). A novel approach to statistical downscaling considering nonstationarities: application to daily precipitation in the Mediterranean area. *Journal of Geophysical Research: Atmospheres*, 118(2), 520-533.

Hewitson, B. C., & Crane, R. G. (1996). Climate downscaling: techniques and application. *Climate Research*, 7(2), 85-95.

Hillel, D., & Rosenzweig, C. (2011). Handbook of climate change and agroecosystems: impacts, adaptation, and mitigation (Vol. 1). *World Scientific*.

Hoekstra, A. Y., Chapagain, A. K., Mekonnen, M. M., & Aldaya, M. M. (2011). The water footprint assessment manual: Setting the global standard. Routledge.

Högy, P., & Fangmeier, A. (2009). Atmospheric CO2 enrichment affects potatoes: 1. Aboveground biomass production and tuber yield. *European Journal of Agronomy*, 30(2), 78-84.

Hsiao, T. C., Heng, L., Steduto, P., Rojas- Lara, B., Raes, D., & Fereres, E. (2009). AquaCrop—the FAO crop model to simulate yield response to water: III. Parameterization and testing for maize. *Agronomy Journal*, 101(3), 448-459.

Hsiao, T.C, Fereres, E., Steduto, P. and Raes, D. (2012). FAO Irrigation and Drainage Paper Nr. 66 'Crop yield response to water'. 'AquaCrop parameterization, calibration and validation guide', Section 3.3.

Hugh, T., Jacob, B., & Faures, JM. (2013). Climate change, water and food security. *Irrigation Science*, 31:179–182.

Huntingford, C., Jones, R. G., Prudhomme, C., Lamb, R., Gash, J. H., & Jones, D. A. (2003). Regional climate- model predictions of extreme rainfall for a changing climate. Quarterly Journal of the Royal Meteorological Society: *A journal of the atmospheric sciences, applied meteorology and physical oceanography*, 129(590), 1607-1621.

Hussain, S., Huang, J., Huang, J., Ahmad, S., Nanda, S., Anwar, S., ... & Zhang, J. (2020). Rice production under climate change: Adaptations and mitigating strategies. *In Environment, Climate, Plant and Vegetation Growth* (pp. 659-686). Springer, Cham.

IFPRI (2009). Impact of climate change on agriculture: Factsheet on Asia. [http://www.ifpri.org/publication/impact-climate-changeagriculture-factsheet-asia] site visited on 20/01/2020.

Imai, K., & Murata, Y. (1979). Effect of Carbon Dioxide Concentration on Growth and Dry Matter Production of Crop Plants: VII. Influence of light intensity and temperature on the effect or carbon dioxide-enrichment in some C3-and C4-species. *Japanese Journal of Crop Science*, 48(3), 409-417.

Imeokparia, P. O. (1994). Weed control in flooded rice with various herbicide combinations in the southern Guinea savanna zone of Nigeria. Int. *J. Pest Manag*. 40(1), 31–39.

IPCC (2000). Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

IPCC (2007) Climate change 2007: the physical science basis. Cambridge University Press, Cambridge.

IPCC (2013a). "Climate Change 2013 the Physical Science Basis: *Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. 9781107057:1–1535.

IPCC (2013b). CLIMATE CHANGE 2013 The Physical Science Basis. Summary for Policymakers, Technical Summary and Frequently Asked Questions.

IPCC (2014a). "CLIMATE CHANGE 2014 Synthesis Report, the Summary for Policymakers." *Report*.

IPCC (2014b). Climate Change 2014 Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer

(Eds.)]. IPCC, Geneva, Switzerland, 151 Pp.

IPCC (2014c). Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from: Http://Www.Tandfonline.Com/Doi/Abs/10.4155/Cmt.13.80.

Iqbal, M. A., Shen, Y., Stricevic, R., Pei, H., Sun, H., Amiri, E., ... & del Rio, S. (2014). Evaluation of the FAO AquaCrop model for winter wheat on the North China Plain under deficit irrigation from field experiment to regional yield simulation. *Agricultural Water Management*, 135, 61–72.

Isik, M., & Devadoss, S. (2006). An analysis of the impact of climate change on crop yields and yield variability. *Applied Economics*, 38(7), 835-844.

IVANAUSKAITĖ, J., BUKANTIS, A., & STANKŪNAVIČIUS, G. (2012). The application of AgroMetShell model for the analysis and prediction of spring barley productivity in Lithuania. *Žemdirbystė (Agriculture)*, 99(2), 213–220.

Jackson, R. B., Sala, O. E., Field, C. B., & Mooney, H. A. (1994). CO 2 alters water use, carbon gain, and yield for the dominant species in a natural grassland. *Oecologia*, 98(3), 257-262.

Jagadish, S. V. K., Craufurd, P. Q., & Wheeler, T. R. (2008). Phenotyping parents of mapping populations of rice for heat tolerance during anthesis. *Crop Science*, 48(3), 1140-1146.

Jahan, M. S. (2016). *Rice production under different water inputs*. LAP LAMBERT Academic Publishing.

JICA and DID (1998). The study on modernization of irrigation water management system in the Granary area of Peninsular Malaysia. Final Report, March 1998, Japan International Cooperation Agency (JICA).

Johnson, D. E., Wopereis, M. C. S., Mbodj, D., Diallo, S., Powers, S., & Haefele, S. M. (2004). Timing of weed management and yield losses due to weeds in irrigated rice in the Sahel. *Field Crops Research*, 85(1), 31-42.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., ... & Ritchie, J. T. (2003). The DSSAT cropping system model. European journal of agronomy, 18(3-4), 235-265.

Kamaruddin, A. H., Din, A. H. M., Pa'suya, M. F., & Omar, K. M. (2016). Long-term sea level trend from tidal data in Malaysia. In 2016 7th IEEE *Control and System Graduate Research Colloquium* (ICSGRC) (pp. 187–192). IEEE.

Kamruzzaman, M., Hwang, S., Choi, S. K., Cho, J., Song, I., Song, J. H., ... & Yoo, S. H. (2020). Evaluating the Impact of Climate Change on Paddy Water Balance Using APEX-Paddy Model. *Water*, 12(3), 852.

Karandish, F., Mousavi, S. S., & Tabari, H. (2017). Climate change impact on precipitation and cardinal temperatures in different climatic zones in Iran:

analyzing the probable effects on cereal water-use efficiency. *Stochastic Environmental Research and Risk Assessment*, 31(8), 2121–2146.

Karim, M. R., Ishikawa, M., Ikeda, M., & Islam, M. T. (2012). Climate change model predicts 33% rice yield decrease in 2100 in Bangladesh. *Agronomy for sustainable development*, 32(4), 821-830.

Karunaratne, A. S., Azam-Ali, S. N., Izzi, G., & Steduto, P. (2011). Calibration and validation of FAO-AquaCrop model for irrigated and water deficient bambara groundnut. *Experimental Agriculture*, 47(3), 509.

Khairi, M., Naqib, S. A., Nozulaidi, M., Hasan, M. M., & Jahan, M. S. (2017) Low water input confers sustainable rice production without affecting soil, plant physiological and yields parameters. *Australian Journal of Crop Science*, 11(8), 1068–1077.

Khairi, M., Nozulaidi, M., Afifah, A., & Jahan, M. S. (2015). Effect of various water regimes on rice production in lowland irrigation. *Australian Journal of Crop Science*, 9(2), 153–159.

Khanal, U., Wilson, C., Hoang, V. N., & Lee, B. (2018). Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. Ecological Economics, 144, 139-147.

Kihara, J., MacCarthy, D. S., Bationo, A., Koala, S., Hickman, J., Koo, J., ... & Jones, J. W. (2015). Perspectives on climate effects on agriculture: *The international efforts of AgMIP in Sub-Saharan Africa*.

Kijne, J. W., Barker, R., & Molden, D. J. (Eds.). (2003). *Water productivity in agriculture: limits and opportunities for improvement* (Vol. 1). Cabi.

Kim, J., Shon, J., Lee, C. K., Yang, W., Yoon, Y., Yang, W. H., ... & Lee, B. W. (2011). Relationship between grain filling duration and leaf senescence of temperate rice under high temperature. *Field Crops Research*, 122(3), 207-213.

Kim, D., & Kaluarachchi, J. (2015). Validating FAO AquaCrop using Landsat images and regional crop information. *Agricultural Water Management*, 149, 143-155.

King, L. M., McLeod, A. I., & Simonovic, S. P. (2015). Improved weather generator algorithm for multisite simulation of precipitation and temperature. *JAWRA Journal of the American Water Resources Association*, 51(5), 1305-1320.

Klink, K., Wiersma, J. J., Crawford, C. J., & Stuthman, D. D. (2014). Impacts of temperature and precipitation variability in the Northern Plains of the United States and Canada on the productivity of spring barley and oat. *International Journal of Climatology*, 34(8), 2805-2818.

Kotir, J. H. (2011). Climate change and variability in Sub-Saharan Africa: a review of current and future trends and impacts on agriculture and food security. *Environment, Development and Sustainability*, 13(3), 587-605.

Kruijt, B., Witte, J. P. M., Jacobs, C. M., & Kroon, T. (2008). Effects of rising atmospheric CO2 on evapotranspiration and soil moisture: A practical approach for the Netherlands. *Journal of Hydrology*, 349(3-4), 257-267.

Kwan, M. S., Tangang, F. T., & Juneng, L. (2013). Projected changes of future climate extremes in Malaysia. *Sains Malaysiana*, 42(8), 1051–1059.

Labrada, R. (1996). Weed control in rice. In B. Auld and K.U. Kim (eds.) Weed Management in Rice. *FAO Plant Production and Protection Paper No*. 139. pp. 3–5.

Lage, M., Bamouh, A., Karrou, M., & El Mourid, M. (2003). Estimation of rice evapotranspiration using a microlysimeter technique and comparison with FAO Penman-Monteith and Pan evaporation methods under Moroccan conditions. *Agronomie*, 23(7), 625-631.

Lam, S. K., Han, X., Lin, E., Norton, R., & Chen, D. (2012). Does elevated atmospheric carbon dioxide concentration increase wheat nitrogen demand and recovery of nitrogen applied at stem elongation?. *Agriculture, Ecosystems & Environment*, 155, 142-146.

Lammertsma, E. I., de Boer, H. J., Dekker, S. C., Dilcher, D. L., Lotter, A. F., & Wagner-Cremer, F. (2011). Global CO2 rise leads to reduced maximum stomatal conductance in Florida vegetation. *Proceedings of the National Academy of Sciences*, 108(10), 4035-4040.

Laux, P., Jäckel, G., Tingem, R. M., & Kunstmann, H. (2010). Impact of climate change on agricultural productivity under rainfed conditions in Cameroon—A method to improve attainable crop yields by planting date adaptations. *Agricultural and Forest Meteorology*, 150(9), 1258-1271.

Le Loh, J., Tangang, F., Juneng, L., Hein, D., & Lee, D. I. (2016). Projected rainfall and temperature changes over Malaysia at the end of the 21st century based on PRECIS modelling system. *Asia-Pacific Journal of Atmospheric Sciences*, 52(2), 191–208.

Leakey, A. D., Ainsworth, E. A., Bernacchi, C. J., Rogers, A., Long, S. P., & Ort, D. R. (2009). Elevated CO_2 effects on plant carbon, nitrogen, and water relations: six important lessons from FACE. *Journal of experimental botany*, 60(10), 2859–2876.

Lee, S. T., Haque, M. A., & Feng, H. Y. (2006). Modeling Water Balance Components in Rice Field Irrigation. *The Institution of Engineers: Kuala Lumpur, Malaysia*, 67, 22–25.

Lenderink, G., Buishand, A., & Deursen, W. V. (2007). Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach. *Hydrology and Earth System Sciences*, 11(3), 1145-1159.

Leung, L., Mearns, L., Giorgi, F., & Wilby, R. (2003). REGIONAL CLIMATE RESEARCH: Needs and Opportunities. *Bulletin of the American Meteorological Society,* 84(1), 89–95. Retrieved from http://www.jstor.org/stable/26215433

Li, T., Hasegawa, T., Yin, X., Zhu, Y., Boote, K., Adam, M., ... & Bouman, B. (2015). Uncertainties in predicting rice yield by current crop models under a wide range of climatic conditions. *Global change biology,* 21(3), 1328-1341.

Li, Y., Šimůnek, J., Wang, S., Yuan, J., & Zhang, W. (2017). Modeling of soil water regime and water balance in a transplanted rice field experiment with reduced irrigation. *Water,* 9(4), 248.

Lieffering, M., Kim, H. Y., Kobayashi, K., & Okada, M. (2004). The impact of elevated CO2 on the elemental concentrations of field-grown rice grains. *Field Crops Research*, 88(2-3), 279-286.

Liu, L., Guo, Z., Huang, G., & Wang, R. (2019). Water productivity evaluation under multi-gcm projections of climate change in oases of the heihe river basin, northwest china. *International journal of environmental research and public health*, 16(10), 1706.

Liu, S., Waqas, M. A., Wang, S. H., Xiong, X. Y., & Wan, Y. F. (2017). Effects of increased levels of atmospheric CO2 and high temperatures on rice growth and quality. *PloS one*, 12(11), e0187724.

Lobell, D. B., & Gourdji, S. M. (2012). The influence of climate change on global crop productivity. *Plant physiology*, 160(4), 1686-1697.

Lobell, D. B., & Field, C. B. (2008). Estimation of the carbon dioxide (CO2) fertilization effect using growth rate anomalies of CO2 and crop yields since 1961. *Global Change Biology,* 14(1), 39-45.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science,* 319(5863), 607-610.

Lobell, D. B., Bänziger, M., Magorokosho, C., & Vivek, B. (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. *Nature climate change*, 1(1), 42-45.

Loh, J., Tangang, F., Juneng, L., Hein, D., & Lee, D. I. (2016). Projected rainfall and temperature changes over Malaysia at the end of the 21st century based on PRECIS modelling system. *Asia-Pacific Journal of Atmospheric Sciences*, 52(2), 191-208.

Loomis, R. S., Rabbinge, R., & Ng, E. (1979). Explanatory models in crop physiology. *Annual Review of Plant Physiology*, 30(1), 339–367.

Lv, Z., Zhu, Y., Liu, X., Ye, H., Tian, Y., & Li, F. (2018). Climate change impacts on regional rice production in China. *Climatic change*, 147(3–4), 523–537.

Maclean, J. L., Dawe, D. C., Hardy, B., & Hettel, G. P. (Eds.). (2002). Rice almanac: *Source book for the most important economic activity on earth. Int. Rice Res. Inst*.

Maina, M. M., Amin, M. S. M., Rowshon, M. K., Aimrun, W., Samsuzana, A. A., & Yazid, M. A. (2014). Effects of crop evapotranspiration estimation techniques and weather parameters on rice crop-water requirement . *Australian Journal of Crop Science*, 8(4), 495.

Malaysian Meteorological Department, (2009). Climate Change Scenarios for Malaysia 2001–2099. *Malaysia Meteorological Department*, *Kuala Lumpur*.

Maraun, D., Wetterhall, F., Ireson, A. M., Chandler, R. E., Kendon, E. J., Widmann, M., ... & Thiele- Eich, I. (2010). Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user. *Reviews of geophysics*, 48(3).

Masasi, B., Taghvaeian, S., Gowda, P. H., Marek, G., & Boman, R. (2020). Validation and application of AquaCrop for irrigated cotton in the Southern Great Plains of US. *Irrigation Science*, 1–15.

Matthews, H. D., & Zickfeld, K. (2012). Climate response to zeroed emissions of greenhouse gases and aerosols. *Nature Climate Change*, 2(5), 338-341.

Matthews, R. B., & Van Laar, H. H. (1995). Modeling the impact of climate change on rice production in Asia. Int. *Rice Res. Inst*.

Medlyn, B. E., Barton, C. V. M., Broadmeadow, M. S. J., Ceulemans, R., De Angelis, P., Forstreuter, M., ... & Jarvis, P. G. (2001). Stomatal conductance of forest species after long- term exposure to elevated CO2 concentration: a synthesis. *New Phytologist*, 149(2), 247-264.

Mehrotra, R., & Sharma, A. (2005). A nonparametric nonhomogeneous hidden Markov model for downscaling of multisite daily rainfall occurrences. *Journal of Geophysical Research*: *Atmospheres*, 110(D16).

Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L., Lamarque, J. F., ... & Van Vuuren, D. P. P. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic change*, 109(1), 213-241.

Mendelsohn, R. (2008). The impact of climate change on agriculture in developing countries. *Journal of Natural Resources Policy Research*, 1(1), 5–19.

Mendonça, J. C., Sousa, E. F. D., Bernardo, S., Dias, G. P., & Grippa, S. (2003). Comparison of estimation methods of reference crop evapotranspiration (ETo) for Northeren Region of Rio de Janeiro State, Brazil. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 7(2), 275-279.

Meng, F., Zhang, J., Yao, F., & Hao, C. (2014). Interactive effects of elevated CO 2 concentration and irrigation on photosynthetic parameters and yield of maize in northeast China. *PloS one*, 9(5), e98318.

Mertz, O., Mbow, C., Reenberg, A., & Diouf, A. (2009). Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. *Environmental management*, 43(5), 804-816.

Mitchell, T. D., & Hulme, M. (1999). Predicting regional climate change: living with uncertainty. *Progress in Physical Geography*, 23(1), 57-78.

Mkhabela, M. S., & Bullock, P. R. (2012). Performance of the FAO AquaCrop model for wheat grain yield and soil moisture simulation in Western Canada. *Agricultural Water Management*, 110, 16–24.

Mondal, A., Khare, D., & Kundu, S. (2015). Spatial and temporal analysis of rainfall and temperature trend of India. *Theoretical and applied climatology*, 122(1–2), 143–158.

Moorthy, B. T. S., & Saha, S. (2005). Studies on crop-weed competition in rainfed direct-seeded lowland rice (Oryza sativa). *Indian Journal of Weed Science*, 37(3and4), 267-268.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, 50(3), 885-900.

Moriondo, M., Giannakopoulos, C., & Bindi, M. (2011). Climate change impact assessment: the role of climate extremes in crop yield simulation. *Climatic change*, 104(3), 679-701.

Moron, V., Boyard-Micheau, J., Camberlin, P., Hernandez, V., Leclerc, C., Mwongera, C., ... & Sultan, B. (2015). Ethnographic context and spatial coherence of climate indicators for farming communities–A multi-regional comparative assessment. *Climate Risk Management*, 8, 28-46.

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., & Van Vuuren, D. P. & Meehl, GA (2010). The next generation of scenarios for climate change research and assessment. *Nature*, 463(7282), 747.

Mottaleb, K. A., Mohanty, S., & Nelson, A. (2015). Factors influencing hybrid rice adoption: a Bangladesh case. *Australian Journal of Agricultural and Resource Economics*, 59(2), 258-274.

Mujumdar, P. P. (2013). Climate change: a growing challenge for water management in developing countries. *Water resources management*, 27(4), 953-954.

Murad, W., Molla, R. I., Mokhtar, M. B., & Raquib, A. (2010). Climate change and agricultural growth: an examination of the link in Malaysia. *International Journal of Climate Change Strategies and Management*.

Murphy, J. M., Sexton, D. M., Jenkins, G. J., Booth, B. B., Brown, C. C., Clark, R. T., ... & Brown, S. J. (2009). UK climate projections science report: *climate change projections*.

Muthayya, S., Hall, J., Bagriansky, J., Sugimoto, J., Gundry, D., Matthias, D., ... & Maberly, G. (2012). Rice fortification: an emerging opportunity to contribute to the elimination of vitamin and mineral deficiency worldwide. *Food and Nutrition Bulletin*, 33(4), 296–307.

Muthayya, S., Sugimoto, J. D., Montgomery, S., & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences,* 1324(1), 7–14.

NAHRIM (2006). Study on the Impacts of Climate Change on Hydrologic Regimes and Water Resources for Peninsular Malaysia: *Final Report, by California Hydrologic Research Laboratory, September 2006*.

NAHRIM (2011). Impacts of Climate Change on Hydrologic Regimes, *Water Resources and Land use Change for Sabah & Sarawak.*

NAHRIM (2012) Managing Lakes and Their Basins for Sustainable use in Malaysia (Lake Briefs Report Series II). *National Hydraulic Research Institute of Malaysia, Seri Kembangan.*

NAHRIM (2014). Climate Projection Downscaling for Peninsular Malaysia and Sabah-Sarawak using Hadley Centre PRECIS Model.

Najafi, E., Devineni, N., Khanbilvardi, R. M., & Kogan, F. (2018). Understanding the changes in global crop yields through changes in climate and technology. *Earth's Future*, 6(3), 410-427.

Nakagawa, H., Horie, T., Goudriaan, J., Kim, H. Y., Ohnishi, H., Homma, K., & Wada K. (2000) Effects of elevated CO_2 concentrations and increased temperature on leaf area, growth and dry matter production of rice as found in TGC study. *Plant Prod Sci* 93:93–99.

Nakagawa, T., Kitagawa, H., Yasuda, Y., Tarasov, P. E., & Nishida, K. (2003) Asynchronous climate changes in the North Atlantic and Japan during the last termination. *Science* 299: 688–691.

Nakicenovic, N., & Swart, R. (2000). *Special Report on Emissions Scenarios*, Edited by Nebojsa Nakicenovic and Robert Swart, pp. 612. ISBN 0521804930. Cambridge, UK: Cambridge University Press, July 2000., 1.

Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part I—A discussion of principles. *Journal of hydrology*, 10(3), 282-290.

Nechifor, V., & Winning, M. (2019). Global crop output and irrigation water requirements under a changing climate. *Heliyon*, 5(3), e01266.

Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., ... & Lee, D. (2009). Climate change: Impact on agriculture and costs of adaptation (Vol. 21). *Intl Food Policy Res Inst*.

New, M., & Hulme, M. (2000). Representing uncertainty in climate change scenarios: a Monte-Carlo approach. *Integrated assessment*, 1(3), 203-213.

NOAA (2018). *National Centers for Environmental Information*, State of the Climate: Global Climate Report for Annual 2018, published online January 2019, retrieved on May 21, 2021 from https://www.ncdc.noaa.gov/sotc/global/201813.

Nordhaus, W. D. (1991). To slow or not to slow: the economics of the greenhouse effect. *The economic journal*, 101(407), 920–937.

NRE (2015). *Malaysia Biennial Update Report to the UNFCC*. Ministry of Natural Resources and Environment Malaysia, Putrajaya, Malaysia.

NRS (2001) National response strategies to climate change. *Ministry of Science, Technology and the Environment, Malaysia*. http://gedung.nahrim.gov.my/wapi/mctweb.dll/getObject?MID=WATER%20RESOURCES&Sn=2038.

Nyang'Au, W. O., Mati, B. M., Kalamwa, K., Wanjogu, R. K., & Kiplagat, L. K. (2014). Estimating rice yield under changing weather conditions in Kenya using CERES rice model. *International Journal of Agronomy*, 2014.

Omar, S. C., Shaharudin, A., & Tumin, S. A. (2019). The status of the paddy and rice industry in Malaysia. *Khazanah Research Institute. Kuala Lumpur*.

Oteng-Darko, P., Yeboah, S., Addy, S. N. T., Amponsah, S., & Danquah, E. O. (2013). Crop modeling: a tool for agricultural research-A. *J Agric Res Dev*, 2(1), 001-006.

Ouyang, F., Zhu, Y., Fu, G., Lü, H., Zhang, A., Yu, Z., & Chen, X. (2015). Impacts of climate change under CMIP5 RCP scenarios on streamflow in the Huangnizhuang catchment. *Stochastic environmental research and risk assessment*, 29(7), 1781-1795.

Özdoğan, M. (2011). Modeling the impacts of climate change on wheat yields in Northwestern Turkey. *Agriculture, ecosystems & environment*, 141(1–2), 1–12.

Pachauri, R. K., & Reisinger, A. (2008). Climate change 2007. Synthesis report. *Contribution of Working Groups I, II and III to the fourth assessment report*.

Parry, M. L., Rosenzweig, C., Iglesias, A., Livermore, M., & Fischer, G. (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global environmental change*, 14(1), 53-67.

Pathak, H., Ladha, J. K., Aggarwal, P. K., Peng, S., Das, S., Singh, Y., ... & Aggarwal, H. P. (2003). Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic Plains. *Field Crops Research*, 80(3), 223–234.

Payne, T. (2018). Summary for Policymakers. In Global warming of 1.5° C. An IPCC Special Report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change (p. 32). *World Meteorological Organization Technical Document*.

Peng, S., Huang, J., Sheehy, J. E., Laza, R. C., Visperas, R. M., Zhong, X., ... & Cassman, K. G. (2004). Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences*, 101(27), 9971–9975.

Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., Li, J., ... & Friedlingstein, P. (2010). The impacts of climate change on water resources and agriculture in China. *Nature*, 467(7311), 43–51.

Pierce, D. W., Barnett, T. P., Santer, B. D., & Gleckler, P. J. (2009). Selecting global climate models for regional climate change studies. *Proceedings of the National Academy of Sciences*, 106(21), 8441-8446.

Pirmoradian, N., Saadati, Z., Rezaei, M., & Khaledian, M. R. (2020). Simulating water productivity of paddy rice under irrigation regimes using AquaCrop model in humid and semiarid regions of Iran. *Applied Water Science*, 10(7), 1-8.

Pirmoradian, N., & Davatgar, N. (2019). Simulating the effects of climatic fluctuations on rice irrigation water requirement using AquaCrop. *Agricultural water management*, 213, 97-106.

Porras-Jorge, R., Ramos-Fernández, L., Ojeda-Bustamante, W., & Ontiveros-Capurata, R. E. (2020). Performance assessment of the AquaCrop model to estimate rice yields under alternate wetting and drying irrigation in the coast of Peru. Scientia Agropecuaria, 11(3), 309-321.

Poulton, P. L., Dalgliesh, N. P., Vang, S., Veasna, T., & Charlesworth, P. (2015, September). Resilience of smallholder farmers in Cambodian lowland rice ecosystems in managing for future climate uncertainty. In *Proceedings of the 17th Australian Society of Agronomy conference: Building productive, diverse and sustainable landscapes* (pp. 20-24).

Prasad, P. V. V., Boote, K. J., Allen Jr, L. H., Sheehy, J. E., & Thomas, J. M. G. (2006). Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice in response to high temperature stress. *Field crops research*, 95(2–3), 398–411.

Prathumchai, K., Nagai, M., Tripathi, N. K., & Sasaki, N. (2018). Forecasting transplanted rice yield at the farm scale using moderate-resolution satellite imagery and the AquaCrop model: A case study of a rice seed production community in thailand. *ISPRS International Journal of Geo-Information,* 7(2), 73.

Prudhomme, C., Jakob, D., & Svensson, C. (2003). Uncertainty and climate change impact on the flood regime of small UK catchments. *Journal of hydrology*, 277(1-2), 1-23.

Raes, D., Steduto, P., Hsiao, T. C., & Fereres, E. (2009). AquaCrop—the FAO crop model to simulate yield response to water: II. Main algorithms and software description. *Agronomy Journal,* 101(3), 438–447.

Raes, D., Steduto, P., Hsiao, T. C., & Fereres, E. (2012). Crop water productivity, calculation procedure and calibration guidance. AquaCrop version 4.0. *reference manual*.

Raes, D., Steduto, P., Hsiao, T. C., & Fereres, E. (2018). In AquaCrop Version 6.0–6.1. Chapter 3: Calculation procedures. FA0. Rome. Italy, 108.

Ramirez-Rodrigues, M. A., Asseng, S., Fraisse, C., Stefanova, L., & Eisenkolbi, A. (2014). Tailoring wheat management to ENSO phases for increased wheat production in Paraguay. *Climate Risk Management*, 3, 24-38.

Randall, D. A., Wood, R. A., Bony, S., Colman, R., Fichefet, T., Fyfe, J., ... & Taylor, K. E. (2007). Climate models and their evaluation. In Climate change 2007: The physical science basis. *Contribution of Working Group I to the Fourth Assessment Report of the IPCC (FAR)* (pp. 589-662). Cambridge University Press.

Ranjbar, A., Rahimikhoob, A., Ebrahimian, H., & Varavipour, M. (2019). Assessment of the AquaCrop Model for Simulating Maize Response to Different Nitrogen Stresses under Semi-arid Climate. *Communications in Soil Science and Plant Analysis,* 50(22), 2899–2912.

Rashid, M. A., Kabir, W., Khan, L. R., Saleh, A. F. M., & Khair, M. A. (2009). Estimation of water Loss from irrigated rice fields. *SAARC Agri,* 7(1), 29-42.

Raziah, M. L., Engku, E., Tapsir, S., & Mohd, Z. (2010). Food security assessment under climate change scenario in Malaysia. *Palawija News,* 27(1), 1-5.

Redfern, S. K., Azzu, N., & Binamira, J. S. (2012). Rice in Southeast Asia: facing risks and vulnerabilities to respond to climate change. *Build Resilience Adapt Climate Change Agri Sector*, 23(295), 1-14.

Reid, S., Smit, B., Caldwell, W., & Belliveau, S. (2007). Vulnerability and adaptation to climate risks in Ontario agriculture. *Mitigation and Adaptation Strategies for Global Change,* 12(4), 609-637.

Reilly, J., Tubiello, F., McCarl, B., Abler, D., Darwin, R., Fuglie, K., ... & Rosenzweig, C. (2003). US agriculture and climate change: new results. *Climatic change,* 57(1), 43-67.

RICE MARKET MONITOR - APRIL 2018. http://www.fao.org/economic/est/publications/rice-publications/rice-market-monitor-rmm/en/

Richter, G. M., & Semenov, M. A. (2005). Modelling impacts of climate change on wheat yields in England and Wales: assessing drought risks. *Agricultural Systems*, 84(1), 77–97.

Rosegrant, M. W., Cai, X., & Cline, S. A. (2002). World water and food to 2025: dealing with scarcity. *Intl Food Policy Res Inst*.

Rosenzweig, C., & Hillel, D. (1998). Climate change and the global harvest: potential impacts of the greenhouse effect on agriculture. *Oxford University Press*.

Rosenzweig, C., & Tubiello, F. N. (1996). Effects of changes in minimum and maximum temperature on wheat yields in the central US A simulation study. *Agricultural and Forest Meteorology*, 80(2-4), 215-230.

Rowhani, P., Lobell, D. B., Linderman, M., & Ramankutty, N. (2011). Climate variability and crop production in Tanzania. *Agricultural and forest meteorology*, 151(4), 449-460.

Rowshon, M. K., Amin, M. S. M., Hassan, S. M. H., Shariff, A. R. M., & Lee, T. S. (2006). New performance indicators for rice-based irrigation systems. *Paddy and Water Environment*, 4(2), 71-79.

Rowshon, M. K., Amin, M. S. M., Mojid, M. A., & Yaji, M. (2014). Estimated evapotranspiration of rice based on pan evaporation as a surrogate to lysimeter measurement. *Paddy and water environment*, 12(1), 35-41.

Rowshon, M. K., Dlamini, N. S., Mojid, M. A., Adib, M. N. M., Amin, M. S. M., & Lai, S. H. (2019). Modeling climate-smart decision support system (CSDSS) for analyzing water demand of a large-scale rice irrigation scheme. *Agricultural water management*, 216, 138-152.

Rowshon, M. K., Amin, M. S. M., Lee, T. S., & Shariff, A. R. M. (2009). GIS-integrated rice irrigation management information system for a river-fed scheme. Water resources *management*, 23(14), 2841-2866.

Rurinda, J., van Wijk, M. T., Mapfumo, P., Descheemaeker, K., Supit, I., & Giller, K. E. (2015). Climate change and maize yield in southern Africa: what can farm management do?. *Global change biology*, 21(12), 4588–4601.

Sadare, O. O., Masitha, M., Yoro, K. O., & Daramola, M. O. (2018). Removal of sulfur (eg DBT) from Petroleum distillates using activated carbon in a continuous packed-bed adsorption column. *In Proceedings of the World Congress on Engineering and Computer Science* (Vol. 2).

Sammathuria, M. K., & Ling, L. K. (2009). Regional climate observation and simulation of extreme temperature and precipitation trends. *In 14th* *international rainwater catchment systems conference* (pp. 3–6).

Schneekloth, J., & Andales, A. (2017). Seasonal water needs and opportunities for limited irrigation for Colorado crops. *Colorado State University Extension Fact Sheet*, (4.718).

Schoof, J. T., & Pryor, S. C. (2001). Downscaling temperature and precipitation: A comparison of regression- based methods and artificial neural networks. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 21(7), 773-790.

Segal, R., & Le Nguyet, M. (2019). Unfair Harvest: The state of rice in Asia.

Semadeni-Davies, A., Hernebring, C., Svensson, G., & Gustafsson, L. G. (2008). The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. *Journal of Hydrology*, 350(1-2), 100-113.

Semenov, M. A., & Stratonovitch, P. (2010). Use of multi-model ensembles from global climate models for assessment of climate change impacts. *Climate research*, 41(1), 1-14.

Senzanje, A., Chimunhu, T., & Zirebwa, J. (2005). Assessment of water productivity trends for parastatal agricultural operations—case of Middle Sabi Estate, Zimbabwe. *Physics and Chemistry of the Earth*, Parts A/B/C, 30(11–16), 767–771.

Sethi, R. R., Mandal, K. G., Sarangi, A., Behera, A., Aggarwal, R., Brar, A. S., ... & Ambast, S. K. (2016). Simulating paddy crop response to irrigation using FAO AquaCrop model: A case study. *Journal of Food, Agriculture & Environment*, 14(2), 99-103.

Shaaban, A. J., Amin, M. Z. M., Chen, Z. Q., & Ohara, N. (2011). Regional modeling of climate change impact on Peninsular Malaysia water resources. *Journal of Hydrologic Engineering*, 16(12), 1040-1049.

Shahid, S., Pour, S. H., Wang, X., Shourav, S. A., Minhans, A., & bin Ismail, T. (2017). Impacts and adaptation to climate change in Malaysian real estate. *International Journal of Climate Change Strategies and Management*.

Shakoor, U., Saboor, A., Ali, I., & Mohsin, A. Q. (2011). Impact of climate change on agriculture: empirical evidence from arid region. Pak. *J. Agri. Sci*, 48(4), 327–333.

Shao, G., Cui, J., Lu, B., Brian, B. J., Ding, J., & She, D. (2015). Impacts of controlled irrigation and drainage on the yield and physiological attributes of rice. *Agricultural Water Management*, 149, 156–165.

Shimono, H., Okada, M., Inoue, M., Nakamura, H., Kobayashi, K., & Hasegawa, T. (2010). Diurnal and seasonal variations in stomatal conductance of rice at elevated atmospheric CO2 under fully open- air conditions. *Plant, cell & environment*, 33(3), 322-331.

Shrestha, S., & Trang, B. T. T. (2015). Assessment of the climate-change impacts and evaluation of adaptation measures for paddy productivity in Quang Nam province, Vietnam. *Paddy and water environment*, 13(3), 241-253.

Shrestha, S., Thin, N. M. M., & Deb, P. (2014). Assessment of climate change impacts on irrigation water requirement and rice yield for Ngamoeyeik Irrigation Project in Myanmar. *Journal of water and climate change*, 5(3), 427-442.
Shrestha, S., Thin, N. M. M., & Deb, P. (2014). Assessment of climate change impacts on irrigation water requirement and rice yield for Ngamoeyeik Irrigation Project in Myanmar. *Journal of water and climate change*, 5(3), 427-442.
Singh, O. P., & Bhan,V.M.(1988) Chemical weed control in lowland transplanted rice under puddle condition. *Indian J. Weed Sci*. 18: 244–249.

Singh, R. K., Sharma, S. N., Singh, R., & Pandey, M. D. (2002). Efficacy of methods of planting and weed control measures on nutrient removal by rice (Oryza sativa L.) and associated weeds. *CROP RESEARCH-HISAR-*, 24(3), 425-429.

Singh, S., Amartalingam, R., Wan Harun, W. S., & Islam, M. T. (1996, August). Simulated impact of climate change on rice production in Peninsular Malaysia. *In Proceeding of National Conference on Climate Change* (Vol. 4149).

Siwar, C., Alam, M., Murad, M. W., & Al-Amin, A. Q. (2009). A review of the linkages between climate change, agricultural sustainability and poverty in Malaysia. *International Review of Business Research Papers* (ISSN 1832-9543), 5(6), 309-321.

Sridevi, V., Jeyaraman, S., Chinnusamy, C., & Chellamuthu, V. (2013). Weed management in lowland rice (Oryza sativa L.) ecosystem a review. *International Journal of Agricultural Science and Research (IJASR),* 3(3), 13-21.

Srivastav, R. K., & Simonovic, S. P. (2015). Multi-site, multivariate weather generator using maximum entropy bootstrap. *Climate Dynamics*, 44(11-12), 3431-3448.

Srivastava, A. K., Mboh, C. M., Zhao, G., Gaiser, T., & Ewert, F. (2018). Climate change impact under alternate realizations of climate scenarios on maize yield and biomass in Ghana. *Agricultural Systems*, 159, 157–174.

Steduto, P., Hsiao, T. C., & Fereres, E. (2007). On the conservative behavior of biomass water productivity. *Irrigation Science*, 25(3), 189-207.

Steduto, P., Hsiao, T. C., Raes, D., & Fereres, E. (2009a). AquaCrop—The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. *Agronomy Journal*, 101(3), 426–437.

Steduto, P., Hsiao, T.C., Raes, D., Fereres, E., Izzi, G., Heng, L., & Hoogeveen, J. (2011). "Performance Review of AquaCrop - the FAO Crop-water Productivity Model", *ICID 21st International Congress on Irrigation and Drainage, Iran*, 231–248.

Steduto, P., Raes, D., Hsiao, T. C., Fereres, E., Heng, L. K., Howell, T. A., ... & Oweis, T. Y. (2009b). Concepts and applications of AquaCrop: the FAO crop water productivity model. *In Crop modeling and decision support* (pp. 175–191). Springer, Berlin, Heidelberg.

Stöckle, C. O., Donatelli, M., & Nelson, R. (2003). CropSyst, a cropping systems simulation model. *European journal of agronomy*, 18(3–4), 289–307.

Streck, N.A. (2005). Climate change and agroecosystems: The effect of elevated atmospheric CO_2 and temperature on crop growth, development and yield. *Cienc. Rural*, Vol. 35, No. 3.

Stricevic, R., Cosic, M., Djurovic, N., Pejic, B., & Maksimovic, L. (2011). Assessment of the FAO AquaCrop model in the simulation of rainfed and supplementally irrigated maize, sugar beet and sunflower. *Agricultural water management*, 98(10), 1615–1621.

Stričević, R., Dželetović, Z., Djurović, N., & Cosić, M. (2015). Application of the AquaCrop model to simulate the biomass of Miscanthus x giganteus under different nutrient supply conditions. *Gcb Bioenergy*, 7(6), 1203-1210.

Sugimoto, K. (1976). Relationship between evapotranspiration and dry matter production of Indica rice. *Tropical agriculture research series*.

Suhaila, J., & Aziz Jemain, A. (2007). Fitting daily rainfall amount in Malaysia using the normal transform distribution. *Journal of Applied Sciences*, 7(14), 1880-1886.

Suhaila, J., Deni, S. M., Zin, W. W., & Jemain, A. A. (2010). Trends in peninsular Malaysia rainfall data during the southwest monsoon and northeast monsoon seasons: 1975–2004. *Sains Malaysiana*, 39(4), 533-542.

Syafrina, A. H., Zalina, M. D., & Norzaida, A. (2017). Climate projections of future extreme events in Malaysia. *American Journal of Applied Sciences*, 14(3), 392-405.

Szczepanski, M., Sedlar, F., & Shalant, J. (2018). Bangladesh: A country underwater, a culture on the move. *Natural Resources Defense Council*. https://www. nrdc. org/onearth/bangladesh-country-underwater-culture-move.

Tabari, H., Grismer, M., & Trajkovic, S. (2013). "Comparative analysis of 31 reference evapotranspiration methods under humid conditions." *Irrig. Sci.*, 31(2), 107–117.

Tabbal, D. F., Bouman, B. A. M., Bhuiyan, S. I., Sibayan, E. B., & Sattar, M. A. (2002). On-farm strategies for reducing water input in irrigated rice; case studies in the Philippines. *Agricultural Water Management*, 56(2), 93–112.

Tamilselvan, N., & Budhar, M. N. (2001). Weed control in direct seeded puddled rice. *Madras Agricultural Journal*, 88(10/12), 745-746.

Tan, M. L., Ficklin, D. L., Dixon, B., Yusop, Z., & Chaplot, V. (2015). Impacts of DEM resolution, source, and resampling technique on SWAT-simulated streamflow. *Applied Geography*, 63, 357-368.

Tang, K. H. D. (2019). Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations. *Science of the Total Environment*, 650, 1858-1871.

Tangang F.T. & Juneng, L. (2011). Climate projection downscaling for Peninsular Malaysia and Sabah-Sarawak using Hadley Centre PRECIS model. *Technical consultation report for National Hydraulic Research Institute of Malaysia* (NAHRIM).

Tangang, F. T., Juneng, L., Salimun, E., Sei, K., & Halimatun, M. (2012). Climate change and variability over Malaysia: gaps in science and research information. *Sains Malaysiana*, 41(11), 1355-1366.

Tao, F., & Zhang, Z. (2011). Impacts of climate change as a function of global mean temperature: maize productivity and water use in China. *Climatic Change*, 105(3), 409-432.

Tausz-Posch, S., Seneweera, S., Norton, R. M., Fitzgerald, G. J., & Tausz, M. (2012). Can a wheat cultivar with high transpiration efficiency maintain its yield advantage over a near-isogenic cultivar under elevated CO2?. *Field Crops Research*, 133, 160-166.

Teng, P. P., Caballero-Anthony, M., & Lassa, J. A. (2016). The future of rice security under climate change. *Non-Traditional Security Report* (4).

Thapa, C. B., & Jha, P. K. (2001). Paddy crop-weed competition in Pokhara, Nepal. *Geobios*, 29(1), 47-51.

Thorp, K. R., Batchelor, W. D., & Paz, J. O. (2005). A cross validation approach to evaluate CERES-Maize simulations of corn yield spatial variability. In 2005 ASAE Annual Meeting (p. 1). *American Society of Agricultural and Biological Engineers*.

Todorovic, M., Albrizio, R., Zivotic, L., Saab, M. T. A., Stöckle, C., & Steduto, P. (2009). Assessment of AquaCrop, CropSyst, and WOFOST models in the simulation of sunflower growth under different water regimes. *Agronomy Journal*, 101(3), 509–521.

Tomar, V. S., & O'Toole, J. C. (1980). Water use in lowland rice cultivation in Asia: a review of evapotranspiration. *Agricultural Water Management*, 3(2), 83-106.

Toriman, M. E., Pereira, J. J., Gasim, M. B., Sharifah Mastura, S. A., & Aziz, N. A. A. (2009). Issues of climate change and water resources in Peninsular

Malaysia: The case of north Kedah. *The Arab World Geographer*, 12(1–2), 87–94.

Tovihoudji, P. G., Akponikpè, P. B., Agbossou, E. K., & Bielders, C. L. (2019). Using the DSSAT model to support decision making regarding fertilizer microdosing for maize production in the sub-humid region of Benin. *Frontiers in Environmental Science*, 7, 13.

Tukimat, N. N. A., Harun, S., & Shahid, S. (2017). Modeling irrigation water demand in a tropical paddy cultivated area in the context of climate change. *Journal of Water Resources Planning and Managemen*t, 143(7), 05017003.

Tuong, T. P., & Bouman, B. A. M. (2003). Rice production in water-scarce environments. Water productivity in agriculture: *Limits and opportunities for improvement*, 1, 13-42.

Tuong, T. P., BAM, B., & Mortimer, M. (2005). More rice, less water. *Plant Production Science*, 8(3), 231–241.

Turner, A. J., Frankenberg, C., & Kort, E. A. (2019). Interpreting contemporary trends in atmospheric methane. *Proceedings of the National Academy of Sciences*, 116(8), 2805-2813.

Tyagi, AC (2012). The new challenges to food security under climate change. *Irrig. and Drain*. 61: 283–284.

Uchida, Y., & von Rein, I. (2018). Mitigation of nitrous oxide emissions during nitrification and denitrification processes in agricultural soils using enhanced efficiency fertilizers. *In Soil Contamination and Alternatives for Sustainable Development*. IntechOpen.

Umair, M., Shen, Y., Qi, Y., Zhang, Y., Ahmad, A., Pei, H., & Liu, M. (2017). Evaluation of the CropSyst model during wheat-maize rotations on the North China Plain for identifying soil evaporation losses. *Frontiers in Plant Science*, 8, 1667.

Vaghefi, N., Shamsudin, M. N., Makmom, A., & Bagheri, M. (2011). The economic impacts of climate change on the rice production in Malaysia. *International Journal of Agricultural Research*, 6(1), 67-74.

Vaghefi, N., Shamsudin, M. N., Radam, A., & Rahim, K. A. (2016). Impact of climate change on food security in Malaysia: economic and policy adjustments for rice industry. *Journal of Integrative Environmental Sciences*, 13(1), 19-35.

Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). Edible insects: future prospects for food and feed security (No. 171). *Food and Agriculture Organization of the United Nations*.

Van Oort, P. A., & Zwart, S. J. (2018). Impacts of climate change on rice production in Africa and causes of simulated yield changes. *Global change biology*, 24(3), 1029-1045.

Van Vuuren, D. P., Ochola, W. O., Riha, S., Giampietro, M., Ginzo, H., Henrichs, T., ... & Kuppannan, P. (2009). Outlook on agricultural change and its drivers.

Vanuytrecht, E., Raes, D., & Willems, P. (2011). Considering sink strength to model crop production under elevated atmospheric CO_2. *Agricultural and Forest Meteorology*, 151(12), 1753–1762.

Vanuytrecht, E., Raes, D., & Willems, P. (2016). Regional and global climate projections increase mid-century yield variability and crop productivity in Belgium. *Regional Environmental Change*, 16(3), 659-672.

Vazifedoust, M., Van Dam, J. C., Feddes, R. A., & Feizi, M. (2008). Increasing water productivity of irrigated crops under limited water supply at field scale. *Agricultural water management*, 95(2), 89–102.

Vinke, K., Schellnhuber, H. J., Coumou, D., Geiger, T., Glanemann, N., Huber, V., ... & Rodgers, C. (2017). A region at risk: the human dimensions of climate change in Asia and the Pacific.

Vorosmarty, C. J., Gutowski, W. J., Person, M., Chen, T. C., & Case, D. (1993). Linked atmosphere-hydrology models at the macroscale. *IAHS-AISH publication*, (214), 3-27.

Wall, G. W., Garcia, R. L., Wechsung, F., & Kimball, B. A. (2011). Elevated atmospheric CO2 and drought effects on leaf gas exchange properties of barley. *Agriculture, ecosystems & environment*, 144(1), 390-404.

Wang, G. Y., Han, Y. Y., Zhou, X. B., Chen, Y. H., & Ouyang, Z. (2014). Planting Pattern and Irrigation Effects on Water- Use Efficiency of Winter Wheat. *Crop Science*, 54(3), 1166-1174.

Wardhana, R. B. J., Winarno, J., & Sutopo, N. R. (2018, November). The impacts of paddy field conversion and climate change on rice production in Tegal Regency, Indonesia. In IOP Conference Series: *Earth and Environmental Science* (Vol. 200, No. 1, p. 012013). IOP Publishing.

Watson, R. T., Meira Filho, L. G., Sanhueza, E., & Janetos, A. (1992). Greenhouse gases: sources and sinks. *Climate change*, 92, 25-46.

Wayne, G. P. (2014). Representative Concentration Pathways. Skeptical science, 24.

WB (2010). *World Development Report*: Climate Change. Retrieved: (http://cdiac.esd.oml.gov/trends/temp/jonescru/jones.html).

Weaver, S. E. (1984). Critical period of weed competition in three vegetable crops in relation to management practices. *Weed Research*, 24(5), 317-325.

Welch, J. R., Vincent, J. R., Auffhammer, M., Moya, P. F., Dobermann, A., & Dawe, D. (2010). Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. *Proceedings of the National Academy of Sciences*, 107(33), 14562–14567.

Wetterhall, F., Halldin, S., & Xu, C. Y. (2005). Statistical precipitation downscaling in central Sweden with the analogue method. *Journal of Hydrology*, 306(1-4), 174-190.

Wickham, T. H. (1978). Water management for lowland rice: water requirements and yield response. *Soils and rice*., 649–669.

Wilby, R. L., & Harris, I. (2006). A framework for assessing uncertainties in climate change impacts: Low- flow scenarios for the River Thames, UK. *Water resources research*, 42(2).

Wilby, R. L., & Wigley, T. M. (1997). Downscaling general circulation model output: a review of methods and limitations. *Progress in physical geography*, 21(4), 530-548.

Wilby, R. L., Charles, S. P., Zorita, E., Timbal, B., Whetton, P., & Mearns, L. O. (2004). Guidelines for use of climate scenarios developed from statistical downscaling methods. Supporting material of the Intergovernmental Panel on Climate Change, available from the DDC of IPCC TGCIA, 27.

Wilby, R. L., Dawson, C. W., & Barrow, E. M. (2002). SDSM—a decision support tool for the assessment of regional climate change impacts. *Environmental Modelling & Software*, 17(2), 145-157.

Wilby, R. L., Orr, H., Watts, G., Battarbee, R. W., Berry, P. M., Chadd, R., ... & Hannah, D. M. (2010). Evidence needed to manage freshwater ecosystems in a changing climate: turning adaptation principles into practice. *Science of the total environment*, 408(19), 4150–4164.

Willmott, C.J. (1984) On the Evaluation of Model Performance in Physical Geography. *In: Spatial Statistics and Models,* Springer, Berlin, 443–460.

Wokker, C., Santos, P., & Bansok, R. (2014). Irrigation water productivity in Cambodian rice systems. *Agricultural Economics*, 45(4), 421–430.

Wolfe DW (2010) Potential impact of climate change on agriculture and food supply, http://www.gcrio.org/USGCRP/sustain/wolfe.html (2013.02.25).

Wong, C. L., Venneker, R., Jamil, A. B. M., & Uhlenbrook, S. (2011). Development of a gridded daily hydrometeorological data set for Peninsular Malaysia. *Hydrological Processes*, 25(7), 1009-1020.

Wood, A. W., Leung, L. R., Sridhar, V., & Lettenmaier, D. P. (2004). Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. *Climatic change,* 62(1), 189-216.

Woodward, F. I., & Bazzaz, F. A. (1988). The responses of stomatal density to CO2 partial pressure. *Journal of Experimental Botany*, 39(12), 1771-1781.

Wopereis, M. C. S., Bouman, B. A. M., Kropff, M. T., Ten Berge, H. F. M., & Maligaya, A. R. (1994). Water use efficiency of flooded rice fields I. Validation of the soil-water balance model SAWAH. *Agricultural Water Management*, 26(4), 277–289.

Xiong, W., Holman, I., Conway, D., Lin, E., & Li, Y. (2008). A crop model cross calibration for use in regional climate impacts studies. *Ecological Modelling*, 213(3-4), 365-380.

Xu, C. Y. (1999). From GCMs to river flow: a review of downscaling methods and hydrologic modelling approaches. *Progress in physical Geography*, 23(2), 229-249.

Xu, H., Twine, T. E., & Girvetz, E. (2016). Climate change and maize yield in Iowa. *PloS one*, 11(5), e0156083.

Xystrakis, F., & Matzarakis, A. (2011). Evaluation of 13 empirical reference potential evapotranspiration equations on the island of Crete in southern Greece. *Journal of Irrigation and Drainage Engineering*, 137(4), 211-222.

Yadav, S. B., Misra, A. K., Mishra, S. K., & Pandey, V. (2018). Crop growth simulation models (InfoCrop v. 2.1, DSSATv4. 5, WOFOSTv1. 5 and Cropsytv 4.19) software. *Water and Energy Security in the Arena of Climate Change*, 34, 456–469.

Yang, S. S., Liu, C. M., & Liu, Y. L. (2003). Estimation of methane and nitrous oxide emission from animal production sector in Taiwan during 1990–2000. *Chemosphere*, 52(9), 1381-1388.

Yashima, S. (1984). Studies on rice double cropping in the Muda area-development of field infrastructure, Tokyo, Japan.

Yinhong K. Y., Khan, S., & Ma, X. (2009). Climate change impacts on crop yield, crop water productivity and food security–A review. *Progress in natural Science*, 19(12), 1665-1674.

Yoo, S. H., Choi, J. Y., Nam, W. H., & Hong, E. (2012). Analysis of design water requirement of paddy rice using frequency analysis affected by climate change in South Korea. *Agricultural Water Management*, 112, 33-42.

Yoro, K. O., Isafiade, A. J., & Daramola, M. O. (2018). Sequential synthesis of mass exchanger networks for CO2 capture. *In Proceedings of The World Congress on Engineering and Computer Science* (pp. 503-508).

Yoshimoto, M., Oue, H., & Kobayashi, K. (2005). Energy balance and water use efficiency of rice canopies under free-air CO2 enrichment. *Agricultural and Forest Meteorology*, 133(1-4), 226-246.

Yuan, M., Zhang, L., Gou, F., Su, Z., Spiertz, J. H. J., & Van Der Werf, W. (2013). Assessment of crop growth and water productivity for five C3 species in semi-arid Inner Mongolia. *Agricultural Water Management*, 122, 28-38.

Zabawi, M. A. G. (2012). Impact of climate change on rice and adaptation strategies. *Report submitted to the Economic and Planning Unit (EPU), Prime Minister Department, Putrajaya, Malaysia.*

Zavala, J. A., Casteel, C. L., DeLucia, E. H., & Berenbaum, M. R. (2008). Anthropogenic increase in carbon dioxide compromises plant defense against invasive insects. *Proceedings of the national academy of sciences*, 105(13), 5129-5133.

Zawawi, M. A. M., Mustapha, S., & Puasa, Z. (2010). Determination of water requirement in a paddy field at Seberang Perak rice cultivation area. *JI Eng*, 71(4), 32–41.

Zeleke, K., & Nendel, C. (2020). Testing and Application of the AquaCrop Model for Wheat Production Under Different Field Management Conditions in South-Eastern Australia. *Agricultural Research*, 9(3), 379-391.

Zeng, Q., Liu, B., Gilna, B., Zhang, Y., Zhu, C., Ma, H., ... & Zhu, J. (2011). Elevated CO 2 effects on nutrient competition between a C 3 crop (Oryza sativa L.) and a C 4 weed (Echinochloa crusgalli L.). *Nutrient Cycling in Agroecosystems*, 89(1), 93-104.

Zhai, B., Fu, Q., Li, T., Liu, D., Ji, Y., Li, M., & Cui, S. (2019). Rice irrigation schedule optimization based on the AquaCrop model: study of the Longtouqiao irrigation district. *Water,* 11(9), 1799.

Zhang, J., & Han, X. (2008). N2O emission from the semi-arid ecosystem under mineral fertilizer (urea and superphosphate) and increased precipitation in northern China. *Atmospheric Environment*, 42(2), 291-302.

Zhang, Z. P. (1996). Weed management in transplanted rice. In: B. Auld and K.U. Kim (eds.) Weed management in rice. *FAO Plant Production and Protection Paper No.* 139: pp. 75–86.

Zhao, H. Y., Yao, F. M., Zhang, Y., Bin, X. U., Jing, Y. U. A. N., Hu, Y. N., & Xu, Y. L. (2007). Correlation analysis of rice seed setting rate and weight of 1000-grain and agro-meteorology over the middle and lower reaches of the Yangtze River, China. *Agricultural Sciences in China*, 6(4), 430–436.

Zhao, J., Han, T., Wang, C., Jia, H., Worqlul, A. W., Norelli, N., ... & Chu, Q. (2020). Optimizing irrigation strategies to synchronously improve the yield and water productivity of winter wheat under interannual precipitation variability in the North China Plain. *Agricultural Water Management*, 240, 106298.

Zin, W. Z. W., Jamaludin, S., Deni, S. M., & Jemain, A. A. (2010). Recent changes in extreme rainfall events in Peninsular Malaysia: 1971–2005. *Theoretical and applied climatology*, 99(3), 303-314.

Zorita, E., & Von Storch, H. (1999). The analog method as a simple statistical downscaling technique: Comparison with more complicated methods. *Journal of climate*, 12(8), 2474-2489.

Zwart, S. J., & Bastiaanssen, W. G. (2004). Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agricultural water management*, 69(2), 115–13.

BIODATA OF STUDENT

Houma Abdusslam Ahmad Ali is a Libyan national, born in Timissah Village, south of Libya situated in the North of Africa. Abdusslam is a PhD candidate in Water Resources Engineering at Universiti Putra Malaysia (UPM). He received his Bachelor’s Degree from University of Sebha, Sebha city, Libya in Geology. He further obtained his Master’s Degree in agriculture engineering from University of Prague, Czech Republic. He is a staff in the Department of Soil and Water, Agriculture Faculty, Sebha University. He has both teaching and research experience. His experiences and skills gathered from the teaching, consultancy works and field-oriented research activities have upgraded the working capability and the level of confidence in handling a particular assignment in the area of expertise.

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.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : Second Semester 2020/2021

TITLE OF THESIS / PROJECT REPORT :

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

NAME OF STUDENT: HOUMA ABDUSSLAM AHMAD ALI

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

[ ]	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
[ ]	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
[√]	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

[ ]	**PATENT**	Embargo from __________ (date) until __________ (date)

Approved by:

____
(Signature of Student)
New IC No/ Passport No.:

Date :

____
(Signature of Chairman of Supervisory Committee)
Name:

Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]