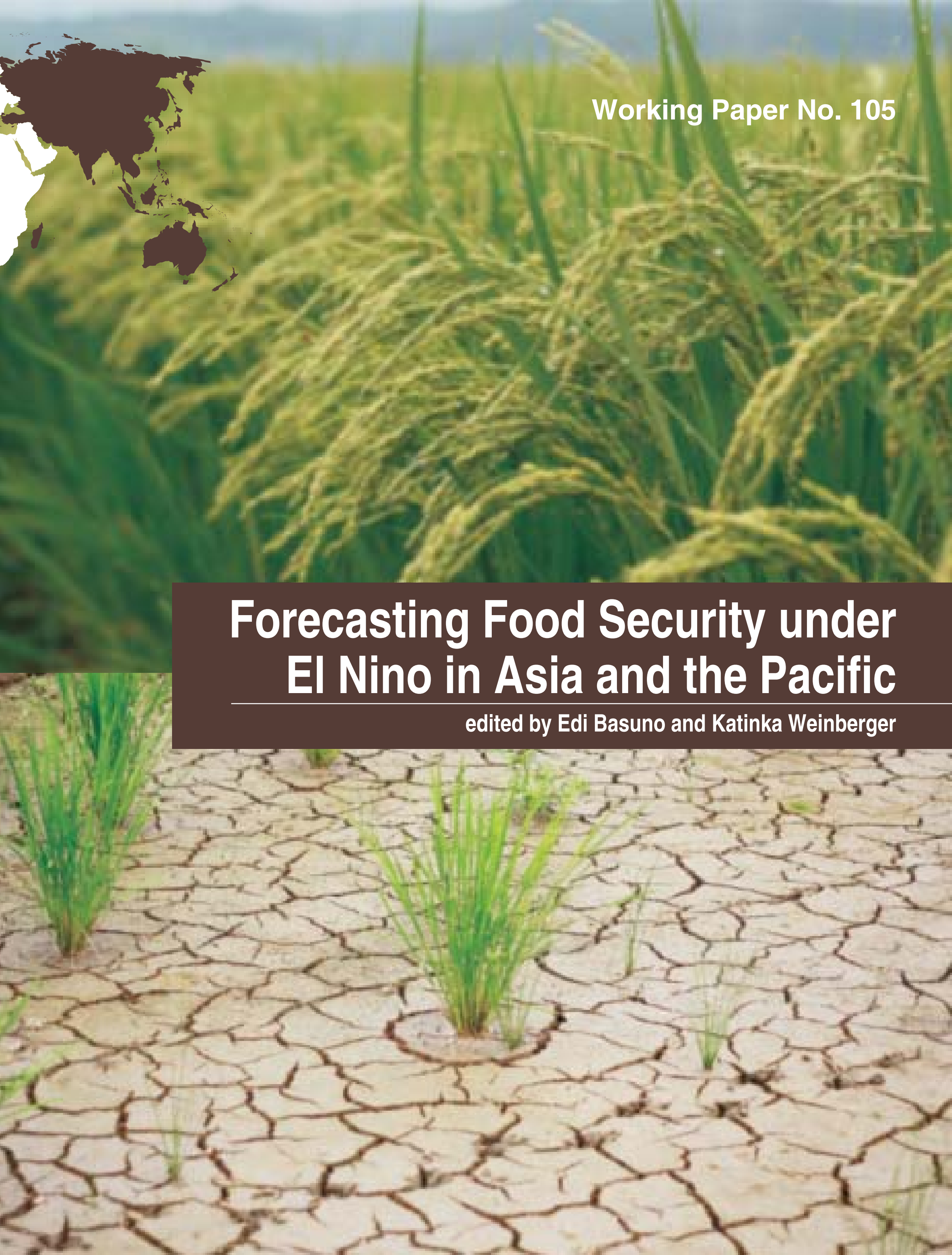


Working Paper No. 105

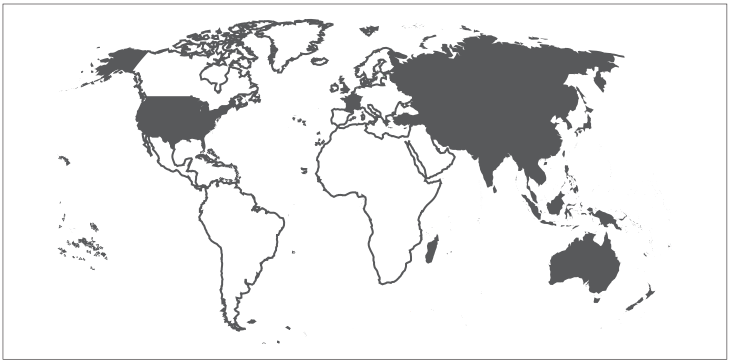
Forecasting Food Security under El Nino in Asia and the Pacific

edited by Edi Basuno and Katinka Weinberger

CAPSA
Centre for Alleviation of Poverty through Sustainable Agriculture

UNITED NATIONS ESCAP
Economic and Social Commission for Asia and the Pacific

ESCAP is the regional development arm of the United Nations and serves as the main economic and social development centre for the United Nations in Asia and the Pacific. Its mandate is to faster co-operation between its 53 members and nine associate members. ESCAP provides the strategic link between global and country-level programmes and issues. It supports Governments of the region in consolidating regional positions and advocates regional approaches to meeting the region's unique socio-economic challenges in a globalizing world. The ESCAP office is located in Bangkok, Thailand. Please visit our website at <www.unescap.org> for further information.



The shaded areas of the map indicate ESCAP members and associate members.

CAPSA-ESCAP

The Centre for Alleviation of Poverty through Secondary Crops' Development in Asia and the Pacific (CAPSA) is a subsidiary body of UNESCAP. It was established as the Regional Co-ordination Centre for Research and Development of Coarse Grains, Pulses, Roots and Tuber Crops in the Humid Tropics of Asia and the Pacific (CGPRT Centre) in 1981 and was renamed CAPSA in 2004.

Objectives

CAPSA promotes a more supportive policy environment in member countries to enhance the living conditions of rural poor populations in disadvantaged areas, particularly those who rely on secondary crop agriculture for their livelihood, and to promote research and development related to agriculture to alleviate poverty in the Asian and Pacific region.

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List of Abbreviations

CAPSA	Centre for Alleviation of Poverty through Sustainable Agriculture
CEC	Cation Exchangeable Capacity
CERES	Crop Environment Resource Synthesis
DOA	Department of Agriculture
DSSAT	Decision Support System for Agrotechnology Transfer
DVS	Department of Veterinary Services
FAO	Food and Agricultural Organization of the United Nations
FRIM	Forest Research Institute Malaysia
GDP	Gross Domestic Product
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse Gas
GIS	Geographical Information Systems
GISS	Goddard Institute for Space Studies
GSO	General Statistics Office
GTAP	Global Trade Analysis Project
HI	Harvest Index
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
IUCN	International Union for Conservation of Nature
JPS	Department of Irrigation and Drainage
KADA	Kemubu Agriculture Development Authority
KPPK	Ministry of Plantation Industries and Commodities Malaysia
MADA	Muda Agriculture Development Authority
MARDI	Malaysian Agriculture Research and Development Institute
MMD	Malaysian Meteorological Department
MOA	Ministry of Agriculture
MONRE	Ministry of Natural Resource and Environment
MPOB	Malaysia Palm Oil Board
NAHRIM	National Hydraulic Research Institute of Malaysia
NuDSS	Nutrient Decision Support System
OLS	Ordinary Least Square

PBLS	Projek Barat Laut Selangor
RH	Relative Humidity
RUE	Radiation Use Efficiency
SFRI	Soil and Fertilizer Research Institute
SRAD	Solar Radiation
SSL	Self-sufficiency Level
SSNM	Site-specific Nutrient Management
UKMO	United Kingdom Meteorological Office

Foreword

The mandate of the Centre for Alleviation of Poverty through Sustainable Agriculture (CAPSA) is to contribute to South-South dialogue and to facilitate intra-regional learning. Since its establishment, CAPSA has published a series of working papers that address issues of regional concern. A key challenge facing the entire Asia Pacific region is how to develop strategies for adaptation to climate change that are easy to integrate into development plans for the agriculture sector. This is true especially for those countries in the region that depend on a limited number of crops to meet the food security needs of their population.

This working paper addresses climate change in the context of rice productivity. It contributes to the literature by forecasting the impact of climate change on rice production in Malaysia, Viet Nam and Indonesia, based on advanced crop modeling and economic regression models. The authors also explore policies responses for adaptation and mitigation strategies to minimize the negative impacts of climate change on food production in the region.

All three studies show that climate change is affecting South-East Asia's weather patterns and crop productivity.The results also show that impact is highly location specific and requires location specific responses. Governments across the region need to prepare themselves. The results highlight the urgent need to think further and in collaboration with research and advocacy partners across the region, on how the use of traditional crops, improved agronomic practices, crop breeding and new technologies can enhance the resilience of agricultural systems to climate change.

I take this opportunity to express my gratitude to the authors of the country chapters, as well as to the Soil and Fertilizer Research Institute (SFRI) for hosting a workshop that brought all the authors together. Taco Bottema, LeRoy Hollenbeck, Amitava Mukherjee, Tomohide Sugino, Yap Kioe Sheng, Agbessi Amewoa, Edgar Dante, Therese Bjork and Edith Johnson have provided support and guidance to the project at various stages. Last but not least, we acknowledge the gracious financial support of the Government of Japan that made this study possible.

February 2011

Katinka Weinberger
Director, CAPSA-ESCAP

Executive Summary

Climate change is one of the greatest challenges facing humanity and it is expected to impact agriculture in many ways. Some of these impacts may be positive, others negative. We recently completed a study in three countries in Asia, namely Malaysia, Viet Nam and Indonesia, on the effects of El Nino-Southern Oscillation on rice production. El Nino is a weather phenomenon characterized by unusually warm water in the Pacific Ocean. El Nino affects ocean temperatures and rainfall patterns in South-East Asia, with consequent effects on agriculture and fishing, including rice crop yields. The research activity, conducted from 2009 to 2010, had two general objectives: to assess the effects of this weather phenomenon on rice production in the three countries using advanced crop modeling and economic regressions models, and to identify policy responses for adaptation and mitigation strategies.

In Malaysia, a process-based decision support system for agrotechnology transfer (DSSAT) model and economic regression model were used to assess climate change impacts on rice production. In Indonesia, baseline climate data as well as climate scenarios based on models of the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL), and the United Kingdom Meteorological Office (UKMO) were used to inform the DSSAT rice growth model. In Viet Nam, weather data from 2005-2009, combined with crop phenotype characteristics, were used for running the Nutrient Decision Support System (NuDSS); its results were then used to inform the DSSAT to simulate scenarios for rice production affected by climate change from 2020 to 2100. Although all three studies used the same tools, differences in data types and variables used in the DSSAT to ensure reliable forecasting prevent cross-country comparison.

Research sites in each country were selected based on their rice yield contributions. In Malaysia, two major rice growing areas in Peninsular Malaysia were selected: Muda Agriculture Development Authority (MADA) in the north-western part of Kedah State and the southern part of Perlis State, and Kemubu Agriculture Development Authority (KADA) in the southern part of Kelantan State and the northern part of Terengganu State. The two areas contribute 60 per cent and 8 per cent, respectively, to Malaysia's total rice production. In MADA, the model specifications resulted in the following estimates. For every 1 per cent increase in temperature, rice yields would increase by an average of 2.3 per cent. In addition, labour variables significantly and positively influenced rice productivity, whereas the variables of input and depreciation did not significantly effect productivity. In contrast, KADA was found to be more vulnerable to climate change. There the model demonstrated a decrease in rice productivity by 2.4 per cent for every 1 per cent increase in temperature, while a 1 per cent increase in relative humidity would decrease rice productivity by 2.9 per cent.

In Indonesia two main rice production areas in Java were selected: Pusakanegara in West Java and Mojosari in East Java. Pusakanegara is a lowland area on the northern coast of West Java. Mojosari is inland on the flood plain of the Brantas river. To simulate future weather in these areas, daily climate data consisting of rainfall, minimum and maximum temperatures, and solar radiation from 1973 to 1992 were used as a baseline. The concentration of CO_2 has doubled against this baseline and annual rainfall has increased significantly in both Pusakanegara and Mojosari. The maximum and minimum temperatures have also increased significantly in both study sites. The model results of simulated rice yields affected by climate change in Pusakanegara and Mojosari showed that rice yields have significantly decreased during El Nino years.

In Viet Nam, the Red River Delta, the second most important rice growing area in the country, was selected as the control site, and Vinh Yen in Vinh Phuc province was selected as the experimental site. The Red River Delta is a lowland area that is expected to be significantly affected by climate change. The common farming systems in this site are rice-rice, rice–rice-vegetables and rice-rice-maize. The model results showed that rice productivity during the spring season could decrease from 5,078 kg/ha in 2020 to 4,368 kg/ha by 2100. During summer, rice productivity could increase from 4,545 kg/ha in 2020 to 4,618 kg/ha by 2100. Compared with yields in 2006, yields would decrease by 1-15 per cent for spring rice and increase by 1-2 per cent for summer rice for the period of 2020-2100. Dividing the forecast period into two, reduction of rice production was estimated at 3-5 per cent for 2020-2059 and at 6-15 per cent for 2060-2100. Climate change will thus be a significant factor in food production and food security in Viet Nam.

The three countries of Malaysia, Indonesia and Viet Nam will need to be proactive in their efforts to deal with expected climate change impacts on rice production by applying three strategies: anticipation, adaptation and mitigation. For instance, definitive planning of infrastructure development planning, water distribution and management systems; improvement of human resource capability to understand climate change; the development of information and early warning systems; plant breeding to produce drought and salt resistant varieties; and biofuel development to produce renewable and sustainable environment are all required. Plant breeding and biotechnology could also play an important role in producing food as climate change impacts continue, mainly by increasing water use efficiency for crops. In order to mitigate, both government agencies and farmers can play their roles by improving: general crop management; farm and livestock management including grazing land; carbon sequestration; water pricing and water management; and more use of biofuel.

The research findings identify necessary steps and preparations to manage future climate change impacts. Only countries that are highly committed to countering the adverse effects of climate change will succeed in overcoming expected challenges to agriculture. Research on how to address future effects of climate change, including best agricultural policies and practices that increase food production while reducing agricultural contributions to greenhouse gas emissions, must remain a priority.

Introduction

Over the past 150 years, the global average surface temperature has increased by 0.76°C (IPCC, 2007). This global warming has caused greater climatic volatility, including changed precipitation patterns; increased frequency and intensity of extreme weather events including typhoons, heavy rainfall, flooding and drought; and a rise in mean global sea levels. It is widely believed that climate change is largely a result of greenhouse gas (GHG) emissions caused by human activity. These emissions are likely to intensify if no action is taken, with serious consequences for the world's growth and development. Higher temperatures could cause reduced crop yields and areas prone to drought could become marginal or unsuitable for the cultivation of some crops.

Climatic changes associated with El Nino and La Nina episodes exert significant influences on agricultural production and food security.

El Nino was originally recognized by fishermen off the coast of South America as the appearance of unusually warm water in the Pacific Ocean occurring near the beginning of the year. La Nina is characterized by unusually cold ocean temperatures in the Equatorial Pacific

The 2007 assessment by the Intergovernmental Panel on Climate Change (IPCC) projected that the global average surface temperature would increase by between 1.4 and 5.8°C from 1990 to 2100, while sea levels could rise by between 9 and 88 cm. Temperatures have already increased by 0.6°C during the twentieth century, and most of this warming is attributable to human activities (IPCC, 2007).

It is widely believed that the rise in temperatures will influence crop production in a number of ways, including shifting optimal crop growing zones, shifting habitats of crop pests and diseases; and changing crop yields through the effects of carbon dioxide and changing precipitation patterns. Increasing temperatures will shorten the generative stage and, along with increasing pest and disease, eventually reduce crop yield. Changing rainfall patterns will alter the cropping calendar and delaying cropping time. The increasing frequency and intensity of extreme climate events, augmenting the risks of flood and drought, will further reduce crop production. Rising sea levels will inundate productive agricultural land and increase soil salinity, which potentially reduces crop productivity. Meanwhile, increased CO_2 in the atmosphere will promote photosynthesis, hence speeding growth, and higher temperatures will increase respiration, resulting in decreasing yield.

Climate change certainly causes higher temperatures and probably shifting rainfall and more solar radiation.

In this study we focus on three different responses to climate change: anticipation, adaptation and mitigation strategies.

Like poverty reduction, reducing vulnerability to climate change through adaptation measures is seen as a prerequisite to achieve sustainable development in the 21st century. There is general agreement that well managed ecosystems support the adaptation of societies to climate change because such systems resist and recover more easily from extreme weather events and provide many benefits on which people depend (IUCN, 2009). Although all households are exposed to risks associated with climate change and are thus potentially vulnerable, poor households are the most at risk because their assets and livelihoods tend to be highly exposed and sensitive to direct and indirect risks associated with climate change and because they lack adaptive capacity (Vernon, 2008; Heltberg *et al.*, 2008). For example, institutional constraints such as lack of property rights or civil protection may prevent poor people from investing their scarce resources in managing climate risk: they could prefer to not make their land climate resilient because they fear that they may be evicted. People have always adapted to a changing climate, and coping strategies exist in many communities, such as changing sowing times or adopting new water-saving techniques. Traditional knowledge and coping strategies must be maintained and strengthened; otherwise, adaptive capacity may be weakened as local knowledge of the environment is lost. In some cases, however, this will not be enough to adapt to new conditions which are outside the range of those previously experienced. New techniques will be needed.

Policy response to climate change to reduce greenhouse gas emissions or enhance the removal of these gases from the atmosphere (i.e., enhancing carbon sinks) is called mitigation of climate change (Verbruggen, 2007). Even the most stringent efforts to reduce emissions would still not prevent further climate change impacts, making adaptation unavoidable (Klein *et al.*, 2007). But without mitigation, climate change would likely reach such a magnitude as to make adaptation impossible for some natural systems, including ecosystems. For human systems, the economic and social costs of unmitigated climate change would be very high.

This working paper investigates this issue by analysing food production patterns under different climate scenarios, especially those related to El Nino. This pilot study also evaluates the impact of climate changes on food production and availability in three countries of Asia, namely Indonesia, Malaysia and Viet Nam. Policy recommendations are formulated and include suggestions for anticipation, adaptation and mitigation strategies for each country.

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Part I
Effects of El Nino on Rice Production in Malaysia

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1. Introduction

The United Nations Framework Convention on Climate Change defines climate change as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods. The effects of climate change are potentially devastating to lives and livelihoods, sustainable agriculture production, fresh water supplies and the survival of native species and ecosystem. Environmental threats such as rising sea levels and inadequate water resources can potentially lead to food shortages.

Although food consumption in Malaysia has shifted away from starchy staples toward wheat-based and livestock products, rice is still the staple food for Malaysians. Per capita consumption of rice constituted about 11 per cent of the total per capita food consumption by weight in the country. Total rice production in 2008 was about 1.5 million tons. With the per capita rice consumption at 82 kilograms, total rice consumption in Malaysia was estimated at 2.3 million tons yearly. Malaysia is thus a net importer of rice.

The current self-sufficiency level (SSL) is about 72 per cent. Malaysia imported rice from Thailand (fragrant rice, 54 per cent), Viet Nam and Myanmar (white rice, 34 per cent) and Pakistan (high quality rice) to supplement domestic production. The import volume was about 752,000 tons (Buku Perangkaan Pertanian, 2008) valued at about USD 413 million (USD 550/ton). Due to the food crisis and for food security reasons, the SSL for rice in Malaysia has been revised to achieve 90 per cent by 2010 (Malaysia, 2008).

Strategies to achieve an SSL of 90 per cent are being debated by the stakeholders concerned: Should Malaysia increase productivity or open new areas for rice cultivation? Suitable land areas for rice cultivations are limited and in competition with other land uses. Hence improving rice productivity by increasing farm efficiency and mitigating climate change effects would be a more feasible option. The national average rice yield was 3.56 tons per ha of paddy. If the national average could be increased to 4.48 tons per ha (an increase of 1 ton/ha), the targeted 90 per cent could be achieved in the Ninth Plan's 10-year period of 2011-2015.

This paper is organized into seven sections. Section 2 presents a literature review of climate change impacts on agriculture production, Section 3 describes the study objectives and scope, Section 4 discusses research methodology, Section 5 describes results of climate change impact modeling and Section 6 presents conclusions and recommendations.

2. Literature Review

A study by Lobell *et al.* (2008) indicates that, given expected climatic changes, southern Africa could lose more than 30 per cent of its main crop, maize, by 2030. In Asia, especially south Asia and South-East Asia, reductions in many regional staple food yields, such as rice, millet and maize, could reach up to 10 per cent. Peng *et al*. (2004) analysed weather data at the International Rice Research Institute (IRRI) Farm from 1979 to 2003 to examine the relatonship between rice yield and temperature by using data from irrigated field experiments. Grain yields decreased by 10 per cent overall for every 1°C increase in the minimum temperature in the dry season. In Thailand it was reported that higher temperatures have led to a reduction in crop yield, particularly in non-irrigated rice. This was attributed to the effect of drought at critical stages of growth, such as the flowering period. It was also shown that drought negatively affected corn productivity by 5 to 44 per cent, depending on where the corn was cultivated (ONEP, 2008).

Mendelsohn *et al.* (1994) developed a new technique known as the "Ricardian' approach that can correct the bias estimates of production function by using the value of land*.* This approach helps determine how climate in different places affects the net rent or value of farmland, instead of studying yields of specific crops. The study showed that climate had a systematic impact on agricultural rents through temperature and precipitation. This effect tends to be highly non-linear and can vary dramatically from season to season. The squared terms for most of the climate variables were significant, implying that the observed relationships were non-linear. However some of the squared terms were positive especially for precipitation, implying that there was a minimally productive level of precipitation and that either more or less precipitation would increase land values. The negative quadratic coefficient implies that there was an optimal level of climatic variable on which the value function decreased in both directions. According to the survey by the IPCC (Houghton, 1992), a 2.24°C temperature increase will be accompanied by an 8 per cent average increase in precipitation. These changes are applied uniformly by season and region to the United States. In conclusion the negative impact is assessed as a 4 and 6 per cent decrease in the value of farm input.

Galeotti *et al.* (2004) used the climate predictors for agriculture products to investigate the production of potatoes, wheat and poultry. The model was estimated by using Ordinary Least Square (OLS) estimators. In summer precipitation, the results showed a significant climate predictor of potato yields. The direction of the effect was estimated to be positive for regional summer rainfall with a 1-year lag, indicating that higher summer precipitation in the previous year tends to increase potato yields. When extreme season dummies were introduced, the estimated coefficient showed that the extremely dry summer of 1985 had a statistically significant, strong and negative impact on potato yields. By repeating the same estimation procedure, the summer dryness index was used as a climate predictor of potato yields. The result showed that the index had a strong and statistically significant negative effect on regional potato yields. The direction of the impact of the 1-year-lagged summer dryness index was instead positive, consistent with the effect of summer precipitation. The model showed high statistical significance and estimates were robust.

The regional average temperature during April and May had significantly negative impacts on wheat yields. The estimated significant coefficient of the lagged average temperature and precipitation over the months of April and May showed a positive sign, indicating that higher temperature and precipitation tend to increase wheat yields. Extreme season dummies were not significant when introduced.

Quiroga *et al.* (2007) estimate the impacts of climate change on European agriculture in monetary terms. The crop functions have been used to derive these monetary impacts in the entire European agricultural sector by using the Global Trade Analysis Project (GTAP) model, which accounts for production, consumption and policy. The analyses compared estimated changes in the export and import of crops and other agricultural variables under the climate socio-economics scenarios with respect to the baseline data. The estimated changes involved the value of GDP, world supply, crop productivity and trade. The results showed a relatively small change in traditionally agricultural Mediterranean countries, which implies that current agricultural systems in these countries needs to be re-evaluated.

3. Objectives and Scope of the Study

Unlike most studies on climate change impacts that focus on macro perspectives at global and regional levels, this study analyses the impact of climate change at micro level, specifically at two major irrigated granary areas in the country. The two major rice growing areas in the country are governed by two federal bodies: Muda Agriculture Development Authority (MADA) and Kemubu Agriculture Development Authority (KADA) (Appendix 3). MADA and KADA contribute 60 per cent and 8 per cent, respectively, of Malaysia's total rice production.

3.1 Muda Agriculture Development Authority (MADA)

The area under MADA is the location of the Muda Irrigation Scheme that covers about 125,155 ha of which 105,851 ha are in the north-western part of Kedah State and 20,304 ha are in the southern part of Perlis State. About 76 per cent of the land is under paddy cultivation (96,558 ha) and approximately 48,500 farm families reside there. The average family has five members. About 38 per cent of the farmers cultivate paddy on their own land, 25 per cent rent land from other farmers and 34 per cent both own and rent land from others.

The average age of farmers is 60 years. The majority of them is more than 55 years old and had some primary school education. The average farm size for each household is 2.2 ha. The majority of paddy farms are small, 0.5-1.5 ha. Some farmers were operating on bigger farms; they usually rented land from inactive farmers in addition to cultivating paddy on their own land.

In general the farmers' net income has been increasing over the years. In the 1960s, 70 per cent of paddy farmers in MADA were categorized as poor. By the 1990s the proportion of farmers under the poverty line had reduced to 18 per cent; by the late 2000s, the number had dropped to 4 per cent. Their income came from both agricultural and non-agricultural activities.

Among the poor paddy farmers, those classified as hardcore poor have reduced in numbers. Under the RMKe-9 plan (Malaysia, 2008), those with a monthly income of RM 720 or less are categorized as poor; those who earn less than RM 430 are categorized as hardcore poor. The number of farmers among the hardcore poor has stabilized at about 2 per cent during the past few years.

The total cultivated rice area in MADA had been stabilized at around 193,000 ha for the last two decades. In general rice productivity has been increasing gradually over the years due to improvements in farm infrastructure and technologies. The Malaysian Agricultural Research and Development Institute (MARDI) has also introduced new rice varieties from time to time. Almost all farmers in granary areas are adopting the recommended varieties and the crop husbandry technologies proposed by MARDI.

3.2 Kemubu Agriculture Development Authority (KADA)

The KADA areas cover southern Kelantan and northern Terengganu States on the east coast of peninsular Malaysia. The total rice area under KADA is 25,459 ha or 8 per cent of the granary areas in the country. It contributed 8 per cent to Malaysia's total rice production. The number of households in KADA in 2000 was 45,000 which increased to 54,405 in 2008, an increase of about 21 per cent in 8 years. The average family size stayed the same during the period at 5.4 members. The average age of farmers has increased from 51.4 years in 2000 to 56 years in 2008, and the average education level was 6 years of primary education. The net household income has increased significantly from RM 6,951 in 2000 to RM 14,884 in 2008, an increase of about 114 per cent in 8 years. The number of households in the poor and hardcore poor categories has decreased during the period. In 2000 those in the poor category was about 4.5 per cent which decreased to 4 per cent in 2008. The portion of households in the hardcore poor category was 2.6 percent in 2000 and decreased to 2.4 per cent in 2008. The average household farm size was 2.4 ha in 2000 and increased to 3.0 ha in 2008. The average rice yield has slightly improved over the years as well, from 3.451 tons in 2000 to 3.586 tons in 2008.

MADA hence represents a relatively high productivity area, while KADA represents a less productive area. Both main-season and off-season rice yield data were included in the study.

4. Methodology

Methods for assessing the impact of climate factors on crop production have been extensively developed and used by scientists, economists, extension agents, commercial farmers and resource managers. The analysis of biophysical and socio-economic impacts poses a major challenge to modeling because these impacts must be derived from complex interactions among biophysical and socioeconomic systems. A combination of empirical yield responses based on statistical data and modeling approaches could provide meaningful assessment of climate impacts on crop production.

Among the major tools and approaches for assessing climate change impacts on agriculture include: agro-climatic indices and geographical information systems (GIS); statistical model and yields functions; and process-based models. In addition, different tools can be applied to examine the socioeconomic impacts of climate change such as economic forecasting and economic regression models.

In this study the process-based Decision Support System for Agrotechnology Transfer (DSSAT) model and economic regression model were used to assess climate change impacts on rice production in Malaysia. The implication of climate change to farmers' well-being and long-term consequences for self-sufficiency and food security for the country were also analysed.

4.1 Process-based DSSAT crop models

The DSSAT models use simplified functions to predict influences on crop growth by including major factors that affect yield. These include genetics, soils, management practices and climate (daily solar radiation, maximum and minimum temperatures, and precipitation). Models are available for many crops, including rice. Modelled processes include phonological development, growth of vegetative and reproductive plant parts, extension growth of leaves and stems, senescence of leaves, biomass production and partitioning among plant parts, and root system dynamics.

4.2 Economics regression models

Complex multivariate models attempt to provide a statistical explanation of observed phenomena by accounting for the most important factors, for example, predicting crop yields on the basis of temperature, rainfall and crop management practices. Multiple regression models have been developed to represent yield responses to these environmental and management variables. Yield functions have been used to evaluate the sensitivity and adaptation to climate.

Economic regression models are designed to estimate the potential impacts of climate change on production, productivity and farm value. This data may give only partial indications for social welfare. Not all individuals and households are appropriately represented by models that are based on producer and consumer theory. Many economic models used in impact analysis do not account for the variability in climate factors such as temperature and rainfall. Models based on market-oriented economies assume profit and use maximizing behaviour.

Several types of economic approaches have been used for agricultural impact assessment. The most useful are simple economic forecasting approaches (Benioff *et al*., 1996) that forecast based on a structured framework of available economic (acreage, production, productivity) and agricultural (technologies, crop management) information. These are simple techniques that can be used in most climate impact studies.

The economic cross-sectional model is one form of economic analysis that uses spatial analogues: cropping patterns in areas with climates similar to what may happen under climate change. This Ricardian approach has been used in a number of applications, (Mendelsohn *et al.*, 1994) in 1994 and 1999. Economic models can be used on statistical relationships between climate variables and economic indicators.

4.3 Data

Secondary data has been collected from past and present literature, statistical data and existing farm data. Apart from projection data provided by the National Hydrology Research Institute of Malaysia (NAHRIM), other climatic details for MADA and KADA were provided by the Malaysian Meteorological Services (MMS). Soil data was obtained from soil survey reports. For the establishment of time series production models for 1988 through 2008, secondary data considered included yearly total production in tons, productivity in tons per ha, site, weather, soil characteristics, soil type and management practices. Seasonal data on climate and rainfall were gathered from MMS for both states, Kedah and Kelantan.

We conducted a study on productivity and technical efficiency of rice production in the country in 2008-2009. Relevant data from the study were selected to model the rice farm production function and estimate the total elasticity of production. The data were collected in

MADA and KADA both during the main season and the off season for rice cultivation. Respondents were selected using stratified random sampling. The relevant data collected included socio-economic, farm production quantities, price, production factors and input costs.

4.4 Model specification

4.4.1 Forecasting climate change impacts on production

In a crop modeling approach, changes in yields and production can be predicted using various crop simulation models. Changes in rice yields under different climate scenarios can be predicted using DSSAT 4.5 because it integrates the effects of soil, crop phenotype, and weather and management options. To describe and simulate the biophysical reactions of rice to changing environmental conditions, sufficient structural details (parameters) are needed to represent specific rice cultivars, farm management and characteristics of the selected site.

Next the econometric regression models were used to test the consistency and validity of the DSSAT results. A relationship between rice production and climate change (temperature, rainfall and relative humidity) was estimated over the period studied (1988-2008). The model to be estimated is in Equation 1:

$$Y_{it} = \alpha + \beta_1 W_{1t} + \beta_2 W_{2\,t} + \beta_3 W_{3\,t}$$

Where:

Y_1 = production (tons),

Y_2 = yield (kg/ha),

α = constant,

W_1 = temperature (^{0}C),

W_2 = rainfall (mm),

W_3 = relative humidity (per cent),

t = years such that t = 0,1,2,3,….n

βi = parameter to be estimated

4.4.2 Hypothesis

H_0 = There is no significant effect of climate change on production.

H_a = Climate change is expected to decrease production

Y_t consists of two dependent variables that are estimated separately: production and productivity. Ordinary Least Square (OLS) was performed on the data to determine any significant correlations between endogenous and exogenous variables. The magnitude of climate change impacts on production were also determined using the model.

To understand more about other factors that influenced rice production other than temperature, rainfall and relative humidity (RH), a production function was estimated using a log linear estimation model. A total elasticity of production was estimated to determine the status of rice farm operations whether production was increasing, constant or decreasing return to scale (Equation 2).

$$\ln Y_t = \alpha_1 + \beta_1 \ln Land + \beta_2 \ln Lab + \beta_3 \ln Input + \beta_3 \ln Deprec + u_i$$

Where:

Y_1 = value production (RM)

Y_2 = productivity index

α = constant

Land = cost of land

Lab = cost of labour

Input = cost of variable inputs

Deprec = cost of capital depreciation

βi = parameters to be estimated

H_0 = There is no significant effect of input factors on value of production

H_a = Input factors is expected to increase the value of production

Y_t consists of two dependent variables that were estimated separately, namely value of production and productivity index. EXCEL, SPSS and E-views software applications were used to run the econometric modeling.

5. Climate Change Impact Modeling

5.1 The impact of temperature on rice yields using DSSAT model

The impact of climate change on agriculture and farmers' well-being include the biological effects on crop yields and their consequent impacts on prices, production and consumption. The biophysical effects of climate change on agriculture induce changes in production and prices which play out through the economic system as farmers adjust by altering crop mix, input use and production quantities. Rising temperatures and changes in rainfall patterns have direct effects on crop yields, as well as indirect effects through changes in irrigation water availability in most regions of the world (Zabawi, 2010).

The average potential yield of rice varieties is about 10 tons per ha in the tropics and over 13 tons per ha in temperate regions. In Malaysia, actual farm yields vary from 3 to 5 tons per ha, whereas potential yields are estimated at 7.2 tons per ha (Raziah, 2010)

The effects of climate change on rice production are felt through the variability in temperature and rainfall. In general, the optimum temperature for rice cultivation is between 24°C and 34°C and optimum annual rainfall is greater than 2,000 mm. The average temperature from 1988 to 2008 in Malaysia's rice-growing areas ranged between 26.5°C and 29.2°C with an average of 28.02°C. In general, temperature increases above the tolerance limit would potentially reduce the yield due to reduced photosynthesis, increased respiration and shortened vegetative and grain-filling periods. The vulnerability of rice to climate change is summarized in Table 5.1.

The average temperature in MADA in 2008 was 27.4°C. The optimum temperature requirement for rice cultivars MR219 and MR232 is 34°C. Table 5.2 shows the effects of climate change on rice production in MADA using DSSAT. Due to insufficient technical data for KADA, effects of climate change on rice production in the area cannot be assessed using DSSAT.

In MADA, a temperature increase from 27.4°C to 30.5°C would decrease the rice yield by 17.8 per cent. For every 1°C increase in temperature, the rice yield decreases by an average of 6 per cent. Compared with data from Thailand, the forecasted yield loss was lower in Malaysia. For every 1°C increase in temperature In Thailand, the rice yield decreases by 10 per cent (Felkner *et al.*, 2008).

Table 5.1 Vulnerability of rice to climate change

Climate change projection	Optimum climatic requirements and potential yield (kg/ha/year)	Vulnerability
Temperature: Average observation 27°C - 29°C Projected: 1.5°C - 2°C increase in 2050	Mean daily temperature 25°C - 28°C Potential yield: 7.2 t/ha/yr	Temperature increase above tolerance limit decreases yield due to less photosynthesis, shortened vegetative and grain-filling periods. 2°C temperature increase reduces yield by about 12%.
Rainfall: Average observation 1 700 - 3 000 mm Projected: +10% (Kelantan, Terengganu, Pahang) -5% (Selangor, Johor) Expected dry year: (2020, 2029, 2034, 2044)	Mean annual rainfall > 2 000 mm Potential yield: 7.2 t/ha/yr	Rainfall increase or decrease by 15% in the early growing stage reduces yields by almost 80%.

Source: Zabawi *et al.*, 2009.

The IPCC (2007) forecasts that temperatures could rise 2.4-6.4°C by the end of the century. However, any drastic increase in temperature in MADA is very unlikely in the near future. As mentioned, the average yearly temperature in MADA area from 1988-2007 was 27.5°C with a minimum temperature of 26.60°C and a maximum of 29.67°C (Buku Perangkaan MADA, 2008). The average percentage change in temperature for the period was only 0.15 per cent (Appendix 1). MADA is expected to be resilient enough to expected increases due to adaptation and mitigation initiatives in the area.

If we assume that IPPC projections for increased temperatures will occur in MADA, then the expected effects on rice yields based on DSSAT modeling are presented in Appendix 4. At 2010 temperatures, potential yield is about 8.0 tons per ha. If the temperature increases by 2°C, the estimated rice yield in MADA will decrease to about 7 tons per ha, a reduction of about 12.5 per cent. If the temperature further increases by 4°C (2100), the reduction in yield is expected to be higher: the estimated yield drops to about 5 tons per ha, a reduction of about 37.5 per cent. Adaptive strategies could minimize yield reductions. Improved technologies and mitigation and adaptation strategies are continuously being improved and adopted by both the authorities and farmers.

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Table 5.2 Projected climate change effects on rice productivity in MADA using DSSAT modeling without CO_2 fertilization

Temperature (°C)	Average yield	
	Tons/ha	% change
27.5	6.10*	-
30.5	5.10	(17.82)
32.5	4.10	(19.51)
34.5	3.33	(17.47)
36.4	2.22	(33.33)
38.4	1.30	(41.89)

* Average yield at MADA in 2008 using MR219 and MR232.
Source: Based on DSSAT modeling.

5.2 Climate change impacts on farmers' incomes

In Malaysia rice is a controlled commodity: The price of rice at harvest is set by the government. In 2008, the price was set at RM 1,250.00 per ton (Buku Perangkaan MADA, 2008). With an average temperature for the country of 27.5°C in 2008, a household earned on average about RM 7,625.00 per ha per season (Table 5.3). At a constant price, household revenue projections tend to decrease as the yield decreases when using DSSAT modeling. At a constant cost for production of about RM 1,807.00 per ha per season (Buku Perangkaan MADA, 2008), the projected net income that farmers earn also decreases. The poverty line for rural households in Peninsular Malaysia is RM 760.00 per month, or RM 9,120.00 per year (Malaysia, 2008). Using 2.2 ha, the average farm size of households in MADA, the majority of farmers in the area would likely earn below the poverty line once temperatures increase to 36.5°C and projected household incomes decrease to RM 4,259.00 per year, based on this simulation. As already stated, however, such a drastic increase in temperature is unlikely in the near future.

Table 5.3 Climate change impacts on farmers' incomes in MADA without government intervention (both price and cost of production are assumed constant)

Temperature (°C)	Price (RM/ton)	Revenue (RM/ha)	Cost of production (RM/ha)	Net income (RM/season)	Net income (RM/year)	Projection
27.5	1 250.00	7 625.00	1 807.00	5 818.00	11 636.00	MADA*
30.5	1 250.00	6 375.00	1 807.00	4 568.00	9 136.00	DSSAT
32.5	1 250.00	5 125.00	1 807.00	3 318.00	6 636.00	DSSAT
34.5	1 250.00	4 163.00	1 807.00	2 356.00	4 712.00	DSSAT
36.5	1 250.00	2 775.00	1 807.00	968.00	1 936.00	DSSAT
38.5	1 250.00	1 625.00	1 807.00	(182.00)	(364.00)	DSSAT

Note: * Actual data from MADA.
Source: MADA 2008 and using DSSAT modeling.

5.3 Climate change impacts on rice yields using economic regression models

Both secondary and primary data were used to assess climate change impacts on rice yields in MADA and KADA using econometric regression models. To establishment a time-series production model for 1988-2008, the secondary data considered included total production (tons), productivity (tons/ha), site, temperature, rainfall and relative humidity.

5.3.1 Impacts of temperature, rainfall and relative humidity on rice productivity

The ordinary least square (OLS) procedure was performed on time-series data using the log linear function to determine whether significant changes in temperature, rainfall and relative humidity had occurred from 1988 to 2008. Results in MADA indicated a significant increase in temperature (Adjusted R square 0.344, F value 22.54) and a significant decrease in relative humidity (Adjusted R square 0.316, F value 19.83) but insignificant changes in rainfall. Results from KADA indicate no significant changes in temperature and rainfall from 1988 to 2008 but quite a significant decrease in relative humidity (Adjusted R square 0.071, F value 44.18).

Assuming temperature, rainfall and relative humidity as exogenous and rice productivity as endogenous, a log linear OLS performed on the data indicated that variations in temperature significantly influenced rice productivity in MADA in a positive direction (Table 5.4). In comparison with the studies done by Lobell *et al.* (2008) and Peng *et al.* (2004), in this modeling, a 1.0 per cent increase in temperature tends to increase rice productivity by 2.3 per cent. This can be explained by the fact that the temperature range in MADA was within the optimum level for the cultivars cultivated: 26.6°C-29.7°C. The temperature increases in the area detected over the years could be due to increasing human interventions arising from MADA's efforts to maximize rice productivity to meet self-sustainability targets. Nevertheless, this model demonstrates that a minor increase in temperature does not hurt rice productivity; it increases farm productivity instead. On the other hand, both rainfall and relative humidity were negatively associated with rice productivity but not significantly. The model explains satisfactorily the relationships between the dependent and independent variables, with F value equal to 5.345 and R square equal to 0.254, which means 25.4 per cent of the variation in productivity could be attributed to temperature, rainfall and relative humidity; the rest were due to other factors.

The situation in KADA was quite different. Results of the OLS indicated that both temperature and relative humidity had a significant, negative effect on rice productivity in

(Table 5.5). A 1 per cent increase in temperature would decrease rice productivity by 2.4 per cent, and a 1 per cent increase in relative humidity would decrease rice productivity by 2.9 per cent based on this model. The model explains satisfactorily the relationships between the dependent and independent variables, with F value equal to 3.643 and R square equal to 0.162. This means that 16.2 per cent of the variation in productivity could be explained by temperature, rainfall and relative humidity.

Table 5.4 Parameter estimates of climate change impacts on rice yield in MADA (1988-2008)

Variables	Co-efficient	Standard error	t-value	Significant level
Constant	3.719	2.126	0.697	0.490
Ln temperature	2.300	0.636	3.308	0.002
Ln rainfall	-0.850	0.072	-1.134	0.264
Ln RH	-0.557	0.926	-0.602	0.551

Dependent variable: Ln yield (ton/ha)
Adjusted R square = 0.241
F value = 5.345

When both MADA and KADA data were combined, OLS results indicated significant changes in temperature and relative humidity in both areas from 1988 to 2008. Temperature was found to increase significantly (Adjusted R square 0.162, F value 17.033) over time, whereas RH was decreasing (Adjusted R square 0.198, F value 11.14).

OLS performed on data from MADA and KADA indicated that variable temperature and rainfall positively influenced rice productivity, but not significantly (Table 5.6). However, variable relative humidity had a significant and negative effect on rice productivity. A 1.0 per cent increase in relative humidity would decrease the rice yield by 2.0 per cent. The model satisfactorily explains relationships between the dependent and independent variables with F value equal to 17.461 and Adjusted R square equal to 0.315. This means that almost 32 per cent of the variation in rice productivity could be due to changes in temperature, rainfall and relative humidity and the rest could be due to other factors.

Table 5.5 Parameter estimates of climate change impacts on rice yield in KADA (1988-2008)

Variables	Co-efficient	Standard error	t-value	Significant level
Constant	28.933	7.273	3.978	0.000
Ln temperature	-2.410	1.429	-1.687	0.100
Ln rainfall	0.008	0.058	0.146	0.885
Ln RH	-2.924	0.901	-3.243	0.002

Dependent variable: Ln yield (ton/ha)
Adjusted R square = 0.162
F value = 3.643

Table 5.6 Parameter estimates of climate change impact on rice yield in MADA and KADA (1988-2008)

Variables	Co-efficient	Standard error	t-value	Significant level
Constant	13.248	5.702	2.323	0.026
Ln temperature	0.986	0.899	1.097	0.279
Ln rainfall	0.072	0.054	1.328	0.192
Ln RH	-1.985	0.895	-2.216	0.033

Dependent variable: Ln yield (ton/ha)
Adjusted R square = 0.316
F value = 17.461

5.3.2 Other factors that influence rice production

To understand further other factors that affected rice productivity, the primary survey data set was used to estimate the rice farm production function using a log-linear Cobb-Douglas function. The dependent variable was specified as production (kg), while the independent variables were specified as land (ha), labour (man hours), inputs (RM) and depreciation (RM). The data was collected in 2009 involving 60 sampled households each in MADA and KADA. Summary results of the OLS for MADA and KADA are presented in Table 5.7 and Table 5.8, respectively.

In MADA, land and labour variables significantly influenced rice production in a positive direction: an increase in land area or an increase in labour would increase rice production. Input and depreciation variables did not influence rice production. The model fit the data very well to explain the relationship between the dependent and independent variables with F value of 158.860 and adjusted R square of 0.828. About 83 per cent of the variation in production was attributed to the four input factors and the rest were caused by other factors, most likely climate factors. The total elasticity of production for this model was 1.036. This means that production could still be increased by manipulating all input factors since the farms in MADA in 2009 were generally operating at increasing return to scale (total elasticity more than 1).

Table 5.7 Parameter estimates of factors that influence rice production in MADA (2008-2009)

Variable	Co-efficient	Standard error	t- value	Significant level
Constant	8.087	0.281	28.814	0.000
Ln Labour	0.147	0.042	3.471	0.001
Ln Land	0.916	0.056	16.219	0.000
Ln Input	-0.018	0.047	-0.376	0.709
Ln Dep	-0.009	0.022	-0.404	0.687

Dependent variable = Ln production
F value = 158.860
Adjusted R square = 0.828
Total elastcity = 1.036

In KADA, land and depreciation variables significantly and positively influence rice production. Increases in land area and capital assets increase farm production. However, labour and input variables do not influence rice production, as shown in the OLS analysis results. The model fits well in explaining the relationship between the dependent and independent variables with F value equal to 43.304 and Adjusted R square equal to 0.741. This means that a 74 per cent variation in production was attributed to the four independent variables, while the rest were due to other factors, most likely climate. The total elasticity of production was <1, indicating that farms in KADA were operating at decreasing return to scale. Increasing and manipulating inputs cannot increase rice productivity in the area using this model. Improvements in infrastructure and mitigation of climate change impacts are potentially viable options since the infrastructure set up in KADA was quite inferior to that of the MADA area. Furthermore, data in this study show that KADA is more vulnerable to climate change than MADA.

Table 5.8 Parameter estimates of factors that influence rice production in KADA (2008-2009)

Variable	Co-efficient	Standard error	t-value	Significant level
Constant	6.573	0.818	8.035	0.000
Ln Labour	-0.070	0.086	-0.823	0.414
Ln Land	0.659	0.117	5.639	0.000
Ln Input	0.176	0.133	1.331	0.189
Ln Dep	0.170	0.068	2.514	0.015

Dependent variable = Ln production
F value = 43.304
Adjusted R square = 0.741
Total elastcity = 0.936

6. Conclusions and Recommendations

Climate change is a global phenomenon and Malaysia is supportive of all efforts to mitigate adverse effects from climate change on its food supply, particularly rice. For the past two decades, there have been indications of increasing temperature in MADA, but the rice productivity in the area has also increased. Improvement in technologies and human intervention in the area to increase productivity may contribute to minor increases in temperature, yet still within the optimum level for rice cultivation. MADA could continue manipulating farm production factors and new technologies to increase productivity and efficiencies, since farm areas in general were operating at increasing return to scale. This would be a feasible strategy to reach the targeted SSL of 90 per cent as set out in the Tenth Malaysia Plan for 2011-2015 (Malaysia, 2010), from the current level of 72 per cent.

In contrast, KADA was found to be potentially more sensitive to the effects of climate change. Increases in temperature and relative humidity were found to affect rice productivity in the area. Options for manipulating production factors to increase productivity are limited since farms generally operate at decreasing return to scale. To increase farm productivity and efficiency, further investment in infrastructure development is needed, since KADA's infrastructure was less development than that of MADA resulting in lower farm productivity.

Malaysia has been proactive in its efforts to deal with climate change impacts on rice production in the granary areas in the country. Various agencies and farmers themselves have put forward three kinds of strategies for implementation: anticipation, adaptation and mitigation strategies.

Anticipation strategy. Anticipation strategies included definitive planning of infrastructure development including water distribution and management systems; improvement of people's capacity to understand climate change and its negative impacts; development of information and early warning systems; plant breeding to produce drought- and salt-resistant varieties; and biofuel development to produce renewable and sustainable energy (Table 6.1).

The development of rice varieties which are tolerant to water stress with high water use efficiency is also needed. Aerobic rice cultivation, an innovative technique for growing rice in aerobic soil without flooding, would be the best alternative to producing rice with water-saving technology. Aerobic rice is a high-yielding rice variety responsive to inputs and grown with supplementary irrigation if rainfall is insufficient. Aerobic rice is intended for off-season planting in rainfed lowland areas with insufficient water and upland areas with access to supplementary irrigation. In aerobic rice systems, potential yields vary from 4.5 to 6.5 tons per ha which is about 20-30 per cent lower than that of lowland varieties grown under flooded conditions. MARDI conducted trials which found that yields are about 4-5 tons per ha and 4.5-5.5 tons per ha for varieties MRQ 50 and MRQ 74, respectively (Zabawi, 2010). However, further study is needed to evaluate crop establishment techniques and varietal performance.

Adaptation strategy. Farmers themselves can take part in most strategic steps to adapt to climate change: manipulating agronomic practices by planting at the most appropriate time and by using more organic fertilizers; using new plant varieties that are tolerant to drought and flood; improving water use efficiency; and practicing crop diversification. Two broad types of adaptation can be applied for rice cultivation, longer term and shorter term. Short-term and midterm strategies can be applied at farm level with involvement of farmers and extension workers; a long-term strategy at national and regional levels would involve reshaping government policies.

Effective use of available water resources through crop management can play a major role in sustainable production with limited water. Farmers can optimize water use patterns throughout the growing season by changing the cropping pattern. The choice of crop species and cultivars to be grown should depend on socio-economic requirements and water factors, including the timing, amount and frequency of rainfall. Use of the best adapted cultivar can maximize yields under limited water conditions by optimizing water capture and minimizing water escape during the reproductive stage. Choosing drought-tolerant cultivars is another means of adapting to newly drought-prone environments and of improving water use efficiency.

The adoption of appropriate soil management practices is essential to conserve water, nutrients and soil, particularly its structure and drainage characteristics. The specific practices required depend on both local climate and soil type. With climate change impacts, additional crop water can be made available by increasing the soil water storage capacity, reducing soil evaporation and increasing soil water extraction. The use of crop residues as mulch reduces the amount of energy that reaches the soil surface, thereby reducing soil evaporation and reducing erosion by wind and water. Such residues also slow moisture loss during the growing season and ensure that water moving into the soil after rainfall is retained, hence supporting crop growth.

In addition to agronomic practices and policies, plant breeding and biotechnology can play an important role in food production tailored to respond to climate change impacts. Plant breeding can aim to provide varieties that increase the water use efficiency of crops. Plant breeding has the potential to ensure highly stable yields under dry conditions, which requires identifying key traits and incorporating them into high-yielding varieties using conventional or biotechnological tools. Biotechnology can be harnessed to improve crop yields by increasing carbon gain during the crop cycle. As with cultivar selection, genes can be targeted which increase water use efficiency without reducing yield. In addition to this target, consideration must also be given to other traits that affect the development of the species so as to engineer varieties for optimal performance under limited water.

Mitigation strategy. In order to mitigate climate change impacts on rice production, both government agencies and farmers can play their roles by improving farm management, livestock management, carbon sequestration, water pricing and management and biofuel use.

Table 6.1 Anticipation, adaptation and mitigation strategies to overcome climate change impacts on rice production in Malaysia

Strategy type	Strategy	Agency or stakeholder
Anticipation	1. Plan infrastructure development (irrigation systems, farm roads) and a water distribution and management system.	▪ MADA, KADA, PBLS, JPS
	2. Improve human capacity to understand climate change and its possible negative effects.	▪ NAHRIM, MMD, MOA, NRE
	3. Develop information and early warning systems for new levels of flooding and drought.	▪ JPS, MMD, NAHRIM
	4. Breed plants breeding to produce drought- and salt-resistant varieties.	▪ MARDI
	5. Develop biofuels to provide renewable and sustainable environmentally friendly fuels (biodiesel, bioethanol, biogass) to partly replace fossil fuels, without additional forest clearance.	▪ KPPK, MARDI, MPOB
Adaptation	1. Agronomy: ▪ Adjust planting time ▪ Use less nitrogen, more organic fertilizer ▪ Adjust cropping pattern	 ▪ Farmer ▪ Farmer ▪ Farmer
	2. Use new varieties drought and flood tolerance	▪ Farmer
	3. Improve water use efficiency	▪ MARDI, MADA, KADA,PBLS ▪ Farmer
	4. Diversify crops	▪ Farmer
Mitigation	1. Farm Management: ▪ Manage soil nutrients ▪ Manage land use ▪ Develop agroforestry ▪ Manage organic matter in soil ▪ Restore degraded land ▪ Manage grazing land	 ▪ DOA, MARDI, KADA, MADA, PBLS ▪ DOA ▪ FRIM, Dept. of Forestry ▪ DOA, MARDI, KADA, MADA, PBLS ▪ DOA ▪ DVS
	2. Livestock management: ▪ Manage feed ▪ Manage waste and manure ▪ Adjust animal breeding	 ▪ Livestock producer, DVS ▪ Livestock producer, DVS ▪ Livestock Biotechnology Institute.
	3. Carbon sequestration: ▪ Zero/minimum soil tillage ▪ Manage straw ▪ Conservation tillage	 ▪ Farmer ▪ Farmer, MARDI ▪ Farmer
	4. Set water prices, ending free water supplies and manage that supply	▪ Federal/ State government ▪ KADA, MADA, PBLS
	5. Increase use of biofuels in the transportation fuel mix.	▪ Long run: public transport

Source: Zabawi, 2010.

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Appendices to Part I

Appendix 1. Rice production, temperature, rainfall and relative humidity in MADA, 1988-2008

		MADA							
Year	Season	Prod. (ton/ha)	% change	Temp. (^{0}C)	% change	Rainfall (mm)	% change	Relative humidity (%)	% change
1988	2/87	4.0		27.6		579.7		85.0	
	1/88	2.9	-29.0	26.7	-3.4	935.1	61.3	86.0	1.2
1989	2/88	3.8	33.8	27.4	2.7	845.2	-9.6	85.0	-1.2
	1/89	3.3	-15.1	26.7	-2.6	1 065.9	26.1	85.2	0.2
1990	2/89	4.0	24.3	27.7	3.8	622.9	-41.6	84.0	-1.4
	1/90	3.6	-11.0	26.8	-3.2	870.1	39.7	85.5	1.8
1991	2/90	4.4	23.1	27.6	2.9	624.4	-28.2	84.5	-1.2
	1/91	3.5	-21.0	26.8	-3.1	905.7	45.1	85.4	1.0
1992	2/91	4.9	39.7	27.9	4.3	1 118.8	23.5	83.2	-2.5
	1/92	3.1	-35.6	26.6	-4.6	789.1	-29.5	85.4	2.6
1993	2/92	4.4	39.3	27.8	4.4	549.8	-30.3	83.7	-1.9
	1/93	3.9	-9.9	26.7	-3.9	736.4	33.9	84.9	1.5
1994	2/93	4.7	19.9	27.6	3.3	701.3	-4.8	85.6	0.8
	1/94	4.0	-15.5	26.6	-3.6	862.0	22.9	86.0	0.4
1995	2/94	5.0	24.1	28.1	5.6	664.9	-22.9	83.6	-2.8
	1/95	3.9	-20.6	26.8	-4.6	788.9	18.6	85.2	1.9
1996	2/95	4.6	17.3	27.8	3.7	496.6	-37.1	85.5	0.4
	1/96	4.0	-12.7	26.6	-4.2	1 010.1	103.4	86.7	1.4
1997	2/96	4.6	13.9	27.9	4.8	986.7	-2.3	83.9	-3.2
	1/97	3.7	-18.5	27.1	-3.0	831.7	-15.7	87.0	3.7
1998	2/97	4.3	14.9	27.5	1.6	460.7	-44.6	82.6	-5.1
	1/98	3.8	-12.5	27.0	-1.9	1 365.8	196.5	87.7	6.2
1999	2/98	4.1	8.0	27.4	1.6	689.8	-49.5	85.4	-2.6
	1/99	4.2	3.2	26.8	-2.4	798.5	15.8	86.5	1.3
2000	2/99	3.9	-6.6	27.6	3.2	662.4	-17.0	85.5	-1.1
	1/00	4.0	1.9	27.0	-2.2	964.8	45.7	85.9	0.5
2001	2/00	3.9	-3.3	28.0	3.7	534.1	-44.6	84.7	-1.4
	1/01	4.3	10.9	27.2	-2.9	655.6	22.7	85.2	0.6
2002	2/01	3.9	-9.2	28.3	4.1	739.8	12.8	81.8	-4.0
	1/02	4.6	19.3	27.0	-4.6	1 118.6	51.2	84.4	3.2
2003	2/02	4.3	-6.9	28.2	4.4	938.4	-16.1	82.9	-1.8
	1/03	4.5	4.1	27.0	-4.3	1 225.2	30.6	85.6	3.3
2004	2/03	4.3	-5.0	28.0	3.7	866.6	-29.3	83.0	-3.0
	1/04	4.5	4.8	27.5	-1.9	1 202.2	38.7	82.5	-0.6
2005	2/04	4.3	-3.6	28.5	3.7	929.2	-22.7	79.8	-3.2
	1/05	4.8	12.0	27.4	-4.0	807.1	-13.1	82.5	3.4
2006	2/05	3.0	-37.5	27.8	1.6	828.4	2.6	81.5	-1.2
	1/06	4.8	58.0	27.5	-1.2	891.8	7.7	80.8	-0.9
2007	2/06	4.4	-8.2	28.0	1.9	660.6	-25.9	81.6	1.1
	1/07	4.7	6.5	27.1	-3.1	813.4	23.1	82.3	0.9
2008	2/07	4.5	-4.5	27.7	2.1	976.6	20.1	82.5	0.2
	1/08	4.7	6.3	27.3	-1.5	952.2	-2.5	84.3	2.1

Appendix 2. Rice production, temperature, relative humidity and rainfall in KADA, 1988-2008

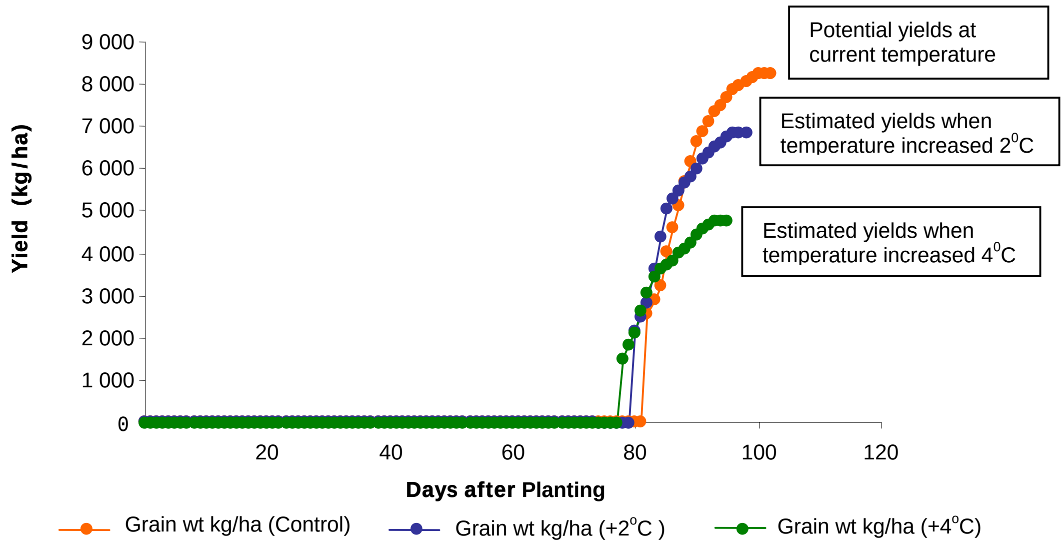
KADA									
Year	Season	Prod. (ton/ha)	% change	Temp. (^{0}C)	% change	Relative humidity (%)	% change	Rainfall (mm)	% change
1988	2/87	3.4		27.6		78.5		227.2	
	1/88	2.3	-33.5	26.6	-3.7	83.1	5.8	646.7	184.6
1989	2/88	3.6	59.2	27.6	3.9	81.4	-2.0	536.6	-17.0
	1/89	3.5	-2.6	26.5	-4.0	84.5	3.7	1 411.0	163.0
1990	2/89	3.8	8.4	27.8	4.9	79.2	-6.2	329.9	-76.6
	1/90	3.6	-5.5	27.1	-2.4	83.2	5.0	1 037.5	214.5
1991	2/90	3.8	5.8	28.1	3.6	80.6	-3.0	831.4	-19.9
	1/91	4.0	4.2	26.7	-4.9	81.9	1.5	851.9	2.5
1992	2/91	3.4	-14.1	28.2	5.5	80.6	-1.6	473.6	-44.4
	1/92	3.5	3.8	26.9	-4.5	83.4	3.5	948.7	100.3
1993	2/92	3.7	4.8	27.9	3.6	79.5	-4.7	480.1	-49.4
	1/93	3.4	-8.9	26.6	-4.7	81.2	2.1	881.7	83.6
1994	2/93	3.5	3.9	27.5	3.5	79.9	-1.6	646.9	-26.6
	1/94	3.5	1.3	26.6	-3.2	84.1	5.3	1 444.7	123.3
1995	2/94	3.6	1.5	28.1	5.5	82.3	-2.2	514.9	-64.4
	1/95	3.7	3.5	26.8	-4.8	83.9	2.0	2 197.4	326.8
1996	2/95	3.6	-3.4	28.2	5.4	79.8	-4.9	434.1	-80.2
	1/96	3.7	2.8	26.7	-5.3	85.0	6.6	1 801.4	315.0
1997	2/96	3.1	-16.3	28.1	5.2	78.9	-7.2	357.6	-80.1
	1/97	3.3	6.3	27.1	-3.6	83.5	5.9	1 390.8	288.9
1998	2/97	3.2	-2.9	28.8	6.3	81.2	-2.8	270.5	-80.6
	1/98	3.3	3.1	27.2	-5.7	85.1	4.9	1 025.0	278.9
1999	2/98	3.5	6.1	27.6	1.7	82.2	-3.4	607.8	-40.7
	1/99	2.8	-20.6	26.8	-2.8	85.0	3.4	1 279.9	110.6
2000	2/99	3.0	7.9	28.2	5.1	80.2	-5.6	598.8	-53.2
	1/00	3.3	11.6	27.5	-2.6	82.4	2.7	1 717.9	186.9
2001	2/00	2.4	-28.3	28.3	3.0	80.9	-1.8	472.1	-72.5
	1/01	3.2	33.6	27.2	-4.0	84.4	4.4	1 003.6	112.6
2002	2/01	3.3	2.9	28.5	4.9	80.1	-5.1	361.0	-64.0
	1/02	2.7	-17.0	27.3	-4.3	83.0	3.6	1 091.6	202.4
2003	2/02	3.6	31.4	28.2	3.4	80.3	-3.2	461.0	-57.8
	1/03	3.2	-11.4	27.2	-3.6	84.2	4.8	1 181.9	156.4
2004	2/03	3.5	9.7	28.5	4.9	78.7	-6.5	346.8	-70.7
	1/04	3.6	3.9	27.1	-5.0	84.2	7.0	1 271.4	266.6
2005	2/04	3.5	-3.8	27.9	3.0	78.5	-6.8	498.4	-60.8
	1/05	3.5	1.4	27.1	-3.0	79.7	1.5	1 133.2	127.4
2006	2/05	3.5	-1.4	27.7	2.3	78.9	-1.0	687.4	-39.3
	1/06	3.6	2.9	27.0	-2.5	81.8	3.6	1 000.0	45.5
2007	2/06	3.6	0.0	28.0	3.7	78.8	-3.6	420.2	-58.0
	1/07	3.6	-0.2	26.9	-3.9	80.4	2.0	1 106.8	163.4
2008	2/07	3.6	0.2	27.7	3.0	78.7	**-2.1**	572.0	-48.3
	1/08	3.6	1.3	27.1	-2.2	79.8	1.3	1 764.4	208.5

Source: (for Appendices 1 and 2) Climate data from Meteorological Department Malaysia (1988-2008), yield data from MADA and KADA (1988-2008).

Appendix 3. Location of MADA and KADA in Peninsular Malaysia

Source: Based on maps from KADA and MADA.

Appendix 4. Potential and estimated rice yields under different temperature



Part II
Long-term Effects of El Nino on Food Security: Indonesia's Experience

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Abstract

Climate changes associated with El Nino and La Nina episodes exert significant influences on agricultural production and food security. There is a growing concern about how global warming may affect the world's food production and availability. This study had two objectives:

- To understand effects on rice production of unfavourable climate scenarios; and
- To formulate policy options to deal with severe effects of climate change on food production, especially rice crops.

The two sites studied are rice-producing centres: Pusakanegara in West Java and Mojosari in East Java. The CERES family of crop models was used to predict rice crop performance. In simulating rice growth, rainfall conditions were applied by using weather data from both normal and dry years. Doubled atmospheric CO_2 was selected as the major change in the scenario from climate change. The baseline climate data as well as climate scenarios from the GISS, GFDL, and UKMO models were used in the DSSAT rice growth model. The results show that:

1. Doubled atmospheric CO_2 can potentially drastically reduce rice yields in the two study sites; and
2. Food security will likely be threatened due to these anticipated yield reductions, continuously high rice consumption per capita and population growth, and ongoing rapid conversion of paddy fields into other land uses.

To lessen the adverse effects of climate change, the present study offers anticipation, adaptation and mitigation measures.

Keywords: El Nino, Food security, Crop model, DSSAT, Climate scenarios.

1. Introduction

In Indonesia, rice has been and is expected to remain the most important staple food crop both in people's diet and in the national economy, affecting food supply, labour absorption and national income generation. The recent situation shows that rice production increases are not keeping pace with population growth rates at risk of increase. Food security faces significant threats if factors influencing rice production, including unfavourable climate conditions, are not anticipated. Understanding climate changes impacts on rice production in the major rice producing areas of Java, therefore, is of crucial importance.

This study had two objectives:

- To understand effects on rice production of unfavourable climate scenarios; and
- To formulate policy options to deal with severe effects of climate change on food production, especially rice crops.

The presentation of findings in Indonesia is organized in five sections, beginning with this introduction. In section 2 we describe the methodology to assess the effects of unfavourable climate scenarios on rice production using Decision Support System for Agrotechnology Transfer (DSSAT) modeling with a focus on the island of Java as the major rice producing region for the country. The third section describes results of the analysis and the fourth section indicates the extent of pressure on food security in Indonesia. Conclusions and recommendations are presented in the last section.

2. Methodology

2.1 Study areas

Two main rice production areas in Java with different geographic conditions were selected for this study, namely Pusakanegara in West Java and Mojosari in East Java. Whereas Pusakanegara is a lowland area on the northern coast of West Java at an elevation of 12 m above sea level, Mojosari is further inland on the flood plain of the Brantas River at an elevation of 30 msl. In the last 5 years, about 1.8 million ha were cultivated in West Java and 1.6 million ha were cultivated in East Java, respectively constituting 15.1 per cent and 13.6 per cent of the country's paddy fields (BPS, 2009). To simulate future weather conditions in the two areas, daily climate data, consisting of rainfall, minimum and maximum temperatures, and solar radiation or day length from 1973 to 1992, were used as the baseline.

The climate profiles of the two study areas are presented in Table 2.1. During 1973-1992, the average annual rainfall in Pusakanegara was higher than that in Mojosari, but the average rainfall during the four El Nino years was only slightly higher in Mojosari. The percentage difference shows the relative difference; Pusakanegara experienced half as much rainfall during El Nino years, whereas Mojosari experienced only 60 per cent of the average.

The average minimum and maximum temperatures show that Pusakanegara is slight cooler than Mojosari, a difference linked to Pusakanegara being on the coast.

For the average maximum temperature and solar radiation the reverse situation prevailed.

Table 2.1 Climate profile of the study areas

Climate variables	Pusakanegara (West Java)	Mojosari (East Java)
1. Average annual rainfall 1973-1992 (mm)	2 031	1 785
2. Average minimum temperature (^oC)	23.0	22.0
3. Average maximum temperature (^oC)	30.7	32.0
4. Average monthly solar radiation (MJ/m^2)	18.3	20.4
5. Average annual rainfall during El Nino years (mm)	1 025	1 074
6. Percentage of El Nino rainfall average to the overall average (%)	50.5	60.2

Source: Amien *et al.,* 1999.

Although temperatures in the tropics are warm all year round, rainy seasons alternate with dry seasons, and each season has its own distinct pattern of prevailing winds. The rainfall pattern affected by El Nino is primarily centred in the Indo-Pacific basin, but has wider, nearly global, impacts and implications. At least four dry years of 1976, 1982, 1987 and 1991 in the baseline climate data, are probably related to El Nino.

2.2 Crop growth simulation model

The Crop Environment Resource Synthesis (CERES) family of crop models is used in the Decision Support System for Agrotechnology Transfer (DSSAT) to predict rice crop performance. In simulating rice growth, rainfed conditions were applied by using weather data from both normal and dry years. Baseline climate data and climate scenarios from the Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and United Kingdom Meteorological Office (UKMO) models were used in the DSSAT rice growth model. Rice cultivars used in running the model were IR42 for the Pusakanegara area and IR36 for the Mojosari area. A standard management practice in the rice intensification programme in Java was also used in the simulation. Rice seedlings were transplanted 18 days after germination, two seedlings per hill with a spacing of 20 by 20 cm. Urea fertilizer was applied twice at a rate of 58 kg N/ha, once before planting and once 30 days after planting. The fertilizer was incorporated into the soil to a depth of 5 cm.

The simulation began at the time of transplantation. Full irrigation with no water stress was applied to simulate years with normal rainfall by using weather data for the rainy season in normal years. This rice growth simulation model has several water management options, including fully irrigated with no water stress and rainfed, which depends fully on rainfall. By using the weather data from normal years during the rainy season, the condition of no water stress can be assured. Two planting seasons were simulated. In Pusakanegara, the first crop started in late November, the second, in early April; In Mojosari, the first crop started in early October at the beginning of the rainy season, and the second started soon after harvesting the first rice crop in February.

2.3 Climate change scenarios

Anticipated climate conditions in both areas were simulated by doubling CO_2 levels of the pre-industrial period, prior to 1850 (IPCC, 2007). We used 555 ppm in the three climate models: GFDL, GISS, and UKMO.

2.4 Data

El Nino events occurred in 1976, 1982, 1987 and 1991. Baseline climate data for these four years and the corresponding years in the transient climate scenario show very little rainfall. The weather data for those years were used to simulate rice performance during dry years under current and future climate conditions. In dry years, water in upstream reservoirs was far less than normal. When agricultural water use must compete with human and animal water use, agriculture, particularly rice cultivation, is given the least opportunity to use the limited water. In dry years, many farmers choose to plant secondary crops that require less water, such as corn, peanut or cassava.

3. Effects of Climate Variability and Climate Change on Rice Production

The effects of different climate scenarios on rice yields at two sites on Java– Pusakanegara in West Java and Mojosari in East Java – were simulated employing the CERES model and three crop growth models of GISS, UKMO and GFDL with DSSAT software.

The results presented in Table 3.1 indicate that annual rainfall increased significantly in Pusakanegara and Mojosari when CO_2 concentrations were doubled from the baseline, with a higher increase in Pusakanegara. UKMO presented the greatest increase. Projected maximum and minimum temperatures also increased significantly in both study sites with almost similar rates; GISS presented the greatest increase. Solar radiation also increased at both sites.

Table 3.1 GISS, GFDL and UKMO climate change simulations based on doubled CO_2 concentrations in Pusakanegara and Mojosari

Scenario and variables	Pusakanegara		Mojosari	
	Units	(%)	Units	(%)
GISS:				
Annual rainfall (mm)	423	20.8	354	10.9
Maximum temperature (°C)	3.9		3.9	
Minimum temperature (°C)	3.9		3.8	
Solar radiation (MJ/m^2)	0.7	3.5	0.6	3.3
GFDL:				
Annual rainfall (mm)	506	24.9	265	14.9
Maximum temperature (°C)	2.3		2.3	
Minimum temperature (°C)	2.3		2.3	
Solar radiation (MJ/m^2)	0.3	2.2	0.3	1.5
UKMO:				
Annual rainfall (mm)	1 681	82.8	1 130	63.3
Maximum temperature (°C)	2.9		3.0	
Minimum temperature (°C)	3.0		2.9	
Solar radiation (MJ/m^2)	0.6	3.3	0.2	1.3

Source: Amien *et al.*, 1999.

Simulated rice biomass results in Pusakanegara and Mojosari, based on climate change and inter-annual climate variability using DSSAT, reveals that rice biomass decreased during ENSO years, compared to the normal years, for both first and second crops in Pusakanegara and in Mojosari in most cases (Table 3.2). Exceptions in Mojosari simulations include first crop using GISS and GFDL and second crop using the baseline.

Table 3.2 Simulated rice biomass as affected by possible climate change and inter-annual climate variability using the DSSAT crop model (in kilograms/ha)

Crop season	Pusakanegara				Mojosari			
	Baseline	GISS	GFDL	UKMO	Baseline	GISS	GFDL	UKMO
Normal years:								
First crop	15 826	16 120	15 082	12 042	10 898	8 727	9 994	8 318
Second crop	11 161	11 223	9 918	10 707	10 323	10 114	10 079	12 042
ENSO years:								
First crop	10 898	12 269	14 228	7 899	9 941	9 090	10 273	7 352
Second crop	9 852	5 964	6 953	6 064	10 984	7 239	9 137	8 438

Source: Amien *et al.*, 1999.

With the added variable of climate change based on doubled concentrations of CO_2, rice yields except for the second crop in Pusakanegara (Table 3.3). The second crop in Mojosari showed a very significant decline in yield.

Table 3.3 Climate change impacts on rice yields in Pusakanegara and Mojosari using the DSSAT crop model (in kilograms/ha)

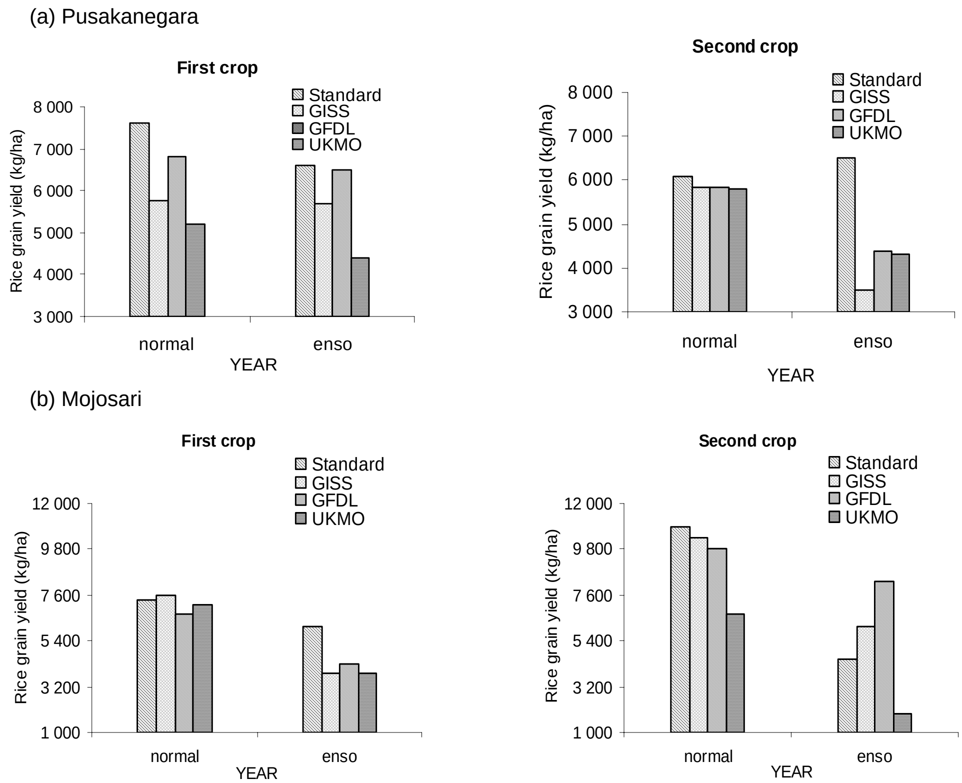
Climate change	Pusakanegara	Mojosari
Normal		
First crop	7 543	7 319
Second crop	5 976	10 823
ENSO		
First crop	6 471	6 051
Second crop	6 348	4 531
Change		
First crop	-1 072	-1 268
Second crop	+372	-6 292
Change in percentage		
First crop	-14.21%	-17.32%
Second crop	+6.22%	-58.14%

Source: Amien *et al.*, 1999.

Results of simulated climate change impacts on rice yields in Pusakanegara and Mojosari using all models (Standard, GISS, GFDL and UKMO) reveal that yields significantly decreased during ENSO-driven dry years except for GISS model results for the first crop in Pusakanegara (Figure 3.1).

The changing rainfall pattern due to ENSO will alter the timing of rice cropping: Late planting of the first crop (October-December) would delay the planting of the second crop (April-June). Late planting would limit the possibility of a third crop when irrigation is unavailable or water supply in the irrigation network is limited. Studying the rainfall patterns in Sumatra, Java, Bali and South Sulawesi, Naylor *et al.* (2007) reported that climate change would increase the probability of a 30-day delay in the onset of monsoon season. Such a delay will certainly have significant adverse impacts on rice production.

Figure 3.1 Simulated rice yield as affected by climate change at Pusakanegara and Mojosari, with 'standard' referring to baseline



If adaptation measures are absent, climate change could significantly reduce food crop productivity (IPCC, 2007). Climate change as projected using twenty-first century climate models will significantly alter food production what has direct implications for food security in the world (Rosenzweig and Hillel, 1998). Cline (2007) predicted that agricultural productivity in Indonesia in 2080 would decrease by 15-25 per cent due to climate change, but the figure is likely to drop to 5-15 per cent after accounting for the positive effects of increasing CO_2 in the atmosphere.

Tschirley (2007) reported that agricultural crop yields overall could decrease by 20 per cent if air temperature increases by more than 4°C, estimating 5 per cent for rice and 10 per cent for maize. The reduction can occur more quickly if degradation of land resources is also considered. Using a crop simulation model, increasing CO_2 to 75 ppm increased yields by 0.5 ton/ha, but decreased yields by 0.6 ton/ha once temperature increased. Further, Peng *et al.* (2004) reported that increasing the minimum temperature by 1°C would reduce rice yields by 10 per cent.

Handoko *et al.* (2008) stated that increased air temperature can affect rice production in three ways: smaller harvested areas with less irrigation due to higher evapotranspiration; decreased yields because of shorter time to maturity: and increased plant respiration. By 2050, the estimated reduction from paddy fields is 3.3 per cent in Java and 4.1 per cent in the outer islands, less than current rice harvested areas. Decreased yields because of earlier maturity is estimated at 18.6 to 31.4 per cent in Java and 20.5 per cent in the outer islands. Increased plant respiration due to increased temperature will reduce rice yields by 19.94 per cent in Central Java, 18.2 per cent in Yogyakarta, 10.5 per cent in West Java, and 11.7 per cent outside Java and Bali.

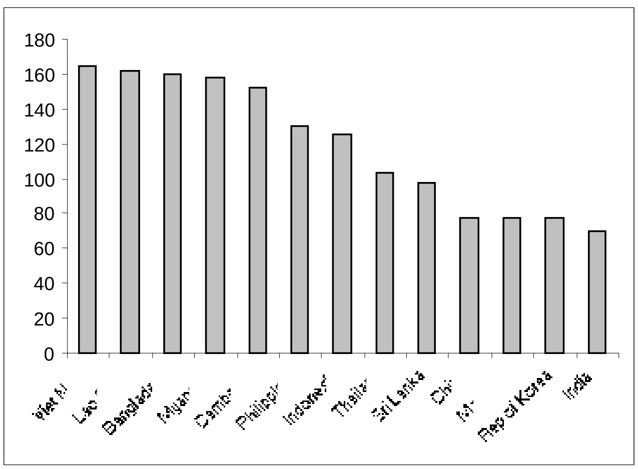
A recent study by the Climate Change Research Consortium in Agriculture (Boer, 2008) also reported that increased temperatures due to increased CO_2 concentrations will reduce crop yields. Assuming no agricultural land conversion and unchanged cropping intensity for rice production at district level in Java, rice production is predicted to decrease by 12,500 to 72,500 tons in 2025. When a land conversion rate of 0.77 per cent annually is considered without any increase in cropping intensity for rice production at district level, rice production is expected to decline by 42,500 to 162,500 tons in 2025. Assuming no agricultural land conversion with an increase in cropping intensity, the negative effects of increased temperature can be minimized. Increased rice cropping intensity can maintain rice production in most districts of Java in 2025, except for the districts of Tulungagung and Kediri in East Java province; the districts of Purworedjo, Wonosobo, Magelang, Klaten and Sukohardjo in Central Java province; and the district of Sleman in Yogyakarta province. However, as long as the rice field conversion rate remains at 0.77 per cent annually, the increased cropping intensity will fail to compensate for the negative effects of increased air temperatures beginning in 2025, particularly in Central Java. Increasing the cropping intensity seems to be effective only in some districts of West Java and East Java.

4. Pressures on Indonesia's Food Security

4.1 Rice consumption remains high

In Indonesia, rice is still the national staple food, although in many countries in which rice is a staple consumption levels are declining as the economy and living condition improve. Rice consumption per capita in Indonesia still exceeds 100 kg per annum compared to China, Malaysia, Korea and India, each with less than 80 kg (Figure 4.1).

Figure 4.1 Per capita rice consumption in Indonesia and other Asian countries, 2007 (in kg)



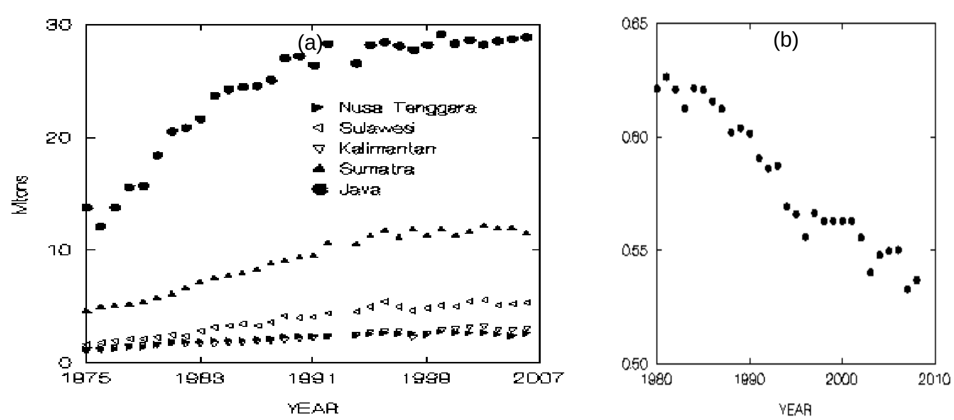
Source: FAOSTAT, Commodity Balances, 2010.

In the last two decades, per capita rice consumption in Indonesia has been decreasing probably due to food diversification, especially more consumption of imported wheat. However, even though the population growth rate is decreasing, population growth in itself will require more food and will discharge more waste. Producing food necessitates energy, land, water and genetic resources, and adapting to the expected climate change impacts. This means that resources that are already scarce will be in demand. The anxiety of Thomas Robert Malthus (1798) seems to have been overcome by the green revolution in the 1960s. The miracle seeds, the major component of the green revolution, require prime land and large modern inputs such as fertilizer, irrigation and other chemicals to protect the crops from pest and disease infestations. These cultivars cannot be cultivated in marginal ecosystems where most poor people earn their living. Although the green revolution has remarkably increased world food production, distributing the food to the needy must be facilitated by sufficient supplies of energy, passion and political will. This has left millions of people in the world, including in Indonesia, still suffering from hunger or malnutrition.

4.2 Java still dominates rice production

Because of its fertile land and large workforce, Java is the centre of political, educational and economic activities since the colonial period. With the largest proportion of suitable lands for agriculture and available workforce, it benefits from government investment in agricultural infrastructure. With the vicinity to the centre of development and well-developed transportation system of the outer islands, Sumatra is the second largest rice producer followed by Sulawesi, Kalimantan and Nusa Tenggara (Figure 4.2). The role of Java as the national rice basket, however, is threatened because of the increasing tight competition for land and water in the island. The increasing population and growing economy have been taking prime agricultural lands for non-agriculture uses such as housing, industry and transportation infrastructure. Water demand in other sectors such as industry, or even high-valued agricultural crops, will deprive water supply to meet the high water use requirements for rice cultivation. In the last three decades, contributions from Java to the national rice production have been declining from approximately 63 per cent to about 53 per cent.

Figure 4.2 Rice production in Indonesia by region (a) and the percentage of Indonesia's rice harvest produced in Java (b)



Source: BPS (various years).

The conversion of agricultural land has been accelerated by the policy of land transportation development. Road building instead of railway construction is expected to speed roadside housing development with business multipliers that follow, in turn causing more agricultural land to become impermeable and increasing soil run-off. If left unchecked, transportation infrastructure development along with its multipliers in West Java is predicted to convert about 40 per cent of agricultural land in the province by 2025 (Brinkman, 2008).

Java's role as the nation's rice basket stems from the demand for rice by its large population, the availability of suitable fertile lands and the well-developed transportation infrastructure. The adoption of modern rice cultivation technology helped bring about the soar in rice production in Java during 1975-1985, far greater increases than in the other regions (Kasryno, 2008). Market demand, available land and developed infrastructure also make Sumatra the second biggest national rice supplier. Besides having more available land than Java has, a well-developed transportation system and its proximity to Java's markets makes Sumatra a better choice for producing rice compared to other regions.

The leveling off in rice production in Java occurred between 1985 and 1990. Slower growth rates started in Sumatra after 1995 and in Kalimantan after 2000 (Kasryno, 2008). This leveling off was probably because available land for conversion became scarcer, cropping intensity had reached its limit and other technological inputs were limited. The leveling-off pattern can indicate limits to growth for other national rice production centres.

Further growth in rice production in Sumatra is constrained by rapid plantation development by large domestic and foreign companies, either state-owned or private. These plantations are especially for oil palm and rubber production. Smallholders also prefer to work on plantations rather than paddy fields. More plantation development is due to labour shortages for annual crop farming and higher financial returns from plantation crops (Susilowati *et al.,* 2009). Many of the farms originally designed for food crops and reserve lands in transmigration areas have been converted into oil palm and rubber plantations (Kustiari *et al*., 2008).

5. Conclusions and Recommendations

El Nino and La Nina have important consequences for weather around the globe. Climate change can affect both agricultural and non-agricultural activities. Climate change will certainly threaten rice production in Java and elsewhere in the tropics, mainly due to increased temperatures that speed crop maturity, more crop failures after increasingly extreme climate events and increasing pests and diseases. The problem is exacerbated by the continuing conversion of agricultural crop land to other uses and competition for water use for non-agriculture activities or higher value agricultural crops. Rice consumption per capita is likely to decrease as Indonesia experiences economic growth and improved well-being, but ever high population growth rates, particularly on islands other than Java, is expected to increase rice demand in Indonesia.

With decreasing agricultural lands and limited lands for expansion on Java, substitutes for the decreasing contribution of Java to national rice production are imperative. With its proximity and better developed infrastructure, Sumatra is the best choice. However, high growth of tree plantations, particularly oil palm, will limit Sumatra's potential as long as agricultural land use is allowed to be driven by market forces alone. Therefore, decisive policies are necessary to ensure lands remain available to strengthen national food security and to support adaptation and mitigation strategies to counter the adverse effects of climate change.

To lessen the adverse effects of climate change, the present study recommends anticipation, adaptation and mitigation measures. Anticipation measures include: (1) definitive planning of infrastructure development, especially irrigation networks, and water distribution and management systems; (2) improvement of people's capacity to understand climate change and its negative effects; (3) development of information and early warning systems about flood and drought phenomena; and (4) plant breeding to produce drought- and salt-resistant varieties. Adaptation measures include: (1) planting time adjustment, more use of organic fertilizer rather than nitrous fertilizer, cropping pattern adjustment, use of new drought- and salt-resistant varieties; (2) improving water use efficiency; and (3) crop diversification to reduce risks. Mitigation measures encompass: (1) crop land management including adjusting strategies for cropping, soil nutrients, soil organic matter, (2) land use management including agroforestry development, degraded land restoration, and grazing land management; (3) livestock management such as feed and waste management and animal breeding; (4) carbon sequestration through zero-soil and conservation tilling; and (5) water pricing to avoid excessive water use.

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Part III
The Food Security Assessment under Climate Changes in Viet Nam

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Abstract

Viet Nam is an agricultural country with limited land and dense population. Agricultural production is being developed and has achieved great progress in recent years. Income from agricultural activity has contributed about 20-40 per cent to state gross domestic product (GDP).

This study was implemented through surveys and field trials in the Red River Delta as a case study. Results indicate that food income and food security can be ensured for the region. Food production increased from 6.1 million tons in 1955 to 43.0 million tons in 2008, equivalent to an increase from 224 to 503 kg per capita per year during the same period. Rice is the main food crop. Recently rice yields have decreased from 52.6 per cent in 2006 to 40.8 per cent in 2009, under expected potential yields.

Based on Viet Nam's climate change scenario for 2020-2100, simulated rice yields show reductions by 1-15 per cent compared to actual yields in 2006. It indicates that climate change could significantly affect the country's future rice production. To address this problem, the government has been proactive in efforts to mitigate climate change impacts on agriculture and food production: State and local governments have: (1) issued policies to support efficient development of food production and security; (2) improved and innovated farming systems and agricultural production; (3) built up capacity in water storage and irrigation systems; and (4) prioritized eliminating hunger and reducing poverty, where people and natural conditions are highly sensitive to climate change, especially for minority groups in mountainous zones.

Key words: Climate change, Food security, Production, Red River Delta, Natural calamity.

1. Introduction

Viet Nam is an agricultural country with more than 86 million people (2008), living on an area of 32,924 million ha. Agricultural production plays an important role in national economic development and food security and contributes 20.3 per cent of the national economy. Changing policies and the land law after 1980 contributed to increased productivity. Before 1980 Viet Nam worked with an economic policy based of self-sufficiency. Since 1980 the government of Viet Nam implemented new economic policies and strategies. The ‘new re-thinking’ policy was issued to move from the self-consumption and self-supply economy into a market economy. Food production was prioritized, with land for rice increasing from 7.3 million ha in 1995 to 8.4 million ha in 2008.

Viet Nam imported rice in the early 1980s but it has become the second-highest rice exporting country. Food production has greatly increased from 6.1 million tons in 1955 to 43.3 million tons in 2008. However, agriculture and food production in Viet Nam faces problems due to climate change. Climate change is threatening human life and is affecting agriculture yields and food production in complex ways. It directly affects food production by changing agro-ecological conditions and indirectly by affecting growth and income distribution.

This paper reviews the current food production situation and challenges under climate change in Viet Nam.

2. Literature Review

2.1 Population growth increases pressure on food security

Viet Nam's population has been increasing, from 72 million people in 1995 to 83.1 million in 2005 and 86.2 million in 2008 (GSO, 2008). The population in rural areas comprises more than 72 per cent of the total population in all regions except the south-east, where the rural population comprises 42 per cent of the total.

Approximately 20 million people live in the Red River Delta region, which is the most densely populated region in the country with 933 people/km^2. The south-east region has the second highest density with 543 people/km^2. This region includes Binh Duong, Dong Nai and Ba Ria-Vung Tau provinces and Ho Chi Minh City which have shifted from primarily agricultural provinces to industrial ones.

Projections for grain food yields are 470 kg/capita in 2010. Yields are expected to decrease to 390 kg/capita/year by 2020. The total food requirement is expected to increase steadily: 47 million tons in 2010; 50.3 million tons in 2015; 53.2 million tons in 2020; and 58.3 million tons in 2030. Of the total food required, the amount of rice required will be: 31.1 million tons in 2010; 32.1 million tons in 2015; 35.2 million tons in 2020; and 37.3 million tons of rice in 2030.

2.2 Agricultural and food production

2.2.1 Background on agricultural production

The total natural area of Viet Nam is 32,924.1 km^2, of which 9.4 billion ha (28.43 per cent) is agricultural land. Annual crops account for 19 per cent of all agricultural land, an area three times larger than the area used to grow perennial crops. Annual crops include rice, maize, sweet potato, peanut, soybean and vegetables cultivated on flat lands in the river deltas. On upland soils, annual crops include maize, cassava and some vegetables.

Viet Nam is divided into seven ecologically distinct regions. The largest agricultural land is distributed in the Cuu Long River Delta region. Other areas, ranked in descending order by size, are the central coast divided into northern and southern parts, central and northern mountain deltas and, finally, the western highlands. Rice production is greatest in both area and yields in the two deltas of the Cuu Long River, southern part and the Red River, northern part.

Table 2.1 Land use for agricultural production in Viet Nam over 53 years

Year	Cultivated area (M ha)	Average area (ha/capita)	Food yields (M tons)	Population (M people)	Food yields (kg/capita)	Rice yields (tons/ha)
1955	4.7	0.19	6.1	25.1	244	1.42
1975	5.6	0.12	11.6	47.6	244	2.14
1980	7.0	0.13	14.4	53.7	268	2.09
1985	6.8	0.11	18.2	59.7	305	2.78
1990	7.1	0.11	21.5	65.7	325	3.21
1995	7.3	0.11	26.1	72.0	363	3.69
2000	8.4	0.10	34.5	77.6	444	4.24
2005	8.4	0.11	39.6	83.1	476	4.48
2008	8.5	0.10	43.4	86.2	503	5.22

Source: GSO, 2009.

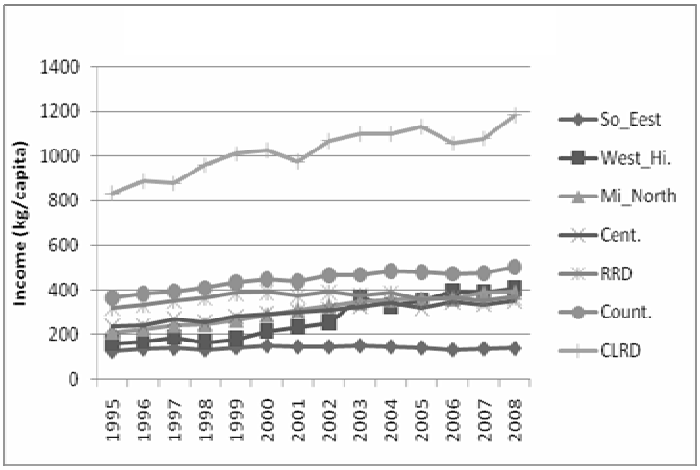
Land designated for agricultural production has been increasing over this period. Table 2.1 shows that agricultural land use almost doubled. Total cultivated land was 4.7 million ha in 1955, increasing to 7.1 million ha in 1990, 8.4 million ha in 2005 and 8.5 million ha in 2008.

By 1988 agricultural products contributed 50 per cent (1988) to the country's GDP, double the contribution from industrial products. These gains were offset by increasing population pressure: The amount of cultivated land per person declined. Cultivated land per capita was 0.19 ha in 1955, and 0.10 ha per capita in 2008.

Data on grain yields are disaggregated into Viet Nam's seven ecological regions (Table 2.2). Grain yields were about 363.1 kg/capita in 1995 and increased to 501.8 kg/capita in 2008 in the whole country. The highest production of grains occurred in the Cuu Long River Delta where the country's largest paddy field area is located. Cereal yields increased in that region from 831.6 to 1,181.8 kg/capita between 1996 and 2008.

The lowest grain yields occurred in the south-eastern region with 127.4-137 kg/ capita. In the Red River Delta, grain yields ranged from a low of 5,462.5 thousand tons in 1955 to a peak of 7,204.1 thousand tons in 2008 (GSO, 2009).

Figure 2.1 Grain yield trends per capita by region, 1995-2008



Source: GSO, 2009.

Staple food crops in Viet Nam

The staple food crops in Viet Nam consist of rice, maize, sweet potato, potato and cassava.

Table 2.2 Land use and yields for staple food crops in Viet Nam

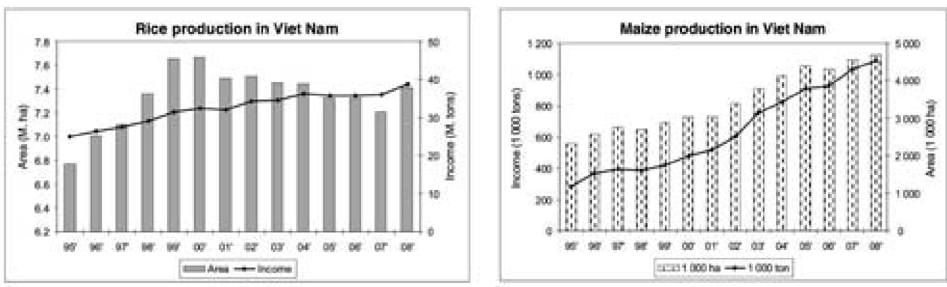
Crop	Area (1 000 ha)				Yields (1 000 tons)			
	1995	2000	2005	2008	1995	2000	2005	2008
Rice	6 765.6	7 666.3	7 329.2	7 414.3	24 963.7	32 529.5	35 832.9	38 725.1
Maize	556.8	730.2	1 052.6	1 125.9	1 177.2	2 005.9	3 787.1	4 531.2
Sweet potato	304.6	254.3	185.3	162.2	1 685.8	1 611.3	1 443.1	1 323.9
Cassava	277.4	237.6	425.5	557.7	2 211.5	1 986.3	6 716.2	9 395.8
Total	9 899.4	10 888.4	10 997.6	11 268.1	32 033.2	40 133.0	49 784.3	55 984.0

Source: GSO, 2009.

Table 2.2 indicates food production has increased since 1995 both in the amount of cultivated land and amount of grain harvested. The total cultivated areas increased from 9,899.4 thousand ha in 1995 to 10,888.44 thousand ha in 2000 and to 11,267.8 thousand ha in 2008. Yields increased from 32 billion tons in 1995 to 56 billion tons in 2008.

Maize is the second most important food crop in Viet Nam after rice. It is the substitute staple in periods of rice shortage, especially for people who live in rural areas and mountainous regions. Maize is also the primary source of feed for Viet Nam's poultry and livestock industry and therefore an important source of income for many farmers. Maize production has risen sharply since 1990, when only 431,800 ha were planted to maize, yielding an average of 1.6 tons/ha for a total production of 671,000 tons. Since then, the government has strongly supported maize hybrid technology and the resultant varieties have been widely adopted by farmers. In addition, the livestock and poultry industry have grown, creating greater demand for maize as feed. From 1990 to 1999, total maize production increased by 161 per cent. A significant increase was achieved in 2008 when the total maize area planted reached 1.13 million ha with an average yield of 4 tons/ha based on total yields of 4.35 million tons in the whole country (GSO, 2009).

Figure 2.2 Rice production (a) and maize production (b) in Viet Nam



a b

Source: GSO, 2009.

2.2.2 Climate change and its effect in Viet Nam

Climate changes have caused higher temperatures and the associated El Nino weather patterns are linked with recent drought. During the last 50 years (1958-2007), the annual average temperature in Viet Nam has increased by 0.5-0.7°C. Winter temperatures have increased faster than summer temperatures. Temperatures in the northern climate zones have increased faster than temperatures in southern climate zones. The annual average temperature for the last four decades (1961-2000) was higher than annual averages during the three previous decades (1931-1960). The Food and Agricultural Organization of the United Nations (FAO) has stated that in 2008 climate change has contributed to an increase in the number of people experiencing hunger. In 2009 the total number of people facing hunger was estimated at 1 billion, 100 million higher than in 2007, in part due to the world financial crisis.

Climate change has caused serious damage through two weather phenomena: flooding caused by severe storms with heavy rain and higher temperatures. Flooding usually occurs at different times in Viet Nam's different regions from May-June to September-October in the northern part; and from June-July to October-November in the northern central part; from October to December in the southern central part; from June to December in the western highlands and from July to December in the southern part. The Red River Delta has experienced two devastating floods, in August 1945 and August 1971. Both damaged many dams and dykes in a number of provinces. During the El Nino year of 1997-1998, the effects worldwide caused 24,000 human deaths and economic losses estimated at 34 billion US$. In Viet Nam, El Nino has caused severe drought in the western highlands and southern provinces with losses estimated at 312 million US$. In the first half of 2010, 47,000 ha of upland crops were grown with insufficient water and seeds could not be sown over an area of 6,250 ha because of serious drought (MARD, 2010).

3. Objectives and Scope of the Study

The general objective of the study is to review the food availability and to evaluate climate change impacts on food production. The specific objectives are to (1) evaluate food production and potential productivity in the country, (2) forecast rice yields as affected by climate change in the Red River Delta and (3) create awareness on climate change and its impacts to policymakers and the public in Viet Nam.

Rice is the most important food crop in Viet Nam. Rice is grown on over 4.1 million ha distributed around the country, with concentrations in the two major delta systems of the Red and Cuu Long rivers. The Red River Delta is the second largest rice-growing area. This delta is part of 11 provinces in the northern part of the country where about 20 million people live in the most densely population part of Viet Nam, at 933 people/km^2. The Red River flows through lowland topography that is expected to be significantly affected by climate change. Paddy fields in the delta experience flooding during the rainy season and under El Nino suffer damages from high temperatures, salinity and soil acidification in coastal areas, including Nam Dinh, Thai Bin and Quang Ninh provinces. Climate change can potentially affect rice yields and food security in this region and nationally.

4. Methodology

4.1 Data collection and review of agricultural practices and yields under climate change

Weather data from 2005-2009 was compiled and crop phenotype characteristics selected to put into the Nutrient Decision Support System (NuDSS). NuDSS results were used to simulate actual and potential rice yields for that data in turn, to inform the Decision Support System for Agrotechnology Transfer (DSSAT) and to simulate how current rice yields can be affected by climate change scenarios. Secondary data on agricultural yields in the country and the study site were gathered from national statistical publications and regional agencies.

4.2 Implementing of the field trials

4.2.1 Site selection

Field experiments were conducted at 21° 20.929’ N and 106° 01.929’ E, 7 metre above sea level, at the same type of site with the same soil types as previous sites where the International Rice Research Institute (IRRI) had led experiments in 2006 and 2007. Results were collected to compare the rice yields using different planting timings and under different weather conditions. Summer rice crops were planted on 3 and 13 July and harvested on 8 and 19 October 2009.

4.2.2 Materials

The same rice variety, fertilizer rates and cultivation techniques were applied during the field trial period, which also matched the technology used in the 2006 and 2007 experiments.

The rice variety used in field experiments was inbred Khang Dan 18. Its growth period is short, 130-135 day in spring and 100-110 days in summer. Plant height is 95-100 cm with hard leave and straight standing plant. The weight of 1,000 grains on average is 19.5-20 g. Average yield is about 4.0-4.5 tons/ha and high yields are about 5.5-6.0 tons/ha (MARD, 2005).

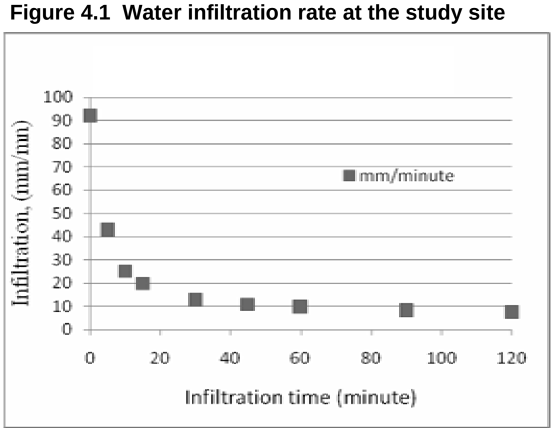
A survey of soil characteristics was conducted in the study area. Soil chemical analysis is presented in Table 4.1. The paddy field under a rice–rice–maize system has a rank of light acidity to acidity with pHw of 5.5-6.2. The soil contains low levels of organic matter and total nitrogen content. Soil organic matter (OM), using the Walkley-Black method, is 1.161 per cent in topsoil and less in deeper layers (0.774-0.420 per cent). Total nitrogen (N) is 0.197 per cent in topsoil and 0.78-0.045 per cent in deeper layers. The total phosphorus and potassium is low (P2O5 is 0.047-0.012 per cent; K2O is 1.39-0.55 per cent).

Table 4.1 Soil chemical analysis at the study site

Soil depth (cm)	pHw (1/5)	Total content in dry soil (%)				Available (mg/100g soil)		Exch. cations (meq/100gsoil)		CEC (meq/ 100gsoil)
		OM	N	P_2O_5	K_2O	P_2O_5	K_2O	Ca^{2+}	Mg^{2+}	
0-20	5.7	1.616	0.179	0.047	0.97	2.67	1.83	2.13	1.35	10.82
20-43	6.2	0.774	0.078	0.012	1.39	0.22	2.16	1.98	1.46	8.42
43-78	5.5	0.639	0.062	0.012	0.93	0.65	1.97	1.22	0.95	9.03
78-120	5.7	0.420	0.045	0.014	0.55	0.78	1.37	1.61	1.61	8.76

The soil was low in available phosphorus and potassium. Bray 2 extracted phosphorus is changed in the rank of 2.67-0.22 mg, P_2O_5 100 g soil-1 and available potassium is 2.16-1.37 mg100g soil-1. The exchangeable cations of Ca_2+, Mg_2+ in soil were 2.13-1.22 meq/100g soil and 1.46-0.9 meq/100g soil, respectively. Cation exchange capacity (CEC) changes in rank of 10.82-8.46 meq/100g soil.

Figure 4.1 Water infiltration rate at the study site



Source: Authors' measurement from the field at the trial, 2009.

Water infiltration rates were measured and shown to change over time (Figure 4.1). When infiltrated continuously for 120 minutes, the minute by minute rate dropped from 91.9 to 7.3 mm/minute. Water infiltration started at the high rate of 91.9 mm/minute at beginning and quickly dropped to 42.9 mm/minute after 5 minutes and to 25.3 mm/minute after 10 minutes. After the first 10 minutes the rate of the decreasing infiltration rate slowed considerably, dropping from 19.9 to 7.3 mm/minute over the remaining 110 minutes.

4.3 Simulating potential rice yields

Plant potential yields are closely related to weather: solar radiation, air temperature, rainfall and day length. Potential yields are also influenced by crop genotype variety and ecological behaviour. The Nutrient Decision Support System (NuDSS) for irrigated rice helps estimate the nutrient requirements in irrigated rice to achieve realistic target yields; select the adequate and least costly combination of quality fertilizer sources to match those nutrient requirements; choose fertilizer split applications and estimate the profit gained from improved nutrient and crop management programmes.

Use of long-term averages for weather data also helped to determine optimal dates for transplanting and harvesting. Other input parameters include radiation use efficiency (RUE) and harvest index (HI).The default value for RUE is 2.6 g MJ-1 for above ground dry matter, for intercepted photosynthetically active radiation, which is derived from the slope of the linear relationship between accumulated intercepted photosynthetically active radiation and accumulated biomass when the crop is growing in adequate conditions of temperature, water and soil nutrient supply. This default value is obtained from very high-yielding rice experiments (Sheehy *et al*., 2004). HI is the ratio of grain yield to the total plant biomass. The HI in the yield potential model is different from the HI in the crop profile settings. The HI in the crop profile settings, with a default value of 0.50 kg kg-1, was used to compute the amount of nutrients removed from the soil through grain and straw.

Outputs from the simulation include harvest date, yield potential, number of days to maturity and the yield goal.

4.4 Use of modeling of DSSAT to simulate the rice yields and scenarios

4.4.1 Model description

The DSSAT model can arrange and store input data on crop, soil and weather and use that data to predict crop yields. For these predictions the model requires daily weather data input including solar radiation (SRAD), maximum temperature, minimum temperature and rainfall. It predicts growth and development of a crop based on its genetic characteristics, temperature, and day length. Besides genetic characteristics and weather information, data from related models for water and nitrogen help predict the growth and development of a crop at different stages of its growth.

Once calibrated, the model predicts and analyses effects of different management options for a particular cropping sequence. In this study, CERES-Rice models integrated in DSSAT were calibrated and validated separately, with data on weather, soil and crop management. The data used for calibration covered the span of 1 year; for validation of CERES-Rice, the data used covered a span of 3 years: 2006, 2007 and 2009. The data on soil characteristics and weather variables were measured and stored in the soil input file. Soil characteristics included pH, organic matter carbon (OC), total and available P and K, exchangeable cations (Ca_2+, Mg_2+) and cation exchangeable capacity (CEC). Weather invariables included daily SRAD, maximum and minimum temperature and rainfall. The input data for calibration and validation of the CERES-Rice models were date of sowing, emergence, flowering and maturity with detailed data on cropping practice and management options. The output data were biomass at different stages of crop growth, yield parameters, harvest index, grain yield and biomass nitrogen.

4.4.2 The Weather Generator Model: SIMMETEO

The weather data for running the model were calculated and stored using the daily data from the weather station closest to the study site. The minimum data set was 5 consecutive years of 4 daily weather variables: SRAD (MJ m-2), rainfall (mm), and maximum and minimum temperatures (°C).

The weather utility programme WeatherMan was used to store, arrange and produce monthly means for local weather variables. These monthly means were then input to the model for calibration and validation purpose. SIMMETEO, an integral part of DSSAT 3.5, was used to generate projections for 30 years from the monthly summaries. The precipitation data were generated independently using SIMMETEO; the variables of SRAD and temperatures were generated depending on the occurrence of precipitation.

4.4.3 Calibrating CERES-Rice in DSSAT 4.0.2

The model was calibrated using data for agronomic management, soil and crop performance. The data for agronomic management included crop residue incorporation, rate of fertilizer nitrogen application and irrigation schedule. The data on crop performance were dates of PI. F. M. panicle number, grain number, biomass yield and grain yield. The calibration of CERES-Rice and CERES-Wheat involved comparison of simulated and measured crop phenological events (dates of PI, F and M), biomass, grain N and grain yields. Calibrations were performed separately for transplanted and directly seeded rice (2002) and wheat (2002-2003). The sensitivity of the models to rate and percentage of incorporated crop residue and to rate of fertilizer N applications was also tested before performing the validations. Coefficient of variation (CV) was calculated for all factors to determine the sensitivity of the model, with higher CV values indicating greater sensitivity.

5. Results and Discussion

5.1 Site characteristics

5.1.1 Population in Red River Delta

The population density in the Red River Delta is the highest of all regions in the country (Table 5.1). Approximately 20 million people live in the delta, 933 people/km^2. In all regions but one, the rural population accounts for more than 72 per cent of the total population. The south-east region is the exception; its agricultural population consists of only 42 per cent of the total population. The south-east region has the second highest population density with 543 people/km^2.

Table 5.1 Area, population and density in country and eco-biological regions (as of 1 Jan 2008)

Eco-biological region	Area (km^2)	Population (1 000 people)			Density (people/km^2)
		Total	Rural	Rural in percentage of total	
Country	33 115.0	86 210.8	61 977.5	71.9	260
Red River Delta	2 097.3	19 654.8	14 284.5	72.7	933
Central & northern mountains	9 543.4	11 207.8	9 455.5	84.4	118
Central coast	9 589.4	19 820.2	15 343.2	77.4	207
Western highlands	5 464.0	5 004.2	3 606.2	72.1	92
South-east	2 360.5	12 828.8	5 391.6	42.0	543
Cuu Long River delta	4 060.0	17 695.0	13 896.5	78.5	436

Source: GSO, 2009.

Less people live in the mountainous areas than in the delta regions. The lowest density is in the western highlands (Dak Lack, Gia Lai, Kon Tum, Dak Nong and Lam Dong provinces) with a population density of 92 people/km^2.

5.1.2 Agricultural and food production in Red River Delta

Rice and maize are the main cereal food crops in Viet Nam. They are increasing in both cultivated area and production. In 1995, rice area was approximately 7 billion ha with production of 26 billion tons.

Table 5.2 Area for cereal food production in Viet Nam, the Red River Delta and its provinces
(in thousands of hectares)

Year	1995	1997	2000	2002	2004	2006	2007	2008
Country	6 765.6	7 099.7	7 666.3	7 04.3	7 45.3	7 24.8	7 207.4	7 414.3
Red River Delta	1 238.1	1 244.3	1 261.0	1 245.8	1 210.0	1 171.2	1 158.1	1 153.2
Hanoi	56.1	54.5	54.2	52.2	47.4	44.0	43.3	206.7
Ha Tay	168.2	166.6	168.8	168.4	164.4	158.7	155.4	-
Vinh Phuc	72.1	71.4	74.8	73.9	72.9	68.3	69.0	57.9
Bac Ninh	78.8	81.2	84.0	83.5	80.8	79.3	78.5	76.2
Quang Ninh	45.1	47.3	48.4	49.2	8.4	47.2	46.4	45.6
Hai Duong	148.6	148.5	147.5	142.4	35.9	130.9	128.6	126.9
Hai Phong	93.7	95.1	95.9	94.0	89.9	86.9	85.6	83.1
Hung Yen	89.4	89.4	89.7	88.7	85.5	81.5	80.4	81.7
Thai Binh	169.4	170.7	173.1	171.8	168.6	166.0	164.9	168.3
Ha Nam	72.9	73.6	75.4	75.1	73.8	71.3	70.7	69.7
Nam Dinh	163.5	165.1	166.2	164.1	161.0	157.3	156.1	156.7
Ninh Binh	80.3	80.9	83.0	82.5	81.4	79.8	79.2	80.4

Source: GSO, 2009.

The country's total area of harvested cereal food crops has increased from 6.77 million ha in 1995 to 7.41 million ha in 2008. The cereal growing area has increased at rates of between 6.5 and 11.3 per cent in the past 13 years (Table 5.2).

Table 5.3 Cereal food production in Viet Nam and the Red River Delta region (in '000 of tons)

Year	1995	1997	2000	2002	2004	2006	2008
Country	26 142.5	29 182.9	34 538.9	36 960.7	39 581.0	39 706.2	43 258.3
Red River Delta	5 462.5	6 143.1	7 056.9	7 212.8	7 288.9	7 068.6	7 204.1
Hanoi	198.9	223.6	256.3	233.2	227.6	211.7	1 287.8
Ha Tay	698.5	755.8	990.4	1 035.3	1 022.7	972.7	
Vinh Phuc	255.7	303.1	381.9	397.8	436.7	382.6	376.1
Bac Ninh	257.4	337.7	453.1	452.8	455.3	442.0	443.9
Quang Ninh	122.7	155.7	189.0	213.8	235.3	221.1	227.7
Hai Duong	697.1	798.2	842.9	841.0	823.2	789.5	770.3
Hai Phong	397.0	430.6	492.1	500.0	512.9	488.2	485.5
Hung Yen	421.7	480.0	549.1	547.4	547.5	535.2	561.7
Thai Binh	966.4	975.5	1 071.2	1 102.6	1 124.9	1 122.1	1 154.2
Ha Nam	312.9	359.1	408.9	424.6	422.1	435.1	456.8
Nam Dinh	807.3	927.6	976.5	993.5	1002.6	984.1	948.1
Ninh Binh	326.9	396.2	445.5	470.8	478.1	484.3	492.0

Source: GSO, 2009.

Income from cereal foods increased from 26.2 million tons in 1995 to 34.5 million tons in 2000 and to 43.26 million tons in 2008. During 1995-2008, cereal food yields increased continuously at rates of between 11.6 and 65.6 per cent for the whole country (Table 5.3). Thanks to the application of intensive crop management techniques, particularly for rice, food production has continuously increased over time, even though the total harvested area has decreased.

In the Red River Delta, soil types are mostly *fluvisols* derived from alluvial sediments of the river. Different cropping systems are appropriate depending on the water regime and topography.

In lowland areas with waterlogging in summer, rice is planted in the spring and grows for 3-4 months, then the field is left fallow. At higher elevations, soils are well drained and dry crops usually lack water in spring, hence rice is only planted once per year. Single rice cropping systems include: rice–upland crop; upland crop–rice –rice; and spring soybean–summer green bean–autumn rice. In even higher elevations, rice is planted after winter and spring crops, such as maize, or after winter vegetables, such as cucumber, tomato, bean, sweet potato and potato.

Delta soils are most suitable for rice cultivation in two crops per year in spring and summer. The cropping calendar can be changed from year to year depending on the rainy season. Lowland rice–rice systems with waterlogging in each crop can be sown in early, middle or late season.

At higher elevations where water in well drained in winter, an additional winter crop can be added to the rice–rice system: rice–rice–maize or rice–rice–vegetables, such as cabbage, pumpkin, or tomato. In such 3-crop systems, climate change could affect rice yields, and yields for the third, winter crop as well. On light-texture soils, crop yields could be more seriously affected by climate change than in lowland with rice–rice system in year (Table 5.4).

Table 5.4 Rice cropping calendar in the Red River Delta

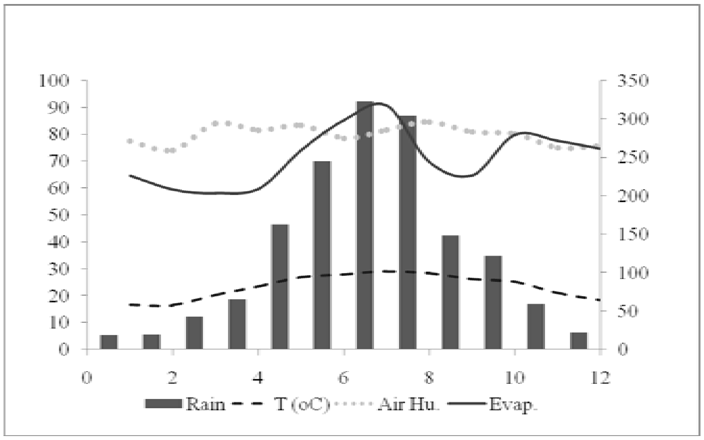
System	Season	Rice	Seed sowing	Planting	Harvesting
Rice–rice	Spring	Early	25 - 30/12	05 - 10/2	20 - 25/5
		Main crop	05 - 20/1	20 - 25/2	01 - 15/6
		Late	25/2 - 05/3	25/1 - 5/2	25 - 30/6
	Summer	Early	20 - 30/5	01 - 10/6	01 - 10/9
		Main crop	01 - 10/6	10 - 20/6	25/10 - 10/11
		Late	25/6 - 05/7	25/6 - 5/7	5 - 25/11

Source: Nguyen Cong Vinh *et al.,* 2007.

5.1.3 Weather conditions

Weather conditions at the study site are presented in Figure 5.5. Air temperature ranged from 16.5°C to 29°C, averaged 23.3°C and totalled 279.9°C per year on average. Air humidity was 74.1-84.6 per cent. Water evaporation changes ranged between 58 and 90.7 per cent. The lowest mean evaporation for the 17-year span is February to April and the highest is May to August. Rainfall varies from 18.5 to 322.8 mm/month, averaged 127.4 mm per month and totalled 1,528.8 mm per year.

Figure 5.1 Weather condition (1992-2009)



Source: Hydrometeorological Service.

In the dry season (December to June), monthly averages were 23.1°C for air temperature, 80.3 per cent for air humidity, 67.3 mm of evaporation, 106.8 mm of precipitation and 118.9 hours of sunlight. During this season significant low temperatures and drought can affect cultivation.

In the wet season (July to November), the averages were 25.9°C, 80.4 per cent for humidity, 76.5mm for evaporation, 190.9mm for precipitation and 136.4 hours of sunlight

5.1.4 Actual and potential rice yields at field trials

Potential crop yields depend on weather conditions (solar radiation, air temperature and sunlight day length). We input long-term averages for the baseline data set before entering the specific date of transplanting to start the simulation. Other input parameters include radiation use efficiency (RUE) and harvest index (HI). The default value for RUE is 2.6 g above ground dry matter MJ-1 of intercepted photosynthetically active radiation, which is derived from the slope of the linear relationship between accumulated intercepted photosynthetically active radiation and accumulated biomass when the crop is growing in adequate conditions of temperature, water and soil nutrient supply.

Total air temperature during spring rice season was 106-113.3°C, in summer rice season, 131-136.7°C. Solar radiation changed following the same trend as air temperature. In spring season it is lower than in summer season. Day length ranged from 11 to 13 hours/day. Day length was the same in spring and summer periods of standing rice (Table 5.5).

Nutrition Decision Support System (NuDSS) is a software application used to estimate potential rice yields under different climate conditions and cultivar phenotypes. The climate factors include precipitation, air humidity, air temperature, sunshine and day length. NuDSS for irrigated rice provides decision support on site-specific nutrient management (SSNM) in the irrigated lowlands. The model also simulates potential rice yields by season. Simulation outputs include harvest date, potential yield (Ypot.), number of days to maturity and the yield goal. Under cold weather conditions, growing time for spring rice is longer than the growing time in summer season.

Table 5.5 Monthly mean weather values for rice seasons at the study site

Month	Day of month (days)	T.mean (^oC)	SRA (M J/ m^2/day)	Length day (hr)	Month	Day of month (days)	T.mean (^oC)	SRA (M J/ m^2/day)	Length day (hr)
	Spring rice – 2006					Summer rice – 2006 (*)			
Feb	28	12.9	12.4	11.6	Jul	31	27.0	15.1	13.0
Mar	31	16.6	11.1	11.9	Aug	31	26.2	13.3	12.7
Apr	30	22.7	14.2	12.8	Sep	30	24.0	17.9	12.1
May	31	26.3	17.1	13.6	Oct	31	23.7	15.2	11.5
Jun	30	27.5	14.7	13.2	Nov	30	20.9	19.9	11.2
total	150	106	69.5	63.1	Total	153	121.8	81.4	60.5
	Spring rice – 2007					Summer rice – 2007 (*)			
Feb	28	19.6	10.6	11.4	Jun	31	26.0	15.5	13.2
Mar	31	18.8	12.3	11.9	Jul	31	27.3	18.6	13.1
Apr	30	20.9	12.3	12.6	Aug	31	27.7	15.8	12.7
May	31	26.6	16.9	13.0	Sep	30	27.4	15.8	12.1
Jun	30	27.4	18.7	13.2	Oct	31	28.3	13.1	11.7
total	150	113.3	70.8	62.1	Total	154	136.7	78.8	62.8
	Summer rice 1 – 2009					Summer rice 2 – 2009 (**)			
Jun	30	27.4	18.7	13.2	Jun	30	27.4	18.7	13.2
Jul	31	27.8	17.7	13.1	Jul	31	28.1	18.1	13.0
Aug	31	27.5	19.0	12.7	Aug	31	27.5	19.0	12.7
Sep	30	26.9	17.6	12.1	Sep	30	26.9	17.6	12.1
Oct	31	24.8	16.3	11.7	Oct	31	24.6	15.9	11.6
Total	153	134.4	89.3	62.8	Total	153	134.4	89.3	62.8

Source: (*)"Integrated crop management of rice for optimizing profit in Viet Nam, 2006-2007" project, Soil and Fertilizer Research Institute and International Rice Research Institute.
(**) Field trials, 2009.

Results are presented in Table 5.6. The actual field yields obtained was between 40.8 and 52.6 per cent of predicted yields, with percentages decreasing from 2006 to 2009. For Khang Dan rice, the growing period is 126-127 days in spring and 104-105 days in summer.

Table 5.6 Potential grain yields for different years (simulated by NuDSS)

Rice grain yield	2006		2007		2009	
	Spring	Summer	Spring	Summer	Crop 1	Crop 2
Transplanting (date)	25 Feb	17 Jul	2 Feb	26 Jul	4 Jul	13 Jul
Harvesting (date)	1 Jul	2 Nov	10 Jun	8 Nov	16 Oct	25 Oct
Growth duration (days)	126	107.9	129	104.6	103.9	104.2
Yield potential (tons/ha^{-1})	9.4	9.3	9.4	8.8	9.6	9.5
Harvest index (HI)	0.54	0.50	0.50	0.50	0.50	0.50
Actual field yield (%)	52.6	49.7	49.9	56.7	45.6	40.8

Source: (*)"Integrated crop management of rice for optimizing profit in Viet Nam, 2006-2007" project, Soil and Fertilizer Research Institute and International Rice Research Institute.
(**) Field trials, 2009.

The potential grain yield is estimated at 9.4 t/ha for spring rice and 8.8-9.5 t/ha for summer rice with a harvest index of 0.5.

5.2 Rice yield affected by weather conditions

Rice yields under weather conditions were simulated using the DSSAT Cropping System Model version 4.0.2.000.

5.2.1 Climate input for modeling

An air temperature for crops (spring rice for 2006/2007 and summer rice for 2006/2007/2009) is simulated by the model. Eighteen consecutive years (1992-2009) of weather data from the study site were stored in SIMMETEO, the weather generator model. The data set included daily weather variables, including SRAD (MJ m-2), rainfall (mm) and maximum and minimum temperatures (°C). The weather utility programme WeatherMan was used to store, arrange and produce monthly means of local weather variables to predict yields for calibration and validation purposes. However, SIMMETEO, an integral part of DSSAT3.5, was used for generating 30 years of projected monthly summaries of the weather variables.

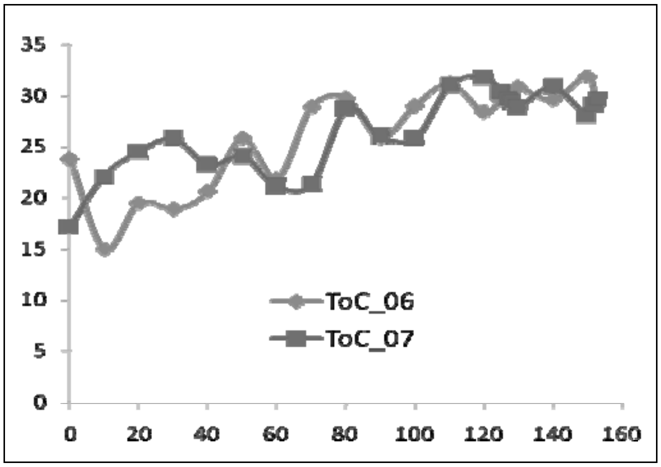
Table 5.7 Solar radiation by day and by crop season simulated by SIMMETEO using averages from 1999-2009

Day during crop season	Solar radiation (SRAD. MJ/m^2.d)					
	Spring 2006	Summer 2006	Spring 2007	Summer 2007	Summer 1 2009	Summer 2 2009
10	8.7	11.6	8.3	11.7	11.7	11.6
0	8.9	11.5	8.6	11.7	11.6	11.6
20	9.3	11.4	8.9	11.6	11.6	11.5
30	9.6	11.3	9.2	11.5	11.5	11.4
40	9.9	11.2	9.5	11.5	11.4	11.3
50	10.2	11.1	9.8	11.4	11.3	11.2
60	10.6	10.9	10.1	11.2	11.1	11
70	10.9	10.3	10.5	11.1	11	10.6
80	11.2	9.8	10.8	11	10.6	10.1
90	11.5	9.3	11.1	10.5	10.1	9.6
100	11.6	9.1	11.5	10	9.5	9.3
110	11.7	9	11.6	9.4	9.2	9.1
120	11.8	8.7	11.7	9.2	9.1	8.9
125	11.75	8.6	11.75	9.1	9	8.8
127	11.73	8.5	11.77	9.1	-	-
128	11.72	-	11.78	9.1	-	-
130	11.7	-	11.8	-	-	-
140	11.7	-	11.8	-	-	-
150	11.6	-	11.7	-	-	-
152	11.6	-	11.7	-	-	-
153	-	-	11.7	-	-	-

Sources: For 2006 and 2007 data, "Integrated crop management of rice for optimizing profit in Viet Nam, 2006-2007" project, Soil and Fertilizer Research Institute and International Rice Research Institute; for 2009 data, author's field trials.

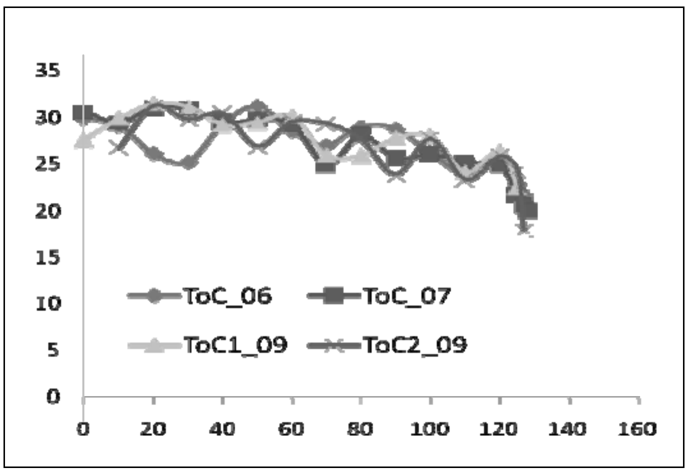
The precipitation data were generated independently by SIMMETEO whereas other variables, such as SRAD and air temperature, were generated depending on the occurrence of precipitation. Simulation results are presented in Figure 5.2 for temperature, Figure 5.3 for actual evaporation. Table 5.7 gives projected data for solar radiation, during the crop growth period for each crop season (Figure 5.2 a, b). Time needed for growth is simulated at 152-153 days in spring and 127-128 days in summer.

Figure 5.2 a Temperatures in spring



Source: Simulated by DSSAT, 2009.

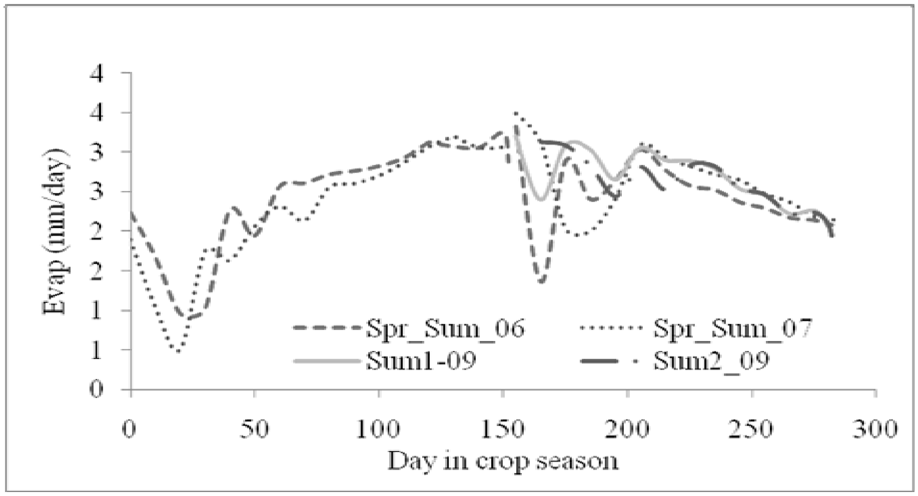
Figure 5.2 b Temperatures in summer



Source: Simulated by DSSAT, 2009.

Evaporation is simulated in Figure 5.3. At the beginning of the spring and autumn rice growing periods, evaporation is low and increases over time. For spring rice, evaporation is highest at harvest; for summer rice, the evaporation decreases over time and the lowest value is at harvest.

Figure 5.3 Evaporation during crop season at site



Source: Simulated by DSSAT, 2009.

5.2.2 Rice yield simulation

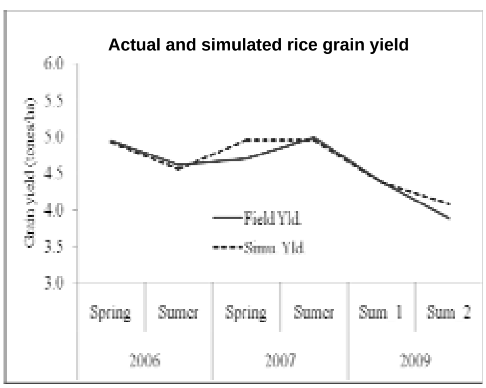
Grain yields were simulated for 6 crops in 3 growing periods (Figure 5.4). Simulated yields were 4.918-4.919 t/ha for spring rice and 3.877-4.978t/ha for summer rice, whereas field grain yields were 4.938 t/ha and 4.692 t/ha for spring rice and 3.87-4.987 t/ha for summer rice. Difference between simulated and field grain yields were (±) 0.25-5.48 per cent. The relationship between simulated and actual yields from field trials is presented in Figure 5.4. Relation coeffectiveness is indicated by a function of Y=1.010x (Figure 5.4 b) with R=0.856, when Y is actual yield and x is dry grain yield, simulated by DSSAT.

These results indicate that the model is suitable for simulating and estimating rice yields within climate change scenarios.

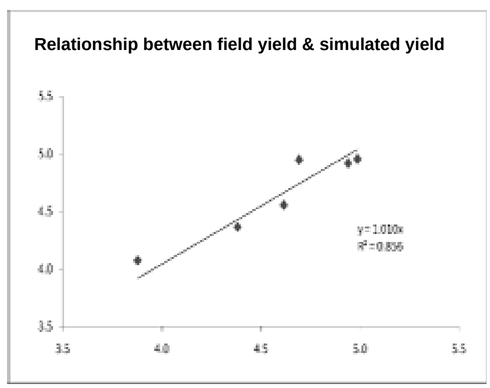
Table 5.8 Main growth and development variables simulated by model

Variable	Spring (06-07)	Sumer (06-07-09)	Mean (6 crops)
Panicle initiation day (dap)	90.0	57.5	68.3
Anthesis day (dap)	124.0	91.5	102.3
Physiological maturity day (dap)	152.5	126.25	135.0
Yield at harvest maturity (kg of dm)	4 933.5	5 613.3	5 386.7
Unit wt at maturity (g of dm/unit)	0.0193	0.0193	0.0193
Number at maturity (no/m^2)	25 563	23 254	24 023
Pod/panicle (no/m^2)	999.9	1 084.9	1 056.5
Leaf area index, maximum	4.54	3.27	3.69
Tops weight at anthesis (kg of dm/ha	9 716.5	6 684.0	7 694.8
Tops N at anthesis (kg/ha)	159.5	111.8	127.7
Tops weight at maturity (kg of dm/ha)	12 733.0	10 387.3	11 169.2
By-product produced (stalk) at maturity	7 799	5 899	6 532
Harvest index at maturity	0.388	0.432	0.417
Leaf number per stem at maturity	19	19	19
Grain N at maturity (kg/ha)	90.0	87.8	88.5
Tops N at maturity (kg/ha)	220.0	179.5	193.0
Stem N at maturity (kg/ha)	130.5	91.5	104.5
Grain N at maturity (%)	1.82	1.96	1.91

Figure 5.4 Relation between field and simulated grain yields



(a)



(b)

Source: Simulated by DSSAT, 2009.

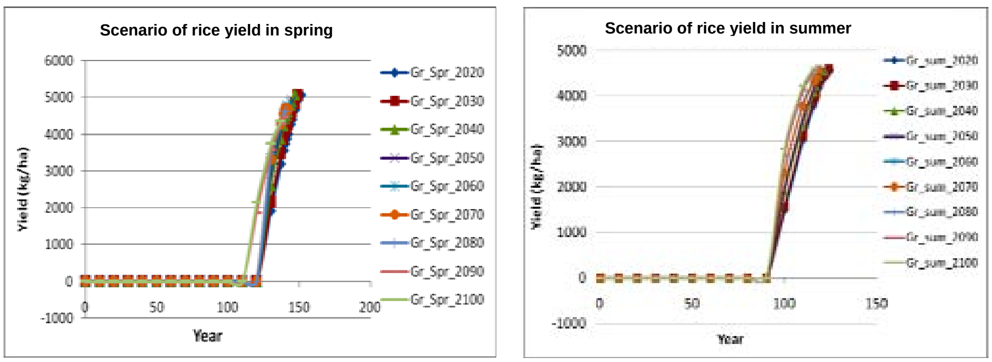
5.2.3 Rice yield under different climate change scenarios

Climate change scenarios give projections for conditions in the Red River Delta by the end of the twenty-first century, compared against climatic conditions in 1980-1999. Annual mean temperature is expected to increase by 0.5-1.6°C in the low emission scenario (B1); by 0.5-2.4°C in the medium emission scenario (B2) and by 0.5-3.1°C in the high emission scenario (A2). Total precipitation is expected to increase about 1.6-5.2 per cent;

1.6-7.9 per cent; and 1.6-10.1 across the same three scenarios, respectively. In the northern climate zones, rainfall is expected to decrease about 3-6 per cent in the period March-May; 6-10 per cent mid rainy season in the low emission scenario; 10-15 per cent in the medium emission scenario and 4-5 per cent in the high emission scenario.

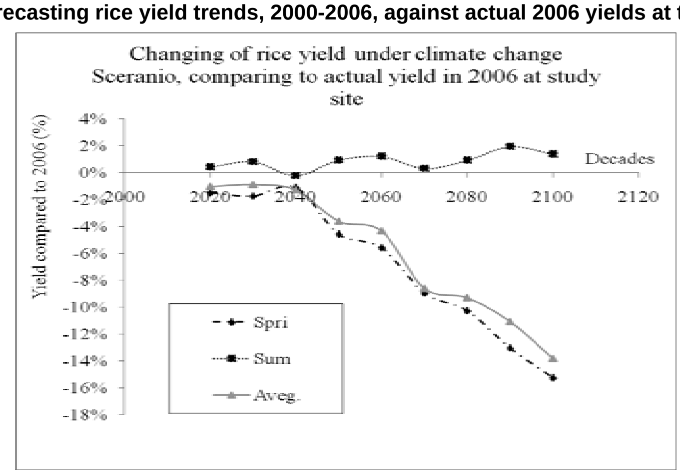
We used DSSAT to simulate future rice production scenarios under these anticipated climate change conditions at the study site for 2020-2100. Weather conditions in 2006 include an average monthly temperature of 23.3°C; 79.7 per cent air humidity; 71.7 per cent evaporation and 127.4 mm of rainfall (Figure 5.5).

Figure 5.5 Climate change effects on rice yields in the Red River Delta



Source: DSSAT simulation.

Figure 5.6 Forecasting rice yield trends, 2000-2006, against actual 2006 yields at the study site



Source: DSSAT simulation.

Due to increased air temperature, the rice growing season would decrease 3-14 days in spring and 3-10 days in summer. Yields for summer rice crops would change little or improve slightly against the baseline. But spring rice crops would yield increasingly less rice after 2040 (Figure 5.6). Figure 5.6 Forecasting the rice yield trend in decades twenty-first compared with 2006.

Rice yields in spring would decrease from 5,078 kg/ha in 2020 to 4,368 kg/ha in 2100 whereas in summer rice yields could increase from 4,545 kg/ha in 2020 to 4,618 kg/ha in 2100. Hence rice yields would decrease by between 1 and 15 per cent for spring rice. Overall rice yield reductions are estimated at 3-5 per cent during 2020-2050 and 6-15 per cent during 2060-2100 (Figure 5.6). However, rice yields could increase by 1-2 per cent for summer rice.

6. Conclusions and Recommendations

Viet Nam is a densely populated agricultural country with limited arable land. The government has made food production a priority to ensure food security and to put Viet Nam in the ranks of the rice exporting countries. Developments in agricultural production have achieved much in recent years, contributing between 20 and 40 per cent to the country's GDP. However, climate changes have affected food production in northern Viet Nam. The area has experienced unsuitable weather conditions, which led to reduced yields and productivity in 2009. Actual field yields were reduced from 52.6 per cent in 2006 to 40.8 per cent in 2009, in comparison with potential yields as simulated by NuDSS. This reduction has signalled the need for policy adjustments to ensure food security at national and regional levels.

Using data from climate change scenarios for Viet Nam for 2020-2100, the forecast for rice yields at the Red River Delta study site shows that yield will decrease by 1-15 per cent, compared to actual yields in 2006. These estimates indicate that climate change impacts can potentially harm food production and undermine food security in Viet Nam in future.

The effects of El Nino on food production and food security is significant and affects many factors: more marginal soils, from acidity or salinity; drier and hotter weather; and drought. The Viet Nam government has been proactive in its efforts to mitigate the regional climate change impacts on agriculture and staple food production that derive from this global phenomenon, with a specific focus on rice production in the two major delta regions of the Red River and the Cuu Long River. Three strategies have been put forward for implementation by various agencies as well as by farmers themselves: anticipation strategies, adaptation strategies and mitigation strategies. To anticipate impacts, state and local governments have issued many policies to support efficient development of food production and food security. To adapt to the impacts, improving and innovating farming structure and agricultural production are proposed. The mitigation strategy focuses on building capacity in water storage and irrigation systems.

In addition, food productivity needs further assessment in the major ecological zones for major crops, including rice and maize, to have a thorough view of food production.

Anticipation strategy. Anticipation strategies include adjusting existing plans for infrastructure development and for water distribution and management systems; improving people's capacity to understand climate change and its negative impacts; and developing information-sharing practices and an early warning system. To meet demands for domestic consumption and export of rice, the amount of land dedicated to paddy fields in future should be maintained. In addition, other food crops should be developed to reduce risks of crop failure due to natural calamity and extreme weather changes due to climate change. Using biotechnology to produce varieties that are more tolerant to drought, salt, acidity and disease should be a priority in the country's agricultural development strategy.

Applied research should focus on technologies to save irrigation water demands by, for example, alternating between dry and wet irrigation or using direct sowing instead of replanting methods.

Adaptation strategy. Two broad types of possible adaptation strategies can be applied to rice cultivation. Short- and medium-term strategies are applicable at the farm level with involvement from farmers and extension workers. Long-term strategies at national and regional levels involve changes to government policies. We recommend two shorter-term strategies. Crop water availability can be improved by using alternating wet and dry irrigation technology to replace continuous irrigation that farmers have practiced in the past. In the southern regions, one rice crop in the three-rice annual crop system can be replaced with one dry crop such as maize or beans.

Apart from agronomic practices and policy, longer-term plant breeding and biotechnology advances could also improve productivity and yield. We recommend that research continues to focus on rice cultivars that increase water use efficiency. Such cultivars can potentially deliver high and stable yields under dry conditions. They require the identification of key traits and incorporation of those traits into high yielding varieties using conventional or biotechnological tools.

Mitigation strategy. To narrow the gap between actual and potential rice yields, both government agencies and farmers can improve farm management through integrated crop management, livestock management, carbon sequestration, water pricing and water management.

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Appendices to Part III

Appendix 1. Meteorological data from the study site used for model (averaged: 1992-2009)

Month	Air Temp. (°C)	Air Humidity (%)	Evaporation (mm)	Rain (mm)	Sun_h (hours)
1	16.7	77.4	64.6	18.5	49.7
2	16.5	74.1	59.4	19.3	45.7
3	20.4	84.0	58.1	42.5	80.5
4	23.5	81.5	59.8	64.6	151.1
5	26.9	83.3	74.2	162.8	154.0
6	28.0	78.5	85.1	244.7	163.0
7	29.0	81.6	90.7	322.8	160.2
8	28.3	84.6	69.7	303.5	156.7
9	26.3	80.8	64.7	147.7	139.4
10	25.1	80.0	79.7	121.4	132.2
11	21.0	74.8	77.6	58.8	93.2
12	18.3	75.7	74.7	22.0	63.3
Monthly average	23.3	79.7	71.5	127.4	115.8
Total	279.9	956.3	858.2	1 528.8	1 389.0
Monthly average in dry rice season	21.8	81.0	306.9	524.3	571.4
Monthly average in rainy rice season	27.2	366.3	347.3	1017.8	670.0

Source: Simulated by DSSAT.

Appendix 2. Plant growth parameter for DSSAT input

Parameter	2006		2007		2009	
	Spring	Summer	Spring	Summer	Summer 1	Summer 2
Date of seed sowing	2/2/2006	7/1/2006	1/15/2007	6/11/2007	6/16/2009	6/26/2009
Transplanting date	2/15/2006	7/19/2006	2/2/2007	6/26/2007	7/4/2009	7/13/2009
Seed age in days	13	18	18	15	18	17
Plant density (hills/m^2)	45	45	45	45	45	45
Spacing in cm	13x17	13x17	13x17	13x17	13x17	13x17
Number of plants/hill	3	3	3	3	3	3
Number of plants/m^2	135	135	135	135	135	135
Harvest date	6/14/2006	10/27/2006	5/25/2007	10/18/2007	10/18/2009	10/28/2009
Number of panicles/m^2	289	225	247	360	348	227
Grain yield (kg/ha)	4 938	4 616	4 692	4 987	4 380	3 877
P1000 (GR)	19.2	19.9	22.1	19.2	17.8	17.5
Total biomass (kg/ha)	9 198	9 425.5	12 866.1	9 183.6	11 355	7 316.7
Effectiveness	54per cent	49per cent	36per cent	54per cent	39per cent	53per cent

Source: Field trial results from 2006, 2007 and 2009 at the study site.

Appendix 3. Input data for crop modeling in DSSAT

Criteria	2006		2007		2009	
	Spring	Summer	Spring	Summer	Summer 1	Summer 2
Sowing date	2/2/2006	7/1/2006	1/15/2007	6/11/2007	6/16/2009	6/26/2009
Retransplanting date	2/15/2006	7/19/2006	2/2/2007	6/26/2007	7/4/2009	7/13/2009
Seed age in days	13	18	18	15	18	17
Hills/m^2	45	45	45	45	45	45
Hill spacing (cm x cm)	13x17	13x17	13x17	13x17	13x17	13x17
Panicles/hill at planting	3	3	3	3	3	3
Panicles/m^2 at planting	135	135	135	135	135	135
Harvest date	6/14/2006	10/27/2006	5/25/2007	10/18/2007	10/18/2009	10/28/2009
Panicles /m^2	289	225	247	360	348	227
Grain yields (kg/ha)	4938	4616	4692	4987	4380	3877
Weight of P1000 (GR)	19.2	19.9	22.1	19.2	17.8	17.5
Total biomass (kg/ha)	9198	9425.5	12866.1	9183.6	11355	7316.7

Source: Actual practices from field trials in 2006, 2007 and 2009 at the study sites.

Appendix 4. Fertilization timing

Time	Percentage of total fertilizer in each crop		
	Nitrogen (N)	P_2O	Potash K_2O
Before planting		60	
10 days after plating	20		45
25 days after plating	35		
45 days after plating	35		45

Source: Fertilizer application methodology.

Appendix 5. GENETIC corrected indexes

P1	P2R	P5	P2O	G1	G2	G3	G4
960	209	465	12.4	43	0.0193	0.75	0.95

Source: Field trial results in 2006, 2007 and 2009 at the study site.

Conclusions and Recommendations

Some important results emerge from these three studies on climate change impacts on rice production in Malaysia, Indonesia and Viet Nam. First, climate change is happening and has already become a global reality. The immediate effect on weather conditions caused by a slight rise in global temperatures is already negatively impacting the availability of food, particularly for developing countries. Hence attention to negative impacts is necessary not only at the global level but also at regional, national and local levels.

Secondly, these studies also provide suggestions for policymakers in all three countries, on needed steps to anticipate, adapt to or mitigate climate change. Detailed policy options are provided for each country including, among others, infrastructure development, research goals for rice breeding, and human capacity building. The policy measures suggested vary by location, thus demonstrating the need to look at climate change impacts from a local perspective.

For instance, in KADA, Malaysia, farms need further investment in infrastructure development to increase their productivity and efficiency. Results in KADA show that this region needs more attention than MADA, because it is more vulnerable to climate change. By adjusting key policies, Malaysia will be in a better position to face negative impacts of climate change once these two rice growing centres can produce rice at optimal levels. In Indonesia, rice yields significantly decreased during El Nino years, suggesting that significant efforts are needed to minimize climate change impacts. In Viet Nam as well, climate change is expected to have a serious impact on rice production. In the Red River Delta, the second most important rice growing area, yields are expected to decline significantly.

To minimize the impacts of climate change, Malaysia will need proactive efforts to deal with the impact on rice production by applying three strategies: anticipation, adaptation and mitigation. Required strategies include: definitive planning of infrastructure development, improving the water distribution and management system, improving human capacity to understand climate change, development of an information and early warning system, plant breeding to produce drought- and salt-resistant varieties and biofuel development to produce renewable and sustainable environment. Plant breeding and biotechnology could also play an important role in producing food under changing climatic conditions, mainly to ensure that water is used more efficiently by increasing the water use efficiency of crops. In order to mitigate, both government agencies and farmers can play their roles by improving farm management, livestock management, carbon sequestration, water pricing and water management and more use of biofuel.

In Indonesia, climate change is expected to threaten rice production in Java and elsewhere in the tropical areas; therefore, the following anticipation, adaptation and mitigation measures need to be considered. Improving infrastructure as well as human capacity and information development are recommended anticipation strategies. Adaptation measures include planting time adjustment, more use of organic fertilizer, cropping pattern adjustment, the use of new drought- and salt-resistant varieties and crop diversification. General crop management, grazing land and livestock management, and water pricing to avoid excessive water use are examples of mitigation strategies.

In Viet Nam, the government has been proactive in dealing with climate change impacts on rice production, particularly in the Red River Delta. Three strategies, anticipation, adaptation and mitigation, have been put forward for implementation by various agencies as well as by the farmers themselves. Application of biotechnology to produce varieties tolerant of drought, salt, acidity and disease, and technologies to save water usage are part of the anticipation strategy. In addition, other food crops should be developed to reduce crop failure due to natural calamity. As adaptive measures, biotechnological tools have the potential to deliver stable, high-yielding varieties under drier conditions, but it requires the identification of key traits. Improving such farm management practices as integrated crop management, livestock management, carbon sequestration, water pricing and water management are mitigation strategies.

Based on the research findings summarized here, governments are confronting the future with climate change with a range of responses. Only countries that are committed to preparing themselves for the adverse effects of climate change will successfully navigate the coming challenges. Further studies need to address the best options for agriculture to increase food production under likely climate change scenarios. Questions such as how to improve the resilience of agricultural systems both against gradual climate change and increased climate variability and extremes, need to be addressed. In particular this includes how the use of traditional crops, improved agronomic practices, crop breeding and new technologies can enhance the resilience of agricultural systems to climate change. More information is needed on required policy changes and incentives for investments to foster more sustainable approaches. While many of the solutions will be location specific, there is also ample opportunity for intraregional learning and adaptation of solutions.

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