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Simulation of Climate Change Impact on Lowland Paddy Rice Production Potential in Savannakhet Province, Laos

A thesis submitted in fulfillment of the requirements for Doctorate degree of Engineering Sciences (Land and Water Management) at BOKU, Austria

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LIST OF ABBREVIATIONS

AR4	Forth Assessment Report
C	Carbon
CCAM	Conformal Cubic Atmospheric Model
CERES	Crop Environment REsource Synthesis
CH_2O	Carbohydrate
CO_2	Carbon dioxide
CSMK3 or CSIRO-Mk3.0	Commonwealth Scientific and Industrial Research Organisation
CSHI	Commonwealth Scientific and Industrial Research Organisation – High Sensitivity
CSLO	Commonwealth Scientific and Industrial Research Organisation – Low Sensitivity
DSSAT	Decision Support System for Agrotechnology Transfer
FAO	Food and Agriculture Organization
GCMs	General Circulation Models
GDP	Gross Domestic Product
GFDL	General Fluid Dynamics Laboratory
GISS	Goddard Institute for Space Studies
HadCM3	Hadley Centre Coupled Model version 3
HCHI	Hadley Centre Coupled Model version 3 – High Sensitivity
HCLO	Hadley Centre Coupled Model version 3 – Low Sensitivity
HadGEM	Hadley Centre Global Environment Model
HGHI	Hadley Centre Global Environment Model – High Sensitivity
HGLO	Hadley Centre Global Environment Model – Low Sensitivity
IBSNAT	International Benchmark Site Network for Agrotechnology Transfer
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
LAI	Leaf Area Index

N	Nitrogen
NAFRI	National Agriculture and Forestry Research Institute
NRRP	National Rice Research Program
SRES	Special Reports on Emissions Scenarios
SO_2	Sulfur dioxide
SRAD	Solar Radiation
TAR	Third Assessment Report
TAVG	Average Temperature
TMAX	Maximum Temperature
TMIN	Minimum Temperature
UKMO	United Kingdom Meteorological Office

ABSTRACT

Lowland paddy rice in Laos is the main crop grown during the rainy season. Climate change is considered as one of the main environmental problems of the current century and it affects directly crop growing conditions such as for rice. This study focus on two objectives which are 1) to estimate the impacts of climate change on rice production in a rice growing region of Savannakhet province and 2) to explore adaption options of local farmers to climate change.

To assess the rice yield potential under climate change conditions, the DSSAT CERES-Rice model was applied under three General Circulation Models (GCMs) such as CSMK3, HadCM3 and HadGEM with high and low climate sensitivity, respectively. The resulting six climate change scenarios were the base for the generated daily weather data input for the rice yield simulation of the 21st century (2001 to 2100). Three periods out of these 100 years were finally selected for comparison of the results (2001 to 2030, 2030 to 2065, and 2070 to 2100).

The results show that rice yield (of the same selected cultivar) under all six climate change scenarios will increase between +6.8% and +12.8% compared with observation years (1995 to 2009), mainly determined by increasing temperatures from currently sub-optimum level for the simulated cultivar TDK 1. However, if comparison between the three simulated periods, the second period (2035 to 2065) will reach the highest yields and in the third period (2070 to 2100) yields will not further increase. According to the results the rice growing period of the same cultivar will be shortened by approximately 5 to 14 days to between 134 and 143 days in average by the end of the 21st century. Adaptation in rice farming practices may include cultivar change, soil preparing, sowing and transplanting date, weeding, timing and amount of fertilization. Farm technologies and cultivar breeding supporting local rice farming will be further challenges beyond the farm level to ensure or further increase rice production for future climate change conditions.

Keywords: Crop Simulation, climate change scenarios, rice yields, low land paddy rice, Savannakhet Laos

ZUSAMMENFASSUNG

Nassfeldreis ist die während der Regenzeit in Laos angebaute Hauptfrucht. Der Klimawandel wird als ein wichtiges Umweltproblem in diesem Jahrhundert angesehen der direkt die Wachstumsbedingungen von Nutzpflanzen, wie Reis, beeinflusst. Diese Arbeit umfasst zwei Ziele und zwar 1) die Bestimmung des Einflusses des Klimawandels auf die Reisproduktion in der Anbauregion und Provinz Savannakhet und 2) die Abschätzung von möglichen regionalen Anpassungsmaßnahmen für Landwirte.

Um das Reisproduktionspotenzial unter Klimawandelbedingungen abzuschätzen wurde das Ertragssimulationsmodell CERES-Rice (DSSAT) für 6 Klimaszenarien unter drei Klimamodellen (CSMK3, HadCM3 und HadGEM) mit jeweils zwei Sensitivitätsstufen angewendet. Die 6 Klimaszenarien bildeten die Basis für generierte tägliche Eingabeparameter von Witterungsparametern für die Reisertragssimulation im 21.Jahrhundert (2001 bis 2100). Drei Perioden aus der 100-jährigen Zeitreihe wurden als Vergleichsperioden ausgewählt (2001 t-2030, 2030 - 2065, und 2070 - 2100).

Die Ergebnisse zeigen dass der Reisertrag (ohne Wechsel der Reissorte) unter allen 6 Szenarien zwischen 6.8% und 12.8% im Vergleich zur Beobachtungsperiode (reale Erträge von 1995 bis 2009) zunimmt, wobei die steigende Temperatur der wichtigste bestimmende Ertragsfaktor für die simulierte Reissorte war. Wenn man allerdings die drei simulierten Perioden vergleicht, werden die höchsten Erträge in der zweiten Periode (2035 bis 2065) erreicht während in der dritten Periode (2070 bis 2100) kaum eine weitere Steigerung erzielt wird. Nach den Ergebnissen wird sich die Wachstumsdauer derselben Reissorte je nach Klimaszenario zwischen 5 und 14 Tagen auf 134 bis 143 bis zum Ende des 21.Jahrhunderts verkürzen. Anpassungsmaßnahmen in der Produktionstechnik aufgrund der gegenwärtigen Bedingungen umfassen Änderungen bei den angebauten Reissorten, bei der Bodenbearbeitung, beim Anbau- und Umsetztermin, bei der Unkrautbekämpfung und dem Düngungsmanagement. Anpassungen in der verfügbaren Produktionstechnik und

Pflanzenzüchtung als Unterstützung für die lokalen Reisbauern sind weitere Herausforderungen auf überregionaler Ebene um die Reisproduktion unter Klimawandelbedingungen weiter zu steigern.

Schlüsselwörter: Ertragssimulation, Klimaszenarien, Reisertrag, Nassfeldreis, Savannakhet Laos

CHAPTER I

INTRODUCTION

I. INTRODUCTION

1.1 Background

Climate change is considered as one of the main environmental problems of the 21st century. Over past three decades, green house gases such as Carbon dioxide (CO_2) and Sulfur dioxide (SO_2) have increased affecting change in temperature and rainfall and affecting agriculture. According to the measurement records, the global temperature has already risen by 0.3 - 0.6°C since 1860 and the last two decades have been the warmest. Over the past 100 years the mean surface temperature has increased by 0.3 - 0.8°C across the Asian region. Temperature increase indicates global warming and climate change, causing many events occurred such as flood, drought, sea level rise, river level, forest fire etc.. Climate change is an environmental concern worldwide and evidence is getting stronger that the global warming has been induced by the present human activities (IPCC, 2001). Nowadays, most scientists agree that global warming is inevitable. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) states that global average surface temperature has increased by 0.74 ± 0.18 °C in the last century and is projected to increase by another 1.1 - 6.0 °C in this century (IPCC, 2007b; Rahmstorf et al. 2007; Reidsma et al., 2010), and that it will have major impacts on the climate worldwide including agricultural productivity (Twomlow et al., 2008).

Agriculture is the most sensitive sector to climate conditions, with both climate variability as well as climate change. For example, seasonal climate has a big influence for crop growing conditions and crop yields. Particularly rainfall amount and rainfall distribution pattern, air temperature, solar radiation, air humidity, wind and so on are very important factors for agricultural production. Agriculture productivity in Asia is likely to suffer from losses caused by weather factors such as high temperatures, drought, flood, and soil degradation. The crop yield in many countries of Asia has declined in the past decade, particularly due to rising temperature and extreme climate events (Cruz et al., 2007). Especially rice production which is major agricultural activity and food source in most Southeast Asian countries largely depends on climate conditions, water availability, soil and other environmental factors. In addition, in term of population increase by 2030 and related increase in the demand of rice by 35% or 880 million tons, rice production will be a significant challenge (FAO 2002) in the next decades. The influence of global climate change on future agriculture production as well as rice is one of the most significant issues (Bouman et al., 2007; Araus et al., 2011) in Asia.

Impacts of climate change on crop productivity are generally assessed with crop models (Easterling et al., 2007; Reidsma et al., 2010). The crop models are generally used to assess climate impacts on crop productivity and were developed for simulations at field level. Crop models strongly emphasize biophysical factors, such as climate and soil conditions. (Tubiello and Ewert, 2002., Reidsma et al., 2010). The dynamic nature of climatic effects is well understood for potential, water and nitrogen limited growth and yield (van Ittersum et al., 2003; Reidsma et al., 2010). Actual farm yields, however, are also affected by other factors, such as pests and diseases, which depend on farm management and regional conditions. How these additional factors will influence crop production under climate change conditions is not yet well understood. The crop model for rice used in this study belongs to the Decision Support System for Agrotechnology Transfer (DSSAT) crop models which were already applied in worldwide.

The potential socio-economic impacts of climate change on rice production were already studied in e.g. Bangladesh, China, India, Indonesia, Japan, Malaysia, Myanmar, Philippines, South Korea, Taiwan and Thailand (Kropff et al., 1995; Horie et al., 1995). Hence not only individual rice farming plays a significant role in providing food for human population, but rice farming provides also major occupation and income to rural people livelihood in many countries. Therefore, it is critical to early find and prepare for adaptation options for the various agroecosystems in order to avoid negative impacts on the often fragile socio-economic conditions in Asian countries.

1.2 Justification

Agriculture plays a most important role in the economy as well as for farmer's livelihood in Laos, which contributes 51 % of Gross Domestic Product (GDP) and employs 86% of the total labor. In the agricultural sub-sectors, rice production is the most important activity and is undertaken by smallholder producers as individual farmer's household. In 2005 the total rice planted area in Laos was approximately 793,980 ha representing more than 80% of the cropped land area (Keovongvichith et al., 2005). In 2009 the total rice planted area increased to approximately 872,896 ha (Department of Agriculture of Ministry of Agriculture, personal communication).

Rice is a staple food for Lao people in daily consumption as well as for household economy. Its cultivation covers more than 80% of the total arable land, and 95% of the population depends on agriculture as the main source of livelihood, particularly in rural areas. Growing rice is the single most important factor determining the well being of the household farmers. Rice production in particular has always been depending on weather conditions very much (Schiller et al., 2006). Rice is the main crop grown during the rainy season, and under usual conditions, rainfall is adequate for rice production. However, if rain ceases to fall for several weeks to a month at a critical time in the rice growing cycle, yields can be significantly affected.

Low land paddy rice production in Laos has been affected by climate variability leading often to lower production, in particularly when rainfall is low or poorly distributed. Drought or flooding can occur in any period of the growing season, especially in the early and later period of the growing season (Keovongvichith et al., 2005). For example from 1991 to 2002 significant areas of lowland rice in the Mekong River Valley (including Laos) were destroyed by floods including losses of more than about 70,000 ha of rice area planting in this region (Schiller et al., 2006). In 2011 the tropical storm Haima and Nock-Ten caused floods and more than 37,000 hectares of rice fields were damaged. More than 300,000 people were affected and the event caused more than US$ 100,000,000 in damage (National Disaster Management Office (NDMO) reported in VIENTIANE, 7 September 2011 Integrated Regional Information Networks (IRIN) http://www.worldweatherpost.com/2011/09/07/laos-floods-highlight-disaster-preparedness-needs/#.TvSlL3qk-hF).

There are six main provinces in the central and southern parts of Laos to produce rice, namely: Vientiane plain, Borikhamxay, Khammoune, Savannakhet, Saravan and Champasak plains. Some small plains along the Mekong River in the northern part of Laos are Odomxay, Louang Namtha, Louang Prabang plains etc.. These areas are important sources for rice production in Laos, particularly Savannakhet province is the largest rice production region in Laos accounting for over 20% of the national production (Bestari et al., 2006), and frequency faces significant climate variability impacts. When climate will change it might affect rice yield in positive or negative ways. Therefore, it is an important issue to investigate how rice productivity performs in term of impacts of climate change, and to develop guide information for farmer’s adaptation options. The potential impacts of climate change and climate variability on crop yields at field level can be assessed by crop models. In this study Decision Support System for Agrotechnology Transfer (DSSAT V.4) crop models were applied for assessing rice production potentials in Savannakhet province, Laos under several climate change scenarios.

1.3 Objectives

To study climate change impacts on rice production in Savannakhet, Laos two objectives are defined as below:

(1) To estimate the impacts of climate change to rice production in a rice growing region of Savannakhet province.

(2) To explore adaption options of local farmers to climate change.

1.4 Research questions and tasks

Based on the two objectives following research questions are defined:

(1) What is the climate change signal of climate change scenarios in the region of Savannakhet ?

(2) What is the influence of climate change scenarios on rice yield?

(3) Which factors cause the change in rice yields under the climate scenarios?

(4) To explore and analyze feasible adaptation options for regional rice farmers.

1.5 Scope of study and conceptual framework

This study will focus on rice yield assessment by application of a crop model under climate change scenarios within 100 years (2001 to 2100) developed from Global Climate Models (GCMs) such as Commonwealth Scientific and Industrial Research Organisation, Australia V3. (CSMK3 or CSIRO-Mk3.0), Hadley Centre Coupled Model version 3 (HadCM3), Hadley Centre Global Environment Model (HadGEM) with high and low climate sensitive and increasing CO_2 concentration (applied stepwise, all 5 years) in the atmosphere. The climate changes scenarios are used to establish a daily weather data input set to the crop model, then to simulate the trend of rice yield in the future and compare it with the base line yields of the present conditions. The causes for yield changes will be analyzed and feasible and potential adaptation options will be identified (Fig. 1). The DSSAT model V.4, Crop Environment REsource Synthesis (CERES – Rice) will be applied for this study (see Material and Methods for more details).

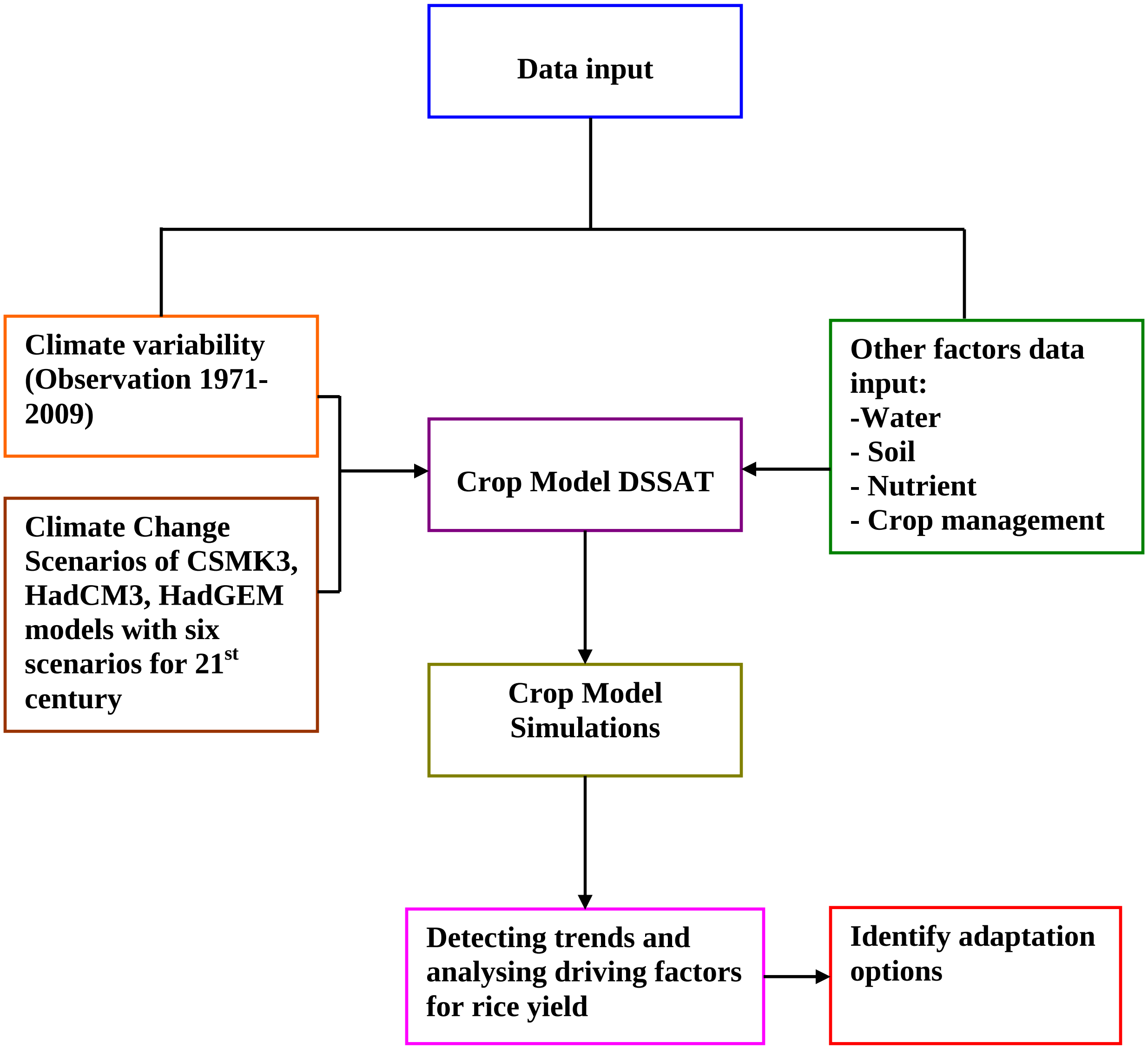


Figure 1.1: Conceptual framework

CHAPTER II

LITERATURE REVIEW

II. LITERATURE REVIEW

2.1 Climate variability and climate change scenarios

2.1.1 Climate variability

Climate variability is temporal variations in the mean state of the climate parameters. Variability may be due to natural internal processes within the climate system, or to variations in natural external variability (Bertmetz et al., 2001). The change in climate variability and extreme climate events have received increased attention. The understanding of changing in climate variability and climate extremes is difficult due to the interactions between the change in the mean and variability (Houghton et al., 2001). Climate variability and occurrence of extreme climatic events are of major concern in the Asian region. Agriculture faced several extreme climatic events, e.g. droughts, floods, and temperature rise every year with substantial economic loss, such as for Indian farmers (Shukla et al., 2003). According to observed climate trends across the seven sub-regions in Asia from Intergovernmental Panel on Climate Change (IPCC) Forth Assessment Report (AR4) increasing surface air temperatures are more pronounced during winter season than during summer season. Some parts of Asia show increased temperatures less than +1^{o}C and up to +3^{o}C per 100 years especially in North Asia (Savelieva et al., 2000; Izrael et al., 2002a; Gruza and Rankova, 2004 in Parry et al., 2007).

In South-East Asia, extreme weather events associated with El-Nino were more frequent and intense in the past 20 years (Trenberth et al., 1997; Aldhous, 2004). Significantly longer heat waves occurred in many countries of Asia and rainfall was characterized by more intense events in many parts of Asia causing floods, landslides, debris and mud flows, while the raining days and total annual amount of precipitation increased as well (Zhai et al., 1999; Khan et al., 2000; Shrestha et al., 2000; Izrael et al., 2001; Mirza, 2002; Kajiwara et al., 2003 ; Lal., 2003; Min et al., 2003; Ruosteenoja et al., 2003; Zhai and Pan 2003; Gruza and Rankova, 2004; Natsagdorj et al., 2005). In addition, the frequency and intensity of tropical cyclones in the Pacific have increased over the last few decades (Fan et al., 2005). Also cyclones from the Bay of Bengal and Arabian Sea increased (Lal, 2001), which affect many countries, particularly India, China, Philippines, Japan, Vietnam, Cambodia, Tran and Tibetan Plateau etc. (PAGASA, 2001 ABI, 2005; GCOS, 2005a,b; Parry et al., 2007).

Monsoon in Asia is characterized by its temperature and wet climate (Watsuji, 1935 in Yasuda et al., 2004) including India, the southern foot of Himalayas, Southeast Asia, south China, east of Sichuan and the Yunnan provinces, north China east of Shianxi and Liaoning provinces, Pacific coastal regions and south of Sakhali. The dominant summer crops in Asian Monsoon climate are rice, fox tail millet (setaria), broom corn millet (Panicum) and sorghum and others. The rainy season falls in summer, thus rice is a summer crop.

Laos is located in the tropical dominated by the south-west monsoon, that brings high rainfall, high air humidity, and high temperatures between mid April until October. Laos is characterized by two climatic seasons: dry season starts from November to March, and rainy season starts from April to October. The Southwest monsoon from April to October causes an annual rainfall range between >1,000 mm to 3,700 mm; Bolaven plateau, Champasak province with the highest precipitation in Laos. There is strong variability in seasonal rainfall distribution with seasonal droughts and floods. Average minimum and maximum air temperature range between 20 – 35°C. January is the coolest, and April is the warmest month. Frost occurs in the mountainous area during November to January. Air humidity ranges from 30% in the dry season to 98% in the rainy season (Durno, 1992). Therefore, in Laos as well as in Southeast Asia farmer practices depend on seasons as paddy rice is grown in the rainy season.

2.1.2 Climate change scenarios

2.1.2.1 Overview of global climate change scenarios for Asia

Climate change scenarios are based on different models and assumptions resulting in different estimations of change in temperature and precipitation. In the past, Watson et al. (1998) reviewed various climate change scenarios for different regions of the world. According to this by 2010 and 2070, temperature increase in south Asia will range between 0.1 – 0.3°C and 0.4 - 2.0°C respectively and CO_2 concentrations will be between 379 – 416 ppm 2010 (390 ppm in 2010 current days) and between 605 – 755 ppm by 2070. Relatively high increase in CO_2 and low increase in temperature can be considered as an optimistic scenario for crop growing conditions and vice versa. Thus 0.1°C increase in temperature and 416 ppm CO_2 (2010 scenario) and 0.4°C temperature and 755 CO_2 (2070 scenario) will constitute the optimistic scenarios due to the CO_2-fertilization effect on crops. On the other hand an increase of 0.3°C temperature and 397 ppm CO_2 (2010 scenario) and 2.0°C temperature and 605 ppm CO_2 (2070 scenario) can be considered as pessimistic scenarios of climate change due to the negative effect of higher temperature on crop growth duration and maintenance losses mainly. The effects of these uncertainties in IPCC 2001 scenarios were determined from the analysis done with gradual change in temperature, CO_2 and their interactions. In another example, the United Kingdom Meteorology Office (UKMO) GCM model (Bhaskaran et al., 1995) predicts a total precipitation increase of approximately 20% and increase in winter season temperature by 1-4°C where increased monsoon rainfall is largely due to increased water content of the atmosphere. The model also predicts a greater number of heavy rainfall days during the summer monsoon and increased inter-annual variability.

Anthropogenic caused climate change is no longer a distant scientific prognosis but is becoming a reality. The anthropogenic increases in emissions of greenhouse gases and aerosols in the atmosphere result in change of the radiative forcing and a rise in the earth’s temperature. The bottom-line conclusion of the Third Assessment Report (TAR) of the (IPCC, 2001) is that the average global surface temperature will increase between 1.4°C and 3°C above year 1900 levels by 2100 for low emission scenarios and between 2.5°C and 5.8°C for higher emission scenarios of greenhouse gases and aerosols in the atmosphere.

Climate scenarios are used in this thesis to describe possible future cropping conditions in Laos. Based on Global Circulation Models (GCM) which represent physical based predictions (Thomas, 2007) regional climate scenarios will be used for crop model application. According to the predictions of the IPCC-AR4 (Parry, et al., 2007), annual mean temperature would increase by about 3°C in the decade of the 2050s and approximately 5°C in the decade of the 2080s. This is more than reported in IPCC 2001 as described below, indicating a higher temperature increase than expected earlier. Rising air temperatures were projected to be most pronounced over boreal Asia in all seasons (Cruz et al., 2007).

2.1.2.2 Climate change scenarios for Laos

Using the Conformal Cubic Atmospheric Model (CCAM) climate model, climate scenarios for future decades in Southeast Asia including Laos were derived and related to 360 ppm of CO_2 concentration of the baseline 1980-1989 (McCarthy et al., 2001). The Special Reports on Emissions Scenarios (SRES) A1FI, IPCC 2000 (Chivanno et al., 2006) was applied by using 540 ppm and 720 ppm of CO_2 concentration, which corresponded respectively to 1.5 and 2.0 times of the concentration compared with the baseline. The result from CCAM suggested that when CO_2 in the atmosphere increases to 540 ppm and 720 ppm, the amount of rainfall would increase by 100-200 mm compared with baseline period of 1,334 mm (Laongmanee, 2005). On the other hand the temperature might slightly decrease by -0.5 to +0°C (compared with baseline of 24°C), and temperature would increase by +0.5 to +1°C, when the amount of CO_2 in the atmosphere increases from 540 ppm to 720 ppm (Laongmanee, 2004).

For this study climate change scenarios based on three climate models were applied, namely CSMK3, HadCM3, and HadGEM with high and low climate sensitivity, respectively. For these six scenarios changing CO_2 concentration in the atmosphere were considered for 100 years runs from 2001 to 2100 (Dubrovsky, Pers.comm 2011). The six scenarios of 100 years were divided into three periods of 2001 to 2030, 2035 to 2065 and 2070-2100 for comparison of simulated crop yields in the different time slices. Additionally, a sensitive analysis of weather parameters in the crop model was carried out (Chapter III).

2.2 Influences of climate and climate variability on rice production

2.2.1 Overview

Generally climate and weather conditions determine plant growth and yield formation, depending on the plant characteristics. Plants normally are adapted more or less to the climatic conditions of their natural growing areas. There are six major climate groups: (1) Tropical/megathermal climates, (2) Dry (arid and semiarid) climates, (3) Temperate/mesothermal climates, (4) Continental/microthermal climate, (5) Polar climates, and (6) Alpine climates. Therefore, vegetation zones of the earth are determined primarily by climate, especially annual rainfall and its seasonal distribution, and also day and night temperatures. The length of the growing season for crops is largely determined by the balance between evapotranspiration of water from plants and soil and the rainfall during periods when the temperature is suitable for crop growth. Other factors are the presence of ground water as in valley bottoms, and soil water shortage and distribution (Wild, 2003).

Climate directly influences the physiological processes that affect all vegetation as well as the rice plant’s growth, development and grain formation. Indirectly, climate influences the incidence of crop pests, diseases and hence, and grain yields. The effect of climate for the environment of rice is a major issue for food security in the world. Basic of understanding climate is knowledge of its elements, especially rainfall, solar radiation, temperature and relative humidity. Rice yields are influenced by many interrelated and often diverse environmental and biological factors, with the result that it is difficult to separate their effects. Climatic variability and occurrence of extreme events are major concerns for the world, particularly for agricultural regions. There is need to quantity the growth and yield responses of important crops and also identify suitable land use options to sustain agricultural productivity under this large range of climatic variations. Climate change can affect rice yield due to direct effects of temperature and carbon dioxide on crop growth and yield. In addition, indirect effects such as availability of irrigation water, competition with animals, change in soil fertility and erosion can also influence yields.

Rice production is facing challenges from global warming such as water shortages and other factors that limit the capacity of farmers to grow the crop (e.g., Horie et al., 1997; Tao et al., 2003, 2006; Peng et al., 2004). Therefore, the vulnerability of rice production to global warming has become of key concern in current days and also in the future. Many studies have used crop models and several climate-change scenarios to simulate the impact of climate change on rice production in Asia (e.g Kropff et al., 1993; Horie et al., 1997; Matthew et al., 1997; Hayashi and Jung, 200?; Aggarwal and Mall, 2002). By 2100, the world will have changed in ways that are difficult to imagine. Therefore, the Intergovernmental Panel on climate Change (IPCC) has used four storylines to describe divergent futures that encompass a marked portion of the underlying uncertainties in the main driving forces called “families” for emission scenarios: A1 (World markets), A2 (Provincial enterprise), B1 (global sustainability), and B2 (local stewardship). Altogether 40 Special Reports on Emissions Scenarios (SRESs) have been developed, and all are considered equally valid with no assigned probabilities of occurrence (Nakicenovic and Swart, 2000). The SRESs cover a wide range of CO_2, other greenhouse gases, and sulfur emissions. Consequently, on the basis of various GCMs global mean temperature it is projected that global mean temperatures can increase in a wide range for example from 1.4 - 5.8 ^{o}C over the period from 1900 to 2100. Projected regional climate changes have even larger uncertainty. Research related to global climate change must deal explicitly with the uncertainties from various sources such as GCMs, emission scenarios, and impact models (Schneider, 1997; Pittock et al., 2001; Challinor et al., 2005a). This study applied SRES A2 to be representative for high climate sensitive scenarios, and SRES B1 to be representative of low climate sensitive scenarios (Chapter 3.4.1.2).

2.2.2 The role of climate parameters for rice growth in South-East Asia

2.2.2.1 Rainfall

Most of the tropical Southeast Asian countries such as Burma, Cambodia, Indonesia, Philippines, Thailand, and Vietnam receive about 2000 mm of rainfall annually. This should be adequate for one rice crop provided rainfall distribution is reasonably uniform. Even in areas where the annual rainfall is only 1200-1500 mm, if rainfall is concentrated in the monsoonal season as is usual, it is adequate for a single rice crop. Unfortunately, the world's two largest rice growing countries particularly India and China have many areas which receive less than 1200-1500 mm amount of rainfall. India with the largest rice growing area in the world, with often has inadequate or excessive rainfall during the rainy season such as drought or flood, and sometimes need full irrigation for planting (Surajit et al., 1981).

2.2.2.2 Effects of temperature

Temperature regime greatly influences not only the growth duration but also the growth pattern of the rice plant. During the growing season, the mean temperature, and the temperature sum, temperature range, temperature distribution pattern and diurnal changes, or a combination of these, may be highly correlated with grain yields (Moomaw and Vergara, 1965). Critical temperatures for germination, tillering, inflorescence initiation and development, dehiscence, and ripening of rice have been identified (Table 2.1).

Table 2.1: Response of the rice plant to temperature at different growth stages (Adapted from Yoshida, 1978).

Growth Stage	Critical Temperature (^oC)		
	Low	High	Optimum
Germination	16-19	45	18-40
Seeding Emergence and establishment	12-35	35	25-30
Rooting	16	35	25-28
Leaf elongation	7-12	45	31
Tillering	9-16	33	25-31
Initiation of panicle			
Primordial	15	-	-
Panicle differentiation	15-20	30	-
Anthesis	22	35-36	30-33
Ripening	12-18	>30	20-29

2.2.2.3 Seasonal solar radiation

The importance of solar energy in tropical agriculture was recognized after World War II (Best, 1962 ; Surajitet al., 1981). The average daily solar radiation available during the monsoon season in the tropics is one and haft times lower than that available in the temperate rice growing regions such as Italy, Spain, New South Wales, Australia, California etc.. Because of rainfall, rainfed rice in tropical areas must grow when there is low sunlight intensity. On the other hand, where irrigation water is available, rice can be grown in dry season and the grain yield will be higher than in the wet season, because of higher intensity of solar radiation received during the crops' grain-filling and ripening stages (De Datta and Zarate, 1970) as shown in figure 2.1.

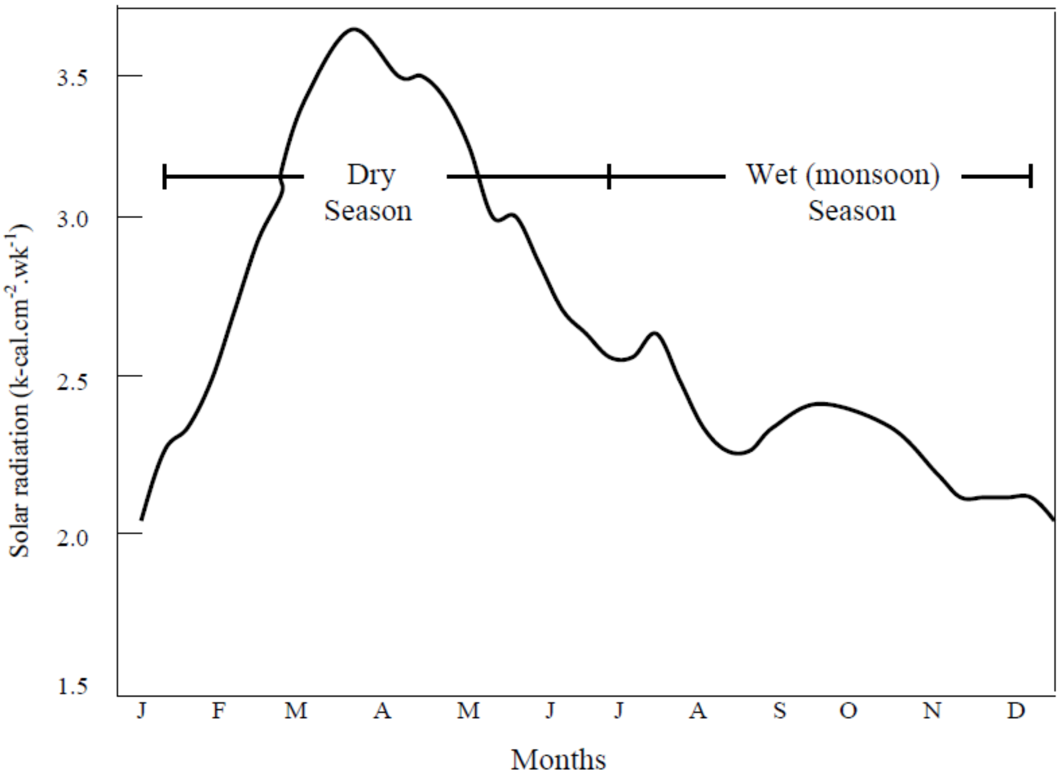


Figure 2.1: In the monsoonal tropics, the intensity of solar radiation is considerably higher during the dry season compared with the wet season. Adapted from Average (1959-1966) annual solar radiation curve for Los Baños , Philippines.

2.2.2.4 Effects of day length

Rice is generally a short-day plant and sensitive to photoperiod. Thus, long days can prevent or considerably delay flowering (Vergara and Chang, 1976). In lowland rainfed rice culture, a delay in transplanting photoperiod-sensitive varieties due to delayed rain does not usually affect the grain yields. It is because of the flexibility at the seeding stage that photoperiod-sensitive varieties have which are traditionally been grown in monsoonal Asia (Vergara, 1976). The photoperiod-sensitive, traditional varieties have provided stability in rice production even though their yield levels have been low. Those varieties produced some yields regardless of lodging, typhoon damage, or inadequate management practices such as no fertilizer or no weeding (Vergara et al., 1966). In some areas, the need to delay harvesting until monsoon-season floodwater has receded makes it essential to grow varieties with long growth duration. This is possible only by using photoperiod-sensitive varieties, but day length or photoperiod-insensitive rice varieties enable the farmer in the tropics and subtropics to plant rice at any time of the year without great changes in growth duration (Chang and Vergara, 1972). In irrigated areas, and in rainfed areas where flooding is limited to a maximum water depth of 15-20 cm, improved photoperiod-insensitive varieties have therefore partially replaced photoperiod-sensitive varieties. Using these short duration varieties, such as IR8, rice can be planted in any month in the tropics, and will mature in a fixed number of days. Thus, it is obvious that insensitivity to day length is essential in one situation and a liability in another.

2.2.2.5 Growth stage and grain yield

Based on experiments (e.g. Stansel et al., 1965 and Stansel.,1975 in Surajit et al., 1981) it is known that the rice plant's most critical period of solar energy requirement is from panicle initiation until about 10 days before maturity (Figure 2.2). In the tropics, the correlation between solar radiation for the 45 days period before harvesting (from panicle initiation to crop maturity) and grain yield, plotted by harvest month was highly significant. Earlier experiments indicated a strong correlation between grain yield and solar radiation during the last 30 days of crop growth (Moomaw et al., 1967; Surajit et al., 1981). Subsequent International Rice Research Institute (IRRI) research indicated that the increase in dry matter between panicle initiation and harvest was highly correlated with yield (De Datta et al., 1968; Surajit et al., 1981).

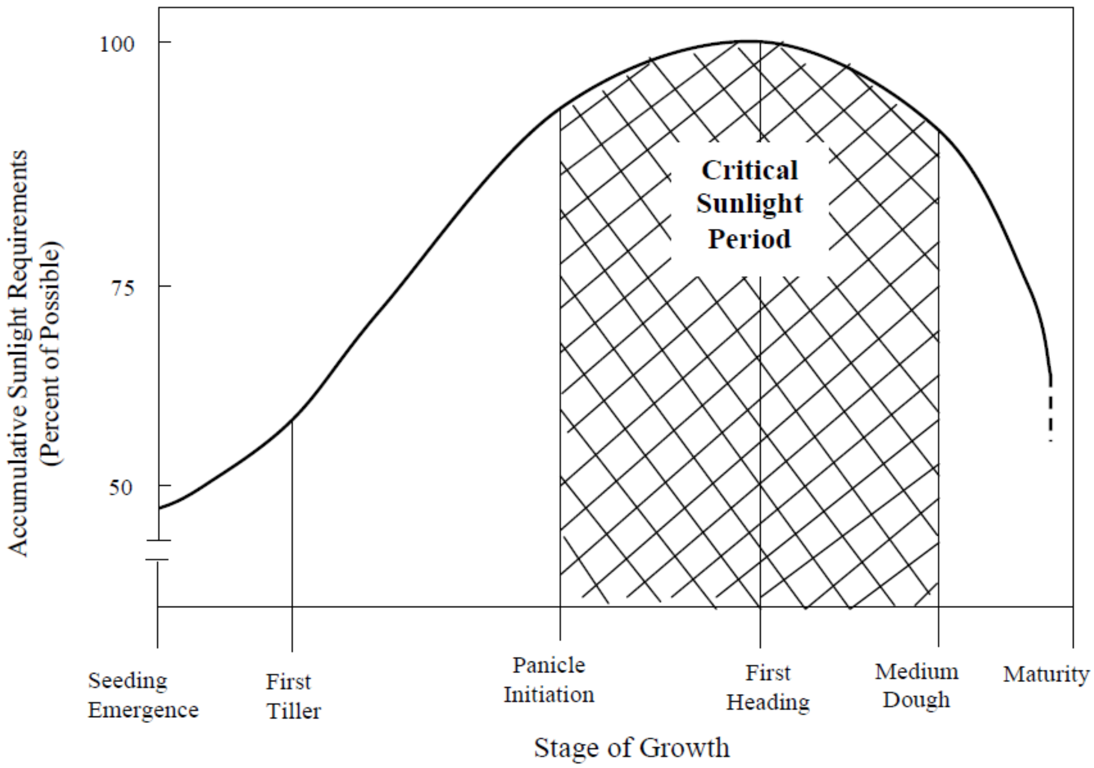


Figure 2.2: Solar radiation requirements of rice at different stages of growth and development (Adapted from Stansel, 1975).

These results indicate that the amount of solar radiation received from as early as panicle initiation until crop maturation is important for the accumulation of dry matter during that period. This may be explained from the result obtained by Murata (1966), who showed that the accumulation of starch in the leaves and culms begins about 10 days before heading. Starch accumulates markedly in the grain during the 30 days period following heading (Murata, 1966; Yoshida and Ahn, 1968), and total period of 40 days before maturity may be considered as the period of grain production (Figure 2.3).

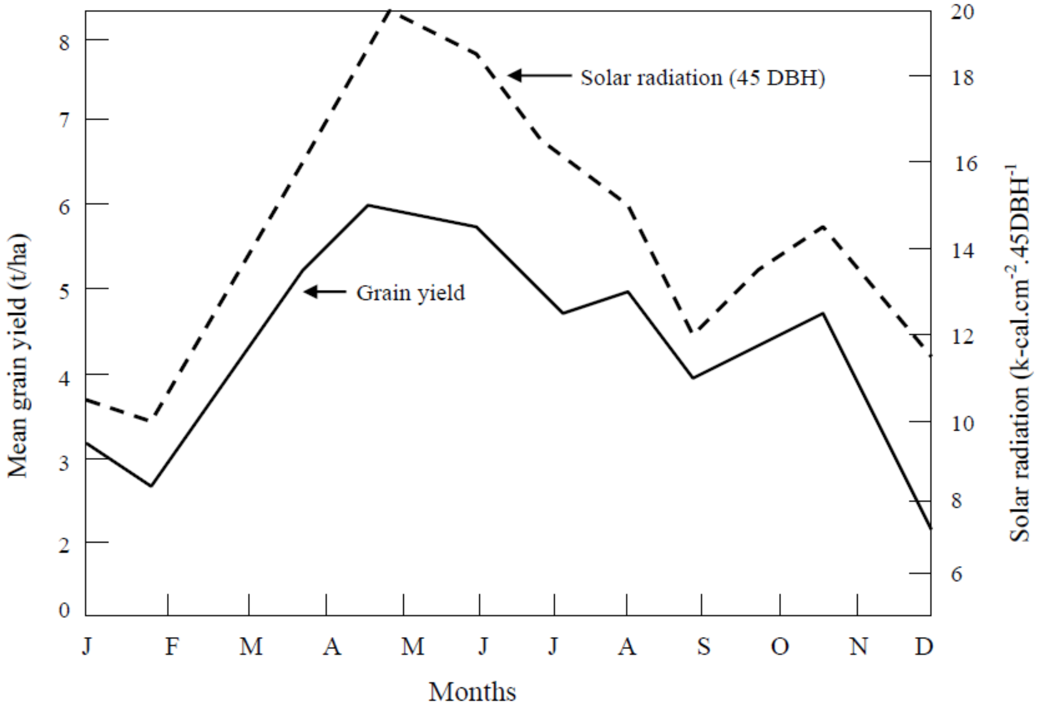


Figure 2.3: Mean grain yield of IR8 for three levels of nitrogen (0, 30 and 90/ha) and three spacing (15x15, 25x25 and 35x35 cm) plotted against solar radiation totals during 45 days before harvest (Adapted from De Datta and Zarate 1970).

2.3 Climate change impacts and rice yield simulations

2.3.1 Overview of climate change impacts on rice growing conditions

According to the TAR projected scenarios climate change in Asia forces an enhanced hydrological cycle and causes an increase of annual mean rainfall in over Asia. The increase of mean annual winter precipitation would be highest in Boreal Asia and leads significantly higher annual runoff of major Siberian Rivers. Precipitation in the summer season would decline over the central part of arid and semi-arid Asia and as a consequence drought risk would increase. In the monsoon areas rainfall in summer season would increase and could increase floods in low land tropical Asia. Approximately 2.5 to 10% decrease of crop yield in some parts of Asia are expected by 2020, and about 5 to 30% by 2050 compared with 1999 without effects of CO_2 increment (Parry et al., 2007).

2.3.2 Impact of climate change on rice production in Asia

For many countries in Asia particularly Bangladesh, China, India, Indonesia, Japan, Malaysia, Myanmar, Philippines, South Korea, Taiwan and Thailand climate change impact on rice production was studied. There are at least three main findings from these studies. First the process-based crop simulation models ORYSA 1 (Kropff et al., 1995) and SIMRIW (Horie et al., 1995) were used to test the sensitivity and predict changes in rice production for the whole region based on fixed increments of air temperature and CO_2 level. The models simulate the development and potential growth of rice in relation to temperature, CO_2, solar radiation and genetic characteristics of the varieties. The outputs of the simulation are summarized as shown in table 2.2. It was shown that at all CO_2 levels an increase in temperature would cause a decline in yields. However, at all temperature increments an increase in CO_2 would cause an increase in yields (table 2.2). It has confirmed by many physiological studies that the increase of temperature (especially the impact of extreme high temperatures) cause sterility of the spikelet; hence decreasing yields.

Based on HadCM2 projections crop yields could likely increase up to 20% in East and South-East Asia while it could decrease up to 30% in Central and South Asia (Murdiyarso, 2000). Combining the influence of fertilization effect and the accompanying thermal stress and water scarcity under the projected climate change scenario, rice production in Asia could decline by -3.8% by the end of the 21st century. Some example in Bangladesh, rice and wheat production might drop by 8% and 32 % by 2050 (Faisal and Parveen, 2004). In case of doubled atmospheric CO_2 concentration rise yield could decrease in many prefectures in central and southern Japan by 0% - 40% (Nakagawa et al., 2003).

Table 2.2: Mean predicted change (%) of rice potential yields in Asia under fixed increase of air temperature and CO_2 level (Source: Matthews et al., 1995b).

	Temperature increment			
	0^oC	$+1^oC$	$+2^oC$	$+4^oC$
ORYZA 1				
340 ppm	0.00	-7.25	-14.18	-31.00
1.5 x CO_2	23.31	12.29	5.60	-15.66
2 x Co_2	36.39	26.42	16.76	-6.99
SIMRIW				
340 ppm	0.00	-4.58	-9.81	-26.15
1.5 x CO_2	12.99	7.81	1.89	-16.58
2 x Co_2	23.92	18.23	11.74	-8.54

Crop simulation modeling studies based on future climate change scenarios indicate that substantial losses are likely for rain-fed wheat, maize and rice yield in South and South-East Asia (Fischer et al., 2002). The studies also suggest that if the temperature increases by 2^oC rainfed rice yield could decrease by 5% to 12% in China (Lin et al., 2004). In South Asia, where no irrigation to wheat and rice is applied a significant temperature increase beyond 2.5^oC could cause rice yield losses between 9% to 25% (Lal, 2007).

2.3.3 Rice yield simulations - main studies from Asia

There are some case studies of rice yield predictions in Asia (Matthews et al., 1995). In India, China, Malaysia, South Korea, and the Philippine were applied the same methodologies, particularly models and climate factors, and models General Fluid Dynamics Laboratory (GFDL), Goddard Institute for Space Studies (GISS), and United Kingdom Meteorological Office (UKMO) General Circulation Models (GCMs). The ORYZA1 model was applied for rice simulation for several climate change scenarios of 1.5 x CO_2, and 2 x CO_2 of the current level (assumed 340 ppm) and increases of temperature by +1^{o}C, +2^{o}C, and +4^{o}C above the current temperature recorded.

Case study in India: There were nine locations representative of the major rice growing regions selected for this study using the GFDL, GISS and UKMO GCMs scenarios. The result shows that the potential change of rice yield increased in the main season by an average of +28.8% and +45.2% for the 1.5 x CO_2 and 2 x CO_2 scenarios when temperature was unchanged. For the second season very similar result were obtained such as +28.5% and +44.6%, respectively. When CO_2 level was not changed, the mean decrease in yield in the main season was 4% per 1^{o}C, and 16% per 1^{o}C in the second season. However, doubled CO_2 was more than able to compensate for the detrimental effect of increased temperature up to +4^{o}C in the main season, but was not in the second season. The three GCM scenarios shown that in the main season substantial yield increases by about +8.8% to +40.2% can be expected in contrast to the second season where large decreases in yield were generally predicted with the corresponding mean yield changes of -18% to -43.3%.

Case study in China: Ten locations were selected for rice simulation in China, with change of 1.5 times and 2 times of CO_2, and increase temperature by +1^{o}C, +2^{o}C, and +4^{o}C, under GFDL, GISS, and UKMO (GCMs), the same case study in India. The rice yield will decrease by -5.2% to -8.2% for every 1^{o}C increase temperature. Rice yield will increase by +34% to +41% when CO_2 is doubled. In average across all sites and the three scenarios yield changes will range from -4.5% to +16%.

Case study in Japan: for nine locations, based on the same climate change scenarios as above, were applied 450 ppm CO_2 concentration with no change in climate, 450 ppm of CO_2 with +2^{o}C temperature rise, and 2 x CO_2 climate. For the nine locations SIMRIW and ORYZA1 crop models were applied. Overall SIMRIW predicted that 450 ppm of CO_2 concentration will increase rice yield by 7 – 8%, at all the locations, whereas ORYZA1 predicted that yields would be increased by 16-17%. However, for the SIMRIW predictions of 450 ppm of CO_2 with +2^{o}C temperature rise, a small negative effect is predicted only in one location. In contrast, ORYZA1 predicted for all study locations rice yield decrease by -3.3 to -14.6%. For 2 x CO_2 concentrations the rice yield will be stabilized in the north and north-central Japan, and for the south-central and south western Japan the yield will decrease, but not much the current level.

Case study in Malaysia: there were three locations selected for the study. The GFDL, GISS, and UKMO GCMs scenarios were applied for this study as well. Rice yields were simulated for particularly changes of 1.5 x CO_2 and 2 x CO_2 to based on current level, and for temperature increase by +1^{o}C, +2^{o}C and +4^{o}C above current temperatures. The average predicted increment of temperature for the mean season and off season found that all simulations received more rice yield in the both seasons, which ranged between 2.8% to 5.27%. However, when CO_2 levels increased by 1.5 times and 2 times combined with temperature increase by +1^{o}C, +2^{o}C and +4^{o}C, the rice yield predicted in the mean season benefit more than in the off season. In the main season rice yield changes ranged between +2.2% to 41.7%, and in the off season rice yield ranged between -12.7% to +41.8%. For the three GCM scenarios it is show that in the main season substantial yield increases are expected, ranging from +12% to +30%. The yield increased by 7.2% to 35.1% in off season.

Case study in South Korea: The ORYZA1 model was applied for rice yield prediction in South Korea under the change of CO_2 concentration by 1.5 times (510 ppm) and 2 times (680 ppm), and temperature change by + 1^{o}C, +2^{o}C, and +4^{o}C above current temperatures for scenarios GFDL, GISS, and UKMO General Circulation Models (GCMs). Here the simulated rice yield change will range between -25% to 1%, and the average rice yield declined by about 11%.

Case study in the Philippines: Twelve locations were selected in Philippines. The ORYZA1 model was applied for rice prediction in the Philippines for the same scenarios as above. The simulation under current climate with doubled CO_2

showed that the rice yield will be increased by +30%. However, the rice yield will be decreased between -4.4% to -10.3% per every 1°C of increasing temperature for the wet and dry seasons. For the three GCM scenarios in average over all sites and all seasons, the predicted changes in rice yield ranged from -11.5% to +7.3%.

Case study in Java, Indonesia: The DSSAT model was applied for this study under climate change scenarios using the GISS, GFDL, and UKMO climate scenarios, with double CO_2, and increased of 1.4% of solar radiation. The rice yield for the first crop will be decreased by -4.7%, and for the second crop will be increased by 20.83% (Amien et al., 1999).

For the Mekong River Basin, rice yield simulation under climate change scenarios was carried out by Crop Environment REsource Synthesis (CERES – Rice) model for the Savannakhet province (Inthavong et al., 2004). Under the different climate conditions atmospheric CO_2 increased to 540 ppm and 720 ppm or proximately 1.5 and 2 times from the baseline of 360 ppm. Many assumptions were taken for this simulation e.g crop calendar, crop management scheme and seed types which were assumed to be homogeneous throughout the province. According to the simulation results rice yield would change under future climate conditions such as the trend of rice yield will increase for minimum yields from 1800 to 2000 kg/ha, and for maximum rice yields from 5100 to 5900 kg/ha for 540 ppm of CO_2 concentration. For the scenario of 720 ppm of CO_2 concentration in the atmosphere the yields again declined, e.g. to 5600 kg/ha in case of the maximum yields (Inthavong et al., 2004).

This study will complete and update the previous studies and simulate the trend of rain-fed rice yields in Laos based on 6 different and updated climate scenarios (CSMK3, HadCM3 and HadGEM with low and high climate sensitivity, respectively, applied for 2001-2100). Three different time slices of 30 years in the 21th century are analysed regarding simulated crop yields, including a sensitivity analysis for eight scenarios on the effect of temperature and precipitation change.

The crop simulation considers the direct effect of increasing CO_2 concentration in the atmosphere by time scale of every five years on rice yield (Chapter III). Therefore, this study is different from the previous studies in the method of applying CO_2 increment for rice yield simulation and by using updated GCMs with six scenarios in three climate models.

2.4 Rice production

Rice is the most important crop for the human diet in many region of the world (FAO, 2004) and it is a staple food for nearly one-haft of the world's population. About 95 % of crop is grown and consumed in Asia. Rice provides 60% of the food intake in Southeast Asia and about 35 % in East Asia and South Asia. The highest consumption level per capital of rice is between 130 kg to 180 kg/capita/year, particularly in Bangladesh, Cambodia, Indonesia, Laos, Myanmar, Thailand and Vietnam (Kiple et al., 2000). Lao people consume 171 kg/capita/year milled rice (FAO, 2004). Particularly Laos has the highest per capita production and consumption of glutinous rice in the world (Linst et al., 2006). Rice provides dietary energy supply which is higher than in other grain such as wheat, maize (FAO, 2004).

Rice is the single most important factor determining the welfare status of the Lao people, particularly in rural areas. The majority of Lao farmers produce a single crop each year, and their use of mechanized and advanced farm technology and institutional instruments is limited. The communities are still surrounded by intact natural ecosystems from which natural products can be harvested. This is a strengths livelihood by supplementing and diversifying the farmer household's food and income sources (Boulidam, 2005; Chinvanno et al., 2006). Rice production is critical for farmers and the base of potential self sufficiency of food production in Laos. Respective of the achievement of rice self sufficiency at the national level, various studies suggest that not all households are able to meet their rice consumption requirements. Therefore the Lao government has been promoting for achieving self sufficient of rice at the national level. It has been a top priority goal of the country since the New Economic Mechanism in 1986. However, among observers different opinions exist on the extent to which country has achieved rice self-sufficiency (Bestari et al., 2006).

There are approximately 111 countries in the world growing rice including all Asian countries, most countries of West and North Africa, some countries in Central and East Africa, most of the South and Central American countries, Australia, and at least four states in the United States. The tropical region comprises the area between (23^o27'N latitude) and the (23^o27'S latitude). The tropics include most of the rice growing regions in India and all of the other South and Southeast Asian countries including Laos, also all of West African rice growing areas and most of rice growing areas of central and South America (Surajit et al., 1981).

In many rice growing areas, the year is divided into wet and dry seasons. In rainfed areas, the rice-cropping season is determined by the rainfall distribution pattern. Especially, in most of the temperate rice growing countries in Asia and in other regions rice cropping is determined primarily by the temperature pattern. Rice is almost entirely an irrigated crop with irrigation and planting can be adjusted to take advantage of favorable climatic conditions such as optimum temperature and high solar radiation. Variability in the onset of the monsoon season is a factor that determines the beginning of planting season for transplanted rainfed rice, because the water is required for land preparation. Variability in the amount and distribution of rainfall is the most important factor limiting yields of lowland rice, which constitutes about 80% of the rice grown in South and Southeast Asia**.**

2.4.1 Rice production ecosystem in Laos

The rice production system in Laos can be classified into two broad production systems which are lowland rice or paddy rice, and upland (dry land) rice cultivation.

2.4.1.1 Paddy rice production in low land ecosystem

Paddy rice areas include: (1) irrigated lowland, (2) rainfed lowland, (3) rainfed upland rice, and (4) dry season irrigated lowland rice. In the irrigated lowland, where rice grows in bunded fields and the fields are flooded for at least part of the season, where water for rice production comes from either rainfall or rivers. In the rainfed lowland the fields are flooded for at least part of the crop season, and all water for growing rice comes from rainfall. For the rainfed upland rice, mostly located in the valley area, particularly in the northern part of Laos, growing rice depends on rainfall rather than on irrigation. For the dry season irrigated lowland rice depends on irrigation (without rainfall) (Linquist et al., 2006). The Mekong River in Laos creates many flood plains where it flows throughout within the plain areas. Six major flood plains along the Mekong River in Laos are Vientiane plain, Borikhamxay, Khammoune, Savannakhet, Saravan and Champasak plains. These areas are in average at 200 meter above sea level and considered being a flood plain. The majority of the present production system is a single wet season cropping, particularly where there is no irrigation supply. The cropping calendar must follow up the growing season as rainy season starts from sowing and seedling in late May to mid June, followed by transplanting in mid June to mid July. However the timing of practices depends on rainfall distribution (Schiller et al., 2001). Rice is produced with minimum inputs and low level technology in Laos. Improved rice varieties were grown in less than 10% of rainfed lowland area in the past, but in 1999 the improved varieties have been grown already in more than 70% of the area in most provinces in the Mekong River Valley (Rao et al., 2001). To estimate that, in the year 2002 about 85% of the rice produced in Laos was glutinous, and over 85% of lowland rice varieties collected between 1995 and 2002 were glutinous (Appa et al., 2002). However, improving seed varieties is ongoing year by year.

Organic fertilizer is usually applied to rice seedbed, inorganic fertilizer is applied after transplanting, and the rate of application is rapidly increasing. Almost no chemical pesticide is used in the rice production cycle. Until about 1995, the level of mechanization in rice farming was very limited. Most land was ploughed by buffaloes. Transplanting and harvesting were done by hand (Figure 2.4). Mechanized threshers (harvesters) are now widely used. Hand-tractors are used for land preparation in about 50% of rice area in the Mekong River Valley. Other activities in the rice production cycle are still done manually. Furthermore, annual rice production remains unstable as much of the rice is produced under rain-fed conditions. Climate factors account for at least about 10% of the annual variability in rice production (Pandey et al., 1998).

Figure 2.4: Low land paddy rice planting in Savannakhet, Laos
Photos by Somkhit Boulidam (15 June 2009 and 10 July 2010)

2.4.1.2 Dry land rice production in the upland ecosystem

Upland rice cultivation in Laos is mostly based on a “slash-and-burn” method, and about 76% of upland rice cultivation in the northern part of Laos has been using this method. The upland rice cultivation occurs at the slope of the mountains ranging from 300 to 800 meters above sea level. It also occurs at the maximum height of 1,500 meters in the northern part of Laos, because northern part of Laos has limited flood plains. Upland rice is grown in combination with vegetables or other crops. Most farmers grow a combination of early, medium and late maturing local rice cultivars. The majority of upland households suffer a chronic rice deficit. The upland rice cultivation system is based on the use of family labor and limited use of organic fertilizer. The major production constraints are weeds, rodents, drought, insects and soil fertility.

The government of Laos has a national policy to stop all upland rice production under “slash-and-burn” shifting cultivation system (Figure 2.5). However, the success of this policy will depend on the implementation of appropriate alternative production systems that are able to achieve the combined objectives which are income generation, food self-sufficiency and ecosystem stability (Schiller et al., 2002).

Figure 2.5: Upland rice in northern part of Laos from Louangprabang to Louangnamtha provinces. Photos by Somkhit Boulidam (May 31, 2009)

2.5 Background of crop growth modeling

Crop growth is a complex system, and crop management can affect it in different ways. For example planting or seeding are always needed, irrigation, fertilization etc. can change inputs. According to their experiences, farmers combine activities effectively and the crop will react to its environmental changes. However, these mental are somewhat crude and quite difficult for improvement as well as explanation to others. Therefore, crop models are needed to identify methods of determining what factors should be included for the assessment of crop yield formation. A crop model is therefore a simple representation of a crop. It is used to study crop growth and compute growth responses to the environmental conditions. Crop models in common can be distinguished to descriptive and explanatory models (Penning, et al., 1989).

2.5.1 Introduction of DSSAT crop model

The Decision Support System for Agrotechnology Transfer (DSSAT) model was developed by International Benchmark Site Network for Agrotechnology Transfer (IBSNAT) in 1989 (Tsuji, et al., 1998). Climate change creates a major problem of agriculture. New agricultural research is needed to supply information to farmers, policy makers, and also for other decision makers, how to accomplish sustainable agriculture over the wide variations of climate, soil, environments, political, social and economic conditions around the world. DSSAT can be used to create virtual "experiments" to simulate, on computers, outcome of complex interaction between crop growth and various agricultural practices, soil and weather conditions and to suggest appropriate solutions to site specific problems (Jones, 1986; Uehara, 1989, Tsuji et al., 1998). This system relies heavily on simulation models to predict the performance of crops for making a wide range of decisions.

The first release of original DSSAT was DSSAT version 2.1 in 1989 (IBSNAT 1989; Tsuji et al., 1998) contained models of the following four crops: Maize (CERES-Maize v2.10; Ritchie et al., 1989), wheat (CERES-Wheat v2.10; Godwin et al., 1989), soybean (SOYGRO v5.42; Jones et al., 1989) and groundnut (PNUTGRO v1.02; Boote et al., 1989; Tsuji et al., 1998). Eight additional crop models have since been added such as rice (CERES-Rice; Godwin et al., 1991, Singh et al., 1993), dry bean (BEANGRO v1.01; Hoogenboom et al., 1991), sorghum (CERES-Sorghum; Alargarswamy and Ritchie, 1991), millet (CERES-Millet; Singh et al., 1991), barley (CERES-Barley; Otter-nacke et al., 1991), potato (SUBSTOR-Potato; Griffin et al., 1993; Tsuji et al., 1998), aroid (SUBSTOR-Aroid; Prasad et al., 1991), and cassava (CROPSIM-Cassava; described by Matthews and Hunt, 1994; Tsuji et al., 1998). The second release was (version 3.0) which was made in late 1994 (Tsuji et al., 1994., Tsuji et al., 1998), and another version 4.0 followed up in year 2003 (Jones et al., 2003).

2.5.2 Description of DSSAT V.3 and V.4

DSSAT was designed to allow user to (1) input, organize, and store data on crops, soil, and weather, (2) retrieve, analyses and display data, (3) calibrate and evaluate crop growth models and (4) evaluate different management practices at a site. In adapting and applying the DSSAT to a location, users typically use the following procedures (Jones, 1993; Tsuji et al., 1998).

(1) Conduct filed experiments on one or more crops, and collect a minimum data set required for running and evaluating a crop model. Field experiments may be needed to calibrate local cultivars. Run the model using the new data to evaluate the ability of the model to predict performance of crops in the region of interest. In many cases, data from previous experiments are used. Modify model if evaluation shows that it does not reach the level of precision required.

(2) Enter other soil data for region and historical weather data for site in the region. Quality check of soil and weather data. Conduct sensitivity analysis on the crop models to gain and overview of model responses to alternative management and practices and weather conditions.

(3) Select a set of new management practices and simulate each of these together with existing practices, over a number of years to predict the performance and uncertainty associated with each practice. Compare the alternative practices using means, variances regarding outputs such as phenology dates, water and nitrogen balance, net profit and other responses. Provide result and recommendations for decision making.

DSSAT crop models are process oriented, and are designed to have global applications; i.e., to be independent of location, season, and management system. The models simulate effects of weather, soil water, cultivar, and nitrogen dynamics in the soil and crop, on crop growth and yield for well drained soils. On modern personal computers they each require only a few seconds to simulate one growing season. DSSAT allows creating different management strategies and simulating performance indicators as listed in table 2.3.

The DSSAT v4 Cropping System Model can compute the daily growth of plants including C and N balance (Jones et al., 2003). The main subroutine of the plant growth model controls the process calculations of rate variables to determine the variable carbon based on daily photosynthesis minus maintenance respiration; the available nitrogen based on N uptake, mobilization, and N fixation, and net tissue growth rate of each plant component. The subroutine grow integrates these process rate variables using a daily time step to update the state variables of the crop after each day's growth. They are 12 crop models available in DSSAT v3, and 41 crops in DSSAT v4.2 Additional research has produced new models that are already integrated into version 4 of DSSAT such as (sunflower by Villalobos et al., 1995; sugarcane by Inman-Bamber, 1991; and tomato by Scholberg et al., 1997; Tsuji et al., 1998).

Table 2.3: Listing of the crop management options to create different strategies, and the crop performance variables that can be studied in DSSAT v3.

Management options	**Variables available for analysis**
Crop cultivar	Grain yield
Planting	Pod yield
Plant population	Biomass
Row spacing	Season length
Soil type	Reproductive season length
Irrigation	Seasonal rainfall
Fertilization (nitrogen)	Seasonal evapotranspiration
Initial conditions	Water stress, reproductive
Crop residue management	Number of irrigations
Crop rotations	Total amount of irrigations
	Nitrogen applied
	Nitrogen uptake
	Nitrogen leached
Weather factors	Nitrogen stress, vegetative
	Nitrogen stress, reproductive
Temperature	Net returns
Solar radiation	Phosphorus applied
Precipitation	Seed used
Carbon dioxide	Runoff
Wind[1]	Soil organic C
Relative humidity[1]	Soil organic N
	Residue applied
	Nitrogen fixation

[1] optional daily weather data requirements. These variables are used in the Penman method for computing daily potential evapotranspiration, if they are available.

2.5.2.1 Cereals: The CERES family of crop models

The individual origin CERES crop models were combined into a single module to simulate wheat, maize, barley, sorghum, and millet (Singh et al., 1991; Tsuji et al., 1998). There is only the CERES rice model kept separate, because its major differences in soil water, nitrogen balance routines, and the need to simulate transplanting effects. The CERES models increment grow in a daily time steps and require daily weather data (maximum and minimum temperature, solar radiation, and precipitation). To compute crop basic morphological development temperature, day length, and cultivar characteristics are input factors. The daily dry matter growth is based on light intercepted by the leaf area index multiplied by conversion factors. Biomass partitioning into various plant components is based on potential growth of organs and daily amount of growth supply to demand ratios of water and nitrogen balance. Sub-models providing daily values of supply to demand ratios of water and nitrogen, respectively, which are used to influence growth and development rates.

2.5.2.2 Grain Legumes: The CROPGRO family of models.

The original models of soybean, peanut and dry bean were programmed as separate computer codes, and were referred as SOYGRO, PNUTGRO, and BEANGRO (Hoogenboom et al., 1992; Tsuji et al., 1998). Because of the similarity and the difficulty of maintaining separate codes for each, authors amalgamated the models into a single set of computer codes (Hoogenboom et al., 1994, Boote et al., 1997; Tsuji et al., 1998) named as DSSAT v3. These models are referred to CROPGRO-Soybean, CROPGRO-Peanut, and CROPGRO-Dry Bean, for soybean peanut and dry bean, respectively (Hoogenboom et al., 1994; Tsuji et al., 1998). The models simulate the timing of phonological stages as affected by temperature and day length. Dry matter production is computed by daily or also hourly canopy photosynthesis models, and dry matter partitioning is based on source-sink relationships during the later vegetative phase using empirical functions. Crop-specific data files provide coefficients that characterize functional responses of each crop to its environment. Cultivar-specific data files provide coefficients to simulate the response of different cultivars to environment. For example, cultivar-specific coefficients quantify the photoperiod and temperature responsiveness of a cultivar as well as characteristics of vegetative and reproductive growth.

The CROPGRO family of models is using the same soil water and soil nitrogen modules as the CERES family. Growth of each crop is based on carbon, water, and nitrogen balances in the plant. In the process of creating a single set of codes, other changes were made to facilitate more applications, such as climate change impact on crops (Curry et al., 1990; Tsuji et al., 1998), pest effects on crops (Batchelor et al., 1993; Tsuji et al., 1998). In current days, there is only the grain legume models in DSSAT that can simulate effects of pest damage (Tsuji et al., 1998).

2.5.3 The application of the DSSAT model

The DSSAT crop models have been used for yield forecasting in several simulation studies (Duchon, 1986; Thornton et al., 1997; Bannayan et al., 2003; Yun, 2003, Soler et al., 2007). These forecasts can be conducted prior of planting or during the actual growing season. In both cases, the information obtained can be used by the farmers for crop management such as scheduling of fertilization or irrigation, or by governments for agricultural planning (Hoogenboom, 2000; Soler et al 2007). However, in research the DSSAT models mostly were and are used for climate change impact studies e.g in Indonesia, India, Malaysia, Japan, Korea, Bangladesh, Nepal etc. as presented case studies above show. The simulations that are conducted during the growing season for yield forecasting normally use the most-recently recorded weather data and for future weather (climate scenarios) daily weather data sets derived, and past weather recorded from GCMs (Duchon, 1986; Thornton et al., 1997, Soler et al., 2007).

CHAPTER III

MATERIALS AND METHODS

III. MATERIALS AND METHODS

3.1 Study area

Laos is a small country that locates in the center of the Southeast Asian peninsular, to cover 236,800 square kilometers. An about of 230,800 square kilometers is consisted of land, and 6,000 square kilometers is water surface. The country is located between longitudes $13^{o}54'$ to $22^{o}03'$ North, and between latitudes $100^{o}05'$ to $107^{o}38'$ East. The length from north to south is approximately 1,000 km, and the width from east to west is approximately 470 km. The location and appearance of the country has influence on the climate, which influence the agricultural production such as rice cultivation. Laos is a land locked country neighboring with five countries: Burma, China, Cambodia, Thailand and Vietnam (Figure 3.1).

The total population is 6,477,211 estimates in July 2011 (http://www.indexmundi.com/laos/population.html). The study area of this thesis is Savannakhet province, Laos; which is located at latitude $16^{o}33'$ North, longitude $104^{o}45'$ East with altitude of 144 m above sea level. It is located in between central to southern part of Laos, with total area of 21,774 km^2 and consists of 15 districts. This province has the highest number of population compared with other provinces. The total population of this province is 900,000 people (survey of 2011). Savannakhet province has the largest paddy rice cultivation area in Laos, which covers 21.48% or 194,157 hectare of total area of paddy rice cultivation of Laos (Annual report Crop statistic of department of Agriculture, 2009).

Figure 3.1: Map of Laos (http://www.psywarrior.com/LaosPSYOP.html)

3.2 DSSAT V. 4 and its Rice Model

Climate and crops in the future may be different from the present days. Crop-climate modeling calibrated for current practices may not be sufficient to measure future sensitivity to climate change. Therefore, it is useful to understand the sensitivity of present rice cultivar and cropping system to a range of potential future climates. Indeed understanding the present sensitivity is essential to setting priority for developing efficient strategies to adapt to future climate conditions. Impacts of climate to agriculture are in various levels, from individual farmers in terms of food consumption, to households in terms of income, to village, regional, national and global levels. Each level requires different methods of assessment (Shukla et al., 2003).

In this research DSSAT V4.2 (Fig. 3.2) rice model was applied for simulation of potential rice yield in term of climate change scenarios in Savannakhet province, Laos. The utility of this system depends on the ability of the crop models to provide realistic estimates of crop performance for a wide range of environment and management conditions and on the availability of data required to operate the models. The CERES rice v4.2 model is included in the DSSAT v4.2. This model simulates the growth, development and yield of a component crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, Carbon (C) and Nitrogen (N) that take place under the cropping system over time. The model consider the effects of weather, genetics, soil water, soil C and N, and management in single or multiple seasons and in crop rotations at any location (Singh et al., 2007).

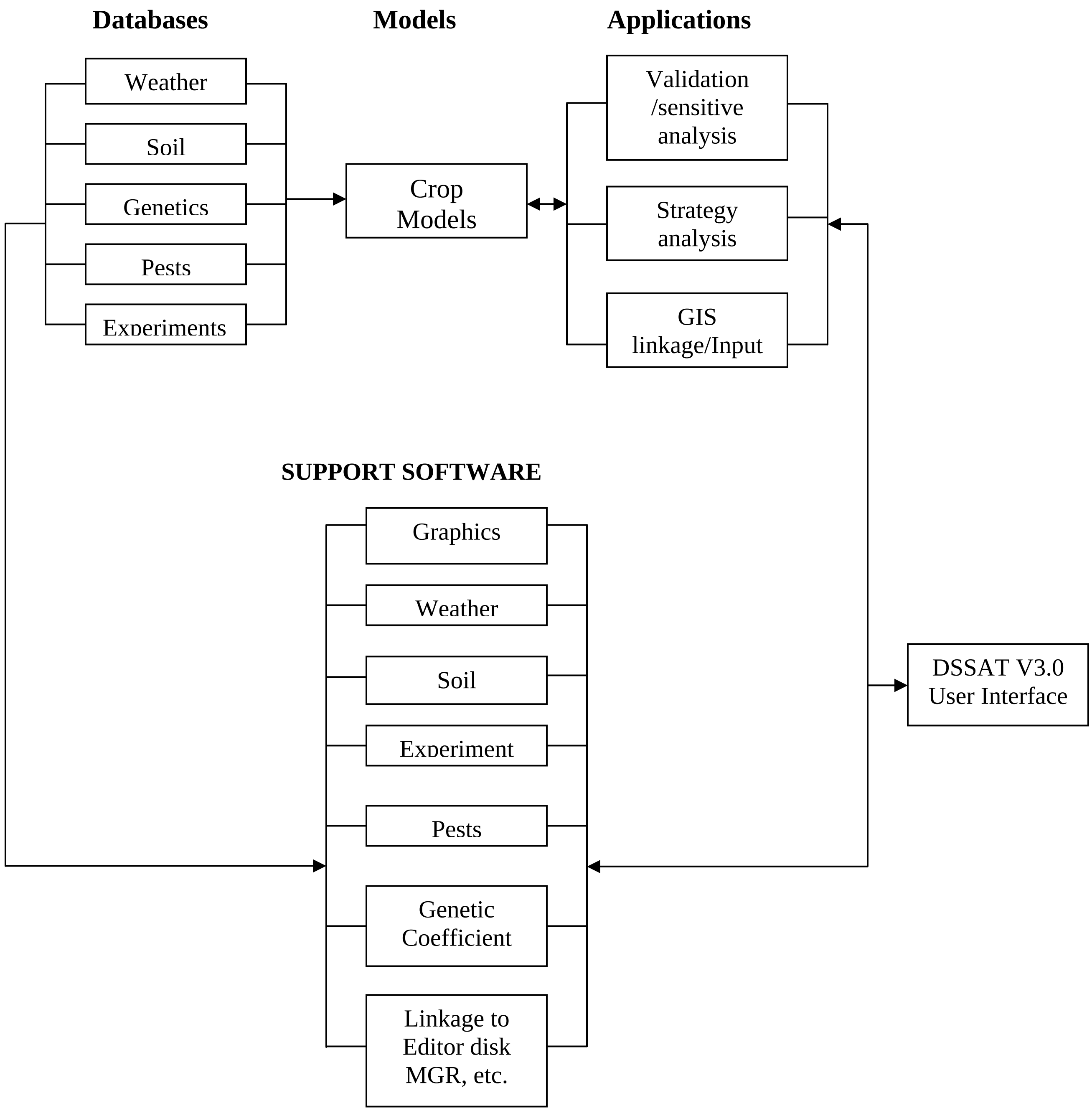


Figure 3.2: Schematic of relationships between the crop model driver program (MDRIV940.EXE), the crop model input program (MINPT940.EXE), the temporary file read by the crop model modules (IBSNAT30.INP), and the crop simulation model modules.

3.2.1 Structure of the DSSAT crop model

Plant growth is simulated by the model by biomass accumulation of the plant components leave, stems, roots, shells, and seed. Tissue dry weight, nitrogen content (N), carbon reserves (C, non-structural Carbohydrates), leaf area and number of leaves on the main stem (V-Stage) are the state variables that describe leaves. Dry weights have the unit gram of [plant material]/m^2. Stems, shells and roots also have tissue dry weights, N and C contents. Tissue dry weight in each plant components includes the weights of C and N that are stored in it.

Seeds are described by their dry weight and N content. In addition, number of seed and shells are state variables that depend on addition and abortion rates. For purposes of computing photosynthesis, C stored in the plant, C used for respiration, and C used for mass growth, the model uses the Carbohydrate form (CH_2O). Tissue growth rates are based on conversion efficiency multiplied by the mass of CH_2O use in growth (g). Nitrogen may be taken up from the soil, mobilized from plant tissue, and assimilated through symbiotic N fixation. After initial assimilation and reduction, N in the plant is assumed to be in the form of protein groups, with a constant proportion of N (16%). As N is assimilated from the different sources, CH_2O is subtracted to account for the energy costs of synthesizing the protein groups. Calculations are also made to convert between fractions of protein using the assumption that protein is 16% N (James et al., 2003).

3.2.2 C and N flow and Utilization

The scheme of the overall C and N flow paths in the plant is assumed to control the flow of C and N during a day. Total CH_2O available for growth in a day is equal to the day’s photosynthesis, maintenance respiration is subtracted and potential amount of C mined in a day. The first source of N available for tissue growth is from the seed itself, then from seed to the leaf, stem and root at emergence, and it is assumed to become available during the first seven thermal days after emergence. After that, N uptake from soil by root length density or by N demands. Seeds have the highest priority for all C and N in determinate crops, this priority is limited to a maximum daily reproductive partitioning coefficient, (g [fruit growth] / g[total plant growth]). For example, peanut varieties may have partitioning coefficients of 0.6 to 0.9 meaning that 40 to 10 percentage of day's C would go to vegetative growth, regardless of the sink strength of seed and shells. Potential growth rates are computed based on available C from the current day's photosynthesis as well as mobilized C.

When N uptake and N_2-fixation are less than N demand, vegetative tissue will grow at lower N concentration. There is a minimum N concentration, specified in the species file, which tissue growth rate is progressively decreased to hold a constant minimum N concentration. A primary consequence of N deficiency is decreased leaf and canopy photosynthesis as leaf N concentration declines, following a quadratic function from maximum to minimum N concentration. If N is deficient, photosynthesis will be decreased, and new vegetative tissue will be produced at a lower N concentration. If tissue concentration approaches the lower N limit, then vegetative growth is reduced and carbohydrate begins to accumulate in vegetative tissues as a certain N deficit. Under this situation, excess carbohydrates will accumulate in leaves and stems. The N_2-fixation rate is also influenced by temperature, soil water deficit, soil aeration (flooding), and plant reproductive age. Costs for N assimilation (carbohydrate cost for N uptake, N_2-fixation, and reduction to amide form) are subtracted from the available assimilate pool after each process is simulated.

3.3 Application of DSSAT Model

The DSSAT modeling system contains an advanced physiologically based rice crop growth simulation model and has been widely applied to understanding the relationship between rice and its environment related. The model estimates yield of irrigated, non-irrigated rice and other crops like wheat, potato etc, determine duration of growth stages, dry matter production and portioning, root system dynamics, effect of soil water and soil nitrogen contents on photosynthesis, carbon balance and water balance. Ritchie et al. (1987) and Hoogenboom et al. (2003). The input data required to run the DSSAT models include daily weather data (maximum and minimum temperature, rainfall, and solar radiation); soil characterization data (physical, chemical and morphological properties for each layer); a set of cultivar coefficients characterizing the cultivar being grown in terms of plant development and grain biomass; and crop management information, such as the established plant population, row spacing seeding depth, and application fertilizer and irrigation. The soil water balance is determined on a daily basis as a function of precipitation, irrigation, transpiration; soil evaporation, runoff, and drainage form the bottom of the profile. The soil water is distributed in several layers with depth increments specified by the user (Ritchie and Godwin, 1989; Ritchie, 1998; Soler, 2007). The DSSAT flow diagram is shown in Figure 3.3.

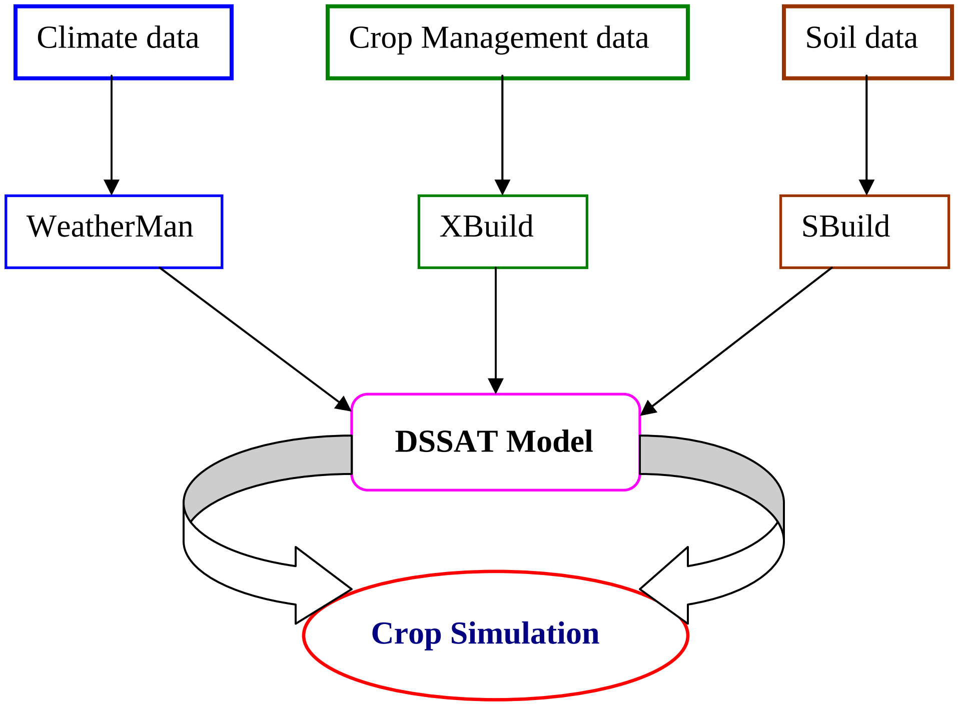


Figure 3.3: The DSSAT flow diagram

The CERES-Rice model (Alocilja and Ritchie, 1998) is included in the DSSAT family of models (Version 4.2; Hoogenboom et al., 2003). The CERES-Rice model has been used extensively to assess crop yields under current conditions. It used daily inputs of solar radiation, minimum of temperature, and precipitation to calculate plant phonological development from planting to harvest, photosynthesis and growth rates, and carbon allocation to grain or fruit. In the model, temperature between 14 and 32 ^{o}C are considered optimal for photosynthesis; therefore, the model also considers the decreasing effect of short episodes of high temperature, a point of concern in a future climate (Horie et al., 1997; Challinor et al., 2005c; Porter and Semenov, 2005). The model uses soil component to calculate water and nitrogen movement, so it is able to assess the effects of seasonal or intra-seasonal rainfall variability and different management practices on rice growth.

3.4 Crop model setup

3.4.1 Input data

3.4.1.1 Climate Data

The DSSAT models require the minimum data set for model operation. The weather data include information on location of the weather station (latitude and longitude) daily of values of incoming solar radiation (MJ/m^{2}-day), maximum and minimum air temperature (^{o}C) and rainfall (mm) as minimum data set. The required weather data record is limited for the study area as well as in Laos. Available weather data for 39 years (1971-2009) of daily minimum and maximum of air temperature and daily rainfall were collected but no solar radiation data are available from the meteorology department. Therefore, an alternative procedure has to be applied for calculating solar radiation from daily maximum and minimum temperature as recommended by FAO (Allen et al., 1998). The steps of calculation are shown below:

Calculation of extraterrestrial radiation for daily period (Ra)

The extraterrestrial radiation (Ra) for daily of the year and for difference location especially different latitudes that can be estimated from the solar constant, the solar declination and the time year by:

$$R_a = \frac{24\,(60)}{\pi} G_{sc}\, d_r\, [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)] \qquad (1)$$

Where G_{sc} : solar constant = 0.0820 MJ m^{-2} min^{-1}

φ : latitude (radians)

d_r : inverse relative distance Earth-Sun

δ : solar declination

ω_s : sunset hour angle

The latitude (φ) expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degree to radians is given by:

$$\text{Radians} = \frac{\pi}{180}\,(\text{decimal degrees}) \qquad (2)$$

According to latitude of the weather station is $16^o33'$N

Decimal degree = 16+33/60

= 16.55

Radians = (π/180) 16.55

= 0.288

The inverse relative distance Earth-Sun (d_r) is given by:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \qquad (3)$$

Where J is the number of the day in the year between 1 (1 January) and 365 days or 366 days (31 December)

The solar declination (δ) is given by

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \qquad (4)$$

Where values of the J is all days of the year

The sunset hour angle ω_s is given by:

$$\omega_s = \arccos\left[- \tan(\varphi) \tan(\delta) \right] \qquad (5)$$

Solar radiation data derived from air temperature differences:

The differences between the maximum and minimum air temperature is related to the degree of cloud cover in a specific area. For example in the clear sky day, the temperature might be higher during the day maximum temperature (Tmax), because the atmosphere is transparent to the incoming solar radiation and in low temperature during the night time, because less outgoing long wave radiation is absorbed by the atmosphere. On the other hand, in overcast conditions, minimum temperature (Tmin) is relatively smaller because a significant part of the incoming solar radiation never reaches the earth’s surface and is absorbed and reflected by the clouds. Similarly, Tmin will be relatively higher as the cloud cover acts as a blanket and decreases the net out going long wave radiation. Therefore, the differences between the maximum and minimum temperature can be used as an indicator of the fraction of extraterrestrial radiation that reaches the earth's surface.

The Hargreaves' radiation formula adjusted and validated at several weather stations in a variety of climate conditions as following:

$$Rs = k_{Rs}\sqrt{(T_{max} - T_{min})}\, R_a \tag{6}$$

Where R_a : extraterrestrial radiation (MJ $m^{-2}d^{-1}$)

Tmax: maximum air temperature (°C)

Tmin : minimum temperature (°C)

k_{Rs} : adjustment coefficient (0.16 or 0.19) ($^oC^{-0.5}$)

The square root of the temperature difference is closely related to the existing daily solar radiation in a given location. The adjustment coefficient k_{Rs} is empirical and differs for "interior" region means location where land mass dominates and air mass are not strongly influenced by a large water body k_{Rs} = 0.16; for the "coastal" regions means locations, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body k_{Rs} = 0.19 (Allen et al., 1998). In this research k_{Rs} = 0.16 is considered, because study area is land locked, and get influence air mass from continent rather than water body.

3.4.1.2 Climate change scenarios applied

Climate change scenarios for this study were developed from General Circulation Models (GCMs). A large number of climate change experiments in the world in the past have been based on GCMs. There are two types of modeling approaches for GCMs to calculate the effect of greenhouse gases (and aerosols) on global temperatures which are called equilibrium and transient modeling (reflecting the climate sensitivity to greenhouse gas changes). A representative subset of GCMs is based on Internal Panel on IPCC-AR4 (Parry, et al., 2007). There are available reliable climate data of Average Temperature (TAVG), Precipitation (PREC) and Solar Radiation (SRAD). Daily weather data which are used for crop model inputs were developed from such GCMs in this study for Savannakhet, Laos.

According to Dubrovsky (pers. Comm., 2011) the downscaled climate scenarios from global scale to regional scale are based on observed daily climate data series for 39 years (1971-2009) at Savannaket weather station in Laos. In this approach, the climate scenarios for specific future climate sensitivity are determined as a product to the change in global mean temperature and the standard scenarios were determined from the outputs of GCMs. High and low climate sensitivity for 100 years (2001-2100) was applied for three GCMs such as Commonwealth Scientific and Industrial Research Organisation, Australia (CSMK3 or CSIRO-Mk3.0), Hadley Centre Coupled Model version 3 (HadCM3) and Hadley Centre Global Environment Model (HadGEM) to develop the climate scenarios. These three models were selected because they show significant differences and can therefore represent the full range of between-GCM variability (and uncertainty) in southern Laos.

The climate scenarios were converted into daily climate data for data input to the crop models. The six scenarios from CSMK3, HadCM3, and HadGEM taking into account high and low climate sensitivity to CO_2 concentration were calculated named as CSHI and CSLO scenarios for the CSMK3 model, as HCHI and HCLO scenarios for the HadCM3 model and as HGHI and HGLO scenarios for the HadGEM model (see also Table 4.1.1).

According to the Integrated Assessment Platform, it is recommended to provide users to select some emissions scenarios (SRES), (A1b, A2, B1 or B2) and/or climate sensitivities of low, medium and high (Dubrovsky et al., 2011). For this study low and high climate sensitivity was applied, where high climate sensitivity was represented by SRES A2, and low climate sensitivity was represented by SRES B1.

The high climate sensitivity criteria were based on CO_2 concentrations in the atmosphere considering a change in every five years. In the high climate sensitivity SRES A2 the amount of CO_2 concentration ranged from 369 ppm to 950 ppm from 2000 to 2100 (Appendix 1).

Also the low climate sensitivity criteria were based on CO_2 concentrations in the atmosphere considering a change in every five years. In the low climate sensitivity SRES B1 the amount of CO_2 concentration ranged from 369 ppm to 491 ppm from 2000 to 2100 (Appendix 1).

The high and low climate sensitive scenario based CO_2 levels were used as well as input for rice simulation. The six scenarios were calculated for 100 years, and divided into three analyses periods 2001 to 2030, 2035 to 2065 and 2070 to 2100 for comparison of changing climate and yield levels.

3.4.1.3 Soil Data

To require soil data of the model include soil classification, surface slope, soil color, permeability, and drainage class. Soil profile data by soil horizons include: upper and lower horizon depths (cm), saturation water content, upper and lower limit (field capacity and wilting point), percentage sand, silt, and clay content, bulk density, organic carbon, pH in water, aluminum saturation, and potential root distribution and depth (Wilkens, et al., 2004).

As the simulation is carried out for paddy rice the soil water related physical soil properties are not critical. According to the result of soil survey in year 1991 – 1992 of National Agriculture and Forestry Research Institute, the soil classification which is based on based on FAO/UNESCO’s criteria in year 1990 there are 11 groups of soil classified for the study region Savannakhet (Fig. 3.4).

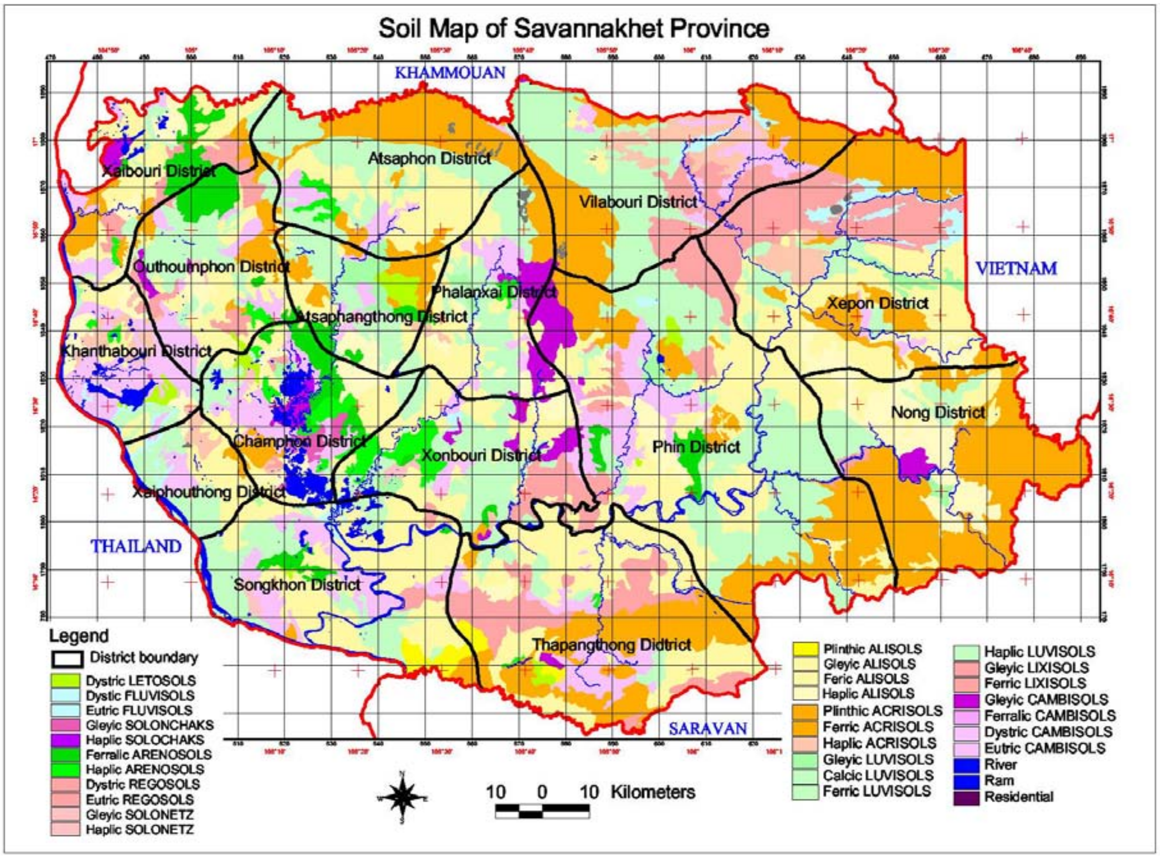


Figure: 3.4: Soil Map of Savannakhet province (source: National Agriculture and Forestry Research Institute)

such as FLUVISOLS (FL), ARENOSOLS (AR), REGOSOLS (RS), CAMBISOLS (CM), ACRISOLS (AC), SOLONCHAKS (SC), SOLONETZ (ZN), LIXISOLS, ALISOLS (AL), LEPTOSOLS (LT), and LUVISOLS (LV) etc.. The majority of the area is covered by CAMBISOLS group which consists of Ferralic CAMBISOLS, Dystric CAMBISOLS, Eutric CAMBISOLS and some other types (Report of Department of Agriculture and Forestry in Savannakhet, 2004). In addition, these soil types are most representative in low land area where paddy rice is grown. According to the result of some simple soil analysis from Department of Agriculture in Savannakhet province an experimental site was characterized by a poor soil with percentage of total N of 1.53%, P of 0%, K of 3.80 %, organic matter of 0.32 % and pH of 5.16. These data were applied for the simulation.

3.4.1.4 Crop management and N-fertilization

Management data includes information on planting date, dates when soil conditions were measured prior to plant, planting density, row spacing, planting depth, crop variety, irrigation, and fertilizer practices. This data are needed for both model validation and strategy evaluation. In addition to site soil and weather data, experimental data includes crop growth data, soil water and fertility measurements. This data are needed for model validation.

For the nursery management, most of growing lowland rice in Laos is transplanted as opposed to direct-seed. The rainfed rice seeding begins in May or early of June at the monsoon rainfall. Seedlings grown about 25 - 40 days can be transplanted, depending on rainfall. Farmer typically plant in hill at a density of 16 plants / m^2 using about 3 seedlings per hill (Linquist et al., 2006). The more recent adoption of fertilizing is largely and increasingly confined to areas of low land rice production in the south and central of Laos (Pandey et al., 1998); where study area is located. Some farmers apply rice husks and manure to their fields, but this is not a common practice.

This study did not use experimental management data for a crop season cycle, but expert assessments on the best practice applied in the region. Even though, I did not all experimental management for this study, but I had interview with Mr. Thilavong Kh (Head of Unit Planting of Department of Agriculture and Forestry, Kaison district, Savanakhet province), and some staffs there, providing information and some necessary data for this study (Figure 3.5).

Figure 3.5: Interview agricultural staffs (10 July 2010)

They were excellent co-operation to answer the questions and to provide necessary information for this study. Particularly information on technical experience for growing paddy rice such as rice varieties, space of planting, the date of sowing, the date of planting, date of harvesting, soil data, characteristic of soil, type of organic, amount of fertilizer to be applied, and another problem that concerned with rice growing etc. was gathered. There are many type of rice varieties grown in Savannakhet province (see 3.4.1.5 rice genotype), estimated dates of sowing were from 15th to 20th May, and transplanting was 15th till 25th June (depends on rainfall). Harvest time after planting was about 110 days for early rice, about 120 days to 150 days for medium late rice and for late season rice was about 150 days or longer then that (Thilavong, Pers.Comm 2010). Farmers of lowland paddy rice in most parts of Laos practice single wet season cropping, which normally starts in May and ends in October to November. They usually start sowing rice at the beginning of rainy season, farmers who implement transplanting technique begin the process in mid-June to mid-July and harvest in October to November (Boulidam, 2005; Chinvanno et al., 2006).

For fertilization, farmers use on their farm both organic and conventional fertilizer. However, more farmers applied conventional fertilizer than organic, because of limited organic sources. The main fertilizer applied was Urea, the rate suggested from Department of Agriculture and Forestry was 300 kg/ha. However, farmers could not apply that amount, because of their limited budget. So in real farmers applied at maximum about 150 kg/ha. Still the majority applied less than that and some farmers didn’t apply any fertilizer for some years, depending on farmer’s economic situation. According to experiments and researches of N supply from rice cultivations in Laos at 20 locations (12 locations in the south, and 8 locations in the north) from 1993 to 1998 by (Lindquist et al., 2005), the rate of N-fertilization applied in our target region of Savannaket ranged between 0 to 120 kg/ha. Therefore, adaptation of the maximum amount of fertilizer in the model was set to 120kg/ha, where for the crop model simulations five N-fertilization levels were selected (0kg/ha, 30kg/ha, 60 kg/ha, 90kg/ha and 120 kg/ha) for all 6 different climate scenarios. This range can therefore cover all currently used fertilization levels in Savannakhet province, Laos for a better estimate of potential climate change impacts and adaptation options. The schedule to apply the fertilizer was divided to three periods: the first part was applied before transplanting (2/3 of total fertilizer), the second part 20 and 25 days after transplanting, and the third part 20 days to 25 days after the second application. Space of planting was 25cm x 25cm, depth of planting was 2cm (Thilavong, Pers.Comm, 2010).

Due to bad weather conditions, for example in years with drought, diseases and insects such as grasshopper, rice stink bugs, armyworm may appear beside direct drought effects on the crop (dried leaves), particularly during sowing period (see figure 3.6). Even sometimes transplanting cannot be carried out. In contrast, a flooding year can force diseases such as Bacterial Leaf Blight (BLB), Blast (Leaf and Neck) etc. (Thilavong Pers.comm, 2010). These events were not considered for the crop simulation. However, it is concerned with rice production.

Figure 3.6: Drought damage appeared during sowing period (dried leaves). Photos by Somkhit Boulidam (10 July 2010).

After finished interviewing we all together visited rice field to observe real practices on the rice field to compare with the interview information (Figure 3.7).

Figure 3.7: Field visit in Kaison district, Savannakhet Province. Photos by Somkhit Boulidam (10 July 2010).

3.4.1.5 Plant data - Rice genotypes

Laos has one of the highest biodiversity of rice varieties in the world, and is the center of glutinous rice varieties. Since 1990 more than 13500 rice samples have been collected of glutinous types of rice which covered 85% of the total samples. These samples represent more than 3000 rice varieties contribution to the International Rice Genebank which ranks in the second apart from India (Bestari et al., 2006).

According to the classification of rice phenology from National Rice Research Program (NRRP), the rice growing period ranged from 140 to 150 days or longer than that in reality. Laos's cultivars with longer growing periods are named TDK 1 and TDK 2. Medium crop growth duration ranges between 130 to 140 days and is represented TDK 3, RD10, NTN 1 varieties. Cultivars with short crop growth duration of 120 to 130 days are PN1, SK12 varieties (Linquist, B., 2005).

There are many rice varieties grown for paddy rice cultivation in Savannakhet province, including traditional rice varieties (Luengboonma, Douyuan, Peutnam, Jasmine, Saiyan, Khaosuong, Dou Obon, Khamnoy, Dounoy, Eephond, Dounuan, Phanbouli, and Eekhaoyai etc.) as well as rice varieties developed by agriculture department (TDK (1 to 11), RD 1, RD 2, RD 4, RD 6, RD 8, RD 10, RD 12, Thasano, Dokkhamkhao, TDK hangdok, Salakham 12, Thasano 1, Phonengam 1 Namtan 1, Salakham 12, Hanggee 71, and Namsakpu 19) (Schiller et al., 2001). The seed varieties that majority of farmers have used are TDK 1, TDK 11, TDK 7, TDK 8, Thasano 1, PG 1, RD 6 and RD 8, and some traditional rice varieties (Thilavong., 2010. pers.comm). However, famers try to select suitable rice varieties for their farms by their own and it depends on characteristics of farm location and elevation. Farmers commonly plant three of four varieties, typically a combination of one early, one medium and one or two late maturing varieties, to provide the continuity in their food supply.

According to lack of model specific rice genotype data rice genotypes available in the model were tested against several years of yield data. Finally the best performing cultivar IR 64 was selected, further adjusted and applied for the simulation study. The validation results of the model test are very good compared with rice yield statistics recorded by Department of Agriculture and Forestry in Savannakhet. The result of model validation for the rice yields simulation is presented in Chapter IV.

3.4.2 Simulation and analysis

The three main groups of crop model input data are climate data, soil data and crop management data which were prepared for the rice simulations. Model validation was done by comparison to the rice yields record from Department of Agriculture and forestry for 39 years from 1771 to 2009. After successful validation the model was applied to the climate change scenarios.

A change of Tmax, Tmin and SRAD under climate scenarios will affect crop growth and production. The crop model therefore simulates the impacts of climate on crop growth and production comprehensively, for example by including the effects of temperature change and the impact of solar radiation change. Both of these are key processes that substantially affect crop growth and production (Monteith, 1972; Alocilja and Ritchie, 1988; Rosenzweig and Tubiello, 1996). The potential biomass yield of a crop is the product of the rate of biomass accumulation and the duration of growth. The rate of biomass accumulation increase from a base value and decrease beyond an optimum limit (Holaday et al., 1992; Vu et al., 1997).

There are six scenarios of rice yield simulation for 100 years (2001 to 2100), divided to three analysis periods 2001-2030, 2035-2065 and 2070-2100 for comparison of changing rice yield levels. In addition, a sensitive analysis for eight scenarios was carried out including increased precipitation, decreased precipitation, increased temperatures, increased both temperatures with increased precipitation and increased temperature with decreased precipitation for 39 years (1971 to 2009) as shown in table 3.1. To sensitivity analysis was carried out to detect potential critical limits for rice production under the conditions in Savannakhet, Laos.

Table 3.1: Sensitivity analysis factors with changing precipitation and temperature based on observation data climate (1971 to 2009) applied on crop model weather input data.

No	Sensitivity analysis factors		Remarks
	Precipitation (%)	Temperature (^oC)	
1	+ 25		Increased Precipitation only
2	-25		Decreased Precipitation only
3		+2	Increased Temperature only
4		+4	Increased Temperature only
5	+25	+2	They are both increased
6	-25	+2	Decreased Precipitation with increased Temperature
7	+25	+4	They are both increased
8	-25	+4	Decreased Precipitation with increased Temperature

CHAPTER IV

RESULTS AND DISCUSSIONS

IV. RESULTS AND DISCUSSIONS

4.1 Climate change and variability in Laos

According to observed climate data over 39 years (1971 – 2009) in Savannakhet province by Department of Meteorology and Hydrology. The average of air temperature for 39 years was 26.14°C, the mean of minimum and maximum of air temperature ranged between 21.17°C to 31.35°C. The highest temperature was 44°C in April 1974, and the minimum temperature was 2.9°C in December 1975. The trend of temperature was slightly increasing in 39 years, by 0.68°C from 1971-2009. We can see that the mean annual temperatures in over last 30 years fluctuated significantly and show an increasing trend (Fig. 4.1).

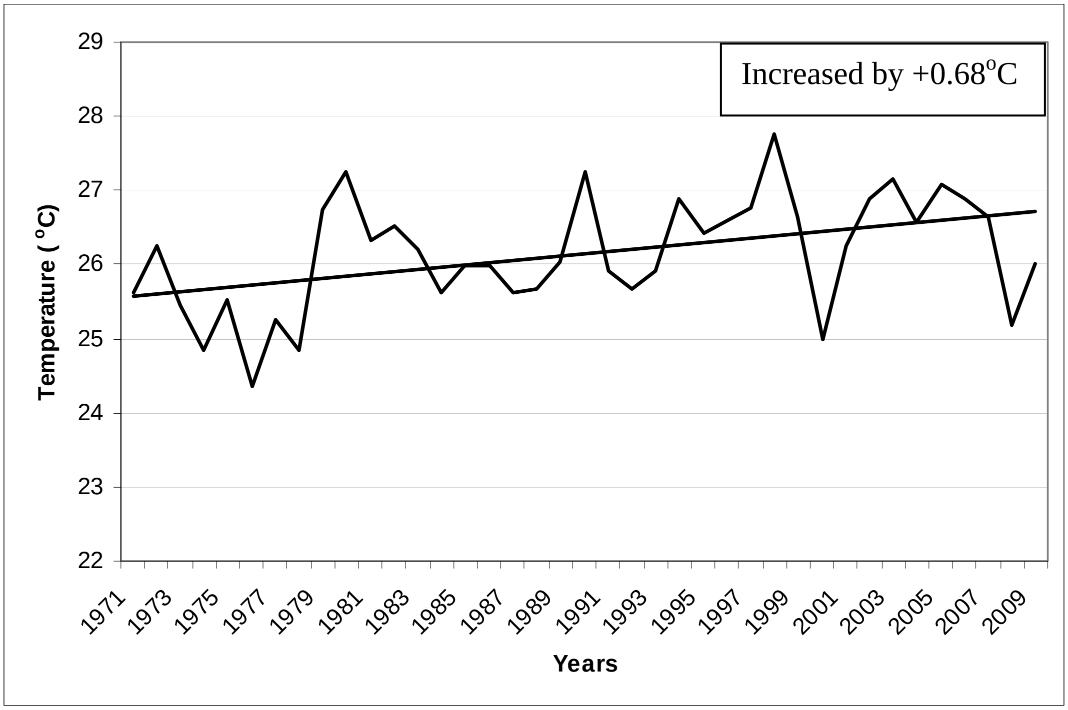


Figure 4.1: Mean annual temperatures over 39 years (Department of Meteorology and Hydrology)

The average annual rainfall for 39 years (1971-2009) was 1426 mm; the highest peak of rainfall was 578.2 mm in August, 1974. From October to April (dry season) the amount of rainfall is less then 100 mm per month. The maximum annual rainfall was 1982 mm in year 2002, and minimum annual of rainfall was 1070 mm in year 1998 within the period of 1971 to 2009. The trend of precipitation also increased from 1971-2009, namely by 143 mm, which is however only around 1% of the total annual precipitation (Fig. 4.2).

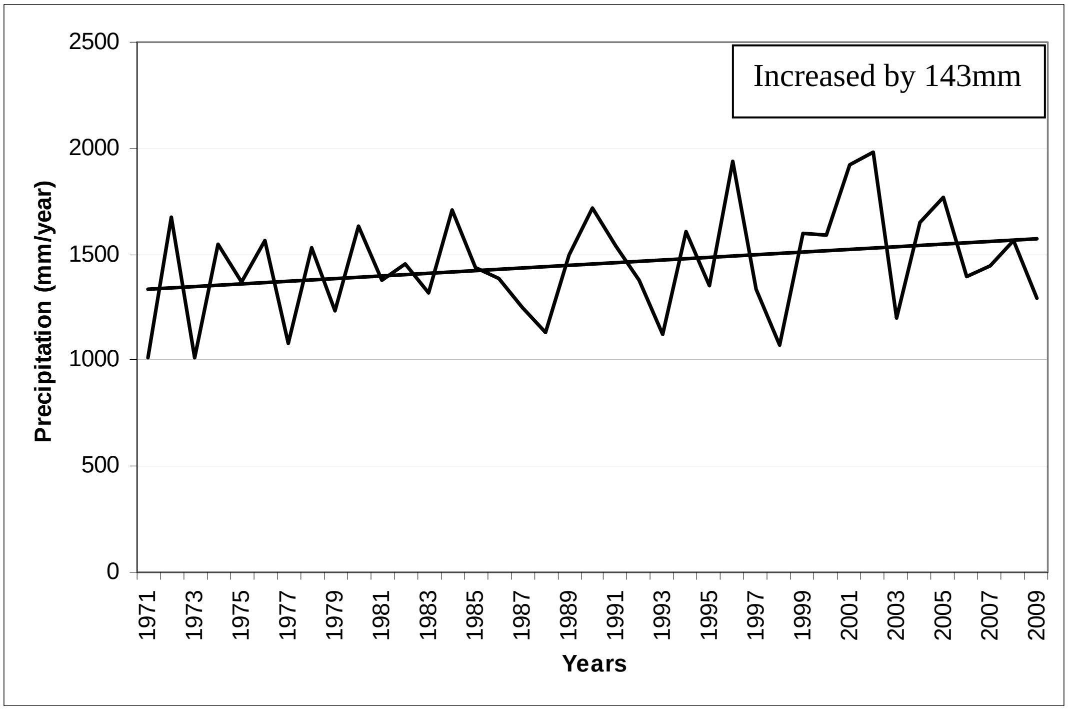


Figure 4.2: Average of precipitation for 39 years (Department of Meteorology and Hydrology)

Solar radiation data were limited; therefore it was calculated by using maximum and minimum of temperature (see Chapter III and the results at Appendix 2). The results from the calculation were compared with observation measurements from the Department of Mathematic, showing similar results. For example, the calculated average of solar radiation in the year 2008 was 16.90 MJ/m^2 while the measured average was 17.15 MJ/m^2 (Khamvongsa et al., 2009). The results of the calculation method for solar radiation from 1971 to 2009 were accepted and applied for the data input of the model, because we have no long term record of solar radiation data from the local weather station.

4.2 Projection of the climate change signal in Savannakhet, Laos

4.2.1 Representative subset of GCMs for Savannakhet, Laos

The projection of climate scenarios by using the General Circulation Models (GCMs), was carried out by Dubrovsky (Pers.comm 2011). It is using database of IPCC-AR4 for Average Temperature (TAVG), Precipitation (PREC) and Solar Radiation (SRAD).

Choosing of the GCM subset, to follow two criteria are:

(1) The quality of the GCMs
(2) The ability of the GCMs to represent the inter GCM variability.

The results of subset of the five GCMs, the first GCM represents the “best” GCM, the second GCM represent of the “central”, and the three others GCMs represent between GCM variability. The best GCMs represent ability of the model to simulate present-climate annual cycle of temperature and precipitation. The central GCM and triplet of most diverse GCMs was based on climate change scenarios, where each GCM is represented by eight dimensional position vector, to simulate change in seasonal means of temperature and precipitation, to quantify the distance in the space. So, in this study were selected three mutually most different (best, central and variability or distant) scenarios, which maximise the sum of between-GCM variability of climate change scenarios. Therefore, Commonwealth Scientific and Industrial Research Organisation, Australia (CSMK3 or CSIRO-Mk3.0), Hadley Centre Coupled Model version 3 (HadCM3) and Hadley Centre Global Environment Model (HadGEM) models were selected for this study (Figure 4.3).

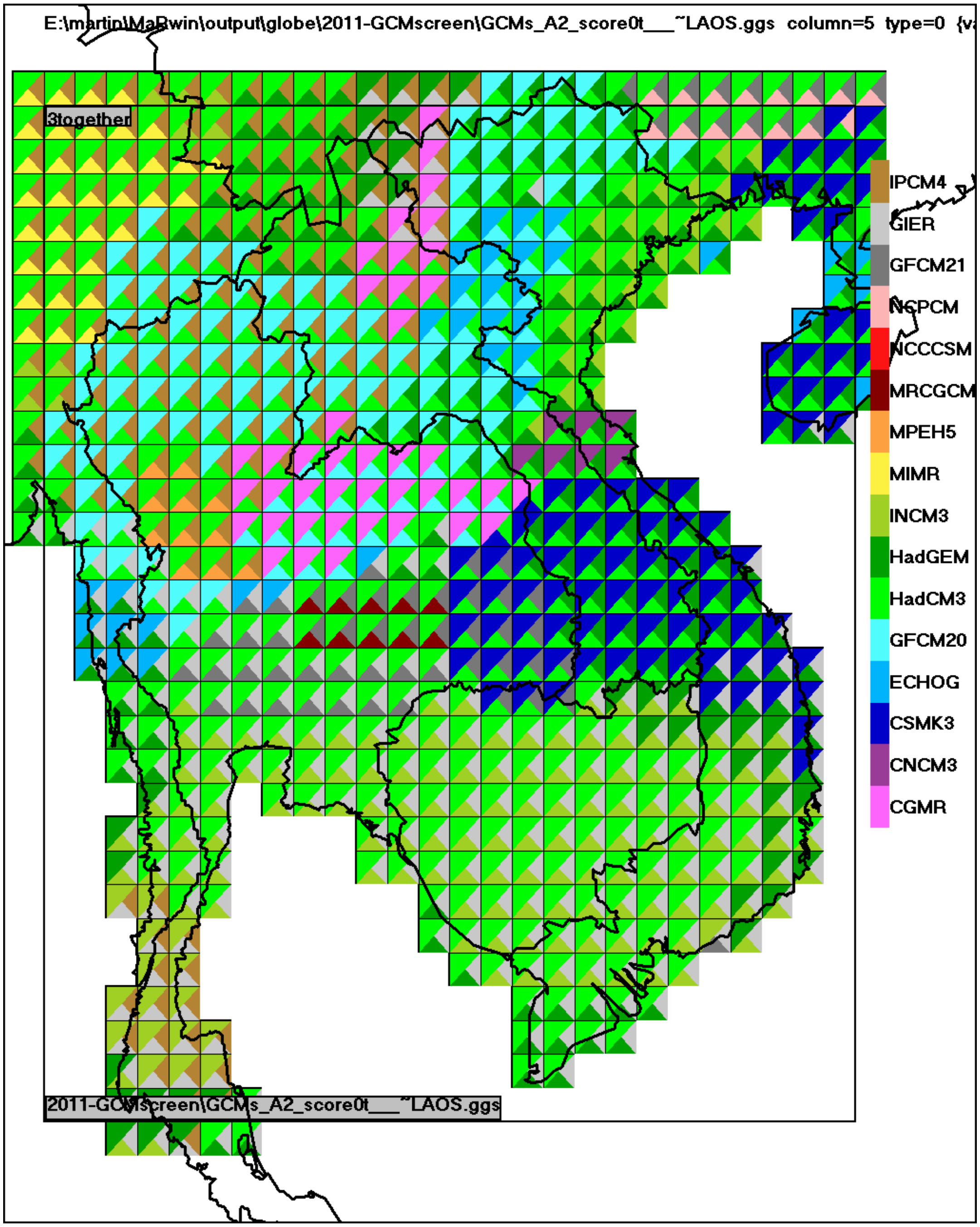


Figure 4.3: The 3 mutually most distant GCMs, based on CSMK3+HadCM3+HadGEM models (Dubrovsky Pers.comm. 2011)

There are some representative models to predict climate change in Laos. The selected CSMK3 (by Australia's Commonwealth Scientific and Industrial Research Organisation, Australia); HadCM3 (by UK Meteorology Office, UK); and HadGEM (by UK Meteorology Office, UK); are shown in table 4.1.

Table 4.1: GCM models, from the subset of GMs shown in the maps were selected.

Center	**Selected for Laos**	**Center Acronym**	**Model**	**Resolution**	
				nx	**ny**
Canadian Center for Climate Modelling and Analysis, Canada		CCCma	CGMR	96	48
Centre National de Recherches Meteorologiques, France		CNRM	CNCM3	128	64
Australia's Commonwealth Scientific and Industrial Research Organisation, Australia	**T**	CSIRO	CSMK3	192	96
Meteorological Institute, University of Bonn Germany Meteorological Research Institute of KMA, Korea and Model and Data Groupe at MPI-M, Germany		MIUB METRI M & D	ECHOG	96	48
Geophysical Fluid Dynamics Laboratory, USA		GFDL	GFCM20	144	90
UK Met. Office, UK	**T**	UKMO	HADCM3	96	73
UK Met. Office, UK	**T**	UKMO	HADGEM	192	145
Institute for Numerical Mathematics, Russia		INM	INCM3	72	45
National Institute for Environmental Studies, Japan		NIES	MIMR	128	64
Max-Planck-Institute for		MPI-M	MPEH5	192	96

Meteorology, Germany					
Meteorological Research Institute, Japan		MRI	MRCGCM	128	64
National Centre for Atmospheric Research, USA		NCAR	NCCCSM	256	128
National Centre for Atmospheric Research, USA		NCAR	NCPCM	128	64
Geophysical Fluid Dynamics Laboratory, USA		GFDL	GFCM21	144	90
Geophysical Fluid Dynamics Laboratory, USA, ModelE20/Russell		GFDL	GIER	72	46
Institute Pierre Simon Laplace, France		IPSL	IPCM4	96	72

The characters in "LAOS" column indicate selected GCMs: T = GCM in the triplet of most distant GCMs http://www.mad.zmaw.de/IPCC_DDC/html/SRES_AR4/index.html

Table 4.1.1 The six climate scenarios applied in the study and their affiliation as named in the analysis.

Climate Scenarios	**Affiliation**
CSMK3 – High Sensitivity	CSHI
CSMK3 – Low Sensitivity	CSLO
HadCM3 – High Sensitivity	HCHI
HadCM3 – Low Sensitivity	HCLO
HadGEM – High Sensitivity	HGHI
HadGEM – Low Sensitivity	HGLO

4.2.2 Climate change signal under the CSMK3, HadCM3, and HadGEM models in Savannakhet Laos

4.2.2.1 Air temperature

The six climate scenarios (Table 4.1.1) were calculated for 100 years, and divided into three periods (2001-2030, 2035-2065 and 2070-2100) for comparison of the changing temperature levels. In general the results of the 100 year period show that the air temperature will increase between +0.64°C and +2.40°C compared with the reference period of observed temperatures (1971 to 2009). In the CSHI scenario temperature will increase by +2.11°C, in the CSLO scenario by +0.77°C, in HCHI scenario by +2.40° C, in HCLO scenario by +0.88° C, in HGHI scenario by +1.75° C and in the HGLO scenario by +0.64°C compared to the reference period. The mean of minimum air temperature and maximum air temperature of the six scenarios ranges between 22.60°C and 32.77°C while the average minimum and maximum of air temperature in the reference period (1971 to 2009) range between 21.17°C to 31.35°C. Therefore, we conclude that the air temperature will increase in the future for all three models within six scenarios projected. Looking at the scenarios period from 2001 to 2100 the mean temperatures of the three high scenarios is 28.35 °C and will increase by +0.13°C during 2001-2100. The mean temperature of the three low scenarios is 27.02 °C and show an increase by +0.12°C during 2001-2100 (Figure 4.4).

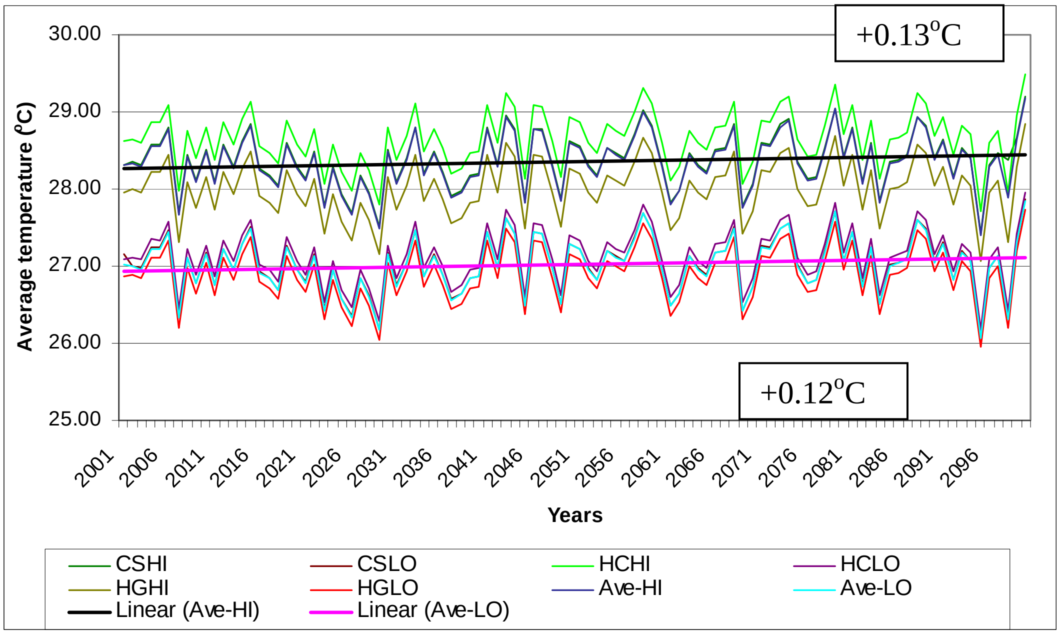


Figure 4.4: Mean annual air temperatures based on model CSMK3 (CSHI, CSLO), HadCM3 (HCHI, HCLO) and HadGEM (HGHI, HGLO).

Although the average maximum temperatures will increase to the highest maximum of 34.62°C till 2100 in HadCM3 (HCHI) scenario, it is still in the range of air temperatures for rice growing conditions not over 36°C, particularly critical during flower period. If the air temperature is higher than that, there might be high risk for yield decrease (Linquist et al., 2005). The optimum temperature for rice anthesis period is between 30 – 33°C (Moomaw et al., 1965; Surajit et al., 1981).

4.2.2.2 Precipitation

The amount of precipitation almost decreased in all models projections, which is in the range between -1.03% to -11.39% in HCHI and HGHI scenarios (see Table 4.1.1) in next 100 years compared with mean of rainfall in observation years of 1426 mm (1971 to 2009). The rainfall of CSHI scenario will decrease by -.35%, CSLO by -1.78%, HCLO by -1.08%, and HGLO by -5.05%. The lowest amount of precipitation was shown in the HGHI scenario with 805 mm (in year 2043), where drought can occur under such conditions in combination with the higher temperatures. The highest amount of precipitation was shown in the HCHI scenario with 1813 mm (in the theoretical year 2045). However, growing paddy rice also concerns rainfall pattern. In some cases, although the total annual amount of rainfall shows not much difference, the differences in its distribution can lead to risk of drought and flood having impact to rice yields as well (Linquist et al., 2005). If rainfall is concentrated in the monsoonal season as it is usual approximately 1200-1500 mm, it is adequate for a single rice crop (Surajit., et al. 1981). Shortage of rainfall in some years is seen in the scenarios, particularly in HGHI scenario, for example in year 2043. However, if we look at the trend of the average of six scenarios of precipitation itself from 2001 to 2100, the amount of precipitation will increase by +15.22mm (figure 4.5).

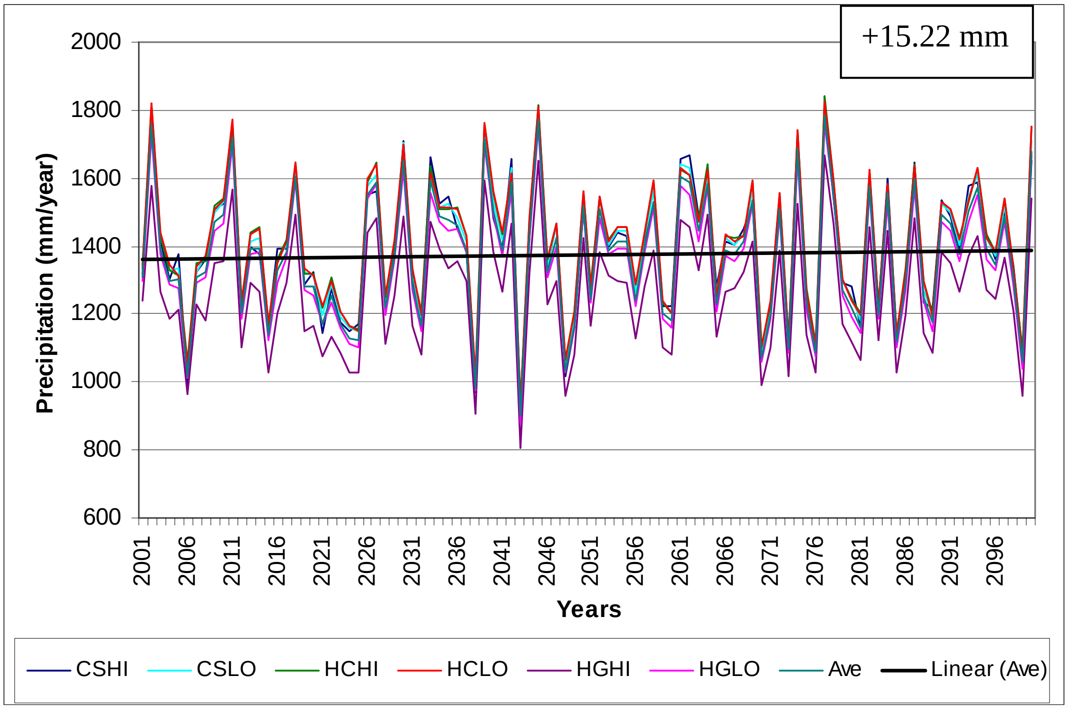


Figure 4.5: Annual precipitation of the scenario period 2001-2100 based on model CSMK3 (CSHI, CSLO), HadCM3 (HCHI, HCLO) and HadGEM (HGHI, HGLO).

4.2.2.3 Solar radiation

The projections of the six scenarios (Table 4.1.1) found that the trends of solar radiation were diverse in positive and negative way compared with air temperature and precipitation. Some of scenarios show the declining values such as HGLO and

HGHI scenarios ranging from -1.11% to -2.99%. The other four scenarios show marginal increasing solar radiation by +0.27% with HCLO scenario, by +0.76% with CSLO scenario, by +0.79% in HCHI scenario and by +2.19% within CSHI scenario. However, in the mean of the three high scenarios and the three low scenarios of solar radiation there is almost no change. The mean daily solar radiation of the three high scenarios will increase by +0.0244 MJ.m^{-2}, and the mean of three low scenarios will increase by +0.0247 MJ.m^{-2} (figure 4.6), which is almost no change. High solar radiation is useful especially during specific crop stages, for example the crops' grain filling and maturity period in case adequate water supply (De Datta et al., 1970; Surajit, 1981).

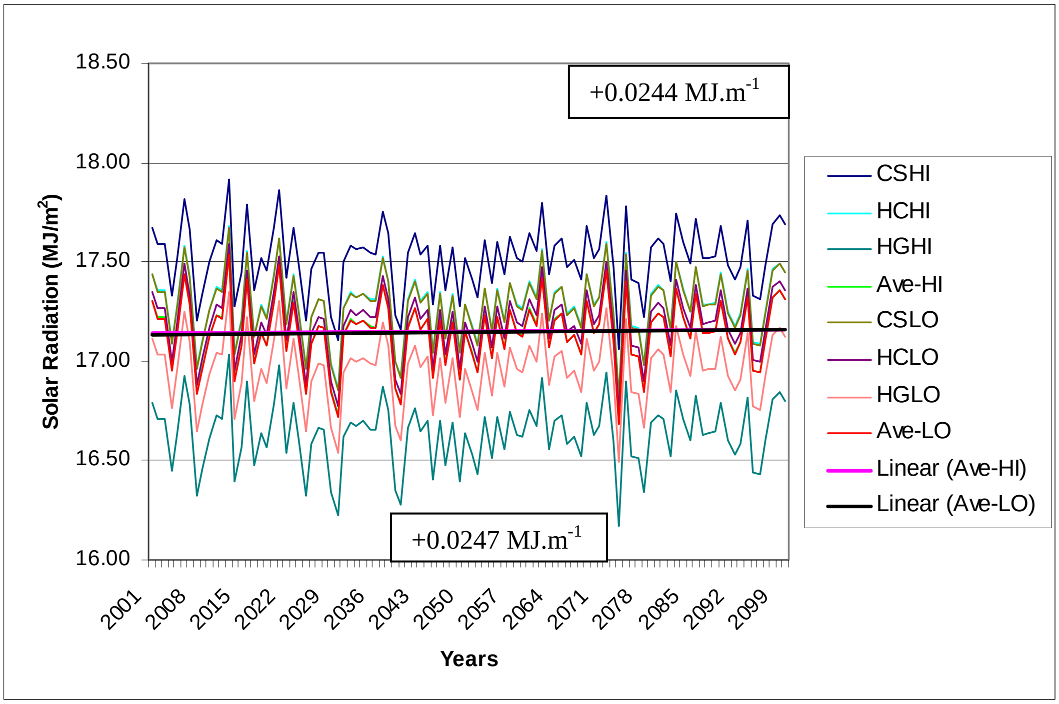


Figure 4.6: Mean annual daily solar radiation based on model CSMK3 (CSHI, CSLO), HadCM3 (HCHI, HCLO) and HadGEM (HGHI, HGLO).

In conclusion we found that the climate change signal in Savannakhet, Laos of three models with six scenarios projected by CSMK3 (CSHI, CSLO), HadCM3 (HCHI, HCLO) and HadGEM (HGHI, HGLO) for 100 years (2001 to 2100) show various trends in temperature, precipitation and solar radiations (Table 4.2). For temperature most significant increase was shown by HCHI of +2.40°C. The trends in precipitation in all six scenarios declined, with the highest value by -11.39% in HGHI. For solar radiation diverse, but only marginal trends of six scenarios are shown.

Table 4.2: Change of temperatures, precipitation and solar radiation during different periods of climate change scenarios by the models CSMK3 (CSHI, CSLO), HadCM3 (HCHI, HCLO) and HadGEM (HGHI, HGLO) projected.

Models	**Scenarios**	**Climate**	**Periods of times**			
			Observe periods (1971-2009)	2001-2030	2035-2065	2070-2100
	Observed	**TMAX (°C)**	**31.35**			
CSMK3	CSHI	TMAX (°C)		33.34	33.48	33.54
	CSLO	TMAX (°C)		32.00	32.14	32.20
HadCM3	HCHI	TMAX (°C)		33.63	33.77	33.83
	HCLO	TMAX (°C)		32.11	32.24	32.30
HadGEM	HGHI	TMAX (°C)		32.99	33.12	33.18
	HGLO	TMAX (°C)		31.87	32.01	32.07
	Observed	**TMIN(°C)**	**21.17**			
CSMK3	CSHI	TMIN(°C)		23.19	23.31	23.40
	CSLO	TMIN(°C)		21.86	21.97	22.01
HadCM3	HCHI	TMIN(°C)		23.48	23.60	23.64
	HCLO	TMIN(°C)		21.95	22.08	22.12
HadGEM	HGHI	TMIN(°C)		22.83	22.95	22.99
	HGLO	TMIN(°C)		21.72	21.84	21.88
	Observed	**TAVG(°C)**	**26.26**			
CSMK3	CSHI	TAVG(°C)		28.27	28.39	28.47
	CSLO	TAVG(°C)		26.93	27.05	27.10
HadCM3	HCHI	TAVG(°C)		28.56	28.68	28.73

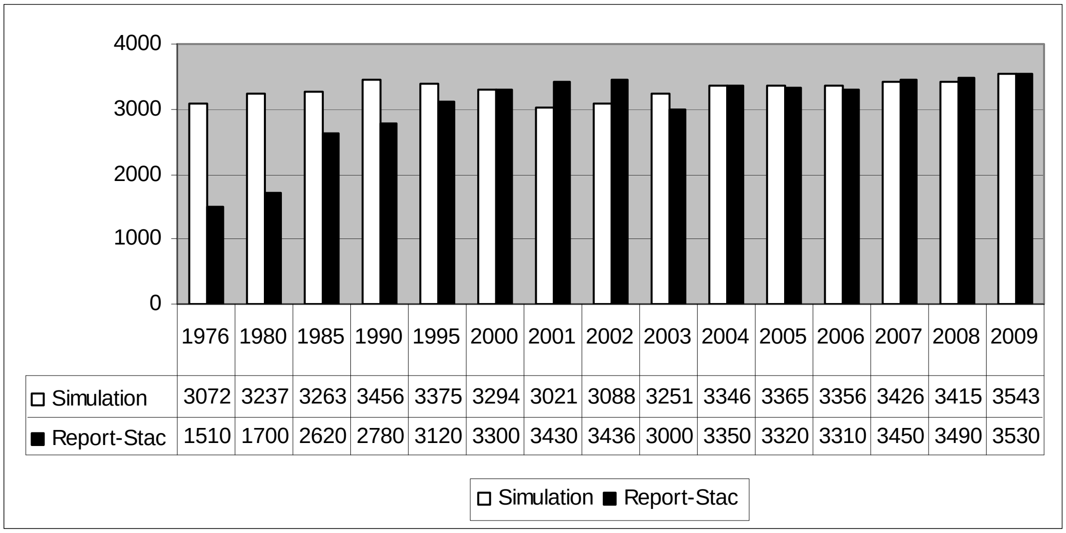
	HCLO	TAVG(^{o}C)		27.03	27.16	27.21
HadGEM	HGHI	TAVG(^{o}C)		27.91	28.04	28.09
	HGLO	TAVG(^{o}C)		26.80	26.93	26.98
	Observed	**PREC(mm/y)**	**1426**			
CSMK3	CSHI	PREC(mm/y)		1373	1407	1387
	CSLO	PREC(mm/y)		1384	1417	1392
HadCM3	HCHI	PREC(mm/y)		1394	1427	1404
	HCLO	PREC(mm/y)		1395	1427	1402
HadGEM	HGHI	PREC(mm/y)		1242	1280	1259
	HGLO	PREC(mm/y)		1336	1371	1346
	Observed	**SRAD(MJ/m^2)**	**17.15**			
CSMK3	CSHI	SRAD(MJ/m^2)		17.514	17.512	17.534
	CSLO	SRAD(MJ/m^2)		17.274	17.271	17.293
HadCM3	HCHI	SRAD(MJ/m^2)		17.278	17.277	17.299
	HCLO	SRAD(MJ/m^2)		17.188	17.187	17.208
HadGEM	HGHI	SRAD(MJ/m^2)		16.629	16.628	16.649
	HGLO	SRAD(MJ/m^2)		16.953	16.950	16.973

Legend: TMAX = Maximum Temperature; TMIN = Minimum Temperature; TAVG = Average Temperature; SRAD = Solar Radiation. All Parameters are annual means of daily data, except precipitation with annual totals.

4. 3 Crop model validation

The model was validated on rice yield reports of agricultural statistics of total annual of Savannakhet province from 1976 to 2009. The data recorded from Agriculture and Forestry Department has gaps in some years, cause of collecting and recording. The comparison between the model simulation results and rice yield statistic record from Agriculture and Forestry Department shows in figure 4.7. According to the practice with mixed fertilization levels in our target region (see chapter 3.4.1.4), all crop model simulations were carried out with five levels of Nitrogen(N)-fertilization including 0, 30, 60, 90 and 120 kg/ha and are presented as the mean of all fertilization steps.

The results of model simulations are in good agreement with the statistical record from 1995-2009. Earlier years such as 1976 and 1980 showed much lower reported yields than the simulated ones, probably due bad farming practice techniques (including much lower N-fertilization rates than under current conditions) in these years, while the model setup remained unchanged and was set to recent management (with a mix of all five fertilization steps). The most of paddy rice cultivation as well as other crops cultivation were based for example on natural organic fertilizers until 1985. In the 1990s the rice yield sharply increased compared to previous time due to the applied additional N-fertilizer and the improved seed varieties.



	1976	1980	1985	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
☐ Simulation	3072	3237	3263	3456	3375	3294	3021	3088	3251	3346	3365	3356	3426	3415	3543
■ Report-Stac	1510	1700	2620	2780	3120	3300	3430	3436	3000	3350	3320	3310	3450	3490	3530

Figure 4.7: Simulated rice yield and the rice yield statistics from Agriculture and Forestry Department (1976-2009) kg / ha on province yields.

From the year 1995 to 2009 the simulated rice yields of the crop model and reported rice yield statistics from the Agriculture and Forestry Ministry were most similar. The average of rice yield from simulation (1995 to 2009) was 3316kg/ha and from the reported statistics it was 3340kg/ha, so rice yield from the model simulation was slightly lower by -0.69% or -23 kg/ha and therefore in good agreement. If we compare the yearly deviations, the range of difference varies between +11.93% to -1.40% with maxima and minima deviation in 2001 and 2006, respectively. However, from 2004 to 2009, the rice yields of the report and simulated ones closely ranged between +2.14% to -1.4% and the rice yields of reported statistics from Department of Agriculture and Forestry were less then simulated rice yields of by -0.19 kg only (figure 4.8). Therefore, these results can be seen as a good validation result with relative deviations below 15 %, proving that this model can be applied in this study of rice simulation for future climate change scenarios.

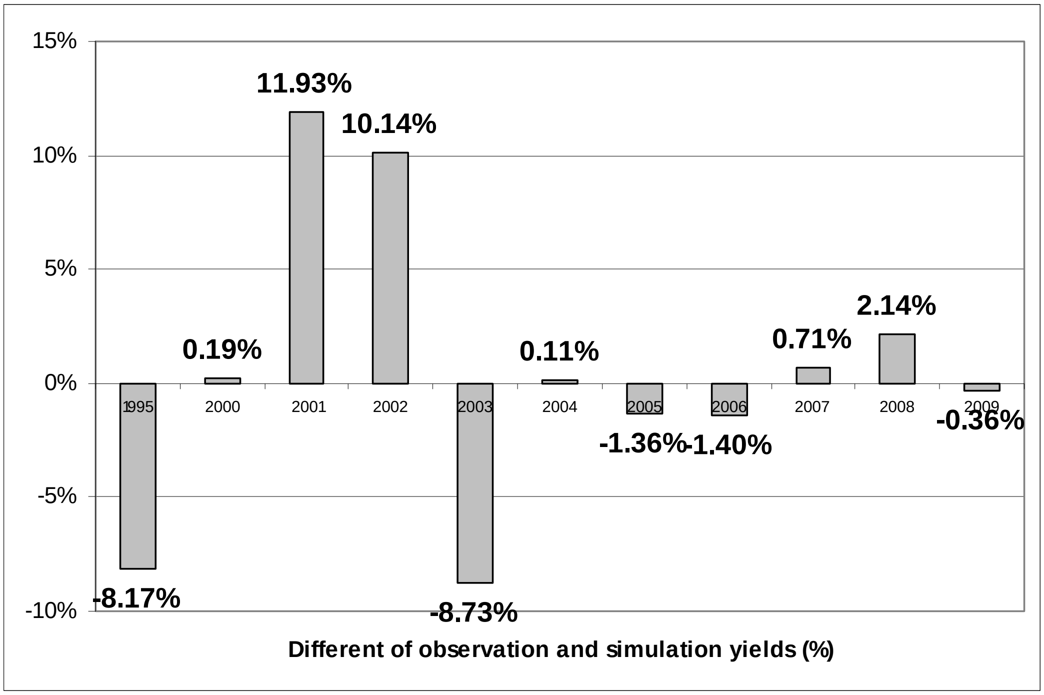


Figure 4.8: Percentage of difference of rice yields between observation and simulation.

4.4 Sensitivity of simulated rice yield to climate parameters

To test the model behavior on changed weather input parameters and to detect the range of model response for evaluating potential critical limits in weather parameters a sensitivity study was carried out (Table 4.3). There were defined 8 sensitivity analysis scenarios based on the climate observations for 39 years (1971 to 2009) with a change in precipitation and temperatures (Chapter III, Table 3.1) but without a change in atmospheric CO_2-concentration.

The eight sensitive analyses scenarios showed increased rice yields ranging between +3.77% to +13.89%. The minimum of rice yields decreased in all cases except when precipitation increased by +25%. For the maximum rice yields, some of them decreased, especially when precipitation increased by +25%. When precipitation decreased by -25% the rice yield will be increased by +4.28%, and precipitation increased by +25% the rice yield will be increased by +3.77%. When the temperature increased by +2^{o}C the rice yield will be increased by +10.72%, when the temperature increased by +4^{o}C the rice yield will be increased by +13.53%; when the precipitation increased by +25% with increased temperature by +2^{o}C the rice yield will be increased by +10.93%, and when the precipitation decreased by -25% with increased of temperature by +2^{o}C the rice yield will be increased by +10.63%, and when the precipitation increased by + 25% with increased temperature by +4^{o}C the rice yield will be increased by +13.89%, and when the precipitation decreased by -25% with increased temperature +4^{o}C the rice yield will be increased by +13.08% (figure 4.9).

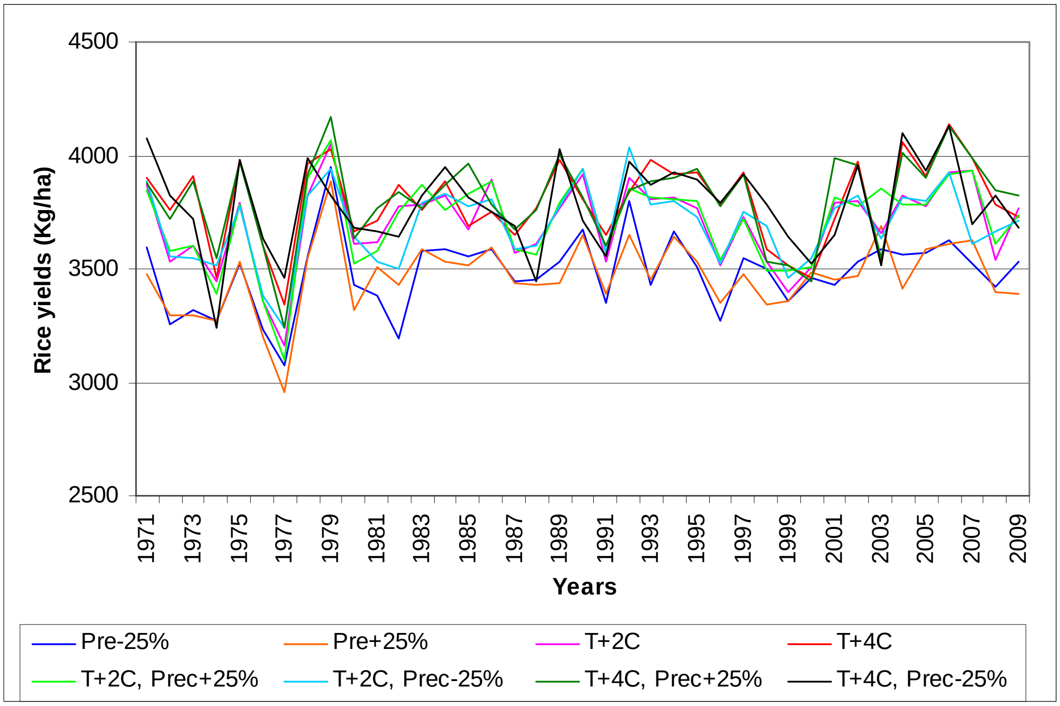


Figure 4.9: The sensitive analysis results (in simulated rice yields) with changed temperatures and precipitation during the simulation run period

We can see that, when the precipitation increased by + 25% and decreased by - 25%, the rice yields were similar compared to the observation years, which means that the increased or decreased of precipitation did not affect rice yield too much. However, when temperature increased by + 2°C and + 4°C or both temperature and precipitation changes the rice yields were significantly increased (Table 4.3). This means also that the simulated cultivar is grown under sub-optimal temperature conditions under the observed weather period.

Table 4.3: Comparison the maximum, minimum and mean of rice yield simulations under the sensitive analysis

Climate factors	Rice yields (kg/ha)			Average duration of growing periods (days)	% change of rice yields
	Maximum	Minimum	Mean		
Observation year	5974	1490	3340	148	
+25% Pre	6394	1656	3466	148	+3.77
-25% Pre	6679	1642	3483	148	+4.28
+2°C	6482	1566	3698	135	+10.72
+4°C	6569	1581	3792	128	+13.53
+25% Pre, +2°C	6690	1576	3705	135	+10.93
-25% Pre, +2°C	6670	1577	3695	135	+10.63
+25% Pre, +4°C	6538	1572	3804	128	+13.89
-25% Pre, +4°C	6536	1604	3777	129	+13.08

4.5 Rice yield simulations under the climate change scenarios in Savannakhet province

4.5.1 Rice simulations under the different climate change scenarios compared with observed rice yields

In general rice production under all six scenarios (Table 4.1.1) increased compared to observed yields (1995-2009). Compared to observed yield statistics of 1995-

2009 the rice simulation of the CSLO scenario show increased mean yields by +6.77%, HCLO show an increased yield by +6.95%, HGLO by +7%, CSHI by +11.43%, HCHI by +11.98% and HGHI by +12.72%. The results of simulations ranged therefore from +6.77% to +12.72% mean yield increase for the period 2001-2100. The average simulated rice yield from the reference (and crop model validation) period was 3316 kg/ha (1995 to 2009). The six scenarios show a mean rice yield from the period 2001-2100 of between 3541 kg/ha to 3738 kg/ha. Under the CSHI scenario mean simulated yields reached 3695 kg/ha, under CSLO scenario 3541 kg/ha, under HCHI scenario 3713 kg/ha, under HCLO scenario 3547kg/ha, under HGHI scenario 3738 kg/ha, and under the HGLO scenario 3548 kg/ha. In the maximum of the mean yield was as 4109 kg/ha in HGHI scenario in the theoretical year 2076, and the lowest mean was 3091 kg/ha in HGHI scenario in theoretical year 2031 (figure 4.10).

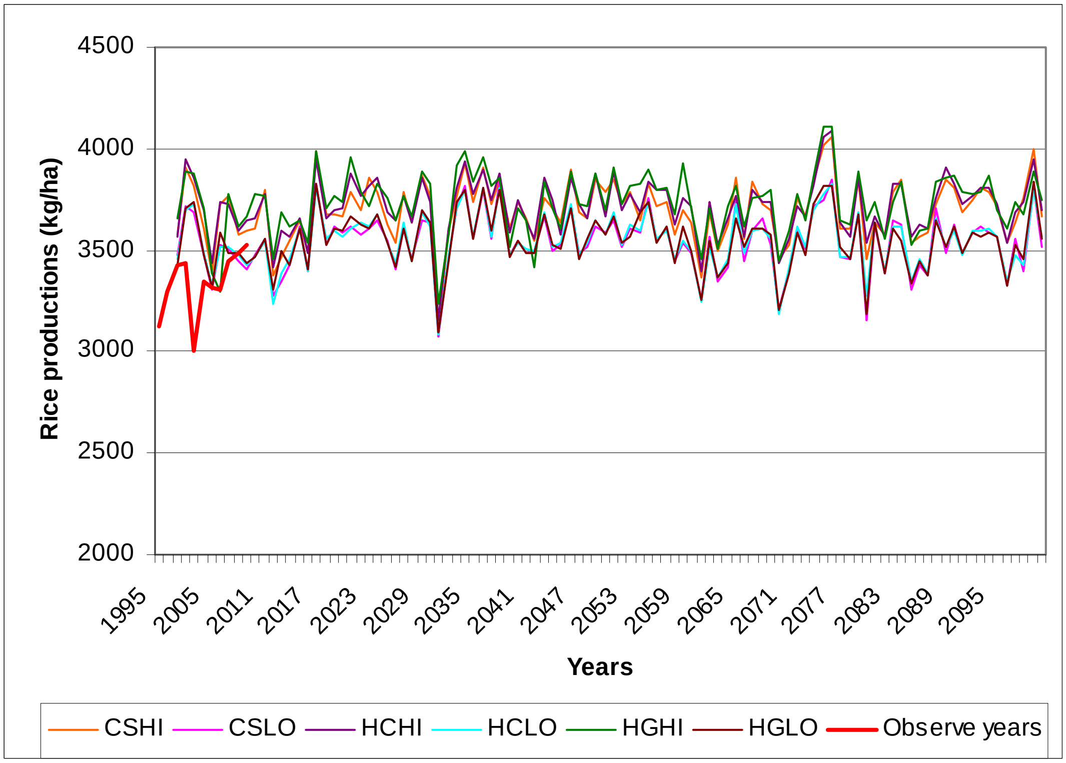


Figure 4.10: Rice yield simulations under six climate change scenarios in Savannakhet province compared to yield statistics of 1995-2009.

4.5.2 Simulated yield variability of the scenarios

The minimum and maximum rice yields of CSHI scenarios ranged between 1.599 to 6.902 kg/ha, and for CSLO scenarios between 1.632 to 6540 kg/ha. The HCHI scenario ranged between 1.579 to 6.876 kg/ha and HCLO scenario ranged between 1.635 to 6.470 kg/ha. The HGHI scenario ranged between 1.602 to 6.898 kg/ha and the HGLO scenario ranged between 1.659 to 6.528 kg/ha. The rice yield of the three high sensitive climate scenarios range from maximum 6902 kg/ha (in CSHI scenarios) to minimum 1579 kg/ha (in HCHI scenarios), while three low sensitive climate scenarios were range from maximum 6540 kg/ha (in CSLO scenario) to minimum 1632 kg/ha (in CSLO scenario). The rice yields from three high sensitive climate scenarios CSHI, HCHI and HGHI show a higher increase than the low sensitive climate scenarios (CSLO, HCLO, and HGLO) in the three periods 2001-2030, 2035-2065 and 2070-2100. In the yield variability, expressed as the 90% percentile of rice yield of the six scenarios not much variation is seen, however, in the period of 2070 to 2100 in all three high scenarios it is reduced compared to the periods of 2001 to 2030 and 2035 to 2065. In contrast, the 90% percentile of the three low scenarios are more stable (figure 4.11).

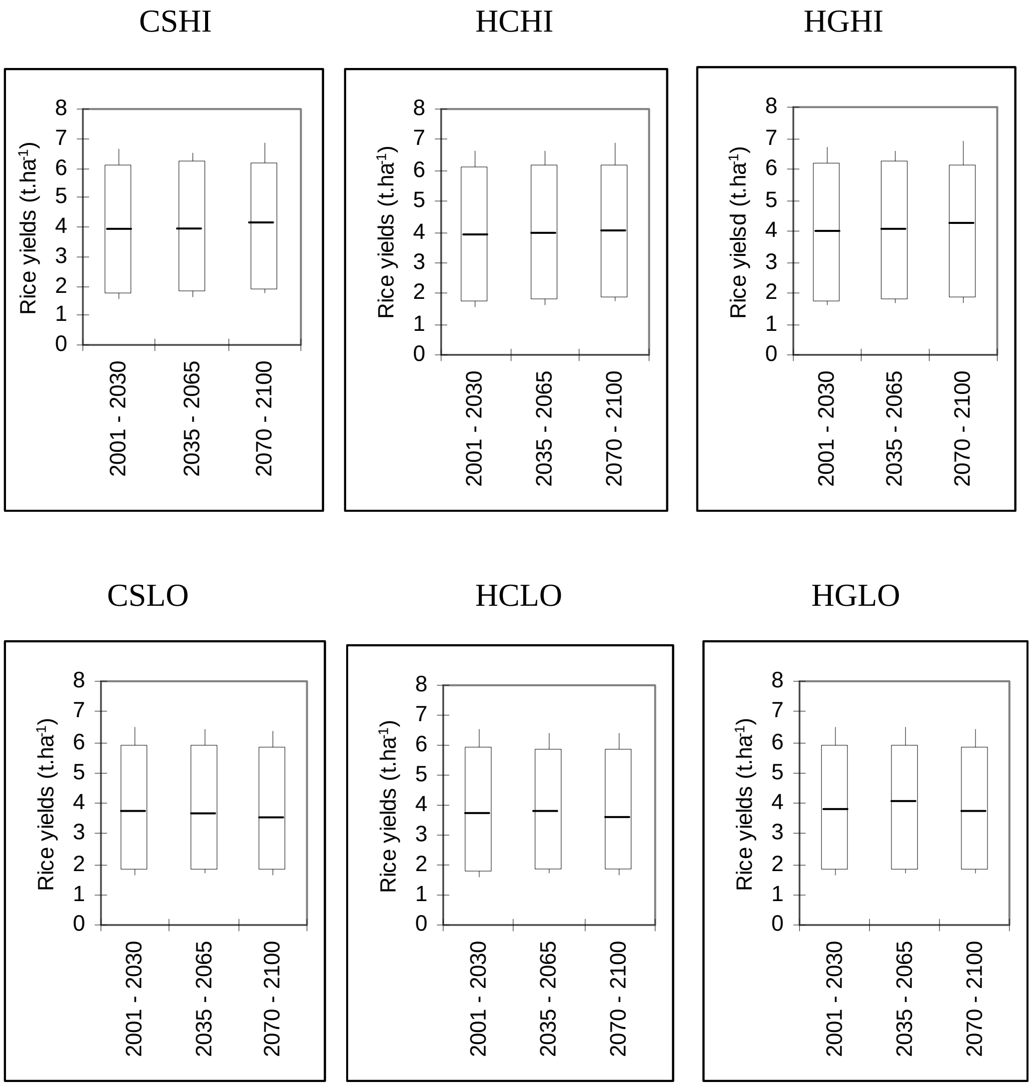


Figure 4.11: Comparison of simulated rice yields of the six scenarios in three periods: Lines indicate the range between maximum and minimum yields, and columns show the 90% percentile with the mean yields value in the three periods 2001 to 2030, 2035 to 2065, and 2070 to 2100.

4.5.3 Yields levels of three different periods related to N-fertilization

From the 100 years simulation period, three 30 year periods of simulated yields (2001-2030, 2035-2065 and 2070-2100) were selected, analysed and compared for the 6 applied climate scenarios (Table 4.1.1). In Table 4.3 we can see that in the mean for all N-fertilization steps all three periods of the six scenarios show higher yields than the observation period 1995-2009. The second period (2035 to 2065) showed higher yield than the first period (2001 to 2030), however the third period

(2070 to 2100) again showed lower yield level than the second period. As N-fertilization has strong influence on the rice yields, the results of the two N-fertilization levels without and with 120 kg/ha N-fertilization are additionally shown in Table 4.4. It can be seen that the highest N-fertilization level of the scenarios comes closest to the observed yield level of 1995-2009, which means that the reduced N-fertilization levels would gain relatively more in yield potential under climate scenarios. In another study the optimal N rate needed with increasing CO_2 to maximize rice yields remains unaddressed (Yang et al., 2011).

Table 4.4: Six scenarios of simulated rice yields in three periods and the observation years

Models	Scenarios	Rice yield in average (kg/ha)	**Periods of times**			
			1995-2009	2001-30	2035-65	2070-2100
	Obs- years	Maximum: with 120kg/ha of N-fertilization	5974	-	-	-
CSMK3	CSHI			6127	6138	6179
	CSLO			5858	5917	5822
HadCM3	HCHI			6138	6181	6175
	HCLO			5864	5917	5821
HadGEM	HGHI			6176	6210	6188
	HGLO			5893	5937	5821
	Mean		-	**6008**	**6050**	**6001**
	Obs- years	Minimum: without N-fertilization	1490	-	-	-
CSMK3	CSHI			1670	1739	1819
	CSLO			1757	1779	1776
HadCM3	HCHI			1671	1736	1816
	HCLO			1754	1782	1780
HadGEM	HGHI			1678	1736	1812
	HGLO			1753	1718	1775
	Mean		-	**1714**	**1759**	**1796**
	Obs- years	Average: with all levels of N-fertilization applied (0, 30, 60, 90, and 120 kg/ha)	3340	-	-	-
CSMK3	CSHI			3674	3708	3713
	CSLO			3531	3562	3530
HadCM3	HCHI			3701	3724	3727
	HCLO			3538	3567	3537
HadGEM	HGHI			3732	3746	3744
	HGLO			3546	3566	3534
	Mean		-	**3620**	**3646**	**3631**

Legend: Minimum= Minimum of rice yield without N; Maximum= Maximum of rice yields with 120 kg of N/ha applied; Average= Average of rice yields which applied 0, 30, 60, 90 and 120 kg/ha N-fertilization; Obs-year: Observation years 1995-2009.

To compare the average rice yields of the three periods of six scenarios (mean of all N-fertilization steps), we can see clearly that the second period (2035 to 2065) of all six scenarios has significantly higher yield level than the first period (2001 to 2030), (figure 4.12). In the third period (2070 to 2100) however only the high sensitive scenarios can keep that yield level, whereas the rice yield declines for low sensitive climate scenarios. In relative terms however the yield changes are marginal, ranging between -0.34% (HGLO) to +1.06% (CSHI) compared to the first period of 2001-2030 (figure 4.13).

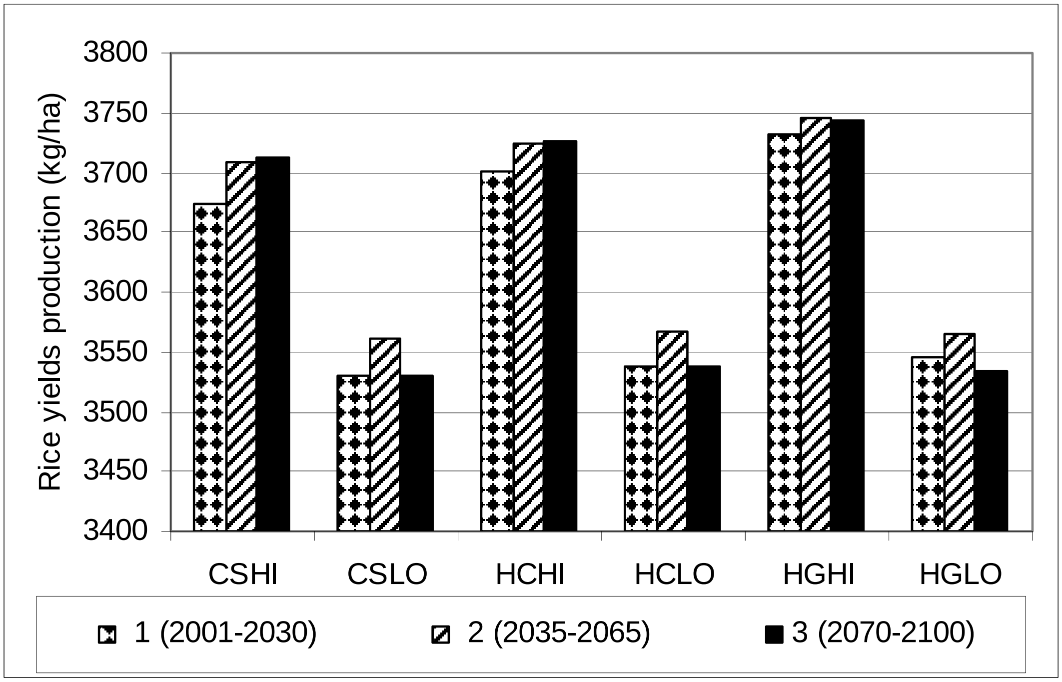


Figure 4.12: Comparison an average rice yield trend of six scenarios (CSHI, CSLO, HCHI, HCLO, HGHI, and HGLO) and the mean of five N-fertilization (0,30,60,90,120 kg/ha N) steps in three periods.

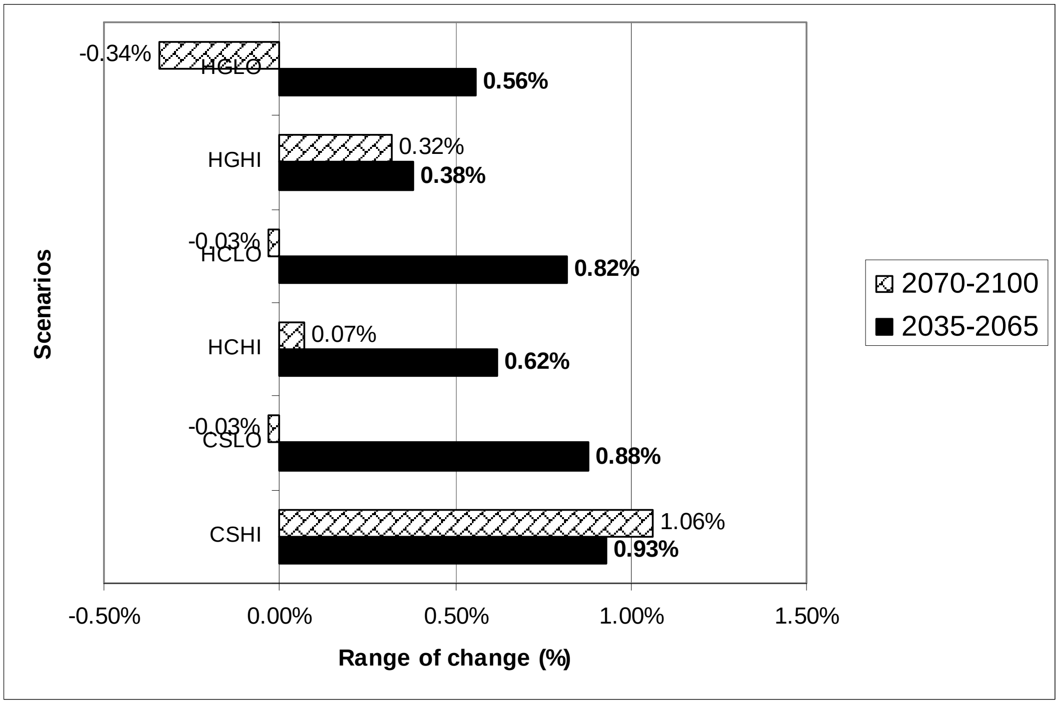


Figure 4.13: Relative change of rice yields of six scenarios compared to the first period (2001 to 2030).

In comparison with previous studies where the same model was applied (DSSAT/CERES-Rice model) our study shows a similar trend under our updated climate scenarios (which is an increase of rice yields towards mid of the 21st century and from there a stabilization or decrease towards end of the 21st century). For example, Inthavong (2004) reported a slight increase in rice yields under climate scenarios with CO_2 concentration in the atmosphere of 540 ppm (rice yield of 2.000 kg/ha as minimum to 5.900 kg/ha as maximum). However, the maximum of rice yields declined to 5600 kg/ha under the climate scenarios of 720 ppm, but it was still higher compared with baseline yields (1.000 kg/ha for minimum and 5.100 kg/ha for maximum yields). This study was based on CCAM climate model for future climate scenarios of the 2040s and 2070s by taking 360 ppm of CO_2 concentration of the baseline of 1980-1989 (McCarthy et al., 2001). The 2040s and 2070s under SRES emission scenarios A1FI, IPCC 2000 (Chivanno et al., 2006) was simulated using 540 ppm and 720 ppm of CO_2 concentration, respectively without NPK- fertilization (Inthavong et al., 2004). In our study we see slightly declining yields in the third period, towards 2100, in particularly for all of three low scenarios (CSLO, HCLO, and HGLO). Although, slightly declining yields compared with the first period, still higher yields than in the observation years are reached as well. However, in our study the range between minimum and maximum of rice yields was larger than in the mentioned study. For example, it ranged from 1.678 kg/ha at minimum to 6.176 kg/ha at maximum in the HGHI scenario, and from 1.757 kg/ha at minimum to 5.858 kg/ha at maximum in the CSLO scenario, respectively (2001 to 2030). It might be related with the levels of N-fertilization applied.

If we look to other similar studies for Asia on climate change impacts on rice yield, for example, in India, Indonesia, Korea, Philippines positive and negative impacts are reported, and in Malaysia positive impacts under projected climate change scenarios are described (see Chapter II).

4.6 Factors influencing simulated rice yield

4.6.1 The differences of the six climate scenarios and its effect on yields

There are four main input data groups in crop simulation models, concerning weather, soil, crop and management data. All input data have influence on simulated rice yields, for example the amount of fertilizer applied for rice planting, characteristic of soil, crop genotype etc.. According to the results of our simulation study the third period (2070 to 2100) of six scenarios shows decreased yields, although all simulations still used the same input data such as soil and crop management data. Therefore, the reason for the changing yield only can be explained by the changing weather data of the applied climate scenarios. For example, in the period 2070 to 2100, especially temperatures increased with decreased precipitation. Rainfall pattern changed as well, particularly maximum of rainfall was decreased, and minimum of rainfall was increased compared with the first and second climate periods (Table 4.5). The (relatively small) decrease in yield compared to the second period could therefore be explained by an increased crop development rate and reduced crop assimilation through the shorter growing period (Table 4.6), moreover as the atmospheric CO_2-fertilization effect of increasing CO_2-level was shown to very low (see chapter 4.6.2). For the crop phenology, according to the shortened growing periods under higher temperatures the rice from all simulations will be matured approximately 5 days to 14 days earlier where the crop growing periods are decreased between 134 days to 143 days in average see table 4.6.

Table 4.5: Comparison of climate factors between six scenarios and three time periods for rice simulations.

Scenarios/ climate/ rice yields	**Three periods**								
	2001 to 2030			**2035 to 2065**			**2070 to 2100**		
Temperature (^oC)	**TMax**	**TMin**	**Mean**	**TMax**	**TMin**	**Mean**	**TMax**	**TMin**	**Mean**
CSHI	33.34	23.19	**28.27**	33.48	23.31	**28.39**	33.54	23.40	**28.47**
CSLO	32.00	21.86	**26.93**	32.14	21.97	**27.05**	32.20	22.01	**27.10**
HCHI	33.63	23.48	**28.56**	33.77	23.60	**28.68**	33.83	23.64	**28.73**
HCLO	32.11	21.95	**27.03**	32.24	22.08	**27.16**	32.30	22.12	**27.21**
HGHI	32.99	22.83	**27.91**	33.12	22.95	**28.04**	33.18	22.99	**28.09**
HGLO	31.87	21.72	**26.80**	32.01	21.84	**26.93**	32.07	21.88	**26.98**
Precipitation (mm)	**PMax**	**PMin**	**Mean**	**PMax**	**PMin**	**Mean**	**PMax**	**PMin**	**Mean**
CSHI	1786	992	**1373**	1805	930	**1407**	1807	1077	**1387**
CSLO	1809	1019	**1384**	1805	926	**1417**	1804	1090	**1392**
HCHI	1817	1061	**1394**	1813	926	**1427**	1827	1105	**1404**
HCLO	1823	1047	**1395**	1812	926	**1427**	1669	1101	**1402**
HGHI	1575	963	**1242**	1650	805	**1280**	1762	990	**1259**

HGLO	1729	1011	**1336**	1749	879	**1371**	1821	1058	**1346**
Solar Radiation (MJ/m^2)	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
CSHI	17.91	17.10	**17.514**	17.80	17.1	**17.512**	17.83	17.06	**17.534**
CSLO	17.67	16.86	**17.272**	17.56	16.92	**17.271**	17.59	16.82	**17.293**
HCHI	17.68	16.86	**17.278**	17.56	16.93	**17.277**	17.60	16.82	**17.299**
HCLO	17.59	16.77	**17.188**	17.47	16.83	**17.187**	17.50	16.73	**17.208**
HGHI	17.03	16.22	**16.629**	16.91	16.28	**16.628**	16.95	16.17	**16.649**
HGLO	17.35	16.54	**16.953**	17.24	16.60	**16.950**	17.27	16.50	**16.973**
Rice yields (kg/ha)	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
CSHI	6127	1670	**3674**	6138	1739	**3708**	6179	1819	**3713**
CSLO	5858	1757	**3531**	5917	1779	**3562**	5822	1776	**3530**
HCHI	6138	1671	**3701**	6181	1736	**3724**	6175	1816	**3727**
HCLO	5864	1754	**3538**	5917	1782	**3567**	5821	1780	**3537**
HGHI	6176	1678	**3732**	6210	1736	**3746**	6188	1812	**3744**
HGLO	5893	1781	**3546**	5937	1718	**3566**	5821	1775	**3534**

Table 4.6: Duration of simulated rice growing periods of the six climate scenarios

Scenarios	**An average of rice growth periods (days)**			
	1971 to 2009	**2001-2030**	**2035 to 2065**	**2070 to 2100**
Observed years	**148**			
CSHI		137	136	136
CSLO		143	143	143
HCHI		135	134	134
HCLO		143	142	143
HGHI		135	134	135
HGLO		143	142	143

The climatic and atmospheric parameters of the six climate change scenarios over the next 100 years (2001 to 2100) in Savannakhet, Laos, will be still in the optimum range of rice growing conditions, particularly CO_2-concentration, precipitation, air temperature and solar radiation. However, we can see an impact on rice yields in the difference scenarios (Table 4.5). Hence, the HGLO scenario was selected to be a representative of negative impacts of climate change and the CSHI scenario to be representative for a positive impact for the period 2070 to 2100. On these two scenarios therefore the effect on yield determining parameters are compared below (Table 4.7). In specific, the change in Leaf Area Index (LAI) [m^2m^{-2}], Leaf weight (Leaf wt) [Kg/ha], Stem weight (Stem wt) [kg/ha] are compared. The results show that the stem weight of CSHI scenarios were a little increase clue, and to be parallel with grain yield. For the stem weight of HGLO scenario were reduce toward of period 2070 to 2100, and parallel with the grain yield of all three periods for both scenarios, while the LAI and Leaf weight were reduced towards 2100, except LAI of CSHI scenario in period 2070 to 2100.

Table 4.7: Comparison of yield determining factors (simulated) of two representative climate scenarios with positive and negative impacts on yield.

Growth Factors	**CSHI scenario**			**HGLO scenario**		
	2001-30	2035-65	2070- 2100	2001- 30	2035- 65	2070- 2100
LAI (m^2m^{-2})	1.95	1.93	1.95	2.00	1.98	1.98
Leaf (kg/ha)	1862	1823	1779	1904	1880	1864
Stem (kg/ha)	**1198**	**1202**	**1206**	**1084**	**1086**	**1083**
Yields (kg/ha)	**3674**	**3708**	**3713**	**3546**	**3566**	**3534**
Days	137	136	136	143	142	143

Remark: LAI: mean of LAI maximum during the growth period, Leaf: mean of Leaf weight during maturity period, and Stem: mean of Stem weight during maturity period.

Also the growing period did not change between the time slices, however they are different between the scenarios. It can be seen that decreasing LAI and leaf weight did not affect yield negatively instead of stem weight in this case. It also can be seen that a longer growing period did not enhance the yield level in the low sensitive scenario with lower atmospheric CO_2-levels. A remaining yield affecting factor could be the CO_2-fertilization effect, which is an often reported dominant positive yield affecting factor for crops. As our sensitivity analysis shows (chapter 4.4) the increased temperature is the main determining factor for the higher simulated yield level in our case, which means that this cultivar is currently grown under below optimum temperature levels in our case study region. This is also supported by the simulated very low CO_2-fetilization effect (see chapter 4.6.2). However, it was not fully tested in our study if the “real” cultivar TDK1 shows the same positive response to increasing air temperatures in our case study region, due to the limited calibration of the genetic coefficients in the crop model.

Additionally, there are yield affecting climatic parameters which can still change inter-annual yield variability without much effect on the mean long term yield level, depending on stress tolerance of different cultivars. For example, any inhibition of photosynthesis and other drought effects during grain filling has strong effect on the grain yield. The panicle, anthesis, filling process requires specific conditions. Flowering development, pollination, and fertilization are also important processes of crop development which are most sensitive to climate (drought) inhibition (Boyer et al., 1976).

4.6.2 Atmospheric CO_2 concentration and its yield effect

The crop growing period of rice will be in general shorter then under current conditions due to faster development under higher temperatures leading to a lower yield potential in general, if not compensated by other factors. Often the fertilization effect of CO_2 is named for cereals as compensating yield factor of shorter growing periods. To check this simulated effect in our case, two simulations without and with increased CO_2 levels were run for the three selected periods (Table 4.8). The same two scenarios as above were used as above representing the most positive and negative yield effects (HGHI and CSLO, respectively). The results show that the rice yields without CO_2 increase simulated under the HGHI scenario increased by +10.83% compared to the observed years, which is lower by -1.56% than the simulated yield including an increased CO_2 level (of up to 950 ppm till 2100 in the HGHI scenario). Similarly, for the simulation with CSLO scenario the yield without CO_2 increase will increase by 5.91% compared with the observed years, which is a decrease of -0.82% compared to the simulation including the CO_2-increase (of up to 490 ppm till 2100 in the CSLO scenario). These results show that in our case changing CO_2 concentration has only a small effect on the simulated yields and is below 2% of yield effect (Table 4.8). Additionally, we have to keep in mind that differences in other changing weather parameters between the scenarios can affect the potential yield level. However, also the study of Inthavong et al. (2004) shows that an increased CO_2 level to 720 ppm causes a moderate decline and negative impact of TDK1 rice cultivar. In general findings from other studies (Yoshida., 1976; Amien et al., 1999) show that when CO_2 concentration in the atmosphere will double till 2100, increased photosynthesis will enhance rice yield potentials and rice still would be tolerant to an amount of CO_2 between 1500 ppm to 2000 ppm. Another study from Bannayan et al (2004) showed that in FACE experiments the growth enhancement by elevated CO_2 was less significant for low N-fertilization (4 g/m^2) compared with medium (8 g/m^2) and high N-fertilization rates (12 g/m^2). For example from the observation, an increase of CO_2 concentration by 200 ppm lead to increased plant biomass by 15% (grain yield by 7%) at low N-fertilization, compared with 30% (grain yield by 14 %) at medium N-fertilization, and increased plant biomass by 30% (grain yield by 15%) for the higher rate of N-fertilization (Kim et al., 2003a; Kim et al., 2003b; Bannayan et al., 2004). Thus, low nitrogen availability is reducing or limiting the positive yield effect of increasing CO_2 levels. Compared with Inthavong et al (2004) without applied NPK and with our study with average of N-fertilization rate of 6 g/m^2, our results confirm the low CO_2 fertilizing effect of sub-optimum N-fertilization. However, our study may slightly underestimate the potential positive effect, but it is in the range of the response uncertainties reported from several other studies.

Table 4.8: To compare rice yields simulations without CO_2 increase and with increased CO_2 of HGHI and CSLO scenarios (see Appendix, Table 1 for stepwise changing CO_2-concentrations during the simulation period)

Scenarios	2001 to 2030 Rice yields (kg/ha)			2035 to 2065 Rice yields (kg/ha)			2070 to 2100 Rice yields (kg/ha)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
HGHI	1661	6107	3713	1665	6080	3706	1661	5918	3621
HGHI+CO_2	**1678**	**6176**	**3732**	**1736**	**6210**	**3746**	**1812**	**6188**	**3744**
CSLO	1734	5853	3524	1735	5868	3539	1725	5698	3473
CSLO+CO_2	**1757**	**5858**	**3531**	**1779**	**5917**	**3562**	**1776**	**5822**	**3530**

4.6.3 The rate of N-fertilization applied and its yield effect

Nutrient availability is one of the most important factors for rice productivity (Yang et al., 2011). This study also showed the strong influence of N-fertilization on the lowland paddy rice yields under the current sub-optimum N-fertilization rates (Table 4.3). A large area of lowland paddy rice in Laos is lacking of Nitrogen, which is a main nutrient which rice needs for growing. According to experiments and researches of N supply in rice cultivations in Laos of 107 locations (32 locations in the north, and 75 locations in the south of Laos) from 1991 to 1999 the grain yield could increase significantly when more than 60 kg/ha N will be applied, particularly for the southern part of Laos. The rate effect of N to grain yield in average ranged between 0 to 38kg of rice grain yield per 1 kg of N, which is depending on location (Linquist et al., 2005).

In our simulations the relative effect of N on grain yield is ranging between 0 to 37 kg of rice grain yield per 1 kg of N applied, which is very close to the experimental results of the National Rice Research Program (NRRP). The strong yield effect of higher fertilization rates than 60 kg/ha is confirmed with our simulations as well

(Figure 4.14). For example, the experimental rice yield of TDK1 varieties increased up to about 5,000 kg/ha with applied rate of N-fertilizer of 120 kg/ha (Inthavong et al., 2004). In our simulations maximum of rice yields ranged between 5,937 kg/ha and 6,248 kg/ha with N-fertilization of 120 kg/ha.

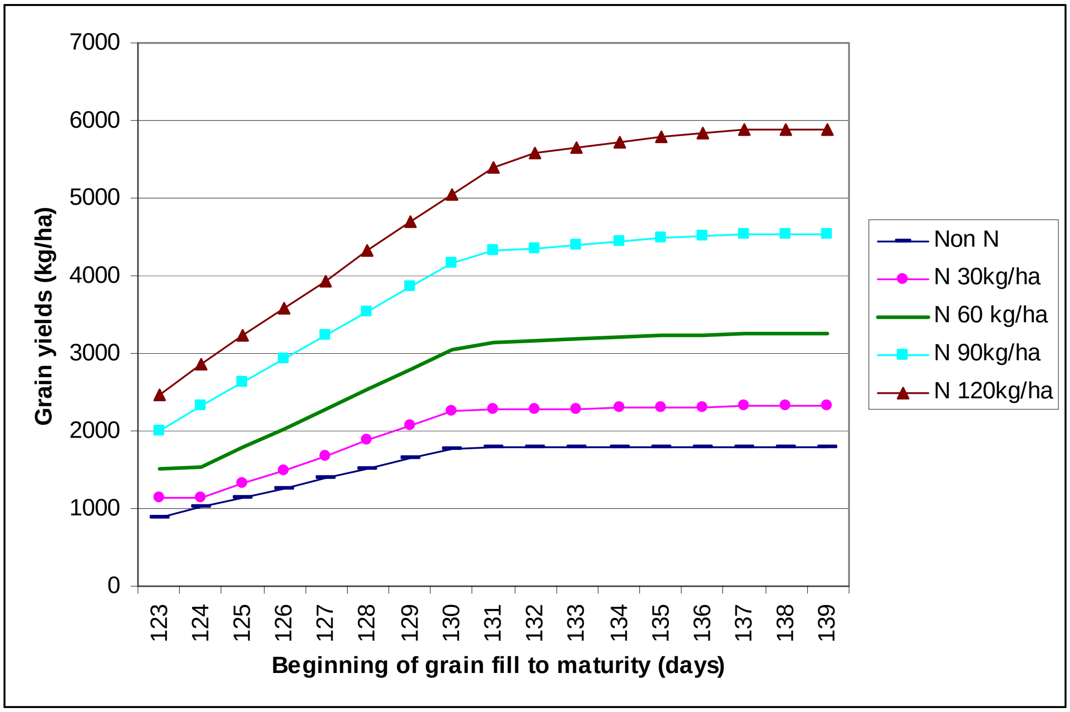


Figure 4.14: Simulated grain yield effect of N-fertilization applied for paddy rice for the HGLO scenario of year 2100.

4.7. Adaptation to climate change impacts on lowland paddy rice

4.7.1 Adjustment of N-fertilization applied

The results of our model simulations show that the climate based rice yield potentials in the future climates in Laos (under the climate change signal from 2001 to 2100 of applied SCHI, SCLO, HCHI, HCLO, HGHI, and HGLO scenarios) will increase compared to the current period. The changes of about up to +12 % however are probably relatively small compared to potentials from crop management options such as a change in cultivars or fertilization. Only few studies report negative rice yield trends in Asia, depending on the region, but also in a relatively small range. Plant breeding is important to develop more nitrogen effective cultivars in Laos. In experiments in 1998 for three sites in southern part of Laos four rice varieties namely TDK1, RD10, TDK3 and NTN1 with the same rate of N-fertilization applied ranged from 0 to 120 kg/ha were compared. TDK1 was a best variety with optimum growing during rainy season and reached higher grain yield than other varieties of about 400 kg/ha (Linquist et al., 2005). This seed variety is in common use in the low land paddy rice farmer's communities currently. However, it has to be kept in mind, that varieties are different stress tolerant which can be an additional factor determining the economy and yield stability of a crop. Therefore cultivars should not be selected only by their potential yield level but also based on their stress tolerance characteristics, because the impact of environmental stresses may change under climate change conditions, such as the frequency of drought occurrence. Regarding the relative yield effect of N-fertilization our study revealed that low N-fertilization rates might gain more yield increase under the applied climate change scenarios than the high application rates, therefore lower application rates would increase their yield effect.

4.7.2 Cultivar adjustment

The rice cultivar for this study was adjusted from cultivar IR 64 in the CERES-rice model as already mentioned in Chapter III. However, the results of rice simulation validation were in good agreement with local TDK1 and TDK2 cultivars. Particularly the duration of growing period from sowing until harvesting were ranging between 140 to 150 days (Linquist, B., 2005) and including grain yields showed acceptable validation (Figure 4.7 and 4.8). In our observation period in Savannakhet province, the average crop growth duration was 148 days and ranged between 140 to 168 days, which is the same range as of rice varieties of TDK 1 and TDK 2 (these two varieties are in common use in the low land paddy rice farmer's communities in Laos). It means that the majority of farmer communities have been already adapted to these cultivars with higher yield potential. This trend can be expected as well with increasing temperatures under future climate scenarios, providing an even higher yield potential as shown in our study for currently used cultivars. According to the shortened growing periods under higher temperatures the rice from all simulations will be matured approximately 5 days to 14 days earlier where the crop growing periods are decreased between 134 days to 143 days in average.

Also in our sensitivity analysis the crop growing periods of rice decreased with the higher temperatures ranging between 0 days to 20 days compared with the observation years. Particularly, when temperature increased by +4^{o}C the rice phenology will be rapidly shortened ranging between 124 to 139 days (128 days in average), which would have a negative effect on yield potential. As for the single increased and decreased precipitation scenarios by +25% and -25%, the growing periods of rice were stable and agree with the observation years (140 to 168 days), we can say that from the atmospheric parameters temperature has a dominating influence on rice yields potential (of the simulated cultivar) in our case study region of Laos under future climate scenarios, beside N-fertilization levels.

4.7.3 Farming practice adaptations

The results of our study confirm that the climate change signal will impact the rice yield in positive way, which will make more benefit for farmers. However, in this study other potential yield limiting factors which could be changed in a negative way due to climate change were not considered. For example, diseases and pest insects damage could increase when drought appears and in term of increased temperatures. Less precipitation might force some insects and diseases such as grasshopper, rice stink bugs, armyworm (larvae and pupae of any worm) dried leaves etc. as previous experiences of staff of Agriculture and Forestry Department reported (Chapter III) confirm. Another problem not assessed by our study is increasing heavy precipitation due to climate change leading to flash floods and destroying rice paddy fields in lowland areas, as it was seen in 2011. So, farmers have to keep in mind for adaptation not only crop management options but also other risk mitigation measures. Regarding adaptation option for Lao farmers within crop management our study supports the change to cultivars with longer growing periods, beside other measures such as optimized fertilization, soil preparing, sowing, planting, and also faster harvesting.

A case study on adaptation potentials was carried out for the Lower Mekong River of Laos, Thailand and Vietnam (Chinvanno et al., 2006). Even thought farmers are not deliberate attempt to adapt of climate change they provide some basic experiences and knowledge skills to develop climate change adaptation measures. Such indigenous adaptation with use of indigenous knowledge to assess seasonal climate predictions is still used in some Lao farmers communities. These are based upon observations and interpretation of natural phenomena, for example, the level of egg’s frog, color of lazards’ tail and various indicators of the drought years and flooding years (Boulidam, 2005; Chinvanno et al., 2006). They also demonstrate and practice a history of farmers’ experiences in the region acting effectively within their constraints, in their self-interest to reduce vulnerability to climate hazards. For example, when a drought year appeared most of farming practices used upland plantation method (directly planting by seed), using local water pond to keep seedling, shifting soil preparation, and adding more fertilizer (Boulidam, 2005). However, despite these efforts the farmers who rely on rainfed crops are still strongly impacted by prolonged dry spells, floods, and other climate events. They are highly vulnerable to climate vulnerability now and might be expected to be highly vulnerable to climate change in the future. The previous studies (Chinvanno et al., 2006) briefly suggested the need of future research for implementation in crop breeding, adjusting planting technique and crop calendar to match with the climate pattern.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Climate change signal projection

Several climate models of General Circulation Models (GCMs) such as CSMK3, HadCM3, and HadGEM models were applied for this study, with six scenarios as high and low climate sensitively are namely CSHI (represented high climate sensitive of CSMK3 model), CSLO (represented low climate sensitive of CSMK3); HCHI (represented high climate sensitive of HadCM3), HCLO (represented low climate sensitive of HadCM3); and HGHI (represented high climate sensitive of HadGEM), HGLO (represented low climate sensitive of HadGEM). These six scenarios were projected for 100 years (2001 to 2100) for climate change scenarios and to be data input for the DSSAT model and simulated performance lowland paddy rice conditions in Savannakhet province, Laos.

According to the six scenarios, compared with temperature observation years (1971 to 2009), the trend of climate change signal in Savannakhet province, Laos indicated that air temperature will be increased between +0.64^{o}C to +2.40^{o}C, the amount of precipitation almost will be decreased were ranged between -1.08% to -11.39%, and solar radiation will be diverse in positive and negative results were ranged between -2.99% to +2.19%. If we look at the three periods of the climate scenarios trend from 2001 to 2030, 2035 to 2065, and 2070 to 2100, the air temperatures will slightly increase from the first period to the second period and further to the third period (2035 to 2065, and 2070 to 2100). Precipitation will be higher in the second period (2035 to 2065), and will slightly decrease in the third period, but remains still higher then in the first period (2001 to 2030). Solar radiation in the first and second period were equivalence and stable, but to be increased in the third period.

In addition, if we look at the trend of climate observed data during 39 years (1971 to 2009) we see also similar signs of changing climate. Compared to the first period of 19 years (1971 to 1989) in the second period of 20 years (1990 to 2009) the air temperature increased by +0.68°C, and precipitation increased by 143 mm. These numbers are a clear evidence of the climate change signal in Laos.

5.1.2 Rice yield simulation

In this simulation study we investigated the climate change of temperature, precipitation and solar radiation on rice yield under consideration of the CO_2-fertilization effect and N-fertilization levels in the 21st century in Savannakhet province, Laos. The potential effects of other yield limiting factors such as pests, diseases and other environmental factors (soil parameters, crop management etc.) are not considered. The crop simulations were based on six climate scenarios. The results show that in all six scenarios grain rice yields will increase ranging between +6.77% and 12.78% compared with the base line (1995-2009). If we look at three selected periods of the rice yields simulations from 2001 to 2030, 2035 to 2065, and 2070 to 2100 there can be seen only small changes. The second period will get higher yields than the first and the third periods. The rice yield in the third period of some scenarios might decline between -0.03% and -0.34% compared with the second period. However, the yield in the third period still higher than in the base line.

We can see also a positive yield effect of increased CO_2-levels (CO_2-fertilization effect). Without a change in CO_2 concentration in 2100 the rice yield will only increase between +5.91% and +10.85% in comparison with observation years (1995-2009). Therefore, without the CO_2-effect the rice yields would be between -0.82% and -1.56% lower, which is a relatively small response for our simulated cultivar (TDK 1).

A climate sensitivity analysis was carried out additionally with eight scenarios of changed climate factors such as increase and decrease precipitation, increased air temperature and increased both air temperature and precipitation. The yield responses of these changes ranged between +3.77% to +13.89%, with showing the strongest positive yield effect by the increased temperatures. The rice yield will gain more benefit by increased temperature of +2^{o}C and +4^{o}C rather then with increased or decreased precipitation of 25%. However, the highest rice yield was simulated for combined increasing air temperature of +4^{o}C and increasing precipitation of +25%.

Due to these results we can conclude that the potential rice yields will be positively impacted due to climate change in Laos (under our applied climate scenarios). Particularly the rice yields will improve when air temperature increase up to +4^{o}C in combination with higher CO_2 concentration in the atmosphere of up to 950 ppm in 2100, where temperature was found to be the main determining factor. However, other not considered yield limiting factors could limit this positive trend in the future, or change the trend if different climate scenarios would become true (e.g. with increasing drought spells).

5.1.3 Adaptation alternatives

In fact, according to results of this study rice production in Laos will get positive impacts of climate change. Although the rice growing period will be shorter due to warming farmers would gain more yields or at least keep current mean yield levels due to changing climate alone. Our simulations however also show that significantly more yield gains could be reached with increased N-fertilization compared to the current level. Also the N-fertilization efficiency would increase under climate scenarios, especially for lower N-fertilization levels. However, the climate pattern can have strong influence to rice yield variability which is determined by extreme weather such as drought. This has to be taken into account as the uncertainty of extreme weather is high in the climate scenarios.

In fact, farmers already have some experiences in term of climate variability impacts. They might adjust some of their old experiences to be applied in the next future of ongoing climate change. Also climate change will change the timing of field operations. For example, the growing rice period will be shorter which means that harvesting period will be earlier than in previous time by approximately 5 to 14 days in the long term. Also for the mid and early rice cultivars this will apply, but this study did not cover those genotypes. So, farmers have to keep in mind and pay attention for the right timing of farming activities such as soil preparing, sowing, transplanting, weeding, and fertilization until harvesting activities. Due to shorter growing period this may increase labor efforts, which is especially critical for larger farms with less developed framing technique. Therefore, regarding adaptation not only farmers themselves have to prepare, but it might concern also extension services to develop more efficient farm technologies, for example the National Rice Research Program (NRRP), National Agriculture and Forestry (NAFRI) of Laos. It might concern also strategies of rice production and food security in the future.

5.2 Limitation of the study and Recommendations

5.2.1 Limitation of study

In this study only a limited set of farming techniques were considered to assess rice yields under climate scenarios, such as N-fertilization. In reality much more factors determine rice yields, especially farming practices such as soil cultivation, crop rotation and many others. However, the crop model simulation was based on local validation under current practices, supported by data collected from Department of Agriculture and Forestry, Unit of Plantation in Kaison District Savannakhet Province, National Agriculture and Forestry Research Institute, National Rice Research Program etc.. Some of the data were adjusted from original data to model input format, particularly for rice genotype factors, because the NRRP lack of these specific data set.

5.2.2 Recommendations for further research

According to the limitations of the study, only one rice genotype for crop yield simulation was assumed for the whole province and compared under climate scenarios. Therefore, it is suggested for the next studies to include more cultivars representing also early and medium rice varieties. These should include varieties which farmers prefer in order to investigate those genotypes response in term of climate change signal in Laos. Also up land rice cultivation should be simulated as well as to look on the trend of grain yield and yield variability when there would be a change in climate extremes. Further long term field experiments should be established with a selected range of cultivars to support such modeling activities with input and calibration data. For example, data on cultivar phenology expressed as growing degree days [GDD] are better than adjusted data. Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate; extent to which phasic development leading to panicle initiation is delayed; potential spikelet number coefficient as estimated from the number of spikelet per g of main culm dry weight; temperature tolerance coefficient etc. are other examples of cultivar characteristic parameters which could be very useful for cultivar specific crop simulation.

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APPENDIX

APPENDIX

1. Values of CO_2 concentration in the atmosphere applied in the climate change scenarios of this study

Years	High climate sensitivity, emissions SRES-A2	Low climate sensitivity, emissions SRES-B1
1765	278	278
1770	278	278
1775	278	278
1780	279	279
1785	279	279
1790	280	280
1795	280	280
1800	281	281
1805	282	282
1810	282	282
1815	283	283
1820	284	284
1825	284	284
1830	284	284
1835	285	285
1840	286	286
1845	286	286
1850	287	287
1855	288	288
1860	288	288
1865	289	289
1870	289	289
1875	290	290

1880	291	291
1885	292	292
1890	294	294
1895	295	295
1900	296	296
1905	297	297
1910	299	299
1915	300	300
1920	302	302
1925	304	304
1930	305	305
1935	306	306
1940	308	308
1945	309	309
1950	311	311
1955	314	314
1960	317	317
1965	320	320
1970	325	325
1975	331	331
1980	338	338
1985	346	346
1990	354	354
1995	361	361
2000	369	369
2005	380	377
2010	**393**	**385**
2015	407	394
2020	424	404
2025	443	415

2030	464	425
2035	486	435
2040	509	446
2045	534	456
2050	559	465
2055	587	473
2060	616	480
2065	647	485
2070	681	489
2075	717	491
2080	756	493
2085	799	494
2090	845	493
2095	896	492
2100	950	491

Sources: Dubrovsky (pers.Comm., 2011)

2. Result of calculation of solar radiation in Savannakhet province, Laos (1971 to 2009)

No	Years	Mean daily solar Radiation (MJ/m^2)
1	1971	16.82
2	1972	16.67
3	1973	18.76
4	1974	19.27
5	1975	17.36
6	1976	17.66
7	1977	18.21
8	1978	16.79
9	1979	17.71
10	1980	16.82
11	1981	16.55
12	1982	17.42
13	1983	17.79
14	1984	17.08
15	1985	17.13
16	1986	17.17
17	1987	17.37
18	1988	17.00
19	1989	16.98
20	1990	16.72
21	1991	16.93
22	1992	16.99
23	1993	16.69
24	1994	16.62
25	1995	17.09
26	1996	16.36

27	1997	16.97
28	1998	16.98
29	1999	16.51
30	2000	16.96
31	2001	16.85
32	2002	17.37
33	2003	17.34
34	2004	17.42
35	2005	16.76
36	2006	17.04
37	2007	17.01
38	2008	16.79
39	2009	17.33

3. Poster presentation

Climate Change Impact on Rice Production Potential in Kaison District, Savannakhet province, Laos

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Abstract

Climate change is considered as one of the main environmental problems of the 21st century, and it will have major impacts on the climate worldwide including agricultural productivity, climatic conditions and hence climate change influence agriculture. Agricultural is one of the most important roles of the economic as well as for farmer's livelihood of Laos, which is contribution to 51 % of GDP and employs 86% of the total labor. So, when climate change appears it might impact in positive or negative ways of agricultural production, particularly paddy rice yield. Therefore, this study will conduct with following two objectives: to investigate the trend of rice yield under influence of climate change, and to explore adaptation options of farmers to climate change impacts. The potential impacts of climate change and climate variability on rice yields at field level was simulated with Decision Support System for Agrotechnology Transfer (DSSAT) crop model that already applied in worldwide. DSSAT version 4.0.20 was applied for this study. The results of the model simulations are used to find out the suitable ways for farmers adaptation options as result of the model suggestion in term of climate change under the conditions in Laos.

Climate Change Impact on Wetland Rice Production Potential in Kaison District, Savannakhet province, Laos

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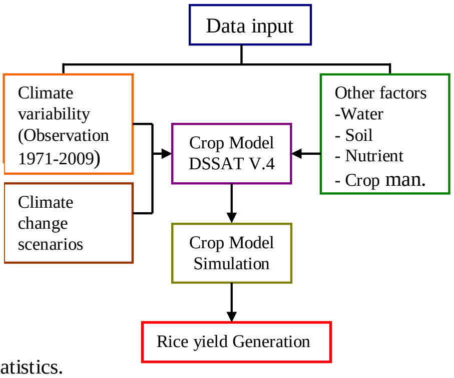
Acknowledgement: This research is supported by Erasmus Mundus External Cooperation Window-ERASIA project

INTRODUCTION

Climate change is considered as one of the main environmental problems of the 21st century, and it will have major impacts on the climate worldwide including agricultural productivity. Rice production is one of the most important food sources as well as important for farmer's livelihood of Laos. So, when climate change appears it might impact in positive or negative ways of paddy rice yield. Therefore, this study will conduct with following two objectives: to investigate the trend of rice yield under influence of climate change, and to explore adaptation options of farmers to climate change impacts.

Yield simulation of wetland rice was carried out with the CERES-Rice model (DSSAT) for a location in Laos (Kaison District, 144 m altitude) using current crop management. The baseline covered the period of 39 years (1971-2009), where 4 stepwise climate change scenarios : +2°C, +4°C, +2°C with 1.5*CO_2, and +4°C with 2*CO_2 were applied.

METHODS



Data input

Climate variability (Observation 1971-2009)

Climate change scenarios

Crop Model DSSAT V.4

Other factors
-Water
- Soil
- Nutrient
- Crop man.

Crop Model Simulation

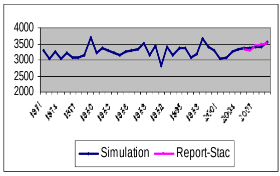
Rice yield Generation

RESULTS

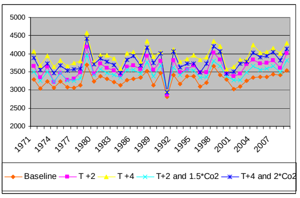
The model was validated on rice yield reports of agricultural statistics.

According to the model simulations the rice yield will increase with increasing temperature, particularly when the temperature is increased by +4°C (both in maximum and minimum temperatures - which is in average 31°C and 21°C, respectively form the baseline period). The rice yield increased from 3275kg/ha to 3921kg/ha under the +4°C scenario. In addition the growing season is shorter, and rice will mature earlier 22 days compared to the baseline period for the +4°C scenario. However, considering additionally CO_2-enhancements the simulated slightly lower leaf area and leaf weight lead to lower grain yields as compared to the only temperature changed scenarios. However, simulated maximum stem weight was not changed be different CO_2-concentration. Also N-fertilization showed significant influence on growth parameters such as LAI and the final grain yield.

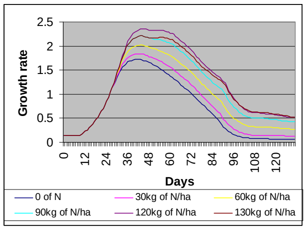
Model simulation of the observation



The trend of rice yield under climate change



LAI under +4°C scenario



CONCLUSIONS

The rice yields tend to be higher and maturity to be earlier in term of temperature and CO_2 increases, but it might be not for all type of rice varieties, and there might be other yield influencing factors which were not considered in pest and diseases). So, adaptations in rice production will be challenging in term of climate change in the future.

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This poster was presented at the conference of COST734 Final Conference. The International Conference on current knowledge of Climate Change Impacts on Agriculture and Forestry in Europe. COST in cooperation with COSTP0703C and OPAG III of CAgM of WMO. Local organizer for the conference was Slovak Hydrometeorological Institute, Slovak University of Agriculture in 3rd to 6th of May, 2011.

4. Curriculum Vitae

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Education	• Bachelor of Geography, Pedagogical University of Vientiane, Laos, 1985 – 1989. • Bachelor of English Language, Faculty of Letter, National University of Laos, 1999 – 2006. • MS.c of Natural Resource Management, Faculty of Environment and Resource Studies, Mahidol University, Thailand 2003-2005. • Doctorate of Department of Water, Atmosphere and Environment. Institute of Meteorology (BOKU-Met). University of Natural Resources and Life Science (BOKU) Vienna, Austria. September 2009 – June 2012.
Job description and duties	• Teaching at high school 1989-2000. • Lecturer at Department of Geography, Faculty of Social Sciences, National University of Laos 2000-2009. • Vice-Head of Department of Geography, Faculty of Social Sciences, National University of Laos 2005-2009. • Coordinator Sida/SAREC project at Faculty of Social Science 2006 to 2009.
Research works	• 2003 to 2005 research assistant for *(SEA START RC)* • 2005 to 2009 some papers concerned with *Vulnerability of Rainfed farmers to impact of climate variability, edible insects etc.* published.
Consultants	• Socio-economic Specialist on project Reduced Emissions from Deforestation and Forest Degradation (REDD) 30th May to 21rst June, 2009. • Local consultant of Climate Impact and Adaptation Sectoral Strategy for Rural Infrastructure in Lao PDR. Pilot project in Lower Mekong river basin covering five southern provinces of Laos. August, 2009.
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