Modelling Economic Crop Yield and Climate Change in Thailand

P. Kuneepong[a], S. Kongton[a], V. Wangwacharakul[b] and S. Sumdin[c]

[a] *Land Development Department, Ministry of Agriculture and Cooperatives, Bangkok 10900, Thailand. (parida@loxinfo.co.th)*

[b] *Kasetsart University, Bangkok 10900, Thailand. (parida@loxinfo.co.th)*

[c] *Department of Meteorology, Ministry of Communications, Bangkok 10110, Thailand. (sumdin@yahoo.com)*

Abstract: Growth and yield of economic crops in Thailand affected by climate change were studied by application of climate scenarios generated by CSIRO, Australia; HadCM2 from Hadley Centre for Climate and Research, UK; ECHAM4 from Max-Planck Institute für Meteorologie, Germany; CGCM from Canada) and IBSNAT crop growth models (CERES-rice and CERES-maize) in four study areas (soil types): Surin and Roi Et Provinces in northeastern part for rice, Nakorn Sawan Province in north-central part and Nakhon Ratchasima Province in northeastern part for maize. Most GCMs that were applied predict that enhanced greenhouse climate change may boost crop productivity. Higher levels of CO_2 should stimulate photosynthesis in certain plants. Doubling of CO_2 may increase photosynthesis rates by as much as 30–100 %. Results from different GCMs show that impacts of climate change are likely to reduce yield of rice and maize but that in some cases the magnitude and direction of the impact varies with GCMs. Besides the uncertainty issue, the results from the selected cases also indicate that the impacts are site specific. Thus, while climate change might result in reductions in certain areas it could possibly make other areas better-off.

Keywords: Crop modelling; Climate change; Crop yield

1. INTRODUCTION

Studies of the impact of global climate change on national development in different sectors of the economy have been conducted comprehensively in many developed countries. Similar studies have also been conducted in developing countries, but to a lesser extent. Since climate change is unavoidable, different sectors will experience the effects to different degrees, the abilities of the sectors to adapt to such changes is highly relevant to their sustainable development. The socio- economic structure of the national economy, knowledge, technology, and risk prevention are important if the country to adapt effectively.

Despite structural change over the past two decades, more than one-half of the population in Thailand will still depend on agriculture for their living. Many commercial crops are major exported products as well as intermediate goods for processing such as rice, maize, cassava and sugar cane. The major crops of Thailand such as aromatic rice, maize and cassava are mainly from rainfed agriculture. Crop production in Thailand is relatively vulnerable to climate change. Study on change impacts on the agricultural sector in Thailand is hence necessary in order to prepare for reduction of damage that might occur.

2. CLIMATE

Climate of Thailand is tropical with long hours of sunshine and high humidity. Mean annual precipitation is about 1,550 mm throughout the country; while in the southern part of the peninsula, rainfall exceeds 4,000 mm, and over the continental part rainfall is only 1,000 mm in some areas.

There are 3 seasons: hot; from March to June, rainy; from July to October and cool; from November to February. Average low temperature is 20°C and high temperature is 37°C.Topographically, Thailand can then be divided into six regions, namely: North, Northeast, Central, East, Southeast and Southwest regions.

3. GENERAL CIRCULATION MODELS (GCMs)

General Circulation Models (GCMs) based on physical processes of the major components of the climate system: atmosphere, ocean and land surface. GCMs do not all give the same results at the regional scale. It is recommended to use more than one GCM for impact and adaptation assessments in order to investigate trend and direction of changes in scenarios and it is recommended to select appropriate GCM models. [IPCC, 1990].

GCMs are commonly used to develop climatic scenarios. Among them are GISSfrom Goddard Institute of Space Studies, UK89 and UKMO from United Kindom. The three GCMs simulated potential increase in mean monthly temperature and precipitation under climate change scenarios of doubling CO_2 levels in Thailand. The magnitudes of increasing are slightly different, ranging from 2.2-6.0 $^{\circ}$ C. [Boonprakob, 1996]

4. OBJECTIVES AND SCOPE

The objective of the study is to analyze climate change impacts on economic crop yields using mathematical models. Its scope is:

• Survey, collect and review climate change studies conducted in Thailand and other countries.

• Conduct field survey and data collection and analyze vulnerability by mathematical models and analyze adaptation of agriculture in climate change.

• Conduct studies in northeastern and northern regions of Thailand. Two major crops (paddy and maize) are conducted at 4 sites in the Northeast and the North.

5. METHODOLOGY

CERES models will be applied to analyze yield levels under different scenarios derived from 3 different GCMs (CGCM1, CSIRO and ECHAM4). The Scenarios that are generated for this study are:

- controlled or non impact from CO_2 (= 330 ppm. at 1990 level).

- GHG impact : assuming that CO_2 will be increased at 1 % every year in the periods 1990-2020, 2020-2050 and 2050-2080). Then CO_2 will be doubled at the end of the third period. While crop variables are temperature ('maximum and minimum), rainfall and solar radiation with the application of nonfertilzed (0-N) and fetilized (25-N for rice and 65- N for maize).

6. REVIEW OF CLIMATIC MODELS

Different GCMs produce substantially different and occasionally contradictory results. At the world level, rice yields had been simulated to drop by 0–5% and prices increased by 10–100%, depending on the type of GCMs used. The effects due to doubled CO_2 vary substantially between models. In some countries, yield of rice could drop by 20% and increased by up to 27%. In Malaysia, Indonesia, Taiwan and Bangladesh the results are positive. [Matthews, et al.,1994]

Climate change impacts on rice culture, in many countries, is still uncertain. This does not mean that the issue is not important but confidence of methodologies and results should be improved. The GCMs are not yet able to produce reliable projection of changes in climate reliability such as alterations in the frequency of draught and storms, eventhough these could affect yield significantly. [Rosenzweig, et al., 1993] Rice production itself has a significant effect on global warming and atmospheric chemistry through methane emission from flooded fields. Water regime and soil properties are major factors controlling the flux of methane in rice fields. Global and regional estimates of methane are still highly uncertain and tentative. [Neue et al., 1995]

7. REVIEW OF CROP MODELS

There are several crop models being used to explain the relationship between the inputs and yields of crops. The models have different strengths and weaknesses. Crop models, in general, are useful in various ways [Jongkaewwattana, 1993], especially in being used to assess the impact of increasing CO_2 in the atmosphere.

DSSAT is a system for crop growth and yield model constructed to answer the question of "What if ? from policy makers as well as farmers. [IBSNAT, 1989]. IBSNAT introduced DSSAT (Decision Support System for Agro-technology Transfer) to support agricultural decision process in 1988. It consists of data management module, crop module, and operational module.

In 1993, the CERES maize and rice models under DSSAT were used extensively in plant growth and development to assess its response to climate conditions, soil and its water availability [Xiachua , 1993].

WOFOST from The Netherlands had been used to assess soil productivity for maize production in Nakhon Ratchasima Province. The validation was found to be acceptable. [Kuneepong, 1996].

PLANTGRO can be simulated crop performance using various assumptions and had been applied to predict tree growth for general regions and specific sites: China, Thailand and Australia. [Davison, 1995].

This study will apply CERES-crop which had been well developed and validated in Thailand as a tool to analyze climate change impact on crops .

8. THE CLIMATE SCENARIOS

It was assumed that GHGs were controlled at the 1990s level as baseline or controlled scenarios. CO_2 was assumed to be increased at 1% per year from 1990 to the end of 21 st century. Under this assumption CO_2 should be double within 70-80 years.

To obtain the climate scenarios for the provinces, the first step is to down scale monthly values from the nearest grid points of the GCM to the locations by using direct interpolation method. Monthly scenarios values are weighted by monthly actual values of the corresponding variables. The ratios are then used to generate daily climate values for different scenarios for four provinces. By using 30 years of average actual daily climate from the provinces as bases then monthly ratios are extrapolated for daily climate values.

To observe the nature of the climate scenarios generated, the actual 30-year climate values were averaged (2010-2039, 2040-2069 and 2070-2099). Hence, each period of time should be viewed as an average long term trend over the century.

Climate scenarios generated from GCMs and the four provinces were compared (Tables 1 and 2). [Office of Environmental Policy and Planning, 2000]. The results indicate that ECHAM4 and HADCM2 which have relatively higher resolution than the other two models seem to be closer to the actual climate.

It should be noted that simulations that are closer may not necessarily produce more reliable scenarios, and vise versa. The variation of actual minimum temperatures is higher than maximum temperatures when comparing with simulations.

Table 1. Actual and climate scenarios for minimum temperatures (°C), Nakhon Sawan Province (1960–1989).

Month	Actual	CGCM1	CSIRO	ECHA M4	HadC M2
Jan	18.1	3.8	12.7	21.0	17.8
Feb	21.6	6.9	16.0	23.5	19.6
Mar	24.1	12.7	20.1	26.4	22.1
Apr	25.7	19.0	22.2	27.5	23.9
May	25.4	22.3	23.3	26.6	23.8
Jun	25.0	23.4	23.6	24.8	23.1
Jul	24.5	23.3	23.8	24.1	22.9
Aug	24.3	22.9	23.8	23.6	22.9
Sep	24.0	22.2	23.8	23.3	22.5
Oct	23.6	16.6	22.9	22.9	20.8
Nov	21.3	9.7	17.0	21.6	18.2
Dec	18.2	4.7	11.8	20.6	17.2

Source: Office of Environmental Policy and Planning, [2000]

Table 2. Actual and climate scenarios for maximum temperatures (°C) Nakhon Sawan Province (1960–1989).

Month	Actual	CGCM1	CGCM	ECHA M4	HadC M2
Jan	32.3	12.9	20.8	30.7	29.8
Feb	34.8	17.2	24.4	34.0	33.2
Mar	36.8	24.3	27.8	37.5	35.3
Apr	38.1	31.7	28.9	38.0	34.8
May	35.9	31.9	28.1	35.7	30.6
Jun	34.6	28.3	27.5	30.9	26.7
Jul	34.0	26.5	26.8	28.4	26.3
Aug	33.3	26.1	26.7	27.9	27.2
Oct	32.1	22.6	27.4	30.0	28.5
Nov	31.5	18.0	23.8	29.6	27.5
Dec	31.0	13.7	20.2	29.0	28.1

Source: Office of Environmental Policy and Planning, [2000]

9. RESULTS

9. 1 The Results of the CGCM1

Base on 1990's level the climate change scenario given by CGCM1 will reduce crop yield in 2020, 2050 and 2080. It shows that climate change will most probably reduce yield of rice both 0-N and 25-N in Roi Et and Surin Provinces (Tables 3 and 4). Climate change could also affect rice development. Rice flowering and late stages in two provinces are shortened by 1–10 days. The generated biomass is closely related to yield level. Less biomass will provide lower yield, and vise versa.

The impact of climate change on maize yield was quite extensive in both provinces, especially in the latter part of the period. Maize yield could drop by 5-44 % due to climate change (Tables 5 and 6). Development of maize in Nakhon Sawan was unaffected by climate change. While in Nakhon Ratchasima, it reduced flowering and late stages by 4–10 days.

Table 3. Rice yield (kg/ha) from CGCM1 model (Roi Et Province).

	1990	2020	2050	2080
RoiEt Province (0-N)				
Controlled	2,102	1,689	1,627	1,668
GHG impact	2,102	1,698	1,650	1,340
% change	-	-0.53	-1.41	-19.66
RoiEt Province (25-N)				
Controlled	3,296	2,327	2,844	2,336
GHG impact	3,296	2,896	2,783	2,574
% change	-	24.46	-2.15	-10.19

Table 4. Rice yield (kg/ha) from CGCM1 model (Surin Province).

	1990	2020	2050	2080
Surin Province (0-N)				
Controlled	3,185	1,766	1,866	1,672
GHG impact	3,185	1,711	1,570	1,448
% change	-	-3.11	-13.29	-13.40
Surin Province (25-N)				
Controlled	1,347	2,980	3,058	2,893
GHG impact	1,347	2,835	2,662	2,628
% change	-	-4.87	-12.95	-9.16

Table 5. Maize yield (kg/ha) from CGCM1 model (Nakhon Sawan Province).

	1990	2020	2050	2080
Nakhon Sawan Province (0-N)				
Controlled	5,919	5,801	5,059	4, 934
GHG impact	5,919	4,835	4,365	3,559
% change	-	-16.65	-13.72	-27.86
Nakhon Sawan Province (65-N)				
Controlled	6,298	6,120	6,259	6,192
GHG impact	6,298	5,146	4,636,	3,702
% change	-	-21.01	-17.58	-34.77

Table 6. Maize yield (kg/ha)from CGCM1 model (Nakhon Ratchasima Province).

	1990	2020	2050	2080
NakhonRatchasima Province (0-N)				
Controlled	3,869	4,465	4,596	3,990
GHG impact	3,869	3,763	3,126	2,720
% change	-	-15.72	-31.98	-31.83
NakhonRatchasima Province (65-N)				
Controlled	4,375	4,280	4,328	5,212
GHG impact	4,375	4,044	3,303	2,910
% change	-	-5.52	-23.69	-44.17

9. 2 The Results of the ECHAM4

Base on 1990's level the climate change scenario given by ECHAM4 will reduce crop yield in 2020, 2050 and 2080. Rice yield was most probably reduced in increasing CO_2 scenarios on 0-N and 25-N rice both in Roi Et and Surin provinces. (Tables 7 and 8). The flowering and late stages of rice in Roi–Et and Surin will be shortened by 3–8%.

Maize yield was gradually reduced by climate change both in Nakhon Sawan and Nakhon Ratchasima Provinces. (Tables 9 and 10) No difference was found between 0-N and 65-N yields. Flowering and late stages of maize in Nakhon Sawan did not change, but 4–10 days period was reduced in Nakhon Ratchasima.

Table 7. Rice yield (kg/ha) from ECHAM model (Roi Et Province).

	1990	2020	2050	2080
Roi Et Province (0-N)				
Controlled	2,102	2,050	1,903	2,065
GHG impact	2,102	1,685	1,467	1,400
% change	-	-17.81	-22.92	-32.21
Roi Et Province (25-N)				
Controlled	3,876	2,709	3,141	2,754,
GHG impact	3,876	2,844,	2,603	2,539
% change	-	4.88	-17.13	-7.81

Table 8. Rice yield (kg/ha) from ECHAM model (Surin Province).

	1990	2020	2050	2080
Surin Province (0-N)				
Controlled	2,006	2,159	2,054	2,099
GHG impact	2,006	936	1,564	1,559
% change	-	-56.00	-23.86	-25.73
Surin Province (25-N)				
Controlled	2,652	3,306	3,158	3,285
GHG impact	2,652	2,022	2,661	2,637
% change	-	-38.84	-15.74	-19.73

Table 9. Maize yield (kg/ha) from ECHAM model (Nakhon Sawan Province).

	1990	2020	2050	2080
Nakhon Sawan Province (0-N)				
Controlled	5,919	5,567	5,454	6,245
GHG impact	5,919	4,859	4,402	4,061
% change	-	-12.72	-19.29	-34.97
Nakhon Sawan Province (65-N)				
Controlled	6,298	6,429	5,454	6,245
GHG impact	6,298	5,129	4,402	3,986
% change	-	-21.0	-19.29	-36.18

Table 10. Maize yield (kg/ha) from ECHAM model (Nakhon Ratchasima Province).

	1990	2020	2050	2080
Nakhon Ratchasima Province (0-N)				
Controlled	3,869	3,878	3,973	4,630
GHG impact	3,869	3,625	2,979	2,657
% change	-	-6.52	-25.02	-42.61
Nakhon Ratchasima Province (65-N)				
Controlled	4,375	4,280	4,328	5,212
GHG impact	4,375	4,044	3,303	2,910
% change	-	-5.52	-23.69	-44.17

9. 3 The Results of the CSIRO.

The result from using climatic scenarios from the CSIRO model shows relatively moderate impact compared to the other two models. Based on 1990's level the climate change scenario by CSIRO reduces crop yield in 2020, 2050 and 2080.

Rice yield in Roi Et Province (table 11) dropped by 13% at the end of the century. Application of 25-N could reduce the impact and yield fluctuation from the 0-N yield. Rice yield in both cases in Surin tend to be reduced over time (Table 12). Flowering and late stages of rice in both provinces were reduced by 5–10 days.

Maize yield in Nakhon Sawan in both cases were impacted by climate change. Reduction in 0-N fluctuated while in 65-N the reduction grew over time. In Nakhon Rachasima, the impact of climate change to maize yield was uncertain. It was increased by first 30 years while reduced in the second and third .

Flowering and late stages of rice in both provinces vary. It was shortened by 5–10 days in Nakhon Ratchasima while those of Nakhon Sawan are stable. Biomass of maize varies closely with the yields.

Table 11. Rice yield (kg/ha) from CSIRO model (Roi Et Province).

	1990	2020	2050	2080
Roi-Et Province (0-N)				
Controlled	2,102	1,905	1,820	1,913
GHG impact	2,102	1,873	1,615	1,666
% change	-	-1.67	-11.26	-12.91
Roi-Et Province (25-N)				
Controlled	3,296	2,459	3,064	2,575
GHG impact	3,296	3,085	2,797	2,790
% change	-	+25.3	-8.71	+8.34

Table 12. Rice yield (kg/ha) from CSIRO model (Surin Province).

	1990	2020	2050	2080
Surin Province (0-N)				
Controlled	2,006	1,906	1,872	5,826
GHG impact	2,006	1,863	1,606	4,546
% change	-	-2.25	-14.21	-14.82
Surin Province (25-N)				
Controlled	3,185	3,102	3,083	3,205
GHG impact	3,185	2,998	2,707	2,730
% change	-	-3.35	-12.19	-14.82

Table 13. Maize yield (kg/ha) from CSIRO model (Nakhon Sawan Province).

	1990	2020	2050	2080
Nakhon Sawan Province (0-N)				
Controlled	5,919	6,090	5,004	5,826
GHG impact	5,919	5,295	4,745	4,546
% change	-	-13.05	-5.17	-21.97
Nakhon Sawan Province (65-N)				
Controlled	6,298	6,370	6,258	6,140
GHG impact	6,298	5,532	4,945	4,732
% change	-	-13.15	-20.98	-22.93

Table 14. Maize yield (kg/ha) from CSIRO model (Nakhon Ratchasima Province).

	1990	2020	2050	2080
Nakhon Ratchasima Province (0-N)				
Controlled	3,869	3,682	4,569	3,717
GHG impact	3,869	4,059	3,705	3,471
% change	-	10.24	-18.91	-6.62
Nakhon Ratchasima Province (65-N)				
Controlled	4,375	4,125	5,192	4,133
GHG impact	4,375	4,675	4,197	3,891
% change	-	+13.33	-19.16	-5.86

9.4 Comparison of Results from Different GCMs

Although the analysis suggests that the impact of climate change is likely to reduce rice and maize yields over time, magnitude and in some cases direction of the impact varies amongst scenarios generated by the GCMs. The scenarios from ECHAM4 model tend to introduce higher level of impact than the rest. The CGCM1, on the other hand introduced relatively moderate impact than the others. (Tables 15 and 16).

Table 15. Change in rice yield (%) by climate impactusing different GCMs in RoiEt and Surin Provinces.

Year	CGCM1		ECHAM4		CSIRO	
	0-N	25-N	0-N	25-N	0-N	25-N
RoiEt Province.						
2020	-0.53	24.5	-17.8	4.88	-1.67	25..3
2050	-1.41	-2.15	-22.9	-17.1	-11..3	-8.7
2080	-19.7	-10.2	-32.2	-7.81	-12.9	8.3

Surin Province						
2020	-3.1	-4.9	-56.0	-38.8	-2.25	-3.4
2050	-13..3	-12.9	-23.9	-15.7	-14.2	-12.2
2080	-13.4	-9.2	-25.7	-19.7	-21.8	-14.8

Table 16. Change in maize yield (%) by climate impact using different GCMs in Nakhon Sawan and Nakhon Ratchasima Provinces.

Year	CGCM1		ECHAM4		CSIRO	
	0-N	65-N	0-N	65-N	0-N	65-N
Nakhon Sawan Province.						
2020	-16.7	-21.0	-12.7	-21.0	-13.1	-13.2
2050	-13.7	-17.6	-19.3	-19.3	-5.17	-20.9
2080	-27.9	-34.8	-34.9	-36.2	-21.9	-22.9
Nakhon Ratchasima Province.						
2020	-15.7	-5.52	-6.5	-5.5	10.24	13.3
2050	-31.9	-23.7	-25.1	-23.7	-18.9	-19.2
2080	31.8	-44.2	-42.6	-44.2	-6.6	-5.86

10. CONCLUSION

Yield and development by climate change scenarios are different in space, time and crops. It was suggested that rice in Surin is more influenced by climate change than in Roi Et Province while maize in Nakhon Ratchasima is more influenced by climate than in Nakhon Sawan Province. The application of 3 GCMs indicate that CO_2 accumulation tends to reduced biomass but the degree of impact is different in space and time and it seems to be more effective in unfertilized crops.

11. ACKNOWLEDGEMENT

The authors would like to thank Dr. Samran Sombatpanit and Dr. Peter Whetton who assisted with the revision of the paper.

12. REFERENCES

Boonprakob, K., Climate Change Scenarios in Thailand Simulated by General Circulation Models. Bangkok, Thailand 31 p, 1996.

Davison, J. Developing PLANTGRO Plant Files for Forest Trees, Paper presented in ACIAR PN 9127 Project, Predicting Trees Ggrowth for General Regions and Specific Sites: China, Thailand and Australia. Bangkok, Thailand 12 pp, 1995.

IBSNAT. Decision Support System for Agrotechnology Transfer, Proceedings of the Symposium on International Benchmark Sites Network for Agrotechnology Transfer, University of Hawaii, 1989.

IPCC, Houghton, J. T., Jenkins, G. J. and Ephraums, J.J. (eds.) *Climate Change: The IPCC Scientific Assessment. International Panel on Climate Change. Cambridge:* Cambridge University Press, 1990.

Jongkaewwattana, S. Model and Plant System Simulation, Agricultural Technical Report No. 26, Multiple Cropping Center, Faculty of Agriculture, Chiang Mai University, 1993.

Kuneepong, P. Application of Information Technology (IT) to soil survey interpretation and suitability classification for economic crops. Technical Report No. 337, Soil Survey and Classification Division, Land Development Department, Ministry of Agriculture and Cooperatives (in Thai). 1996.

Matthew, R.W., M.J. Kropff, D, Bachelet & H.H. van Laar (eds.), The Impact of Global Climate Change on Rice Production in Asia: A simulation study. Report commission by US Environment Protection Agency, Corvallis, Oregon. 270pp, 1994.

Neue, H.U., L.H. Ziska, R.B. Matthews & D. Qiujie , Reduced Global Warming - the role of rice . *GeoJournal* 35: 351-362, 1995.

Office of Environmental policy and Planning, A Study of Climate Change Impacts on Various Sectors (Executive Summary), Ministry of Science, Technology and Environment. Thailand. 14p, 2000.

Rosensweig, C., M. L. Parry, G.Fischer, and K. Frohberg. Climate Change and World Food Supply. Research Report No. 3. Oxford: University of Oxford, Environmental Change Unit. 21p, 1993.

Xiachua,Y. Possible Impacts of Climate Change on Rice Crops in Southeast Asia, EPRI: 3412, Hillview Avenue, Palo Alto, CA 94302-1344, 1993.