Assessing Impacts of ECHAM4 GCM Climate Change Data on Main Season Rice Production Systems in Thailand

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Abstract
Main season rice-based cropping systems in Thailand are sensitive to the influence of climatic characteristics and patterns, which are induced by global warming. Despite uncertainties regards the precise magnitude of climate change projection at high resolution at regional scales as well as the timescales which are far into the future, an assessment of the possible impacts on our agricultural resources is important in formulating an adaptive response for rice production strategies. In the present study, CropDSS shell was used to link the CSM-CERES-Rice model version 4.0.2.0 with future climate scenarios from the PRECIS regional climate model (RCM) to downscale the ECHAM4 Global Climate Model (GCM) for Thailand. Data obtained from the ECHAM4 GCM under SRES A2 and B2 GHG emission scenarios were downscaled to higher resolution to project climate scenarios for the period 1980-2099. A slight decline in main season rice yields was predicted under all production systems before the 2040 period with a drastic decline in yield after the 2040 period. However, one should also bear in mind the predicted amount of rainfall and the relationship of more incidents of insect pests. The CropDSS shell and the CSM-CERES-rice model may be used to evaluate alternative adaptive production strategies under future climate scenarios projected by the ECHAM4 GCM in Thailand and other countries, providing that datasets are available for model testing and evaluation.

Keywords: *CSM-CERES-rice model, PRECIS RCM, ECHAM4 GCM, CropDSS, large area rice production estimation, Thailand*

Introduction
The majority of main season rice production systems in Thailand are rainfed systems, which are one of the most sensitive systems to the impacts of climate change. Thailand is a major exporter of rice to the world market, thus any changes in production systems especially main season rice production systems, in various parts of the country are important for the export and domestic decision-making processes. Despite uncertainties about the precise magnitude of climate change projections at high resolution on regional and time scales, an assessment of the possible impacts of change in key climatic elements on our agricultural resources is important for formulating appropriate response strategies.

The purpose of the present paper is to report on the assessment study undertaken and performance of the main season rice production in Thailand, using the CSM-CERES-Rice model together with climate change

A2 and B2 scenarios as predicted by the PRECIS RCM, using ECHAM4 GCM dataset as initial data for future climate simulation.

Materials and Methods

The CSM-CERES-Rice model

The CSM-CERES-Rice model (Cropping System Model-Crop Environment Resource Synthesis) was developed along the lines of the CERES-Maize and the CERES-Wheat models (Jones and Kiniry, 1986). It was modified for transplanted rice by researchers at the International Fertiliser Development Centre (Godwin and Singh, 1989) and tested in various production systems in Thailand (Jintrawet, 1991). It is still undergoing testing and refinement by scientists of the International Consortium of Application of System Approaches (ICASA).

The model requires daily weather data including solar radiation, maximum and minimum air temperature, and rainfall. Initial soil conditions required by the model include drainage and runoff coefficients, evaporation and radiation reflection coefficients, rooting preference factors, and initial soil water, mineral nitrogen and organic matter content for each horizon. Day-length is calculated from latitude and day of the year. Grain yield is determined by the rate and duration of panicle growth as influenced by genotype and environmental conditions. The model, as yet, does not incorporate genetic coefficients for resistance to insects and pathogens.

The PRECIS RCM and ECHAM4 climate dataset

We used the PRECIS regional climate model (RCM) to downscale the ECHAM4 GCM data, based on SRES A2 and B2 GHG emission scenarios, which represent the high and low atmospheric concentration of GHGs in the future (SRES, 2000). The downscaling resolution was 20x20 km. The model was designed to cover the domain between 0-30^{o} North Latitude and 90-112^{o} East Longitude. A detailed description of the ECHAM4 climate model can be found in Roeckner *et al.* (1996). Daily weather data generated from ECHAM4 GCM was formatted for CSM-CERES rice model for the period 1980-2099 for Thailand (Chinvanno *et al.*, 2009).

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Research Highlights

- The present paper details an assessment study of the performance of main season rice production in Thailand, using the CSM-CERES-Rice model together with climate change A2 and B2 scenarios as predicted by the PRECIS RCM, using ECHAM4 GCM dataset.
- Impact of climate change during the period 1980-2099 on rice production in Thailand was studied and a slight decline in main season rice yields is predicted for all production systems before 2040 and a drastic decrease predicted after the 2040 period.
- Simulation of adaptive production options show that, during the period 2010-2019, an application of 60 kg of urea per ha can produce 15% and 36% higher simulated rice yield than an application of 200g of green manure per m^2 or no nitrogen application production option, respectively.

CropDSS shell framework

CropDSS shell (Jintrawet, 2009) includes SDBMS (Spatial Database Management System), MBMS (ModelBase Management System), the analysis module, and the visualisation module for map display. The CropDSS shell requires two kinds of minimum dataset (MDS) for crop yield and production estimation at the various administrative levels, which are the spatial and attributes datasets. These datasets have the smallest possible number of spatial and attributes for a practical assessment.

Rice production systems simulation settings

To assess the impacts of future climate pattern under A2 and B2 SRES scenarios on rice production in Thailand, we used the CropDSS shell to simulate rice yields under three production practices; namely; potential production practices, well-irrigated and well-fertilised production practices, and rainfed and nitrogen-limited production practices (Penning de Vries, 1982). We used one planting date, August 15, for main season rice, with three 25 day-old seedlings per hill, at 16 hills per square meter plant density. The rice variety was a non-photoperiod sensitive variety, Rice Department #7, thus RD7.

Results

Table 1 presents simulated rice yields of RD7 in the main season cropping systems for Thailand based on three production scenarios, namely; potential production scenarios, well-irrigated and well-supplied nitrogen fertiliser, and rainfed with no nitrogen fertiliser application. Potential rice production scenario yields ranged from 4,100-6,400 and 4,900-6,000 kg/ha for A2 and B2 SRES scenarios, respectively. Well-irrigated and well-supplied nitrogen fertiliser rice production scenario yields ranged from 3,700-6,000 and 4,000-5,700 kg/ha for A2 and B2 SRES scenarios, respectively. Rainfed with no nitrogen fertiliser application rice production scenario yields ranged from 2,100-2,200 and 2,000-2,100 kg/ha for A2 and B2 SRES scenarios, respectively.

Table 1. Mean and standard deviatioin of simulated rice yields in Thailand under ECHAM4 A2 and B2 SRES scenarios for three production options

Potential production

	A2		B2	
Year	Mean	SD	Mean	SD
1980-1989	6,190	660		
1990-1999	6,030	663		
2000-2009	5,901	624		
2010-2019	5,881	620	5,963	945
2020-2029	5,829	665	5,956	681
2030-2039	5,797	676	5,815	758
2040-2049	5,522	691	5,718	689
2050-2059	5,191	644	5,568	763
2060-2069	4,919	714	5,381	740
2070-2079	4,692	723	5,240	738
2080-2089	4,387	762	5,146	692
2090-2099	4,060	710	4,857	708

Well-irrigated and well-supplied nitrogen fertiliser production

	A2		B2	
Year	Mean	SD	Mean	SD
1980-1989	6,023	692		
1990-1999	5,841	715		
2000-2009	5,719	679		
2010-2019	5,684	673	5,714	996
2020-2029	5,629	713	5,695	772
2030-2039	5,585	742	5,542	865
2040-2049	5,276	760	5,403	817
2050-2059	4,947	732	5,282	912
2060-2069	4,622	812	5,004	927
2070-2079	4,373	831	4,886	938
2080-2089	4,026	923	4,781	879
2090-2099	3,706	869	4,427	955

Rainfed and no nitrogen application production

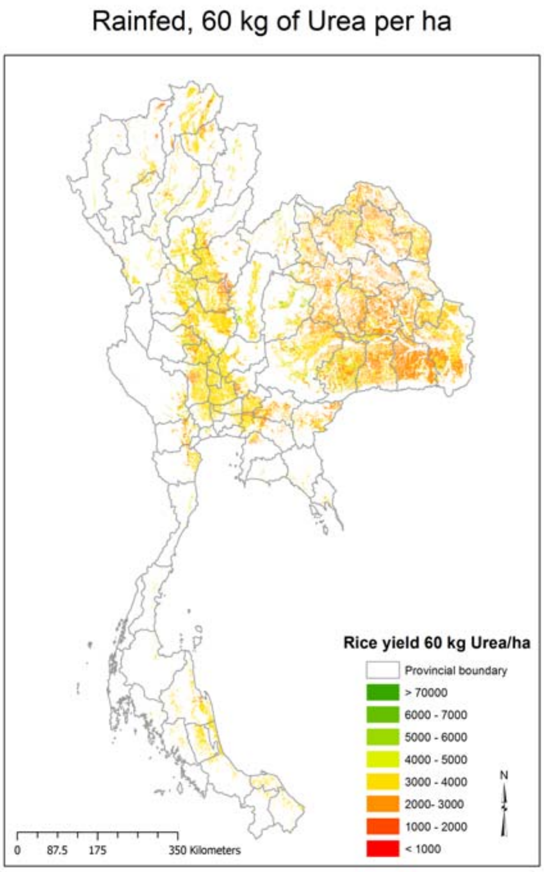
	A2		B2	
Year	Mean	SD	Mean	SD
1980-1989	2,215	795		
1990-1999	2,231	785		
2000-2009	2,226	773		
2010-2019	2,234	773	2,026	693
2020-2029	2,221	772	2,045	696
2030-2039	2,252	766	2,049	701
2040-2049	2,239	749	2,050	683
2050-2059	2,230	732	2,054	681
2060-2069	2,217	712	2,048	685
2070-2079	2,200	699	2,050	684
2080-2089	2,158	687	2,044	675
2090-2099	2,125	664	2,029	672

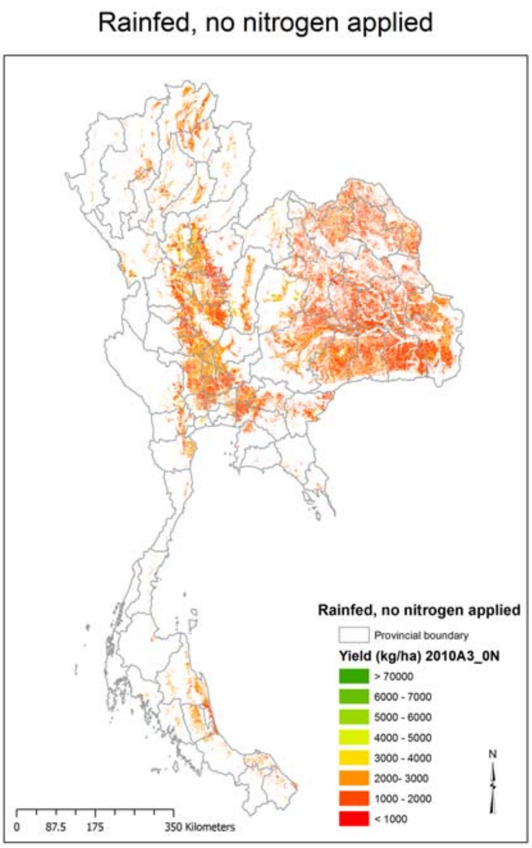
Impacts of future climate pattern under A2 and B2 SRES scenarios on potential rice production

Simulated potential rice yields governed by air temperature, solar radiation, and crop characteristics, averaged yields using simulated climate data for the baseline period of 1980-89 was 6,190 kg/ha. As compared to the 1980-89 period, rice yields during 1990-2049 period decreased by 2.6-6.4 and 3.7-6.1 percent from change in climate pattern based on A2 and B2 SRES scenarios, respectively. However, rice yield reduction was more pronounced after the 2040 period towards the 2090 period. Simulated rice yields reduction ranged from 10.8-34.4 and 7.6-21.5 percent under future climate pattern based on A2 and B2 scenarios, respectively, as compared to simulated yields during 1980s.

Impacts of future climate pattern under A2 and B2 SRES scenarios on well-irrigated rice production

In addition to air temperature, solar radiation, and crop characteristics, water in the soil and plant systems is the key factor influencing simulated rice yields under well-irrigated and well-supplied nitrogen fertiliser production practice. An averaged simulated yield using simulated climate data for the baseline period of 1980-89 was 6,023 kg/ha. As compared to the 1980-89 period, rice yields during 1990-2049 decreased by 3.0-





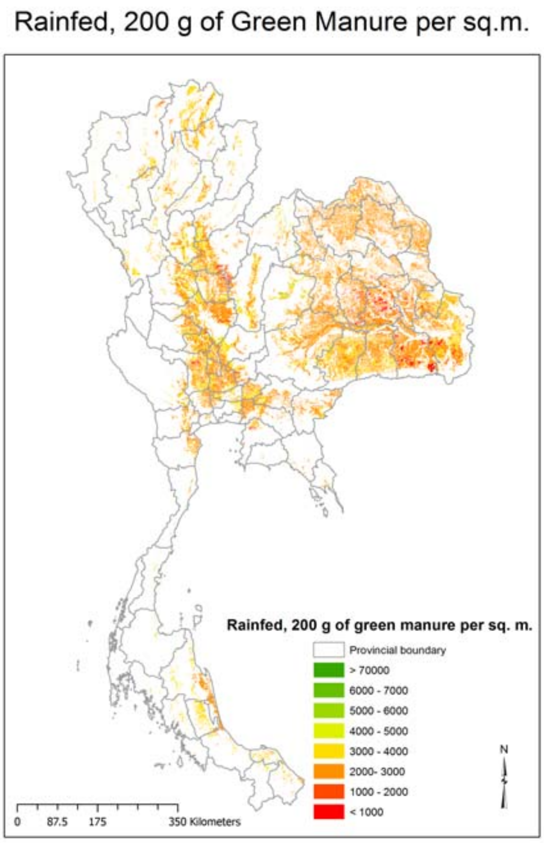


Figure 1. Distribution of simulated rice yields (kg/ha) in Thailand, under ECHAM4 A2 SRES scenario during 2010s, for three production options

7.3 and 5.1-8.0 percent from changes in climate pattern based on A2 and B2 SRES scenarios, respectively. However, rice yield reduction is seriously affected between the 2040 and 2090 period. Simulated rice yields reduction ranged from 12.4-38.5 and 10.3-26.5 percent under future climate patterns based on A2 and B2 GHG scenarios, respectively, as compared to simulated yields during 1980s.

Impacts of future climate pattern under A2 and B2 SRES scenarios on rain fed rice production

Simulated rice yields in this production scenario are further constrained by nitrogen in the soil and plant systems. An averaged simulated yield using simulated climate data for the baseline period of 1980-89 was 2,215 kg/ha. As compared to the 1980-89 period, rice yields during the 1990-2039 period under future climate pattern based on A2 SRES GHG scenario would increase by 0.8-1.7 percent and decrease by 7.5-8.5 percent under future climate pattern during 2010-2049 based on B2 SRES GHG emission scenario. However, rice yield reduction is more pronounced in the 2040-2090 period. Simulated rice yields reduction ranged from 1.1-4.0 and 7.4-8.4 percent under future climate patterns based on both A2 and B2 scenarios, respectively, as compared to simulated yields during 1980s.

In addition, we used the CropDSS shell to simulate main season rice yields during the 2010-19 period under two soil nutrient management options, namely; a) Application of 200 g of green manure per m^2 (200GM), and b) Application of 60 kg of urea per ha (60UREA) and compared with the averaged simulated rice yield (0N) of the same period to illustrate adaptive production strategies. The 60UREA production strategy produced 15% and 36% higher simulated rice yield than 200GM and 0N, respectively (Figure 1).

Discussion

The potential and well-irrigated scenarios gave averaged yields of 6,040 and 5,861 kg/ha, respectively, and were relatively higher than reported averaged national rice yields during the period 1980-2009 by the Office of Agricultural Economics (OAE, 2010) of Thailand. The averaged and standard deviation of reported rice yields during the periods 1980-89, 1990-99, and 2000-2008 were 2,024±66, 2,335±166, and 2,690±313 kg/ha, respectively. The rainfed with no nitrogen fertiliser application production scenarios yielded closer to the reported rice yields by OAE, and averaged 2,224±772 kg/ha. This is due mainly to the fact that the majority of rice fields in Thailand are under rainfed conditions and low nitrogen fertiliser applications, with the exception of the central plain of Thailand. Improving and maintaining rice production under rainfed conditions can be achieved by introducing green manure crop or adding chemical fertiliser.

Simulated rice yields decreased drastically after 2040 due mainly to increases in air temperature that result in slower crop growth rate. Future research needs to be conducted to fully develop and disseminate such new rice varieties for higher temperature environments during the reproductive phase of the crop, which is particularly prone to male sterile phenomenon and thus reduced yields. The other aspect of climate change is the increase of surface air temperature, which will reduce the total duration of the crop by inducing early flowering and maturity, thus causing shortening of the grain filling period. The shorter the crop duration, the lower the yield per unit area. A warmer atmosphere could therefore lead to reduced agricultural productivity.

Both climate and rice models were based on certain assumptions. The PRECIS-ECHAM4 climate model resolution is 20x20 km and needs a great deal of work on its prediction as influenced by increased CO_2 concentration and the tropical monsoon system. The CSM-CERES rice model assumed that weeds, insects, and disease are fully controlled by farmers during the growing season. Crop losses, which may accrue due to the occurrence of extreme events such as floods, are also not accounted for. Currently, the model does not allow for a gradual increase of gas. The current version of the DSSAT-CERES rice simulation model handles only plant and soil processes at the field level, with uniform management practices.

Conclusions

Assessing impacts of climate change scenarios by linking crop simulation models to geographic information system (GIS) databases, with its data handling capabilities and its spatial manipulation functions, makes it practical to apply the CSM-CERES-Rice model together with the PRECIS RCM-ECHAM4 GCM climate models over a large area for yield estimation of rice and other crop production systems. Climate change under SRES A2 and B2 scenarios, produced by PRECIS RCM-ECHAM4 GCM climate models, impacted rice production scenarios in Thailand in similar trends, i.e., simulated rice yields decrease with a more pronounced decrease observed after the 2040 period, assuming no policy and implementation decisions are taken to adapt to these changes.

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