Impacts of climate change on rice production in Siem Reap, Cambodia

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ABSTRACT: Rice (*Oryza sativa* L.) is one of the most important staple crops in Cambodia. Elevated CO_2 concentration and temperature associated with climate change may greatly affect rice production. This study attempts to estimate the potential impact of the climate change on rice production in Siem Reap province, one of the most important rice production regions in Cambodia. The ORYZA2000 rice growth model was used to simulate the impacts of change in temperature and CO_2 on rice yields during the rice-growing seasons for thirteen years (1998-2011). The simulation study was performed under the non-limiting conditions of nutrient and water. In addition, ORYZA2000 were employed to simulate the potential effects on rice yield grown under the various scenarios of climate change. Three major scenarios were composed as follows: the existing level of temperature and CO_2 as scenario I; change in temperature only (+2 ºC above the current level) as scenario II; and change in CO_2 concentration (+1.5 times above the existing level) and temperature (+2 ºC above the current temperature) as scenario III. We will report study results on simulation outputs according to these climate scenarios. Based on the simulated potential impacts, we assume that adaptation and mitigation strategies can be further performed and recommended to overcome the adverse effects of climate change on rice production in future.

INTRODUCTION

Rice (*Oryza sativa* L.) is consumed almost 40% of the world population as a major staple food crop. Most people who depend on rice as the primary food source live in the less developed countries. In Cambodia, rice (*Oryza sativa* L.) is the dominating crop in agriculture which contributes to around 26% of the GDP (MAFF, 2017). It is estimated that rice production, processing, and marketing employ around 3 million of the 17 million population. Paddy rice production occupies around 75% of the cultivated lands, contributing to around 15% of the total agricultural value (IFC, 2015). The cultivated areas for paddy rice in Cambodia are around 3,000 million hectares in 2016. It comprises two main seasons, i.e., wet and dry. The wet season covers around 74% of the total cultivated lands while the dry season occupies at approximately 16% (MAFF, 2017). The climate in Cambodia is hugely dependent on the arrival of seasonal monsoon rains that occur from May onwards often extending until November.

Most climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy that our planet receives. One of the most serious long-term challenges facing the world today is climate change. A sector that is most affected is agriculture since the climate is a primary determinant of agricultural productivity (Adams et al., 1998). This will consequently affect the future food supply as the food production is being directly threatened by climate change. Therefore, continuous efforts are required to mitigate such impacts on food production

(McCarl et al., 2001). To quantify climate change, understanding interactions between global carbon dioxide (CO_2) and temperature is of paramount importance. On the other hand, CO_2 influences the biomass productions of crops through changes in solar radiation use efficiency.

A crop simulation model is a suitable tool for evaluation of potential impacts of climate change on crop production (Ko et al., 2012). Also, there are many case studies that have already been carried out to understand rice productivity in a changing climate (Hatfield et al., 2011; Kim et al., 2013; Matthews et al., 1997). Some of these efforts were based on experimental field studies (e.g., Kim et al., 2011), but most have exclusively employed using crop simulation approaches (e.g., Izumi et al., 2011; Kim et al., 2013). The objective of this study was to estimate potential impacts of climate change (increases in temperature and CO_2) on rice production using the ORYZA2000 model to understand the relationship between rice production and climatic variables in Siem Reap, Cambodia.

MATERIALS AND METHODS

Study area: The study was conducted from 1998 to 2011 in Siem Reap province (103° 48ˈ N, 13° 24ˈ E; 15 m), a part of the northern rice production area in Cambodia. This area is designed as one of the permanent producing areas of rice. Siem Reap belongs to a tropical climate zone with dry and wet seasons. The dry season runs from November to April while the wet season continues from May to October. The average annual temperature in Siem Reap is 27.1 °C. About 1,312 mm of precipitation falls annually. The area receives an annual sunshine of about 2,315 h.

ORYZA2000 model: ORYZA2000 was developed by IRRI in Philippines in collaboration with Wageningen University, Netherlands. This university is an exponent of the modeling 'School of De Wit'. The basic principle of ORYZA2000 is rate calculation and state integration. The model can simulate the growth and development of lowland rice and the potential productivity under water and nitrogen limitation conditions (Bouman et al., 2001). ORYZA2000 is an updated and integration of the models of ORYZA1 for potential production, ORYZA-W for water-limited situations, and ORYZA-N for nitrogen-limited production. ORYZA2000 contains new features that allow more explicit simulation of rice management options. It can also be used in the ex-ante analysis of the effects of climate change on crop growth. In this case study, ORYZA1 was technically adopted. The model was validated with experimental data.

Data input: The data input required for simulations using ORYZA2000 included experimental data, soil conditions, and weather data. The experimental data contained information on the run mode of ORYZA2000, the site and experimental conditions for simulation practices, and observed variables. The rice data file contained all the parameter values that characterize the rice cultivars. The soil data file had all the data required to run the soil-water balance module. The daily weather data were obtained from the Siem Reap station for 14 years from 1998 to 2011.

Climate change scenarios

In this study, the ORYZA2000 model was used to simulate potential rice yields under three major climate change scenarios composed as follows: the existing level of temperature and CO_2 as scenario I; change in temperature only (+2 ºC above the current level) as scenario II; and change in CO_2 concentration (+1.5 times above the existing level) and temperature (+2 ºC above the current temperature) as scenario III. For each of the rice-growing regions, potential yields of rice were simulated under 30 different combinations of CO_2 and temperature, including those with the 'fixed increments' in CO_2 (340 and 530 ppm) and temperature (ambient, +1.5 ºC, and +2 ºC) individually and all the combinations of these levels of CO_2 and temperature. The actual daily weather data collected for fourteen consecutive years from each of these sites were used for simulation. Table 1 shows the annual average values of the temperatures.

Table 1: Annual average values of minimum, maximum, and mean temperatures

Year	Temperature		
	Minimum	Maximum	Mean
1998	24.60	34.00	29.30
1999	23.40	32.50	27.95
2000	23.40	32.90	28.15
2001	23.70	33.20	28.45
2002	23.70	32.90	28.30
2003	23.70	32.70	28.20
2004	23.80	33.20	28.50
2005	23.90	33.00	28.45
2006	20.50	32.70	26.60
2007	23.50	32.60	28.05
2008	23.60	32.30	27.95
2009	23.80	32.60	28.20
2010	24.60	34.10	29.35
2011	23.50	32.10	27.80

RESULTS AND DISCUSSION

Scenario I: Atmospheric CO_2 concentration was considered as the main climate factor and the other environmental factors were assumed to be constant, which include management practices and water and soil conditions. Major climate factors affecting rice yield include light, temperature, and CO_2. Limiting factors are fertilizers and H_2O, other abiotic and biotic factors being considered as reducers. All of them can have profound effects on rice yield, but in this model, only temperature and CO_2 have been deliberated under the best management practice. Table 2 presents the observed actual yields in comparison with simulated rice yields under the current mean temperature and CO_2 concentration with the potential best management practice, using ORYZA 2000 for years 1998-2011.

Scenario 2 (Effects of increase in temperature on potential rice yield): The model predicted that rice yield would decline with an increase in temperature by +2 ºC (Table 3). This result is supported by Furuya and Koyama (2005). It is assumed that high temperature accelerates heading and delays flowing while low temperature delays heading. Elevated temperature can cause increased plant growth rate and decreased growth duration leading to shorter grain filling period (Streck, 2005).

Scenario 3 (Effects of increase in temperature and CO_2 on potential yield): Table 4 shows a negative effect on rice yield with increases at 2 ºC above the current temperature and at +1.5 times of the current CO_2 level (530 ppm). Substantial reduction in rice yield as a result of increased temperature will not usually be compensated by an increased level of CO_2. Increase in the CO_2 concentration will increase yield while elevated temperature will reduce yield (Matthews et al., 1997). The results of the current study corroborated with those reported by Singh et al. (1996) and Krishnan et al. (2007). Increased CO_2 and higher temperatures have the effect on both photosynthesis and growth of crops. Based on the present simulation result on predicting rice yield under different scenarios, it is clear that temperature is one of the most dominant climatic factors, which may affect rice yield significantly in future.

Table 2: Simulated yields with the potential best management practice compared with the observed actual yields.

Year	Simulate yield (Kg ha^{-1})	Observed yield (Kg ha^{-1})
1998	7905.6	2340
1999	7205.7	2500
2000	8218.6	2900
2001	7297.9	2500
2002	7244.1	2496
2003	7479.0	2135
2004	7189.5	3005
2005	7545.5	3241
2006	7793.8	3530
2007	7058.0	3237
2008	8573.6	3800
2009	8426.2	3862
2010	8138.7	3899
2011	8477.4	3894

Table 3: Effect of 2°C increase in temperature on yield

	Yield (Kg ha^{-1})													
Average temperature ^{0}C	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
30	7905.6	7205.7	8218.6	7297.9	7244.1	7479	7189.5	7545.5	7793.8	7058	8573.6	8426.2	8138.7	8138.7
32	6202.5	6222.4	6812.1	6114.3	6911.5	6676.8	6528.7	6419.9	6824.2	6006	7541.3	7159.6	7345.5	7419.3

Note CO_2 = 340 ppm

Table 4: Comparison of yields with increase in temperature and CO_2 concentration with those at the base level

	Yield (Kg ha^{-1})													
Temperature and CO_2	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
30°C and 340 ppm	7905.6	7205.7	8218.6	7297.9	7244.1	7479	7189.5	7545.5	7793.8	7058	8573.6	8426.2	8138.7	8138.7
32°C and 530 ppm	6583.5	6222.4	7294.8	6664.6	7650	7320.4	7095.5	6972.7	7493.5	6649.3	8274.5	7873.5	8063.2	8170.2

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