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The Economic Impacts of Climate Change on the Rice Production in Malaysia

N. Vaghefi, M. Nasir Shamsudin, A. Makmom and M. Bagheri
Faculty of Environmental Studies, University Putra Malaysia, 43400 UPM Serdang, Malaysia

Corresponding Author: Mad Nasir Shamsudin, Faculty of Environmental Studies, Universiti Putra Malaysia, 43400 UPM Serdang, Malaysia Tel: 00603-89464170 Fax: 00603-89464151

ABSTRACT

This study attempts to estimate the potential impacts of climate change on the rice production in Malaysia. The crop model ORYZA 2000 was used to simulate rice yield of MR 219 variety in eight granary areas of Malaysia from 1999-2007. The model predicted a reduction in rice yield of 0.36 t ha^{-1} under the scenario of an increase in temperature by 2°C and at the current CO_2 level of 383 ppm. With the reduction in rice yield, the economic loss to the Malaysian rice industry was estimated at RM162.531 million per year. Under the scenario of increase of CO_2 concentration from 383 to 574 ppm and with 2°C rise in temperature, it can be predicted that there will also be a decline in rice yield by 0.69 t ha^{-1} and consequently the economic loss will be at RM299.145 million per year for the rice industry. With the above potential impacts, some adaptation and mitigation strategies to overcome the adverse effects of climate change on rice production were recommended.

Key words: Economic impacts, climate change, carbon dioxide, temperature, rice production

INTRODUCTION

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. However, an attempt to reduce Green House Gas emission is likely to mitigate such impacts on food production (McCarl *et al.*, 2001).

The climatic variability and the predicted climatic changes are of major concerns to the crop scientists (Krishnan *et al.*, 2007). Aggarwal (2003) noted that among the global atmospheric changes, the increasing concentrations of greenhouse gases such as CO_2 may have profound effect on rice productivity, due to increase in both the average surface temperature and the amount of CO_2 available for photosynthesis.

Simulation analyses by using different models and field experiments have shown that the potential impacts of climatic change on the variability of rice productivity (Baker *et al.*, 1990; Peng *et al.*, 2004; Kim *et al.*, 2003). Studies have shown that the net effect of doubling of CO_2 has increased in the rice yield (Kim *et al.*, 2003). Similarly Sheehy *et al.* (2006) found that increasing CO_2 concentration in the atmosphere has a positive effect on crop biomass production, but its net effect on rice yield depends on the rising of the temperature. For every 75 ppm increase in CO_2 concentration, rice yields will increase by 0.5 t ha^{-1}. However, the yield will decrease by

0.6 t ha^{-1} for every 1°C increase in temperature. Thus an assessment of the potential impacts of interactive changes of CO_2 and temperature is crucial to determine the future of agricultural strategies maintaining higher rice productivity.

Rice (*Oryza sativa* L.), the basic food of Malaysia, is the most important source of employment and income of the rural population. Currently, the self-sufficiency level of rice is about 75%. Thus, there is growing concerns that the global warming would affect the productivity of rice crop (Tao *et al*., 2008). This study, therefore, attempts to determine the potential economic impacts of climate change, namely changes in CO_2 and temperature, on the rice yield and economy of Malaysia.

MATERIALS AND METHODS

Study areas: The study was conducted at eight granary areas in Malaysia, namely, MADA, KADA, Kerian, Barat laut, Seberang Perak, Ketara and Kemasin in 2008-2009 (Fig. 1). They are designated as permanent rice producing areas, fulfilling 75% of the rice demands of the country (Lee *et al*., 2004). In 2008, these granary areas covered 36% of the total physical rice areas, but constituted 57% of the total area planted and contributed 72% of the total national rice production.

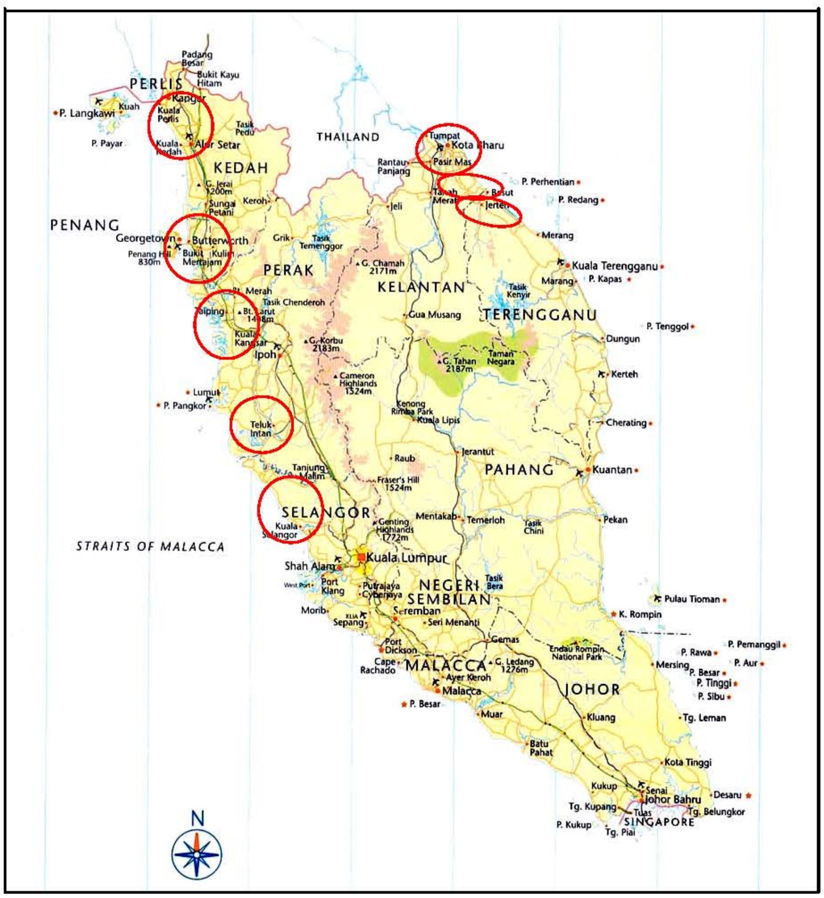

Fig. 1: The eight granary areas in Malaysia

Malaysia characteristically experiences heavy rainfall (above 2,540 mm per annum), average daily temperatures of 21-32°C and a humidity averaging about 85%. The seasonal variation in solar radiation is low, resulting in an annual difference in day length of only 2 min along the equator and 49 min in northern regions. In consequence, there is a year round day length of 12.5 h.

ORYZA 2000 model: The ORYZA 2000 crop growth model was used to simulate the effect of temperature and CO_2 on growth and yield of rice in a situation where nutrient and water were assumed to be non-limiting. In this model we used of MR-219 variety as high yielding rice variety. MR-219 is the most common rice variety planted by Malaysian rice growers (Suswanto *et al*., 2007).

ORYZA2000 is a crop model to simulate the growth, development and water balance of rice under conditions of potential production, water and nitrogen limitations. ORYZA2000 contains new features that allow a more explicit simulation of crop management options. It can also be used in the ex-ante analysis of the effects of climate change on crop growth. ORYZA2000 is an updated and integration of the models ORYZA1 for potential production, ORYZA-W for water-limited situations and ORYZA-N for nitrogen-limited production. In this study ORYZA1 crop growth model was used. The model was validated with experimental data for variety MR-219, with the application of 240 kg N ha^{-1}. In this study ORYZA1 model was used to simulate the potential rice yields under three scenarios; they are scenario 1 was the situation at the existing level of temperature and $CO_{2;}$, scenario 2 was with the changes of temperature only (+2°C above current level); and scenario 3 was with changes in CO_2 (1.5 times of the existing level) and temperature (+2°C above current temperature).

Data input: The data input required for the simulations by using the ORYZA 2000 crop growth model included; experimental data, crop production data, soil condition and weather data. The experimental data contains information on the run modes of ORYZA 2000, the site and experimental conditions of the simulation run and any observed variables. The crop data file contains all the parameter values that characterize the rice crop. The soil data file contains all data to run the soil-water balance module. The daily weather data was taken from Petaling Jaya station for nine years (1999-2007).

RESULTS

Scenario 1: Simulation under current level of ambient temperature and CO_2: In this study average temperature (Table 1) and atmospheric CO_2 concentration are considered as the major climate factors. The other factors, such as management practice, technology, water, air pollution and soil, that have also effect on rice yield, were assumed to be constant. According to this relationship:

- Yield = f (climate, technology, management, land)

Climate factors include temperature and CO_2. Technology and management are considered as systematic factors under the control of producers and land represents soil conditions. There are determinant, limiter and reducer factor in this equation. Determinant factors are such as light, temperature and CO_2. Limiter factors are fertilizer and H_2O and reducers are biotic and abiotic. All of them can have profound effect on the rice yield, but in this model, only temperature and CO_2 have been considered under the best management practice and other conditions.

Simulation results of the potential production of MR-219 variety rice plant under the current temperature (27°C) and CO_2 (383 ppm) by using ORYZA 2000 model for the duration of 1999-2007 are presented in Table 2.

Scenario 2: Effect of increase in temperature on potential yield: The predicted changes in yield under the 2°C increase in temperature and at current CO_2 level (383 ppm) are shown in Table 3. The results indicate that rice yield would decline with increase of temperature at 2°C.

Scenario 3: Effect of increase in temperature and CO_2 on potential yield: Table 4 shows the predicted changes in yield with increased 2°C above the current temperature level and 1.5 times increased CO_2 concentration than the existing concentration. Studies found that with increase

Table 1: Average minimum, maximum and mean temperature

	Temperature (°C)		
Year	Minimum	Maximum	Mean
1997	24.24	33.11	27.64
1998	25.03	34.43	28.57
1999	24.47	32.47	27.62
2000	24.88	32.75	27.88
2001	24.11	32.80	27.60
2002	22.91	33.38	28.10
2003	24.60	32.80	27.80
2004	24.43	33.14	28.00
2005	24.70	32.95	28.10
2006	24.37	32.38	27.40
2007	24.28	31.78	27.30

Source: Petaling jaya meteorological station

Table 2: Simulated, observed and actual yield within the best management practices

Year	Simulated yield (kg ha^{-1})	Observed* yield (kg ha^{-1})	Actual yield (kg ha^{-1})
1999	9658.8	3696	3960.108
2000	9690.6	3749	3973.146
2001	9585.8	3833	3930.178
2002	9297.8	3904	3812.098
2003	9503.6	4106	3896.476
2004	9532.9	4051	3908.489
2005	9077.4	4132	3721.734
2006	9834.9	3771	4032.309
2007	9921.6	4207	4067.856

*Source: Department of Agriculture, Malaysia

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

	Yield (kg ha^{-1})								
Average temperature (°C)	1999	2000	2001	2002	2003	2004	2005	2006	2007
27	9658.8	9690.6	9585.8	9297.8	9503.6	9532.9	9077.4	9834.9	9921.6
29	9376.5	9403.1	8717.8	7847.2	9048	6840.2	8038.9	9369.1	9579.2

Note: CO_2 = 383 ppm

in atmospheric CO_2 concentration, could produce beneficial effects in grain production, photosynthetic rates and decrease in stomata conductance and transpiration rates (Olszyk and Ingram, 1993). However, in this study, increasing both the temperature and CO_2 level would have profound negative effects on the rice yield.

Economic impacts of climate change: Increasing the temperature by 2°C would decrease the rice yield by 0.359 t ha^{-1}. By multiplying the yield loss by the planted area for each year, the estimated average production loss from 1999 to 2007 would be 147,755 metric tone (Table 5). With the average price of rice of RM1.10, the average of economic loss for the second scenario is estimated to be RM162.531 million per year. Under third scenario (increasing both temperature 2°C and CO_2 574 ppm), the average of yield loss would be 0.689 t ha^{-1} and the economic loss would be RM299.145 million per year (Table 6).

Table 4: Comparison of yield (kg ha^{-1}) with increased in temperature and CO_2 concentration and base level

	Yield (kg ha^{-1})								
Temperature and CO_2	1999	2000	2001	2002	2003	2004	2005	2006	2007
27°C and 383 ppm	9658.8	9690.6	9585.8	9297.8	9503.6	9532.9	9077.4	9834.9	9921.6
29°C and 574 ppm	8543.7	8576.4	7716.7	6946.8	8168.8	6061.5	7247.1	8519.4	8731.3

Table 5: Economic loss in the second scenario

Year	Actual yield	Predicted yield (t ha^{-1})	Yield loss	Planted area (ha)	Production loss (metric tone)	Economic loss (RM)
1999	3.960	3.844	0.116	394,076	45,712.8	50,284.09
2000	3.973	3.855	0.118	391,012	46,139.4	50,753.35
2001	3.930	3.573	0.357	375,116	230,321.2	253,353.32
2002	3.812	3.217	0.595	382,355	22,7501.2	350,251.30
2003	3.896	3.709	0.187	381,310	71,304.9	78,435.46
2004	3.908	2.804	1.104	377,794	417,084.5	458,793.03
2005	3.721	3.295	0.426	384,112	16,3631.7	179,994.88
2006	4.032	3.841	0.191	387,312	73,976.5	81,374.25
2007	4.067	3.927	0.140	386,592	54,122.8	59,535.16

Average = 162,530.53

Table 6: Economic loss in the third scenario

Year	Actual yield	Predicted yield (t ha^{-1})	Yield loss	Planted area (ha)	Production loss (metric tone)	Economic loss (RM)
1999	3.960	3.502	0.458	394,076	180,486.8	198,535.48
2000	3.973	3.516	0.457	391,012	178,692.5	196,561.76
2001	3.930	3.163	0.614	375,116	287,713.9	316,485.29
2002	3.812	2.848	0.964	382,355	368,590.9	405,449.99
2003	3.896	3.349	0.547	381,310	208,576.8	229,434.26
2004	3.908	2.485	1.423	377,794	537,600.9	591,360.99
2005	3.721	2.971	0.750	384,112	288,084.0	316,892.40
2006	4.032	3.492	0.504	387,312	209,148.4	230,063.24
2007	4.067	3.579	0.488	386,592	188,656.8	207,522.58

Average = 299,145.10

DISCUSSION

Results have indicated that the increase in temperature by 2°C at the current level of CO_2 concentration, the rice yield would be declined. Such finding corresponds to the findings of Furuya and Koyama (2005). Temperature affects both the photoperiod-sensitive and photoperiod-insensitive cultivars (Alagarswamy *et al*., 1998). Generally, high temperature accelerates heading and low temperature delays heading. Moreover high temperature delays flowering. Increased temperature can cause increased plant growth rate and decreased growth duration leading to shorter grain filling period (Streck, 2005).

On the other hand, increasing atmospheric CO_2 concentration could only have beneficial effects on rice production. Potentially great negative effects are also possible, if maximum daily atmospheric temperatures also rise. With increasing temperatures at higher CO_2 levels the decline in rice production will be much higher. Substantial reduction in rice yield as a result of increased temperature will not usually compensated by increased level of CO_2. Matthews *et al*. (1997) reported that increase in CO_2 level will increase yields and while increment in temperature will reduce yields. The results of this study are consistent with the findings of Resenzweig and Hillel (1995), Singh *et al*. (1996), Timsina and Humphreys (2006) and Krishnan *et al*. (2007). Increased CO_2 and higher temperatures have a negative effect on both photosynthesis and growth of crops. Thus, it seems that there is interactive effect of CO_2 and temperature on rice yield.

Results showed that if temperature increases by 2°C and also the level of carbon dioxide increases to 574 ppm, the economic loss will be very high and it will effect on the market price of rice. Crops that decline in supply will rise in price. Higher prices reduce consumption levels and adversely affect on consumer welfare. Thus, future food supply may be directly threatened by the scenario of climate change.

Adaptation and mitigation strategies: The Malaysian rice industry is highly regulated. Adaptation strategies could help mitigate the impact of climate change on the world's poor. Designating paddy producing areas is one of the major strategies whereby the eight granary areas are designated as permanent paddy producing areas, to realise a minimum self-sufficiency level for rice of 65% (FAO, 2005).

Another strategy is the identification of suitable areas for large-scale commercial paddy production by the private sector. Selection for varieties with a higher tolerance of spikelet fertility to temperature was shown to be capable of restoring yield levels to those predicted for current climates. Breeding for new cultivars Varieties that are tolerant to higher temperatures likely to be encountered under the changed climatic scenario, possibly through genetic engineering (Singh *et al*., 1996). Varieties with improved tolerance to heat or drought, or adapted to take advantage of a longer growing season for increased yield, will be available for some crop species. Changing varieties, like changing planting date, is a first line of defence for farmers to consider (Wolfe *et al*., 2008).

Among farmer adaptation options, changing planting and/or harvest date can be an effective, low-cost option to take advantage of a longer growing season or to avoid crop exposure to adverse climate (e.g., high temperature stress, low rainfall) (Wolfe *et al*., 2008). The use of longer-maturing varieties to take advantage of longer growing seasons at higher latitudes may instead result in lower yields, due to the grain formation and ripening periods being pushed to less favorable conditions later in the season. A better strategy might be to select for shorter-maturing varieties to allow a second crop to be grown in these regions (Matthews *et al*., 1997).

Management practice is one of the important strategies to overcome the adverse effects of climate change on rice production (Matthews *et al*., 1997). Agronomic practices such as fertilizer application, weed control, pest and disease management need to be adjusted under the changed climate (Singh *et al*., 1996). Warmer temperatures, longer growing seasons and increased drought will lead to increase agricultural water use. Water storage facilities should be expanded and managed more efficiently. Controlled supply of irrigation water could avoid oversupply at critical stages.

Controlling emissions and concentration can be one of the most important mitigation strategies, such as controlling emission of greenhouse gases and/or enhancing carbon sinks, alter fertilizer application, lower use of herbicide and pesticide sprays, reduces fuel requirements and use of conservation tillage on herbicide tolerant plants. There are some innovative approaches for reducing emissions which can succeed to capture significant amounts of carbon and other greenhouse gases from the atmosphere; therefore it can mitigate the future climate change.

CONCLUSIONS

This study attempted to investigate the economic impacts of climate change (changes in temperature and CO_2) on the rice economy of Malaysia. The methodology involved pooling data on crop yields and climate and non-climate related variables which were used to simulate the impact of changes in temperature and CO_2 on rice yield. ORYZA 2000 model was employed to simulate the potential effects on rice yield under various scenarios of changes in temperature and CO_2 levels. The results indicated that there would be negative effects on rice yield and hence production and farm income as well as the future food supply. Thus policies on mitigation need to be formulated and adaptive farm practices need to be adopted to overcome the adverse affects of climate change to ensure sustainable farm income and self-sufficiency level.

Policies on rice production are closely associated with poverty alleviation and priorities for sectoral growth. Some adaptation and mitigation strategies to overcome the adverse effects of climate change on rice production are recommended.

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