International Journal of the Physical Sciences Vol. 6(7), pp. 1742-1748, 4 April, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.028
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Climate change impacts: Prioritizing mechanism and needs for future Malaysian agriculture

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Accepted 18 February, 2011

This paper empirically explored climate change, its related impact on rice agriculture and proper policy-related strategies and mechanism. Our current assessment provided the expected climate change impact based on observational records of inter-annual variability in precipitation and warming climatic factors up to the year 2080. In this study, an analysis of the impact due to climate change and vulnerabilities is performed using Global Circulation Models together with Crop Modelling to represent a range of plausible climate scenarios. The approach used follows a bottom-up strategy, focusing on the vulnerability of Malaysian rice agriculture under various climatic conditions and gives a wide range of potential climate outcomes for rice agriculture in Malaysia. Our projections generated likely future changes and uncertainties on rice production, the potential path for planning strategies and, finally, prioritizing requirements and influences in investment decisions to reduce vulnerabilities. The data is discussed and can be used for climate-related agriculture policies in Malaysia and elsewhere.

Key words: Climate change, rice agriculture, long-term scenario analysis, prioritizing mechanism and decision, policy strategy.

INTRODUCTION

Climate change presents a significant risk to people. The scientific evidence is now irrefutable (Naomi, 2004). The range of time scales, consequences, perspectives and methods of addressing these issues are still open for dispute, but scientists publicly agree that human-based greenhouse gas emissions and the changing patterns of climate factors adversely affecting the social, economical and environmental agents are a serious problem facing the world now. Reference is made to a recent publication by IPCC (IPCC, 2007). Developing countries will be hit first and foremost by climate change, though they have contributed little to causing the problem (Nicholas, 2007). The direct impact of climate change including loss of life, destruction of resources, infrastructure and livelihoods are well evident in literature and Malaysia is not an exception. Over the decades, Malaysia has experienced rapid climate change which is apparent in meteorological scenarios published by NAHRIM (2006). Temperature is projected to rise in Malaysia and the surrounding sub-tropical regions by 0.3 to 4.5°C in the next 50 years (NAHRIM, 2006; NRS, 2001). The initial simulated results

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Abbreviations: EDMs, Empirical downscaling models; **LESTARI,** Institute for Environment and Development (dialect); **NAHRIM,** National Hydraulic Research Institute of Malaysia**;** **NRS,** National response strategies. **SSL,** Self-sufficiency level.

indicate both an increase and decrease in rainfall (±30%) but would be temperate that are well obvious (NAHRIM, 2006). Lobell et al. (2008) also estimated that climate change may result in a drop of 30% in the main crop, maize, by 2030 in Southern Africa, and South East Asia (that is, Malaysia) may lose around 10% of many regional staples such as rice, millet, groundnut, rapeseed, wheat and soybean. However, Malaysian grain production has been at risk due to climate variability (increase and decrease in rainfall by ±30%), temperature fluctuations and a fall in efficiency. The climatic effect on pests together with the impact of other factors caused agricultural syndrome outbreaks, such as a decrease in agricultural productivity, increase in food chain uncertainty, and areas vulnerable to drought may become marginal for the cultivation of some crops such as rubber, oil palm, cocoa or rice, thus posing a threat to national food security and export earnings (NRS, 2001; Al-Amin et al., 2010). The impact on agriculture, especially on rice and grain production, has been subjected to many scientific research projects during the last two decades (Tilman et al., 2002; Ching-Cheng, 2005; Ahmed et al., 2010). Generally, the average potential yield of rice varies from about 10 tons ha^{-1} in the tropics and over 13 tons ha^{-1} in temperate regions, but actual farm yields in Malaysia vary from 3 to 5 ton ha^{-1}(NRS, 2001).

MMD (2009) estimated that the average temperature in Malaysia (that is, 26°C) may become warmer by the end of the century and a substantial amplification of climate change would occur in Malaysia. Considerable studies have been undertaken in Malaysia recently to simulate climate change issues and vulnerabilities. Pioneer studies have been carried out by the Malaysian Meteorological Department (MMD), National Hydraulic Research Institute of Malaysia (NAHRIM) and Institute for Environment and Development (LESTARI). Based on three emission scenarios, using global circulation modelling (GCM) designated by MMD, projecting the range of highest temperature increase within 2.3 to 3.6ºC for Peninsular Malaysia and 2.4 to 3.7ºC for East Malaysia (MMD, 2009). Similar references and scenarios (that is, 3 to 4ºC) are revealed earlier by NAHRIM (2006) and projected possible vulnerable regions up to the year 2050. The scientific evidence compiled by the IPCC in its series of assessment reports together with the Stern Review's study looking at the economic impact of climate change brought Malaysians to rethink the stark reality that climate change, if left unchecked, poses a significant danger in the future.

Therefore, climate change impact on rice agriculture and awareness of policies for implementation are frequently voiced in Malaysian mainstream climate policies. However, specific operational findings and empirical analysis on rice agriculture are still lacking institutionally. Relevant policies adapted to the framework to contribute in shaping nationally appropriate policies which are in fact absent in Malaysia. Long-term agricultural policies require a feasible structure which is therefore employed in our study. As we know that climate change is real and current, its impact is well evident, we must therefore try to investigate possible planning strategies for investment choices to reduce vulnerabilities and finally prioritize requirements and influences in investment decisions, particularly with rice agriculture. Our projections signify possible future changes in rice agriculture and uncertainties as regards coping with doubts on climate uncertainty and vulnerability.

MATERIALS AND METHODS

This study focuses on analyzing environmental changes on agriculture, based on the context of future risks of climate change on the production process using regional resources. Understanding the magnitudes of temperature and seasonality of rainfall on agricultural production, we have created a link between climate change issues and their impact on rice agriculture. Due to the complex interaction between climate change and climate variability to the regional agriculture level, our assessment study has involved the use of computer simulations based on Global Circulation Models (GCMs) together with Crop Modelling (Tsuji et al., 1994). Our assessment represents a range of plausible climate scenarios for Malaysia from the year 2020 to 2080. We follow the bottom-up approach[1], focusing on the vulnerability of Malaysian rice agriculture given a wide range of potential climate outcomes, rather than on a specific climate forecast on a global level. As a result of some constraints of GCMs[2], we developed an empirical downscaling model (EDMs) and genotype coefficient (between 20 and 40°C) to observe large-scale vulnerability for Malaysia up to the year 2080. We have constructed the EDM by applying maximum covariance analysis to the (a) predictor annual cycle observed large-scale circulations fields (west and East Malaysia) and (b) predicted annual cycle of observed regional precipitation. We then comprise the monthly averaged circulation variables as predictor and monthly average rainfall as predicted. We assumed that changes in large-scale circulation variables due to greenhouse gases project into predictor modes that account for precipitation. This variable accounts for possible changes in the hydrological cycle as a result of mean warming climatic cycle. Our predictor modes in EDMs captured the annual cycle of local precipitation. The detailed findings and forecasting of predictor and predicted recently published by MMD (2009). In our analysis, all large-scale predictor data were taken from the Malaysian Meteorological Department (MMD), National Hydraulic Research Institute of Malaysia (NAHRIM). However, there are some modifications of their data in our modelling exercise to fulfil our scope of studies.

To capture the long-term temperature and rainfall effects, we utilized an annual cycle of local temperature latitude 7°0' N and longitude 120°0' E with a standard elevation setup by MMD (2009) beginning from 2020 to 2080 (Figure 1). Likewise, an annual cycle of local rainfall Latitude 8°0' N and longitude 120°0' E was analyzed

[1]Bottom-up approach indicates individual countries tackling climate change issues and then aggregating them to measure the global change.

[2]Empirical downscaling is one commonly used approach for regional computational difficulties which encompasses not only linear statistical techniques, but also neural nets and analogue methods.

Typically, one identifies a statistical relationship between fields that are believed to be well represented by reanalysis and observed values of the local variable of interest, and then uses this relationship to provide an 'improved' prediction of the local variables.

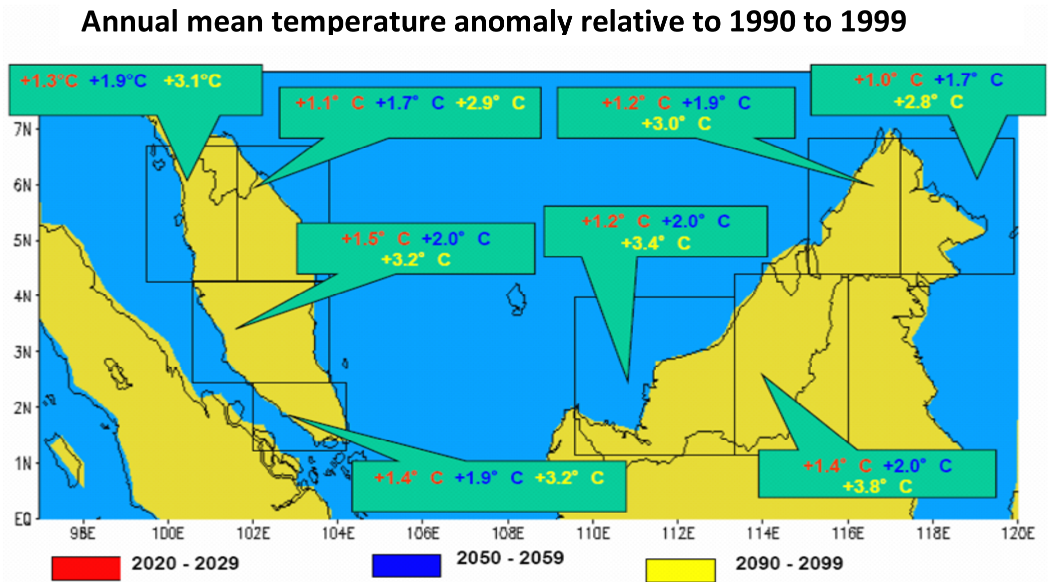

Figure 1. Projected temperature in Malaysia up to 2099. Source: MMD (2009)

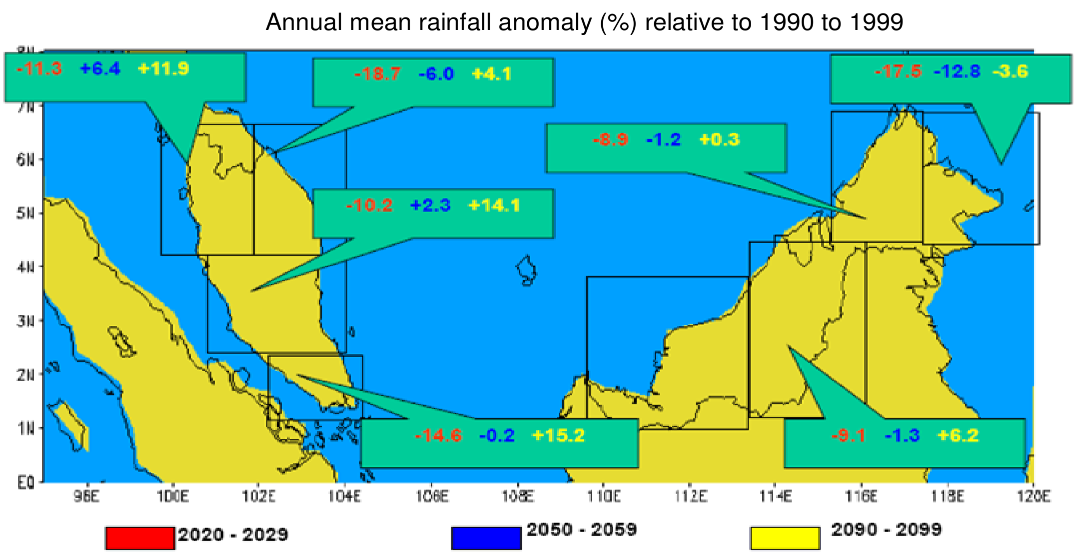

Figure 2. Projected rainfalls in Malaysia up to 2099. Source: MMD (2009).

with identical elevation by MMD (2009) beginning from 2020 to 2080 and from 2020 to 2050 by NAHRIM (Figure 2). The experimental fields were located both in east and West Malaysia. Malaysian Meteorological Department (MMD, 2009) analyzed Regional Climate Model (PRECIS) for only long-term temperature and rainfall scenarios and National Hydraulic Research Institute of Malaysia (NAHRIM, 2006) involved in Regional Climate Model (REG-HCM-PM) for simply medium-term temperature and rainfall scenarios. We additionally estimated vulnerability to rice production given a wide range of possible climate change outcomes. Therefore, we relied on GSMs followed by bottom-up approach of EDMs and genotype coefficient (between 20 and 40℃) together with MMD and NAHRIM projections.

Our EDMs provide efficient regional projections by using output from GCMs where large-scale precipitation and large-scale atmospheric climatic variables are reliably simulated by GCMs. Precipitation variations derived from historical records are superimposed on the annual cycle of precipitation and then we apply EDMs to project changes in the large-scale variation forces by following different concentrations of greenhouse (CO_2/ppm 400-800[3]) gases to produce approximations of Malaysian vulnerability to climate change. This approach enables us to build a rough

[3] ppm-parts per million

Table 1. Projected rice yields (kg/ha/year) for short to long-run climate variations.

Year 2020				Year 2040				Year 2080			
CO_2 (ppm)	400	400	400	CO_2 (ppm)	600	600	600	CO_2 (ppm)	800	800	800
V rainfall (%)	V temp (℃)			V rainfall (%)	V temp (℃)			V rainfall (%)	V temp (℃)		
	0.30	0.80	1.40		0.40	1.40	2.40		0.60	2.00	3.40
0	7,202	6,860	6,642	0	9,042	8,642	8,242	0	11,017	10,454	9,690
14	6,156	5,801	5,586	23	7,342	6,942	6,542	32	8,662	8,099	7,536
7	6,646	6,301	6,086	11	8,200	7,800	7,400	15	9,883	9,320	8,758
-7	6,698	6,380	6,177	-11	8,047	7,691	7,335	-15	9,365	8,886	8,408
-14	6,194	5,900	5,712	-23	6,962	6,654	6,346	-32	7,491	7,108	6,726

Source: Authors assessments following on NRS (2001) studies.

Table 2. Earning impacts (RM/year)* of rice production.

Year 2020				Year 2040				Year 2080			
CO_2 (ppm)	400	400	400	CO_2 (ppm)	600	600	600	CO_2 (ppm)	800	800	800
V rainfall (%)	V temp (℃)			V rainfall (%)	V temp (℃)			V rainfall (%)	V temp (℃)		
	0.30	0.80	1.40		0.40	1.40	2.40		0.60	2.00	3.40
0	0	0	0	**0**	0	0	0	**0**	0	0	0
14	-415.7	-414.2	-415.7	23	-669.1	-669.1	-669.1	**32**	-926.711	-926.711	-926.711
7	-218.9	-218.1	-218.9	11	-331.4	-331.4	-331.4	**15**	-446.12	-446.12	-446.12
-7	-198.4	-188.2	-168.0	-11	-391.6	-374.3	-357.0	**-15**	-650.235	-617.07	-583.805
-14	-396.8	-376.7	-366.0	-23	-818.6	-782.4	-746.2	**-32**	-1387.5	-1330.32	-1245.5

Source: Authors simulations; *Standard grade of rice price= RM 110.00/100kg, and normal grade = RM 100/100 kg.

distribution of possible future outcomes for the annual cycle of precipitation and variability of climatic factors over East and Peninsular Malaysia.

More detailed modelling, related mathematical approaches and explanations can be found in the supplementary materials on Lobell et al. (2008), Tilman et al. (2002) and Gunther et al. (2005). Our modelling helps us to quantify the likelihood of exceeding thresholds for agriculture up to the year 2080. The threshold here indicates a point beyond the institutional and socioeconomic system affected by or fundamentally changed in response to climate change issues. Without knowing the institutional and socioeconomic system affected by or fundamentally changed in response to climate change, it not possible to find out how alternative options would be altered by climate change issues. Our threshold variables were developed by (a) identifying climate variables with clear effects on rice productivity, (b) determining the probability of unexpected climatic shocks under current and future (that is, year 2080) climate conditions. The selection of threshold level and climate variables was facilitated by the MMD (2009) study.

Our Global Circulation Models (GCMs) together with a Crop Modelling, Decision Support System for Agrotechnology Transfer (DSSAT) framework synthesizes essential components and the potentiality of crop production and uses detailed agronomic-based knowledge, options and future investment decision potentials. Together with the probability, we have chosen three different scenarios (between 0.3 and 0.8℃ of temperature and under the 400 to 800 CO_2 (ppm) concentration with certain levels of rainfall fluctuation) to quantify the full range of future climate-related vulnerability with different climatic patterns. Our EDMs receive the same weights as GCMs in the assessment results for projected scenarios and quantify the regional scale impact for Malaysia over the next 60 years from 2020 to 2080.

RESULTS

Following our methods and approaches, the likely distributions of scenario figures are presented in Tables 1 and 2. We assessed likely future changes between 2020 and 2080 on rice production based on temperature, rainfall fluctuations and related CO_2 (ppm) concentrations. The combination of GCMs and EDMs present a clear impact of rice yields under 400 to 800 CO_2 (ppm) concentration with certain levels of rainfall. We synthesized 30 years of data from 1970 to 2000 on temperature, precipitation and CO_2 concentrations to forecast yields for the period 2020 to 2080. The figures in Table 2 reveal a significant relationship between climate change and rice yields (kg/ha/yr). Here, together with GCMs and EDMs, we applied a simple model for a 60-year period following climate change impacts and possible improved management option as:

$$\Delta Yield = m + y_m \Delta CChange + \varepsilon$$

where $\Delta yield$ is the observed trend in yield;

$\Delta CChange$ is the observed trend in temperature, precipitation, and CO_2 concentration; y_m is the proper management option; *m* is the average yield change with current management option and other non-climatic factors; and ε is the indication of statistical errors.

The results specifically indicate that temperature fluctuations between 0.3 and 1.4°C (Table 1), a variation of CO_2 between 400 and 800 ppm and rainfall fluctuations between -32 and +14% reduce Malaysian rice production. Without extra management options (y_m), rice yield trends are significantly correlated (P <0.01) with observed temperature trends for the period between 2020 and 2080. Our findings indicate that rather than rainfall fluctuations (from -32 to +14%), carbon concentration is playing a significant role on rice yields. Rice yields may decline between 4.6 and 6.1% for every 1°C rise in temperature (from the mean level: >26°C) under the present CO_2 concentration level, but a doubling in CO_2 concentration from 400 to 800 ppm will offset the detrimental effect of a temperature increase on rice production. The findings are not paradoxical; these impacts offset the detrimental effects of doubling CO_2 concentrations. The reasons are straightforward from a biophysical perspective. A study by Kim et al. (2001) also found that current climate change scenarios under different temperatures above 25°C, cause food grain yield to decline by as much as 10% for every 1°C rise in temperature (>26°C). The combination of GCMs and EDMs used in the analysis represents similar scenarios as in Kim et al. (2001). As temperature is projected to increase by 3.4°C, rice production may decline by 6% up to the year 2080 if there is no extra management (y_m) input option. Consequently, higher agricultural productivity or investment is required in order to sufficiently raise production to offset the negative impact. We firstly utilized NRS[4] (2001) on projected rice yields (kg/ha/year) for the year 2020 and then extended up to 2080.

A variation in temperature of 0.3°C and rainfall variation of ±14% will also cause a negative change in earnings up to RM415.7 /year ($US1= RM3.1). Similarly, a variation in temperature of 0.6°C and rainfall variation of ±32% will cause a negative change in earnings up to RM1245.5/year. Our results indicate that moderate rainfall fluctuations of ±14% and carbon concentration of 400 to 800 (ppm) could have negative effects on farmers' earnings of up to RM1387.5. Here rice yields would decline between 4.6 and 6.1% for every 1°C rise in temperature under the present CO_2 concentration level, but a doubling in CO_2 concentration from 400 to 800 ppm would not offset farmers' income. The question for Malaysia is how to offset these impacts?

[4] NRS estimation was based on time-series data (1970-2000)

DISCUSSION

The scenario figures indicate that the variation of climate factors may cause the agricultural system to be more vulnerable in Malaysia by the year 2080. The gradual change in climate may cause a measurable impact on rice yields, decreasing rice productivity by up to 34.8%/ha^{-1}. Therefore, Malaysia could become a future insecure economy in terms of food. Our focus is to show how Malaysia would offset the negative impacts of climate change in the future. As an alternative option, we tried to investigate improved management options and their possible effects. As it is evident that climate change will take place in the years ahead, it is therefore necessary to introduce climate change mitigation measures to offset the negative impacts. The Malaysian government plans to increase the self-sufficiency level (SSL) from 70 to 90%[5]. In order to support the 90% self-sufficiency level, Malaysia will require additional rice production of 1,320,000 tonnes per year to fulfil the desired self-sufficiency level in 2080. Further to the results of the scenario, we focus alternative policy options to cope with the impact of climate change issues. Under the climatic conditions scenario, we find that rice production may decline by 6% instead of productivity being increased. If this were the case, how Malaysia could offset the issues in question. A straightforward option is for Malaysia to increase agricultural production, that is, aggressive agricultural productivity is required to raise production sufficiently in order to offset the negative impact (by 6%). This is possible if Malaysia invests efficiently in management options (y_m) following the simple model addressed previously:

$\Delta yield$ = *constant* + $y_m \Delta CChange$ *(improved management options) + statistical error*

To increase the self-sufficiency level (SSL) from 70 to 90%, our main intention is to improve y_m to a certain level which could offset the negative impact of productivity of $\Delta yield$. Here we utilized the management options (y_m) as a substitute for climate change issues which refers to the efforts of implementing protected cultivation, integrated pest management (IPM) for crop loss, develop early warning systems for seasonal weather predictions and forecasts, diversification of crop production on irrigated areas, protected cultivation and, finally, improvement of post-harvesting technology. Following our prioritizing, an alternative option such as y_m can be improved easily by 10%. In this case, the government will invest in y_m from the agricultural budget and no cost will be borne by farmers. Our simple statistical results

[5] Currently, Malaysian imports 30% of rice (that is, 800,000 tonnes/yr).

(p<0.001) indicate that within our climate change issues (which had been discussed in the results and discussion), a fall in rice yield trends (6%) can be fully offset up to the year 2080 by increasing the cost of the annual agricultural budget by less than 1%.This would then fulfil the Malaysian government policy for the self-sufficiency level (SSL) of 90%. Here, additional efforts would determine substitute effects (y_m /Δ% ha^{-1}) of climate change-related impact and proxy levels of rice production.

Almost similar result found by Slingo et al. (2005); Ziska et al. (1997) about impacts of climate change on agricultural yields. Besides, earlier modelling studies such as Lobell et al. (2008), Siwar et al. (2009), Naylor et al. (2007), Tilman et al. (2002), Socolow (1999), Alexandratoss (1999), Reilly (1999) and Schimmelpfennin (1996) were used to predict the changes in agricultural yields due to climate change. Those studies predicted the future scenario for the short-term period and some of them are theory based. Our novelty in this study is to explore the climate change impacts which generated the long-term projections up to 2080 on likely future changes and uncertainty on rice agriculture. We also visualized alternative relative policy strategy or potential path for planning strategies by statistical analysis.

Conclusion

This paper explores and provides expected climate change impacts on rice agriculture based on observational records of inter-annual variability in precipitation and warming climatic factors up to 2080. This was demonstrated with GCM modelling using simple statistical analysis, focusing on the vulnerability of Malaysian rice agriculture under various climatic conditions and giving a wide range of potential climate outcomes for rice agriculture in Malaysia. Even though, there is great uncertainty in both the scientific projections and technical, social, and economic aspects of climate change, we identified some features for prioritizing requirements and factors in investment decisions to reduce vulnerabilities. Here we analyzed Empirical Downscaling Model (EDMs) with Crop Modelling (DSSAT) to represent a range of plausible climate scenarios following a bottom-up strategy.

Looking at the Malaysian rice self-sufficiency level (SSL) of 90% from the current 70% level, our projections signify the likely future changes, potential path and prioritizing requirements to reduce vulnerabilities. Within the framework of this paper, evidence gathered indicate that rice yields could decline by up to 6.1% for every 1°C rise in temperature given concentration levels of 400 to 800 CO_2 (ppm) and under the climate change issues in question, and this can, in turn, lead to negative changes in yearly earnings (RM) for rice cultivation by up to RM 1,387.5. Following our GCM results, we were not very confident of the success of the current policy. Therefore, we tried to find alternative relevant policy strategies, such as an improved management option as an alternative mitigation/adaptation option to reduce climate change-related vulnerability for rice agriculture. We worked out that with our climate change issues, the improvements in a management option by about 10% can fully offset declined rice yield trends up to the year 2080. The results can be used for Malaysian long-term climate-related agriculture policies and elsewhere.

ACKNOWLEDGEMENTS

This work was prepared under UKM-OUP-PI-25-111/2009 and UKM-AP-PI-18-2009-3 projects led by Professor Joy Jacqueline Pereira at Universiti Kebangsaan Malaysia (UKM). The authors would like to thank Universiti Kebangsaan Malaysia for financial support.

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