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Impact of Climate Change on Rice Yield in the Main Rice Growing Areas of Peninsular Malaysia

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ABSTRACT

Agricultural sector is one of the sensitive areas that would be affected by the changes in key climatic elements. This study assesses the possible impact of climate change on the Malaysian rice production. The study employed DSSAT Crop Simulation Model to predict the rice yields in the eight granary areas of Peninsular Malaysia until 2030, based on projected weather data and current management practices. Increase in temperature and variations in rainfall pattern over the growing period were found to affect the rice yield. The results indicated that rice yield, during 2013 to 2030, compared to the base values are expected to decrease by12.2, 13.6, 8.7, 8.4, 15.2, 16.8, 11.4 and 18.6% for the main season and 45.5, 19.4, 33.9, 36.3, 34.5, 47.8, 21.8 and 7.5% for the off season for MADA, KADA, Kerian, BLS, Pulau Pinang, Seberang Perak, Ketara and Kemasin, respectively. These results showed that rice yield would be more negatively affected by the climate change during off season rather than main season.

Key words: Climate change, rice, eight granary areas, Malaysia

INTRODUCTION

After wheat, rice is the most important crop in the world (Matthews *et al.*, 1997) and the dominant staple food crop in Asia with more than 90% of the rice produced and consumed. However, due to rapidly expanding population, increasing in rice production is required. Since rice is a highly water demanded plant, unpredicted climatic changes like extreme weather (flood and drought) are expected to influence its water use required. Previous studies have shown that increased air temperature adversely affect rice yield and its grain quality (Baker *et al.*, 1992; Saseendran *et al.*, 2000). However, more solar radiation has beneficial effect on rice grain yield. Furthermore, increased atmospheric Carbon Dioxide (CO_2) concentration increase growth and development of rice plant and consequently rice yield but potentially large negative effects are possible if temperature also rise (Baker *et al.*, 1995; Matthews *et al.*, 1997). Among these factors, temperature has a major influence on rice growth and yield.

In many Asian countries, potential rice yield will be lower by increasing in mean daily temperature due to global warming. Nevertheless, it may also enable the northern limits of rice growing regions to expand, especially in northern China and Japan (Bachelet and Gay, 1993). Cure and Acock (1986) reported that changes in rice production would be higher in cooler climates, specifically for rain-fed conditions. However, the same study by Baker *et al.* (1992) indicated a sharp decline in grain yield and then potential negative effects on rice production in warmer regions if temperatures increase. In a warmer climate, the demand for water for irrigation will be increased and thus more water will be needed per unit area under drier conditions.

The annual trend of temperature and rainfall has been analyzed by Malaysian Meteorological Department (MMD 2009) for the period of 1968-2007. Based on MMD report, an average temperature increase of 0.5-1.5°C is recorded for Peninsular Malaysia and 0.5-1.0°C for East Malaysia which shows Western Peninsular Malaysia experiences more significant rise in temperature than other regions in Malaysia. Furthermore, for the last 20 years, rainfall has reduced in Peninsular Malaysia. Hence, present regional climatic trends for Malaysia are in line with the increase in average surface temperature observed and rainfall trends for Malaysia have large spatial and temporal variation.

The focus of this study is on the eight granary areas in Peninsular Malaysia. The Decision Support System for Agrotechnology Transfer (DSSAT) modelling system which is a physiologically based crop growth simulation model was used to understand the relationship between rice yield and climatic variables (temperature and rainfall).

MATERIALS AND METHODS

Study areas: This study covers the eight granary areas in Peninsular Malaysia comprise of MADA, IADA PP, Kerian, Seberang Perak, Barat Laut Selangor, KADA, Kemasin and Ketara. They are designed as permanent paddy producing areas, to realize a minimum self-sufficiency level for rice of 65% and this is one of the major strategies to enhance rice production. In Malaysia, there are two major rice cropping seasons, main season and off season. Generally, the rice planting date for the main season is from September through December and for the off season from February to May. However, these times may vary a little, depending on the region.

The Muda Agricultural Development Authority (MADA) is in the North-west of Peninsular Malaysia which is the largest rice granary area of the country. This area covers about 125,555 ha which 105,581 ha are located in the north-western part and 20,304 ha are in the southern part of Perlis state. Approximately 76% of the land is under paddy cultivation and around 48,500 farm families live in there (Lin *et al.*, 2010). Kemubu Agricultural Development Authority (KADA) areas cover southern Kelantan and northern Terengganu states on the east coast of Peninsular Malaysia. This area is characterized by a very heavy rainfall season from October to December due to the north-east monsoon. Rice is mostly grown on the river terraces of the flood plain and soils are of medium to heavy texture in this area (Singh *et al.*, 1996). The total rice area under KADA is about 25,447 ha which contributed around 8% to total rice production of Malaysia. Kerian Sg. Manik (KSM) is located in the district of Hilir Perak. The planted area of paddy in KSM is almost same with KADA, around 26,594 ha.

Projek Barat Laut Selangor (PBLS) region is located in the west coast zone. The major climatic characteristic of this region is the more even seasonal distribution of rainfall. Dry periods often occur in February, June and July. They are mostly very short, lasting for less than one month. This region also experiences infrequent strong gusts of wind and morning rainfall, especially during the south west monsoon season which is from May to September. In addition, soils are mostly marine and riverine alluvia of medium to heavy texture (Singh *et al.*, 1996). Rice is the major crop along the coastal plains. Hence, BLS considered as the most productive rice growing areas in the country. This area actually performed better than MADA with increasing trend in yield as well as paddy production. IADA P.Pinang area is located at north-west of Peninsular Malaysia which is relatively small granary area with about 10,305 ha planted area for both main and off season. However, yield performance can be considered a success with an annual growth rate of about 4.5 and 3.3% in the main and off seasons, respectively.

Seberang Perak which located at western Peninsular Malaysia could be considered as one of the high performing granary areas. KETARA or Northern Terengganu Integrated Agricultural Area covers a very small area but its performance for both production seasons was good. In this area, most of the gains are belonged to the growth in yield rather than the planted area as it remained almost stagnant particularly in off season. Integrated Agricultural Development Area (IADA) Kemasin Semerak which is located in Kota Bharu district and Kelantan state is the smallest granary areas. In this area, during 1991-2011, the average yield had downward trend in the main season and was much fluctuated in the off season.

DSSAT model: The Decision Support System for Agrotechnology Transfer (DSSAT) was developed by an international network of scientists which was collaborated with the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project, to make easy the use of crop models in a systems approach to agronomic research (Jones *et al*., 2003). DSSAT is capable to predict yield as a function of weather, soil condition, crop management and genetic information. It also includes a basic set of tools (XBuild, SBuild, GBuild and WeatherMan) to prepare the input data. This model requires a minimum data set as inputs for simulations. These were included the basic crop management data, soil profile information and daily weather data which was imported into the model through XBuild, SBuild and WeatherMan, respectively. A detailed description of the DSSAT crop simulation model is given by Jones *et al*. (2003). This model has been widely used to simulate the impact of climate change on crops in all over the world (Al-Bakri *et al*., 2011; Amien *et al*., 1999; Basak *et al*., 2010).

All the required data in this study are based on secondary data and collected from different sources. The daily projected weather data (minimum and maximum temperature, rainfall and solar radiation) for 2013-2030 were projected based on HadCM3-PRECIS climate model under SRES A1B IPCC scenarios. The configuration and validation of the PRECIS regional climate simulation results was discussed by Kwan *et al*. (2013). Data on soil types and their physical and chemical properties were obtained from the soil division in Malaysian Department of Agriculture (DOA).

Model calibration: Model calibration includes reducing the error between outputs and observed data and determining the model parameters for an intended purpose. In regional climate change impact assessments which have the large geographical area and limited observed data, the calibration is generally limited to applying results from yield trials from agricultural experiment stations, or the most commonly cultivated crop varieties. For this purpose, the rice variety MR-219 which is the most popular rice variety in these granary areas was selected. An experimental dataset of crop management for rice variety MR-219 was obtained from Malaysian Agricultural Research and Development Institute (MARDI). Crop performance needs to be calibrated to Reduce the Root Mean Square Error (RMSE) of simulated and observed yields, for example, date of emergence, date of flowering, date of physical maturity, amount of yield, harvest product individual dry weight and harvesting date.

Model evaluation and testing: Model evaluation includes comparison of outputs of the model with actual data and a determination of suitability for a future purpose. In fact, it is a documentation of the accuracy of the output for particular predictions in specified environments, with appropriate consideration given to possible errors in input variables or evaluation data. For the model validity, RMSE, Root Mean Square Percentage Error (RMSPE) and Coefficient of Residual Mass (CRM) can be used to evaluate the error:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} \quad (1)$$

$$\text{RMSPE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\frac{(P_i - O_i)}{O_i}\right]^2} \times 100 \quad (2)$$

$$\text{CRM} = \frac{\sum_{i=1}^{n}O_i - \sum_{i=1}^{n}P_i}{\sum_{i=1}^{n}O_i} \quad (3)$$

where, P_i is the predicted value of the ith year, O_i is the ith year observed value. These statistics have been widely applied for model evaluation (Kobayashi and Salam, 2000; Willmott, 1982; Xiong *et al.*, 2008).

RESULTS AND DISCUSSION

Model validation: The basic assumption in crop modelling applications is that the model can precisely simulate the processes happening in the agricultural system (Thorp *et al.*, 2005). The model was validated by applying the observed daily weather data (maximum and minimum temperature, rainfall and solar radiation) obtained from MMD (Petaling Jaya station) for the years 1998-2011. The simulated yields were compared with the actual yields in the main season of Selangor (BLS).

The validation result indicated that the DSSAT simulated yield differs around 503 kg ha^{-1} from the observed. The model simulated reasonable rice yield with RMSPE = 11.2%. A value of CRM showed that the most of simulated values are greater than the observed values. The mean simulated yield is slightly higher (about 3%) than the mean observed yield.

Impact of projected climate change on rice yield: In this study, the impact of temperature and rainfall in eight granary areas for both main and off seasons was predicted for the time period of 2013 to 2030. The predicted changes in yield for each granary areas in both Main Season (MS) and off Season (OS) are shown in Fig. 1-8.

The prediction results for MADA area indicated the reduction in yield for both main and off seasons until 2030. During main season, the maximum and minimum temperature and rainfall was projected to increase about 0.05°C and 0.12 mm per year, respectively. The yield in main season was expected to decline by 12.2% over the next 18 years. During off season, the minimum and maximum temperature was projected to increase about 0.19 and 0.08°C per year, respectively. However, rainfall would decrease about 0.18 mm per year during 2013 to 2030. Compared to the base value, in off season, the yield was expected to decrease by 45.5% in next 18 years which is more than main season.

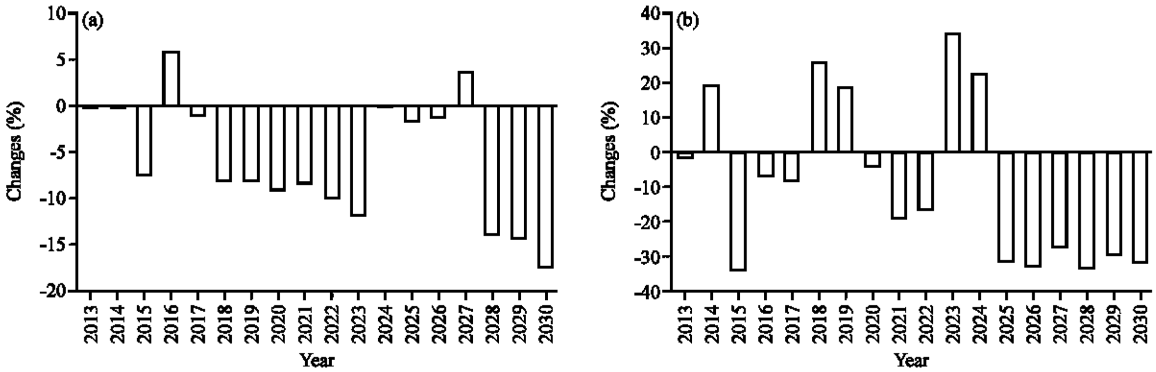

Fig. 1(a-b): Percentage changes of rice yield for BLS area in (a) MS and (b) OS

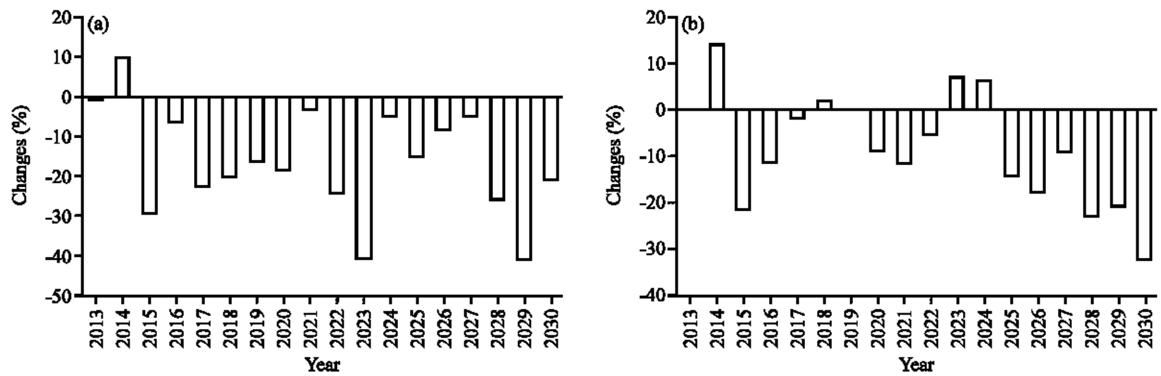

Fig. 2(a-b): Percentage changes of rice yield for KADA area in (a) MS and (b) OS

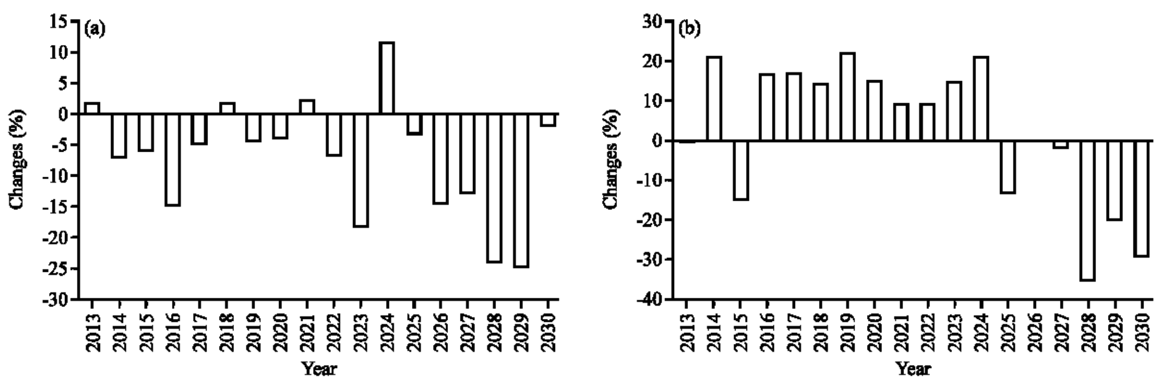

Fig. 3(a-b): Percentage changes of rice yield for KSM area in (a) MS and (b) OS

The decreasing trend was predicted for KADA in main and off seasons during 2013-2030. In main season, the maximum temperature, minimum temperature and rainfall was projected to increase yearly about 0.03, 0.04°C and 0.15 mm, respectively. However, in off season, the maximum and minimum temperature was projected to increase about 0.13 and 0.06°C per year, respectively. Rainfall was also projected to decrease by 0.26 mm per year. In the next 18 years, the rice yield in KADA may be reduced by 13.6 and 19.4% in the main and off season, respectively.

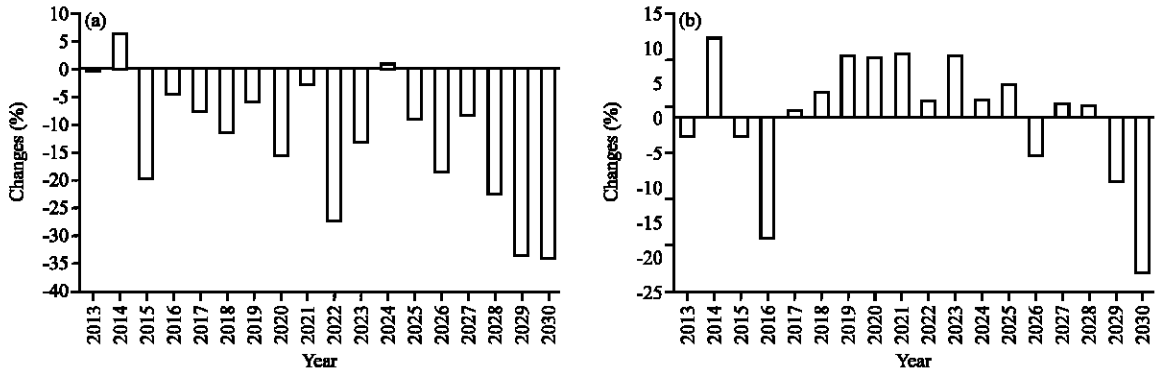

Fig. 4(a-b): Percentage changes of rice yield for Ketara area in (a) MS and (b) OS

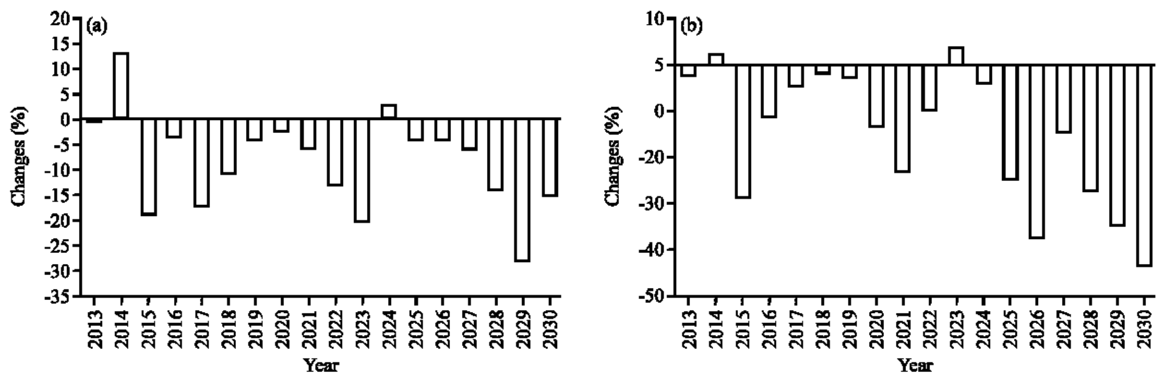

Fig. 5(a-b): Percentage changes of rice yield for Ketara area in (a) MS and (b) OS

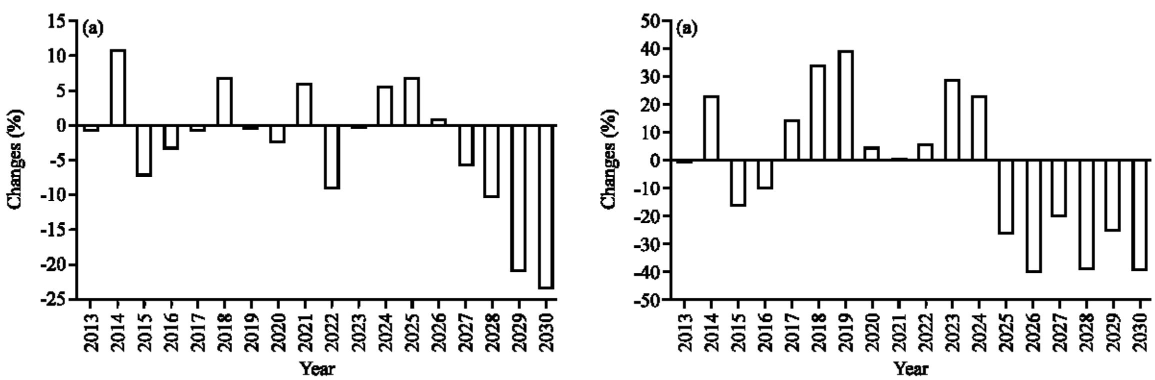

Fig. 6(a-b): Percentage changes of rice yield for MADA area in (a) MS and (b) OS

In Kerian, the downward yield trend was also predicted for both seasons. During main season, the maximum temperature, minimum temperature and rainfall may increase by 0.05, 0.06°C and 0.06 mm per year, respectively. During off season, the maximum and minimum temperature may increase by 0.11 and 0.09°C per year, respectively. However, the rainfall may decrease by 0.04 mm per year. Over the next 18 years, the yield was expected to decrease by 8.7 and 33.9% during main and off seasons, respectively.

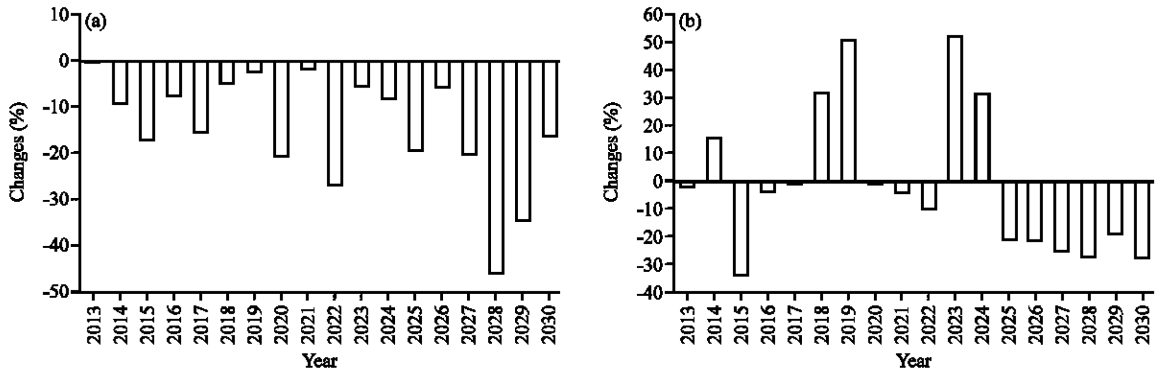

Fig. 7(a-b): Percentage changes of rice yield for P. Pinang area in (a) MS and (b) OS

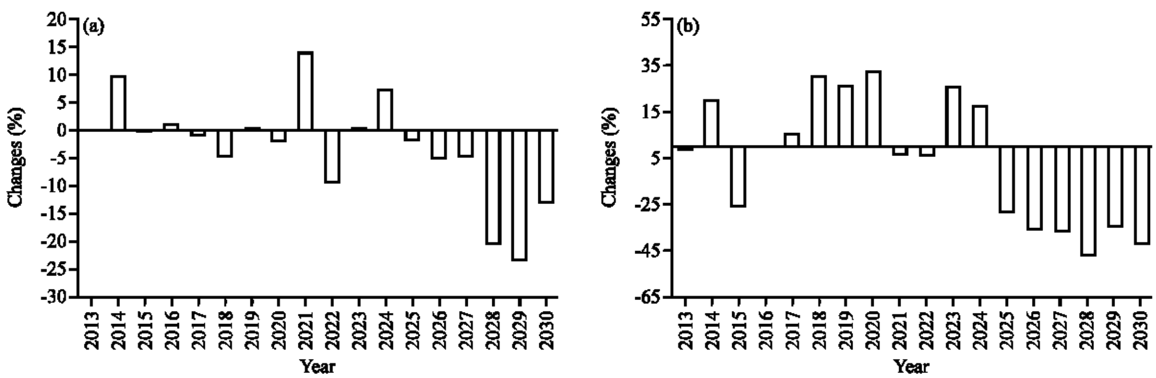

Fig. 8(a-b): Percentage changes of rice yield for Seberang Perak in (a) MS and (b) OS

The prediction results for BLS also indicated reduction in yield for main and off seasons. The projected maximum and minimum temperature in main season showed the yearly increase of about 0.06 and 0.04°C, respectively. However the rainfall was projected to decrease by 0.03 mm per year. In the off season, the yearly increase of maximum and minimum temperature was projected about 0.17 and 0.18°C, respectively. The rainfall may also decrease by 0.27 mm per year. Compared to the base value for main and off seasons, the yield of BLS was expected to decrease by 8.4 and 36.3%, respectively. Highest reduction in yield is expected for the last three years.

In Pulau Pinang, during the main season, the maximum temperature, minimum temperature and rainfall were projected to increase by 0.08, 0.06°C and 0.03 mm per year, respectively. During the off season, the maximum and minimum temperature was projected to increase about 0.16 and 0.09°C per year, respectively. However, rainfall may decrease about 0.15 mm per year. Compared to the base values for main and off seasons, the yield was expected to decline by 15.2 and 34.5%, respectively, until 2030. Among the granary areas, Pulau Pinang may experience highest reduction in yield during the main season. That is due to highest increasing of maximum and minimum temperature during the time period of rice plant growth. However, significant fluctuation in yield was also predicted for off season.

The prediction results for Seberang Perak also indicated the fluctuation as well as reduction in yield for both seasons. During the main season, the projected maximum temperature, minimum temperature and rainfall indicated the yearly increase of about 0.04, 0.06°C and 0.16 mm, respectively. During the off season, the yearly increases of maximum and minimum temperature were projected about 0.22 and 0.07°C, respectively. However, the rainfall may decrease by 0.14 mm per year. Compared to the base values for main and off season in Seberang Perak, the yield was expected to decrease by 16.8 and 47.8%, respectively.

The predicted yield for Ketara demonstrated the decreasing trend of yield for main and off seasons from 2013 to 2030. In the main season, the maximum and minimum temperature and rainfall in this area may increase by 0.04°C and 0.14 mm per year, respectively. However, in the off season, the maximum temperature and minimum temperature may increase by 0.13 and 0.06°C per year, respectively and rainfall may decrease by 0.29 mm per year. Consequently, the yield in this area during main and off seasons was expected to decline about 11.4 and 21.8%, respectively, over the next 18 years.

The projected trend (2013-2030) of maximum and minimum temperature and rainfall for Kemasin in the main season showed that yearly increase was about 0.04°C and 0.2 mm, respectively. However, in the off season, the maximum temperature and minimum temperature was projected to increase about 0.07 and 0.05°C per year, respectively. The rainfall was also projected to decrease by 0.22 mm per year. In Kemasin which is the smallest area, reduction of rice yield was estimated at 18.6% in main season and at 7.5% in off season from 2013 to 2030.

Significant reductions in rice yields for main and off seasons in all areas, due to changes in climatic conditions, were predicted. These results indicated that rice yield would be more negatively affected by the climate change scenario during off season rather than main season, due to reduction in rainfall and higher increasing in temperature during off season. Some regional variations could also be observed in the predictions for main season, with somewhat higher reductions predicted for Pulau Pinang, KADA, Kemasin, Ketara, Kerian, Seberang Perak, MADA and Selangor (BLS), respectively.

In the off season, similar reduction in yield were predicted, however for some areas in certain years (e.g., 2014, 2018, 2019, 2020 and 2023), significant increase in yield were also predicted. The fluctuation in yield depends on the increase or decrease of temperature and rainfall in certain time period of plant growth. In other word, it mainly depends on planting date. Rice yield during off season varies from year to year and, for the most of areas, the maximum yield was predicted during the years 2019 and 2023. During off season, a certain amount of yield varied at different locations for different climatic conditions, with somewhat higher reductions predicted for Seberang Perak, Ketara, MADA, Kerian, Selangor (BLS), KADA, Pulau Pinang and Kemasin, respectively. It should be noted that the predicted increase in yield for most areas in 2014, 2019 and 2023 could also be explained by the reduction in predicted minimum and maximum temperature and increasing in rainfall during these years.

CONCLUSION

The predictions that were carried out in this study provided useful insight on the possible effects of climate change on the Malaysian rice yield. The results indicated that the rice yield in the main and off season could decrease. Although there are significant uncertainties in the predicted climate parameters, the DSSAT simulation results suggest that if climate change causes significant increase in temperature and changes in rainfall patterns, these may in turn cause significant reduction in rice yield. Most areas, during the off season, were obtained the highest reduction of yield rather than main season. Rising Temperature and changes in rainfall patterns have direct effects on rice yield, as well as indirect effects through changes in irrigation water availability in most regions. Increasing temperature results in shorter growing seasons, shorter maturity date and consequencely, lower rice grain yields. This negative impact could be greatly mitigated by adjusting the planting date. Once that planting date is adjusted, the increased expected rainfall during the main season results in increasing grain yield.

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