Simulating Climate Change Impact on Rice Yield in Malaysia using DSSAT 4.5: Shifting Planting Date as an Adaptation Strategy

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Summary: The effect of changing the planting date on rice production was simulated by using Decision Support System for Agro-technology Transfer (DSSAT 4.5) software for both off-season and main season in the area of Muda Agriculture Development Authority (MADA) under expected climate change. Daily weather data on temperature, solar radiation and rainfall up to year 2080 were obtained from the National Hydraulic Research Institute of Malaysia (NAHRIM) which are generated from climate model i.e. Providing Regional Climate for Impacts Studies (PRECIS). Simulations using DSSAT 4.5 were then carried out to predict yield production under forecasted weather conditions to analyse the impact of weather trends on yield. Results showed that averaged seasonal daily solar radiation and seasonal total rainfall have the most significant impact on annual yield production. DSSAT 4.5 was applied again to simulate future rice production grown in MADA area for off-season and main season under five different planting dates. Results showed that generally for the main season, shifting planting date increased rice productions whereas for the off-season, rice production decreased when planting date shifted. This can be identified as a non-cost climate change adaptation strategy for rice cultivation in MADA area.

Keywords: rice production, DSSAT 4.5, planting date, climate change adaptation, PRECIS

1. INTRODUCTION

In the past 20 years, climate change caused by human activities has emerged as a global concern (Sarker 2012). One particular worry is the potential disastrous consequence for agriculture and food security in many parts of the world, especially in developing countries (Kotir 2011). Rice (*Oryza sativa* L.) is the second most important crop in the world after wheat, with about 522 million tons being produced from 148 m hectares in 1990 (Matthews et al. 1997). The largest production of rice is from Asia which produces about 94% of the total world production (Matthews et al. 1997). Rice is one of the most important crops in Malaysia as rice is the staple food for the country. In Malaysia, the actual farm yields vary from 3-5 tons/ha, whilst potential yield estimated is around 7.2 tons/ha (Singh et al. 1996). However, due to the effects of climate change, the average temperature for the country is projected to rise by 0.3-4.5°C (Zabawi 2010). The optimum temperature for rice cultivation in Malaysia is between 24-34°C and the optimal average annual rainfall is not less than 2,000 mm per year (Radziah et al. 2010).

Decision Support System for Agro-technology Transfer (DSSAT) was developed by the International Benchmark Systems Network for Agro-technology Transfer (IBSNAT). DSSAT includes 16 types of crop growth model in which the soil and weather data can be accessed with specific crop management data that can be used to predict the growth rate and the expected results that may be acquired (Jones et al. 2003; Sarkar 2006). Farmers can adapt to climate change to some degree by shifting planting dates, choosing varieties with different growth duration or changing crop rotations (Wassmann and Dobermann 2007). Many studies found that changing the planting date of rice could be a very good solution to improve rice yield under the impacts of climate change (Desiraju et al. 2010). Studies by Dharmarathna et al. (2014) showed that shifting planting date forward by 1 month in Sri Lanka increased yield production up to 120 kg/ha. In addition, simulation analysis for developing strategies for adapting rice to climate change scenarios emphasised low-cost adaptation strategies, which include improved crop variety, improved crop management, efficient utilisation of irrigation and fertiliser, increased seed replacement by the farmers and increased fertiliser application (Aggarwal et al. 2010). Therefore, the main objective of this study was to understand the effect of different planting dates towards the yield production of rice under changing climate conditions.

2. MATERIALS AND METHODS

This study was conducted at MADA area, Kedah, Malaysia. MR 219 was used for planting as this variety is the most popular among farmers. Rice cultivation activity is based on the norms by MADA. Rice yield variations were analysed for five different planting dates: (1) planting on 15th April for off-season and on 15th October for main season – base condition; (2) advanced the planting date by 7 days; (3) advanced the planting date by 14 days; (4) delaying the planting date by 7 days; and (5) delaying the planting dates by 14 days. Daily weather variables for MADA area up to 2080 were obtained from the NAHRIM where they used a regional climate model named PRECIS to generate daily weather data needed for running the DSSAT model. The PRECIS outputs that were used in the DSSAT model include daily temperature, daily incoming solar radiation, and daily rainfall. The DSSAT modelling system is an advanced physiologically based rice crop growth simulation model that has been applied widely to understand the relationship between rice and its environment. The model involved is CERES-Rice model which is specific only for rice (Jones et al. 2003).

3. RESULTS AND DISCUSSION

The DSSAT model was calibrated and validated by using previous yield data on selected rice area under study which was provided by MADA, and past climatic details were obtained from Malaysian Meteorological Department (1998 to 2007). Figure 1 shows the comparison of observed and simulated rice yield for calibration and validation. Yield productivity was simulated in DSSAT by using projection daily weather conditions. The forecasted averaged seasonal daily temperature in Figure 2 shows marginally increasing trend where the highest temperature value is 31.6°C for the main season in year 2074, while the lowest value is 31.6°C for the off-season in 2012. The value of R^2 shows that averaged seasonal daily temperature does not show a significant increasing trend (R^2 = 0.3908). Generally, optimum temperature for rice cultivation is between 24–34°C. Surface air temperature has direct effect on yield, particularly on increasing total crop biomass. It determines crop photosynthesis and respiration losses, both of which contributed to yield and plant biomass (Peng et al. 2004). Temperature forecasted is between the ranges of 24.42–33.98°C, therefore it will not show significant impacts towards yield production.

Another important climate variable is daily solar radiation. Forecasted averaged seasonal daily solar radiation (Figure 3) also shows marginally increasing trend with the highest value recorded is 25.8 mJ/m^2 for the off-season in 2078 and the lowest value recorded is 19.08 mJ/m^2 for the main season in year 2048. The value of R^2 shows that seasonal daily solar radiation does not show a significant increasing trend (R^2 = 0.1138). Solar radiation is one of the main factors influencing biomass and yield production and its quality besides other factors associated with prolonged solar radiation in the phase of stem elongation and grain filling while low intensity of solar radiation during grain filling phase negatively influences grain yield (Trnka et al. 2001).

Similar to average seasonal daily solar radiation forecasted, seasonal total rainfall forecasted also shows marginally increasing trend with the highest value is 100 mm for the main season in year 2079, whereas the lowest value is 963 mm for the main season in year 2068 (Figure 4). The value of R^2 shows that seasonal total rainfall does not show a significant increasing trend (R^2 = 0.0525). Rice crops use large quantity of water for cultivations. Water deficit may affect rice growth and reduces grain yield and quality (Carlos et al. 2008). In Malaysia, total rainfall which is high ensures continuous and direct supply of water to many of the rainfed areas. Under rainfed cultivation systems, the optimum rainfall required is not less than 2,000 mm per year. Total rainfall forecasted for every season is between the ranges of 100–970 mm which is very low and definitely will affect yield productivity.

Simulations then were carried out to predict yield production under the forecasted weather conditions to analyse the impact of weather trends on yield (Figure 5). The value of R^2 shows that simulated yield production for every year does not show a significant increasing or decreasing trend (R^2 = 0.2720). Generally, it can be concluded simulation results suggest that weather trends forecasted up to 2080 does not have a clearly significant impact on rice productivity. However, there is unexpected yield production reduction in the year 2012 and 2020 where the yield simulated is below 4 tons/ha. Simulations were then carried out to analyse the impact of weather variable trends on yield. Of the three climatic factors used (temperature, rainfalls and solar radiation), there are two factors which have the most significant impact on annual production based on the forecasted values obtained which are averaged seasonal daily solar radiation and seasonal total rainfall. Averaged seasonal daily temperatures are not one of the factors as the value temperature recorded is between 24-34 °C which is considered as in the range of optimum temperature for rice growth (Sys et al. 1993). Based on the graph (Figure 6), reduced in potential yield productivity simulated likely to occur due to the forecasted averaged daily solar radiation for the year 2012 and 2020 (both main season) were below 20 mJ/m^2. In addition, Figure 7 shows that forecasted seasonal total rainfall may also influence the reduction in potential yield productivity simulated even though the effects seems to be minimal as compared to the effects by the reductions in forecasted averaged daily solar radiation.

Simulations then were carried out for another four cases to examine the effect of planting date on the potential yield production: (1) shifting the planting date backward by 7 days; (2) shifting the planting date backward by 14 days; (3) shifting the planting date forward by 7 days; (4) shifting the planting date forward by 14 days. Simulated potential yield production for all the four cases over the simulation period from 2010 to 2080 were averaged into 10-year periods and plotted to compare the yield variations (Figure 8). Based on simulations, rice production will not be significantly affected by the climate trend over the next 70 years. Generally, shifting planting date either backward or forward does affect yield production depending on the season. For the main season, shifting planting date increased yield production. Rice production increased when shifting the planting date backward by 14 days in 5 ranges out of 7 ranges; 4 ranges out of 7 ranges when shifting the planting date backward by 7 days; 5 ranges out of 7 ranges when shifting the planting date forward by 7 days and 4 ranges out of 7 ranges when shifting the planting date forward by 14 days. In the other hand, for the off-season, shifting planting date decreased yield production. Rice production decreased when shifting the planting date either backward or forward by 7 days or 14 days in ranges 7 out of 7 ranges.

4. CONCLUSION

The effect of changing the planting date for rice productivity in MADA area was investigated. PRECIS was used to generate daily weather data up to 2080. DSSAT model was used to simulate rice yield under four conditions for off-season and main season. Simulations generally showed that for main season, shifting planting date increased rice productions whereas for off-season, rice production decreased when planting date shifted. Therefore, shifting planting date for main season is recommended as a non-cost climate change adaptation strategy for rice cultivation in MADA area.

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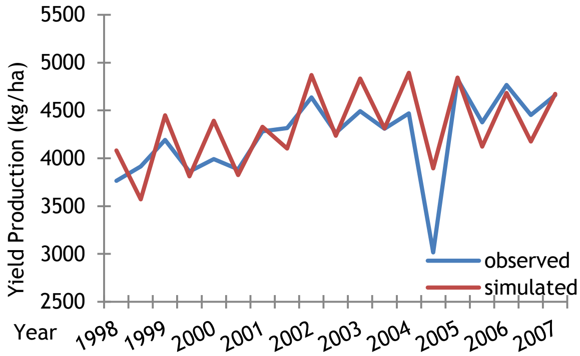

Fig. 1. Calibration and validation for yield simulation

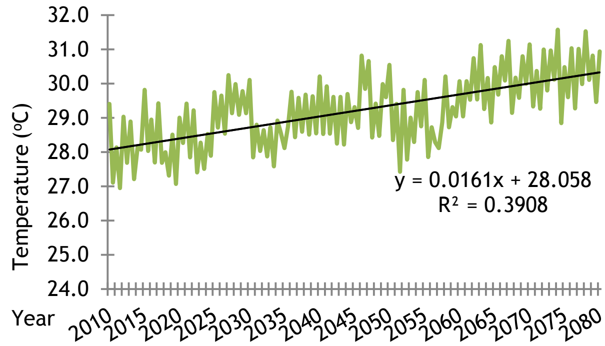

Fig. 2. Seasonal averaged daily temperature forecasted

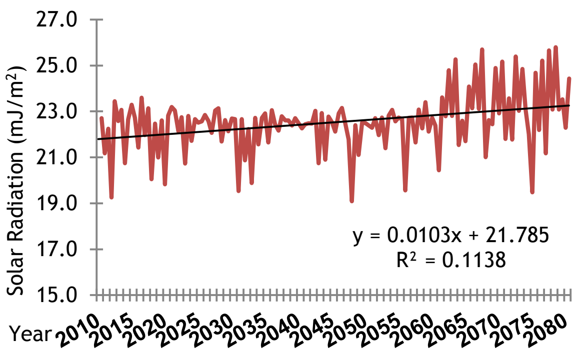

Fig. 3. Seasonal averaged daily solar radiation forecasted

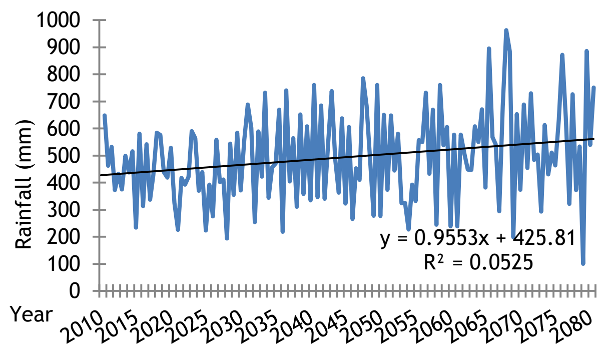

Fig. 4. Seasonal averaged total rainfall forecasted

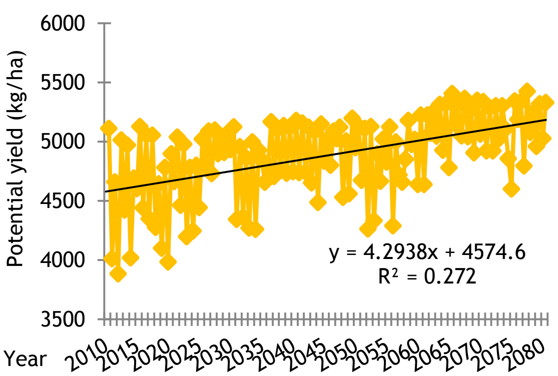

Fig. 5. Simulated potential yield productions

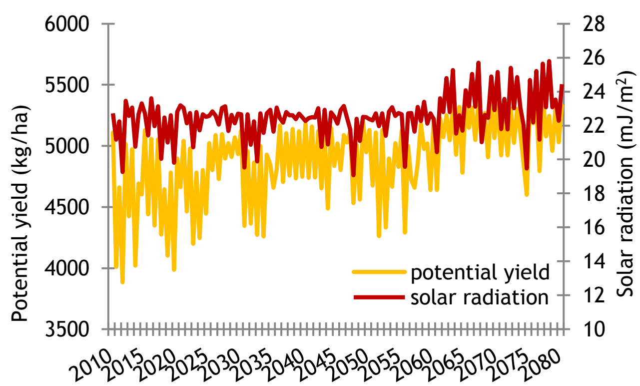

Fig. 6. Potential yield simulated and averaged daily solar radiation forecasted

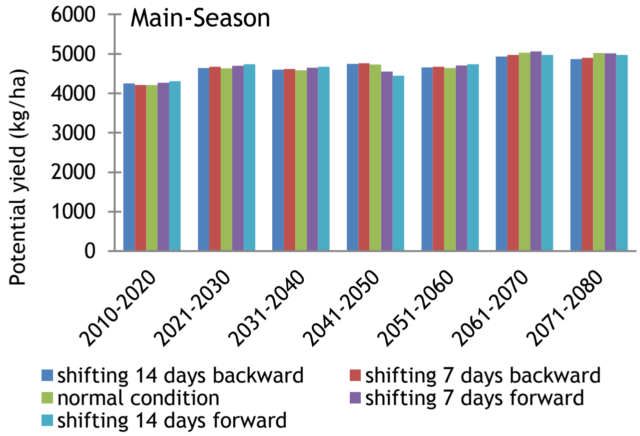

Fig. 7. Potential yield production variations for main season

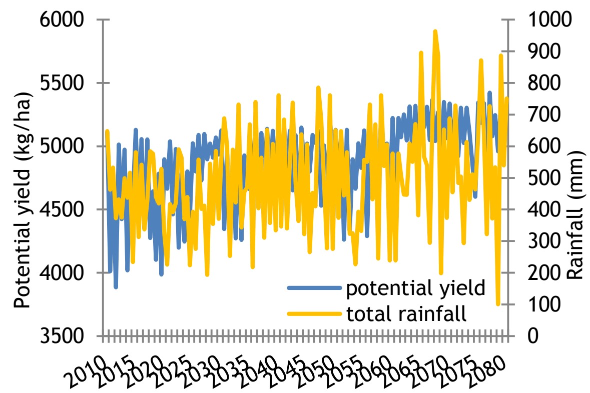

Fig. 8. Potential yield simulated and seasonal total rainfall

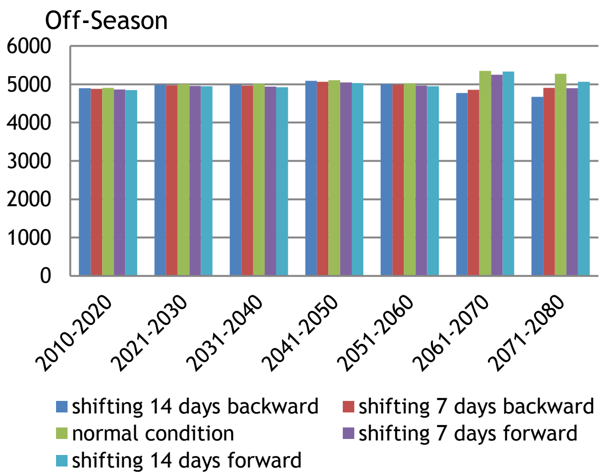

Fig. 9. Potential yield production variations for main season and off-season