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

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Abstract

The effect of changing the planting date on rice production was simulated by using Decision Support System for Agrotechnology Transfer (DSSAT 4.5) software for both off-season and main season in the area of MADA under expected climate change. Daily weather data on maximum and minimum temperature, solar radiation and rainfall up to year 2080 were obtained from the Malaysian Meteorological Services 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 projected 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 offseason and main season under five different planting dates. Results show 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: climate change adaptation, DSSAT 4.5, planting date, PRECIS, rice production

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1. Introduction

Malaysia, located in South East Asia, lies between 1˚N and 7˚N of the equator, and 99.5˚E and 120˚E. The country experiences relatively uniform temperatures throughout the year with the temperature in the lowlands ranging between 21˚C at night and 32˚C during the day. The daily mean temperature is between 26˚C and 28˚C (Anonymous, 2011). Malaysia receives abundant rainfall with average annual rainfall ranging from about 2,000 mm to 4,000 mm (Anonymous, 2011). 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 t ha^{-1}, whilst potential yield estimated is around 7.2 t ha^{-1} (Singh et al., 1996). The most popular rice varieties used among farmers in Malaysia is MR 219 besides MR 220 and MR 232. This choice is based on the varieties potential high yield, resistant to disease, better taste (soft and fragrant rice) and short maturity period (Shaidatul Azdawiyah et al., 2014). However, due to the effects of climate change, the average temperature for the country is projected to rise by 0.3˚C to 4.5˚C (Mohamad Zabawi, 2010). The optimum temperature for rice cultivation in Malaysia is between 24˚C and 34˚C and the optimal average annual rainfall is not less than 2,000 mm per year (Radziah et al., 2010).

Higher temperatures will reduce crop yields due to reduction rate of photosynthesis, increase of respiration process and also a shortened vegetative and grain-filling period (Radziah et al., 2010). This may eventually reduce the yield and rate of productivity. Farmers can adapt to climate change to some degree by shifting planting dates, choosing varieties with different growth duration or changing crop rotations (Wassman 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). In Vietnam, there is a need to change rice crop sowing dates and management procedures to optimise rice yield under climate conditions (Salim, 2009). The sowing date of spring rice is to be advanced by 15–25 days while the sowing date of summer rice is to be delayed by 20–25 days (Salim, 2009). In India, the rice yield can be improved when the sowing date of rice was advanced (Krishnan et al., 2007).

Scientific studies, typically based on computer models, have been used to examine the effects of postulated climate and atmospheric carbon dioxide changes on specific agroecosystems. A number of modelling studies of the likely effects of climate change on rice have emerged. The most commonly used approaches, methodology and tools applied are the analytical approach, mathematical modelling, remote sensing (GIS), surveys and field trials (Mohamad Zabawi, 2010). Generally, climate change models applied to the agriculture sector are non-existent and non-empirical formation in most cases. Information has been drawn from past and present literatures, statistical data and existing farm data. Currently two basic methods have been used to estimate the effect of climate on crop production namely structural modelling of crop and farmer responses combining the agronomic response of plants with the management decisions of farmers (Matthews et al., 1997), and spatial analogue models that exploit observed differences in agricultural production and climate among regions (Darwin and Tol, 2001).

Decision Support System for Agro-technology Transfer (DSSAT) was developed by the International Benchmark Systems Network for Agro-technology Transfer (IBSNAT). DSSAT has been used since 15 years ago by researchers around the world in an effort to establish a system of best crop management to maximise the production of yield. 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).The latest version of DSSAT crop model used presently is DSSAT 4.5. The model involved in DSSAT 4.5 is CERES-Rice model which is specified only for rice (Jones et al., 2003). Actually, CERES-Rice has been applied and its effectiveness extensively evaluated in Asia (Timsina and Humphreys, 2006). CERES-Rice simulate growth and yield, taking into account the influence of weather, plant genetics, soil water content, carbon and nitrogen content and crop management systems, irrigation and fertiliser (Ritchie, 1998). Timsina and Humphreys (2006) concluded that the CERES-Rice has successfully predicted the important dates in the process of growth and yield of rice after reviewing the results of application of CERES-Rice in the rice and wheat in Asia and Australia. Similar 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^{-1}. 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 in Malaysia.

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 1st April for off-season and on 1st 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 Malaysian Meteorological Services where they used a regional climate model named Providing Regional Climate for Impacts Studies (PRECIS) to generate daily weather data needed for running the DSSAT model. The PRECIS outputs that were used in the DSSAT model include daily maximum temperature (TMAX), daily minimum temperature (TMIN), daily incoming solar radiation (SRAD), 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). The model can be used to determine duration of growth stages, dry matter production and portioning, root systems dynamics, effect of soil water and soil nitrogen content photosynthesis, carbon balance and water balance (Basak, 2009).

Besides, DSSAT takes in amounts and timing of application of non-labour and non-equipment production factors such as seeds and fertiliser, as well as detailed data on inherent soil quality and climatic conditions. It then employs physical and biophysical models of soil-plant atmosphere interactions to simulate day by day the biological growth responses, measured precisely under laboratory conditions (Felkner et al., 2009). A detailed description of the model was provided by Ritchie (1998) and Hoogenboom et al. (2003). Growth duration of plant is governed by thermal time and is expressed in growing degree days (GDD).

$$GDD = \sum_{i=1}^{n} \left(T_{di} - T_{base}\right) \quad (1)$$

Where T_{di} is the daily averaged temperature and T_{base} is the base temperature. The base temperature is considered as 9°C for rice. The biomass production is calculated within the model as follows:

$$PCARB = RUE \times IPAR \quad (2)$$

$$IPAR = PAR \times [1 - e^{(-K * LAI)}] \quad (3)$$

$$CARBO = PCARB \times Min\ (PRFT, SWDFI, NDEFI, 1) \quad (4)$$

Where PCARB is the potential biomass production in g m^{-2} day^{-1}; RUE is the radiation use efficiency in g MJ^{-1}; PAR is the photo synthetically active radiation in MJ m^{-2} day^{-1}; IPAR is the fraction PAR intercepted by the plants; K is the extinction coefficient (0.65 for rice); LAI is the green leaf area index; CARBO is the actual biomass production in g m^{-2} day^{-1}; PRFT is the temperature reduction factor (0 or 1); SWDFI is the soil water deficit factor (0 or 1) and NDEFI is the nitrogen deficit factor (0 or 1) where 0 represents the maximum deficit and 1 is for no deficit (Hoogenboom 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). Fig. 1 shows the comparison of observed and simulated rice yield for calibration and validation. Yield productivity was simulated in DSSAT by using projected daily weather conditions. The projected averaged seasonal daily temperature in Fig. 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 ($R^2 = 0.3908$). Temperature affects rice growth in two ways firstly; a

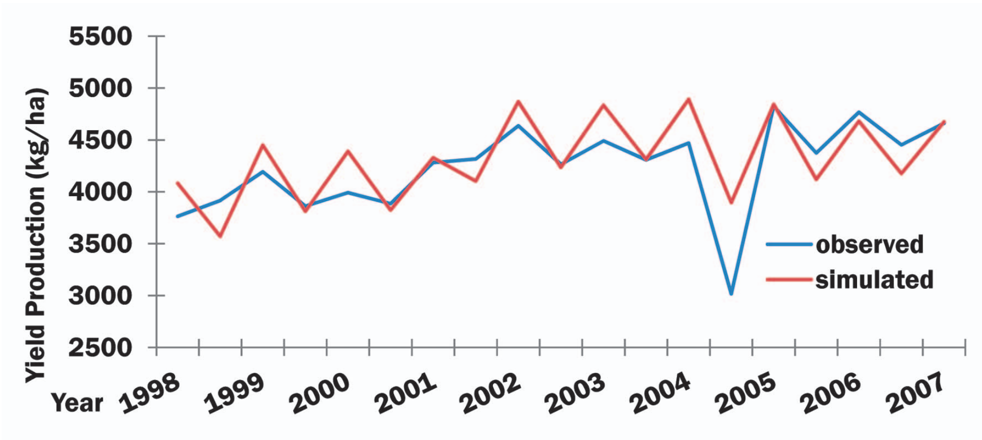

Fig. 1 Calibration and validation for yield simulation

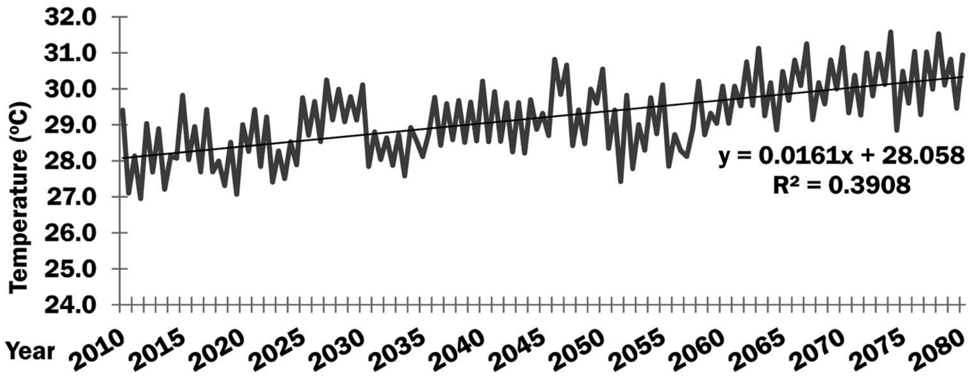

Fig. 2 Seasonal averaged daily temperature projected

critically low or high temperature defines the environment under which the life cycle can be completed. Secondly, within the critically low and high temperature range, temperature influences the rate of development of leaves and panicles and the rate of ripening, thereby fixing the duration growth of a variety under a given environment and eventually determining the suitability of the variety to the environment (Siwar et al., 2009). Generally, optimum temperature for rice cultivation is between 24–34˚C. If the temperature increases above the tolerance limit, potential production of rice will be mainly negative due to reduction in photosynthesis, increase respiration and shorten vegetative and grain-filling period. 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 projected 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 SRAD. Projected averaged seasonal daily SRAD (Fig. 3) also shows marginally increasing trend with the highest value recorded is 25.8 mJ m^{-2} for

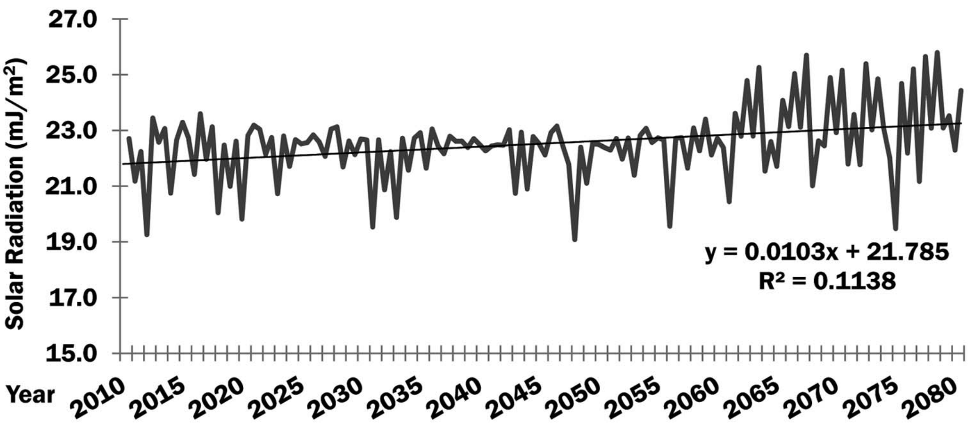

Fig. 3 Seasonal averaged daily solar radiation projected

the off-season in year 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 ($R^2 = 0.1138$). SRAD is one of the main factors influencing biomass and yield production and its quality besides other factors associated with prolonged SRAD in the phase of stem elongation and grain filling while low intensity of SRAD during grain filling phase negatively influences grain yield (Trnka et al., 2001). The yields are correlated with the solar energy received during the 45 days that precede the harvest. Mitin (2009) described the effects of solar radiation as more profound under conditions of which water, temperature and nitrogenous nutrients are not limiting factors.

Similar to average seasonal daily SRAD projected, seasonal total rainfall projected 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 (Fig. 4). The value of R^2 shows that seasonal total rainfall does not show a significant increasing trend ($R^2 = 0.0525$). Normally, rice is grown as lowland crop with standing water as well as upland crop under rainfed conditions. Rice crops use large quantity of water for cultivations. The crops stand water logged conditions. Water is a major constituent of plant tissue as reagent for chemical reactions and solvent for translocation of metabolites. Therefore, water deficit may affect many of the physiological processes such as photosynthesis and transpiration resulting in reduced growth and contributes towards low grain filling (Samonte et al., 2001).Water deficit may affect rice growth and reduces grain yield and quality (Crusciol 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 projected 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 projected weather conditions to analyse the impact of weather trends on yield (Fig. 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

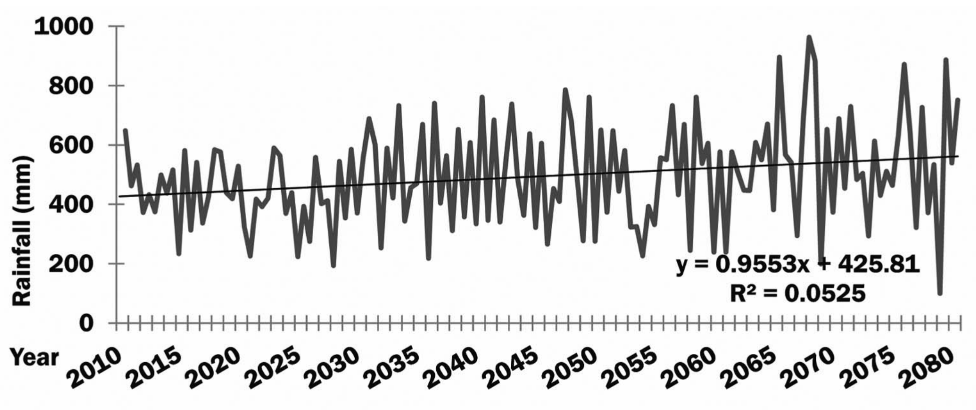

Fig. 4 Seasonal averaged total rainfall projected

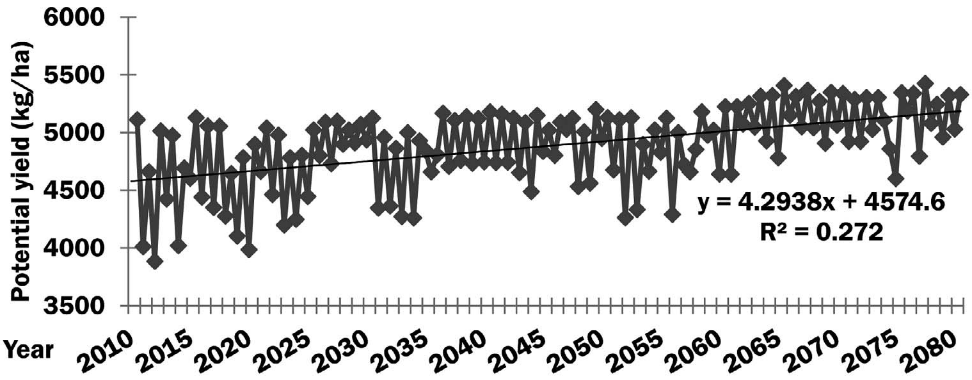

Fig. 5 Simulated potential yield productions

projected 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 t ha^{-1}. Therefore, simulations were carried out to analyse the impact of weather variable trends on yield. Of the four climatic factors used (TMAX, TMIN, rainfalls and SRAD), there are two factors which have the most significant impact on annual production based on the projected values obtained. These two factors are averaged seasonal daily SRAD and seasonal total rainfall.

SRAD in the forms of sunshine contributes significantly to growth development and yield production as it controls photosynthesis process. Similarly to sunshine, water also plays a major role in plant development. In Malaysia, rainfed area relies on rainfall distribution as the main water source for irrigation. Averaged seasonal daily maximum and minimum temperatures are not one of the factors as the value temperature recorded is between 24˚C and 34˚C which are considered as in the range of optimum temperature for rice growth (Singh et al., 1996). Based on the graph (Fig.6), reduced in potential yield productivity simulated likely to occur due to the projected averaged daily solar radiation for the year 2012 and 2020 (both main season) were

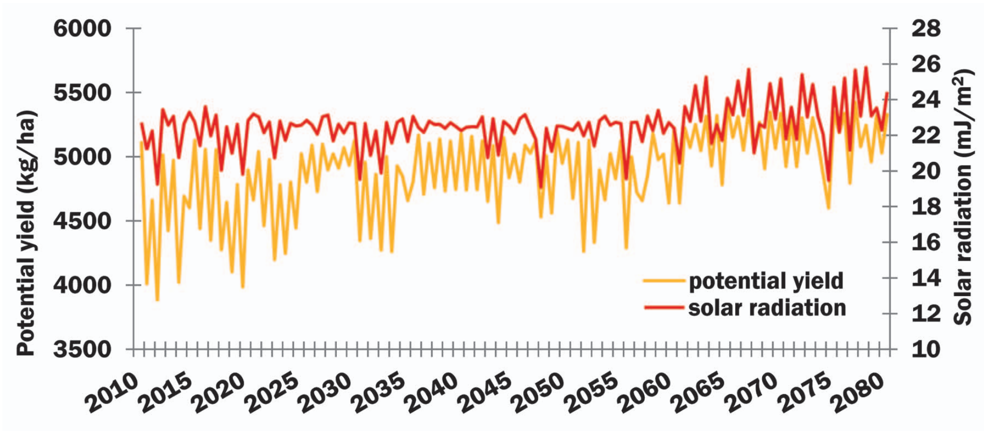

Fig. 6 Potential yield simulated and averaged daily solar radiation projected

below 20 mJ m^{-2}. In addition, Fig. 7 shows that projected 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 projected 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 (Fig. 8 and Fig. 9). 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

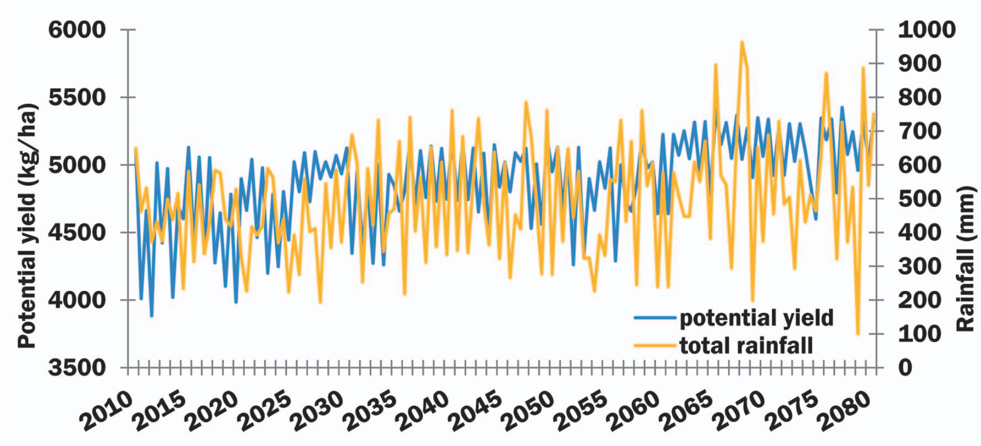

Fig. 7 Potential yield simulated and seasonal total rainfall

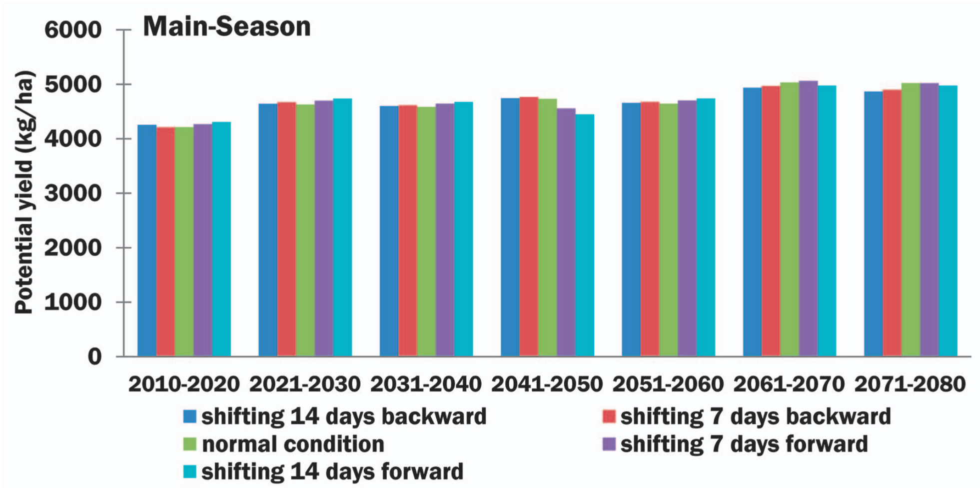

Fig. 8 Potential yield production variations for main season and off-season

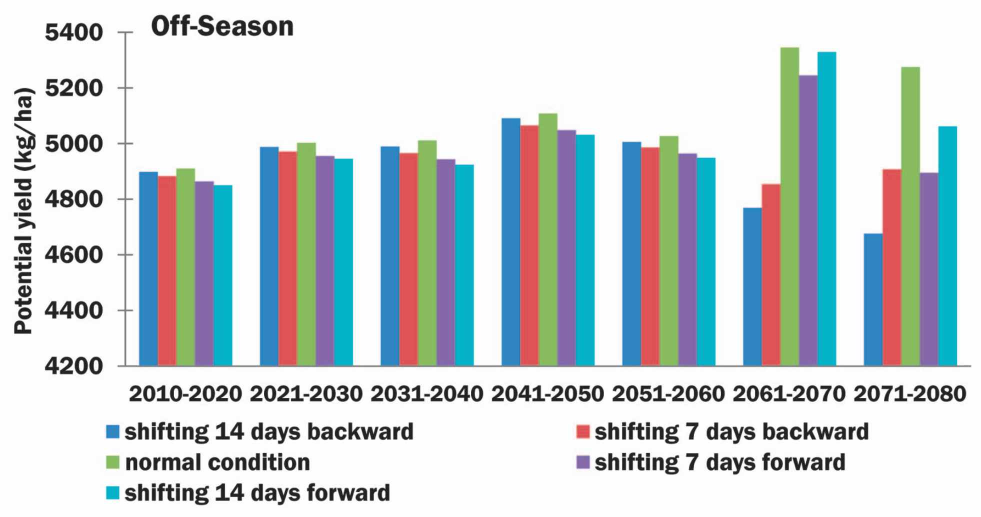

Fig. 9 Potential yield production variations for main season and off-season

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. Conclusions

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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