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Impact of climate change on food security in Malaysia: economic and policy adjustments for rice industry

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ABSTRACT

Rice paddies production in Malaysia, as in other parts of the world, is extremely vulnerable to weather changes and extreme conditions such as drought and flooding. Such situations forced Malaysia to maintain a protectionist regime with respect to its rice industry to better ensure food security for the country. In this study, a crop simulation model (DSSAT) and system dynamics approach were used to assess the impact of climate change on future rice production, self-sufficiency level of rice, and farmers' gross income in Malaysia. Results from the DSSAT model show that during the main and off growing seasons, increase in temperature and changes rainfall pattern can be expected to reduce the rice yield by 12 and 31.3%, respectively, until the year 2030. Based on the system dynamics' results, the reduction in rice yield was expected to reduce farmers' gross income and the rice self-sufficiency level of the country. The study suggested two different policy scenarios to overcome these adverse effects. The overall policy implication is that the Malaysian rice industry cannot be sustained if government takes no action to change its current policies.

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Climate change; food security; self sufficiency level; farmers' income; policy analysis

1. Introduction

Climate change poses challenges for all sectors of an economy, particularly those dependent on natural resources such as agriculture. The relationship between climate change and agriculture is an extremely important issue since the world's food–production resources are under pressure from a rapidly increasing population (Matthews & Wassmann 2003). Hence, one of the most important driving forces in agriculture is the increasing demand for food all over the world. However, potential changes in climate may reduce productivity and output in agricultural industries. Studies have shown that overall agricultural productivity in low latitudes (tropical and semitropical) are likely to decline due to climate change (Rosenzweig & Liverman 1992; Huang et al. 2011). This finding has implications for world food security and farm incomes since most developing countries, including Malaysia, are located in lower–latitude regions. Falling farm incomes will increase poverty and reduce households' ability to invest for a better future.

The rice industry is one of the most highly protected and regulated industries in Malaysia. Policy measures and interventions are aimed at reducing dependency on external sources and protecting incomes of rice farmers, as well as to ensure that rice prices are reasonable for consumers, especially the urban poor. Malaysian rice policy has been formulated to achieve at least three main objectives: First, ensuring food security is a main objective. Since rice is considered a security commodity, national policy is to maintain a prudent level of self-sufficiency, 65% at minimum. The second main objective is to increase productivity and farm incomes. Government support is provided to make rice cultivation financially feasible and to support the rice industry. Government supports farmers by keeping the price of farm products high to boost farm income and by subsidizing the cost of inputs, especially fertilizer, to reduce production costs. The third objective is to ensure a sufficient food supply for consumers at stable, fair prices. To protect the interests of low-income consumers, market forces are allowed to determine rice quality and price, with only one price-controlled grade (MARDITECH 2004). The “Reasonable Returns to Producers and Affordable Price to Consumers” (RRAP) is therefore another rice policy.

Many empirical studies have used different models to investigate the impact of climate change on rice production. At the regional level, ORYZA series (Berge & Kropff 1995) and Decision Support System for Agrotechnological Transfer (DSSAT-CERES-Rice) (Godwine et al. 1990) are the most commonly used models, especially in Asian countries. However, DSSAT (CERES-Rice) received more attention than ORYZA series, because it has been well tested in a range of environments and could simulate the growth and development of rice crop under both upland and lowland conditions (Saseendran et al. 1998; Vaghefi et al. 2013).

A wide variety of models have been used for socio-economic and policy analyses which are mostly based on optimization, econometrics, simulation or system dynamics. The optimization model includes constraints, decision variables, and an objective function (Bazaraa et al. 1990). The main purpose of this model is to find the best outcome like maximum profit or minimum cost. It has been widely applied in area of environmental management and agricultural economics (Zilberman 1982; Solano et al. 2002). Econometrics models deals with statistical analysis of economic data to evaluate economic theories and models (Sterman 2000). It refers to a way of describing economic relationships, especially for short-term forecasting. However, it is not the most sophisticated forecasting tool. Optimization and econometrics models could not show the interrelationship between variables, since it is important to recognize that a change in one variable causes feedback to the others. In this case, the system dynamics (SD) model could be suitable. SD model provides an integrated analysis of policy options related to different issues that occur in complex economics, social, environmental, and managerial systems (Sterman 1988). Because of causality and feedback loops in its analytic framework, SD model would be capable to provide deeper insights than one possible with parameter based optimization and econometrics frameworks.

The SD methodology has been widely used by policy makers and researchers in area of environmental management, decision-making, socio-economics, and agricultural economics to conduct policy-related experiments. For instance, Saysel et al. (2002) used SD approach to analyse potential long-term environmental problems of the South-eastern Anatolian agricultural development project related to water resources, land use, land degradation, and agricultural pollution. For this purpose, a SD simulation model was developed as an experimental platform for policy analysis. They suggested that this SD model could be applied as an experimental laboratory for the policy makers in the future.

Anand et al. (2005) applied SD-based simulation system to estimate the methane emissions from rice field in India. Implications of various policy options was analysed to evaluate their contribution to methane emissions reduction. They used SD approach to develop a model for scenario building, conducting policy experiments and making the projections. They analysed and suggested possible strategies to mitigate the emissions of methane from this sector. Budiharti et al. (2008) examined the effect of postharvest technology input on the increase of rice production. They applied SD to find out the interaction among the elements of rice mills related to each other. The simulation was carried out to evaluate the rice production increase by improving the machine configuration of small scale rice mill that could increase the rice quality and to decrease the loss.

Arshad et al. (2011) assessed the effect of fertilizer and cash subsidies, as well as land conversion and fertility on the self-sufficiency level (SSL) of rice production in Malaysia. They used SD model to analyse the causal and feedback relationships of these variables in the paddy production system framework under six different scenarios. The results indicated that Malaysia may not be able to achieve the targeted SSL without sufficient Research and Development (R&D) to address the production constraints especially below-optimum yield and the threats of climate change. Despite SD is well suited to analyse the policy changes, there are limited published studies in Malaysia that applied this approach in area of environmental and agricultural economics.

In this paper, DSSAT model and SD simulation system are presented to assess the impact of climate change on the Self-Sufficiency Level (SSL) of rice and paddy farmers' income in Malaysia until 2030. Implications of different policy options are analysed to evaluate the various options' contributions to reducing adverse impacts of climate change on the Malaysian rice industry.

2. Materials and methods

2.1. Study area

Around 85.5% of Malaysia's total paddy production is planted in Peninsular Malaysia (Firdaus et al. 2012). The eight main rice production areas there, namely, MADA, IADA PP, Kerian, Seberang Perak, Barat Laut Selangor, KADA, Kemasin, and Ketara, were selected for this study (Figure 1). They cover about 383,990 ha and account for more than 70% of the national rice production. These granary areas are designed as permanent paddy production areas, to realize a minimum self-sufficiency level for rice of 65%. This is one major strategy to increase the country's rice production. Most government subsidies and interventions in the rice sector focus on these granary areas, making them important areas for research and development activities (Firdaus et al. 2012).

Malaysia has a humid, tropical climate that is influenced by complex land-sea interactions and mountainous topography. Due to an increase in tropical storms in South China, both East and West Malaysia have been experiencing more extreme events of rainfall and gusting. The regional climatic trends in Malaysia are in accord with the increase in average surface temperature and large variation in rainfall trends. A higher regional temperature increase is indicated for the western region of Malaysia than for the eastern region. However, the frequency of relatively drier years has increased for the whole of Malaysia (MMD 2009). Of the two major rice-cropping seasons, the main season corresponds with the wetter, northeast

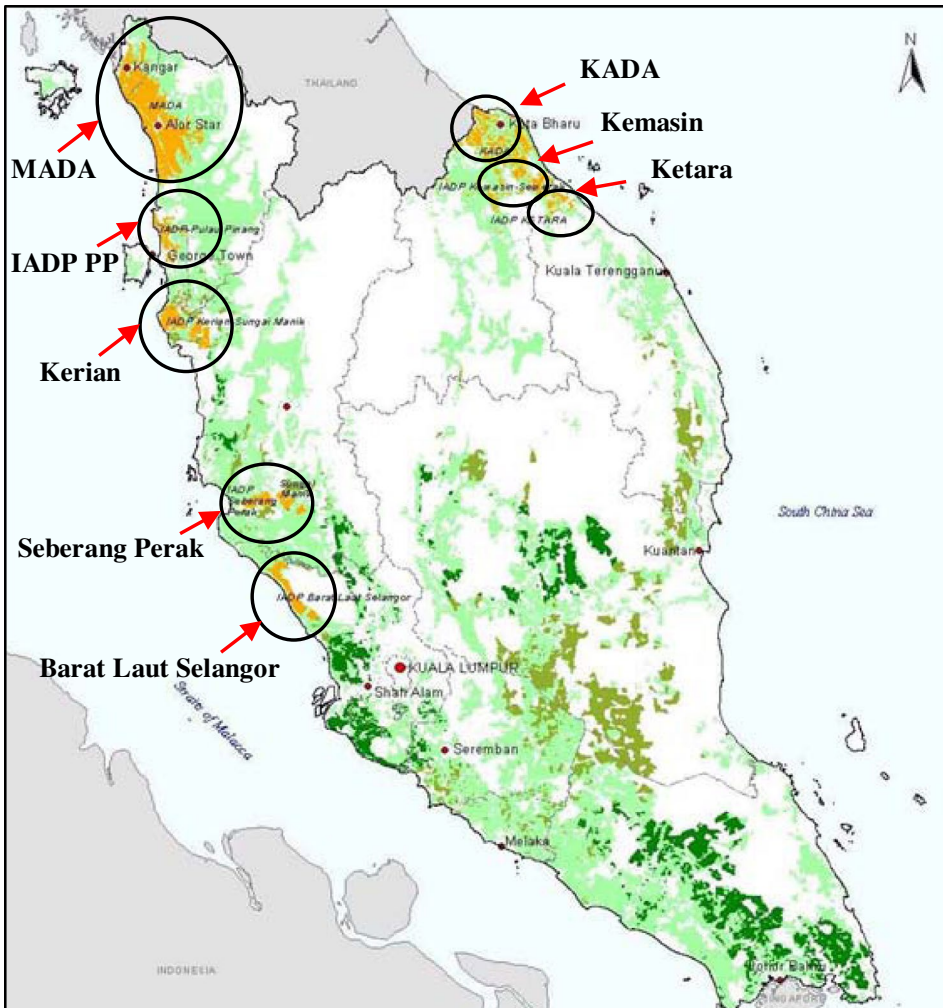


Figure 1. The eight main rice production areas in Peninsular Malaysia. Source: Adapted from NPP (2005).

monsoon, and the off season corresponds with the dry period before the beginning of the southwest monsoon. Generally, rice planting for the main season is from September to December, and for the off season from February to May (Singh et al. 1996).

2.2. Data collection

All the required data in this study are based on secondary data and were collected from several different sources. The daily projected weather data (minimum and maximum temperatures, rainfall, and solar radiation) for 2013–2030 were obtained from the Research Centre for Tropical Climate Change System in National University of Malaysia. These weather data were projected based on the HadCM3-PRECIS climate model under the Special Report on Emissions Scenarios (SRES) A1B IPCC scenarios. The configuration and validation of the PRECIS regional climate simulation results are discussed in Kwan et al. (2013).

An experimental data-set of crop management for rice variety MR-219 from the Malaysian Agricultural Research and Development Institute (MARDI) was used in this study. Data on soil types and their physical and chemical properties were obtained from the soil division in the Department of Agriculture (DOA). All of these datasets were put into the DSSAT model to simulate yields for the years 2013–2030. Historical daily minimum and maximum temperature, rainfall, and solar radiation data for the period of 1998–2011 were obtained from the Malaysian Meteorological Department (MMD). The average rice yield of the overall granary areas for the duration of 1998–2011 was collected from DOA. These two datasets have been used to validate the DSSAT model.

To run the SD model, supplemental statistics such as population growth rate and average human lifetime were obtained from the Department of Statistics (DOS); the per capita consumption of rice, variable cost, fertilizer price, fertilizer subsidy, price support and market price of rice were obtained from the Ministry of Agriculture (MOA) and the Farmers' Organization Authority (LPP) in Malaysia.

2.3. DSSAT model

Crop simulation models are often used to estimate impacts of climate change on agricultural production. They are known to be very useful tools in agricultural research. Specifically, they can help to compare experimental research findings across sites, extrapolate experimental field data to broader environments, develop management recommendations and decision-support systems, examine effects of climate change, and predict yields. In this study, the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al. 2003), a crop simulation model, was applied to predict rice yields in eight granary areas until 2030. The DSSAT model can simulate growth, development, and yield of a crop growing on a uniform area of land under recommended or simulated management, as well as changes in soil water, carbon, and nitrogen that happen under the cropping system over time.

The DSSAT model needs daily weather data (minimum and maximum temperatures, rainfall, and solar radiation), soil data (physical and chemical characteristics of the field), and crop management data (planting date, planting depth, row spacing, etc.). This model is reasonably accurate, process-oriented, simple, and needs minimum data input (Al-Bakri et al. 2010). Hence, it has been widely used for assessing the impact of climate change on crops all over the world (Amien et al. 1999; Felkner et al. 2009; Al-Bakri et al. 2010; Basak et al. 2010).

2.3.1. Calibration and validation of the DSSAT model

DSSAT model calibration is necessary to reduce the root mean square error (RMSE) and increase the accuracy of rice yield prediction. Several adjustable genetic coefficients in the CEREC-Rice module of the DSSAT need to be calibrated before prediction. They are applied in this model to describe the growth and development of rice varieties that differ in such aspects of their maturation as: the thermal units needed to complete the juvenile stage (P1), critical photoperiods (P20), the extent to which phasic development leading to panicle initiation is delayed for each hour increase in the photoperiod above the critical photoperiod (P2R), and the time period from the beginning of grain-filling to physical maturity (P5). Other genetic coefficients that describe growth and yield characteristics are also included, such as the number of spikelets per unit of dry weight of the main culm (G1), the single grain weight under ideal growing conditions (G2), the relative tillering potential (G3), and the

temperature-tolerance coefficient (G4). Calibration of the model was then carried out for the MR-219 rice variety, which most farmers were cultivating in this study’s eight granary areas. Because the genetic coefficients of MR-219 were not available, the estimates were made by repeated iterations until a close match between simulated and observed phenology, growth and yield were obtained.

Crop performance also needs to be calibrated to reduce the RMSE of simulated and observed yields: for example, the date of emergence, date of flowering, date of physical maturity, yield amount, the harvest product’s dry weight of a single grain, and the harvesting date.

For model validation purposes, the daily weather data of the Petaling Jaya station for the period of 1991–2011 was used to run the calibrated model and to simulate rice yield under normal climate conditions. The simulation results were then compared with the DOA’s observed yield data.

2.4. System dynamics model

System dynamics means the “application of the attitude of mind of a control engineer to the improvement of dynamic behaviour in a managed system” (Coyle 1996). It is an approach for analysing and solving complex problems, and focuses mostly on policy analysis and design.

In this study, an SD model is developed for the Malaysian rice industry by establishing a causal loop diagram which shows interrelationships among components of the model with application of each policy option (Figure 2). Each arrow in this diagram shows the effect of one element on the other. If increasing one element causes another to increase, the effect is considered positive (+), or negative (–) in the opposite case.

A stock and flow diagram is then constructed to show details of the model (Figure 3). Stocks, flows, and auxiliary variables are the SD model’s initial components. In this diagram, each stock is symbolized by a rectangular box and needs an initial value. Flows are symbolized by a double-lined arrow with “valves”. The total inflow less total outflow is the rate of change of a stock. The variables that need an initial value and do not vary over the run

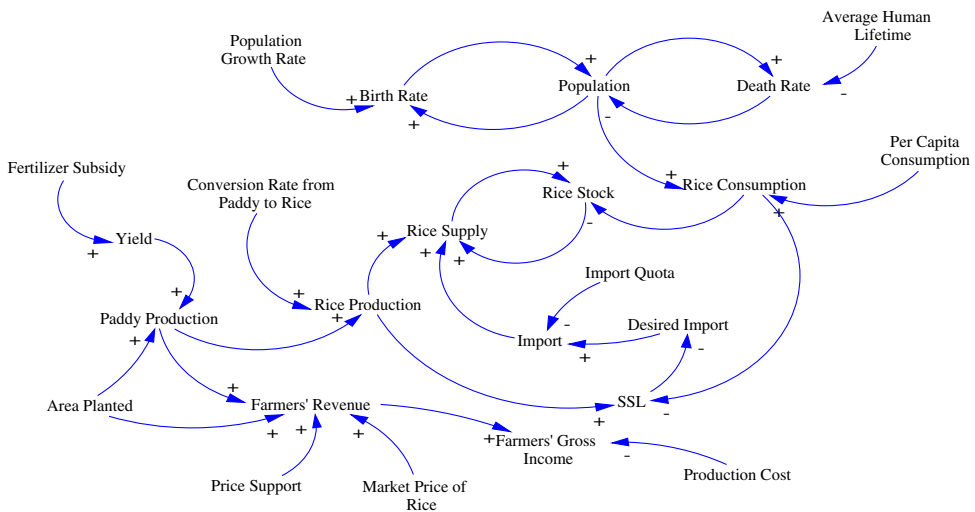


Figure 2. Causal loop diagram of system dynamics model for Malaysian rice industry.

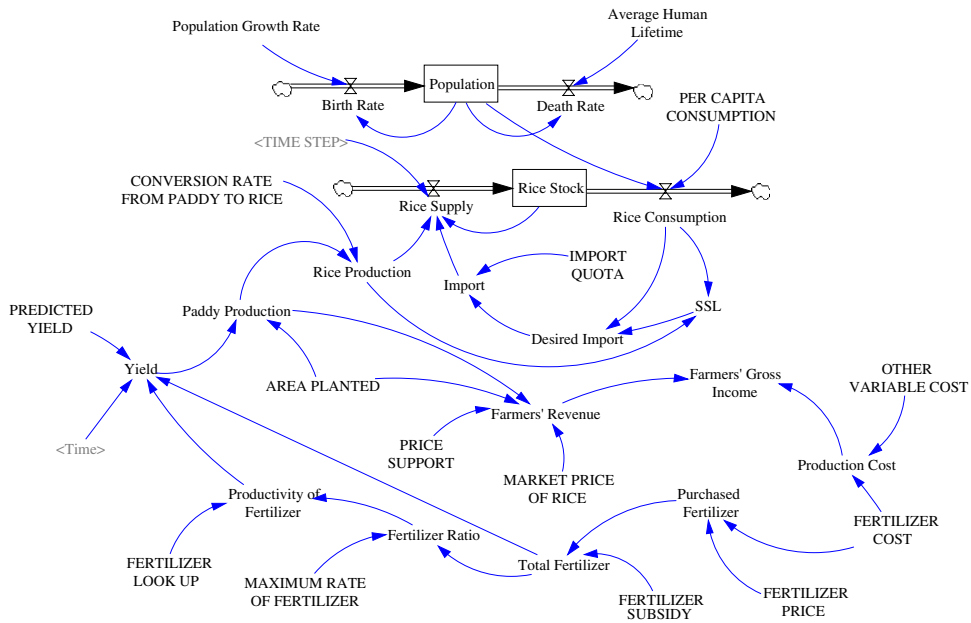


Figure 3. Stock and flow diagram of the Malaysian rice industry.

period of simulation are called *constant* variables. In this diagram, the variables designed with all capital letters are constant variables.

Based on this study's objectives, the stock and flow diagram can be divided into two sections. The first represents the effect of predicted yield on SSL; the second section represents the effect of predicted yield on farmers' gross income. Policy options for improving the Malaysian rice industry are also incorporated in the model. The population and rice stock are taken as stock variables. Paddy production in the first section is affected by area planted and yield. It is obviously linked to rice production. Rice production was estimated by multiplying paddy production by the conversion rate of paddy to rice. SSL is affected by rice production and consumption. Rice consumption was calculated on the basis of per-capita consumption and population. Hence, its variation depends on both the birth rate and death rate. Rice stock as a stock variable was estimated to be the supply of rice less rice consumption. The supply of rice is also affected by rice production and importation. Imports were estimated from the import quota and desired import, which depends on rice consumption and SSL. The dynamo equations used in the model for this section follow:

$$\begin{aligned} \text{Population} &= \text{INTEGRAL}(\text{Birth Rate} - \text{Death Rate}, \text{Population}_{t_0}). \\ \text{Birth Rate} &= \text{Population} * \text{Population Growth Rate}. \\ \text{Death Rate} &= \text{Population} / \text{Average Human lifetime}. \\ \text{Rice Stock} &= \text{INTEGRAL}(\text{Rice supply} - \text{Rice Consumption}, \text{Rice Stock}_{t_0}). \\ \text{Rice Consumption} &= \text{Population} * \text{Per Capita Consumption}. \\ \text{Rice Supply} &= \text{MIN}(\text{Rice Stock} / \text{TIME STEP}, \text{Import} + \text{Rice Production}). \\ \text{SSL} &= \text{Rice Production} / \text{Rice Consumption}. \\ \text{Desired Import} &= (1 - \text{SSL}) * \text{Rice Consumption}. \\ \text{Import} &= \text{IF THEN ELSE}(\text{Desired Import} < \text{Import Quota}, \text{Desired Import}, \text{Import Quota}). \end{aligned}$$

Table 1. Comparisons of actual and simulated data (1991–2010).

Variable	RMSPE (%)	Theil inequality statistics		
		U ^M	U ^S	U ^C
SSL	4.7	0.47	0.003	0.53
Paddy production	6.9	0.84	0.02	0.14
Import	12.9	0.17	0.33	0.50

Rice Production = Paddy Production * Conversion Rate from Paddy to Rice.

Paddy Production = Yield * Area Planted.

Rice production can also be linked to farmers' revenue, which is also affected by area planted, price support, and the market price of rice. Consequently, farmers' gross income was estimated from their revenue and production cost. In this diagram, the production cost is divided into fertilizer cost and other variable cost (e.g. seed purchase, pesticide). Purchased fertilizer depends on fertilizer cost and fertilizer price. The total fertilizer that farmers used was derived from fertilizer purchased by farmers and a fertilizer subsidy given by government. The total fertilizer use can affect land productivity, positively impacting the yield and paddy production. If total fertilizer used is the recommended rate of fertilizer (0.8 tonne ha⁻¹), the yield obtained will be maximized. The equations used for this part of the study follow:

Farmers' Revenue = ((Market Price of Rice + Price Support) * Paddy Production)/Area Planted.

Farmers' Gross Income = Farmers' Revenue – Production Cost.

Production Cost = Other Variable Cost + Fertilizer Cost.

Purchased Fertilizer = Fertilizer Cost/Fertilizer Price.

Total Fertilizer = Purchased Fertilizer + Fertilizer Subsidy.

Fertilizer Ratio = Total Fertilizer/Maximum Rate of Fertilizer.

Productivity of Fertilizer = Fertilizer Look Up (Fertilizer Ratio).

Yield = IF THEN ELSE (Time > 2012, Predicted Yield + (Productivity of Fertilizer * Total Fertilizer), Predicted Yield + (Productivity of Fertilizer * Total Fertilizer * 0)).

2.4.1. Validation of system dynamics model

Appropriate summary statistics to evaluate the historical fit of SD models are discussed in Sterman (1984). To validate the model, the root mean square percent error (RMSPE) is a common, easily interpreted dimensionless measure.

$$\text{RMSPE} = \sqrt{\frac{1}{n} \sum_{t=1}^n \left[\frac{(S_t - A_t)}{A_t} \right]^2} * 100 \quad (1)$$

To know sources of error, the Theil inequality statistics (U^M, U^S, and U^C) were used. The U^M, U^S, and U^C variables represent systematic error, variance proportion and unsystematic error, respectively. They apply to the decomposition of the mean square error:

$$\frac{1}{n} \sum_{t=1}^n (S_t - A_t)^2 = (\bar{S} - \bar{A})^2 + (S_S - S_A)^2 + 2(1 - r)S_S S_A \quad (2)$$

$$r = \frac{\frac{1}{n} \sum (S_t - \bar{S})(A_t - \bar{A})}{S_S S_A} \tag{3}$$

$$U^M = \frac{(\bar{S} - \bar{A})^2}{\frac{1}{n} \sum_{t=1}^n (S_t - A_t)^2} \tag{4}$$

$$U^S = \frac{(S_S - S_A)^2}{\frac{1}{n} \sum_{t=1}^n (S_t - A_t)^2} \tag{5}$$

$$U^C = \frac{2(1 - r)S_S S_A}{\frac{1}{n} \sum_{t=1}^n (S_t - A_t)^2} \tag{6}$$

where S_t and A_t are the simulated and actual values, respectively; \bar{S} and \bar{A} are the means of S and A , respectively; S_S and S_A equal the standard deviations of S and A , respectively; and finally, r is the correlation coefficient between the simulated and actual data. Comparisons of the actual and simulated values for SSL, paddy production, and imports are presented in Table 1 and Figure 4–6, respectively.

RMSPE provides a normalized measure of the magnitude of error and the inequality statistics provide a measure of the total error. The RMSPE value for these variables shows

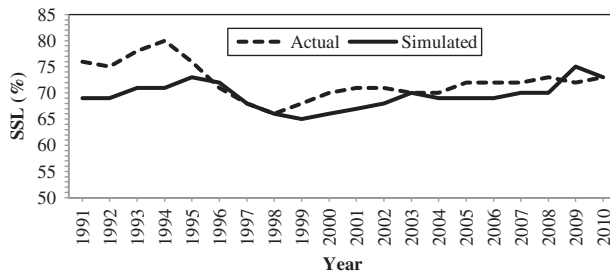


Figure 4. Actual vs. simulated in self sufficiency level.

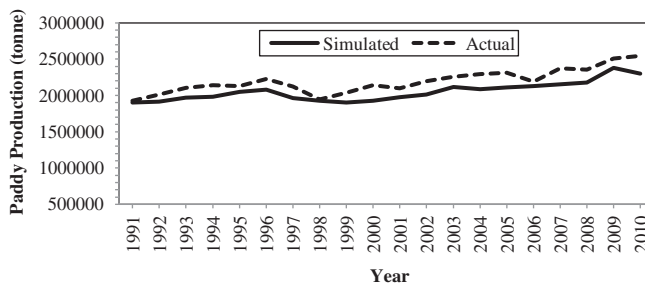


Figure 5. Actual vs. simulated in paddy production.

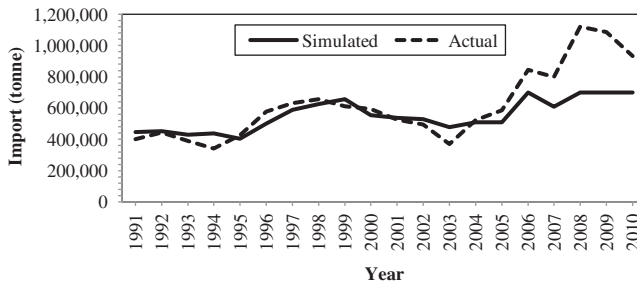


Figure 6. Actual vs. simulated in import.

that the coordination between simulated and actual values is almost good. The inequality statistics, which indicate the source of error, reveal a systematic difference between model and reality, which could be due to elements we didn't consider in the SD model. Since the purpose of this study is to see how changes in yield (due to climate change) can affect certain parameters, such as farmers' gross income and SSL, we considered only the main related parameters. When U^5 is small, the trends in the simulated and actual values are the same, while those for SSL and paddy production are close to zero. In this case, the SD model captures the magnitude of a cyclical mode in the data.

3. Results and discussion

3.1. Effect of climate change on rice yield

The DSSAT crop simulation model, which provides a reasonably good fit between observed and simulated values (RMSPE = 11.2%), was employed to estimate the biological impact of climate change on the rice yield in eight granary areas during the main and off seasons until 2030. In this research, we assumed there to be best management practices, with only climatic factors changed. Since the DSSAT output is input to the SD model as representative of the country's yield, the average predicted yield of each granary area can be calculated. Figure 7 shows the percentage changes in overall yield for all the granary areas combined in the main and off seasons for the duration of 2013–2030.

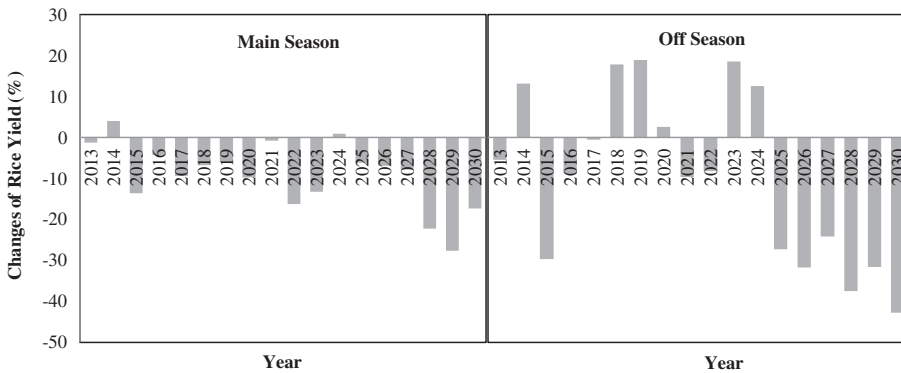


Figure 7. Percentage changes of rice yield for overall granary areas.

These predictions were made using projected weather data based on the HadCM3 model under the A1B scenario. Based on these projected weather data (2013–2030), the average maximum and minimum temperature and rainfall during the main season for the overall granary areas may increase about 0.05 °C and 0.11 mm per year, respectively. Compared to the base value for the granary areas overall, during the main season, the yield was expected to decrease by 12% over the next 18 years. However, the highest reduction in yield was expected for the last three years, which are associated with the highest temperatures. During the main season, the increase in yield due to increased rainfall was less than the reduction in yield due to increased temperatures. Results show that the increase in rainfall could not reduce the adverse impacts of increased temperature on rice yield.

In the off season, yearly increases of the average maximum and minimum temperatures were projected to be around 0.15 and 0.08 °C, respectively. However, average rainfall was projected to decrease by 0.19 mm per year. During this season, the yield also was expected to decline by 31.3% until 2030, with the highest reduction expected for the last six years.

The time periods from emergence to flowering and from flowering to maturity play a critical role in crops' yield, rice included. Basically, longer periods allow for higher yields (Van Oort et al. 2011). In this case, the temperature increase was expected to reduce the length of the growing season, as well as the grain-filling period. The shortened grain-filling period would result in smaller grains, negatively impacting grain yield.

Results from the DSSAT model indicate variations in the predicted yield for different seasons and years. However, increasing temperature and changes in the rainfall pattern were found to negatively impact rice yield in both seasons. During the off season, the reduction in yield was higher than during the main season, due to higher increase in temperature and reductions in rainfall. This showed that temperature and rainfall (water) are the limiting growth factors for rice plants. This negative impact could be greatly mitigated by adjusting the planting date. Once that date is adjusted, the increase in expected rainfall during the main season increase grain yield.

3.2. System dynamics simulation under the baseline scenario

Since this study's purpose is to evaluate the effect of predicted yield on SSL and farmers' income in the SD model, the output of the DSSAT model or the predicted yield (2013–2030), together with actual data (1991–2012) were imported into the SD model (Figure 8). In this research, data for granary areas overall were used because the study attempts to predict national SSL and farmers' gross income.

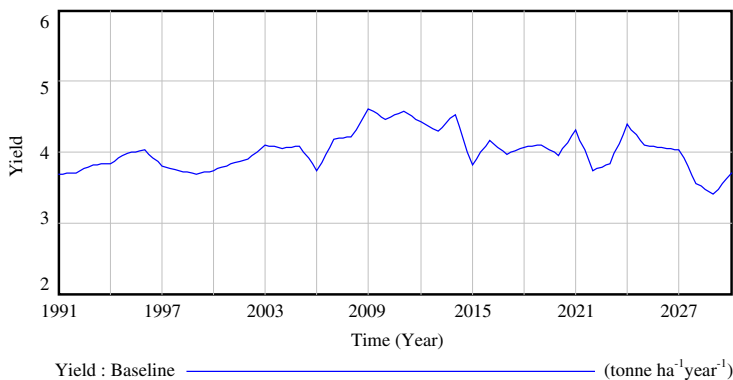


Figure 8. Trend of time series data imported into SD model.

The baseline scenario follows: The price support remains the same, at RM248.10 per tonne; the market price of rice is RM1100 per tonne. The import quota is 700,000 tonnes per year, amount set by government in 2010. The area planted is assumed to be 515,656 ha. The paddy to rice conversion rate is 65%. The population growth rate is also assumed to be constant, at 2.1% per year, and the average lifetime of the population is 74 years.

The baseline scenario's simulation results for SSL and farmers' gross income are presented in Figures 9 and 10. The simulations indicate that a reduction in yield adversely affects SSL and farmers' gross income by 1.2–27 and 15–31%, respectively. Based on Figure 3, a reduction in yield will affect paddy production and consequently, rice production. Since SSL depends on rice production and consumption, decreased rice production is expected to reduce the SSL. The country therefore needs to import more rice for its increasing population and its total rice consumption. However, the import policy stipulated an import quota to protect domestic producers. Thus, if the import quota remains the same until 2030, Malaysia won't have enough rice, as the SSL is declining.

Farmers' gross income is a function of the farmers' revenue and total production cost. The simulated trend for farmers' gross income, presented in Figure 10, shows that income is expected to decrease trend based on predicted yield. Due to the decreasing yield and paddy

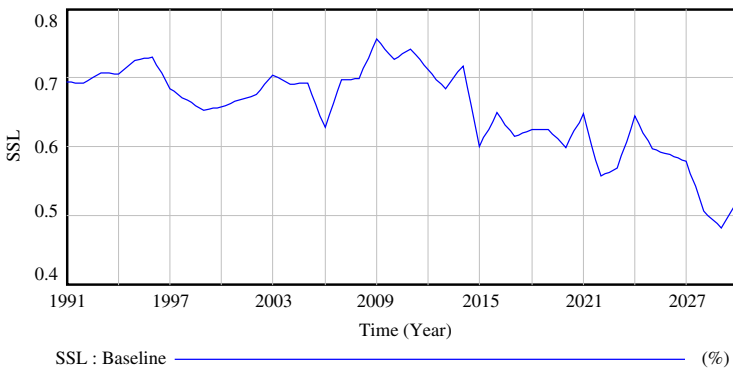


Figure 9. The baseline scenario for SSL.

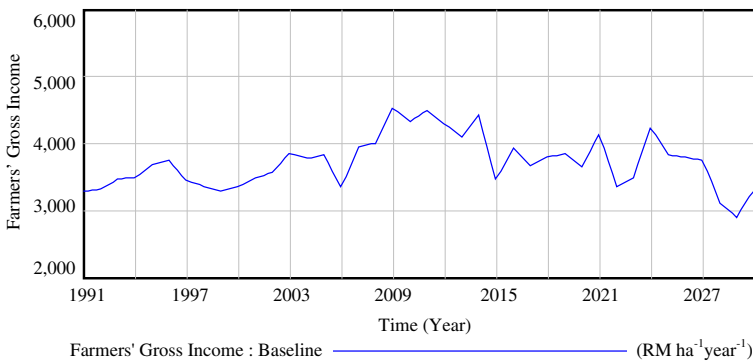


Figure 10. The baseline scenario for farmers' gross income.

production, paddy farmers receive less revenue. At a constant average paddy production cost of about RM1,681.43 per ha (MOA 2012), the projected gross income that farmers earn would also decrease.

Poverty is relatively high among paddy farmers (Chukwukere & Baharuddin 2012). Based on the 9th Malaysian Plan (Malaysia 2008), the poverty line for rural households in Peninsular Malaysia is about RM760.00 per month (RM9,120.00 per year). The average farm size for each paddy farmer is about 3.9 ha. Using that farm size, most farmers would likely earn near to the poverty line until 2030. The poverty line is also expected to increase during the next 18 years (2013–2030), due to the increasing population and incomes. Hence, without any policy changes, most paddy farmers may earn below the poverty line until 2030, according to this simulation.

One of the main aims of this research is to build a model structure for policy makers to formulate policy options, and then find optimal policies with regard to increasing rice yield, and consequently to SSL and farmers' income. Based on this problem statement, optimal policies were found. In order to increase the yield, SSL, and farmers' gross income, the effects of increasing the factors of fertilizer subsidy and price support were analysed.

3.3. Scenario 1: simulation of a doubled fertilizer subsidy

In this scenario, the impact of doubling the fertilizer subsidy for 18 years, from 2013 to 2030, is simulated. A description of Scenario 1 resembles the baseline scenario, differing only in terms of fertilizer used. The simulation results for Scenario 1 are presented in Figure 11.

Based on Scenario 1, doubling the fertilizer subsidy will increase the yield, SSL, and farmers' gross income about 3–4, 0.3–5.6, and 8.3–12.7% per year from 2013 to 2030, respectively. Since paddy farmers heavily depend on subsidized fertilizer, increasing the fertilizer subsidy positively affects yield. This result is consistent with the findings of Abd Razak et al. (n.d). They found that increasing the fertilizer rate could significantly increase the rice yield in granary areas of Peninsular Malaysia. They suggested that to achieve the high yield target set by the Ministry of Agriculture, additional fertilizer should be considered. It could be incorporated into the present policy of fertilizer subsidy to assist poor small-scale paddy farmers. Besides that, applying organic fertilizer can improve rice yield. In addition, applying effective micro-organism could significantly reduce the methane emission. This is a sustainable approach to rice production.

According to Figure 3, the yield depends on fertilizer productivity and the total amount of fertilizer used. In this case, a lookup function was used in order to determine the impact of fertilizer used on yield. If the total fertilizer used equals the recommended rate of fertilizer (0.8 tonne ha⁻¹), the yield obtained will be maximized. Government is subsidizing farmers 0.31 tonne ha⁻¹ of fertilizer; and the remaining fertilizer required should be purchased by paddy farmers. Farmers do not buy all the additional fertilizer required for paddy production, however. So, if government does not change the fertilizer policy until 2030, the country's rice production will face serious problems, due to climate change.

3.4. Scenario 2: simulation of increased price support and fertilizer subsidy

In this scenario, both the fertilizer subsidy and the price support are increased (by 100% – i.e. doubled – and by 10%, respectively). The Malaysian government's policies on rice focus

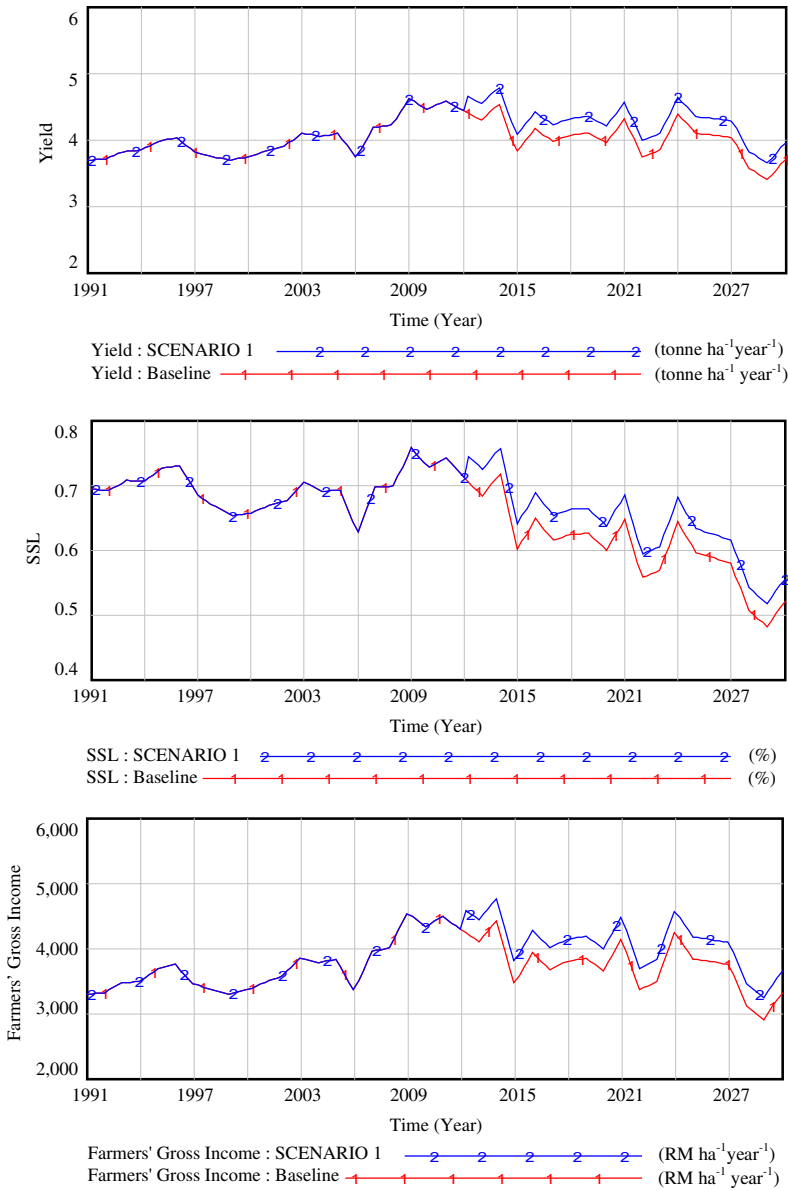


Figure 11. Scenario 1 output (simulation under doubled fertilizer subsidy).

mostly on eliminating poverty. Since poverty among Malaysian paddy farmers is high, the government considers it to be an important and sensitive political issue. Price support, such as by subsidy or incentive, is one means of government intervention in this market sector. Price supports increase the government budget, as well, being funded by sales taxes on consumers. Farmers receive a RM248.10 subsidy for each tonne of rice sold.

The price support impacts mainly the rice industry's financial outputs, e.g. farmers' income, and does not directly impact the increment in yield (Baharumshah 1991; Ramli et al. 2012). We therefore tested only the effect of increasing the price support on farmers' gross income.

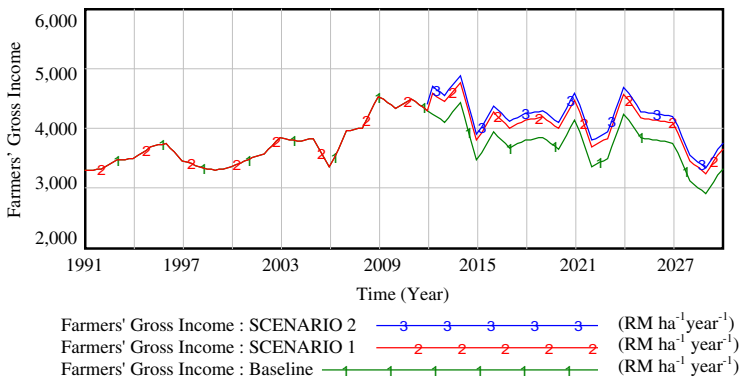


Figure 12. Effect of price support on farmers’ gross income.

Figure 12 indicates the effect of increasing the price support by 10% on farmers’ income from the year 2013 to 2030. In this figure, the lines marked as (1), (2), and (3) show the primary model (baseline) and the effects of a fertilizer subsidy policy and a price support policy, respectively.

The results show that increasing the price support by 10% (i.e. by RM 279.91 per tonne) leads to an increase in farmers’ gross income of 1.7% per year from the year 2013 to 2030. Farmers’ income increases because farmers can earn extra money for each tonne of yield produced based on the particular price support policy implemented.

4. Conclusions

This study’s results show that Malaysian rice production is highly vulnerable to the increasing temperatures and declining rainfall expected with climate change. Hence, the selection of temperature-tolerant rice varieties, adjustment of the planting date, and adoption of soil water conservation could be important adaptation measures. Results also indicate that the DSSAT crop simulation model is useful for tracing the general trend of yields and their possible changes under the climate change scenario. This study also applied a system dynamics approach to investigate the effect of predicted rice yield on farmers’ gross income and SSL of the country. The government as policy-maker has to play the most influential role to support farmers and farm level production by defining appropriate subsidies and incentive programs. Rice policies and investments must be increasingly strategic.

This study proposes, two relevant policy recommendations to policy makers: To increase rice yield, increasing the fertilizer subsidy could be a very good policy option. It could also help to increase the SSL and farmers’ income. Increasing price support also could increase farmers’ gross income as well as encourage farmers to produce more paddies. The overall policy implication is that the Malaysian rice industry cannot be sustained if government takes no action to change current policies. Policy can be implemented best by introducing new cultivation technologies, better management practices, using hybrid varieties, and encouraging farmers to use extra fertilizer.

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