Impacts of climate change on oil palm production in Malaysia

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Abstract

Studies reveal that climate change (CC) has higher negative impacts on agricultural production than positive impacts. Therefore, this article attempts to explore the impacts of CC on oil palm production in Malaysia and provides mitigation and adaptation strategies towards reducing such impacts. The multiple regression analysis is applied to assess the impacts of CC on oil palm production by using time series data in the period of 1980 to 2010. A negative and significant relationship is found between annual average temperature and oil palm production. If temperature rises by 1 °C, 2 °C, 3 °C, and 4 °C, production of oil palm can decrease from a range of 10 to 41%. This article has also found a negative impact of sea level rise (SLR) on oil palm production. Findings reveal that if areas under oil palm production decrease by 2%, 4%, and 8% due to SLR of 0.5, 1, and 2 m, oil palm production can decrease by 1.98%, 3.96%, and 7.92%, respectively, indicating that CC has a significant impact on the reduction of oil palm production in Malaysia, ultimately affecting the sustainability of oil palm sector in Malaysia. Finally, this study suggests to practice appropriate mitigation and adaptation strategies, including promotion and development of climate resilient varieties, soil and water conservation, afforestation, insurance and other risk transfer mechanisms, emission reduction technology, protection of coastal flooding for reducing the impacts of CC on oil palm production.

Keywords Climate change · Oil palm production · Impacts · Mitigation · Adaptation · Malaysia

Introduction

Climate change (CC) is considered one of the largest threats to the economy, environment, and the livelihood of people in different countries and regions. Human activities contribute to CC, which affects human and natural systems in all countries, regions and across the oceans (IPCC 2014a). Anthropogenic emissions of greenhouse gases (GHGs) are increasing over time, leading to rise of global temperature (IPCC 2007a, 2014a). The global average temperature increased by 0.85 °C from 1880 to 2012 (IPCC 2014a). Thus, the increased global temperature contributes to the rise of sea level. Global average sea level rose at an average rate of 1.8 mm per year from 1961 to 2003 and at an average rate of 3.1 mm per year from 1993 to 2003; the total sea level rise (SLR) of the twentieth century is estimated by 0.17 m (IPCC 2007a). Therefore, the increasing trend of temperature and sea level is already affecting many countries and regions.

Agriculture is one of the most vulnerable sectors to the risks and impacts of global CC (Parry and Carter 1989; Reilly 1995; Reilly et al. 1996). Despite the technological advances and Green Revolution, weather and climate remain as key factors in determining agricultural productivity in most areas of the world. Changes in temperatures and rainfall patterns, as well as their associated impacts on water availability, pests, diseases, and extreme weather events all substantially affect the potential of agricultural production (Zhai and Zhuang 2009). However, the impacts of CC are not felt equally across the world because of its spatial level variability

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(Challinor and Wheeler 2008). The impacts can differ in different continents, countries, and regions. Certain nations may likely experience more adverse effects than others, whereas other nations may benefit from CC (EPA 2016). Thus, CC can have positive and negative impacts on spatial level of agricultural production. However, studies suggest that the negative impacts of CC can be higher than positive impacts (IPCC 2012). Research on the economics of CC indicates that although global crop production may be slightly boosted by global warming in the short term (before 2030), it can ultimately turn negative over the long term ((Bruinsma 2003; IPCC 2007b).

However, the impacts of CC on agricultural production can vary amongst crops and regions (Zhai and Zhuang 2009; IPCC 2014b). A growing evidence is found amongst the scientific community that changing temperatures and precipitation levels caused by CC can be unfavorable for crop growth and yield in many regions and countries (Yesuf et al. 2008). Low latitude and developing countries are expected to suffer from the agricultural effects of global warming, reflecting their disadvantaged geographic location, great agricultural share in their economy and limited ability to adapt to CC. By contrast, crop production in high latitude regions can generally benefit from CC. Cline (2007) conducted a global comprehensive estimate for over 100 countries and predicted that without global warming mitigation, global agricultural productivity can fall by 15.9% in the 2080s, whereas developing countries can experience a disproportionately large decline of 19.7%.

The frequency and severity of extreme weather events increase due to CC, which significantly damage agricultural production. Huang et al. (2014) estimated that annual average crop area suffering from drought in China increased from 11.6 million ha in the 1950s to 25.1 million ha in the first decade of the twenty-first century. Crop production can reduce more or less in all regions, except Australia and New Zealand due to temperature rise (Calzadilla et al. 2013). Such an estimation is shown in Table 1. Southeast Asia is predicted to face the highest loss in crop production with the rise of temperature. Table 1 presents the crop yield responses to changes in temperature in different countries and regions.

The agriculture sector plays a significant role in Malaysia's development even though its share to the GDP dropped from 30% in the 1970s to only 7% in 2013 (Othman and Jafari 2014). The sector comprises various sub-sectors, including, rubber, livestock, forestry and logging, fisheries, aquaculture and other agriculture (paddy, fruits, vegetables, coconut, tobacco, tea, flowers, pepper, cocoa, and pineapple) (MPC 2015). Malaysia's agriculture is largely dominated by oil palm production, which contributed 36.6% to the agriculture sector in 2014 (DoS 2015). The country is the world's largest exporter and second-largest producer of palm oil after Indonesia. Malaysia accounts for 39% of the world's palm oil production and 44% of the world's exports (MPOC 2014). Thus, oil palm

Table 1 Crop yield responses to changes in temperature by crop type in different regions

Region	Temperature			
	+ 2 °C		+ 4 °C	
	C3 crops	C4 crops	C3 crops	C4 crops
USA	− 18.67	− 10.67	− 34.00	− 20.33
Canada	− 21.14	− 21.14	− 37.14	− 37.14
Western Europe	− 4.06	− 1.06	− 12.71	− 9.82
Japan and South Korea	− 10.33	− 4.50	− 18.00	− 17.83
Australia and New Zealand	10.59	10.59	− 1.57	− 1.57
Eastern Europe	− 4.06	− 1.06	− 12.71	− 9.82
Former Soviet Union	− 21.50	− 21.50	− 39.00	− 39.00
Middle East	− 17.29	− 13.03	− 29.32	− 24.95
Central America	− 13.93	− 8.81	− 29.08	− 18.87
South America	− 14.57	− 10.37	− 30.20	− 19.83
South Asia	− 16.38	− 16.38	− 30.49	− 30.49
Southeast Asia	− 23.71	− 23.71	− 43.60	− 43.60
China	− 0.67	− 7.00	− 7.33	− 17.00
North Africa	− 17.29	− 13.03	− 29.32	− 24.95
Sub-Saharan Africa	− 10.91	− 10.91	− 25.40	− 25.40
Rest of the world	− 13.93	− 8.81	− 29.08	− 18.87

Source: Calzadilla et al. (2013) based on Rosenzweig and Iglesias (1994) and Zhi-Qing and Zhu (2008). Note: Rice, wheat, vegetables, fruits, nuts, oil seeds and other agricultural products are considered C3 crops. Cereal grains, sugar cane, and sugar beet are considered C4 crops

cultivation and production are important for Malaysia's economy. However, CC increases the intensity and severity of phenomena such as drought, heat stress, heavy precipitation, and flood, all of which have potential impacts on crop production. Malaysian Palm Oil Board reported that oil palm production (oil palm fruit) has declined due to the direct and indirect uncertainties of CC (MPOB 2010). Zainal et al. (2012) estimated that CC has significant nonlinear impacts on the net revenue of oil palm production. Paterson et al. (2015, 2017) recognized the negative impact of CC on oil palm production, especially in tropical countries. Their studies are considered critical for the understanding of CC effect on oil palm production. Furthermore, Paterson and Lima (2018) projected 30% decrease of oil palm production in Malaysia if temperature increases 2 °C above optimum level and rainfall decreases by 10%. Paterson (2019a) estimated that oil palm production can be significantly reduced after 2050 due to the predicted unsuitable climate for growing oil palm. Moreover, the unsuitability of the climate for oil palm is predicted to dramatically increase after 2050. By contrast, Paterson (2019b) projected that oil palm resistance to CC can deteriorate between 2070 and 2100. This projection can make oil palm production unsustainable. Thus, the impacts of CC on oil palm production can be enormous due to climate severity and intensity, for

instance, the land for oil palm production can be dry and degraded, and oil palm plantation can become susceptible to diseases and pests due to temperature rise. Therefore, the present study attempts to assess the relationship between CC and oil palm production, especially the impacts of CC on oil palm production in Malaysia.

Data and methods

Data sources

To assess the relationship between CC and oil palm production, particularly the impacts of CC, this study has used secondary data related to production area, oil palm production and annual average temperature in Malaysia. Data for production and area under oil palm production have been extracted from the Department of Statistics (DoS 2014), whereas the annual average temperature has been collected from the Malaysian Meteorological Department (MMD 2014). All data are based on the period 1980–2010 in Malaysia and are presented in Table 7 in Appendix.

Determination of CC states

This study has assessed the impacts of CC in terms of temperature rise and SLR on oil palm production. Several CC states for Malaysia have been determined through this research. Several global and Malaysian studies have projected an increase of temperature ranging from 1 to 4 °C by the end of 2100 (IPCC 2007a; NRS 2001; MMD 2009).

According to IPCC (2007a), global surface temperature can increase by 1.8 °C and 4.0 °C based on the low emission scenario (B1) and the high emission scenario (A1FI), respectively. In the case of Malaysia, the projected temperature increases based on the A1B scenario using Atmosphere-Ocean General Circulation Models for East Malaysia and Peninsular Malaysia are 1.0 °C–3.5 °C and 1.1 °C–3.6 °C, respectively (MMD 2009). Considering the high greenhouse gas emission, the temperature in Malaysia is projected to rise by 0.3 °C–4.5 °C (NRS 2001). Therefore, this study has determined four states of CC in Malaysia, such as 1 °C, 2 °C, 3 °C, and 4 °C, temperature rise by the end of the twenty-first century. These different degrees of temperature have been transformed into percentage increases of temperature on the basis of the level of average annual temperature in 2010, as shown in Table 2. This transformation of temperature is done for assessing the impacts of temperature increase on oil palm production by using a multiple regression model (MRM), which provides the percentage (%) loss of oil palm production due to temperature rise.

Meanwhile, sea level increases due to global warming and ice melting. Global sea levels rose from 10 to 25 cm over the last century and are expected to rise approximately

Table 2 CC states of temperature rise by 2100 in Malaysia

CC states of temperature rise (°C)	Temperature increase (%) (base year: temperature of 2010)
1	3.57*
2	7.15
3	10.72
4	14.29

*The annual average temperature of 2010 in Malaysia was 27.99 °C. If temperature increases by 1 °C, then the percentage increase of temperature can be 3.57%

0.5 m by 2100, equivalent to a two- to five-fold acceleration (Warrick et al. 1996). A range of estimates, such as 0.09–0.88 m (IPCC 2007a), 0.2–2.0 m (Parris et al. 2012), 0.5–1.4 m (Rahmstorf 2007), 0.55–1.10 m (Vellinga et al. 2008), and 0.8–2.0 m (Pfeffer et al. 2008), is found for the projected SLR by 2100. Malaysia also faces an increase in the sea level by 1.3 mm per year (DID 2007). Thus, the present study has also taken CC states for SLR by 0.5, 1, and 2 m by the end of the twenty-first century. Then, the loss of production area (land) for oil palm has been determined due to the increase of sea level by 0.5, 1, and 2 m. It has been estimated that with 1 m rise of sea level, Malaysia would lose of its 7000 km^2 land area if no adaptation measures are taken (Nicholls et al. 1995). According to Initial National Communication, Malaysia would lose 1,00,000 ha of oil palm land and 80,000 ha of rubber land due to 1 m sea level rise (INC 2000; Chong 2000; Al-Amin et al. 2011). Moreover, one third of Kedah rice field (Malaysia's biggest rice zone) is situated in coastal areas, which are at risk due to sea level rise (Hakim et al. 2010). Moreover, Malaysia's Second National Communication (NC2) also stressed that Malaysia may face a decrease in agricultural lands due to sea level (MNRE 2010). Based on the previous studies and reports, and considering other risk factors, such as salinization, erosion and coastal flooding, this study has assumed that another 80,000 ha of agricultural land (for rice, fruits, vegetables, food crops, and others) might be inundated due to 1.0 m sea level rise by the end of twenty-first century. Thus, about 2,60,000 ha of agricultural land out of 6,891,000 ha might be lost due to 1.0 m sea level rise which is about 4% of total agricultural land. However, according to the simple proportional relationship, the present study assumes that Malaysia can lose 2%, 4%, and 8% of oil palm production area due to 0.5 m, 1.0 m, and 2 m SLR, respectively. Assembly, production may be affected if production area decreases. Considering this possibility, the present study has considered the total area of oil palm production as a variable of SLR. The percentage loss of oil palm production is calculated using the multiple regression analysis, which reveals the relationship between area under oil palm production and oil palm production.

For assessing the impacts of CC on oil palm production, this study has measured production loss for the seven states of CC, such as temperature rise by 1 °C, 2 °C, 3 °C, and 4 °C and SLR by 0.5, 1, and 2 m. The study has calculated the percentage increase of temperature from the degree of temperature rise and the percentage loss of oil palm production area from SLR, which is used for the interpretation of multiple regression analysis as the variable converted into logarithm. The linkages between CC states and loss of oil palm production are displayed in Fig. 1.

Multiple regression model

This study has used multiple regression analysis, which is a powerful technique for predicting the value of Y (dependent variable) for given values of $X_1, X_2\ldots, X_k$ (independent variables). Multiple regression analysis is conducted when one is interested in predicting a continuous dependent variable from several independent variables. Multiple regression has one dependent variable whose value is to be predicted and two or more independent (exploratory) variables. In general, the multiple regression equation can be written as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots\ldots\ldots\ldots\ldots + b_kX_k$$

Multiple regression model (MRM) has been employed to investigate the relationships and impacts of CC variables, such as temperature and SLR on oil palm production, by using time series data. For temperature rise, the time series data of the annual average temperature from 1980 to 2010 have been used. In the case of SLR, the annual data for SLR are unavailable for Malaysia. Moreover, if sea level rises, Malaysia may face a decrease of oil palm production area that can affect production (INC 2000; Hakim et al. 2010). Therefore, this study has considered the total area of production as a variable of SLR. Based on a production function framework, a model for oil palm production has been estimated using the ordinary least squares (OLS) approach. The assumption is that oil palm production is a function of oil palm production area and annual average temperature. Note that the time series data of this study are found to be nonstationary. Logarithmic transformations (double log transformation) have been employed for all the variables to make the relationship effective (Benoit 2011).
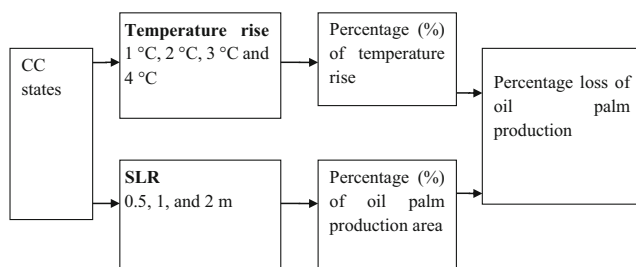

Fig. 1 Linkages between CC states and loss of oil palm production

Given that dependent and independent variables are log-transformed, the coefficient interpretation of MRM has been given as the percentage change in dependent variable when independent variables increase by certain percentages. An MRM for oil palm production has been conducted with production area and climate variables, such as annual average temperature. This study has regressed oil palm production by production area and temperature variables using a time series data of 31 years (1980–2010). The regression equation is provided as follows:

$$\mathrm{Log(OPPN)} = \beta_0 + \beta_1\mathrm{Log(AOP)} + \beta_2\mathrm{Log(TEM)}$$

where

OPPN   oil palm production (t)
AOP   area of oil palm production (ha)
TEMP   annual mean temperature (°C)

To avoid spurious results, augmented Dickey-Fuller (ADF) test has been conducted to examine each variable for the presence of a unit root, which indicates stationarity. The ADF test minimizes autocorrelation in the error term because it involves the first difference in lags, such that the error term is distributed as white noise. The modified regression equation for ADF test is shown as follows:

$$\Delta\mathrm{Log(OPPN)} = \beta_0 + \beta_1\mathrm{Log(AOP)}_{t-1} + \beta_2\mathrm{Log(TEM)}_{t-1}$$

To assess the impacts of CC variables on oil palm production, all the variables have been tested and subjected to stationarity through ADF. Doing so can also ensure the order of integration of the variables. The unit root test attempts to determine whether the given time series data are consistent with a unit root process, as the presence of unit roots can lead to false inferences in regression amongst time series (Mbanasor et al. 2015). The results of the ADF unit root test are presented in Table 3. All the variables are found non-stationary at certain levels. However, the coefficients, compared with the critical values, suggest that all the variables are stationary at first difference. The null hypothesis of nonstationarity is also rejected. Therefore, the variables are stationary. This conclusion implies that the variables are integrated in order one. Thus, the nonstationary time series data have been converted into stationary data by logarithmic transformations and unit root test. Data processing and logarithmic transformation have been done using Excel, whereas Eviews software has been used to run unit root test and regression model.

Finally, the loss of oil palm production for temperature and SLR has been calculated using the coefficient analysis of MRM by the following equations:

$$\mathrm{LOPP_{TR}} = \mathrm{Coeff_{TEM}} \times \%\mathrm{TR}$$
$$\mathrm{LOPP_{SLR}} = \mathrm{Coeff_{AOP}} \times \%\mathrm{AOPL_{SLR}}$$

where

Table 3 Result of unit root test for the time series data

	ADF statistics (level)	Order of integration	ADF statistics (first difference)	Order of integration
Oil palm production	− 2.333629	I(0)	− 6.792017***	I(1)
Production area	− 2.148914	I(0)	− 4.949034***	I(1)
Annual average temperature	− 0.233650	I(0)	− 5.260076***	I(1)

***The ADF test statistics are significant at 1% level, whereas − 4.1498, − 3.5005, and − 3.1793 are the Mackinnon critical values for the rejection of the hypothesis of unit root applied at 1%, 5%, and 10% levels, respectively (Mbanasor et al. 2015)

$LOPP_{TR}$	loss of oil palm production (%) due to temperature rise
$Coeff_{TEM}$	coefficient of annual average temperature
%TR	percentage of temperature rise
$LOPP_{SLR}$	loss of oil palm production (%) due to SLR
$Coeff_{AOP}$	coefficient of oil palm production area
$%AOPL_{SLR}$	percentage of production area loss due to SLR

Results and discussion

Trend of oil palm production and its area

Oil palm production is crucial for the economy of Malaysia, as the country is the world's largest exporter and second-largest producer of palm oil after Indonesia. Malaysia is an important global player in terms of palm oil production and export (MPOC 2014). The palm oil industry is a significant source of employment with a total labor force of 1.16 million people, representing 40.45% of the employment in the agriculture sector in Malaysia. The area under oil palm production in Malaysia (oil palm estate) has significantly increased over the years from 0.55 million ha in 1980 to 4.4 million ha in 2012, as illustrated in Fig. 2. Palm oil production in Malaysia has also sharply increased over the years, with 7.64 million tons in 1980 and reaching 69.83 million tons in 2012. With the increase in production and prices, the contribution of palm oil

to the national economy has risen over the years. The gross production value of palm oil significantly increased from RM 7018 million in 1980 to RM 193022 million in 2012. The increasing trend of oil palm production and its area is presented in Fig. 2.

Relationship between CC and oil palm production

This study has investigated the relationship between CC variables and oil palm production by using MRM on the basis of the time series data from 1980 to 2010. Although oil palm production depends on many factors, such as area, temperature, rainfall, labor, and capital, this research has considered production area and annual average temperature, as they are the major influencing factors of oil palm production. Annual average temperature and production area have been treated as independent variables. In addition, oil palm production has been considered a dependent variable. The estimated results of the MRM of oil palm production are presented in Table 4. The final multiple regression equation is estimated by using the coefficient results of the determining factors affecting oil palm production as follows:

$$\Delta Log(OPPN) = 9.43 + 0.99(AOP)_{t-1} - 2.85(TEM)_{t-1}$$

The results of this model are satisfactory and appropriate. The model has found that most predictions are correct. The R^2 value is 0.70, which is found to be high. The R^2 value is 0.70,

Fig. 2 Trend of oil palm production and its area in Malaysia in the period 1980–2012
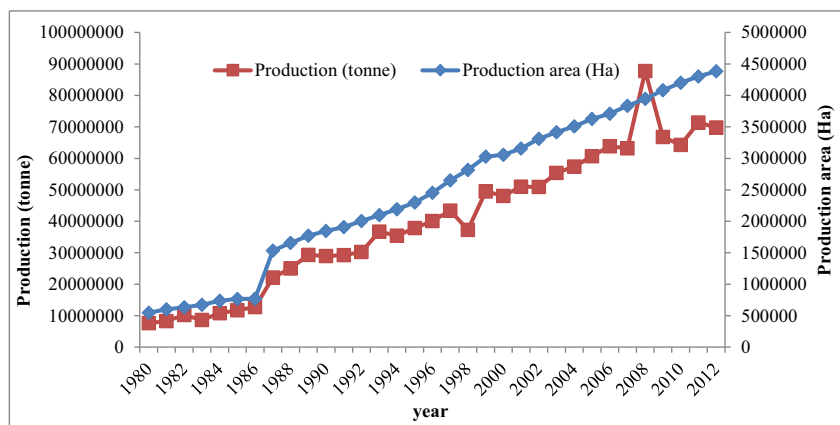
Table 4 Multiple regression results for oil palm production

Dependent variable: oil palm production (OPPN)				
Method: OLS				
Sample (adjusted): 1981–2010				
Included observations: 30 after adjustments				
Variable	Coefficient	Standard error	t-Statistic	Probability (Prob.)
Constant	9.426569	3.507230	2.687754	0.0122
Production area (AOP)	0.990641	0.150637	6.576368	0.0000***
Temperature (TEM)	−2.851922	1.060462	−2.689319	0.0121**
R-squared	0.697963	Mean dependent variable		0.071011
Adjusted R-squared	0.675590	Standard deviation dependent variable		0.154259
Standard error of regression	0.087862	Akaike info criterion		−1.931468
Sum of squared Residual	0.208431	Schwarz criterion		−1.791348
Log likelihood	31.97202	Hannan–Quinn criterion		−1.886642
F-statistic	31.19649	Durbin–Watson statistic		2.783202
Prob. (F-statistic)	0.0000*			

**Significance at 0.05% level; ***significance at 0.01% level

which indicates that 70% of the variation in oil palm production can be explained by the variables included in model, and the remaining 30% can be explained by other variables, which are excluded in the model. The model also shows that each independent variable is significant to explain the dependent variables. In addition, the P value is an important statistic, which is related to the test of significance. The P value of production area is 0.00, representing the significant relationship between oil palm production and its area. The P value of temperature is 0.012, suggesting a significant relationship between temperature and oil palm production. Moreover, the Prob. (F-statistic) is 0.00 (< 0.05), which indicates that all independent variables are jointly significant to influence/explain the dependent variables. The Durbin–Watson statistic is 2.78, revealing no serial autocorrelation amongst the residuals.

The result of MRM shows a positive relationship between production area and oil palm production and a negative relationship between annual average temperature and oil palm production. The coefficient of production area is 0.99, which indicates that if the area for oil palm production increases by 1%, then oil palm production can increase by 0.99%. Moreover, if area for oil palm decreases by 1%, oil palm production can decrease by 0.99%. Given that the dependent and independent variables are log-transformed, the coefficient interpretation of MRM has been treated as percentage change in dependent variables when independent variables increase by certain percentages. As previously stated, a negative relationship exists between oil palm production and annual average temperature. If temperature increases, then oil palm production can decrease and vice versa. The coefficient of annual average temperature is −2.85, which indicates that if temperature increases by 1%, then oil palm production can reduce by 2.85%. The result is in line with Caswell et al. (2001) where they found that a 1% increase in temperature leads to a 1.5%

decrease in crop yield. If temperature increases, then water evaporation increases, leading to further cloud formation. Great amount of clouds can reduce the amount of solar radiation reaching the oil palm fields. High temperature can also increase the respiration and hamper the growth of plants; such an increase can ultimately reduce net gain in the form of grain yield (Rasul et al. 2011). Some studies confirm that oil palm is susceptible due to CC and its related disease, which hampers its growth and production (Paterson and Lima 2018; Paterson 2019b).

Impacts of CC on oil palm production

The present study has explored the impacts of CC on oil palm production from the result of multiple regression analysis. Weather and climate are the key factors in determining agricultural productivity in most areas of the world (Zhai and Zhuang 2009). The result shows that oil palm production is negatively related to CC. Moreover, temperature rise has a significant and negative relationship with oil palm production. The impacts of temperature rise on oil palm production are presented in Table 5. It reveals that if temperature increases by 1 °C (3.57%), 2 °C (7.15%), 3 °C (10.72), and 4 °C (14.29%), then oil palm production can decrease in Malaysia by 10.17%, 20.38%, 30.55%, and 40.73%, respectively. However, the NC2 of Malaysia has predicted that if temperature increases by 2 °C from the optimum levels and rainfall decreases by 10%, oil palm yield can decrease by 30% in the country (MNRE 2010). Zainal et al. (2012) projected that an increase in rainfall and high temperature can negatively impact oil palm production. Therefore, the negative impacts of temperature rise on oil palm production reveal that if temperature rises by 1 °C, 2 °C, 3 °C, and 4 °C, oil palm production can fall at 10–41%. However, the projected loss of oil palm production

Table 5 Impacts of temperature rise on oil palm productions

Temperature rise	Loss of oil palm production (%)
1 °C* (3.57%)	10.17
2 °C (7.15%)	20.38
3 °C (10.72%)	30.55
4 °C (14.29%)	40.75

*For 1 °C temperature rise, $LOPP_{TR} = Coeff_{TEM} \times \%TR = -2.85 \times 3.57 = 10.17$

is found comparatively lower than that of NC2 and Paterson and Lima (2018) for rising of 2 °C temperature. Nevertheless, this projected loss is close to Cline's (2007) prediction on global agricultural productivity loss, which might decrease 15.9% globally and 19.7% for developing countries in the 2080s due to global warming.

Similarly, SLR also has negative impacts on oil palm production estimated by the loss of oil palm production area due to SLR. Table 6 shows how the coefficient value of production area has been used to calculate the percentage loss of oil palm production due to SLR. The coefficient value has been obtained from the results of multiple regression model. The finding also reveals a positive relationship between production area and oil palm production, indicating that if the production area for oil palm decreases by 1%, oil palm production can be reduced by 0.99%. Thus, if production area under oil palm decreases by 2%, 4%, and 8% due to SLR of 0.5, 1, and 2 m, oil palm production can decrease by 1.98%, 3.96%, and 7.92%, respectively. Therefore, the SLR of 0.5, 1, and 2 m may result in a loss of oil palm production along the range of 2–8%. The impact results of SLR are also similar with those obtained in certain studies. Dasgupta et al. (2009) revealed that Vietnam can lose 7% agricultural land due to 1 m SLR, whereas Chen et al. (2012) estimated that global rice production can decrease from 1.60 to 2.73%.

Conclusion and potentials for mitigation and adaptation strategies

Agriculture sector plays a dual role in CC. On one hand, agricultural production is affected due to CC in terms of temperature rise and SLR. On the other hand, agriculture sector

Table 6 Impacts of SLR on oil palm production

SLR	Loss of oil palm production (%)
0.5 m* (2% loss of production area)	1.98
1 m (4% loss of production area)	3.96
2 m (8% loss of production area)	7.92

*For 0.5 m SLR, $LOPP_{SLR} = Coeff_{AOP} \times \%AOPL_{SLR} = 0.99 \times 2 = 1.98$

activities contribute to the production of GHG emissions, which cause CC. Agriculture and related land use changes are estimated to contributed approximately 17% of world's anthropogenic GHG emissions in 2010 (Richards et al. 2018). The negative relationship between CC variables and oil palm production indicates a reduction of oil palm production with the rise of temperature and sea level. Thus, the findings demand for urgent need to implement both mitigation and adaptation strategies to reduce the negative impacts of CC on agriculture sector. Mitigation strategies include conservation of existing carbon stocks; conservation of forest biomass and soil carbon; reduction of carbon losses from biota and soils through management changes; reduction of losses of carbon-rich ecosystems; prevention of deforestation; and enhancement of carbon sequestration in soils and biota through increases of forests (Smith et al. 2014; Paterson and Lima 2018; Raihan et al. 2019). Per-area mitigation options that reduce emission intensity also need to be promoted by improving the efficiency of production (i.e., less GHG emissions per unit of agricultural products) (Burney et al. 2010; Bennetzen et al. 2012) and the sustainable intensification of agriculture (Tilman et al. 2009; Smith 2013; Garnett et al. 2013). The cost-effective mitigation options in agriculture are afforestation, sustainable forest management and deforestation prevention, cropland management, grazed land management, and organic soil restoration (FAO 2011). Adaptation strategies should consider current technological perspectives and future technological changes that can shape adaptation choices in future. Thus, adaptation strategies include a range of factors, such as land tenure, technology choice, food insecurity, and ecosystem-based approach (Amjath-Babu et al. 2019; Iglesiasa and Garroteb 2015) as well as improving adaptive capacity and responding to changes in water demands. However, the implementation of these strategies requires revamping current water and agriculture policy and providing adequate training to farmers and viable financial instruments.

The results indicate that a huge loss of oil palm production may occur due to temperature rise and SLR. Developing climate resilient varieties with high tolerance planting materials and new crop varieties is critical for the changing climate condition (Joseph and Keddie 1981; Major et al. 1991; Smithers and Blay-Palmer 2001; Elum et al. 2017). Hence, research and development should promote the application of climate resilient varieties. Soil and water conservation are crucial for oil palm production to increase water infiltration and reduce water run-off that can overcome crop failure during extreme weather or climate change conditions (Sutarta et al. 2015). The application of organic matter reduces the inorganic fertilizer application and improves the water-holding capacity (Friedrich 2011). Reducing water evaporation can be managed by mulching, weed and cover crop management that can prevent soil erosion, maintain soil moisture, improve

water infiltration and reabsorb CO_2 emission from land. Moreover, palm oil and its industry produces abundant organic matters, such as empty fruit bunch, palm oil mill effluent and solid waste, that also need proper waste management. Involving multiple stakeholders, such as private decision makers, including industry and individual producers and consumers, and public decision makers are important to facilitate mitigation and adaptation strategies in the agriculture sector. Stakeholders such as Ministry of Agriculture, Malaysian Agricultural Research and Development Institute, Malaysian Palm Oil Board and Federal Land Development Authority are involved in oil palm production. Thus, the sharing of costs and benefits amongst governments, industries and farmers are key concerns in understanding mitigation and adaptation in oil palm and other agricultural sectors. The successful engagement of stakeholders is essential to achieve viable adaptation responses (Webb and Stokes 2012). Thus, effective coordination and collaboration amongst stakeholders are necessary to accelerate the implementation of mitigation and adaptation strategies for sustainable oil palm production.

The negative impacts of CC on oil palm production also affect households (farmers, consumers, and so on) and manufacturing industries (for palm oil). Insurance and other risk transfer mechanisms can manage or reduce climate-related risks, for example, index-based micro-insurance, flood insurance, and crop insurance should be promoted to reduce the adverse impacts of CC (GAR 2011; Swain 2014). However, governments can introduce or modify the existing insurance programs to influence farm-level risk management strategies with respect to climate-related losses. Furthermore, providing early warming and disseminating real-time weather forecasting to farmers and other stakeholders is crucial, so that they can adjust planting schedule, cropping pattern, and choices for possible measures of the changing climate. To limit the impacts of SLR on oil palm production, multiple adaptation measures and responses must be implemented. Malaysia should increase the establishment of physical barriers to prevent coastal flooding and erosion, loss of agricultural land and other infrastructures through coastal bunds, sea wall, dike, river embankment, and flood gate (Sarkar et al. 2014). Other measures, such as planting seaweeds and mangroves and preventing mangrove harvesting can be useful to reduce the impacts of SLR.

The practices of mitigation and adaptation measures, especially for the agricultural sector, are also important in reducing food price volatility through sustainable production which can address the food security issues in Malaysia. Moreover, both mitigation and adaptation strategies will essentially contribute to achieve Malaysia's voluntary commitment of reducing 45% of emissions intensity by 2030 relative to the emissions intensity of GDP in 2005. Notably, Malaysia has already made in progress of implementing two important policies, namely, National Policy on Climate Change aiming to reduce the impacts of CC and increase the capacity of nations and

communities to implement climate-resilient development (MNRE 2009), whereas the National Green Technology Policy focusing to build a low carbon economy by using green technology (MEGTW 2009). A long-term emission reduction target is found to be useful for cost-effective mitigation (Sarkar et el. 2019; Hasegawa and Matsuoka 2015); however, the nationally appropriate mitigation actions and national adaptation programs of action should be promoted. Moreover, the suggested mitigation and adaptation strategies should be prioritized by the governments and non-government stakeholder to limit the impacts of CC on oil palm production and palm oil sector in Malaysia.

Appendix

Table 7 Oil palm production and its area and annual average temperature in Malaysia

Year	Production area (ha)	Production (t)	Annual average temperature
1980	545,462	7,636,569	26.76
1981	599,592	8,276,852	27.38
1982	633,693	10,192,780	26.71
1983	672,499	8,666,976	27.15
1984	735,306	10,784,695	26.40
1985	766,756	11,703,242	26.60
1986	768,351	12,745,840	26.73
1987	1,534,927	22,122,414	27.07
1988	1,654,607	25,011,949	26.9
1989	1,770,972	29,286,681	26.68
1990	1,845,781	28,950,735	27.87
1991	1,906,240	29,246,850	26.97
1992	2,005,254	30,272,879	27.00
1993	2,096,480	36,692,298	26.87
1994	2,191,941	35,440,485	27.44
1995	2,298,095	37,880,312	27.05
1996	2,453,362	40,064,507	26.99
1997	2,649,802	43,354,995	27.32
1998	2,813,755	37,274,708	27.92
1999	3,026,880	49,513,377	26.99
2000	3,055,846	48,052,132	27.14
2001	3,155,670	50,981,495	27.66
2002	3,311,148	50,884,876	27.48
2003	3,414,042	55,373,112	27.21
2004	3,508,841	57,386,394	27.73
2005	3,626,801	60,657,740	27.84
2006	3,710,319	63,828,086	27.64
2007	3,834,758	63,181,503	27.59
2008	3,947,763	87,749,835	27.42
2009	4,082,124	66,766,810	27.69
2010	4,202,381	64,282,738	27.99

Source: DoS 2014; MMD 2014

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