Assessing the Economic Impact of Climate Change on Paddy Farming in Malaysia: A Ricardian Analysis Approach

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Abstract

Given the vulnerability of Malaysia's paddy sector to climate change, this study aims to quantitatively assess the effects of climate variables on paddy yields in the country's granary areas using a Ricardian regression model. The analysis is based on secondary panel data spanning nine years (2013–2022), covering two planting seasons across eight granary areas in Peninsular Malaysia, resulting in 144 total observations. The findings reveal that paddy yields are highly sensitive to climate, particularly during the vegetative and maturity stages of growth. A rise in maximum temperature negatively impacts paddy yields, even in areas with sufficient irrigation. Marginal impact estimates suggest that increasing temperatures during these critical growth stages will further reduce yields. However, the effect of precipitation on paddy yields was found to be insignificant. These empirical results highlight the importance of tailoring climate adaptation strategies to the specific conditions of granary areas, urging policymakers to incorporate localized climate effects into their decision-making processes.

Keywords: Climate change, granary area, growth stages, paddy yields, Ricardian model.

1.0 Introduction

Global climate change has had an impact on the economic sector in various regions over the next decade. According to a WMO report (2022), the global average temperature is now estimated to have increased by about 1.15°C during the 10 years from 2013 to 2022, compared to 1.09°C from 2011 to 2020. The rise in global temperature will lead to various threats such as rising sea levels, an increase in tropical cyclones, loss of land in low-lying areas, and natural disasters. This phenomenon will directly affect global food production (IPCC, 2018). According to the Childs and Kiawu (2009), this climate change has a direct physiological effect on crop growth processes. The impact of climate change is already visible today in the world's major agricultural-producing countries.

In China, rice production decreased by 3.0 million metric tons, from 148.99 million metric tons in 2021 to 145.9 million metric tons in 2022. This decline in rice yields in China was caused by high temperatures and extreme drought in July and August in the Yangtze Valley and the provinces of Sichuan, Hunan, Jiangxi, Hubei, and Anhui (USDA, 2023). Areas that practice double cropping of rice annually experienced a loss of up to 1.9 percent, while single-crop areas saw a reduction of up to 3.0 percent (Chao C. et al., 2014). According to Lobell et al.

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(2008), the impact of climate change on rice production in Brazil, Central America, and Southeast Asia is expected to result in losses of up to five percent by 2030. India is also not immune to the effects of climate change, which threaten its rice yields. Soora et al. (2013) stated that rice production in India decreased by four percent in 2020, seven percent in 2050, and 10 percent in 2080 due to temperature increases exceeding 23°C from June to September, especially in the East, North, and Northeast regions. In Indonesia, a one-degree Celsius increase in temperature will reduce overall rice yields by 11.1 percent (Yuliawan T. & Handoko I., 2016).

This global scenario is also being felt in Malaysia. Malaysia is located in Southeast Asia, north of the equator, and is categorized as a hot and humid region year-round, with an average daily temperature between 21°C and 32°C throughout the year (Tan et al., 2021). The average rate of temperature change in Malaysia in 2020 increased to 1.4°C compared to 1.2°C in 2015. This clearly shows that Malaysia is also not exempt from the temperature increases that can result in climate change. The effects of climate change in Malaysia can lead to extreme floods and droughts, further disrupting the country's agricultural production. Rice is among the crops most affected by natural disasters such as droughts and floods. The optimal temperature for rice cultivation is between 25 and 35 °C, and rice growth is favored in an area with moderate temperature (Reyes et al. 2003). Temperature beyond optimum is detrimental for rice and negatively affects growth, development and ultimately reduces the grain yield (Fahad et al. 2015). Fahad et al. (2016) explain that every 1 °C increase in temperature may decrease the grain yield by 10% in rice.

Figure 1 shows a decline in rice production alongside rising temperatures. In Malaysia, temperatures increased by 1.18°C to 1.45°C from 2017 to 2021 (FAO, 2023), while rice production dropped by 5.5% over the same period. This illustrates the link between reduced yields and rising temperatures. Additionally, MAFI (2021) reported 9,336 hectares of rice fields in Peninsular Malaysia were damaged by drought.

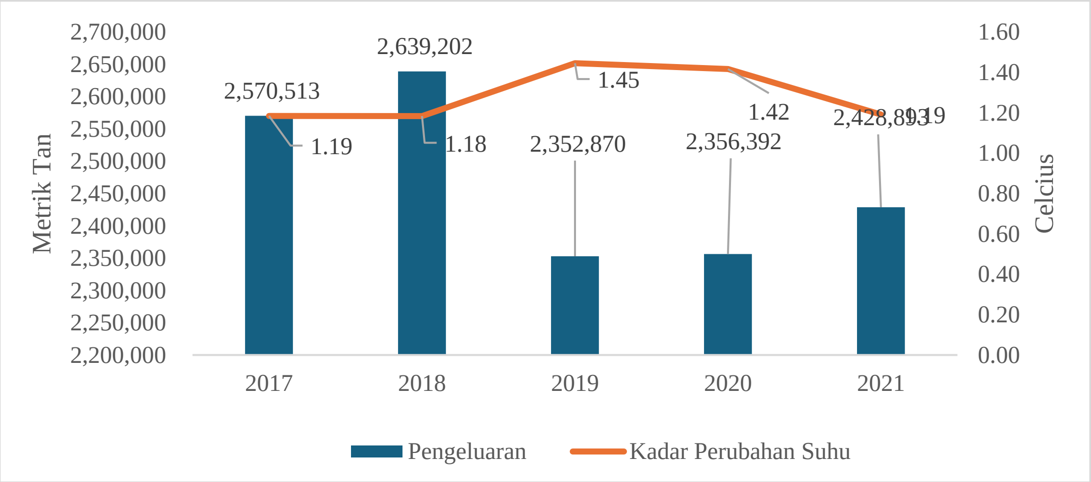

Figure 1: Total Rice Production and Temperature Change Rate in Malaysia (2017 -2021)
Source: Department of Agriculture, Malaysia, 2022

Given the vulnerability of Malaysia's paddy sector to climate change, the primary objective of this study is to assess the effect of climate variables on paddy yields in the country's granary areas using Ricardian regression model. Based on the findings, key policy measures are recommended to mitigate the effects of climate change on the paddy sector.

2.0 Literature Review

The Ricardian approach assumes that agricultural productivity is affected by climate factors like temperature and rainfall. This method has been widely used to estimate the impact of climate change on crop farming by analyzing the relationship between climate variables and farm revenues or land values.

Several studies have applied this approach to assess the economic impact of climate change. Darwin (1999) found that farmers' adaptation strategies to climate change varied based on their socio-economic conditions. Gbetibouo and Hassan (2005) showed that higher temperatures in South Africa reduced crop yields. Similarly, Hossain (2019) and Jane & Fredrick (2007) found that increased temperatures and rainfall changes negatively impacted crop yields in Bangladesh and Kenya, respectively. In Sri Lanka, Kurukulasuriya and Ajwad (2007) found a significant drop in smallholder farm productivity due to climate change, while Seo and Mendelsohn (2008) observed similar effects on livestock in Africa.

This study applies the Ricardian method to assess climate impacts on paddy farming in eight granary areas in Peninsular Malaysia. Past research has shown that higher temperatures and changing rainfall patterns lower farming productivity, with adaptation strategies like crop diversification and better irrigation being essential. Rice grows well in warm climates, and Malaysia's weather supports year-round rice cultivation, but rising temperatures can affect moisture levels, crucial for rice production. Bouman and Tuong (2001) found that water scarcity due to climate change could reduce rice yields by 50% in rainfed areas and up to 80% in upland regions. The IPCC (2014) also warned of more frequent extreme weather events, which could further harm rice production.

Climate change also worsens pest and disease risks. Liska et al. (2014) found that pests like the brown planthopper could spread more in Southeast Asia, leading to significant rice losses. Additionally, heatwaves can disrupt key processes like photosynthesis and nutrient uptake, reducing yields. Zhang et al. (2021) suggested that breeding heat-tolerant rice varieties could help mitigate these effects.

3.0 Methodology

3.1 Ricardian Approach

The Ricardian approach (Mendelsohn et al., 1994) is the primary method that was employed in this study. The Ricardian model assumes that each farmer wishes to maximize income, subject to the exogenous conditions of their farm. Specifically, the farmer chooses the crop and inputs for each unit of land that maximizes:

$$\text{Max } \pi = \Sigma P_{qi}Q_i(X_i, L_i, Ki, IR_i, C, W, S) - \Sigma P_x X_i - \Sigma P_L L_i - \Sigma P_K K_i - \Sigma P_{IR} IR_i, \qquad (1)$$

where π is net annual income, P_{qi} is the market price of crop i, Q_i is a production function for crop i, X_i is a vector of annual inputs such as seeds, fertilizer, and pesticides for each crop i, L_i is a vector of labor (hired and household) for each crop i, K_i is a vector of capital such as tractors and harvesting equipment for each crop i, C is a vector of climate variables, IR_i is a vector of irrigation choices for each crop i, W is available water for irrigation, S is a vector of soil characteristics, P_x is a vector of prices for the annual inputs, P_L is a vector of prices for each type of labor, P_K is the rental price of capital, and P_{IR} is the annual cost of each type of irrigation system. If the farmer chooses the crop that provides the highest net income and chooses each endogenous input in order to maximize net income, the resulting net income will be a function of just the exogenous variables:

$$\pi * = f(Pq, C, W, S, PX, PL, PK, PIR). \quad (2)$$

With perfect competition for land, free entry and exit will ensure that excess profits are driven to zero. As a consequence, land rents will be equal to net income per hectare (Mendelsohn et al., 1994). The Ricardian function, Eq. (2), captures the locus of maximum profits for each temperature or precipitation level. Studies in the United States, Brazil, Sri Lanka, and South America, showed the land value per hectare of cropland has been found to be sensitive to seasonal precipitation and temperature (Mendelsohn and Dinar, 1999, 2003; Seo and Mendelsohn, 2008; Seo et al., 2005). In some countries, land markets do not function and thus there are no land values. Instead, net revenue per unit of land is calculated. Similar results have also been found for crop net revenue in India, Africa, South America, and Israel (Kurukulasuirya & Ajwad, 2007; Mendelsohn and Dinar, 1999; Seo and Mendelsohn, 2008).

3.2 Data and model specifications

The secondary panel data used in this study spans a period of nine years, from 2013 to 2022, and includes observations from two planting seasons throughout eight granary areas in Peninsular Malaysia, and as a result, there were 144 total observations. The granary areas involved in this study as listed below. These areas were selected based on the stability and availability of data.

i. MADA (Muda Agricultural and Development Authority),
ii. KADA (Kemubu Agricultural and Development Authority),
iii. IADA (Integrated Agricultural Development Area) Kerian,
iv. IADA BLS (Barat Laut Selangor),
v. IADA P. Pinang,
vi. IADA Seberang Perak,
vii. IADA Ketara, and
viii. IADA Kemasin Semerak

These data came from a variety of sources, including the Ministry of Agriculture and Food Security (MAFS), the Department of Agriculture (DOA), the Malaysian Meteorological Department (METS), and the Malaysian Agricultural Research and Development Institute (MARDI). Data for all variables in the model were only available from 2013 to 2022, with 18 seasons comprised of 9 Main Season and 9 Off Season.

In order to analyse the relationship between net revenue and climate, we specify the following model to examine the impacts of climate change on paddy yield in Malaysia:

Y = f (RD1, RD2, RD3), (MTmax1, MTmax2, MTmax3), (MTmin1, MTmin2, MTmin3), (V1, V2, V3, V4, V5, V6, V7, V8), (PM1, PM2, PM3, PM4, PM5), (M1, M2, M3, M4, M5, M6), S, L, PD, ND

where:
Y = Paddy Yield (RM/ha)

RD_{1-3}= Numbers of rainy days according to growth level (1=vegetative, 2 = reproductive, 3 = maturity)
$MTmax_{1-3}$ = Average of maximum temperature according to growth level (1=vegetative, 2 = reproductive, 3 = maturity)
$MTmin_{1-3}$ = Average of minimum temperature according to growth level (1=vegetative, 2 = reproductive, 3 = maturity)
V_{1-8} = Percentage of farmers by seed varieties (%) (1= MR219, 2 = MR220, 3 = MR220/CL-1, 4 = MR220/CL-2, 5 = MR263, 6 = MR269, 7 = MR284, 8 = MR297
PM_{1-5} = Percentage of farmers by planting method (%) (1=Manual Plantation, 2=Transplanter Plantation, 3=Broadcasting/Puddled Field, 3=Broadcasting/In Water Field, 4=Broadcasting/Dry Field)
M_{1-6} = Percentage of farmers used machine by activities (%) (1=Land Preparation, 2=Transplanter, 3=Sowing/Broadcasting, 4=Manuring, 5=Chemical Spraying, 6=Harvesting
S = Subsidies (RM)
L = Planted area/land (ha)
PD = Pests and Diseases (%)
ND = Natural disasters (drought and flood) (%)

3.3 Description of variables

Variable	Description
Paddy Yield (RM)	Paddy Yield refers to the amount of rice produced per unit area of land in each of the eight selected granaries, and will be multiplied with price of rice per kilogram which is RM1.28.
Rainfall	The Rainfall variable measures precipitation in millimeters for each month at the selected granary locations, categorized by the three paddy growth stages: vegetative, reproductive, and maturity. Monthly rainfall data for each stage is averaged to represent rainfall patterns accurately. Data was collected from the nearest weather station to each granary.
Average of Maximum Temperature	The Average of Maximum Temperature is the highest average temperature recorded during the vegetative, reproductive, and maturity stages of paddy growth across eight granaries in Peninsular Malaysia.
Planting Method	The Planting Method variable captures the different techniques used for planting paddy. It includes the percentage of farmers in each granary area using methods such as: 1) manual planting, 2) transplanters, 3) broadcasting on puddled fields, 4) broadcasting on in-water fields, and 5) broadcasting on dry fields.
Planted Area	Planted Area/Land refers to the total area of land on which paddy is grown in the selected eight granaries. The measurement is in hectares.
Subsidies	Subsidies refers to the amount of financial support provided to each granary in Ringgit Malaysia (RM). The subsidies can include various forms of financial assistance such as grants, loans, subsidies for fertilizers, pesticides, irrigation, machinery, and other farming inputs.
Natural Disaster	The Natural Disaster variable represents the percentage of farmers in eight granary areas affected by drought or flood events. Droughts cause water shortages, reducing paddy productivity, while floods lead to waterlogging and soil erosion, also harming crop yields.

4.0 Results and Discussion

A descriptive analysis was conducted to examine the characteristics of the sample population, with the results presented in Table 1. The table includes descriptive statistics for 27 variables, such as mean, minimum, maximum, and standard deviation, providing key data about the entire sample. In addition to climate and paddy yield, important determinants of paddy revenue are included, such as planted area, subsidies received by each granary, the presence and severity of pests, diseases, and natural disasters. Other significant variables, such as seed varieties, planting methods, and machinery usage, are also highlighted.

Table 1: Descriptive statistics for major variables used for analyzing the determinants of paddy yields

	Min.	Max.	Mean	Std. Deviation
Yield per season (RM/ha)	2526	6560	4726	918
Average precipitation during vegetative phase (mm)	35.1	597.8	214.65	116.53
Average precipitation during reproductive phase (mm)	0.6	1340.8	187.51	171.48
Average precipitation during maturity phase (mm)	1.2	575	117.65	92.17
Average of maximum temperature (vegetative)	30.2	36.3	32.83	1.13
Average of maximum temperature (reproductive)	28.3	34.9	32.51	1.47
Average of Maximum temperature (maturity)	29.2	35.6	32.82	1.14
Manual Plantation	0	10.1	0.47	1.40
Transplanter Plantation	0	90.9	6.18	16.86
Broadcasting - Puddled Field	8.2	100	79.81	20.68
Broadcasting - In Water Field	0	29.4	1.22	3.85
Broadcasting - Dry Field	0	62.2	12.32	15.60
Land Preparation	0	100	98.67	10.41
Planted area (hectare)	748	100,680	24,543	28,766
Subsidies (RM Million)	36.55	1,314.80	257.42	297.36
Pest and disease	0	100	45.17	16.00
Natural Disaster	0	100	26.50	20.91

In Table 2, we explore a regression model of yield per hectare on climate variables, planted area, planting methods and government subsidies for paddy sector. All farm in granaries area are systematically irrigated farm. The goodness of fit measures (adjusted R2) for the model is 0.375, a level that is relatively high for panel data. The analysis of all granaries area reveals that many of the control variables are highly significant. Planted area have positive influence with paddy yield. Planting methods like Puddled Field Broadcasting and Dry Field Broadcasting decrease yield per hectare (compared to trans-planter, in water field broadcasting as well as manual plantation). Other factors such as input subsidy from government and natural disaster occurrence were not significant.

Table 2: Ricardian Regressions models explaining paddy yield in granary areas of Malaysia

	Model 1		Model 2	
Independent variable	Coefficients	t	Coefficients	t
(Constant)	-	7.564**	-	6.659
Average precipitation during vegetative phase (mm)	-.072	-.630	.092	.876
Average precipitation during reproductive phase (mm)	.010	.120	.070	.907
Average precipitation during maturity phase (mm)	.020	.248	.061	.838
Average of maximum temperature (vegetative)	-.335	-3.054**	-.411	-3.937**
Average of maximum temperature (reproductive)	.227	1.337	.499	3.018**
Average of Maximum temperature (maturity)	-.379	-3.127**	-.571	-4.816**
Trans-planter Plantation			-.529	-1.654
Broadcasting - Puddled Field			-.935	-2.462*
Broadcasting - Dry Field			-.616	-2.125*
Planted area (hectare)			.795	2.582*
Subsidy for paddy sector			-.399	-1.324
Natural disaster			.083	1.051
n	144		144	
F	5.033		6.653	
R^2	0.181		0.379	

Most important for this article are the results for the climate variables. Maximum temperature variables were significant in every stage of paddy growth However precipitation variables were not significant. To be more specific on climate variables, findings showed that higher maximum temperatures in all growth stages (vegetative, reproductive and maturity) slightly reduce yield per hectare in Malaysia. Consistent with Tenorio et al. (2013), Gbetibouo and Hassan (2005), Hossain (2019), Jane and Fredrick (2007) and Abbas et.al., (2020) revealed that higher temperatures had a negative impact on crop yields. Li et al., 2017 in their research indicating that the vegetative stage is the most sensitive to changes in climate. However according to Cao et al. (2008) the impact of high temperature stress mainly depends on duration, intensity, and timing of stress; however, it is more harmful during reproductive stage.

During the vegetative stage, lower temperatures help seedlings grow well, and early fertilization can be effectively implemented. According to Sreenivasan (1985), temperatures exceeding 35°C will halt seedling germination because temperature significantly influences seedling germination, especially during the first week of plant growth (Yoshida, 1985). Modarresi et al. (2012) and Sreenivasan et al. (1985) found that an increase in maximum temperature during the vegetative stage reduces the number of rice seedlings. Similarly, high maximum temperatures during early fertilization lead to reduced rice yields due to the high rate of fertilizer absorption by seedlings when temperatures rise (Mahbubul et al., 1985).

While during the reproductive stage, the heat stress on flower initiation, pollen development, flowering and anthesis, and grain yield. High temperature affects the reproductive and developmental stages of rice by decreasing plant height and root elongation, causing poor anther dehiscence and spikelet sterility, and hindering the process of pollination (Jagadish et al. 2010). In rice, heat stress delayed the flowering, and affects pre-fertilization development more than post development. During flowering, heat stress reduces the pollen production and severe loss in grain yield (Hussain et. al., 2019).

During the maturation stage, temperatures above 35°C negatively affect rice plants, and minimum temperatures exceeding 18°C reduce the grain weight. Additionally, an average temperature increase above 25°C extends the maturation period of rice plants, which adversely affects and reduces rice production during the maturation phase (Tashiro and Wardlaw, 1991 & Yoshida, 1981).New rice varieties for heat tolerance at the different stages are needed to reduce the yield losses. Different crop management strategies such as balanced use of crop nutrients and changing the planting time should be studied more in the future for enhancing the rice tolerance against temperature stresses (Hussain, et.al. (2019).

Regarding precipitation, previous studies by Gill et al. (2013) found a positive and significant relationship between average rainfall and rice production during the vegetative stage. High rainfall during this stage supports effective seedling germination. However, Abbas et al. (2020) revealed a negative relationship between rainfall and rice production during the reproductive stage. This finding is supported by Aslam (2018), which found that high rainfall during the reproductive stage leads to lower rice yields. Heavy rainfall during this stage can cause fields to become waterlogged, preventing rice plants from absorbing the necessary nutrients for growth (Balasubramanian et al., 2014).

5.0 Conclusion and recommendations

Climate change poses significant and multifaceted challenges to rice production in Malaysia, affecting critical factors such as water availability, pest and disease prevalence, and temperature patterns. These changes can have a profound impact on rice yields, threatening food security, farmer livelihoods, and the overall economy. If not addressed, the consequences could lead to reduced agricultural output, higher food prices, and greater pressure on rural communities. To counter these effects, it is imperative to adopt long-term adaptation strategies. A key approach would be the development and promotion of climate-resilient, heat-tolerant rice varieties that can better withstand changing environmental conditions.

Based on the findings, several recommendations are proposed to improve rice yields and ensure the sustainability of paddy farming in the eight granary areas of Peninsular Malaysia. To sustain and enhance paddy production, continued government assistance is crucial. Subsidies for essential farming inputs—such as land preparation, fertilizers, and chemicals for pest and disease control—should be maintained and possibly expanded. These subsidies will ease the financial burden on farmers, enabling them to access resources necessary for increasing crop productivity. In addition, financial support should be directed toward research and development initiatives aimed at improving rice production technologies. By fostering innovation and providing adequate support, the government can help farmers maintain yields in the face of rising environmental challenges.

Traditional planting techniques often limit the potential for higher rice yields. Farmers should be encouraged and supported to adopt more efficient planting methods that improve productivity. For example, transplanter plantation, which involves transplanting young rice seedlings into prepared fields, ensures more uniform plant spacing and can result in higher yields compared to direct seeding. Additionally, broadcasting in water fields, a method where seeds are sown directly into flooded fields, can help optimize the use of water and reduce labor costs. Promoting these advanced planting techniques through training and equipment subsidies will allow farmers to maximize their land's potential and increase overall rice production.

As climate change continues to exacerbate droughts, unpredictable rainfall, and extreme weather events, farmers must adopt climate-smart agriculture practices. These include rainwater harvesting, which allows farmers to capture and store rainwater for use during dry periods, and the development and use of drought-resistant rice varieties that can thrive in water-scarce conditions. Furthermore, improved irrigation systems that optimize water use efficiency can help farmers manage water resources more sustainably. By integrating these practices into their farming systems, farmers will be better equipped to mitigate the negative impacts of climate change and ensure consistent crop yields.

Rising temperatures and changing weather patterns are likely to increase the prevalence of pests and diseases, posing a major threat to rice production. To combat this, farmers need to be trained in integrated pest management (IPM), a holistic approach that combines biological, cultural, mechanical, and chemical control methods to manage pests in an environmentally sustainable way. Regular field monitoring, crop rotation, and the use of natural predators can help reduce reliance on chemical pesticides, which can have harmful environmental effects. By adopting effective pest and disease management practices, farmers can minimize crop losses and enhance rice yield without damaging the ecosystem.

Natural disasters such as floods, droughts, and storms are becoming more frequent and severe due to climate change, posing a significant risk to rice farming communities. The government should establish comprehensive disaster risk reduction (DRR) strategies, which include early warning systems, flood protection infrastructure, and emergency response plans tailored to the specific risks in the granary areas. In addition, providing crop insurance would help farmers recover from losses caused by natural disasters. Insurance schemes can be designed to cover the cost of damage from floods, droughts, and pest outbreaks, giving farmers a safety net and the financial stability to recover and continue farming.

By implementing these recommendations, Malaysia can enhance the resilience of its rice production system, increase paddy productivity, and safeguard the livelihoods of farmers in the granary areas of Peninsular Malaysia. This holistic approach will not only ensure food security in the face of climate change but also contribute to the sustainability and prosperity of the agricultural sector.

Acknowledgement

We acknowledge Ministry of Higher Education (MoHE) of Malaysia for providing research grant under Long Term Research Grant Scheme (LRGS/1/2019/UPM/01/2/4).

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