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The impact of climate change, fertilizer consumption, and agricultural employment on crop production: A panel regression analysis of the Philippines, Thailand, and Malaysia

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Abstract

Agriculture is an integral part of the Philippine, Thai, and Malaysian economy. However, in recent years, there has been a rise in temperatures, droughts, and extreme weather events, all of which have significantly impacted crop productivity. The changes in climate patterns have led to prolonged dry spells, altered precipitation patterns, and an increased frequency of storms and floods, disrupting planting and harvesting cycles. The instability in crop production not only threatens food security but also contributes to rising food inflation, as the reduced supply of agricultural commodities drives up prices. This study examined the impact of climate change, fertilizer consumption, and agricultural employment on crop production in the Philippines, Thailand, and Malaysia. The study used panel data from the World Bank from 1997 to 2022. Using Random Effects Generalized Least Squares (GLS), the study has found that rising temperatures significantly reduce crop production in the Philippines, Thailand, and Malaysia, while annual precipitation and fertilizer consumption turned out to be insignificant determinants. Meanwhile, agricultural employment yielded a significant positive relationship with crop production. The findings from this study highlight the importance of enhancing agricultural resilience and sustainability in the face of changing climatic conditions.

Keywords: Agricultural employment, Climate change, Crop production, Fertilizer consumption, Food security, Generalized least squares, Panel data analysis, Southeast Asia.

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Contents

Contribution of this paper to the literature
To the best of our knowledge, this study is among the first to simultaneously examine climate change, fertilizer consumption, and agricultural employment in relation to crop production across the Philippines, Thailand, and Malaysia using panel regression, providing a multi-country panel data analysis that is limited in existing literature.

1. Introduction

Agriculture is an integral part of the economy. It has been a crucial aspect of human civilization since time immemorial. It serves an instrumental role in food production, and without it, the world would face severe food scarcity. Agriculture is arguably one of the most important sectors in society. Without agriculture, human life would not be possible.

More often than not, the agricultural sector's contribution to the economy is overlooked due to its diminishing returns. Yet, by looking at the bigger picture, agriculture's role in the survival of individuals and the development of an economy cannot be overstated. Over time, economies shifted towards industrialization and later to service sectors (Gabardo, Pereima, & Einloft, 2017). However, this does not mean that agriculture is no longer as important as it was centuries ago. In fact, it is much more important now that the world is faced with a rapidly growing population and a climate crisis that poses a threat to food production.

Over the past decade, there has been an unprecedented rise in extreme weather events, prolonged droughts, changes in weather patterns, and shifts in surface temperature, all of which have imposed a greater challenge in the agricultural sector, causing a decline in agricultural output and creating agricultural shocks, leading to an increase in most food prices (Khalfaoui, Goodell, Mefteh-Wali, Chishti, & Gozgor, 2024). The agricultural sector is heavily dependent on the environment, as it relies on land, water, and climate. Environmental quality is crucial in most agricultural activities, including fishing and crop production. Climate change makes it difficult for farmers to forecast their planting and harvesting seasons due to the changes in weather patterns. Agricultural productivity is expected to be adversely affected by increased climate variability, as climate is one of the main determinants of agricultural production.

There is a current need for climate change adaptation measures, especially in the field of agriculture. There is an urgency for concrete agricultural planning that takes into account the effects of climate change on food security and food systems. The resulting effects of reduced productivity and production on the accessibility of agricultural commodities for consumption are substantial. Agricultural food commodity prices are projected to increase in 2030 and 2050 due to climate change, making food commodities less accessible, especially for poor people (Rosegrant, Perez, Pradesha, & Thomas, 2016).

This study aims to conduct a panel regression analysis on the impacts of climate change, fertilizer consumption, and agricultural employment on crop production in the Philippines, Thailand, and Malaysia. Similar to the Philippines, Thailand, and Malaysia have agricultural sectors that play a vital role in their economies. Additionally, all three countries share relatively similar socioeconomic statuses and geographical locations and are all prone to extreme weather events, such as typhoons and droughts, affecting agricultural productivity.

Climate change poses a threat to food security, particularly in agricultural economies such as the Philippines, Thailand, and Malaysia. These three countries are among the most vulnerable to climate change, primarily due to their geographical location. Related literature indicates that rising temperatures, unpredictable weather patterns, and extreme weather events are expected to disrupt agricultural production. Investigating the implications of climate change on crop production in these three countries provides critical insights into agricultural productivity and food security. Despite the wealth of existing literature on the impact of climate change, fertilizer consumption, and agricultural employment on crop production, there is a lack of empirical studies in the Philippines, Thailand, and Malaysia. Additionally, there is a lack of studies that apply panel regression analysis on these three Southeast Asian economies. This study aims to bridge those research gaps.

The findings of this study can guide policymakers in developing climate-resilient agricultural policies and targeted interventions to mitigate the impact of climate change on crop production. Insights from this study will help identify strategies to improve agricultural resilience and address climate-induced agricultural challenges. Understanding the linkages between climate change, fertilizer consumption, agricultural employment, and crop production is imperative in stabilizing food markets and preventing inflationary pressures.

2. Review of Related Literature

2.1. Climate Change to Crop Production

The vulnerability of agricultural production systems to extreme weather events raises significant concerns about food and crop production (Yuan et al., 2024). Climate change, predominantly driven by human activities, poses a significant threat to the earth's ecosystems (He & Silliman, 2019). The agricultural sector is among the most vulnerable to the adverse impacts of climate change. Related literature suggests that climate change can lead to a decline in crop production (Arora, 2019; Bouteska, Sharif, Bhuiyan, & Abedin, 2024; Irawan & Antriyandarti, 2021). Climate change affects precipitation patterns, leading to more frequent and severe droughts in some regions but increased rainfall and flooding in others. These changes disrupt traditional farming practices and can severely affect crop yields (Manucharyan, 2025). A wealth of related literature suggests a negative relationship between climate change and agricultural productivity (Bouteska et al., 2024; Chalise, Naranpanawa, Bandara, & Sarker, 2017; Sinore & Wang, 2024).

Agriculture is one of the most climate-sensitive sectors of an economy. Generally, a suitable temperature is beneficial to the growth of crops, but a temperature that is too high or too low will have adverse effects on the growth of crops (Falco, Galeotti, & Olper, 2019). With the rising temperature of the earth's surface, the risk of crop yield reduction has been increasing in recent years (Soureshjani, Dehkordi, & Bahador, 2019). Although several research studies have proven that climate change has an adverse impact on crop production, some studies prove otherwise. In the study by Fei et al. (2020) climate change has contributed to an increase in the production potential of maize and rice in China, suggesting that the effects of climate change on agricultural production are crop-specific.

2.2. Fertilizer Consumption to Crop Production

As the climate changes, farmers' practices change, often increasing fertilizer use and, as a result, nitrous oxide emissions (Ma, Karimi, Mohammed, Shahzadi, & Dai, 2024). Related literature shows that fertilizer consumption positively and significantly influences crop production (Guo, Liu, & He, 2022). Fertilizer use immensely contributes to higher crop productivity and ensures food security (Bora, 2022). However, excessive or imbalanced fertilizer use can lead to soil degradation and environmental problems. Excessive fertilizer application without proper management practices could lead to soil acidification and soil degradation (Zhang et al., 2022).

2.3. Agricultural Employment to Crop Production

Labor is one of the fundamental factors of production, and an increase in agricultural employment is presumed to lead to an increase in crop production. Agricultural employment and output are intertwined, with increased labor input potentially leading to higher yields. The study by Dait (2022) shows that agricultural employment has statistically significant effects on agricultural production in the Philippines, indicating that a rise in agricultural employment increases agricultural production.

On the contrary, in the study of Özbek and Özbek (2024) long-run findings show that agricultural employment decreases crop production. According to the study, the decline in crop production due to an increase in agricultural employment can be attributed to factors such as reduced productivity, rising costs, suppression of innovation in the sector, and overuse of land. On the other hand, in the study by Zhang and Diao (2020) it was stated that rising labor productivity in agriculture has driven rapid agricultural growth without the need for an increase in agricultural employment, enabling agriculture to indirectly contribute to overall productivity growth through structural change.

3. Methodology

This study employed panel regression analysis to examine the effects of climate change indicators, fertilizer consumption, and agricultural employment on crop production across the Philippines, Thailand, and Malaysia over time. Panel regression is appropriate as it allows the model to account for unobserved heterogeneity across countries while utilizing both the cross-sectional and time-series dimensions of the data.

The researchers employed the standardized method, which involves transforming variables into z-scores (Subtracting the mean and dividing by the standard deviation) before running the regression, creating standardized coefficients (Betas) that allow direct comparison of predictor importance across different units, simplifying interpretation by showing effects in standard deviation units. This process removes scale dependency, helping identify key drivers in models with mixed units of measurement.

The researchers made use of Gretl software to generate the panel regression model and run different diagnostic tests to check the robustness of the model. The researchers also made use of Microsoft Excel for the standardization of values.

The Philippines, Thailand, and Malaysia were strategically selected as countries for panel regression, as these countries share a relatively similar economic status and geographical location. These countries also have significant exposure to the impacts of climate change, making them suitable reference points for assessing the implications of climate change on agriculture and food security.

The researchers decided to use the observed annual average mean surface air temperature and observed annual precipitation as indicators for climate change, fertilizer consumption (% of fertilizer production) for fertilizer consumption, and employment in agriculture (% of total employment) (Modeled ILO estimate) for agricultural employment. As for the dependent variable, the researchers decided to use the crop production index (2014-2016 = 100) as an indicator for crop production. The researchers decided to omit GHG emissions and CO_2 emissions as indicators for climate change to avoid potential multicollinearity with the indicator for fertilizer consumption.

The researchers made use of secondary data, which were collected from reputable institutions, such as the World Bank. All data sets used in this study are publicly available and accessible. The data are presented at the national level, representing aggregated figures for each country.

The data set on mean surface air temperature and annual precipitation was sourced from the World Bank's Climate Change Knowledge Portal. The data set on fertilizer consumption (% of fertilizer production), employment in agriculture (% of total employment) (Modeled ILO estimate), and crop production index (2014-2016 = 100) were all sourced from the World Bank's World Development Indicators.

The researchers utilized annual data from 1997 to 2022 for the Philippines, Thailand, and Malaysia due to the limited availability of historical data on fertilizer consumption and agricultural employment. This results in a panel dataset comprising three cross-sectional units and 26 time-series observations for each country, providing a sufficient number of observations for panel regression analysis.

3.1. Model for the Effect of Climate Change, Fertilizer Consumption, and Agricultural Employment on Crop Production

$$CROP_{it} = \beta_0 - \beta_1 TEMP_{it} - \beta_2 PRECIP_{it} + \beta_3 FERT_{it} + \beta_4 EMP_{it} + \varepsilon_{it} \quad (1)$$

Where:
i = Country.
t = Time Period.
CROP = Crop Production Index.
TEMP = Mean Surface Air Temperature.
PRECIP = Annual Precipitation.
FERT = Fertilizer Consumption.
EMP = Employment in Agriculture.

β_0 = Intercept.
β_1 = Regression Coefficient of Mean Surface Air Temperature.
β_2 = Regression Coefficient of Annual Precipitation.
β_3 = Regression Coefficient of Fertilizer Consumption.
β_4 = Regression Coefficient of Employment in Agriculture.
ε = Error Term.

3.2. Diagnostic Tests

The researchers used the Levin-Liu-Chu (LLC) test to check the stationarity of the data set. This is to ensure that there is no unit root in the panel data set, which means there is no trend or random walk. To further examine the robustness of the model, the researchers used the Variance Inflation Factor for multicollinearity, the Breusch-Pagan test for heteroskedasticity, the Jarque-Bera test for normality of residual, and the Wooldridge test for first-order autocorrelation. The researchers also made use of the Joint Test on Named Regressors to test whether the independent variables significantly impact the dependent variable and the Hausman test to determine whether fixed effects or random effects is more appropriate. Finally, the researchers made use of the Pesaran CD test to determine whether or not there is a cross-sectional dependence.

4. Results and Discussion

This study examined the effects of climate change, fertilizer consumption, and agricultural employment on crop production in the Philippines, Thailand, and Malaysia. Using panel regression analysis with the standardized method, the researchers were able to determine the effects of the independent variables on crop production in the selected Southeast Asian countries for the years 1997 to 2022 due to the limited historical data on fertilizer consumption and agricultural employment.

The researchers gathered statistical data from the World Bank's Climate Change Knowledge Portal and the World Bank's World Development Indicators. The data sets for the observed annual average mean surface air temperature and observed annual precipitation were collected from the World Bank's Climate Change Knowledge Portal, while the data sets for fertilizer consumption, agricultural employment, and crop production index were all gathered from the World Bank's World Development Indicators.

4.1. Random Effects Generalized Least Squares (GLS) Regression Results

Model 1: Random-effects (GLS), using 75 observations.
Using Nerlove's transformation.
Included 3 cross-sectional units.
Time-series length = 25.
Dependent variable: d_CROP.

Table 1. Regression results for the impact of climate change, fertilizer consumption, and agricultural employment on crop production in the Philippines, Thailand, and Malaysia.

Variables	Coefficient	Std. Error	z	p-value
const	0.155	0.036	4.338	0.000***
d_TEMP	-0.158	0.030	-5.243	0.000***
d_PRECIP	-0.050	0.031	-1.584	0.113
d_FERT	-0.043	0.028	-1.560	0.119
d_EMP	0.319	0.144	2.212	0.027**
Mean dependent var	0.109		S.D. dependent var	0.301
Sum squared resid	4.192		S.E. of regression	0.243
Log-likelihood	1.745		Akaike criterion	6.509
Schwarz criterion	18.097		Hannan-Quinn	11.136
rho	-0.159		Durbin-Watson	2.145
'Between' variance = 0.000				
'Within' variance = 0.056				
theta used for quasi-demeaning = 0.072				
corr(y,yhat)^2 = 0.376				

Note: **, and *** indicate statistical significance at different levels. Specifically, level ($p < 0.10$), ** denotes significance at the 5% level ($p < 0.05$), and *** denotes significance at the 1% level ($p < 0.01$). If the p-value is less than 0.1, then * indicates that the variable is significant at the 0.1 alpha level. If the p-value is less than 0.05, ** indicates that the variable is significant at the 0.05 alpha level, and if the p-value is less than 0.01, *** indicates that the variable is significant at the 0.01 alpha level.

Table 1 presents the Random Effects Generalized Least Squares (GLS) regression results for the impact of climate change, fertilizer consumption, and agricultural employment on crop production in the Philippines, Thailand, and Malaysia. The model includes 75 observations across 3 cross-sectional units with a time-series length of 25 and uses Nerlove's transformation.

The Random Effects Generalized Least Squares (GLS) model for panel data was used to account for variability across countries and over time. It was also used to examine the relationships that are present between the independent variables, climate change, fertilizer consumption, and agricultural employment, and the dependent variable, crop production index.

Based on the regression results, the constant has a coefficient of 0.155, which is significant at a 0.01 alpha level, indicating an upward trend in the dependent variable, crop production index. This implies that, even when all independent variables are held at zero, the model predicts a positive baseline value for the dependent variable.

Among the independent variables, the observed annual average mean surface air temperature exhibits a negative and significant relationship with the crop production index, with a coefficient of −0.158 at the 0.01 alpha level. Since both variables are regressed at first difference and are both standardized, this means that if the annual variation in mean surface air temperature increases by 1 standard deviation unit, the average value of the annual variation in crop production index decreases by about 0.158 standard deviation units.

Meanwhile, the agricultural employment exhibits a positive and significant relationship with the crop production index, with a coefficient of 0.319 at the 0.05 alpha level. Since both variables are regressed at first difference and are both standardized, this means that if the annual variation in agricultural employment increases by 1 standard deviation unit, the average value of the annual variation in crop production index increases by about 0.319 standard deviation units.

As for the other independent variables, the observed annual precipitation shows a negative relationship with the crop production index, with a coefficient of −0.050. However, the relationship is statistically insignificant. Similarly, fertilizer consumption demonstrates a negative but insignificant relationship with the crop production index, having a coefficient of −0.043.

The variance decomposition of the random effects GLS model shows that the within variance is 0.056, while the between variance is 0.000. As the within variance is greater than the between variance, the variability of the data occurs over time rather than across countries. This indicates that most of the changes in crop production index are driven by time variations, rather than the differences between the countries.

The squared correlation between the observed values and the fitted values from the Random Effects GLS model, corr(y,yhat)^2, is 0.376, which indicates that the model explains a moderate proportion of the variation in the dependent variable. Specifically, the fitted values generated by the Random Effects specification account for approximately 37.6% of the overall variation in the dependent variable across cross-sectional units and over time. While this measure is not directly comparable to the conventional R^2 in Ordinary Least Squares (OLS) method, it nevertheless provides a useful indication of the model's overall goodness of fit. In the context of panel data, particularly in applied economics and cross-country analyses where unobserved heterogeneity is prevalent, this level of explanatory power is considered acceptable and suggests that the included explanatory variables capture a meaningful, though not exhaustive, share of the factors influencing the dependent variable, crop production.

The regression result for the observed annual average mean surface air temperature is similar to the findings in the majority of related literature, which denotes a negative and significant relationship between crop production and climate change. As suggested in the studies of Arora (2019), Bouteska et al. (2024), Irawan and Antriyandarti (2021), Kogo, Kumar, and Koech (2021), Wing, De Cian, and Mistry (2021) and Yuan et al. (2024) among others, climate change can adversely affect agricultural productivity, leading to a reduction in overall crop yields and agricultural output. Additionally, as denoted in the study of Mekonnen, Tessema, Ganewo, and Haile (2021) climate change is projected to negatively impact agricultural yields, particularly in regions where crop production is highly dependent on climatic variables such as precipitation patterns and temperature.

Since the Philippines, Thailand, and Malaysia are all agricultural economies and are all heavily dependent on favorable climatic conditions for staple crops such as rice and corn, the three countries are especially vulnerable to the adverse effects of rising temperatures and increasing climate variability. Climatic variations, such as changes in temperature, disproportionately affect smallholder and subsistence farmers, who often lack access to modern technologies, irrigation facilities, and financial safety nets, making them more exposed to crop failures and income instability (Akinkuolie, Ogunbode, & Adekiya, 2025; Omokpariola et al., 2025). Climate-induced declines in crop production can threaten not only the livelihoods of farmers but also national food security and rural development (Onyeaka et al., 2024). This underscores the urgency of implementing climate-resilient agricultural practices and adaptive policies to mitigate potential productivity losses and safeguard food security.

According to the study of Manucharyan (2025) rising global temperatures, as a direct consequence of climate change, have profound impacts on crop growth and yields. Such climatic shifts disrupt agricultural practices and pose significant risks to overall crop productivity. The panel regression result for the Philippines, Thailand, and Malaysia is consistent with the findings in the studies of Bouteska et al. (2024), Chalise et al. (2017), Sinore and Wang (2024) and Xiang, Malik, Hou, and Ma (2022) which suggest a negative relationship between climate change and agricultural productivity. It is also consistent with the findings in the study of Chandio, Jiang, Rehman, and Rauf (2020) which state that temperature has a negative impact on agricultural output, both in the short run and in the long run. Extreme climate change is projected to substantially reduce crop production due to the strong dependence of crop yields on temperature (Mubenga-Tshitaka, Mwamba, Dikgang, & Gelo, 2023). Rising temperatures shorten the growth period of staple crops such as rice and corn, thereby limiting the accumulation of essential nutrients and ultimately decreasing both yield and quality (Luo & Dou, 2024).

As mentioned in the study of Tripathi, Tripathi, Chauhan, Kumar, and Singh (2016) one of the fundamental challenges posed by climate change on a global scale is the decline in both the quality and quantity of major food sources. The Philippines, Thailand, and Malaysia are no exception. In the Philippine context, rising temperatures directly reduce crop production because most staple crops, such as rice and corn, are highly sensitive to heat stress (Kaushal, Bhandari, Siddique, & Nayyar, 2016; Wang, Rejesus, Tack, Balagtas, & Nelson, 2022). Increased temperatures shorten the growing period, limiting the time for nutrient accumulation and grain filling, which ultimately lowers yields (Hatfield & Prueger, 2015; Shrestha, Mahat, Shrestha, Madhav, & Paudel, 2022). Additionally, excessive heat accelerates soil moisture loss, increases evapotranspiration, and heightens the risk of drought, which further reduces agricultural productivity, especially in rainfed areas that dominate much of the country's farming system (Ahmed et al., 2022). Higher temperatures also encourage the spread of pests and crop diseases, resulting in yield losses and decreasing crop quality (Das et al., 2025).

The inverse relationship between mean surface air temperature and the crop production index is predominantly due to the geographic, climatic, and economic conditions of the Philippines, Thailand, and Malaysia, which make their agricultural sector highly sensitive to climate variability. Since the three countries are all situated in a tropical zone, staple crops are already cultivated near their optimal temperature thresholds, which means that even slight increases in temperature can result in heat stress, reduced photosynthesis, and shortened growing periods, thereby lowering yields.

Rising temperatures intensify evapotranspiration, which diminishes soil moisture and places additional stress on crops (Barzigar, Hosseinalipour, & Pani, 2025). Moreover, the three Southeast Asian countries are oftentimes subjected to extreme weather events such as typhoons and El Niño, whose adverse impacts are amplified by elevated baseline temperatures (Climate Change Commission, 2024). Limited access to climate-resilient seeds, irrigation infrastructure, and adaptive technologies further constrains the ability of farmers, most of whom are smallholder farmers with minimal capital, to cope with these challenges (World Bank, 2019). Collectively, these factors explain why the regression results show that increasing temperatures significantly reduce crop production in the Philippines, Thailand, and Malaysia, which underscores the agricultural sector's fragility to climate change and the urgent need for adaptive and climate-resilient agricultural policies.

For the observed annual precipitation, the coefficient is consistent with the researchers' hypothesis that there is an inverse relationship between observed annual precipitation and crop production index. However, the insignificant relationship can be attributed to several factors. For instance, the Philippines experiences highly uneven rainfall distribution due to its archipelagic geography and exposure to monsoons, typhoons, and the Intertropical Convergence Zone (Philippine Atmospheric, 2022). While some regions may experience excessive rainfall, others may simultaneously suffer from drought conditions, which makes the aggregate national precipitation data a poor measure of localized agricultural outcomes. The same goes for Thailand and Malaysia. Although these countries are not archipelagic in nature, they also experience a highly uneven rainfall distribution. Moreover, crop productivity is more sensitive to the timing and distribution of rainfall rather than its annual total. For instance, rice production requires adequate water during planting and growing stages, yet excessive rainfall during the harvest season sometimes leads to flooding, soil erosion, and post-harvest losses. This means that higher overall precipitation does not necessarily translate to improved crop yields.

Additionally, many agricultural regions across the three countries rely on irrigation systems that reduce dependence on rainfall, thereby weakening the observable relationship (Silva, Reidsma, Velasco, Laborte, & van Ittersum, 2018). The Philippines, Thailand, and Malaysia are also highly vulnerable to typhoons, which can destroy large areas of farmland in a short period. However, such extreme events are not fully captured in the annual precipitation data, as averaging tends to smooth out their impact. In other words, precipitation does not affect crops in a strictly linear manner. Excessive rainfall can potentially lead to flooding, waterlogging, and pest outbreaks, while insufficient rainfall can cause drought stress (Oishy et al., 2025) which suggests that the timing and distribution of rainfall during the growing season are often more critical than its total amount. Apart from that, it is also possible that the farmers have historically adapted their cropping calendars, crop varieties, and practices to cope with rainfall variability, which further weakens the statistical relationship between precipitation and crop production.

The insignificant relationship between precipitation and crop production is similar to the results in the study of Farajzadeh, Ghorbanian, and Tarazkar (2024) which argues that the impacts of climate change in the agricultural sector are still unclear. It is also consistent with the study of Iqbal and Siddique (2015) in which it was established that the overall impact of climate change on agriculture is complex and cannot be generalized. Some crops are considered rainfed, while some are not, and some regions experience more rainfall than others, which contributes to the reason why there is a statistically insignificant relationship between the two variables.

Based on the regression results, the fertilizer consumption likewise exhibits a negative relationship with the crop production index. However, the relationship is insignificant. Fertilizer use in the Philippines is often inefficient due to issues such as overapplication, misuse, and poor knowledge of proper nutrient management among farmers (Briones, 2017). Similarly, studies have noted that many farmers in Malaysia tend to apply fertilizers in excess or without precision, often as a safeguard against potential agricultural loss (Ali & Shaari, 2015) but this does not necessarily improve agricultural productivity. In fact, overapplication has been linked to declining soil quality in some areas and may even give rise to issues of nutrient imbalance when fertilizers are not tailored to specific soil conditions (Derpsch et al., 2024). Hence, whether or not fertilizer consumption increases or decreases crop production predominantly depends on the specific area, crop variety, or soil conditions.

The negative coefficient is likely due to the excessive fertilizer application, which has the potential to degrade soil quality, reduce long-term fertility, and even harm crops rather than increase productivity. In addition, many smallholder farmers face high input costs and therefore use fertilizers inconsistently which makes national fertilizer consumption data a weak predictor of crop production. The Philippines' heavy reliance on imported fertilizers also makes fertilizer usage highly sensitive to global price fluctuations, which can disrupt consistent application across regions (Mula & Coronado, 2022). This might have also contributed to the panel regression results. The same goes for Thailand and Malaysia. Both countries are import-dependent when it comes to fertilizers (Food and Agriculture Organization of the United Nations, n.d) which might have also affected the panel regression outcome.

Moreover, crop yields are influenced not only by fertilizer use but also by complementary factors such as irrigation, seed quality, pest control, and farming practices. Without these complementary inputs, fertilizer alone cannot drive productivity improvements. Government programs promoting organic fertilizers, such as the National Organic Agriculture Program (NOAP) of the Department of Agriculture in the Philippines, further diversify fertilizer usage patterns (Department of Agriculture, 2025) making aggregate consumption data less reflective of actual agricultural productivity. These conditions suggest that while fertilizer is a crucial input to agricultural production, its effect on crop production on a national level appears statistically insignificant due to inefficiencies, external market dependencies, and the interplay of multiple production factors in the agricultural sector.

The regression result for the Philippines, Thailand, and Malaysia is similar to the findings in the study of Abdullahi, Ibrahim, Ahmad, and Huo (2024) which suggested an insignificant relationship between fertilizer consumption and crop production. This is primarily because some fertilizers are used inefficiently, and in the case of the Philippines and Malaysia, many smallholder farmers apply either below or above the recommended levels due to limited technical knowledge, inadequate access to extension services, and reliance on traditional practices. Moreover, the effectiveness of fertilizer use also depends on the type of fertilizer applied. The studies of Irawan and Antriyandarti (2021) and Mohammed et al. (2024) argue that the increase or decrease in crop production predominantly depends on the type of fertilizer used. For instance, organic fertilizers have a positive impact on crop production, whereas chemical fertilizers have a negative impact. These inefficiencies and mismatches reduce the potential yield gains from fertilizer inputs, thereby diminishing their overall contribution to crop production. This also explains the insignificant relationship as observed in the regression results.

Meanwhile, the agricultural employment exhibits a positive and significant relationship with the crop production index. The positive and significant relationship is consistent with the findings in the study of Dait (2022) which suggests that greater labor input within the agricultural sector contributes to higher agricultural output. Since many farming activities, such as land preparation, planting, weeding, and harvesting, remain labor-intensive, an increase in the agricultural workforce potentially translates to improved productivity and higher crop yields. This reflects the importance of human capital in agriculture, particularly in contexts where mechanization and advanced technologies are not yet fully widespread. In the case of the Philippines, Thailand, and Malaysia, the regression result can be attributed to the countries' reliance on labor-intensive agricultural practices, especially in rice cultivation, which requires substantial human effort throughout its production cycle (International Trade Administration, 2024). Despite growing mechanization in some regions, many smallholder farmers continue to depend on agricultural labor (Kaewtrakulpong, Fuprasert, Sermsak, Ahamed, & Jedsadathammasathit, 2023).

Table 2. Regression diagnostic test results for the model on the impact of climate change, fertilizer consumption, and agricultural employment on crop production in the Philippines, Thailand, and Malaysia.

Diagnostic Test	P-value	Results	Interpretation
Levin-Lin-Chu (LLC) Test	-	P-value is < 0.05	No presence of unit root and the panel data is stationary
Variance Inflation Factor (VIF) Test	-	All values are < 10	No evidence of excessive collinearity
Joint Test on Named Regressors	1.521e-08	P-value is < 0.05	Independent variables significantly impact the dependent variable
Breusch-Pagan Test for Heteroskedasticity	0.264	P-value is > 0.05	No presence of heteroskedasticity
Hausman Test	0.871	P-value is > 0.05	Random effects model is appropriate
Jarque-Bera Test for Normality of Residual	0.745	P-value is > 0.05	Residuals are normally distributed
Wooldridge Test for Autocorrelation	0.377	P-value is > 0.05	No presence of autocorrelation
Pesaran CD Test for Cross-Sectional Dependence	0.099	P-value is > 0.05	No presence of cross-sectional dependence

4.2. Random Effects Generalized Least Squares (GLS) Regression Diagnostics

Table 2 summarizes the results of the regression diagnostic tests for the Random Effects Generalized Least Squares (GLS) model used in this study. The diagnostic tests on the regression model revealed satisfactory results, which affirm the robustness and reliability of the model.

The Levin-Liu-Chu (LLC) test, which is primarily used to assess stationarity, yielded a p-value less than the 0.05 significance level for all variables. This confirms that there is no presence of a unit root, and the panel data is stationary.

The Variance Inflation Factor (VIF) test reveals no evidence of excessive collinearity. This means that there is no multicollinearity within the variables in the model, which ensures an accurate estimation of the effects of the independent variables on the dependent variable for the model. The Variance Inflation Factor (VIF) test was used to identify if two or more independent variables have an existing linear relationship. Based on the diagnostic test result, each independent variable's Variance Inflation Factor is less than 10. Therefore, there is an absence of multicollinearity.

The Joint Test on Named Regressors produced a p-value less than the 0.05 significance level, indicating that the independent variables significantly explain the variations in the dependent variable. This confirms the overall relevance of the regressors in the model.

The Breusch-Pagan test for heteroskedasticity was conducted to determine whether the variance of the regression errors in the panel data depends on the values of the independent variables, indicating the presence of unequal residual variances across cross-sectional units or over time. Based on the results, the Breusch-Pagan test produced a p-value greater than the significance level of 0.05, supporting the null hypothesis that there is no presence of heteroskedasticity in the regression model. This indicates that the variance of the residuals is constant across both cross-sectional units and time periods, satisfying the assumption of homoskedasticity.

The Hausman test yielded a p-value greater than the 0.05 significance level, supporting the null hypothesis that the Random Effects model is appropriate. For the Jarque-Bera Test for Normality of Residual, the p-value is greater than the significance level of 0.05, which supports the null hypothesis that the residuals are normally distributed.

The Wooldridge test examined the presence of autocorrelation in the residuals of the regression models. Since the p-value is greater than the significance level of 0.05, this means that there is an absence of first-order autocorrelation, which means that the residuals are independent over time within each cross-sectional unit. Finally, the Pesaran CD test was conducted to detect cross-sectional dependence. Since the p-value is greater than the significance level of 0.05, this means that there is no presence of cross-sectional dependence in the regression model.

5. Conclusion

This study examined the impact of climate change, fertilizer consumption, and agricultural employment on crop production in the Philippines, Thailand, and Malaysia. Using panel regression analysis, the researchers assessed how climate-related and production-related factors influence crop production across the selected countries. The results revealed that temperature and agricultural employment are significant determinants of crop production, while precipitation and fertilizer consumption do not exhibit statistically significant effects.

In the case of the Philippines, Thailand, and Malaysia, temperature was identified as a significant determinant of crop production, exhibiting a negative relationship with the crop production index. This indicates that rising surface air temperatures, a direct manifestation of climate change, adversely affect agricultural productivity. This finding underscores the vulnerability of the selected Southeast Asian countries to climatic variations, largely due to their tropical geography, limited irrigation infrastructure, and the predominance of smallholder farmers with constrained adaptive capacity. The regression results further highlight that thermal stress and prolonged exposure to high temperatures reduce crop yields, particularly for heat-sensitive crops such as rice and palm oil.

Agricultural employment was also found to be a significant determinant of crop production. This result suggests that labor availability remains a critical input in agricultural production within the selected countries, where farming practices are still relatively labor-intensive. A higher level of agricultural employment contributes positively to crop production by ensuring adequate labor for planting, cultivation, and harvesting activities.

In contrast, precipitation and fertilizer consumption were not found to be statistically significant determinants of crop production. This may reflect the uneven distribution of rainfall, the presence of irrigation systems that mitigate reliance on precipitation, or inefficiencies in fertilizer application that limit its marginal contribution to output. This suggests that simply increasing fertilizer use may be insufficient to improve agricultural productivity without complementary improvements in management practices and technology.

Given these findings, the central challenge lies in enhancing agricultural and climate resilience. Policymakers should therefore prioritize adaptive agricultural strategies, including the promotion of climate-resilient crop varieties, strengthening agricultural extension programs, improving labor productivity through capacity building for farmers, and promoting efficient input use, including efficient fertilizer management.

Overall, the findings for this paper emphasize the need for resilient and forward-looking agricultural policies that address both climatic and economic vulnerabilities. Strengthening domestic agricultural production, improving input efficiency, and implementing climate-adaptive strategies are essential for sustaining agricultural productivity. By reinforcing stable domestic crop production, the Philippines, Thailand, and Malaysia can better safeguard their national food security and economic stability amidst the challenges brought about by climate change.

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