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Climate change and crop production nexus: assessing the role of technological development for sustainable agriculture in Vietnam

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Abstract

Purpose – This study aims to examine the effects of climate change and agricultural technologies on crop production in Vietnam for the period 1990–2018.

Design/methodology/approach – Several econometric techniques – such as the augmented Dickey–Fuller, Phillips–Perron, the autoregressive distributed lag (ARDL) bounds test, variance decomposition method (VDM) and impulse response function (IRF) are used for the empirical analysis.

Findings – The results of the ARDL bounds test confirm the significant dynamic relationship among the variables under consideration, with a significance level of 1%. The primary findings indicate that the average annual temperature exerts a negative influence on crop yield, both in the short term and in the long term. The utilization of fertilizer has been found to augment crop productivity, whereas the application of pesticides has demonstrated the potential to raise crop production in the short term. Moreover, both the expansion of cultivated land and the utilization of energy resources have played significant roles in enhancing agricultural output across both in the short term and in the long term. Furthermore, the robustness outcomes also validate the statistical importance of the factors examined in the context of Vietnam.

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Research limitations/implications – This study provides persuasive evidence for policymakers to emphasize advancements in intensive agriculture as a means to mitigate the impacts of climate change. In the research, the authors use average annual temperature as a surrogate measure for climate change, while using fertilizer and pesticide usage as surrogate indicators for agricultural technologies. Future research can concentrate on the impact of ICT, climate change (specifically pertaining to maximum temperature, minimum temperature and precipitation), and agricultural technological improvements that have an impact on cereal production.

Originality/value – To the best of the authors' knowledge, this study is the first to examine how climate change and technology effect crop output in Vietnam from 1990 to 2018. Various econometrics tools, such as ARDL modeling, VDM and IRF, are used for estimation.

Keywords Climate change, Agricultural technologies, Crop production, ARDL modeling

Paper type Research paper

1. Introduction

The world has undergone continuous change, which has had progressive effects on the sustainability of resources, but it has also caused significant environmental problems, such as climate change. The climate is the long-term pattern of meteorological conditions, whereas any change in climate after a lengthy period due to human or nonhuman activities is considered climate change (Ahsan *et al.*, 2020; Menegaki *et al.*, 2022). For instance, the increasing concentration of emissions and greenhouse gases (GHG) resulting from human activities predicts an increase in temperature and a shift in rainfall patterns, thereby causing climate change (Gul *et al.*, 2022a). National Aeronautics and Space Administration (2020) estimated that the average global temperature has augmented by 1.02°C since 1880. It caused an increase in temperature, CO_2 emissions, flooding and droughts, which diminished agricultural output (Jan *et al.*, 2021). Whereas climate change posed a threat to food security by reducing the yield of primary cereals like maize, wheat and rice (He *et al.*, 2022).

In pursuit of this objective, the existing body of scholarly works provides substantiation about climatic variables, including temperature and precipitation, and their impacts on agricultural and cereal productivity (Gul *et al.*, 2022b; Sivakumar, 2011), for example, stated that crop production is heavily dependent on climatic conditions and thus the principal victim of climatic vulnerabilities. According to Urban *et al.* (2012), by 2030–2050, aggregate crop yield could decrease by 18% on average, while temperature could rise by 1.8°C–2.2°C. As a result of their prominence and impact on global food security, the United Nations (2015) designated zero hunger and climate action as sustainable development goals (SDGs 2 and 13) for 2030.

The utilization of agricultural technologies, including fertilizers and pesticides, amplifies the climate-induced effects on agricultural systems. The extended duration of farming seasons and elevated temperatures foster the expansion of insects and weeds, hence leading to heightened utilization of fertilizers and insecticides. Nonetheless, these technologies are the principal means of preserving soil fertility and crop yields. Fertilizers (both organic and inorganic) serve as plant feeding (Guo *et al.*, 2021). These are either produced via natural processes (e.g. animal waste, plant-based materials and biosolids) or created artificially (e.g. ammonium nitrate, di-ammonium phosphate and potassium chloride) (Finch *et al.*, 2014). Pesticides, on the other hand, are inorganic or organic chemicals used to manage diseases, pests and weeds. Insecticides, herbicides, rodenticides, fungicides and nematicides are forms of pesticides (Sharma *et al.*, 2019).

Fertilizers and pesticides are now an essential aspect of crop improvement and plant protection, making farming reliant on the extensive use of these technologies. Ali *et al.* (2020) also confirmed that the surge in crop yields in the postgreen revolution era primarily attributes to the enormous use of agricultural technologies, especially chemical fertilizers and pesticides. Besides, farmers now use these formulations due to inadequate resources, degraded arable land and an increasing population. However, the usage of fertilizers varies in countries. Isherwood (1996) reckons that fertilizer consumption was once highest in developed countries (88%); however, the developing countries (55%) are now using these more to meet their food demand. A report by FAO (2017a, 2017b, 2017c, 2017d) provides that the global consumption of three primary fertilizers, i.e. nitrogenous (N), phosphorous (P) and potassium (K), can reach 186.67 million tons (Mt). In contrast, the annual demand can grow by 1.5%, 2.2% and 2.4%, for N, P and K, respectively, during 2015–2020. In particular to nitrogenous fertilizers, which are used in more quantity, their annual consumption can reach 110 Mt, with an annual increase of 2% (FAO, 2017a, 2017b, 2017c, 2017d). A detailed map of fertilizers (N, P and K) consumption can be found in Online Supplemental Figure S1 (FAO, 2017a, 2017b, 2017c, 2017d).

The trend of pesticide utilization is also not different, as China is the leading country with 1.77 Mt, followed by the USA (0.41 Mt), Brazil (0.38 Mt) and Argentina (0.20 Mt). In contrast, it is the lowest in the developing nations in Asia and Africa (FAO, 2017a, 2017b, 2017c, 2017d). A detailed map of pesticides consumption can be found in Online Supplemental Figure S2. Besides this, the annual consumption of pesticides reached 3.5 Mt in 2020, with a greater share of herbicides (≈47.5%) and insecticides (≈29.5%) (Sharma *et al.*, 2019). Therefore, due to the dominance and impact on global food security, the area is crucial for researchers and practitioners in determining the global and country-specific impact of agricultural technologies and climatic changes on agricultural productivity.

Specific to the Socialist Republic of Vietnam, agriculture is considered one of the primary contributing sectors to the national gross domestic product (GDP), adding nearly 20% (Trinh, 2018). It also employs half of its labor force (GFDRR, 2011) and offers a livelihood for one-third of its people (Shrestha, 2014). However, the United Nations Development Organization has ranked Vietnam vulnerable to climatic changes owing to regular floods, droughts, intrusion of saltwater and increased temperature. Figure 1 provides the annual average increase of 1.02°C in Vietnam's temperature since 1961 (Bank, 2020).

At present, Vietnam's agriculture industry is dealing with a decrease in arable area, increased attacks of pests and droughts and negative effects on farming. These are mostly the result of climate change (Yen, 2021), as rising temperatures reduce water resources and affect crop and animal outputs. It also turns cultivable areas into barren lands due to water shortage. Furthermore, climate change reduces biodiversity, induces untimely rainfall, supports the lives of harmful pests and encourages agricultural diseases (Huynh *et al.*, 2020). These concerns call into question farmers' livelihoods and threaten Vietnam's national food security (Huynh *et al.*, 2020). Therefore, the government made many initiatives to modernize crop production through automation and technology use, as well as through government-backed financing schemes (Linh *et al.*, 2019). These technologies range from farm inputs and machines to the most recent precision agriculture technology. Their use increased the efficiency of farm methods, resulting in higher crop yields in terms of both quality and quantity. Figure 2 and Online Supplemental Figure S3 provide the trend of agricultural technology application (i.e. nitrogenous fertilizers and pesticides) and explain the adoption by farmers. However, the Vietnamese government banned many hazardous pesticides due to their adverse, residual impact on human health and the environment (Hoi *et al.*, 2016). Therefore, the pesticide application trend remains flat from 2001, as shown in Online Supplemental Figure S3. Likewise, several developed countries, i.e. the USA, China, the EU countries and Brazil, are also phasing out the use of hazardous pesticides (Donley, 2019).

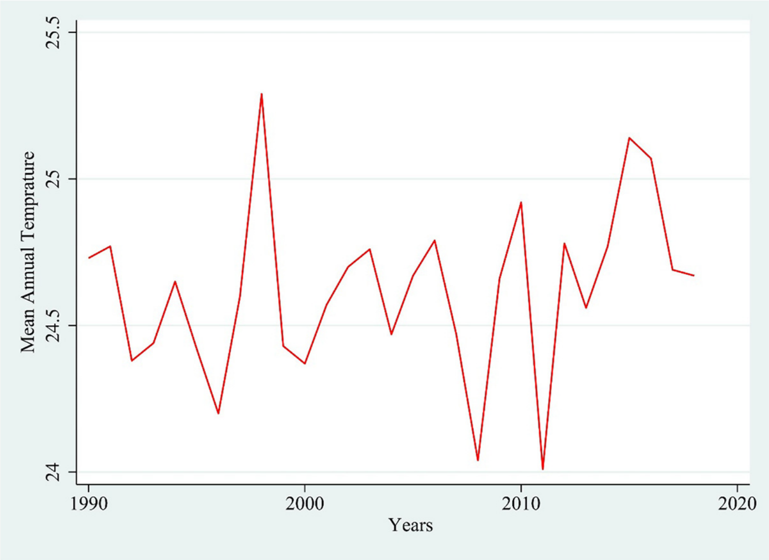


Figure 1.
Mean annual temperature in Vietnam (1990–2018)

Source: World Bank data

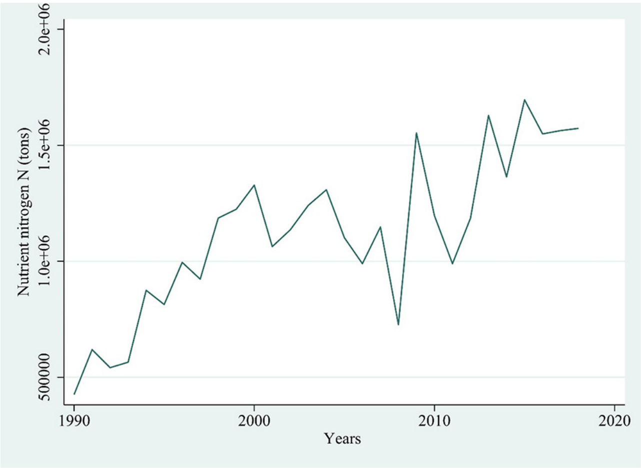


Figure 2.
Usage of nitrogen fertilizer in Vietnam (1990–2018)

Source: World Bank data

Due to escalating environmental issues in Vietnam and around the globe, sustainable technological methods are urgently required in the current context (Baker *et al.*, 2020; Migheli, 2020; Baker *et al.*, 2020) suggested the use of integrated nutrient management – balancing organic and chemical fertilizers as per the crop nutrients requirement and integrated pest management – balancing chemical, physical, biological controls over pests' management. In addition, the current literature requires more country-specific evidence to mitigate climatic effects and formulate future policies. This study examines the impact of agricultural technologies and climate changes on crop productivity in Vietnam using time series data from 1990 to 2018 and the autoregressive distributed lag (ARDL) modeling. The study concentrates on these elements' immediate and long-term effects.

Additionally, a number of studies have looked at how climate change is affecting a number of variables, such as Vietnamese households' livelihoods and adaptation strategies (Duffy *et al.*, 2021; Gilfillan *et al.*, 2017; Lindegaard, 2020; Phuong *et al.*, 2018; Thuc *et al.*, 2016; Thuy, 2019; Van Huynh *et al.*, 2020); the relationship between pesticide use and vegetable production (Hoi *et al.*, 2016); and the impact of weather variations and natural disasters on the agriculture sector (Huong *et al.*, 2019; Trinh *et al.*, 2021; Trinh, 2018; Van Phu, 2021). However, this study's goal is to investigate how, between 1990 and 2018, agricultural technologies and climate change affected Vietnam's crop productivity. The empirical analysis in this paper used a diverse range of econometric methodologies. The results of this study will provide valuable insights for scholars and policymakers in shaping their research inquiries and formulating policies specific to Vietnam.

The following paper is organized as follows: Section 2 elaborates on the existing body of literature on the topic under consideration and presents hypotheses, followed by data and methodology in Section 3. Section 4 contains the results and discussion, and Section 5 final portion concludes the complete research.

2. Literature review and research hypothesis

The agricultural sector in Vietnam has been a major source of employment in other economic sectors, employing nearly 18.8 million people as of 2019. During the 1990s, agricultural and aquacultural exports grew exponentially. However, the expansion of the tourism industry and urbanization have reduced the agricultural sector's output. In addition, climate change, coastal erosion and salinity intrusion have led to a decline in the fertility of the nation's agricultural lands. Therefore, the difficulty resides in institutionalizing the use of modern agricultural technologies to increase crop yield and productivity in this economic sector. Hence, the impact of climatic variations on agriculture and the use of agricultural technologies for crop production across countries have been extensively discussed in this study.

2.1 The nexus of crop production and climate change

The intergovernmental panel on climate change (IPCC, 1990) recognized the effects of climatic changes on agricultural production. However, the economic impact of climatic changes on agricultural yields still needs to be explored (Adams *et al.*, 1990; Mendelsohn *et al.*, 1994). Further, the literature records a shift of studies/researchers focusing on the USA to developing countries in this aspect. The assessment of the economic effect of climatic changes on crops/cereals production includes two primary approaches. The former is the computed general equilibrium model, which considers complex interactions of different segments of the economy (Winters *et al.*, 1996). Whereas the latter is the partial equilibrium model, which can further be classified into the Ricardian approach, agroecological zoning approach and production function approach (Fonta *et al.*, 2018).

Deressa and Hassan (2009) conducted a study based on farm households' responses toward climate change and agricultural production in different agroecological zones in Ethiopia. Their results predicted a gradual decrease in net revenue from each hectare by 2050, indicating the detrimental impacts of climatic changes. Sridharan *et al.* (2019) studied the impact of climatic changes on the production of rain-fed crops in Uganda, the irrigation needs of such crops in different climatic regions and the energy consumption required for the same. The results predict an increase of 8% and a reduction of 11% in rainfed crops' production in wet and arid climates, respectively.

Wielogorska *et al.* (2019) assessed samples of crops like maize, sorghum and wheat in Somalia, which revealed the presence of mycotoxins produced by a particular type of fungus, which usually grows under unfavorable and harsh environmental conditions, which subsequently tend to affect the pre- and post-harvesting yield. Sperry *et al.* (2019) hold global warming as a repercussion of excessive concentration of GHG to be a significant cause of reduction in agricultural yields, which would, in turn, threaten global food security.

FAO (2017a, 2017b, 2017c, 2017d) argue that extreme climatic conditions reduce the crop yield in Asia and Africa, which would, in turn, hamper the economic growth of the economy. Cline (2007), Bruinsma (2017) and UNCTAD (2015) explored the influences of climatic changes on agricultural productivity in developing and least developing countries located in South-eastern Asia, sub-Saharan Africa and Western Asia. Similarly, Attiaoui and Boufateh (2019), Fonta *et al.* (2018) and Sadiq *et al.* (2019) assert that the short-run influences of precipitation on crop yields are positive. At the same time, the long-run impacts of climatic changes on crop production are negative. However, Abbas and Mayo (2021) carried out research to look at how temperature and precipitation affected rice productivity in Pakistan's Punjab province between 1981 and 2018. The study found a statistically significant positive relationship during the tillering season between rainfall and rice yield. However, detrimental impacts were observed in the flowering and fruiting phases. Similarly, the yield of rice is negatively impacted by rising temperatures.

Researchers Kumar *et al.* (2021) examine how variations in the climate between 1971 and 2016 affected the output of grain crops in low- and middle-income nations. Along with control variables, including CO_2 emissions, the population of rural areas and the amount of land already farmed for cereal production, the main variables considered for estimation were yearly rainfall and temperature. The FGLS model's output determined how rainfall and temperature rise affected cereal production in the relevant nations. The outcomes were further validated by the Driscoll–Kraay standard regression robustness tests. On the other hand, Warsame *et al.*'s study from 2021 presents conflicting results regarding how precipitation affects Somalia's agricultural production. Higher rainfall and agricultural production appear to have a positive long-term association but a negative short-term relationship, according to the results of the Granger causality analysis and ARDL testing.

Moreover, Ali *et al.* (2021) investigated the combined effects of modern agricultural techniques and climatic factors on sugarcane in Pakistan by using the data from 1989 to 2015. Results obtained from bounds *F*-test for cointegration confirm a positive and insignificant relationship between temperature and sugarcane yield and a significant negative impact of the use of agricultural machinery on the same. Thus, the researchers hypothesize the following:

H1. Crop productivity is negatively impacted by climate change.

2.2 The nexus of crop production and agricultural technologies

There has been growing literature on the connection between technological advancements and crop production globally. Green technologies encompass various aspects of sustainable development, including energy production, waste management and opening up opportunities for a clean environment (Ismael *et al.*, 2018). The most important factors influencing the yield of crops in different climatic zones are the availability and accessibility of water, consumption and expenditure on fertilizers and availability and distribution of credit at cheaper rates of interest. Winpenny *et al.* (2010) reveal that the agriculture sector uses 70% of the extracted global freshwater. Owing to the increasing demand for freshwater by households and industries in urban areas, there has been an increase in the use of wastewater for irrigation purposes (Scott *et al.*, 2004).

Wanyama *et al.* (2009) studied the positive and significant effects of fertilizers, seeds, pesticides and modern technology consumption in improving the total yield of crops in sub-Saharan Africa. Chandio *et al.* (2021b) indicated a rise in agricultural income and productivity as a result of fertilizer usage in Pakistan. Financial development is also a critical factor in enhancing agricultural production. Financial development is broadly perceived to let farmers invest and adopt new technologies, which can increase the income from agriculture. An accessible financial system with lower interest rates would encourage poor farmers to purchase inputs like fertilizers, seeds, pesticides and other agrochemicals, that boost yield.

Zakaria *et al.* (2019) investigated how financial development impact agricultural productivity during 1973–2015. Their results report the existence of an inverted U-shaped relationship between the variables. Ismael *et al.* (2018) confirmed the positive effects of modern agricultural techniques on agricultural productivity and yield. However, research evidence also supports the argument that modern agricultural techniques like tractors have been a significant source of carbon dioxide emissions (Arapatsakos and Gemtos, 2008).

Zou *et al.* (2015) found that 60% of emissions in the agriculture sector in China are due to energy activities related to irrigation facilities. Conversely, Directorate-General for Internal Policies (2014) indicated a decline in the emission of GHG with the reduction in the use of fertilizers and fossil fuel energy as agricultural inputs. Chandio *et al.* (2021a) investigated the impact of technological improvements and climatic changes on rice production in Nepal. The authors used proxy variables such as carbon emissions, average rainfall, temperature, usage of fertilizer and improved seeds. The ARDL model results indicate that a 1% surge in carbon emissions decreases rice production by 0.13%. In contrast, a 1% increase in fertilizer use and easy agricultural credit leads to 0.05% and 0.02% increase in rice production. The results were verified with appropriate robustness tests of impulse response and variance decomposition models.

Rehman *et al.* (2019) explored the impact of the adoption of modern agricultural techniques like fertilizer use, water and credit availability on Pakistan's agricultural value addition to national GDP for the period 1978–2015. They found a long-term, significant positive association between the variables except for water availability, which had negative yet insignificant effects. Thus, the researchers hypothesize the following:

H2. Technological advancement is expected to play a dynamic role and improve crop production.

Irrespective of the numerous investigations on the effects of climate change and technological development on crop production, a rigorous study is missing for Vietnam to the best of our knowledge. Therefore, the researchers organized this scholarship to fill this gap. The dynamic nexus between climate change, agricultural technologies and crop production are shown in Figure 3.

3. Data and methodology

3.1 Data

This research investigates the impacts of agricultural technologies and climate change on crop production in Vietnam, using annual data spanning from 1990 to 2018. The average yearly temperature data was sourced from the website of the World Bank Group Climate Change Portal, whereas the data on crop production index (2014–2016 = 100) and cultivated

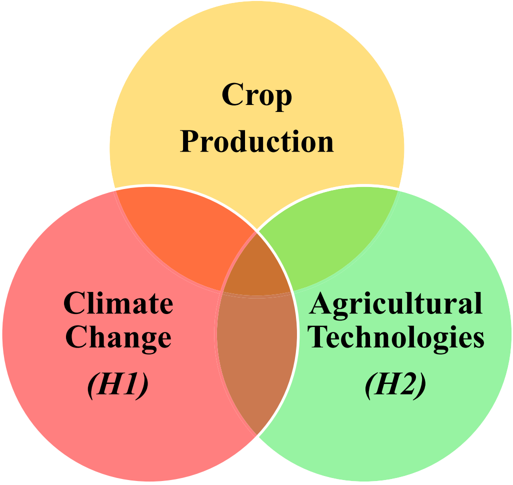


Figure 3.
Dynamic connection between agricultural technologies, climate change and crop production

Source: Authors' own creation

area (hectares) were gathered from the website of the World Bank. Similarly, data on the total fertilizer consumption by nutrient (tons) and the total pesticide use (tons) were acquired from the FAOSTAT database. Finally, data on energy consumption (million tons of oil equivalent) was taken from the Statistical Review of World Energy (SRWE). Table 1 provides the description, measurement and data sources of the undertaken antecedents. Figure 4 displays the trends of the variables.

3.2 Model construction

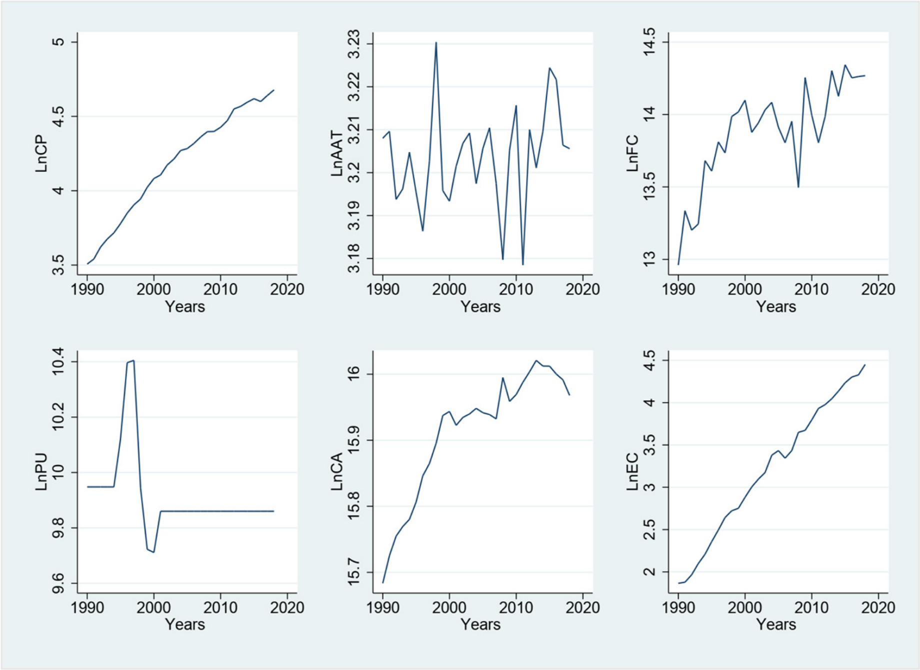
Keeping in view the studies of Ahsan *et al.* (2020) and Kumar *et al.* (2021), the present paper undertakes average annual temperature as a proxy to measure climatic changes. Furthermore, based on the latest studies of Ali *et al.* (2020), Ali *et al.* (2021) and Chandio *et al.* (2021a), this study uses fertilizer use and pesticide usage as indicators of agricultural technologies. Furthermore, the article incorporates farmed area and energy consumption as control variables. Equation (1) establishes the relationship between agricultural technologies, climate change and their respective effects on crop production:

$$CP_t = f(AAT_t,\ FC_t,\ PU_t,\ CA_t,\ EC_t) \tag{1}$$

Table 1.
Unit of measurement and data sources of the variables

Variables	Measurement unit	Data sources
CP	Crop production index (2014–2016 = 100)	World Bank
AAT	Average annual temperature (°C)	World Bank
FC	Fertilizer consumption (tons)	FAOSTAT
PU	Pesticide use (tons)	FAOSTAT
CA	Cultivated area (hectares)	World Bank
EC	Energy consumption (million tons of oil equivalent)	SRWE

Source: Authors' own creation



Notes: LnCP, LnAAT, LnFC, LnPU, LnCA and LnEC denote the natural logarithm of crop production, average annual temperature, fertilizer use, pesticide use, cultivated area and energy consumption, respectively

Source: Authors' generated by using the Stata software

Figure 4.
Time series plots of the study variables

To get consistent outcomes, the researchers transformed all the study variables into a log form; therefore, equation (2) is as follows:

$$LnCP_t = \beta_0 + \beta_1 LnAAT_t + \beta_2 LnFC_t + \beta_3 LnPU_t + \beta_4 LnCA_t + \beta_5 LnEC_t + \varepsilon_t \qquad (2)$$

where $LnCP$ donates the natural log of crop production, $LnAAT$ denotes the natural log of average annual temperature, $LnFC$ shows the natural log of fertilizer consumption, $LnPU$ symbolizes the natural log of pesticide use, $LnCA$ means the natural log of cultivated area and $LnEC$ defines the natural log of energy consumption. β_0 represents the constant term, β_1, β_2, β_4, β_4 and β_5 indicate the coefficients, and ε_t is the error term. Figure 5 shows the research framework of the study.

3.3 Autoregressive distributed lag method

The present study used an appropriate and unique ARDL bounds cointegration or error correction modeling approach of Pesaran *et al.* (2001), which has statistical superiority over other cointegrating procedures (Menegaki, 2019; Pesaran *et al.*, 2001; Shahbaz *et al.*, 2013), as it gives both long-term and short-term estimations in a single step. In addition, this technique can be used whether the variable is stationary at a level $I(0)$ or first difference $I(1)$

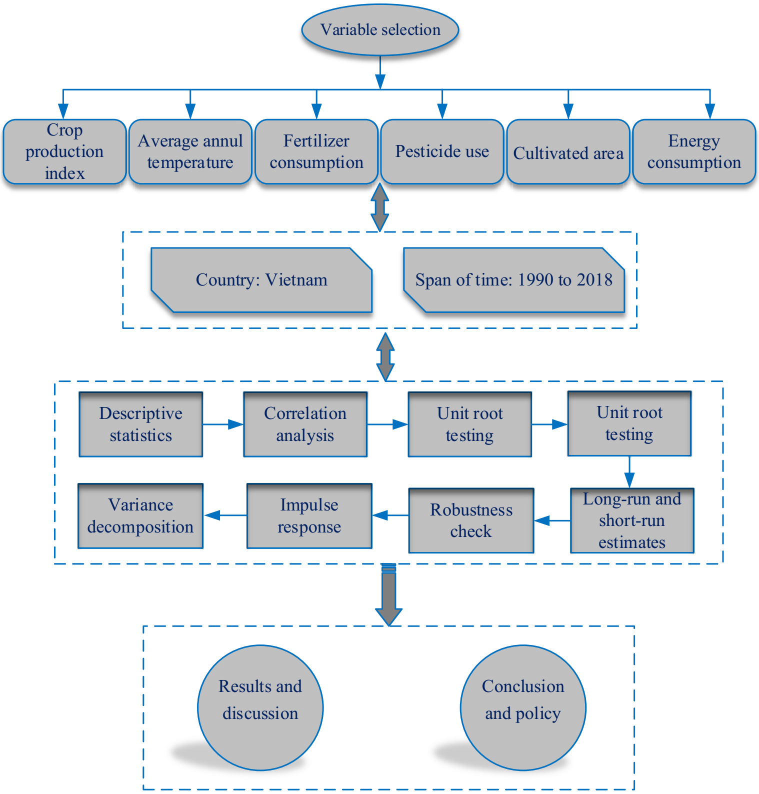


Figure 5.
Research framework of the study

Source: Authors' own creation

and mixed of integration other than $I(2)$ series. Pesaran *et al.* (2001) also suggested the appropriateness of the ARDL approach for a small sample as it testifies robust and reliable long-term and short-term estimates in a small data set. So, we modify equation (3) in error correction format as given below:

$$\Delta LnCP_t = \Upsilon_0 + \sum_{i=1}^{p} \Upsilon_1 \Delta LnCP_{t-i} + \sum_{j=0}^{q} \Upsilon_2 \Delta LnAAT_{t-j} + \sum_{k=1}^{r} \Upsilon_3 \Delta LnFC_{t-k} + \sum_{l=1}^{s} \Upsilon_4 \Delta LnPU_{t-l} + \sum_{m=1}^{t} \Upsilon_5 \Delta LnCA_{t-m} + \sum_{n=1}^{u} \Upsilon_6 \Delta LnEC_{t-n} + \delta_1 LnCP_{t-1} + \delta_2 LnAAT_{t-1} + \delta_3 LnFC_{t-1} + \delta_4 LnPU_{t-1} + \delta_5 LnCA_{t-1} + \delta_6 LnEC_{t-1} + \varepsilon_t \tag{3}$$

The first set of parameters in equation (3) (γ_1, γ_2, γ_3, γ_4, γ_5, γ_6) shows the short-run dynamics, while the second set of parameters (δ_1, δ_2, δ_3, δ_4, δ_5, δ_6) signifies the long run. This study tests the null hypothesis that a long-term cointegration relationship exists between the study variables against the alternative hypothesis as follows:

$$H_0 : \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$$

$$H_1 : \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq 0$$

The reliability of the long-run cointegration association among the undertaken variables is verified through the F-test of Pesaran *et al.* (2001). It implies that when the estimated values of the F-test fall below the lower bound $I(0)$, we reject the null hypothesis and suggest the absence of long-run cointegration. Whereas if the values fall above the upper bound $I(1)$, the conclusion is the presence of long-term cointegration. The outcomes are inconclusive when the F-test values fall between the $I(0)$ and $I(1)$ bounds limit. In addition, the short-run dynamics association between the variables can be observed from the following equation as:

$$\Delta LnCP_t = \Upsilon_0 + \sum_{i=1}^{p} \Upsilon_1 \Delta LnCP_{t-i} + \sum_{j=0}^{q} \Upsilon_2 \Delta LnAAT_{t-j} + \sum_{k=1}^{r} \Upsilon_3 \Delta LnFC_{t-k} + \sum_{l=1}^{s} \Upsilon_4 \Delta LnPU_{t-l} + \sum_{m=1}^{t} \Upsilon_5 \Delta LnCA_{t-m} + \sum_{n=1}^{u} \Upsilon_6 \Delta LnEC_{t-n} + \theta_1 ECT_{t-1} + \varepsilon_t \quad (4)$$

4. Results and discussion

4.1 Descriptive and correlation analysis

Table 2 reports the summarized descriptive statistics. The mean crop production, average annual temperature, fertilizer consumption, pesticide use, farmed area and energy use are 4.18, 3.20, 13.87 nutrients tons, 9.91 tons, 15.91 hectares and 3.21 million tons of oil equivalent, respectively. In addition, the correlation matrix shown in the lower panel of Table 2 reveals that average annual temperature, fertilizer usage, cultivated area and energy use are positively and significantly associated with crop production. Whereas pesticide use is negatively correlated with crop production.

4.2 Unit root test results

The present study used the Phillips–Perron (PP) (Phillips and Perron, 1988) and augmented Dickey–Fuller (ADF) (Dickey and Fuller, 1979) unit root tests to check the order of integration of the selected variables. The PP and ADF estimations include trend as well as intercept. Table 3 provides the estimated results of the PP and ADF tests on the integration properties of crop production *(LnCP)*, average annual temperature *(LnAAT)*, fertilizer consumption *(LnFC)*, pesticide use *(LnPU)*, cultivated area *(LnCA)* and energy consumption *(LnEC)*. The results reveal that both estimations generate mixed outcomes for the undertaken variables, i.e. integrated at the level $I(0)$ and the first difference $I(1)$. Furthermore, the unit root techniques estimates show that among all variables, only *LnAAT*, *LnFC* and *LnPU* are stationary at the level. Thus, the unit root tests are applied to the study variables, taking the first difference. The results demonstrate that *LnCP*, *LnCA* and *LnEC* are stationary at first difference.

4.3 Determination of the cointegration relationship

Once the validation of the study variables' combined degree of integration, specifically I(1) and I(0), is completed, the ARDL bounds approach is used to ascertain the presence of the

	LnCP	LnAAT	LnFC	LnPU	LnCA	LnEC
Mean	4.1834	3.2035	13.8752	9.9147	15.9132	3.2158
Median	4.2708	3.2051	13.9532	9.8602	15.9397	3.3436
Maximum	4.6785	3.2304	14.3436	10.4048	16.0209	4.4518
Minimum	3.5067	3.1784	12.9607	9.71123	15.6834	1.8646
SD	0.3630	0.0117	0.3540	0.15277	0.0944	0.8050
Kurtosis	1.9163	3.3240	3.1884	7.9204	2.8694	1.8440
Skewness	−0.3909	−0.0136	−0.9054	2.2453	−0.9993	−0.1756
Jarque–Bera	2.1576	0.1277	4.0051	53.6232	4.8477	1.7638
Pro.	0.3399	0.9381	0.1349	0.0000	0.0885	0.4139
Observations	29	29	29	29	29	29
LNCP	–					
t-stat	–					
p-value	–					
LnAAT	0.1728	–				
t-stat	0.9117	–				
p-value	0.3700	–				
LnFC	0.8151	0.3286	–			
t-stat	7.3114	1.8081	–			
p-value	0.0000	0.0817	–			
LnPU	−0.4318	−0.1480	−0.3190	–		
t-stat	−2.4881	−0.7776	−1.7494	–		
p-value	0.0193	0.4436	0.0916	–		
LnCA	0.9482	0.1067	0.8503	−0.4323	–	
t-stat	15.5228	0.5577	8.3951	−2.4917	–	
p-value	0.0000	0.5816	0.0000	0.0192	–	
LnEC	0.9940	0.1974	0.8013	−0.4019	0.9235	–
t-stat	47.4172	1.0468	6.9619	−2.2810	12.51691	–
p-value	0.0000	0.3044	0.0000	0.0307	0.0000	–

Table 2.
Descriptive statistics and correlations

Notes: Ln = natural logarithm; CP = crop production; AAT = average annual temperature; FC = fertilizers consumption; PU = pesticides use; CA = cultivated area and EC = energy consumption
Source: Authors' own creation

	ADF		PP		
Variables	Level	First difference	Level	First difference	Integration order
LnCP	−0.8101 (0.9526)	−6.0829 (0.0002)	−0.3424 (0.9849)	−8.1839 (0.0000)	*I(1)*
LnAAT	−5.1615 (0.0015)	−5.1419 (0.0018)	−5.1620 (0.0014)	−15.8709 (0.0000)	*I(0)*
LnFC	−4.0507 (0.0184)	−5.8372 (0.0003)	−4.0318 (0.0192)	−12.9554 (0.0000)	*I(0)*
LnPU	−4.7810 (0.0036)	−6.2190 (0.0003)	−4.9153 (0.0025)	−11.8785 (0.0000)	*I(0)*
LnCA	−1.4336 (0.8280)	−5.9325 (0.0002)	−1.2956 (0.8682)	−5.9808 (0.0002)	*I(1)*
LnEC	−1.5858 (0.7708)	−6.7209 (0.0000)	−2.2567 (0.4422)	−10.4871 (0.0000)	*I(1)*

Table 3.
Unit root test results

Notes: PP = Phillips–Perron; ADF = Augmented Dickey–Fuller; Ln = log from; CP = Crop production; AAT = Average annual temperature; FC = Fertilizer consumption; PU = Pesticide use; CA = Cultivated area and EC = Energy consumption
Source: Authors' own creation

long-term cointegration connection. Table 4 displays the empirical findings obtained from the application of the ARDL bounds technique to cointegration. At a significance level of 1%, the estimated value of the *F*-statistic (5,1161) exhibits statistical significance. The findings suggest the presence of long-term cointegration among crop production (*LnCP*),

Table 4.
Results of bounds testing

Test stat.	Value	*k*
F-stat.	5.1161	5
Levels of significance	I0 Bound	I1 Bound
10%	2.26	3.35
5%	2.62	3.79
1%	3.41	4.68
F-stat.	8.2675	
Pro. (*F*-stat.)	0.0075	
R^2	0.9632	
Adjusted R^2	0.8467	

Source: Authors' own creation

annual average temperature (*LnAAT*), fertilizer consumption (*LnFC*), pesticide use (*LnPU*), cultivated area (*LnCA*) and energy consumption (*LnEC*).

To assess the reliability of the ARDL bounds test, this study also uses the Johansen cointegration technique, using the trace statistic and Max–Eigen statistic tests. The outcomes of the previously described cointegration analysis exhibit similarities with the ARDL bounds test, indicating the presence of a long-term cointegration association among *LnCP*, *LnAAT*, *LnFC*, *LnPU*, *LnCA* and *LnEC* variables (see Table 5). Based on the empirical findings, it can be concluded that the variables exhibit integration at both I(0) and I(1) levels, indicating the presence of long-term cointegration. Therefore, we proceed to examine the effects of fertilizer use, pesticide use, cultivated area, average yearly temperature and energy consumption on crop output in both the short- and long-term.

Table 5.
Results of Johnson's cointegration test

Hypothesized No. of CE(s)	EV**	TS	0.05 CV***	Prob.
None*	0.9008	150.6501	107.3466	0.0000
At most_1*	0.7997	88.2629	79.3414	0.0090
At most_2	0.6230	44.8472	55.2457	0.2951
At most_3	0.3126	18.5050	35.0109	0.7962
At most_4	0.2396	8.3816	18.3977	0.6437
At most_5	0.0357	0.9830	3.8414	0.3214

TS = trace test specifies two cointegrating eqn(s) at 0.05 level
**Shows that the hypothesis is rejected at 0.05 level*

Hypothesized No. of CE(s)	EV**	M-E Stat.	0.05 CV***	Prob.
None*	0.9008	62.3872	43.4197	0.0002
At most_1*	0.7997	43.4156	37.1635	0.0085
At most_2	0.6230	26.3422	30.8150	0.1600
At most_3	0.3126	10.1233	24.2520	0.8972
At most_4	0.2396	7.3985	17.1476	0.6693
At most_5	0.0357	0.9830	3.8414	0.3214

Notes: Max-eigen stat test indicates two cointegrating eqn(s) at 0.05 level. *Indicates that the hypothesis is rejected at 0.05 level; **hows eigenvalues; ***Shows critical values
Source: Authors' own creation

4.4 Long- and short-run outcomes from the autoregressive distributed lag

Table 6 indicates the baseline ARDL estimations for a linear specification of the impacts of our explanatory variables (agricultural technologies and climate change) on crop production in Vietnam.

Temperature: The data, both short- and long-term, show that temperature has a detrimental effect on crop productivity. It suggests that there will be a short-term reduction in production of 0.67% and a long-term reduction of 2.74% with every 1% increase in temperature. There are multiple arguments to support the results of this investigation. First, research has shown that growing global warming affects the output of cereals (Hansen *et al.*, 2010). Rice production decreased as a result of the planet's recent 0.5°C–0.6°C warming (Zhao and Fitzgerald, 2013). According to Nelson *et al.* (2009), there could be a 10%–15% decrease in cereal production as a result of climate change, which could drive up costs. Additionally, it was proven by Chandio *et al.* (2021a, 2021b) that the temperature decreased rice yield by 4% in a number of Asian countries, including Bangladesh, India, Indonesia, Pakistan, Sri Lanka, Thailand and Vietnam. Furthermore, Kumar *et al.* (2021), Ozdemir (2021) and Attiaoui and Boufateh (2019) have all found similar detrimental effects of temperature on agricultural productivity.

Fertilizer: Fertilizer consumption, as a technological component, has a significant beneficial long- and short-term impact on crop productivity. More specifically, crop productivity will increase by 0.02% and 0.04% for every 1% increase in fertilizer consumption. Improved seed

Table 6.
ARDL estimation results

Variables	Coeff.	Std. er.	*t*-stat.	Pro.
Long-run effect				
LnAAT	−2.745446	1.596272	−1.719911	0.1362
LnFC	0.041211	0.091647	0.449667	0.6687
LnPU	−0.091006	0.093599	−0.972299	0.3685
LnCA	0.927176	0.443691	2.089689	0.0816
LnEC	0.314171	0.024062	13.056935	0.0000
Short-run effect				
D(LnAAT)	−0.670538	0.344152	−1.948375	0.0993
D[LnAAT(−1)]	−0.395244	0.371838	−1.062945	0.3287
D[LnAAT(−2)]	0.169470	0.217643	0.778658	0.4658
D(LnFC)	0.020983	0.023008	0.912006	0.3969
D[LnFC(−1)]	−0.031949	0.025096	−1.273063	0.2501
D(LnPU)	0.035414	0.043801	0.808524	0.4497
D[LnPU(−1)]	−0.182566	0.059713	−3.057402	0.0223
D[LnPU(−2)]	0.132170	0.036800	3.591570	0.0115
D(LnCA)	0.540827	0.176103	3.071082	0.0219
D[LnCA(−1)	−0.429411	0.328884	−1.305660	0.2395
D(LnEC)	0.099550	0.068511	1.453063	0.1964
D[LnEC(−1)]	−0.316860	0.077573	−4.084683	0.0065
D[LnEC(−2)]	0.060496	0.074968	0.806953	0.4505
CointEq(−1)	−0.645231	0.153563	−4.201725	0.0057
Constant	−1.535148	7.123762	−0.215497	0.8365
R-squared	0.999793			
Durbin–Watson stat	2.417901			
SE of regression	0.009029			
F-statistic	126.951			
Pro. (*F*-statistic)	0.000000			

Source: Authors' own creation

quality, fertilizer application and pesticide use are examples of advanced agricultural technology that have a major impact on agricultural output. Nitrogen fertilizers are being used not just to increase crop yields but also to reduce pollution to the environment and transition to long-term sustainable agricultural production. For example, Chandio *et al.* (2021a) found that the use of fertilizers and higher-quality seeds increased rice production in Nepal. Similarly, more recently, Ozdemir (2021) looked at how fertilizer use and climate change affected agricultural productivity in a few Asian nations. The results showed that while fertilizer consumption greatly increased agricultural productivity, climate change drastically decreased it. The present study's findings are consistent with previous research in the literature (Ali *et al.*, 2020; Chandio *et al.*, 2021a; Chandio *et al.*, 2021b; Rayamajhee *et al.*, 2021; Rehman *et al.*, 2019), who examined the impact of fertilizer usage on cereal output.

Pesticide: When considered as a technological element, the predicted results show how pesticide affect agricultural productivity both short- and long-term. The implication is that extended pesticide use has a negative effect on agricultural productivity. Specifically, a 1% increase in pesticide would result in a 0.09% decrease in crop productivity. To increase agricultural yields of both food and nonfood crops and generate large profits, pesticides have become a crucial input ingredient for plant protection (De Bon *et al.*, 2014). Agriculture in emerging nations, particularly in Southeast Asia, is using more pesticides than ever before (Schreinemachers and Tipraqsa, 2012). More than 20% of pesticides are used in emerging countries, according to the WHO report, and this percentage is rising. According to Schreinemachers *et al.* (2020), Southeast Asia imports 61% of all pesticides, 5% from Laos and 10% from Vietnam.

Cultivated area and energy consumption: Cultivated area and energy consumption have beneficial long- and short-term effects on crop productivity as control variables. The findings support the earlier research of (Qureshi *et al.*, 2016; Warsame *et al.*, 2021). They suggest that a 1% increase in cultivated area and electricity consumption can increase crop yield by 0.54%, 0.92%, 0.09% and 0.31%.

4.5 Diagnostic and stability tests

The results of the ARDL estimations in Table 6 provide that the model fits well ($R^2 = 0.9997$). The Durbin–Watson stat value, 2.42, negates the presence of spurious regression in the ARDL estimation. The present scholarship also uses other diagnostic tests (i.e. serial correlation, ARCH, normality and Ramsey RESET) to check the consistency of the ARDL estimations. Table 7 shows the results of the diagnostic tests, confirming that the ARDL is free from all problems and stable. In addition, the present study also applied the CUSUM and CUSUM square tests to verify the stability and reliability of the ARDL estimations. The test results prove the stability of the ARDL model (see Online Supplemental Figures S4 and S5).

Tests	*F*-stat.	Pro.
Serial correlation	1.778381	0.2802
ARCH	2.260308	0.1463
Normality	0.96104	0.61846
Ramsey RESET	1.610357	0.1682

Source: Authors' own creation

Table 7.
Diagnostic tests results

4.6 Robustness check

Table 8 exhibits the robustness check of findings with the robust least-squares technique. The outcome reveals that temperature as a proxy for climate change negatively affects crop production. It is evident that temperature, the primary variable of interest, reduces crop production. Besides, fertilizers usage as a technological input variable affects crop production positively. The robustness check results provide that extensive usage of pesticides negatively affects crop production. Additionally, cultivated area and energy consumption significantly increase crop production in line with robust least-squares method results.

4.7 Results of impulse response function and variance decomposition method

This paper used the impulse response function (IRF) and variance decomposition method (VDM) to investigate the association among temperature, cultivated area, pesticide use, fertilizer, energy use and crop production for additional periods in Vietnam. The outcomes of IRF suggested that average temperature has negatively affected rice production, and variations are not apparent during these periods. On the other hand, energy use, fertilizer and cultivation area have a significant positive impact on crop production. Though minor variations occurred, the positive response is relatively stable at the end for these variables. The response of pesticide use confirmed gradual improvement. Initially, it did not work, and the impact remained negative for some time. The use of pesticide positively impacts crop production after the fifth period and remains steady till the last (see Figure 6).

Similarly, Table 9 displays the VDM test results. Crop production breaks down to reveal that 97.57% of its value can be explained by novel shocks. Both energy usage and fertilizer contribution are increasing over time, although fertilizer's share is larger. Furthermore, while at a slower rate, pesticide and the farmed area also showed an increase. When compared to all other factors exhibiting a negative correlation, the average contribution of temperature to crop output is minimal. The VDM further verifies that while the intensity of these effects varies, their overall impact increases progressively. As a result, both the short- and long-term effects of climate change on crop productivity in Vietnam are consistent. Ozdemir (2021) verified that although fertilizer consumption greatly increased agricultural productivity, climatic change dramatically decreased agricultural output. Likewise, Warsame *et al.* (2021) discovered that fertilizers and energy use had a favorable effect on agricultural yield. As a result, the current study's findings are solid and in line with previous long- and short-term research.

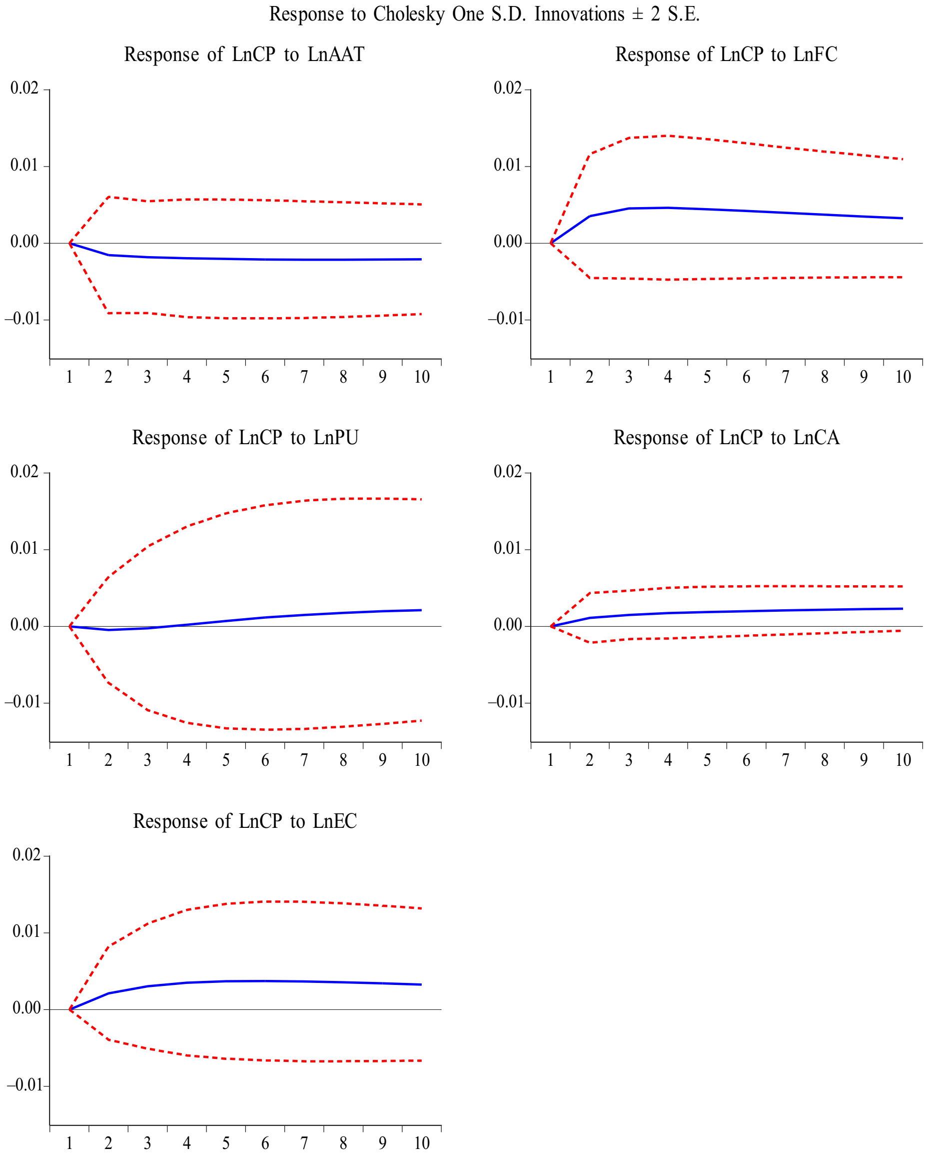
5. Conclusion and policy recommendations

This study uses cultivated area and energy consumption as control variables to experimentally investigate the short- and long-term effects of pesticide, fertilizer and climate

Variables	Coeff.	Std. er.	z-stat.	Pro.
LnAAT	−0.553539	0.374669	−1.477408	0.1396
LnFC	0.008800	0.022646	0.388605	0.6976
LnPU	−0.050152	0.027442	−1.827524	0.0676
LnCA	0.635646	0.131884	4.819745	0.0000
LnEC	0.374650	0.012419	30.16658	0.0000
Constant	−4.993111	2.701616	−1.848194	0.0646
R-squared	0.734964			

Source: Authors' own creation

Table 8.
Robust least squares method results



Source: Authors' generated by using the EViews software

Figure 6.
Impulse response function

change on crop output in Vietnam from 1990 to 2018. Our research primarily aims to address agricultural sustainability in the examined area by examining the relationship between crop output and climate change in the context of agricultural technologies. The ARDL approach was used in our analysis to estimate the equilibrium relationship over the long run between the independent and dependent variables under investigation. To confirm

Table 9. Variance decomposition results

Period	SE	LnCP	LnAAT	LnFC	LnPU	LnCA	LnEC
Variance decomposition of LnCP							
1	0.02148	100.0000	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.02934	97.57708	0.27610	1.45327	0.02485	0.14100	0.52767
3	0.03492	95.37443	0.46566	2.71803	0.02271	0.28496	1.13419
4	0.03933	93.73720	0.61681	3.51836	0.02109	0.41933	1.68720
5	0.04300	92.51364	0.74272	4.01051	0.04578	0.54219	2.14513
6	0.04615	91.56617	0.85274	4.31175	0.10273	0.65699	2.50960
7	0.04890	90.80977	0.94983	4.49416	0.18659	0.76661	2.79302
8	0.05135	90.19265	1.03519	4.59979	0.28897	0.87332	3.01006
9	0.05355	89.68115	1.10962	4.65389	0.40239	0.97878	3.17414
10	0.05553	89.25153	1.17400	4.67226	0.52149	1.08422	3.29647
Variance decomposition of LnAAT							
1	0.01163	21.51075	78.48925	0.00000	0.00000	0.00000	0.00000
2	0.01347	16.79659	58.60057	9.61147	5.78659	5.64542	3.55933
3	0.01438	14.83699	51.38019	10.59587	11.70464	8.08247	3.39982
4	0.01522	13.27105	46.01096	11.14709	16.35293	10.15936	3.05862
5	0.01592	12.21129	42.12572	11.44953	19.53514	11.85981	2.81850
6	0.01654	11.45066	39.11110	11.74073	21.62544	13.35672	2.71535
7	0.01709	10.86192	36.66402	12.05323	22.99334	14.70673	2.72076
8	0.01760	10.36891	34.59995	12.39273	23.89898	15.94107	2.79834
9	0.01807	9.93090	32.80851	12.75306	24.51072	17.07567	2.92113
10	0.01853	9.52704	31.22040	13.12693	24.93400	18.12064	3.07099
Variance decomposition of LnFC							
1	0.19012	1.61001	1.50322	96.88676	0.00000	0.00000	0.00000
2	0.19942	1.63537	4.64911	89.90101	0.63713	1.40053	1.77683
3	0.20120	1.74581	4.68730	88.71674	1.20541	1.71875	1.92597
4	0.20255	1.99389	4.72668	87.53314	1.76128	2.00974	1.97525
5	0.20371	2.28418	4.71829	86.55221	2.22235	2.25249	1.97046
6	0.20477	2.58922	4.70005	85.67718	2.59621	2.48369	1.95363
7	0.20575	2.88553	4.67615	84.89277	2.90103	2.70925	1.93524
8	0.20666	3.16217	4.64960	84.17990	3.15667	2.93294	1.91870
9	0.20751	3.41408	4.62172	83.52449	3.37872	3.15605	1.90493
10	0.20833	3.63982	4.59329	82.91538	3.57832	3.37916	1.89401
Variance decomposition of LnPU							
1	0.12044	0.00219	5.27706	2.74667	91.97407	0.00000	0.00000
2	0.14619	0.03660	8.05172	2.70672	88.84407	0.30061	0.06025
3	0.15544	0.03870	8.53590	2.57337	88.28542	0.51274	0.05385
4	0.15949	0.03814	8.66297	2.58587	87.90228	0.74550	0.06520
5	0.16150	0.03722	8.64122	2.66202	87.58132	0.97952	0.09867
6	0.16270	0.03803	8.57789	2.77692	87.24452	1.21453	0.14809
7	0.16356	0.04142	8.50641	2.91491	86.88071	1.44839	0.20815
8	0.16428	0.04761	8.43693	3.06729	86.49313	1.68030	0.27470
9	0.16493	0.05654	8.37133	3.22862	86.08854	1.90981	0.34513
10	0.16554	0.06803	8.30912	3.39550	85.67282	2.13665	0.41787
Variance decomposition of LnCA							
1	0.01837	23.40690	1.96484	7.041204	1.23091	66.35614	0.00000
2	0.02409	22.52216	2.67983	7.444116	1.82803	63.38855	2.13729
3	0.02958	21.03258	1.88819	10.06463	5.16321	59.25775	2.59364
4	0.03456	19.46329	1.40575	11.56233	8.83684	55.80974	2.92205

(*continued*)

Period	SE	LnCP	LnAAT	LnFC	LnPU	LnCA	LnEC
5	0.03918	18.00576	1.09430	12.54898	12.04941	53.15894	3.14262
6	0.04345	16.69619	0.89127	13.24911	14.65580	51.17500	3.33262
7	0.04742	15.52069	0.75168	13.81076	16.72403	49.68144	3.51139
8	0.05114	14.45865	0.65009	14.30235	18.36225	48.53912	3.68753
9	0.05465	13.49198	0.57244	14.75676	19.66813	47.64698	3.86370
10	0.05798	12.60669	0.51076	15.18936	20.71884	46.93386	4.04047
Variance decomposition of LnEC							
1	0.05651	4.392982	4.04496	1.52714	7.50447	1.41046	81.11997
2	0.07186	10.75166	3.25962	3.18050	12.34539	0.87256	69.59026
3	0.08482	18.33381	4.20772	4.18013	13.97466	0.63050	58.67317
4	0.09525	24.96921	4.69786	5.23680	13.79587	0.50001	50.80024
5	0.10394	30.54313	4.91544	6.05852	12.92056	0.41990	45.14244
6	0.11134	35.13595	4.94544	6.69595	11.89473	0.36603	40.96188
7	0.11777	38.90560	4.88059	7.18281	10.93229	0.32718	37.77151
8	0.12345	42.00846	4.77391	7.55500	10.09715	0.29781	35.26765
9	0.12851	44.58067	4.65435	7.84042	9.39292	0.27493	33.25669
10	0.13306	46.73282	4.53626	8.06024	8.80336	0.25682	31.61048

Source: Authors' own creation

Table 9.

the resilience of the ARDL limits test, we additionally use the Johansen cointegration technique in conjunction with the trace and Max–Eigen statistical tests. To verify the trend and intercept, as well as the order of integration of the chosen variables, we use the PP and ADF unit root tests. Additionally, the Durbin–Watson stat and diagnostic tests suggest that the ARDL is stable and devoid of errors, and they also rule out the possibility of false regression in the ARDL estimation. Furthermore, the results of the CUSUM and CUSUM square tests validate the stability of the ARDL model.

According to the estimates, crop productivity is negatively impacted by climate change in the short- and long-term. Our research supports *H1*, which states that agricultural productivity is negatively impacted by climate change. On the other hand, the results of agricultural technology exhibit variability due to the influential role of fertilizer application on the production of crops. Moreover, it is worth noting that the utilization of pesticides has the potential to enhance agricultural yield in the short term; nevertheless, it is important to acknowledge that their long-term impact is predominantly detrimental. Therefore, in the long run, agricultural technology, such as the use of fertilizers, supports *H2*, but the use of pesticides contradicts it. The anticipated impact of technological progress on crop output is projected to be significant and transformative. Besides, crop output is positively affected by cultivated area and energy usage. The study also uses several robustness methods, i.e. ROBUST OLS, IRF and VDM. These tests also confirm the significant impact of technological and climatic factors on crop production; however, intensity varies among these factors. Henceforth, the impact of climatic changes on crop production is consistent in Vietnam in the long- and short-run.

The researchers propose policies for practitioners and farmers based on their findings. First, as pesticides have a negative long-term impact on crop production, policies should encourage the use of biopesticides or natural methods (organic pest control) and enhance plant- and society-friendly environmental conditions. Thus, policymakers and the Government of Vietnam must frame policies that encourage the use of biopesticides as a better substitute for the use of pesticides in the agriculture sector. Findings of our study help policymakers to frame policies that encourage subsidies for the use of biopesticides and impositions of tax on the use of pesticides which ultimately helps to attend agricultural sustainability by enhancing crop productions. Second, the extension services must adequately advise farmers on the most effective and optimal use of pesticides and fertilizers with an aim to enhance agricultural productions in Vietnam. From a policy implications point of view, our study suggested to adopt agricultural extension services that provide technical aid to farmers, essential inputs and services which helps to increase agricultural production in Vietnam. The inclusion of agricultural extension services should be prioritized in many programs, schemes and activities aimed at providing farmers with access to scientific research and novel knowledge in agricultural practices, hence augmenting agricultural productivity.

Dissemination of new ideas, techniques and information regarding effective use of fertilizers and pesticides, risk and farm management in agriculture sector to increase agricultural productions via different sources of communications to farmers must give priorities in Vietnam. Agricultural productions can be enhanced by using cost-effective agricultural technologies, i.e. biopesticides or natural methods, new and effective agricultural tools, techniques and methods. Third, when developing strategies to combat climate change, policymakers should take a comprehensive approach. To this end, the banking sector (public and private institutions) that provides growers with access to input credit at a lower markup may assist in the adoption of climate change strategies and the improvement of crop production. The researchers conclude that agricultural research centers should implement crop production technologies to meet future needs. Thus, our study add to existing literature as well as it helps to formulate policies that help to enhance agricultural production in Vietnam.

Basic limitations of our study are discussed as follows: first, our study considers only single country, Vietnam. Second, our study only considers climate change, fertilizer consumption, pesticide use, cultivated area and energy consumption variables and ignores the impacts of other variables on agricultural production. The variables i.e. agricultural credit, ICT, carbon emissions (CO_2), methane (CH_4), carbon footprint and timely irrigations that play a significant role in determining agricultural productions are not considered in our study. Third, due to the lack of data on the aforementioned variables, our study limits its test to a certain extent. Fourth, we used annual temperature as a proxy for climate change, and for agricultural technologies, we used fertilizer consumption and pesticide use as a proxy. However, we could use precipitations, deforestations, humidity, populations and human capital as a proxy for climate change that affects agricultural productions and other agricultural technologies can be used as a proxy in further research. While more precisely considering opportunities of future research, our study could be expanded to several geographical regions as well as different income groups of countries.

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Further reading

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Supplementary material

The supplementary material for this article can be found online.

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