The Open Agriculture Journal

Content list available at: https://openagriculturejournal.com

RESEARCH ARTICLE

Agricultural Production Factors and Their Effect on Agricultural Production and Carbon Emissions: Evidence from the Greater Mekong Subregion

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Abstract:

Introduction:

The purpose of this research is to investigate the effect of agricultural production on economic output (agricultural production value) and the environment (carbon dioxide emissions) in Cambodia, Thailand, and Vietnam. These three countries, all located in the Mekong River region of Southeast Asia, are similar in terms of climate and agricultural potential, but the agricultural sector plays a different economic role in each of these three countries. While Thailand has had an export-oriented cash crop-based agricultural sector for decades, Cambodia and Vietnam continue to produce predominantly for domestic consumption. These differences have some implications for differences in economic productivity (output) and environmental effects (agricultural carbon emissions).

Methods:

This study investigates the effect of agricultural inputs, including the use of fertilisers, pesticide, agricultural land, irrigation, and agricultural employment, along with the rural population, GDP growth, exchange rates, and producer price indices, on agricultural output value and emissions using time series AR(1) analysis.

Results:

The results show different patterns for Thailand in comparison to Cambodia and Vietnam.

Conclusion:

This implies that no single agricultural policy can be used to promote agricultural growth in Mekong Delta countries.

Keywords: Agricultural inputs, Agricultural prices, Agricultural output, Greenhouse gas emissions, Land use, Greater mekong subregion.

1. INTRODUCTION

The Greater Mekong Subregion (GMS) is a regional cooperation body established in 1992. It includes six countries in the Mekong Delta (the People's Republic of China's Yunnan Province, Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam) [1]. These countries have worked together in the past on policy areas, including agriculture, although such efforts have been inconsistent [1]. Perhaps more importantly, the countries in the GMS region are similar both in agricultural capacity and challenges to their agricultural industry [2]. For example, all three countries have similar subtropical climates and seasonal systems as well as relatively similar profiles in

terms of land quality and other aspects. All countries in the GMS are also highly vulnerable to climate change, especially variations in rainfall patterns, increased temperature, and increased risk of extreme weather events [2]. Despite these environmental similarities, GMS countries have very different agricultural sectors. This research focuses on three GMS countries: Cambodia, Thailand, and Vietnam. These countries are neighbours and have similar environments but very different agricultural sectors.

While it employs about 40% of the country's labor force, Cambodia's agricultural sector is a low-tech primary production industry [3]. Farming, which mostly focuses on domestic commodity crops, like rice, has low mechanisation and typically involves smallholdings. While there has been some effort to develop an export sector, this has been difficult to date since much more development in farming capacity,

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mechanisation, and output improvement is needed [3].

In contrast, Thailand's agricultural sector, which employs about 35% of its workforce, is heavily export-oriented and increasingly efficient, with farmers focusing on high-value cash crops like specialty rice (especially Jasmine), fish and aquaculture, and sugar cane and rubber [4]. This export-oriented sector is heavily mechanised and serves as one of Thailand's economic growth engines [4]. However, it still has problems, especially the overuse of fertiliser and pesticide which is both inefficient and harmful to the environment [5].

In Vietnam, the agricultural sector has also been the focus of export policies, beginning with the *Doi moi* or Renovation market reforms of the 1980s [6]. About 20% of Vietnam's GDP is attributable to agriculture, and the country holds leading positions in high-value commodity markets for cashews, black pepper, rice, fishery, and coffee, and cassava. However, the country still struggles to compete in global agricultural markets since most of its production is exported as raw commodities, therefore subject to commodity market fluctuations [6].

In addition to their own individual challenges, all three countries must compete in a globalised agricultural market, where there are few barriers to the trade of commodity goods [7]. This means that firms are vulnerable to both competition and fluctuations in input and market prices [7]. All three countries also share the challenge of climate change. For example, one estimate indicates that agriculture accounts for about 17% of greenhouse gas emissions [8]. Since climate change is also one of the major threats to agriculture in the GMS region [2], it is essential to consider how agricultural practices affect both output and the environment.

1.1. Objective

The objective of this research is to investigate the effect of agricultural input on agricultural productivity and the environment in selected countries of the GMS. The research questions formulated to answer this research objective are as follows:

(1) How does the use of agricultural inputs affect agricultural production in Cambodia, Thailand, and Vietnam?

(2) How does the use of agricultural inputs affect agricultural carbon emissions in Cambodia, Thailand, and Vietnam?

1.2. Literature Review

1.2.1. Agricultural Inputs

To answer the first research question, it must be established which agricultural inputs are likely to influence both agricultural productivity and carbon emissions. Such inputs could include fertilisers, pesticides, irrigation, land use, and employment.

1.2.2. Fertilisers

Although the use of chemical fertilisers is not a traditional part of many agricultural smallholding practices, it is known to improve agricultural productivity and can enable an increased output level while using the same resources [9]. Thus, a higher rate of chemical fertiliser use could be expected to increase agricultural output [9]. However, chemical fertilisers have a carbon cost associated with them, since they are made in petrochemical factories and transported, potentially releasing previously sequestered carbon [10]. Thus, while fertiliser use would theoretically increase productivity levels in the agricultural sector, it could also increase carbon emissions at the same time.

1.2.3. Pesticides

Agricultural pesticides, if used effectively, help to increase the productivity of agricultural land and can enable agricultural land-use intensification and/or increase agricultural output [11]. However, this effect is not fully efficient (on average, a 1.8% increase in pesticide use is needed to produce 1% agricultural output) [11]. A previous study has estimated the lifecycle of carbon emissions associated with production, transportation, and use [12]. These authors estimated total pesticide energy between 357 and 4883 megajoules/hectare for a variety of crops in Northern Europe, where pesticides are commonly used [12]. While a similar comparison is not available for the GMS, the same effect is likely to be observed.

1.2.4. Irrigation

Irrigation, or the redirection of water resources for agricultural land, can have a significant positive effect on agricultural output [13]. This effect comes from both increasing the productivity of existing crops and enabling the farmers to grow higher value but more water-intensive cash crops [13]. Although it seems counterintuitive, the irrigation of croplands can also have a negative effect on carbon emissions [14]. This effect is observed because although irrigation has a carbon cost (for example, relating to equipment manufacture and the energy required to run pumps and other equipment), it also prevents carbon dioxide flares from drying vegetation and wildfires [13].

1.2.5. Land Use

There is no clear answer as to whether the amount of land used for agriculture affects the overall output. In part, this is because different types of agriculture have very different land-use efficiencies [15]. It is also because land nominally devoted to agricultural use may not be fully efficient (for example, it may be fallow or marginal) [16]. Agricultural land use, especially involving changes (clearing or abandonment), also has a complex relationship with carbon emissions [17]. While agriculture falls in a lower-carbon land use category, it produces higher carbon emissions than forests and other natural environments which are often cleared for use [17]. Thus, the effect of agricultural land use on emissions is likely to be highly dependent on its previous use.

1.2.6. Employment (Labour)

The relationship between agricultural employment and agricultural productivity is usually dependent on the level of mechanisation. High employment in the agricultural sector is typically associated with low-tech, traditional farming systems, such as smallholdings, which have low production and productivity compared to modern mechanised agriculture [18]. In contrast, systems with greater mechanisation tend to have higher productivity rates and lower employment [18]. It is unclear whether agricultural employment levels have a direct impact on carbon emissions. However, in China, it has been noted that off-farm employment, which often increases with larger agricultural workforces, is also associated with higher carbon emissions [19].

1.2.7. Control Variables

Several control variables have also been identified, including the rural population, GDP growth, exchange rates, and producer prices.

1.2.8. Rural Population

Previous studies have shown that rural population density has a negative relationship with agricultural productivity [20]. Specifically, countries with high rural population density tend to have a larger number of smaller farms that rely less on mechanisation and more on manual labour, thereby reducing productivity [20].

1.2.9. Economic Growth

The relationship between economic growth (GDP growth) and agricultural production is more complicated [18]. Specifically, under conditions of very low productivity, GDP growth can drive agricultural output by creating demand. However, higher GDP growth typically comes from more efficient economic sectors, and GDP growth could actually reduce agricultural output because resources are utilised elsewhere.

1.2.10. Exchange Rates

Exchange rates can generally be a driver of agricultural output, especially in export-oriented economies which depend on international competitiveness [21]. Farmers may also rely on imported inputs, which can further impose an exchange rate cost [7].

1.2.11. Producer Price Levels

Finally, producer prices can affect agricultural output, especially in the transition towards more efficient (but also more costly) production methods such as mechanisation [22]. However, these differences may rapidly disappear as market supply and demand adjust [22].

2. MATERIALS AND METHODS

2.1. Variables and Data Collection

This article mainly collected annual data of the three selected countries (*i.e.*, Thailand, Cambodia, and Vietnam) from the United Nations Food and Agriculture Organisation (UN-FAO) FAOSTAT database during 2004-2018 [23]. This FAOSTAT database is the only source that provides comprehensive cross-country data overtime required for the analysis as suggested by the theory. The database simultaneously included physical data of crops-related inputs and output plus demographic and socio-economic characteristics of countries. Variables and their definitions are summarized in Table **1**.

2.2. Analysis

Each country was analysed separately using the open-source econometrics package GRETL. Time series analysis was conducted using an AR(1) model with covariates to capture trend effects within the data [24]. AR(1) with covariates is modelled using the Wooldridge (2013) equation [25].

Following this equation, the regression models used are:

The analysis process included an investigation of time series stationarity using the unit root test (augmented Dickey-Fuller), along with AR(1) regression and modelling. For the modelling process, the most extensive model was analysed first, and the variables were then eliminated based on collinearity (VIF). An ARCH test (to determine the presence of autoregression effects) and a chi-square test (to investigate the normal distribution of the error term) were also conducted. For both these tests, the null hypothesis is that the phenomenon is observed; therefore, $P < 0.05$ would be the cause of concern.

Table 1. Summary of variables and sources.

Variable	Abbreviation	Definition	Notes
		Inputs	
Fertilizer Use	FERT	Nutrient use (kg/ha)	N + P205 + K20
Pesticide Use	PEST	Total use (kg/ha)	
Land Use	LAND	Area of land under use for all types of agriculture	1,000-hectare units
Irrigation	IRRIG	Land area equipped for irrigation	% of agricultural land area
Employment	EMP	% of the population employed in agriculture	
		Controls	
Rural Population	RURAL	Share of population living in the rural area	
GDP Growth	GDPG	Increase in GDP per capita year (annual)	% growth (Value $US (2010))
Exchange Rate	EXCHANGE	Local Currency/$US	

(Table 1) contd.....

Variable	Abbreviation	Definition	Notes
Producer Prices	PPI	Producer Price Index	2004-2006 = 100 Not available for Cambodia
		Outcomes	
Agriculture Gross Output	OUTPUT	Agricultural Production	(Constant 2004-2006 = 1000 lx)
Emissions	EMISSIONS	Emissions from agricultural production	CO_2 equivalent (gigagrams)

3. RESULTS

3.1. Unit Root Test

The unit root test (Table **2**) was conducted using the augmented Dickey-Fuller (ADF) test under the null hypothesis that a unit root is present. The tests show no evidence of a unit root in any of the three countries for either OUTPUT or EMISSIONS ($P < 0.05$ in all cases). Therefore, the time series test was chosen on the assumption that the time series were stationary. The AR(1) test was selected because upon an investigation of the autocorrelation graphs for OUTPUT and EMISSIONS, the AR effects were shown to be more dominant than the MA effects, which made fitting an ARCH model more difficult.

3.2. Regression Results

The regressions for OUTPUT in Models 1 to 3 (Table **3**) show that some differences exist in the causal models for OUTPUT between the three countries. For Cambodia (Model 1), significant factors ($P < 0.05$) included LAND, IRRIG, GDPG (-), and EXCHANGE (-), while PEST was of marginal significance ($P < 0.10$). In Thailand (Model 2), significant factors included LAND, IRRIG, and GDPG. In Vietnam, significant factors included FERT, IRRIG, EMPLOY (-), and EXCHANGE. Thus, a combination of production factors and broader macroeconomic indicators were significant for all three models, but IRRIG was the only significant factor in all three cases.

Table 2. Unit root test.

	Cambodia	Thailand	Vietnam
OUTPUT			
With Constant			
Test statistic	3.291	-1.148	0.101
P	0.036	0.665	0.953
With Constant and Trend			
Test statistic	-1.798	-2.538	-2.747
P	0.651	0.314	0.236
EMISSIONS			
	Cambodia	Thailand	Vietnam
With Constant			
Test statistic	-2.126	-2.43	-0.896
P	0.238	0.1333	0.79
With Constant and Trend			
Test statistic	-1.616	-3.141	-5.095
P	0.733	0.097	0.106

Table 3. Estimated coefficients for the agriculture gross output model (OUTPUT).

	Cambodia (Model 1)	Thailand (Model 2)	Vietnam (Model 3)
Constant	4311220	-149383000**	-48139900*
FERT	1350.64	†	22824.9***
PEST	2342630*	406397	†
LAND	3898.63***	4114.28***	67.084
IRRIG	41***	15.364**	14.019**
EMPLOY	†	212089	-264233***
RURAL	†	†	†
GDPG	-168188***	682934**	719019
EXCHANGE	-8824.94***	†	1355.11***
PPI	‡	-39334.3	†
	Test Statistic	Test Statistic	Test Statistic

(Table 3) contd.....

	Cambodia (Model 1)	**Thailand (Model 2)**	**Vietnam (Model 3)**
R-Squared	0.979	0.912	0.986
Adj. R-Squared	0.961	0.837	0.974
F(p)	126.471***	32.392***	235.967***
Durbin-Watson	1.983	2.311	2.217
Chi-Square ()	1.485	1.06	0.241
ARCH	0.004	1.451	2.296

Notes: Dependent Variable OUTPUT * $P < 0.10$ ** $P < 0.05$ *** $P < 0.01$† eliminated due to collinearity (VIF > 10)‡ Data unavailable

Table 4. Estimated coefficients for the Emission model (EMISSIONS)

	Cambodia (Model 4)	**Thailand (Model 5)**	**Vietnam (Model 6)**
Constant	65513.4***	-101912	48251.6
FERT	2.257	†	-8.564
PEST	2658.65	240.552	†
LAND	-5.994***	3.626	2.695**
IRRIG	0.095***	0.007	-0.0006
EMPLOY	†	1141.6**	-65.848
RURAL	†	†	†
GDPG	-308.702***	84.848	-903.585
EXCHANGE	-12.047***	†	†
PPI	‡	†	-28.156
OUTPUT	†	-0.00005	†
	Test Statistic	Test Statistic	Test Statistic
R-Squared	0.938	0.749	0.816
Adj. R-Squared	0.885	0.534	0.659
F(p)	31.593***	2.813	11.9353**
Durbin-Watson	2.807	1.902	2.783
Chi-Square ()	2.128	1.018	2.317
ARCH	0.086	1.538	0.02

Notes: Dependent Variable OUTPUT * $P < 0.10$ ** $P < 0.05$ *** $P < 0.01$ † eliminated due to collinearity (VIF > 10) ‡ Data unavailable

In Models 4 to 6, the EMISSIONS output variable was tested (Table **4**). For Cambodia (Model 4), several significant factors were identified, including LAND (-), IRRI, GDPG (-), and EXCHANGE (-). The Thailand model (or Model 5) was not a successful fit ($F = 2.813$, $P > 0.05$). The only significant factor in EMISSIONS was EMPLOY. For Vietnam (Model 6), only one significant factor was identified, namely LAND. Thus, while Cambodia had a more comprehensive set of factors influencing EMISSIONS, including both agricultural factors of production and macroeconomic variables, only a few influenced EMISSIONS in the other two countries. Another surprising finding for Cambodia was that LAND, GDPG, and EXCHANGE each had a negative effect on EMISSIONS, whereas a positive effect was expected. This could be related to the replacement of high-emission economic production with lower-emission activities. It could also be due to other factors, such as unrelated emission reduction activities, which are outside the scope of this research.

4. DISCUSSION

The time series tests show that the role of agricultural inputs on agricultural production output varies between the countries, which may be related to the different economic roles played by the agricultural industry. These findings demonstrate significant differences between the nominally similar countries.

In all three countries, irrigation had a positive effect on agricultural output, with stronger effects observed for Cambodia than Thailand or Vietnam, as was expected given the lower productivity of Cambodia compared to the other countries [13]. None of the other productivity factors, including EMPLOY, FERT, LAND, and PEST, were consistently significant, but in some cases, this was because of their elimination due to multicollinearity (VIF > 10). This suggests that none of the countries have an entirely consistent production environment.

Another finding of interest was that while GDP growth had a negative relationship with output in Cambodia, for Thailand, it was positive, and non-significant for Vietnam. This is probably due to the difference in the economic development of the agricultural industry in Cambodia, which is mainly domestic and a major part of the overall economy [18]. This implies that GDP growth in Cambodia is driven mainly by the reallocation of resources to higher productivity sectors. In contrast, GDP growth in Thailand and Vietnam mainly occurs in the industry and the service sectors, diverting resources from agricultural production. In Thailand, the export-oriented

agricultural policy means that growth in the agricultural sector is typically focused on high export-value crops, increasing sector productivity [4]. It is possible that neither effect may dominate in Vietnam.

Furthermore, only Thailand showed a negative effect on producer prices, which was not significant. This may be because Thailand is dependent on mechanisation, equipment, and imported inputs, thereby increasing the price of farming compared to traditional smallholder farming [23].

Furthermore, employment had a negative effect on output in Vietnam, but mixed effects on emissions were observed in the three countries. The effect on output is probably because, in Thailand and Vietnam, higher agricultural employment implies less mechanisation and thus greater efficiency [18]. The mixed effects on emissions may be related to differences in non-farm employment [19].

It is also notable that Cambodia showed positive effects for land use, irrigation, and rural population on emissions, which were not observed in Thailand or Vietnam. This may be because Cambodia's pattern of land use and irrigation is different from the other two countries [15], or changes in land use [17]. It may also simply be because the effect of agricultural activity is far greater in Cambodia, where it remains the dominant agricultural sector than in the other two countries. This finding most clearly shows that Cambodia's agricultural sector is noticeably different from that of Thailand and Vietnam.

CONCLUSION

This research demonstrates that the use of agricultural inputs creates different economic and environmental impacts on the agricultural sector, depending on the country. These differences are reflective of significant differences in the structure and role of the agricultural sector in the countries investigated. The findings indicate that it is not possible to make a single statement about the use of agricultural technologies and inputs. However, it is possible that any given use of an agricultural input may *not* lead to improved output, although it is likely to affect emissions. Therefore, the policy implication of this is that the governments of Greater Mekong Subregion countries should not just support the use of agricultural inputs, like fertilisers, pesticides, or irrigation, but instead, critically investigate how this would affect outputs prior to limitation.

This research does have some limitations, mainly relating to the data source and data availability. It would have been interesting to include the smaller countries of the GMS, such as Lao PDR and Myanmar, but there is no reliable data available. Some data variables, such as mechanisation, were only partially available, which would have been interesting to study. Furthermore, the data in this research was collected till 2002 for some of the variables, constraining the depth of analysis. Consequently, while agricultural output was predicted moderately well, the models were not highly effective at predicting emissions. This is most likely due to the complexity of total emission calculations, along with trends in industrialisation and changes in technology, occurring at a rapid pace during the years under study, but which were not

included in the model. Therefore, this research should be considered more effective at measuring agricultural output than emissions.

Therefore, there are some opportunities for further research stemming from this study. Firstly, extending the analysis to additional countries will allow for the comparison of growing conditions in other areas. Secondly, it helps in investigating the impact of other types of agricultural inputs, for example, agricultural mechanisation, on the output and emissions of the agricultural industry or specific sectors. Finally, additional research into agricultural carbon emissions and their causes in the ASEAN would also be useful since this could help identify all the influential factors.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

CONFLICT OF INTEREST

The author(s) confirm that this article's content has no conflicts of interest.

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