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Sustainable Agriculture and Rural Development in the Era of Climate Change: Asian Perspectives

Editor
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AJI BOOKS

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Sustainable Agriculture and Rural Development in the Era of Climate Change: Asian Perspectives

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Editor's Preface

This book, entitled "Sustainable Agriculture and Rural Development in the Era of Climate Change: Asian Perspectives," provides detailed documentation of the 2nd Asia-Japan Research Institute (AJI) International Workshop, which took place on August 15, 2023, at Nong Lam University in Ho Chi Minh City, Vietnam. This event marked a significant milestone as the first face-to-face workshop following the pandemic period. The workshop emerged as a vital component of the International Collaborative Research Program, representing a strong partnership between the Asia-Japan Research Institute of Ritsumeikan University and Nong Lam University's Faculty of Economics. The primary objective was to create a dynamic platform for international dialogue and facilitate the exchange of cutting-edge scientific findings among researchers specializing in sustainable agriculture and rural development. The focus was particularly directed toward Southeast Asia, a region that faces increasing challenges from extreme weather events and growing concerns about food insecurity due to accelerating climate change impacts. In keeping with its inclusive approach, the workshop welcomed participation from a diverse audience, encompassing not only academics but also farmers, agricultural officers, students, and members of the public interested in these critical issues.

Agriculture plays a fundamental role in ensuring global food security and sustaining rural livelihoods across communities worldwide. In the current context, climate change has emerged as a significant threat, profoundly impacting both agricultural production systems and rural communities, particularly in regions already experiencing vulnerability such as Asia. Sustainable agricultural practices have shown promising potential as effective solutions for both mitigating the adverse effects of climate change and enhancing rural livelihoods.

This consideration holds particular significance for Asian nations, which constitute the world's primary rice-producing region. Although sustainability principles have gained widespread recognition and acceptance as fundamental guidelines for developing low-carbon economies and agricultural systems, the practical implementation of sustainable practices continues to present substantial challenges, even as some successful initiatives have been documented.

This volume delivers in-depth analyses and valuable insights into sustainable agriculture and rural development in the context of climate change. The book's scope is enriched through detailed case studies drawn from various Southeast Asian countries, including Thailand, Cambodia, Indonesia, and Vietnam, offering diverse perspectives and practical experiences from across the region.

The first part of the book explores rural strategies for mitigating climate change and sustainable rice farming through social and economic approaches. In Chapter 1, Dr. Ha Anh Hoang investigates farmers' intentions and behaviors regarding sustainable agriculture in Vietnam. In Chapter 2, Dr. Orawan Srisompun examines poverty and vulnerability among farmer households in Northeastern Thailand, analyzing the combined impact of drought and COVID-19. In Chapter 3, Dr. Dinh Quy Mai studies pig farmers' preferences for adopting Good Animal Husbandry Practices (GAHP) in Vietnam using a choice experiment. In Chapter 4, Dr. Mohammad Rondhi analyzes farmers' perceptions and adaptation strategies in response to climate change, focusing on shallot farmers in Indonesia. In Chapter 5, Dr. Phuc Trong Ho evaluates cost efficiency and its determinants in rice farming in the Mekong River Delta. In Chapter 6, Dr. Hay Chanthol discusses agriculture and poverty reduction in Cambodia, emphasizing the role of rice yield. In Chapter 7, Dr. Thanh Tam Ho examines the benefits of sustainable rice farming and factors influencing rice farmers' choices in

Long An Province, Vietnam.

The second part of the book focuses on technological innovations and soil management in sustainable agriculture. In Chapter 8, Dr. Thi Huong Sen Tran examines Ca^{2+-} Sensitive and Non-selective Na^{+}/K^{+} Channel Activity of a Barley Aquaporin HvPIP2;8 under Saline Condition. In Chapter 9, Dr. Loc Thuy Tran investigates the effect of high temperature on Vietnamese rice cultivars and strategies to cope with it. In Chapter 10, Dr. Quoc Thinh Tran presents SOFIX analysis for soil fertility evaluation in Japan.

I would like to express my deepest and most sincere appreciation to the Asia-Japan Research Institute of Ritsumeikan University for their invaluable support in facilitating, and to Nong Lam University for their generous hospitality in hosting this significant international workshop. I extend my heartfelt gratitude to Professor Yasushi Kosugi, Director of the Institute, whose thoughtful guidance and consistent encouragement have been instrumental throughout this entire process. I am particularly thankful to Professor Anthony Brewer, our distinguished special advisor, whose meticulous editorial guidance and insightful feedback have substantially enhanced the quality and coherence of this booklet. I would like to express my profound gratitude to Professor Koji Shimada for his unwavering and dedicated support, not only during the workshop but throughout my entire academic journey, which has been truly transformative. I also extend my sincere appreciation to Nong Lam University – Ho Chi Minh City, Vietnam, for their exceptional assistance in organizing and coordinating the workshop onsite. I am particularly grateful to Associate Professor Nguyen Tat Toan (President), Dr. Nguyen Ngoc Thuy (Director, International Relations Office), Professor Nguyen Kim Loi (Director, Climate Change Research Institute), Associate Professor Do Tien Duy (Director, Scientific Research Office), Dr. Le Cong Tru (Dean, Faculty of Economics), and all other faculty members who contributed their time and expertise to make this workshop a success. I extend my heartfelt thanks to our international authors and collaborators who, despite the challenges of different time zones, contributed valuable time, expertise, and insights to enrich this book with their meaningful contributions. Finally, I would like to express my deepest gratitude to my partner and family for their unwavering emotional support, endless patience, and constant encouragement throughout this challenging but rewarding academic endeavor.

Thanh Tam HO

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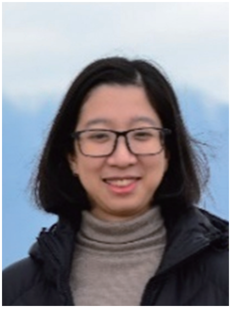

Chapter 7. Benefits of Sustainable Rice Farming and Influential Factors on Rice Farmers' Choice: A Case Study in Long An Province, Vietnam

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8. Dr. Thi Huong Sen TRAN

Chapter 8. Ca^{2+-} Sensitive and Non-selective Na^+/K^+ Channel Activity of a Barley Aquaporin HvPIP2;8 under Saline Conditions

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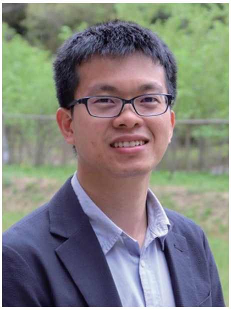
10. Dr. Quoc Thinh TRAN



Chapter 10. Using SOFIX Analysis for Soil Fertility Evaluation in Japan

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Chapter 1
Farmers' Intentions and Behavior toward Sustainable Rice Farming in the Mekong Delta of Vietnam: An Application of the Theory of Planned Behavior

Ha Anh HOANG

Summary: Despite some benefits of sustainable agriculture, sustainable rice farming in the Mekong Delta faces barriers and adoption has been limited. Government programs like "Three Reductions, Three Gains" aim to improve income and environmental outcomes, but implementation depends on farmers' awareness. This study examines factors influencing rice farmers' intentions toward sustainable practices in Long An Province through interviews with 163 farmers. Using structural equation modeling based on the Theory of Planned Behavior, results show knowledge significantly affects attitude and intention, while subjective norms influence intention. The knowledge-intention-behavior pathway has a mediating effect, though subjective norms have less direct influence on sustainable farming behavior than on climate change responses. Recommended policy initiatives include educational programs, demonstration fields, and land consolidation to support technological adoption.

1. Introduction

Rice is a crucial staple food for over three billion people across the world, especially in Asia. Asia is responsible for 88% of global rice consumption and 89% of global rice production (Papademetriou 2020).

Vietnam is the third largest rice exporter in the world, and this trade contributes 3% to the national GDP. The remarkable increase in rice productivity in Vietnam, rising from 4.3 tons/ha in 2001 to 6.01 tons/ha in 2020, is the outcome of new cultivation technologies, the intensification of high-yielding varieties, and the growing use of chemical inputs, such as synthetic chemical fertilizers and agricultural products. Recently, Vietnam's rice exports have had a sharp shift to the segment of fragrant rice and high-quality rice such as Dai Thom 8 rice, OM 5451, OM 18, etc., pushing up the price of Vietnam rice to a high level.

However, the long-term excessive use of chemical fertilizers and pesticides poses numerous threats to the environment and lowers the brand value. Farmers have increased their pesticide usage, applying 160,000 tons in 2022 (FAOSTAT 2024).

Rice production accounts for 48% of the agriculture sector's greenhouse gas (GHG) emissions and over 75% of methane emissions in the country (World Bank 2022). Figure 1.1 shows an increase in expenditure for imported pesticides in Vietnam from 2006 to 2018.

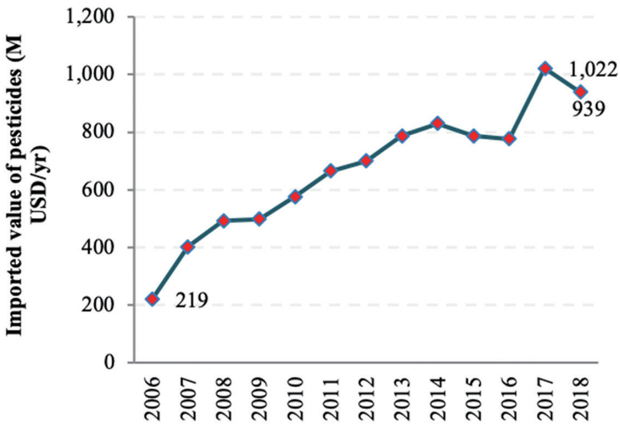

Figure 1.1. Imported Values of Pesticides in Vietnam from 2006 to 2018
Source: Thanh and Tran (2020)

It is crucial to improve the value of Vietnamese rice, move toward sustainable agriculture, monitor the use of fertilizers and pesticides in the Mekong Delta and implement effective measures to reduce their negative impact. Vietnam promoted two national programs: "Three Reductions, Three Gains" and "One Must Do, Five Reductions" (Figure 1.2). "Three Reductions, Three Gains" (3R3G) was first developed by the International Rice Research Institute (Huelgas et al. 2008) and introduced to rice farmers in Vietnam in the early 2000s. 1M5R promotes the use of high-quality and certified seeds (the "One Must Do") and the reduction of seed rates, chemical fertilizer inputs, synthetic pesticide use, irrigation water use, and postharvest losses (the "Five Reductions"). In many regions, farmers have been changing from planting three seasons to two seasons per year, so the soil has time to regain its fertility.

Figure 1.2. "One Must Do Five Reduction — 1M5R" and "Three Reductio, Three Gain — 3R3G"
Source: National Agricultural Extension Center of Vietnam (2016a, b)

In addition, Table 1.1 shows the difference in pesticide use between 1M5R and conventional farming in the Mekong Delta.

Table 1.1. Pesticide Use in Rice Production in the Mekong Delta in 2014

Respondents (%)	Control	1M5R	T-test
According to farmers' habits	16.22	2.86	*
Farmers observed rice field	81.08	48.57	*
Farmers applied based on recommendation	2.70	48.57	*
Pesticides application times/crop			
Winter-spring	7.97 ± 0.29	5.2 ± 0.14	*
Summer-autumn	7.38 ± 0.27	6.25 ± 0.40	*
Autumn-winter	7.11 ± 0.24	4.3 ± 0.12	*
Annual average	**7.49**	**5.25**	*

Source: MDI surveys in Kien Giang and An Giang Provinces, 2015.

Note: * Difference at statistical significance α=5 percent.

Source: Nguyen (2017)

The government's efforts to encourage Sustainable Agricultural Practices (SAPs) continue to encounter numerous significant barriers despite ongoing initiatives and policy implementations. These challenges persist across various agricultural regions and impact adoption rates considerably.

Farmers' insufficient understanding of the potential environmental and health hazards associated with conventional farming methods, coupled with a general lack of interest in addressing environmental issues, creates a fundamental knowledge gap. Additionally, their deep-seated fear of experiencing reduced crop yields and subsequent income loss if they transition to sustainable methods significantly contributes to their reluctance to engage in sustainable agriculture. These concerns are often reinforced by limited access to information about successful implementation strategies.

The primary aim of this research study is to thoroughly investigate and analyze the complex factors that influence rice farmers' intentions and subsequent behavior toward adopting sustainable rice farming practices in the Mekong Delta region. By examining these underlying motivations and barriers, the study seeks to provide insights that could inform more effective policy approaches.

2. Materials and Methods

(1) Study Site and Data Collection

We conducted a comprehensive study on rice farming practices and agricultural techniques in Long An province, which is one of the largest and most significant rice-producing regions in Vietnam, with a total cultivated area of approximately 511,300 hectares according to the Vietnamese General Statistics Office (GSO 2022). This extensive agricultural area contributes substantially to Vietnam's position as a leading global rice exporter.

The selected farmers who participated in our research were strategically located in two distinct districts — Duc Hue and Tan Hung — within Long An province. These districts were chosen to represent different ecological and economic conditions within the region. Long An province has gained recognition for having the highest quantity of officially recognized fertilizer products in the country, with 2,403 registered products (accounting for 9.8% of the national total and a substantial 45.6% of all fertilizer products in the Mekong Delta region).

In-depth interviews with 163 rice farmers were conducted throughout November 2022, ensuring comprehensive data collection across diverse agricultural regions (Figure 1.3). We utilized a carefully designed, structured questionnaire consisting of two main sections. The questionnaire included inquiries about farming practices, cultivation techniques, yield management, and farmers' understanding and perspectives on organic farming methodologies. The first section focused on farmers' demographic characteristics, experience levels, and operational backgrounds, while the second explored their thought processes and decision-making approaches when considering agricultural innovations.

Figure 1.3. Field Survey with Rice Farmers in Long An Province, Vietnam
Source: Author's survey

(2) Methodology

The Theory of Planned Behavior (TPB) (Ajzen 1991) provides a comprehensive framework that systematically describes how three key psychological factors — attitude, subjective norms, and perceived behavioral control — interact to influence an individual's intention and subsequent behavior. This theoretical model has been widely applied across various disciplines to understand human decision-making processes.

This model has been modified and adapted to fit real-world contexts and applications. In agricultural settings specifically, farmers' understanding and knowledge of farming practices plays a significant and determinative role in their complex decision-making process. Positive *Attitudes* toward Sustainable Agricultural Practices (SAPs) can substantially influence an individual's *Intentions* to adopt these practices and ultimately motivate their actual *Behavior* in implementing them on their farms.

The modified model incorporates *Knowledge* as an additional construct to thoroughly examine how farmers' understanding and awareness of SAPs affects their attitudes toward these practices and shapes their intentions to adopt them. This addition acknowledges the critical role that information and education play in agricultural decision-making (Guru et al. 2021).

Additionally, social relationships and community networks among farmers in the Mekong Delta region are particularly strong and tightly woven, which can significantly influence their agricultural decision-making processes. These social dynamics create powerful normative pressures. Therefore, *Subjective Norms* — the perceived social pressure to engage or not engage in certain behaviors — are expected to affect both the farmers' intention to adopt sustainable practices and their actual behavior in implementing them.

Perceived behavioral control (PBC) represents another crucial construct in the modified model that describes how easy or difficult an individual perceives it is to perform the behavior of interest or make decisions regarding adoption of new practices. This factor encompasses both internal factors (skills, abilities, knowledge) and external factors (resources, opportunities, barriers) that may facilitate or impede the performance of the behavior.

Finally, *Intention* — the readiness to perform a given behavior — has a direct and positive influence on actual *Behavior*, serving as the most immediate determinant of whether an individual will engage in a particular action or practice.

Using structural equation modeling (SEM), this study identified factors affecting farmers' intention and behavior toward sustainable rice farming based on the theoretical framework in Figure 1.4.

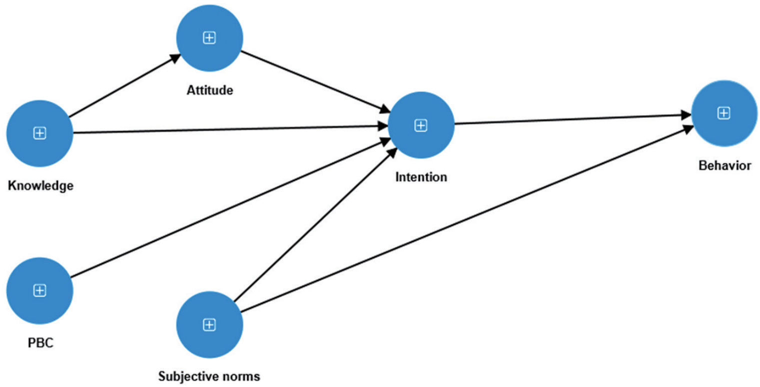

Figure 1.4. The Proposed Model of Farmers' Intention and Behavior to SAPs
Source: Author

3. Results and Discussion

(1) Summary of Data

Table 1.2 shows a summary of collected data. The farmers in the study were predominantly middle-aged individuals, with demographic analysis revealing that less than half of the participants had successfully completed their secondary education. They demonstrated considerable agricultural expertise, possessing an average of 27 years of practical experience specifically in rice farming techniques and management. Most participants in the survey owned agricultural land holdings that ranged in size from approximately 1 to 5 hectares, which represents typical small to medium-scale farming operations in the region.

Table 1.2. Summary of Farmer and Farm Characteristics

Characteristic	Observation	Percentage	Mean
Age (years)	163		49.7423
Household size (members)	163		4.2576
Farming experience (years)	163		26.9754
Gender (respondents base)			
Male	147	90.18	
Female	16	9.82	
Marriage status			
Single	5	3.1	
Married	154	94.5	
Divorced	4	2.5	
Education			
No education	3	1.8	
Primary school	49	30.1	
Secondary school	77	47.2	
High school	31	19.0	
Higher education	3	1.8	
Social groups	50	30.67	
Total cultivated area (ha)			
Less than 1 ha	13	8	
1–5 ha	108	66.2	
More than 5 ha	42	25.8	

Source: Author's survey

(2) Factor Analysis and Evaluation of the Model's Factor

1) Convergent Validity and Reliability

The study utilizes SmartPLS software (Ringle 2022) as the primary tool to estimate the specified model. For the formative construct, it is crucial to thoroughly test the significance of factor loadings and assess multicollinearity to ensure the robustness of the analysis. Initially, the model comprised 34 items; however, after careful examination and refinement, only 15 items were retained (Figure 1.5).

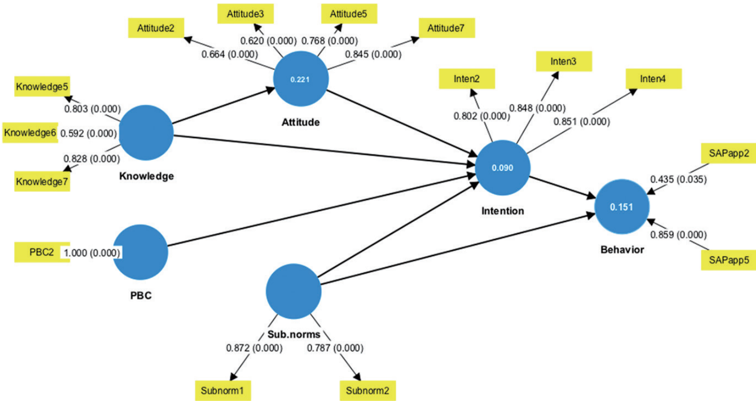

Figure 1.5. Factor Analysis
Source: Author

After the first step of factor analysis, several items were deliberately removed from the constructs to enhance the validity and reliability of the final outcomes, thereby strengthening the model's overall integrity and performance (Table 1.3).

Table 1.3. Construct Validity and Reliability

	Cronbach's alpha	Average variance extracted (AVE)
Attitude	0.7	0.533
Intention	0.8	0.696
Knowledge	0.6	0.560
Subjective norms	0.6	0.690

Source: Author's calculation

2) Discriminant Validity

To ensure that discriminant validity is achieved and to minimize any potential overlap or similarity between survey questions designed for different constructs, we applied multiple rigorous statistical techniques.

Fornell-Larcker Criterion: This method involves examining the square root of the AVE (Average Variance Extracted) values for constructs such as *Attitude*, *Intention*, *Knowledge*, and *Subjective norms*. These values must be greater than the correlations of these constructs with others in the measurement model, which was confirmed in our analysis (Table 1.4).

Table 1.4. Fornell-Larcker Criterion

	Attitude	Intention	Knowledge	Subjective norms
Attitude	0.730			
Intention	0.056	0.834		
Knowledge	0.470	0.225	0.749	
Subjective norms	0.144	0.219	0.152	0.831

Source: Author's calculation

Cross-loadings: We verified that each variable's loading on its respective construct was significantly higher than its loading on any other constructs, thus ensuring proper construct differentiation (Table 1.5).

Table 1.5. Cross-loading Values

	Attitude	Behavior	Intention	Knowledge	PBC	Subjective norms
Attitude2	**0.664**	0.007	0.085	0.235	0.158	0.138
Attitude3	**0.620**	0.147	0.083	0.288	0.060	0.174
Attitude5	**0.768**	0.066	0.010	0.328	0.051	0.056
Attitude7	**0.845**	0.087	0.015	0.464	0.180	0.084

SAPapp2	0.059	**0.455**	0.203	0.047	0.002	0.065
SAPapp5	0.097	**0.931**	0.347	0.097	0.179	0.128
Inten2	0.130	0.313	**0.802**	0.198	0.072	0.193
Inten3	-0.010	0.332	**0.848**	0.149	0.112	0.163
Inten4	0.014	0.318	**0.851**	0.212	-0.015	0.189
Knowledge5	0.366	0.186	0.225	**0.803**	0.197	0.183
Knowledge6	0.266	-0.061	0.093	**0.592**	0.044	-0.088
Knowledge7	0.408	0.065	0.169	**0.828**	0.218	0.181
PBC2	0.158	0.161	0.067	0.220	**1.000**	0.156
Subnorm1	0.156	0.127	0.200	0.212	0.142	**0.872**
Subnorm2	0.076	0.101	0.16	0.02	0.116	**0.787**

Source: Author's calculation

Heterotrait-monotrait ratio (HTMT): To evaluate the true correlations between the measurement models, we utilized the HTMT ratio. A value below the threshold of 0.9 indicates that the latent variables successfully achieve discriminant validity, and this criterion was met in our assessment (Table 1.6).

Table 1.6. Heterotrait-monotrait Ratio (HTMT)

	Attitude	**Intention**	**Knowledge**	**PBC**	**Subjective norms**
Attitude					
Intention	0.143				
Knowledge	0.677	0.315			
PBC	0.182	0.090	0.263		
Subjective norms	0.240	0.328	0.334	0.208	

Source: Author's calculation

3) Collinearity Analysis

Multicollinearity was not observed among any of the indicators included in the measurement models, as the calculated variance inflation factors (VIFs) were all found to be below the ideal threshold value of

3.3 (Ringle et al. 2015), ensuring the absence of multicollinearity issues (Table 1.7).

Table 1.7. Collinearity Analysis

	VIF
Attitude2	1.341
Attitude3	1.212
Attitude5	1.581
Attitude7	1.588
Inten2	1.416
Inten3	1.856
Inten4	1.826
Knowledge5	1.299
Knowledge6	1.116
Knowledge7	1.337
PBC2	1.000
SAPapp2	1.010
SAPapp5	1.010
Subnorm1	1.174
Subnorm2	1.174

Source: Author's calculation

(3) The Structural Model of Farmers' Intention and Behavior

The result of the structural model shows that higher levels of knowledge and understanding about sustainable agriculture practices are strongly linked to the development of more favorable and positive attitudes toward such practices (B=0.470, $p<0.05$) and significantly enhances farmers' intentions to adopt sustainable agriculture techniques in their daily operations (B=0.236, $p<0.05$) (Figure 1.6). Furthermore, the social environment and community factors surrounding farmers (subjective norms) can play a crucial role in shaping and reinforcing their intentions to pursue sustainable agriculture (B=0.195, p<0.1). Over time, these strengthened intentions are likely to translate into consistent, positive actions and behaviors that promote and align with the principles of sustainable agriculture (B=0.177, p<0.05).

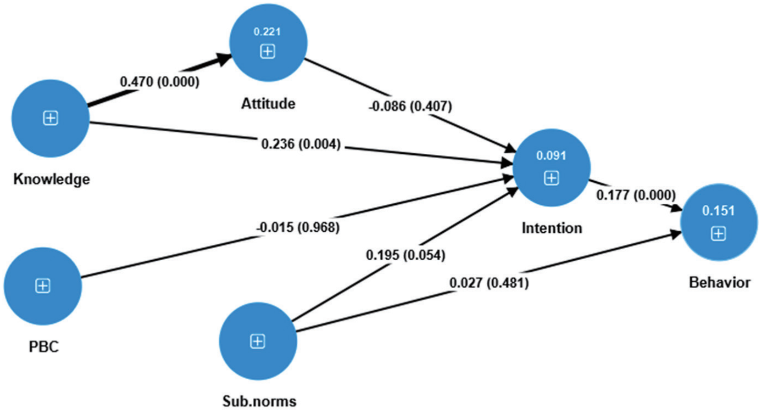

Figure 1.6. The Structural Model of Farmers' Intention and Behavior to SAPs
Source: Author's calculation

Table 1.8 effectively demonstrates the mediation effects observed among the constructs analyzed in the study. Specifically, the influence along the path from subjective norms to behavior occurs only when the mediator—intention—is present, signifying a positive and complete mediating effect. Moreover, the links from *Subjective norms* to *Attitude*, and from *Attitude* to *Behavior*, are both positively aligned, highlighting a constructive and beneficial relationship. Thus, this framework exemplifies a robust and definitive full mediating effect.

Table 1.8. Mediation Effects

	Original sample	Sample mean	Standard deviation	P values
Direct effects				
Knowledge → Intention	0.236	0.249	0.083	0.004
Subjective norms → Behavior	0.027	0.026	0.039	0.481
Total indirect effects				
Knowledge → Attitude → Intention	-0.042	-0.045	0.055	0.450
Subjective norms → Intention → Behavior	0.035	0.037	0.021	0.094
Total effects				
Knowledge → Intention	0.194	0.204	0.086	0.024
Subjective norms → Behavior	0.062	0.063	0.039	0.115

Source: Author's calculation

4. Discussion

Better knowledge can lead to positive attitudes and intentions toward sustainable agriculture. Specifically, farmers with greater knowledge of sustainable rice farming are more likely to express favorable attitudes (B = 0.236) and intentions (B = 0.194) toward sustainable agriculture. Participants who apply sustainable agricultural practices (SAPs) express stronger belief in and commitment to continuing these practices. Only 32% of farmers practiced sustainable agricultural methods, either through 1M5R or 3R3G. Among the remaining 68%, 37.5% cited a lack of technical skills as their reason for not employing modern methods, and 12.5% stated they did not know enough about the new methods to implement them.

Subjective norms are a major driving force behind farmers' intention to implement SAPs. Farmers' intentions to adopt sustainable farming are significantly influenced by the social dynamics within their surrounding communities, including immediate family members, close friends, and neighboring farmers who share similar agricultural challenges and opportunities. According to comprehensive surveys conducted in rural farming communities, approximately 20.2% of valuable information regarding sustainable farming practices is directly obtained from neighboring farmers through informal conversations and observations. Research indicates that farmers demonstrate a substantially higher likelihood of implementing SAPs when they perceive positive support from their social network, or when they can directly observe successful implementation of these methods by people they trust and respect within their immediate community. This social validation plays a crucial role in reducing perceived risks associated with adopting new farming techniques.

Stronger intentions can lead to positive behavior towards SAPs. The study shows farmers who fully implemented sustainable farming guidelines demonstrated stronger environmental stewardship intentions. They were satisfied even with modest profit improvements, recognizing long-term benefits beyond immediate financial gains. These farmers had clear plans to further invest in sustainable farming practices by reducing chemical inputs or substituting them with organic alternatives that promote soil health and biodiversity.

5. Conclusion

This study attempts to investigate the complex factors influencing rice farmers' intentions and subsequent behavior toward adopting sustainable rice farming practices in the Mekong Delta region. Findings show that 32% of farmers surveyed have adopted Sustainable Agricultural Practices (SAPs), indicating significant but limited penetration in the agricultural community. Statistical analysis revealed important relationships: *Knowledge* on *Attitude* (B=0.470) demonstrates how information shapes farmers' perspectives; *Knowledge* on *Intention* (B=0.236) shows direct influence on decision-making; *Subjective norms* on *Intention* (B=0.198) highlights the importance of social influences; and *Intention* on *Behavior* (B=0.175) confirms the link between planned and actual actions. The *Subjective norms*-*Intention*-*Behavior* pathway exhibits a full mediating impact, suggesting that social pressures and community standards completely shape intentions before manifesting as observable behaviors. Results indicate that encouraging and strengthening intention among farmers is the most effective method for promoting sustainable agricultural practices in rural communities.

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Chapter 2
Examining Poverty and Vulnerability among Farmer Households in Northeastern Thailand: Analyzing the Interplay of Drought and the COVID-19 Pandemic

Orawan SRISOMPUN

Summary: The Northeastern region of Thailand, an area with a high number of peasant households relying on rain-fed water for rice production, suffers from extensive problems caused by the limited availability of sources of water for irrigation. This has resulted to a low yield of rice compared to other regions, aggravated by long drought and socioeconomic effect of COVID-19. This article examines interlinkages between the influence of drought and the effect of COVID-19 on household income and poverty in Northeastern Thailand. Using descriptive statistics and the methods of probability, in particular, the three-step Feasible Generalized Least Squares (FGLS) for analyzing the vulnerability to poverty of the households who had an income under the limit of poverty line. Findings highlight significant income declines during the COVID-19 outbreak, affecting farmers across different farm sizes. Large farms exhibit greater resilience to both the pandemic and drought, emphasizing the complexity of vulnerabilities. The study reveals a rise in poverty rates from 43.64% in 2019 to 49.59% in 2020, disproportionately affecting households relying on agricultural employment and those headed by the elderly. Vulnerability analysis exposes increased susceptibility among previously non-poor farmers, emphasizing the substantial impact of the COVID-19 outbreak.

Drought-affected farmers face higher vulnerability, emphasizing the compounding challenges. This study offers a fuller understanding of poverty dynamics among farmers, indicating the necessity of some evidence-based policies to overcome difficulties resulting from the drought and the COVID-19 pandemic.

1. Introduction

The Northeastern region of Thailand, commonly referred to as "Isan," is characterized by a substantial concentration of peasant households whose primary livelihood revolves around rice cultivation. Given the limited availability of sources of water for irrigation in most areas, rice farming heavily relies on rainwater. Consequently, the average rice yield in this region tends to be lower than other regions within the country. As a result, some members of these households seek non-agricultural employment opportunities to augment their income (Rambo 2017).

The challenges faced by peasant households in the Northeastern region are compounded by the persistently worsening drought situation that has persisted for nearly a decade. This prolonged period of water scarcity has increased the difficulties already experienced due to limited access to irrigation, further impeding agricultural productivity (Felkner et al. 2009). Additionally, the region has not been immune to the far-reaching effects of the global COVID-19 pandemic, which emerged towards the end of 2019. The outbreak of the virus has had profound socio-economic ramifications, intensifying the economic and income crises facing peasant households in the area.

The confluence of drought and the spread of the COVID-19 pandemic has had significant repercussions for the regional economy, particularly for agricultural households in the Northeastern region of

Thailand. These households are highly vulnerable to enduring poverty, a susceptibility that has been amplified by recurring droughts and the ongoing COVID-19 pandemic. Consequently, these events render households vulnerable to falling into poverty or increase the likelihood of future impoverishment (Srisompun 2022). The impact on households when unforeseen circumstances occur can vary. Swift recovery and restoration to their pre-crisis state allow households to withstand temporary disruptions. However, severe economic consequences, such as income decline leading to reduced risk-bearing capacity, elevate the risk of descending into poverty (Siamwala et al. 2006).

The paper[1] that this chapter is based on aims to provide an analysis of poverty and vulnerability to poverty among Isan peasant households in the face of drought situations and the spread of the COVID-19 pandemic. The analysis serves as essential groundwork for formulating policy recommendations to mitigate and address the challenges posed by drought and the COVID-19 outbreak.

2. Research Methodology

(1) Data Sources

The data used from primary data collection involved a range of methods, including questionnaire surveys, in-depth interviews, and small group discussions. The questionnaire employed a closed-ended format and was administered to sample farmers in the target provinces

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1 The paper forms a part of the research project titled "Study on Economics and the Social Effect of Drought and the COVID-19 Pandemic on Farmers in Northeast Thailand." Invaluable financial support has been provided by the National Research Council of Thailand (NRCT) through the Coordination Office for Agricultural Policy Research Networking Enhancement, the Knowledge Network Institution of Thailand (KNIT).

of the northeastern region between January and December 2020. It encompassed topics such as changes in income, agricultural production, debt levels, and the impacts of drought and the COVID-19 pandemic.

(2) Data Analysis

The examination of the impacts of drought and the COVID-19 pandemic on household income and poverty entailed the application of descriptive statistics. Specifically, this methodology was instrumental in assessing the vulnerability of households to poverty, particularly when their income descended below the minimum living expenses or the designated poverty line. To ascertain the probability of households being susceptible to poverty both in the present and future, wherein their income may fall below the poverty line, advanced probability estimation techniques were employed. To conduct this analysis, the three-step feasible generalized least squares (FGLS) method was chosen to estimate the fragility coefficient. This methodological selection was grounded in the precedent set by prior studies (Siamwala et al. 2006; Shahida and Patta 2016). The utilization of the three-step FGLS method is underpinned by its established efficacy in delivering robust estimates and facilitating comprehensive analyses of vulnerability to poverty.

3. Results and Discussions

(1) Effect of Drought and COVID-19 on Household Income and Its Changes

The COVID-19 pandemic has emerged as an unprecedented global crisis, posing profound challenges to societies worldwide. Governments across the globe have implemented a range of policies, including social distancing, lockdowns, and quarantine measures, to contain the spread of the virus. However, these measures have had far-reaching implications, disrupted production and consumption activities and generated uncertainties and potential long-term disruptions across various economic sectors. Consequently, the resulting market downturn has had severe consequences, with a significant portion of the workforce confined and numerous businesses compelled to suspend operations (UNDP 2020). These circumstances have had a substantial impact on labor markets and household incomes, exacerbating the issue of poverty, particularly among agricultural households reliant on remittance income.

The study's findings revealed a pronounced impact on farmers residing in regions characterized by drought, as they faced heightened vulnerability to the combined challenges posed by both drought conditions and the onset of the COVID-19 pandemic. This impact was particularly pronounced among households reliant on income generated through the hiring of agricultural workers. In this demographic, the entirety of farmers surveyed faced repercussions from drought conditions, with an additional 47% grappling with the adverse effects of the COVID-19 outbreak. An analysis of the data concerning farm size disclosed noteworthy trends. Specifically, "large farms" emerged as comparatively less susceptible to the dual challenges of the COVID-19 pandemic and drought, registering lower impact rates at 35% and 67%, respectively, in contrast to their counterparts with smaller-sized farms. This observation underscores a potential resilience among larger-scale agricultural operations in mitigating the multifaceted risks associated with both climatic and pandemic-related factors.

The examination of the impact of both drought and the spread of COVID-19 on household income and income fluctuations revealed notable patterns. In the year of the COVID-19 outbreak (2020), a substantial majority of farmers experienced a decline in income, even in the absence of drought-related issues. Specifically, income reduced from 187,986 to 158,048 baht per year for farmers affected by the COVID-19 outbreak, compared to their counterparts unaffected by COVID-19. Noteworthy differentials in income reduction were observed among affected farmers in both drought-prone areas and non-drought regions, with income decreasing by 21.10% and -29.61%, respectively (see Figure 2.1).

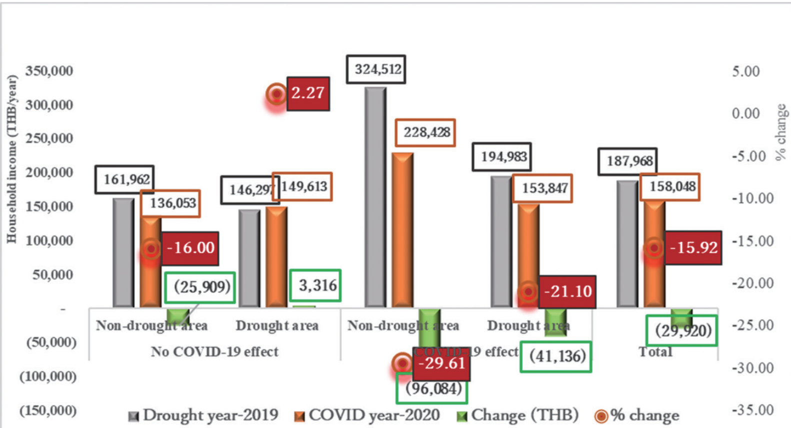

Figure 2.1. Household Income and Its Changes, Categorized by the Effects of Drought and COVID-19
Source: Srisompun (2022)

Conversely, farmers who remained unaffected by the COVID-19 outbreak experienced the least proportionate decrease in income, amounting to -2.62%. During the same period, i.e., the year of the COVID-19 outbreak (2020), farmers residing in areas not prone to drought exhibited a more substantial income reduction compared to their counterparts in other regions. Specifically, income for this group decreased from 239,486 to 180,109 baht, representing a significant decline of 24.79% (see Figure 2.2). This underscores the sweeping ramifications of the COVID-19 pandemic, going beyond the confines of drought-affected areas and significantly impacting the income stability of farmers even in regions where drought was not a prevailing concern.

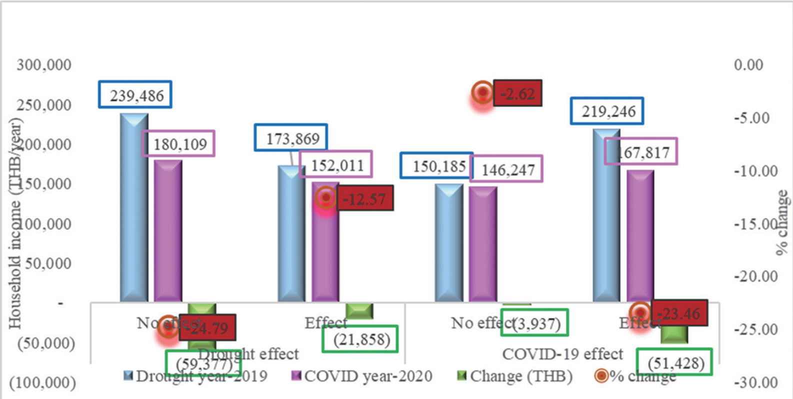

Figure 2.2. Household Income and Its Changes, Categorized by the Effects of Drought or COVID-19

Source: Srisompun (2022)

(2) The Poverty Situation during the Periods of Drought and the COVID-19 Pandemic

The study's findings reveal that a predominant segment of farmers sustained an average income falling within the range of approximately 1,000 to 4,000 baht per person per year. Comparing this income profile with the poverty line established in 2019 at 2,262 baht per person per year underscores a disconcerting reality: more than half of the farming population exhibits per capita income levels below the poverty line.

Moreover, a discernible trend emerges when scrutinizing the prevalence of poverty, with the proportion of individuals categorized as impoverished escalating from 43.64% in 2019 to 49.59% in 2020. Categorizing farmers based on the impact of the COVID-19 outbreak reveals a notable rise in the proportion of impoverished individuals among those affected, both in regions experiencing drought and those in non-drought areas, surging from 47.7% in 2019 to 51.3% in 2020. In areas unaffected by drought, poverty rates decreased from 52.3% in 2019 to 47.7% in 2020 (see Figure 2.3).

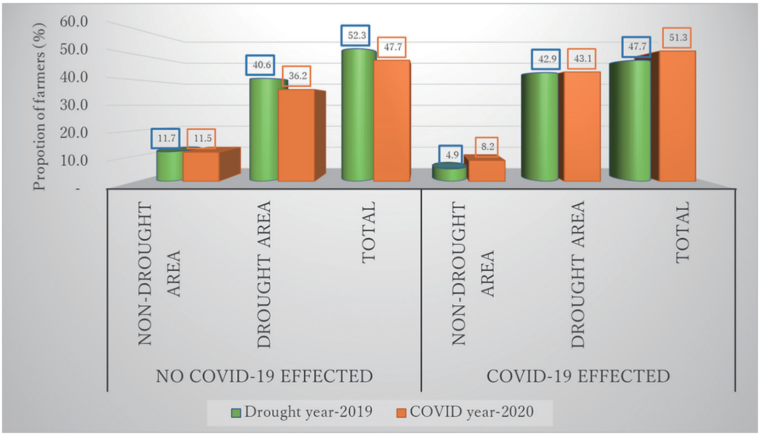

Figure 2.3. Proportion of Poverty among Sample Farmers Classified by the Effects of COVID-19 and drought
Source: Srisompun (2022)

Further categorization of farmers based on key variables in 2020 reveals a universal increase in poverty ratios across all identified groups compared to 2019. Particularly noteworthy is the substantial rise in the proportion of impoverished individuals within households reliant on income derived from the agricultural sector and those headed by the elderly, recording increases of 11.76% and 10.38% among each respective group of farmers. Even though, in 2019, groups predominantly reliant on income from hiring agricultural workers exhibited the lowest proportion of impoverished individuals, the shifting dynamics in 2020 led to a considerable upswing in poverty rates within this demographic (see Figure 2.4).

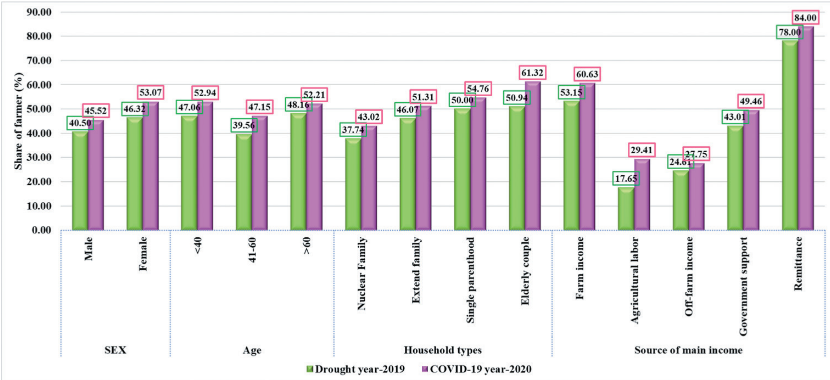

Figure 2.4. The Proportion of Poverty among Farmers Categorized by Various Socio-economic Characteristics
Source: Srisompun (2022)

Despite the expectation that the COVID-19 outbreak would have a relatively diminished impact on the agricultural sector compared to other production sectors, the study unravels nuanced complexities. While the outbreak may exert a more direct influence on non-agricultural sectors, the stringent disease surveillance measures have reverberated significantly within the agricultural domain. The resultant decrease in produce prices, coupled with disruptions in the market, disproportionately affected households within low-income and precarious strata, intensifying the adverse impact on these groups more than their counterparts in more economically stable circumstances.

(3) Vulnerability to Poverty during the Periods of Drought and the COVID-19 Pandemic

Research conducted on vulnerability to poverty compared to the poverty line in 2018 (2,262 baht/person/year) reveals significant findings. The ratio of farmers vulnerable to poverty increased from 40.83% in 2019 to 59.17% in 2020 among sample farmers who were not poor in 2019. Conversely, farmers who were poor in 2019 exhibited a smaller increase in vulnerability to poverty in 2020 (19.50% and 11.90% respectively). This suggests that the impact of the COVID-19 outbreak had a greater effect on farmers vulnerable to poverty, while the probability of falling deeper into poverty increased for farmers who were already poor. Furthermore, farmers whose primary source of income is remittances exhibited the highest proportion of vulnerability to poverty. The compounding effects of drought and the COVID-19 epidemic complicated the struggles faced by Isan farmers. A coefficient of Log Per Capita Income was calculated using FGLS (Feasible Generalized Least Squares) analysis, and statistical significance was observed at different confidence levels (90%, 95%, and 99%).

For farmers residing in areas affected by drought in 2019 and contending with the COVID-19 situation in 2020, probability analysis revealed a higher vulnerability to poverty. The proportion of farmers affected by drought and living in poverty was higher than that of those not impacted by drought (46.32% and 50.53% respectively in 2019, and 33.85% and 46.15% respectively in 2020). The analysis further revealed that drought-affected farmers had a higher proportion (61.89%) of households vulnerable to poverty compared to the 12.66% among farmers who did not experience drought. These findings emphasize that drought not only has economic consequences for affected households but also impairs their ability to cope with risks and unforeseen events, rendering them even more susceptible to poverty when faced with the COVID-19 pandemic in 2020.

4. Conclusion and Policy Implications

The findings of this study shed light on the critical issue of poverty and vulnerability among Isan peasant households in Northeastern Thailand, particularly in the context of drought and the COVID-19 pandemic. The analysis reveals that the COVID-19 outbreak has had a substantial negative impact on household incomes, with a notable decline observed among farmers in the study area. This decline can be attributed to the stringent measures implemented to control the spread of the virus, which resulted in reduced remittances and decreased income from non-farm sectors. Furthermore, the study highlights the vulnerability to poverty among agricultural households, with a significant proportion falling below the poverty line. Their vulnerability has been exacerbated by the compounding effects of drought and the COVID-19 pandemic. Farmers heavily reliant on remittances and those residing in drought-affected areas are particularly susceptible to poverty and face heightened challenges in coping with risks and unexpected events. The findings emphasize the need for targeted policy interventions to address the multifaceted challenges faced by Isan peasant households. Based on the research results, the following policy implications are recommended:

1. Scaling-up social protection – Strengthening social protection including safety nets to provide assistance to vulnerable agricultural households, particularly those affected by drought and the COVID-19 pandemic. This might involve cash transfers, subsidies, and targeted help to cover basic needs and to prevent further impoverishment.
2. Diversifying household income sources – Promoting income diversification among farm households to decrease reliance on a sole sector and increase resilience. This can be facilitated by encouraging non-farm activities, greater market connectivity of farm produce, skill development, and entrepreneurship.

3. Increasing access to financial services, including credit and insurance, for agricultural households. This can help them to manage income fluctuations, reduce risks, and invest in sustainable farming techniques.
4. Systems for managing water should be strengthened, resources for irrigation infrastructure should be mobilized, and sustainable water conservation practices should be promoted to reduce the effects on agricultural production and livelihoods of drought.
5. Encouraging the adoption of modern agricultural technologies and practices that improve productivity, help adapt to climate-related risks, and strengthen the resilience of agricultural systems.

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Chapter 3
Pig Farmers' Preferences for the Adoption of Good Animal Husbandry Practices in Vietnam: A Choice Experiment

Dinh Quy MAI

Summary: In response to increasing food safety concerns, consumer demand has risen substantially for pork products featuring robust safety certifications and comprehensive tracking systems. The Good Animal Husbandry Practice (GAHP) guidelines for pig farming establish a systematic framework to enhance food safety standards in Vietnam. GAHP guidelines establish a framework for food safety standards in Vietnam's pig farming sector. However, widespread adoption faces significant challenges related to the substantial initial investment required to implement these guidelines. The study aims to investigate the key factors influencing Vietnamese pig farmers' willingness to implement GAHP protocols. The results indicate strong farmer support for GAHP implementation when accompanied by secured contractual agreements, enhanced productivity metrics, and premium pricing structures. These empirical findings provide valuable insights for policymakers to develop effective regulatory frameworks supporting GAHP adoption. Additionally, the research outcomes offer strategic guidance for stakeholders across the supply chain to establish optimized distribution channels for GAHP-certified products. For pig farmers specifically, these insights facilitate informed decision-making regarding contractual arrangements, operational efficiency, and market accessibility for GAHP-certified livestock.

1. Introduction

Pig farming represents one of the cornerstones of Vietnam's diverse agricultural landscape, playing a vital role in both the nation's food security and economic development. The scale of this sector is substantial, with Vietnam currently supporting approximately 2.6 million pig farm households that collectively provide employment opportunities for around 7 million workers across the country (Ministry of Agriculture and Rural Development, Livestock Department 2022). Within Vietnam's regional distribution of pig farming, the Southeast region emerges as a significant contributor, hosting 11.5% of the country's total pig population, which translates to approximately 2.86 million pigs, highlighting the region's important role in the national pork production ecosystem.

The industry currently grapples with increasingly complex sustainability challenges that demand immediate attention. Pig farms face persistent difficulties in maintaining control over the unauthorized use of growth-promoting substances, particularly salbutamol and clenbuterol, which pose serious risks to both livestock welfare and human health. Additionally, the sector continuously confronts the devastating impact of recurring disease outbreaks, most notably the highly infectious African Swine Fever and Porcine Reproductive and Respiratory Syndrome (Blue Ear), which have the potential to devastate entire pig populations and severely compromise the operational efficiency and economic viability of farming enterprises.

In response to these pressing challenges and the increasing consumer demand for verified safe pork products, Good Animal Husbandry Practice (GAHP) safety standards have emerged as a comprehensive and systematic solution. These meticulously developed standards serve multiple critical objectives: the complete elimination of prohibited substances from the production chain, the implementation of robust biosecurity measures to prevent and control disease outbreaks, and the significant reduction of environmental impacts through the adoption of advanced waste management techniques and environmentally conscious farming practices.

GAHP represents a comprehensive framework of standardized guidelines designed to optimize pig farming operations. These carefully developed protocols encompass various aspects of livestock management, with a specific emphasis on implementing evidence-based practices that effectively reduce piglet mortality rates while simultaneously enhancing overall farm productivity and operational efficiency. Initially implemented in Vietnam in 2008, the GAHP framework consisted of 17 detailed criteria for farm management. In response to practical practical experience and evolving industry needs, these guidelines underwent strategic refinement in 2015, resulting in a more streamlined set of 14 essential criteria that better addressed the practical challenges of modern pig farming operations. Figure 3.1 shows a certificate of VietGAHP.

Figure 3.1. A Cerificate of VietGAHP by a Private Livestock Company
Source: Author's survey

Despite the clear benefits of GAHP for pig farming operations, its adoption rate among Vietnamese pig farmers remains notably low, with statistical data from 2019 indicating that only 18% of Vietnam's pig farming operations had implemented these standardized practices. This relatively modest adoption rate presents an intriguing challenge for agricultural policymakers and industry stakeholders.

Various scholarly investigations and field studies have identified multiple interconnected factors contributing to this limited adoption (Ngoc et al. 2016; Nguyen et al. 2021; Vu et al. 2016). These barriers encompass significant financial considerations, such as the substantial initial investment requirements and difficulties accessing credit facilities. Economic uncertainties also play a crucial role, including fluctuating market prices for pork products and concerns about achieving consistent profitability. Additionally, structural challenges such as the predominance of small-scale farming operations, limited access to agricultural extension services, and the absence of established contract farming arrangements further complicate adoption decisions. The influence of neighboring farms' practices and success rates has also been documented as a significant factor in farmers' decision-making processes regarding GAHP implementation.

This study aimed to examine farmers' preferences regarding GAHP adoption in Vietnamese pig farming. A choice experiment is used to simulate a real-world scenario where farmers must implement GAHP standards.

2. Materials and Method

(1) A Choice Experiment

A choice experiment is used to evaluate participants' preferences for specific goods or services not available in real markets (Louviere et al. 2000). A choice experiment study involves four key steps: selecting attributes and corresponding levels, designing choice cards, collecting data, and analyzing farmers' preferences.

1) Careful Selection of Attributes along with Their Corresponding Levels

First, we created a list of potential attributes based on GAHP characteristics and previous studies. We then conducted group discussions with experts and pig farmers to identify key attributes from this list (Table 3.1). Attributes that could influence farmers' preferences and adoption of GAHP included initial investment, increased yield, output contracts, GAHP certification, higher prices, neighbor impact, uncertainty, farm scale, credit accessibility, and agricultural extension services. Twenty-one pig farmers from medium and large-scale farms evaluated these attributes through a group discussion session.

Table 3.1. The Potential Attributes, Statements, and Measurements about GAHP

No	Attribute	Statement	1	2	3	4	5
1	Initial investment	I believe that the initial investment required for implementing GAHP is too high.	0	0	14	48	38
2	Increased yield	I believe that GAHP helps increase yield in pig farming by decreasing the mortality rate.	0	5	14	43	38
3	Output contract	I expect that by adopting GAHP, I will no longer have to worry about pig price fluctuations.	0	0	24	33	43
4	GAHP certification	I expect that by adopting GAHP, pig products will be safe for consumers.	0	0	24	48	29
5	Traceability	I believe that by adopting GAHP, traceability will provide consumers with information about the raising process.	0	0	24	50	27
6	Price premium	I believe that the implementation of GAHP will result in higher pig product pricing.	0	0	14	48	38
7	Influence of neighbor	If other farms have successfully used GAHP, I will invest in it.	5	14	48	19	14
8	Uncertainty	I am concerned about the uncertainties associated with GAHP implementation.	0	14	38	29	19
9	Farm scale	I believe that farm scale influences the adoption of GAHP.	0	24	33	19	24
10	Credit accessibility	I am unable to invest in GAHP because of a lack of credit.	0	0	43	33	24
11	Agricultural extension services	I believe that extension services will be useful in my farm with GAHP.	0	19	29	24	29

Source: Author

The level of the initial cost attribute was established by conducting a survey among pig farmers. The attribute level for increased yield is based on the study of LIFSAP, which stated that pig farmers applied GAHP (Table 3.2).

Table 3.2. Attributes and Corresponding Levels

Attribute	Unit	Level
Initial cost	Million VND/1000 m^2 pigsty	1200; 1400; 1600; 1800
Increased yield	%	5; 10
Output contract	0 = No; 1 = Yes	0; 1
Price premium	%	10; 20; 30

Source: Author

2) Designing Choice Cards

The second step is to create choice cards that present various combinations of those attributes in a systematic and balanced manner. Using 2 attributes with 2 levels, 1 attribute with 3 levels, and 1 attribute with 4 levels would yield a full factorial design of 48 alternative sets. However, following the best practices of Allenby et al. (1998), each survey questionnaire should be limited to 10 choice sets or fewer. In this study, we presented six choice sets using choice cards that gave pig farmers two options: (1) non-adoption of GAHP or (2) adoption of GAHP. Table 3.3 shows an example of a choice card.

Table 3.3. An Examples of Choice Cards

Attribute	Non-Adoption GAHP	Adoption GAHP
Increased yield	0%	+10%
Output contract	0 = No	1 = Yes
Price premium	0%	+10%
Initial cost	1,200 million VND	1,400 million VND
Please choose your preferred option.	☐	☐

Source: Author

3) Data Collection

Data collection was from study participants, ensuring a representative sample and thorough documentation. The survey was conducted in two provinces: Dong Nai (Trang Bom and Thong Nhat districts) and Binh Duong (Phu Giao district) in May 2022 (Figure 3.2). These areas were selected for their high concentration of pig farms and their importance in promoting GAHP implementation. Using stratified random sampling in each district, we selected 50 pig farmers who operate open-cycle pig rearing systems. In total, we interviewed 150 pig farmers, each of whom was the primary decision-maker in their household.

Figure 3.2. Map of Study Sites
Source: Author

4) Measurement and the Empirical Model

Farmers' preferences regarding GAHP adoption in Vietnamese pig farming were analyzed using the choice experiment. Based on Lancaster's Theory of Consumer Behavior, the Mixed Logit model (MXL) with 2 models was used:

The Main Effect MXL Model

The model is displayed as follows:

$V_{ab} = \beta 0 + \beta_1 *$ initial cost + $\beta_2 *$increased yield + $\beta_3 *$output contract + $\beta_4 *$price premium

The MXL Model with Individual Characteristics

The MXL model with individual characteristics is shown as follows:

$V_{ab} = \beta 0 + \beta_1 *$initial cost + $\beta_2 *$increased yield + $\beta_3 *$output contract + $\beta_4 *$price premium + $\alpha_1 *$gender + $\alpha_2 *$education + $\alpha_3 *$age + $\alpha_4 *$income

Where willingness to pay (WTP_a) for each attribute is the ratio of the marginal utility of the attribute to the marginal utility of the monetary attribute.

The monetary aspect considered in this study is the initial investment cost:

$WTP_a = -\beta_a / \beta_{cost}$

The model estimations and analysis preparation in this study were carried out using Stata 16.0.

3. Results and Discussions

(1) Social Characteristics of Pig Farmers

According to the survey data, 70% of pig farmers were male and 30% were female. The majority of farmers (56%) were aged 45–59, while 30% were aged 30–44, 10% were aged over 60, and 4% were aged under 30. More than half (54%) of the surveyed pig farmers had completed secondary school education. Regarding experience levels, 44% had 10–19 years of experience, 30% had 20–30 years, 22% had less than 10 years, and 4% had over 30 years. For farm size, 66% operated medium farms (30–300 pigs), while 34% managed large farms (over 300 pigs). Annual household income distribution showed that 30% earned 100–199 million Vietnamese Dong (VND), 28% earned 200-299 million VND, and 20% earned 300-400 million VND. The remaining farmers earned either below 100 million VND (4%) or above 400 million VND (18%). Table 3.4 presents these characteristics in detail.

Table 3.4. Characteristics among Pig Farmers

Variables	Categories	Frequency	Percentage (%)
Gender	Male	105	70
	Female	45	30
Age	Under 30	6	4
	30–44	45	30
	45–60	84	56
	Above 60	15	10
Education	Primary school	39	26
	Secondary school	81	54
	High school	18	12
	University	12	8
Experience	Under 10	33	22
	10–19	66	44
	20–30	45	30
	Above 30	6	4
Number of pigs	30–300	99	66
	Above 300	51	34
Household income	Under 100 million VND (4200 USD) per year	6	4
	100–199 million VND (4200–8400 USD) per year	45	30
	200–299 million VND (8400–12,600 USD) per year	42	28
	300–400 million VND (12,600–16,800 USD) per year	30	20
	Above 400 million VND (16,800 USD) per year	27	18

Source: Author's calculation

(2) Pig Farmers' Preferences for the Adoption of GAHP

To examine pig farmers' preferences regarding GAHP attributes, we estimated a Mixed Logit (MXL) model. Table 3.5 presents the main effect model. The MXL results reveal that initial cost, increased yield, output contract, and price premium attributes all had significant positive coefficients, suggesting farmers would favor adopting GAHP over other alternatives.

Table 3.5. The Main MXL Model

Attribute	Coefficient	Standard Error
ASC	2.6506 ***	0.9124
Initial cost	−0.0015 **	0.0007
Increased yield	0.1681 ***	0.0446
Output contract	0.9931 ***	0.3608
Price premium	0.0854 ***	0.0208
Standard deviations		
Increased yield	0.0595 **	0.081
Output contract	0.2929 *	0.899
Price premium	0.0612 *	0.3145
Model fit statistics		
Number of respondents	150	
Number of observations	1800	
Log-likelihood	−401.19	
Wald chi2	45.64 ***	
AIC	812.38	
Likelihood ratio test	9.67 ***	

Note: ***, **, * represent significant levels at 1%, 5%, 10%, respectively.
Source: Author's calculation

Table 3.6 presents the estimated results of the MXL model with individual characteristics. The model incorporating individual characteristics shows improved goodness-of-fit with better log-likelihood (−393.095) and AIC values (806.19) compared to the main model without these characteristics (−401.19 and 812.38). The Wald chi-square (47.64) and Likelihood ratio test (10.74), both significant at the 1% level, further confirm the goodness-of-fit of the model with individual characteristics.

Table 3.6. The MXL Model with Individual Characteristics

Attributes	**Coefficient**	**Standard Error**	**Pig farmers' WTP (million VND/1000 m^2)**
Initial cost	−0.0015 **	0.0007	
Increased yield	0.1729 ***	0.0457	115.9
Output contract	1.0215 ***	0.3705	685.3
Price premium	0.0878 ***	0.0213	58.9
ASC	3.5410 ***	1.3133	2360
Characteristics of respondents			
Gender	0.3943 *	0.2323	
Education	0.0139	0.0428	
Age	0.0277 *	0.0147	
Income	0.0004 *	0.0002	
Model fit statistics			
Number of respondents	150		
Number of observations	1800		
Log-likelihood	−393.09		
Wald chi2	47.64 ***		
AIC	806.19		
Likelihood ratio test	10.74 ***		

Note: ***, **, * represent significant levels at 1%, 5%, 10%, respectively.
Source: Author's calculation

Finally, the study used the Latent Class Model (LCM) to assess the heterogeneity of farmers' preferences (Table 3.7). The farmers surveyed were divided into three groups based on their priorities: productivity-concerned (22%), contract-concerned (48%), and price-concerned (30%). The productivity-concerned group valued higher productivity from GAHP adoption but needed additional incentives to participate. The contract-concerned majority preferred guaranteed market access through output contracts and showed a willingness to adopt GAHP. The price-concerned group was motivated by premium pricing for GAHP-certified products, highlighting the role of economic incentives in adoption decisions.

Table 3.7. The MXL Model with Individual Characteristics

Variables	Class 1 (Productivity Concerned)		Class 2 (Contract Preferred)		Class 3 (Price Concerned)	
	Coefficients	**S.E.**	**Coefficients**	**S.E.**	**Coefficients**	**S.E.**
Initial cost	−0.005 *	0.061	−0.003 **	0.017	−0.007 **	0.094
Increased yield	0.468 ***	0.161	0.231	0.181	0.479	0.113
Output contract	2.597	1.131	1.538 ***	0.712	1.414	0.447
Price premium	2.267	1.072	4.213 *	1.365	2.105 ***	0.972
ASC	−4.877 **	1.638	4.125 ***	1.421	5.213	1.672
Class Prob.	0.22		0.48		0.30	

Note: ***, **, * represent significant levels at 1%, 5%, 10%, respectively. S.E. is standard error

Source: Author's calculation

(3) Clarification of GAHP Adoption Decision

According to the survey, pig farmers explained their reasons for adopting GAHP (Figure 3.3). The main motivations included guaranteed output contracts (68%), improved economic efficiency (44%), high and stable output prices (42%), and compatibility with existing farm conditions (30%). Farmers also cited their interests in technological innovation (18%) and access to training support (16%) as additional factors.

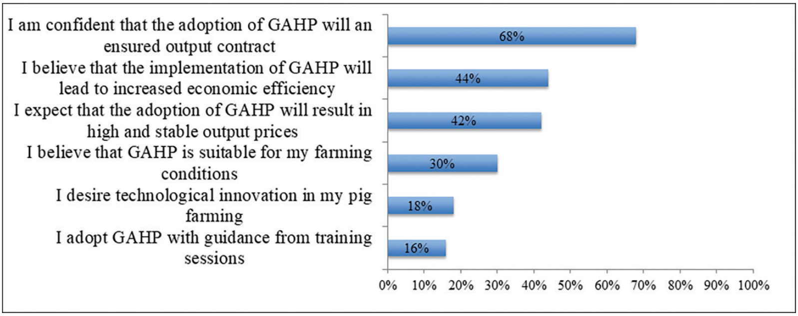

Figure 3.3. Reasons for the Adoption of GAHP
Source: Author's survey

The survey also shows the reasons why pig farmers did not adopt GAHP (Figure 3.4). The main barriers to GAHP adoption were high initial costs (50% of farmers), lack of knowledge about standards (43%), difficulty understanding certification (37%), limited credit access (33%), and skepticism about price premiums (30%).

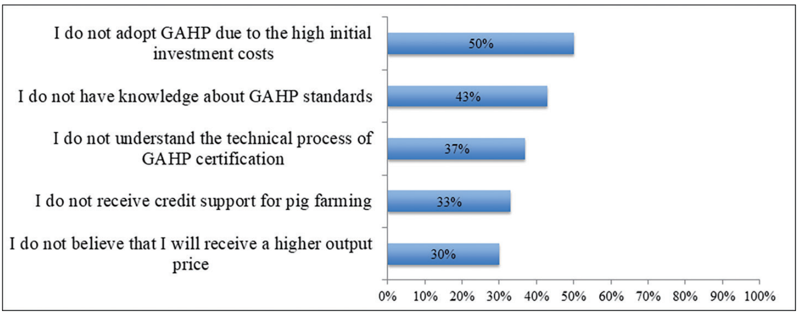

Figure 3.4. Reasons for Non-Adoption of GAHP
Source: Author's survey

4. Conclusion and Policy Implications

The implementation of GAHP in pig farming stands as a fundamental transformation in livestock management, representing a critical advancement toward ensuring comprehensive food safety standards for consumers while simultaneously creating opportunities for farmers to optimize their operational efficiency and economic outcomes. This systematic approach to pig farming integrates modern scientific practices with traditional knowledge to create a more sustainable and profitable farming model.

In-depth research investigations have demonstrated strong support among pig farmers for adopting GAHP protocols, with many expressing enthusiasm and willingness to make necessary investments when certain favorable conditions are met. The study identified three primary motivating factors that significantly influenced farmers' decisions to adopt these practices: the establishment of guaranteed output contracts that provide market security, the potential for achieving higher yields through improved farming methods, and the availability of price premiums that reward quality production and adherence to GAHP standards.

The findings from this research provide valuable insights with significant implications across the pig farming industry.

- Policymakers can implement comprehensive incentive programs and targeted support mechanisms to drive agricultural transformation. This includes offering substantial financial assistance for infrastructure modernization, facilitating access to guaranteed output contracts through strategic partnerships, and developing long-term sustainability frameworks that can effectively encourage more farmers to invest in GAHP, ultimately enhancing the overall industry's sustainability and resilience.

- Buyers, processors, and retailers have a unique opportunity to leverage the growing willingness of pig farmers to invest in GAHP by establishing robust and well-structured market channels specifically designed for GAHP-certified products. Through the implementation of attractive price premium structures and the development of comprehensive marketing strategies that effectively communicate the superior quality and enhanced safety aspects of GAHP-certified pigs, market actors can stimulate stronger consumer demand and create compelling incentives for farmers to adopt these improved practices.
- The research findings provide valuable guidance for pig farmers in making strategic decisions about their farming operations. They can conduct thorough assessments of various opportunities, including the feasibility of securing and maintaining output contracts, implementing efficiency measures to increase productivity, and strategically positioning themselves to capitalize on emerging market opportunities specifically available for GAHP-certified pigs.

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Chapter 4
Farmers' Perceptions and Adaptation Strategies in Response to Climate Change: A Case Study of Shallot Farmers in Indonesia

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Summary: Climate change is a global issue that threatens agriculture, especially in developing countries. Shallots are a seasonal crop that are particularly threatened by climate change. The negative impact of climate change is a decrease in production. Farmers can prevent or mitigate risks through adaptation strategies based on their understanding and knowledge. This study aims to determine the level of farmers' perceptions of the impacts of climate change, the factors that influence farmers' perceptions of the impacts of climate change, and farmers' adaptation strategies to address the impacts of climate change. This study used data from the 2014 Horticultural Household Survey (SHR) from the Central Statistics Agency (BPS), with a research focus on shallot farmers with a total of 9,147 respondents. The methods used were descriptive analysis and ordinal logistic regression. The results showed that 1) 40% of farmers are affected by climate change, 9% of them are highly affected, while 31% are partially affected. 2) Factors that significantly influence shallot farmers' perceptions of climate change impacts include education, gender, cropping system, and rainfall. 3) The most common adaptation strategy carried out by shallot farmers in dealing with the impacts of climate change is to become a member of a farmer group with a percentage of 23.75%. This research recommends that farmers should be encouraged to increase their participation in farmer groups.

1. Introduction

Climate change is characterized by changes in the average value and diversity of climatic factors, with a tendency for temperatures to increase over time or for more frequent climate anomalies than before (Gao et al. 2022). The direct impact of climate change on the agricultural sector can manifest as damage and shrinkage of cultivated land areas, lack of water availability, and destruction of genetic resources or biodiversity (Qazlbash et al. 2021). The negative impacts of climate change cannot be avoided, but prevention or mitigation can reduce the risk of a decrease in production through adaptation in the face of climate change impacts (Guo et al. 2021).

Adaptation is a form of adjustment to changes in the surrounding environmental conditions. This adaptation is very important to reduce the impact of climate change, to minimize the level of vulnerability of communities and ecosystems, build resilience to climate change, support smooth production, and minimize the risks that will occur (Mulwa et al. 2017). This adaptation is based on the knowledge and skills of farmers in analyzing the level of impact of climate change. Farmers' perceptions of the impact of climate change also vary, depending on how they perceive changes in climate conditions. Understanding farmers' perceptions of the impact of climate change is crucial for preparing them to implement adaptations or adjustments to their farming techniques. Farmers' adaptation of farming methods due to climate change can be achieved in several ways, such as improving drainage, agronomic control of vegetation and soil, using biological agents, participating in partnerships, and selecting varieties that have resistance to climate change.

Research related to farmers' adaptation to the impacts of climate change on agriculture has been widely conducted in the world such as in China, Mexico, Pakistan, Nepal, Kenya, Tanzania, Benin, Malawi, Indonesia, and some other developing countries (Fadina and Bajolle 2018; Gao et al. 2022; Gebre et al. 2023; Khanal et al. 2018; Kogo et al. 2021; Orduño et al 2020; Qazlbash et al. 2021). Farmers' ability to perceive climate change impacts to vary from high to low depending on several factors, including their gender, age, education, family size, access to credit, and income from farming.

Farmers' strategies for dealing with climate change are carried out by adjusting planting time, crop rotation, semi-organic farming, spraying medicines, tillage according to recommendations, making drainage channels, and replacing or adding work. In Indonesia, similar studies have also been conducted in Batu and Malang, East Java, and in Central Java. These studies focus more on the impacts of climate change on the production of and income from food commodities for food security. There is still very limited research on the impact of climate change on shallot commodities, especially at the national level. Some of these studies still have regional limitations, so research was conducted on the perceptions and adaptation strategies of shallot farmers in Indonesia. The results of this study can be useful as a recommendation material for increasing farmers' resilience in the face of climate change.

2. Materials and Methods

(1) Research Method

This research employs a combination of quantitative and qualitative methods. Quantitative research methods in this study include explaining and interpreting the perceptions of shallot farmers on the impact of climate change with a Likert scale; measuring factors that influence the perceptions of shallot farmers in dealing with the impact of climate change on the decline in shallot production with ordinal logistic regression; and analyzing the adaptation strategies of shallot farmers in dealing with the impact of climate change using descriptive analysis with quantitative data from the Central Statistics Agency (BPS) survey results in the form of the Horticultural Household Survey (SHR) in 2014. The qualitative research method in this study is used to explore in depth the results of secondary data analysis by conducting in-depth interviews with shallot farmers in Probolinggo Regency, which is one of the centers of climate change.

(2) Data and Method

This study used data from the 2014 Horticultural Household Survey (SHR) conducted by the Central Statistics Agency (BPS). The data used included 9,147 shallot farming households in Indonesia. Data was taken from horticultural business households and included, demographic information of the selected farmers, namely their gender, age, and education level, planting system by farmers, harvest area of shallot plants, the impact of pest attacks, the main control method if exposed to pest attacks, the impact of climate change or natural disasters, the percentage of farmers' perceptions of the impact of climate change on the decline in production, as well as farmers' membership in partnerships and farmer groups.

Farmers' perceptions of the impacts of climate change were analyzed using a scoring analysis method with a Likert scale and descriptive analysis to describe and elaborate on its interpretation. The scoring analysis was conducted in 4 stages, the first stage being the determination of the answer scale with value of 1, where farmers felt no impact of climate change; 2, where farmers felt low impact of climate change; and 3, where farmers felt high impact of climate change. The second stage is determining the answer score by multiplying the scale value with the respondent's answer for each category. The third stage is determining the scale range of the score results that have been obtained. The fourth stage is obtaining the final score. Thus, the Likert scale value of farmers' perceptions of the impacts of climate change is obtained.

Factors affecting farmers' perceptions of climate change impacts were analyzed using ordinal logistic regression analysis. The dependent variable used in this study is the farmer's perception of the impact of climate change on the decline in shallot production analyzed on an ordinal scale with three levels of impact, namely Y1 = farmers feel unaffected with a percentage of 0%, Y2 = farmers feel low impact with a percentage of 1–50%, and Y3 = farmers feel high impact with a percentage of 51–100%. The independent variables in this study consist of several ratio-scale factors and dummies, namely age (X1), education (X2), harvest area (X3), cropping system (D1), partnership (D2), gender (D3), and rainfall (D4). A description of each variable is provided in Table 4.1.

Table 4.1. Summary of Variables and Statistical Definitions of Each Variable

No.	Variable	Description	Percentage
Dependent variable (Y)			
1	Farmers feel unaffected (Y1)	0% impact rate on production decline	5.495 farmers (60,07%).
2	Farmers perceive low impact (Y2)	1–50% impact rate on production decline	2.809 farmers (30,71%).
3	Farmers feel high impact (Y3)	Farmers feel high impact	843 petani (9,22%).
Independent variables (X)			
1	Age(X1)	Year	48
2	Education (X2)	Year	6
3	Area (X3)	m^2	2.171
4	Cropping pattern(D1)	Dummy variables (0 = monoculture, 1 = polyculture)	0: 8.039 farmers (87,89%), 1: 1.108 farmers (12,11%).
5	Contract farming (D2)	Dummy variables (0 = contract, 1 = not contract)	0: 9.059 farmers (99,04%), 1:88 farmers (0,96%).
6	Gender (D3)	Dummy variables (0 = female, 1 = male)	0: 695 farmers (7,60%), 1:8.452 farmers (92,40%).
7	Farmer group participation (D4)	Dummy variables (0 = participated, 1 = not participated)	0: 6.975 farmers (76,25%), 1:.172 farmers (23,75%).

Source: Author's survey

The adaptation strategy of shallot farmers is analyzed using descriptive analysis by describing the precautions or adaptations taken by farmers in the face of climate change that occurs, where the level of adaptation will be presented in the form of percentages and categorization of farmers affected and not affected by climate change. Indicators of shallot farmer adaptation strategies in the face of climate change include agronomic control (by fertilizing, tillage, irrigation arrangements, etc.), using intercropping or intercropping systems, making partnerships with companies or partner businesses, performing biological control, performing mechanical control, and becoming members of farmer groups (Fadina and Bajolle 2018; Mulwa et al. 2017).

3. Impacts of Climate Change by Shallot Farmers

The results of the analysis showed that out of 9,147 samples, 39.93% of farmers were affected by climate change in the form of drought, flooding, high rainfall, and other disasters. The greatest impact was high rainfall at 59.47%, drought was 24.56%, flooding was 11.58%, and other disasters were 4.38%. Farmers' perceptions of climate change impacts were also accumulated based on the criteria for the level of impact, such as not affected, low impact, and high impact based on the percentage level of impact.

(1) Influencing Factors on Farmers' Perceptions

Factors influencing farmers' perceptions of climate change impacts were analyzed using ordinal logistic regression analysis. The results of the ordinal logistic regression analysis are presented in Table 4.2.

Table 4.2. Results of Ordinal Logistic Regression Analysis

Variables	Coefficient	S.E.	Wald	df	Sig.	Exp(B)
Constant	2,470	0,574	18,490	1	0,000	
Age (X_1)	-0,010	0,004	5,985	1	**0,014** **	0,990
Education (X_2)	-0,036	0,011	9,881	1	**0,002** **	0,965
Gender (D_4)	-0,219	0,157	1,963	1	0,161	0,803
Area (X_3)	0,000	0,000	0,693	1	0,405	1,000
Cropping pattern (D_1)	-0,443	0,145	9,386	1	**0,002** **	0,642
Contract farming (D_2)	-0,345	0,504	0,468	1	0,494	0,708
Rainfall (D_3)	0,514	0,092	31,182	1	**0,000** **	1,671

Note: ** denote significant at 5%
Source: Author's calculation

Of the seven independent variables analyzed using ordinal logistic regression analysis, four variables were found to significantly influence farmers' perceptions of climate change impacts, namely age, education, cropping system, and high rainfall intensity. The variable that positively influenced the impact of climate change was the high intensity of rainfall, while the variables that negatively influenced it were age, education, and cropping system.

The estimation results show that the variables of age and education of farmers have a significantly negative effect. The results show that if the age and education of farmers increase by 1 year, it will reduce the odds ratio of farmers having the perception of being affected by climate change. Many studies have discussed the role of age and education in farmers' perceptions of climate change impacts. A study in Padang Jaya Sub-district, North Bengkulu Regency, showed that older farmers will have a better understanding of climate change and strategies to deal with climate change impacts due to their greater experience.

The farmers' education variable has a significantly negative effect. Another study on the role of education related to the perception and adaptation of farmers of rice commodities in Indonesia showed that the ability to adopt technology and information was higher for farmers with higher levels of education. Therefore, better educated farmers can understand the indicators of the impact of climate change on crop land and are able to implement appropriate adaptations in the face of the impact of climate change. The results of the ordinal logistic regression analysis are also adjusted to the SHR data, where farmers with three perceptions of the impact of climate change have the highest level of education at the level of elementary school graduates, so it is in line with the results of the study that a higher level of education can increase the knowledge and skills of farmers in dealing with the impacts of climate change.

The variable of harvest area in the study did not have a statistically significant effect, so it can be said that if there is an increase in harvest area, it will not affect the perception of farmers. This can be caused by the fact that the majority of farms have a small land area, with a harvest area of <2,500 m^2 at 69.59%. Furthermore, the cropping system dummy variable is negative and statistically significant, with a significance value of 0.002. It can be said that if the intercropping system increases, it will reduce the odds ratio of farmers having the perception of being affected by climate change by -0.443. This is also in accordance with previous research, which found that uncertain climatic conditions lead farmers to intercrop shallot plants with other commodities, such as chili plants, to reduce the risk of production loss and a decrease in the income of shallot farmers due to the impact of climate change their land.

The estimation results also show that the gender dummy variable has no statistically significant effect. This is in line with the results of research in Amadanom Village, Dampit Subdistrict, Malang District, which indicate that gender as an internal factor of farmers has no significant effect on farm risk. This was because the majority of farmers in the 2014 SHR data, were male, amounting to 92.40%. This causes the data to be biased and causes the gender variable to have no effect on farmers' perceptions of the impact of climate change on reducing shallot production in Indonesia.

Furthermore, the study also revealed that the variable of farmers' participation in partnerships had no effect on farmers' perceptions as the majority of farmers - 99.04%- have not joined a partnership. The low rate of partnership in the shallot commodity is because the shallot downstream industry is a small business industry player whose raw material needs are not large.

The ordinal logistic estimation shows that high rainfall intensity has a positive effect and is statistically significant. The dummy variable of high rainfall intensity shows that if the intensity of high rainfall increases, it will increase the odds ratio of farmers having the perception of being affected by climate change. A study shows that high rainfall from La-Nina events causes soil moisture to also tend to be higher, which can make it easier for mold to develop and attach to plants, especially on the bulbs of shallots. This can cause the bulbs in the soil to rot and potentially reduce shallot production.

(2) Adaptation Strategies in Facing the Impact of Climate Change

Adaptation strategies carried out by shallot farmers in the face of climate change consist of seven controls, including agronomic control, using intercropping or intercropping systems, making partnerships with companies or partner businesses, carrying out biological control, carrying out mechanical control, and becoming members of farmer groups. Table 4.3 presents the distribution of sample farmers based on adaptation strategies in Indonesia.

Table 4.3. Distribution of Sample Farmers Based on Adaptation Strategies Practiced in Indonesia

No.	Adaptation strategy	Frequency	Percentage (%)
1	Performing Agronomic Control	114	1,58
2	Applying an Intercropping Cropping System	1.108	12,11
3	Generating Partnerships with Partner Companies or Businesses	88	0,96
4	Performing Biological Control	16	0,22
5	Performing Mechanical Control	60	0,83
6	Become a Farmer Group Member	2.172	23,75

Source: Author's calculation

The results of the analysis show that the most common adaptation strategy carried out by shallot farmers is to become members of farmer groups at 23.75%, while the least common adaptation strategy is to carry out biological control at 0.22%. The description of each adaptation strategy carried out by shallot farmers in Indonesia in facing the impacts of climate change is as follows:

1) Agronomic control is carried out as one of the adaptation strategies for dealing with attacks by plant pest organisms (OPT) on shallots due to indications of climate change in the form of extreme differences between temperatures during the day and night. The temperature difference causes plants to experience frost or haze disease, where these symptoms allow soil-borne pathogens to infect plants, resulting in haze disease and plant death in the early phase. The 2014 SHR data shows that the percentage of farmers who apply agronomic adaptation strategies is 1.58%. Agronomic control by shallot farmers is the second most common pest control after chemical control. This shows that shallot farmers still fertilize to control pests, but most farmers still use chemical fertilizers compared to the use of organic fertilizers for shallot plantations. The results of a simple field survey of shallot farmers in Dringu Village, Dringu Subdistrict, Probolinggo

Regency show that, on average, shallot farmers in the village apply tillage once in shallot farming before the planting period.

2) Intercropping is another adaptation strategy used by shallot farmers to reduce the production risk due to the impact of climate change, where farmers generally intercrop shallot plants with chili plants. SHR 2014 data shows that the percentage of farmers who apply intercropping adaptation strategies is 12.11%. The reason intercropping systems are seldom applied by farmers is due to some shortcomings or weaknesses in their application, where a study revealed the application of intercropping systems allows competition between plants that are above and below the ground, so that the existence of different morphologies and physiologies between intercropped plants causes farmers to have more knowledge and experience related to the application of the cropping system.

3) Partnerships carried out by shallot farmers are usually in an informal form through general trading patterns or sales contracts between farmers and sellers without going through formal or written contracts. The advantages for shallot farmers in following the partnership are the availability of assistance in the form of business capital, assistance in cultivation training in providing superior seeds, and the certainty of shallot marketing at an agreed price, so that farmers do not have to worry about production risks in the form of climate change. The percentage of farmers who follow partnership activities based on 2014 SHR data is only 0.96%. Based on SHR 2014 data, shallot farmers have partnerships with State-Owned Enterprises (BUMN) as many as 9 people, Village-Owned Enterprises (BUMD) as many as 37 people, private companies as many as 33 people, and cooperatives as many as nine people, where the most partner businesses that cooperate with farmers are BUMD, and the least are BUMN and cooperatives. A few partnership agreements require farmers to cultivate shallots outside the

season or during the off-season. This is done to fulfill the supply needs of partners.

4) The percentage of farmers who apply biological control adaptation strategies is only 0.17%. Biological control in the form of the use of Trichoderma in each planting hole can reduce the risk of being attacked by diseases such as Fusarium wilt, which attacks the base of the layer bulbs, and the use of natural enemies of dragonflies, as well as biological agents Feromon exi, Beauveria bassiana, and SE-NPV can reduce the attack of onion caterpillar pests on shallots. A study shows that the lack of shallot farmers who apply adaptation strategies in the form of biological control can be caused by the additional higher costs of using biological agents compared to farming without using biological agents.

5) Mechanical control is also a form of control for shallot plants that employs fencing or barriers to prevent pest attacks, such as installing mulches, traps, and so on. The percentage of farmers who apply mechanical control is 0.83%, while farmers who use protective nets are only 0.53%. This shows that the overall number of farmers practicing mechanical control is still relatively low, although the number is still higher than that of biological control.

6) The most common adaptation strategy followed by farmers is participation in farmer groups. Farmer groups serve as a forum for providing information about prices, partnerships, and agricultural production facilities for farmers. Shallot farmers who are actively involved in farmer groups benefit from the availability of information related to farming activities with the help of agricultural field extension (PPL) in the application of information technology, so that they can jointly anticipate pest attacks and the impact of climate change that occurs. The percentage of farmers who apply adaptation strategies to become members of farmer groups amounted to 27.65%.

4. Conclusion and Policy Implications

Shallot farmers perceive that climate change reduces production. 39.93% of shallot farmers experienced climate change impacts from drought, flooding, and excessive rainfall. Farmers' perceptions are influenced by geographic and demographic factors including age, farmers' education, cropping system, and rainfall. The variable that positively influences the impact of climate change is rainfall, while the variable that negatively influences is intercropping.

The most common adaptation strategy among farmers for dealing with climate change impacts is joining farmer groups (23.75%), while the least common is biological pest control (0.22%). Farmers' limited use of biological agents stems from their preference for chemical controls, despite these being potentially harmful to the environment and worsening climate change effects. This preference is driven by farmers' goals of maintaining shallot production levels and controlling pests and diseases. This study recommends that Indonesian shallot farmers should enhance their knowledge and skills regarding climate change by learning how to implement more appropriate and environmentally friendly adaptation strategies. Additionally, farmer group participation should be further encouraged as a key adaptation strategy.

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Chapter 5
Measuring Cost Efficiency and Its Determinants in Rice Farming in the Mekong River Delta

Phuc Trong HO

Summary: This chapter investigates rice production cost efficiency and investigates the determinants of cost inefficiency in rice production using a true random-effects model approach. The study used the survey data of 350 rice farmers in the Mekong River Delta, Vietnam. The findings show that the mean cost efficiency score is 0.92, with a wide variation (0.26–0.99). This study indicates that there is still room for inefficient rice farmers to save production costs by improving their cost efficiency. The research also finds that farm size, natural disasters, and rice diseases have a positive effect on cost inefficiency, implying that rice farmers lack the skills to manage input costs if farm sizes increase or when natural disasters and rice diseases occur. This study suggests that supportive policies should focus on improving rice farmers' skills to manage production inputs and deal with rice diseases and natural disasters to minimize production costs.

1. Introduction

Rice plays a crucial role in economic development and food security across developing and underdeveloped nations, sustaining populations and driving agricultural economies (Trong Ho et al. 2022). However, contemporary farming practices, particularly the excessive application of chemical fertilizers and pesticides, have created a complex web of challenges: farmers face mounting production costs, ecosystems suffer from environmental degradation, communities grapple with emerging health concerns, and the resulting rice crops often exhibit diminished quality. The implementation of more efficient input management strategies could offer a pathway to address these interconnected issues. While numerous research efforts have investigated rice farming efficiency on a global scale (Trong Ho et al. 2022), the academic literature has predominantly concentrated on measuring technical efficiency aspects. This narrow focus has led to an unfortunate oversight of input prices, a crucial economic factor that substantially shapes farmers' decision-making processes regarding input utilization and resource allocation (Trong Ho 2021).

Various research efforts have previously explored the relationship between price effects and efficiency measurements in rice farming through the application of cost frontier functions to calculate cost efficiency (CE) (Coelli et al. 2002; Huang et al. 2002; Siagian and Soetipto 2020; Thanh Nguyen et al. 2012; Tu and Trang 2016). These studies have provided valuable insights into the economic aspects of rice production and farming practices. Nevertheless, a significant limitation of these prior investigations lies in their failure to account for farm heterogeneity — the inherent differences between individual farming operations — which could potentially result in skewed estimates and inaccurate cost-efficiency scores.

To address this crucial research gap and enhance the accuracy of efficiency measurements, our study implements the sophisticated true random-effects (TRE) model (Green 2005a; b). This advanced methodological approach allows us to comprehensively evaluate both cost efficiency and its key determining factors in rice farming throughout the Mekong River Delta region, while properly accounting for the diverse characteristics and conditions of individual farms.

2. Data and Methodology

(1) Data Collection

This study used detailed farm-level data collected through an extensive survey conducted in the Mekong River Delta region of Vietnam. This important area serves as Vietnam's primary rice cultivation region, accounting for more than half of the country's total paddy production and harvested rice area, making it an ideal location for agricultural research.

To ensure representative sampling across the region's diverse agricultural landscape, we employed a carefully designed stratified random sampling methodology to identify study participants. Data collection was conducted through comprehensive face-to-face interviews with selected rice farmers, allowing us to gather insights and detailed information about their farming practices and experiences. The final dataset encompasses 350 rice farmers, yielding 918 distinct observations. This expanded sample size was achieved because each farmer typically cultivates rice across multiple growing seasons, with individual farmers managing two or three seasonal harvests throughout the year.

(2) Research Methodology

This study employs the True Random Effects (TRE) Model to measure cost efficiency and investigate its key determining factors that influence cost efficiency in rice farming. This analytical approach allows for a comprehensive examination of both cost inefficiency and stochastic noise components. Based on this econometric framework, the study can identify input allocation strategies and socio-economic characteristics that significantly contribute to cost efficiency variations among rice farmers. The first step is to run a translog cost frontier function (1) and then implement the inefficiency model (2).

Translog cost frontier function

$$\ln C_{it} = \alpha_0 + \sum_{j=1}^{2} \alpha_j \ln W_j + \beta_1 \ln Y + \frac{1}{2} \sum_{j=1}^{2} \sum_{h=1}^{2} \alpha_{jh} \ln W_j \ln W_h + \frac{1}{2} \beta_{11} \ln Y^2 + \sum_{j=1}^{2} \gamma_j \ln W_j \ln Y + \sum_{m=1}^{3} \delta_m D_m + w_i + v_{it} + u_{it} \quad (1)$$

Inefficiency model

$$\log \sigma^2_{uit} = \delta_0 + \sum_{m=1}^{10} \delta_m Z_{mit} \quad (2)$$

where, C is the variable cost, Y is the output quantity and W_j is a vector of input prices. α, β, γ, and δ are parameters to be estimated, v_{it}, u_{it}, and w_i are random noise, inefficiency terms, and farm heterogeneity. Z_m are explanatory variables.

3. Estimation of Cost Efficiency and Influential Factors

Table 5.1 provides a detailed analysis of rice production costs utilizing the Translog Stochastic Cost Frontier Function methodology, which enables a comprehensive assessment of cost production efficiency under socio-economic, farm, and variable weather conditions. As expected, all input variables (i.e., seed cost and fertilizer cost) and output quantity are positively significant at the level of 0.01. The results from the TRE model provide an effective assessment by producing more statistically reliable and robust estimation results. In addition, the analysis of cost inefficiency models identifies three key factors that significantly increase farmer inefficiency: rice cultivation area size, natural disaster impact, and rice disease prevalence. All three factors show positive correlations with higher cost inefficiency, highlighting critical areas needing improvement.

Table 5.1. Estimates of the Translog Stochastic Cost Frontier Function

Variable	**Pooled**		**TRE**	
	Coef.	**S.D.**	**Coef.**	**S.D.**
Constant	-0.304***	0.023	-0.320***	0.022
lnWseed	0.252***	0.035	0.250***	0.040
lnWfert	0.587***	0.042	0.555***	0.055
lnY	0.914***	0.013	0.872***	0.015
0.5lnWseed_sq	0.176	0.107	0.196*	0.109
0.5lnWfert_sq	0.424	0.274	0.686***	0.328
0.5lnY_sq	0.091***	0.015	0.113***	0.015
lnWseed_Wfert	-0.118	0.134	-0.201	0.133
lnWseed_Y	0.002	0.027	0.000	0.026
lnWfert_Y	0.104***	0.040	0.074	0.045
D_{S_A}	0.184***	0.017	0.178***	0.010
D_{A_W}	0.205***	0.019	0.180***	0.012
D_{HQV}	-0.047***	0.017	-0.028*	0.016
Estimates of cost inefficiency model				
Constant	-3.541***	0.640	-4.500***	0.821
Gender	-0.586	0.506	0.032	0.690
Education	-0.088	0.120	-0.082	0.140
Experience	0.044	0.119	-0.071	0.142
Extension	-0.078	0.109	-0.104	0.136
House-size	-0.197*	0.111	-0.156	0.120
Land-own	-0.178	0.110	0.081	0.136
Farm-size	0.188	0.120	0.299**	0.124
Disaster	1.121***	0.156	1.211***	0.147
Disease	0.231**	0.103	0.219**	0.096
Distance	0.164*	0.091	0.101	0.120
Model properties				
σ_{w_i}	-	-	0.174***	0.009
E ($\sigma_{u_{it}}$)	0.163	-	0.139	-
$\sigma_{v_{it}}$	0.192***	0.006	0.106***	0.005
Log-likelihood	130.05		286.65	

"Note: ***, **, * represent for significant levels at 1%, 5%, 10%, respectively. S.D. is the standard deviation

Source: Author's calculation

Table 5.2 presents the summary of partial cost elasticities with respect to both input prices and output quantity. These elasticities provide valuable insights into how changes in various input costs and production volumes affect the overall cost structure, allowing for a deeper understanding of the economic relationships underlying the production process.

Table 5.2. Summary of Partial Cost Elasticities to Input Prices and Output Quantity

Variable	**Pooled**		**TRE**	
	Coef.	**S.D.**	**Coef.**	**S.D.**
Seed price	0.239	0.065	0.239	0.067
Fertilizer price	0.543	0.137	0.521	0.165
Labor price	0.218	0.159	0.240	0.162
Output quantity	0.876	0.093	0.827	0.107

Source: Author's calculation

A summary of cost efficiency by cropping seasons and rice varieties is shown in Table 5.3. The overall cost efficiency (TRE model) is 0.92, with efficiency scores ranging substantially from 0.26 to 0.99. The efficiency scores vary widely, indicating that less efficient rice farmers could significantly reduce production costs through better resource management and targeted efficiency improvements.

Table 5.3. Summary of Cost Efficiency by Cropping Seasons and Rice Varieties

Variable	**Observation**	**Pooled**		**TRE**	
		Coef.	**S.D.**	**Coef.**	**S.D.**
By cropping season					
Winter–Spring	339	0.920	0.089	0.936	0.080
Summer–Autumn	329	0.905	0.073	0.924	0.062
Autumn–Winter	250	0.875	0.115	0.890	0.114

By rice variety					
High–quality rice varieties	384	0.893	0.114	0.909	0.106
Conventional rice varieties	534	0.910	0.074	0.926	0.070
Overall cost efficiency	918	0.903	0.093	0.919	0.087

Source: Author's calculations

4. Conclusion

This study attempted to measure cost efficiency and influential factors on rice farming in the Mekong Delta.

A consideration in the analysis is accounting for unobserved farm heterogeneity, which the True Random Effects (TRE) model effectively addresses by producing more statistically reliable and robust estimation results. This methodological approach ensures that the analysis captures the complex variations between individual farming operations that might otherwise remain hidden.

The analysis reveals a mean cost efficiency of 0.92, with efficiency scores ranging substantially from 0.26 to 0.99. This wide variation in efficiency scores indicates significant room for improvement among less efficient rice farmers, who could potentially achieve considerable reductions in their production costs through targeted efficiency enhancements and better resource management practices.

Through detailed examination of the cost inefficiency model estimates, the study identifies three factors that significantly contribute to increased cost inefficiency among farmers: the size of rice cultivation areas, the impact of natural disasters, and the prevalence of rice diseases. Each of these factors demonstrates a positive correlation with higher levels of cost inefficiency, highlighting key areas that require attention for improvement.

Based on these findings, the study strongly recommends the development and implementation of comprehensive training programs specifically designed to enhance rice farmers' production capabilities. These programs should focus particularly on three critical areas: advanced input cost management strategies, effective disease prevention and control methods, and improved disaster preparedness and response techniques. Such targeted training initiatives would help farmers minimize paddy losses and optimize their operational efficiency.

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Chapter 6
Agriculture and Poverty Reduction in Cambodia: The Role of Rice Yield

Hay CHANTHOL

Summary: Cambodia's rapid economic growth in the past decades was largely supported by the garment, tourism, and construction sectors, while the agricultural sector showed slow growth. There were various causes for stagnation in the agriculture sector, including low rice yield, migration of workers, poor irrigation, inadequate use of fertilizer, and inability to adopt new seed varieties. This chapter aims to discuss two main agricultural issues: (1) stagnation of rural households agricultural income and (2) stagnation in rice output in Cambodia. Regression analysis using the rice production function will be used to analyze the effects of various inputs on rice productivity.

1. Introduction

During the past two decades of high economic growth, Cambodia's poverty rate has been greatly reduced. Over the 2000–2015 period, the average annual GDP growth rate was about 7%, with a low average annual population growth rate of 1.2% and an average annual real GDP per capita growth rate of 6.4%. Recently, the World Bank raised Cambodia's status from a low-income economy to a lower-middle-income country, based on the Bank's estimate that Cambodia's gross national income (GNI) per capita for 2015 was US$1,070, above the required threshold of US$1,026. The poverty rate was more than halved, from 53% in 2004 to 20.5% in 2011 (Table 6.1).

Table 6.1. Poverty Rate in Cambodia

	Food Poverty			Total Poverty			
Year	Phnom Penh	Other Urban	Rural	Phnom Penh	Other Urban	Rural	Cambodia
2004	3.81%	11.43%	17.89%	15.83%	39.67%	58.97%	53.20%
2007	0.06%	8.70%	15.26%	2.66%	35.04%	57.86%	50.10%
2008	0.62%	4.54%	7.17%	2.54%	26.83%	44.60%	38.80%
2009	0.56%	1.98%	6.28%	4.27%	12.67%	27.53%	23.90%
2010	0.74%	2.84%	5.86%	4.54%	12.61%	25.42%	22.10%
2011	0.00%	3.75%	4.38%	1.53%	16.10%	23.72%	20.50%

Source: Sobrado et al. (2013)

However, since the global financial crisis of 2008, international rice prices have shown declining trends, and the growth rate of Cambodian agriculture has declined from an average of 5% to just about 0.2% (Figure 6.1). Rice production, which accounts for about 60% of value added in the agriculture sector, has also reached a plateau (Figure 6.2). This slow growth rate in the agriculture sector may impede poverty reduction and the growth of other economic sectors. Research indicates that growth originating in agriculture contributes more to poverty reduction than growth in other sectors, and that enhancing agricultural productivity is critical for poverty reduction (Christiaensen et al. 2006; World Bank 2007).

The following sections will explore the causes of slow growth in the agriculture sector, the relationship between agricultural development and poverty reduction, and finally, provide policy recommendations for reviving the agriculture sector.

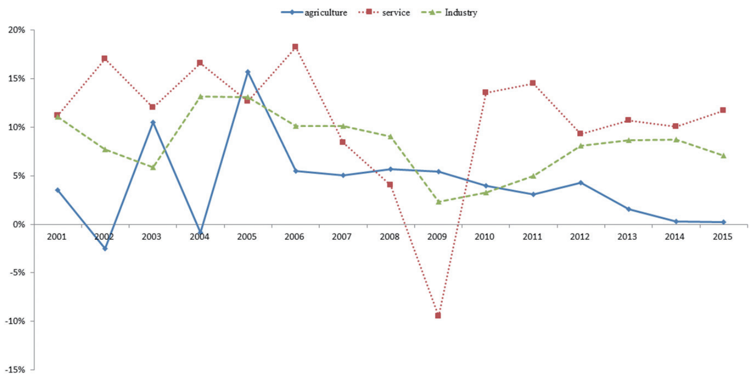

Figure 6.1. Decline in Agriculture Growth
Source: Statista, 2023

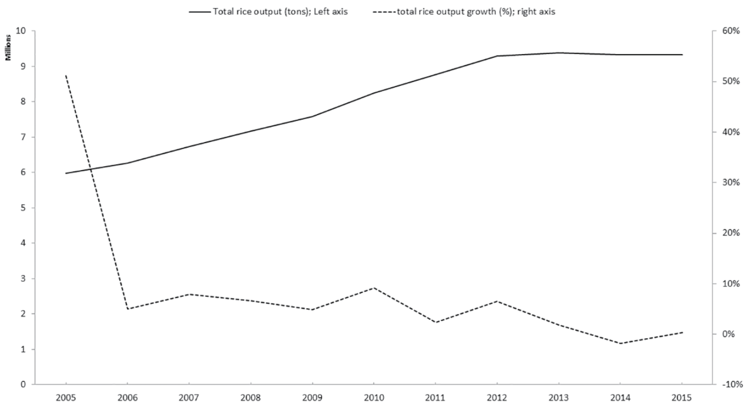

Figure 6.2. Total Rice Output Reached Its Plateau
Source: Ministry of Agriculture, Fisheries and Forestry, 2015

2. Agriculture and Poverty in Cambodia

The agriculture sector in Cambodia was one of the engines of economic growth at least until 2012 and was recognized as the primary source of poverty reduction in Cambodia as about 90% of the poor in the country live in rural areas. So far, the four engines of growth over the past decades have been agriculture, construction, tourism, and the garment sectors. However, the agriculture sector showed slower growth in recent years. The recent slow growth in the agricultural sector has been a concern for poverty reduction in the future. Agricultural growth declined from an average of 5% to just about 0.2% in the past 4 years (also shown in Figure 6.1). The slow growth may cause many more poor people who live near the poverty line to fall into poverty, and it may also cause the relative price of agriculture product in terms of other industrial products to increase, which could, in turn, destabilize the development of the industrial sector. It was argued that the process of industrialization could be smooth if the so-called "food problem" faced by low-income economies could be avoided. Rapid population growth and high food demand elasticity can result in high food prices, which pull up the cost of living and the wage rates of workers in non-farm sectors and thereby suppress industrialization and overall economic growth (Hayami 2008; Shultz 1953).

Stagnation in the agricultural income of rural households may cause more farmers to leave their farms and therefore future rice production could be reduced. The more rapid growth in industry and service sectors made the agriculture share of the GDP fall from 45% in 1993 to about 30% in 2016 (Figure 6.3). However, the number of agricultural workers in total employment is still the largest among the three sectors. About 48% of the 7.9 million employed workers are in the agriculture sector (Table 6.2).

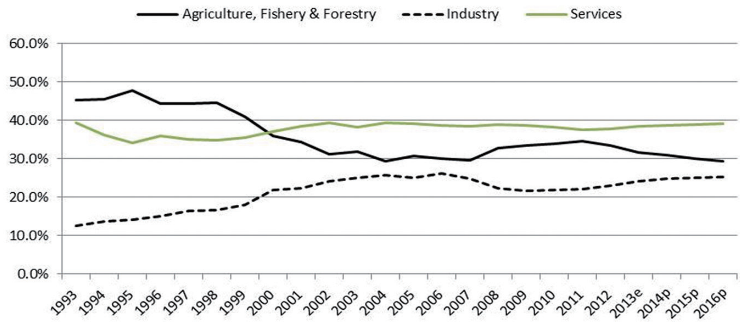

Figure 6.3. Agriculture Share in GDP (at current prices) Continues to Fall. Source: Statista, 2023

Table 6.2. Employment by Sector

Industrial sector (main occupation)	2004			2007	2008	2009	2010	2011	2012	2013		
	Women	Men	both	both	both	both	both	both	both	Women	Men	Both
Employed population, (thousand)	3,035	3,068	6,103	6,828	6,824	7,469	7,673	7,890	7,706	3,882	4,068	7,951
Agriculture (Primary)	57.1	57.8	57.4	57.7	55.6	57.6	54.2	55.8	51.0	50.0	47.4	48.7
Industry (Secondary)	14.0	12.6	13.3	14.9	15.8	15.9	16.2	16.9	18.6	19.2	20.5	19.9
Services (Tertiary)	28.6	29.5	29.1	27.4	28.6	26.5	29.6	27.3	30.4	30.8	32.1	31.5
Other/Don't know/Not stated	0.2	0.1	0.2	-	-	0.0	0.0	0.0	0.0	-	-	-
Total	100	100	100	100	100	100	100	100	100	100	100	100

Source: National Institute of Statistics of Cambodia, 2015b

The slow growth in the agriculture sector is accompanied by slow growth in the agricultural income of rural households. Looking at the source of income of rural households, it can be seen that income from agriculture was stable, and represented about 24% of total rural household income in 2014. This income from agriculture is lower than income from wages and salaries. The growth of total income of rural households mainly came from a rapid increase in wage and salary income. In 2014, the total income of an average rural household increased by 25% of which 12% came from wages and salaries while agricultural income contributed only about 4% (Figure 6.4). Rural agricultural income was increasing slowly because of many reasons. One reason could be the high prices of agricultural inputs such as fertilizers, pesticides, seeds, and so on. Most of those inputs were imported. Some farmers bought those inputs on credit with the expectation that they could pay the input sellers when they harvested their crops.

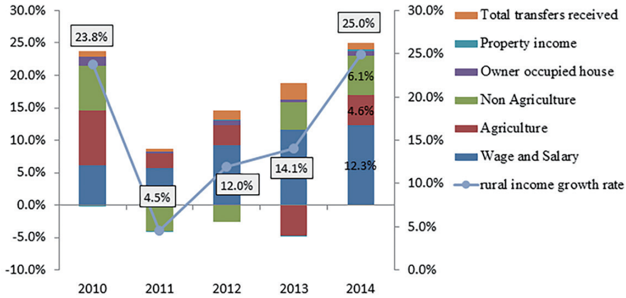

Figure 6.4. Contribution to Total Income Growth of an Average Household in Rural Areas
Source: National Institute of Statistics of Cambodia, 2015b

However, crop prices during the harvest season sometimes were not as high as expected. Therefore, some farmers, mostly small holders, sold their land to pay the debt they owed to microfinance institutions or input sellers and then migrated to work in urban areas or in Thailand or other countries. Another reason is that most farmers were forced to sell their crops during harvest time, even though the price was low at that time, in order to pay their debts. Most farmers had to take on loans, because, in addition to demand for funds to buy agricultural inputs, they also needed to smooth consumption over the year, or to pay for medical costs. Lenders monitored farmers closely to know when they sold crops so that they could collect their funds back. Thus, this reduced the ability of farmers to store their grain and to wait for the high price season to come. Therefore, rice prices in urban areas were so stable for many years, at least until 2011, despite a surge in 2009 due to global food crisis (Figure 6.5). But when we look at the food price index, which includes many imported items, it continues to surge over a longer period (Figure 6.6). However, the price of food is a double-edged sword. The poor spend a considerable amount of their household income on food. How a given policy affects the well-being of the poor depending on how the wage rate responds to the enhanced opportunities. If the increased profitability of agriculture results in a surge in investment, the productivity of workers will increase, and so will the wage rate. If the wage rate increases by a greater amount than the price, the poor will benefit.

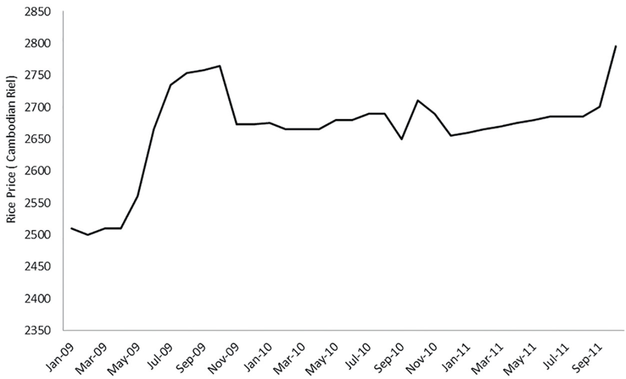

Figure 6.5. Rice Price (Cambodian Riel, 1$= 4000 Riels)
Source: National Institute of Statistics of Cambodia, 2015a

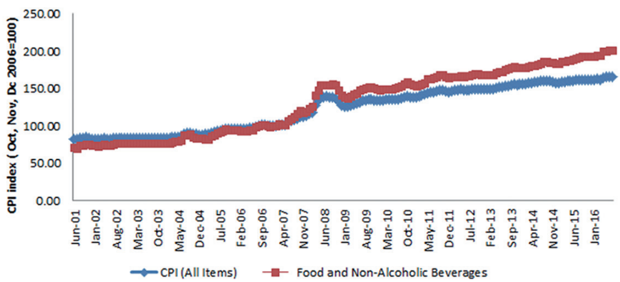

Figure 6.6. Surge in Food Price
Source: National Institute of Statistics of Cambodia, 2015b

The rice sector, which is one of the main sectors in agriculture, has shown stagnation since 2012. Cambodia has achieved a rice surplus for export since 1996, despite some segments of the population including urban poor and landless people continuing to face a food shortage. The total rice surplus reached 2.9 million tons in 2015 (Table 6.3). After the adoption of the government rice policy in 2010, a fairly large number of rice millers have been established for milling rice to export, and as a result, Cambodian milled rice was exported to international markets such as Europe and the US. In 2016, the total quantity of milled rice exports which was officially registered increased to 0.54 million tons from 0.37 million tons in 2013. This export figure is officially recorded by the Ministry of Agriculture, Fisheries and Forestry. A large quantity rice paddy trade was made across borders to neighboring countries. Foreign traders in collaboration with local rice buyers often bought the entire harvest of a rice paddy directly from the farmer's gate. Local rice buyers collected information about when farmers would harvest their crops, and then they negotiated the purchase price with the farmer. But most viewed that buyers had monopoly power to set the price, as they would divide up the regions among themselves, and there were no competitors. The phenomenon of selling low and buying high also happened in Cambodia. Cambodia exported mostly high-quality rice during the harvest season and at times when rice was in short supply, different quality rice was imported.

Table 6.3. Rice Production, Rice Surplus, and Yield

Item	Unit	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cultivated area	ha	2,374,175	2,443,530	2,541,433	2,585,905	2,615,741	2,719,080	2,795,892	2,968,529	3,007,545	3,052,420	3,055,507	3,051,412
Rainy	ha	2,075,646	2,121,591	2,212,015	2,241,114	2,255,104	2,334,228	2,391,016	2,496,569	2,512,038	2,567,723	2,564,572	2,561,957
Dry	ha	298,529	321,939	329,418	344,791	360,637	384,852	404,876	471,960	495,507	484,697	490,935	489,455
Harvested area	ha	2,109,050	2,414,455	2,516,415	2,566,952	2,613,363	2,674,603	2,777,323	2,766,617	2,980,297	2,968,967	3,028,836	3,025,630
Rainy	ha	1,815,619	2,093,564	2,188,726	2,222,596	2,252,733	2,290,552	2,372,519	2,294,784	2,484,832	2,485,521	2,537,976	2,536,175
Dry	ha	293,431	320,891	327,689	344,356	360,630	384,051	404,804	471,833	495,465	483,446	490,860	489,455
Yield	tons/ha	1.977	2.479	2.489	2.621	2.746	2.836	2.97	3.173	3.117	3.163	3.079	3.085
Rainy	tons	1.725	2.261	2.272	2.413	2.54	2.62	2.76	2.92	2.872	2.925	2.815	2.827
Dry	tons	3.536	3.901	3.938	3.959	4.03	4.126	4.201	4.406	4.349	4.383	4.443	4.422
Total rice output (tons)	tons	4,170,284	5,986,179	6,264,123	6,727,127	7,175,473	7,585,870	8,249,452	8,779,365	9,290,940	9,389,961	9,324,416	9,335,284
Rainy	tons	3,132,581	4,734,300	4,973,694	5,363,690	5,722,142	6,001,385	6,548,709	6,700,439	7,136,139	7,271,251	7,143,521	7,170,684
Dry	tons	1,037,703	1,251,879	1,290,429	1,363,437	1,453,331	1,584,485	1,700,743	2,078,926	2,154,801	2,118,710	2,180,896	2,164,600
Consumption	tons	1,905,896	2,013,533	2,053,983	2,096,025	1,970,270	1,979,214	2,076,542	2,108,022	2,142,178	2,137,878	2,178,050	2,222,078
Surplus (rice)	tons	416,118	1,319,571	1,433,880	1,649,640	2,025,033	2,244,598	2,516,752	2,780,328	3,031,017	3,090,452	3,013,783	2,975,809
Surplus (paddy)	tons	650,184	2,061,830	2,240,438	2,577,562	3,164,114	3,507,185	3,932,425	4,344,263	4,735,964	4,828,832	4,709,036	4,649,702

Source: Ministry of Agriculture, Forestry and Fisheries, 2015

The slowdown in rice production resulted from the decrease in yield and slow growth in rice cultivated areas (Table 6.4). Over the 2004–2015 period, the average annual growth of yield per hectare was 4.1% and 3.3% for cultivated areas. However, when we look at the shorter 2010–2015 period, the average annual growth of yield per hectare was -0.7% and 2.2% for cultivated areas. Productivity or yield decrease is influenced by two main factors, mechanization and the concentration of the land in the hands of the better farmers. When many farmers migrated to work in urban areas or in other countries, wages in rural areas started to increase, and farmers started to use tractors or harvesting machines to replace farm workers. Some migrant farmers also sold their land to better farmers or if they did not sell, they spent less time taking care of their crops. Greater concentration of the cultivated areas leads to an increase in hired labor in rice cultivation. However, hired labor suffers from problems of adverse selection and moral hazard, problems that do not affect family labor, where members are residual claimants on the fruits of their work efforts (De Janvry and Sadoulet 2016). Now, mechanization has been implemented at almost all stages of the rice cultivation process from ploughing land to harvesting rice. Although mechanization varies across provinces, about 76% of rice fields are ploughed by tractors. Figure 6.7 seems to show a negative relationship between rice yield per hectare and the percentage of land ploughed by tractors. Using a tractor can be less productive than using traditional methods because the land quality resulting from ploughing by tractor is worse.

Table 6.4. Decomposition of Rice Production Growth

	2004–2015	**2004–2010**	**2010–2015**
Average annual yield growth	4.13	7.02	(0.70)
Average harvested area growth	3.34	4.69	2.26
Total rice output growth	7.60	12.04	1.55

Source: Ministry of Agriculture, Forestry and Fisheries, 2015 and Author's calculation

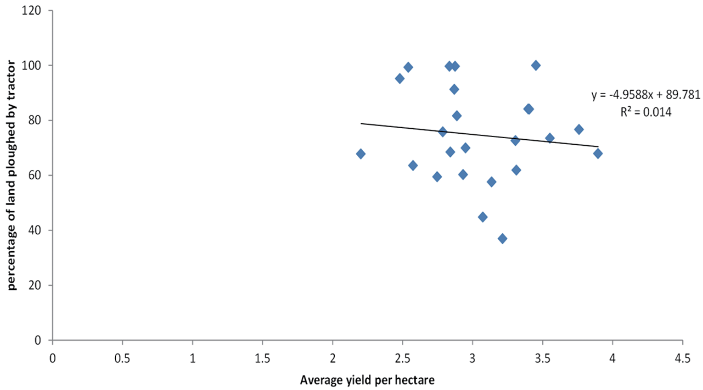

Figure 6.7. Mechanization and Yield
Source: Ministry of Agriculture, Fisheries and Forestry, 2015

The recent decline in rice prices in international markets caused some rice millers which were springing up across many provinces after the adoption of rice policy by the government in 2010 to go bankrupt. Rice millers have a facility to store rice in their warehouses. Some rice millers borrow funds to buy paddy for storage. The government provided subsidies in the form of a lower interest rate than the market rate to rice millers. The Rural Development Bank, with support from government subsidies provided loans at lower interest rates to millers. However, many millers still cannot get this low-interest loan as it is so limited, so the rationing mechanism of the loan was through connection or relationship with the lenders. Many rice millers complained about high interest rates on loans from banks or microfinance institutions. For a large loan, a bank charged an interest rate of about 10%.

The huge migration from rural to urban areas and to other countries such as Thailand, Korea, and Malaysia may cause a severe labor shortage in the agricultural sector. The main reason for migration is to find work (Figure 6.8). The garment, construction, and tourism sectors in urban areas which are mainly supported by foreign direct investment, help release surplus labor from the agricultural sector. Wages in investor host countries such as China, Hong Kong, and Korea are higher, and investors in those countries avoided high labor costs by exporting their capital to countries where there is still abundant labor at a subsistence wage. The garment sector, which is the main industry sector, has absorbed mostly female workers from rural areas. The number of garment factories has grown from 20 in 1995 to 742 in May 2014. Moreover, the total employment in the industry (textile, non-textile, and footwear) increased from 18,700 in 1995 to 681,182 workers in May 2014. The total monthly wage payment for all garment workers reached US$93,707,224.90 for May 2014. On average, a worker received US$137.5 /month in May 2014.

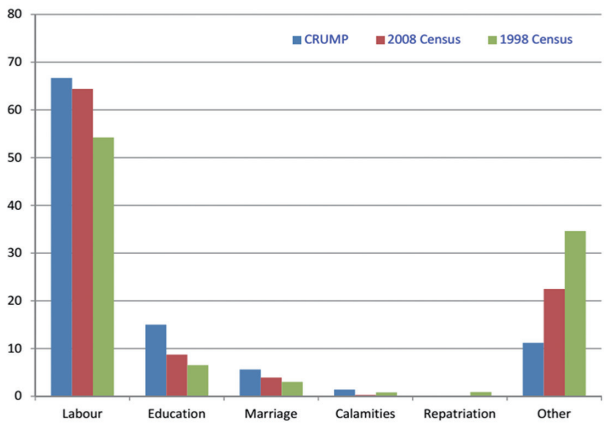

Figure 6.8. The Causes of Migration
Source: Ministry of Planning, 2012

The wage rate in the garment sector remains relatively low, but it continues to increase in nominal and real terms. The garment workers were successful in demanding better working conditions and a higher minimum wage, which was previously believed to be too low and even below the subsistence level, through tripartite negotiation of a body consisting of representatives from the Ministry of Labor, employer associations, and trade unions. The basic minimum wage increased from US$40 in 1997 to US$140 in 2016 (Figure 6.9). Considering an average meal in the capital of Phnom Penh, which costs US$3, the total payment for 90 meals in one month should be US$270. In addition to the monopsony power of labor unions, the increase in wages in the garment sector can be attributed to the increase in migration to foreign countries, which leads to a speedy shortage of surplus labor with zero marginal product of labor in the agricultural sector. Lewis (1954) argued under the assumption that the subsistence sector consists of peasants producing food, while the capitalist sector produces everything else, industrialization is dependent upon agricultural improvement; it is not profitable to produce a growing volume of manufactures unless agricultural production grows simultaneously. Because the expansion of the industrial sector (capitalists) increases the demand for food, raises the price of food in terms of capitalist products, and so reduces profits and capital accumulation. The increase in price of rice can be good for net rice sellers who are farmers, but it cannot be good for industry development.

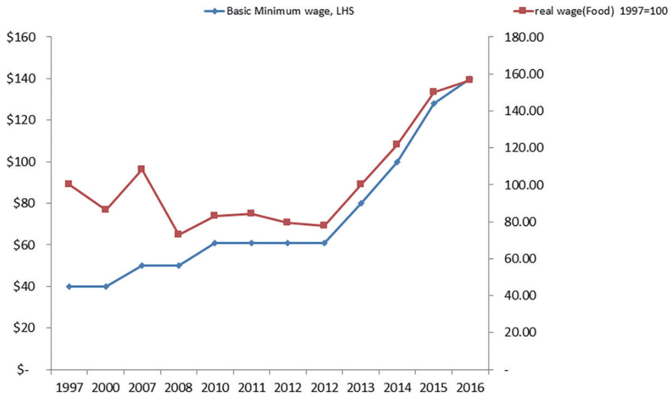

Figure 6.9. Real Wage and Nominal Wage in Garment Sector
Source: International Labor Organization (ILO), 2016 and Author's calculation

Rice yield per hectare in Cambodia is low compared to other countries and varies across provinces and seasons and with farm size. The average yield in Takeo province was 3.9 tons per hectare compared to 2.2 tons in Ratanak Kiri province. The average yield in the dry season was 4.4 tons per hectare, while it was 2.8 tons per hectare for the rainy season in 2015. Cross-provincial data from 24 provinces in Cambodia also suggests a negative correlation between farm size and yield per hectare (Figure 6.10). Figure 6.10 shows a negative relationship between average farm size and average yield in each province without controlling the difference in land quality. The land quality among those provinces cannot be the same because some farms are located near lakes with water, and some are in highland areas. Rice yield per hectare across provinces is shown in Figure 6.11. If there is an inverse relationship between farm size and land productivity, the land reform is a win-win scenario, and can be Pareto optimal after compensation, as small farmers could compensate large farmers for their losses and keep for themselves the productivity gains achieved (Lipton 2009).

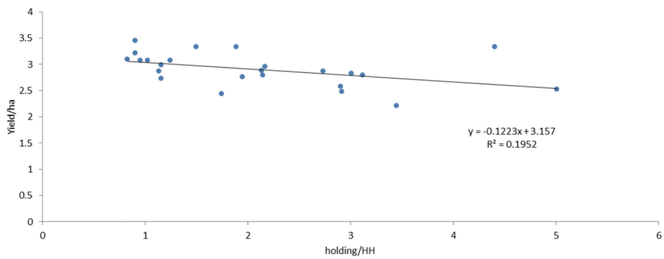

Figure 6.10. Farm Size and Yield (cross provincial data)
Source: Ministry of Agriculture, Fisheries and Forestry, 2015

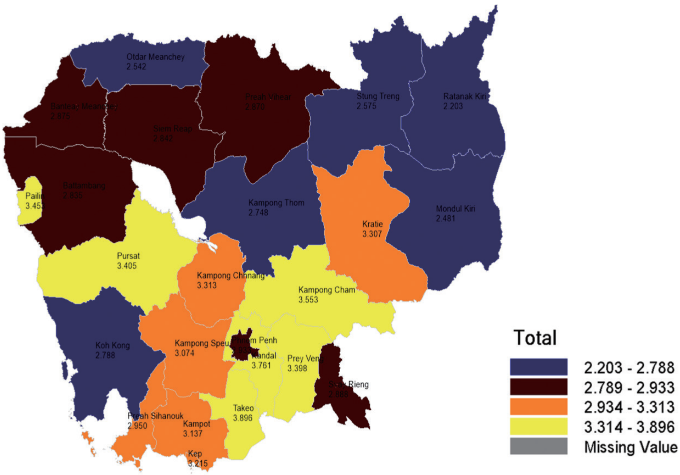

Figure 6.11. Rainy Season Rice Yield across Provinces 2014
Source: National Institute of Statistics, Cambodia, 2015b

While some farmers have successfully switched to high-yield varieties and high-valued-added varieties, many farmers are reluctant to use new varieties even though those varieties can provide higher gross margins. Traditional farmers use varieties that have been used for generations, as those varieties are already suited to their soil and the natural water level in their fields. The high-yielding varieties have higher expected yield but also higher exposure to climatic risk. In Cambodia, farmers do not make much use of irrigation systems to adjust water for growing rice, as irrigation systems are very limited. Rice grows largely depending on rainfall. According to the Census of Agriculture in Cambodia 2013, around 32% of the country's agricultural holdings used irrigation in growing their crops. So, farmers do not want to use new varieties that are risky in terms of being too fast or too late to get a yield.

Compared to some African countries, farm size in Cambodia is small; it was about 1.64 hectares per agricultural household in the first agricultural census in 2013, but this is higher than some countries in Asia, such as China, Vietnam, Korea, and Japan. The number of Cambodian normal households is about 3.3 million, with 15.2 million people living in Cambodia as of 2014. Of the 1.87 million agricultural households with separate agricultural land with a total land of 3,267,302 hectares, around 47% had plots of land measuring less than 1 hectare in size. A further 45% comprised agricultural land measuring between 1 and 3.99 hectares. Thus, 90% of Cambodian household agricultural holdings with separate land conducted their agricultural activity on less than 4 hectares of land. A very small number (1.21%) of household agricultural holdings reported separate agricultural land of 10 hectares or more.

There have been opposing views on the economic effects of large farms and small farms. At the beginning of industrialization, large farms were viewed as a good way to advance it, but as countries became more industrialized, small farms were regarded as beautiful. In the 1960s small farms were regarded as being efficient because they could fully use their resources, particularly family labor, and they could monitor their production activities more closely (Fan and Chan-Kang 2005). In the 1970s and 1980s, however, as many Asian countries moved rapidly toward industrialization and urbanization, small farms were regarded as a major obstacle in this process. In the 1990s, however, "the small is beautiful" view was once again revived. Large farms and input-intensive practices (i.e., fertilizer, pesticides, and machinery) have led to the degradation of natural resources and the environment. When these externalities are considered, large farms may no longer be viewed as efficient.

Land concentration seems to increase when a country becomes more industrialized. The farm size in Japan and Korea became larger when those countries grew more industrialized, as more and more people moved to urban areas (Table 6.5). Land concentration in Cambodia has also been observed recently as some farmers sold their land and migrated to urban areas or other countries because they were heavily in debt and the return from farming was too low. However, the key to social welfare is the pace at which land concentration may occur relative to the labor-absorption capacity of the non-agriculture sectors. If the land concentration is too rapid, displaced farm labor will accumulate in urban slums; if it is too slow, rural poverty will be reproduced, and rural-urban income disparity will grow. Securing the competitiveness of the family farm without excessively rapid land concentration in relation to employment creation in the non-farm economy is thus a necessity for both efficiency and rural welfare (World Bank 2007).

Table 6.5. Farm Size in Selected Countries

Country	**Smaller farm**	**Other farms**	**Nationally**
Niger, 2011	2.63	9.38	4.13

Ethiopia, 2012	1.01	4.18	1.82
Bolivia, 2005	0.89	15.97	1.5
Tanzania,2009	0.9	4.1	1.5
Uguanda,2012	0.7	2.39	1.12
Nepal,2003	0.55	2.63	0.94
Kenya, 2005	0.47	2	0.86
Malawi, 2011	0.46	1.48	0.72
Vietnam, 2002	0.32	2	0.65
Bangladesh,2005	0.24	1.1	0.41
China,* 1999			0.4
Korea,* 1999			1.37
Japan,* 1999			1.5
Cambodia, 2013			1.64

Sources: National Institute of Statistics, 2015a and * from Fan and Chan-Kang, 2005

The rural-urban income disparity has been narrowed down recently. The total income of households in Phnom Penh was about 3.6 times more than the total income of rural households in 2009. This figure shrank to 2.5 in 2014 (Figure 6.12). The main driving force of this convergence in income was a surge in rural wage income which increased about 25% annually over the 2009–2014 period (Table 6.6).

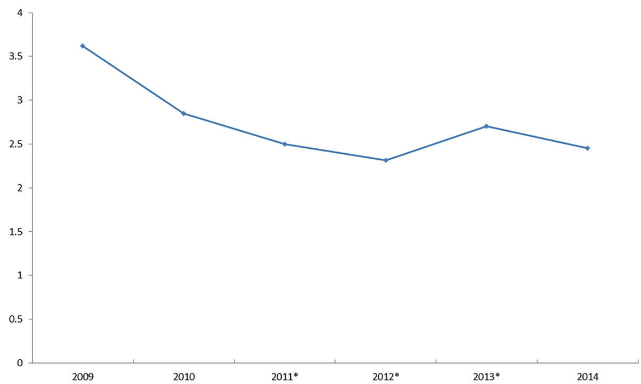

Figure 6.12. Urban-Rural Income Gap
Source: National Institute of Statistics, 2015b

Table 6.6. Household Income Composition in Urban Areas and Rural Areas

Source of income (Value in thousand Riels)	2009	2010	2011	2012	2013	2014	average growth
Phnom Penh							
Primary income	1,986	1,940	1,770	1,847	2,478	2,806	7.2%
Wage and Salary	765	910	991	930	1,135	1,385	12.6%
Self-employment Income	1,203	1,023	769	909	1,326	1,399	3.1%
Agriculture	22	20	8	22	11	27	4.2%
Non-Agriculture	878	650	423	560	935	957	1.7%
Owner occupied house	304	354	338	327	381	415	6.4%
Property income	17	7	10	8	17	22	5.3%
Total transfers received	54	47	50	40	38	50	-1.5%
Total Income	2,039	1,987	1,819	1,886	2,517	2,856	7.0%
Total transfers paid	24	44	26	17	19	20	-3.6%
Disposable Income	2,016	1,944	1,793	1,870	2,498	2,836	7.1%
Rural							
Primary income	550	679	707	784	878	1,101	14.9%
Wage and Salary	167	202	241	309	403	518	25.4%
Self-employment Income	382	476	465	474	474	580	8.7%
Agriculture	189	237	253	276	237	280	8.2%
Non-Agriculture	152	190	162	143	178	235	9.1%
Owner occupied house	41	49	50	55	59	65	9.7%
Property income	2	1	1	1	1	3	8.4%
Total transfers received	13	18	21	32	53	62	36.7%
Total Income	563	697	728	816	931	1,163	15.6%
Total transfers paid	10	21	16	3	3	8	-4.4%
Disposable Income	554	676	713	813	928	1,155	15.8%
Income gap (Phnom Penh/Rural)	3.64	2.87	2.52	2.30	2.69	2.46	

Source: National Institute of Statistics, 2015b

Despite a sharp increase in salaries and wages in rural areas, the agricultural income of households remained stable (Figure 6.13). The wage income in Phnom Penh increased only 12.5% per year over the same period. The gap in household wage income between Phnom Penh and rural areas decreased to 2.7 in 2014 (Figure 6.14). In addition, according to a study by the World Bank in Cambodia, for 1 hectare under cultivation, farmers had a gross margin of US$296 for dry season rice, and US$245 for wet season rice (Eliste and Zorya 2015). The gross margin here is defined as gross revenue less intermediate inputs and hired labor. This phenomenon suggests that the labor in rural areas has become scarce, and to attract more labor to work in the industry sector, wages must be increased to a level higher than the subsistence level. The "Lewis turning point" takes place and the labor supply curve becomes positively sloped as modern-sector wages and employment continue to grow.

Figure 6.13. Household Agriculture Income and Salary Income in Rural Areas
Source: National Institute of Statistics, 2015b

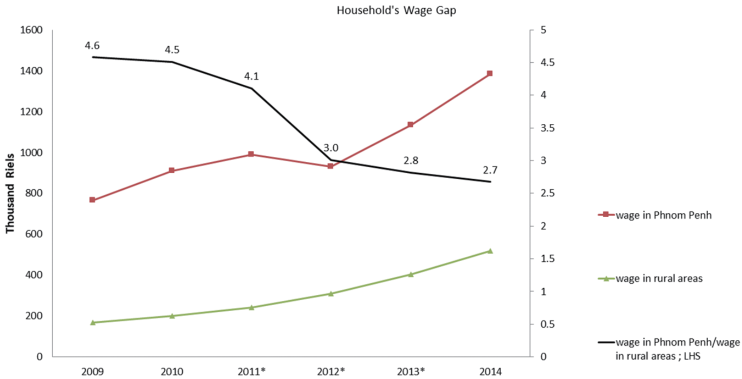

Figure 6.14. Rural-Urban Wage Gap Shrank
Source: National Institute of Statistics, 2015b

3. Policy Implications

At the early stages of development, agricultural growth is the main engine of poverty reduction because most of the poor are in rural areas. Supplying food at reasonable prices to the industrial sector makes industrialization possible, and the growth also helps agriculture itself to continue to prosper. However, after 2012, the Cambodian agricultural sector, including rice production, became stagnant. This can be a concern for industrialization and poverty reduction in the country, and in the worst case it may drag poor people who live just above poverty line down into poverty. The following are policy recommendations to overcome this problem:

- Improving rice yield to increase the income of agricultural households while maintaining rice price stability to stabilize development of the non-agriculture sector. Since there is market failure due to positive externalities in developing high-yielding varieties, the public sector should work more on developing new rice varieties that meet the demand of international markets.

- Maintaining a private sector-friendly agricultural policy environment, with added attention to lowering the regulatory burden in farm input sectors to lower the cost of production. The private sector should be encouraged to participate in providing high-yielding seeds and fertilizers on a competitive basis.
- Continuing to develop the agribusiness and agro-processing industry to curb the export of unprocessed rice and to maintain reasonable prices for farmers through the development of storage facilities.
- Providing a mechanism for farmers to take the risk of using new high-yielding varieties by providing clear guidance about growing techniques, timing of receiving yields, etc.
- Providing clearer information about job markets available outside farming in the industrial sector, so that labor cannot be thrown into slum areas in urban areas or become unemployed for a long time in rural areas. The speed of land concentration can be well adjusted.
- Promoting trade in agricultural products, in particular, rice, with other trading partners.
- Improving irrigation and transportation systems to reduce transportation costs.
- Promoting land-saving technological innovation favoring smallholder farming. Because many farmers have little land, smallholder farmers need access to land-saving technological change. This includes farming systems for high-value crops and agro-ecological production techniques, with low use of purchased inputs if they have liquidity constraints.

- Encouraging farmers to acquire financial literacy to understand more about the costs and benefits of borrowing to avoid an over-indebted situation. Some farmers are forced to sell their land to pay their debts because the funds they borrowed were not well utilized in productive agriculture.
- Providing more short-course vocational training at the farm level to farmers about job markets in the industrial sector or in foreign countries, so that they could be ready to work without being unemployed while searching for a job in urban areas. Most Cambodian farmers, as well as employed workers, do not have a high level of education, as they do not finish primary school. About 65% of rural employed workers had an education below the primary school level in 2012 (Table 6.7).

Table 6.7. Education Level of Employed People

Unit: person	**Cambodia**	**Urban**	**Rural**
Total	7,197,416	1,783,646	5,413,770
In percentage (%)			
None	12.5	5.8	14.7
Primary	44.9	31.8	49.2
Secondary	35.5	44.1	32.7
Vocational	3.3	6.9	2.2
University	3.8	11.4	1.2

Source: National Institute of Statistics, 2023

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Chapter 7
Benefits of Sustainable Rice Farming and Influential Factors on Rice Farmers' Choice: A Case Study in Long An Province, Vietnam

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Summary: Environmentally friendly agriculture is being explored as a potential method for carbon sequestration to combat climate change. It can also increase crop productivity and farmer income while meeting societal needs for healthy and safe food. This study attempts to investigate the benefits of environmentally friendly agriculture and its determinants among rice farmers in Long An Province, Vietnam. Data was collected from face-to-face interviews with 152 rice farmers in two districts of Long An Province. The results show that environmentally friendly agricultural practices slightly enhance rice productivity and transaction prices. Additionally, membership in farming associations can boost the adoption of environmentally friendly practices. Based on these findings, we propose policy recommendations to promote the activities of agricultural cooperatives effectively. Furthermore, we suggest implementing a 3G3R or 1M5R certification system and displaying the certification mark by agricultural cooperatives. This would help achieve the adherence to 3G3R or 1M5R, which are the main environmentally friendly farming methods in Vietnam.

1. Introduction

Vietnam has demonstrated remarkable economic growth, securing the second-highest growth rate among ASEAN nations. The agricultural sector plays a particularly significant role in Vietnam's economy, contributing 11.9% to the country's GDP — a notably higher share compared to developed nations like Japan, where agriculture accounts for only 1.1% of GDP. Agriculture remains a vital part of Vietnam's economic development and social stability. Vietnam is one of the world's leading farming countries, with rich soil that helps grow many different types of crops including rice, sugarcane, cassava, and many others. According to the U.S. Department of Agriculture (USDA) (2025) and Statista (2025), Vietnam ranks as the world's fifth-largest rice producer and third-largest rice exporter. The country's agricultural sector demonstrates remarkable efficiency, achieving exceptional yields relative to its available farmland — highlighting agriculture's vital role in the nation's economy and food security. Figure 7.1 shows the trends of Vietnamese rice production, consumption, and exports in the period 1960–2023.

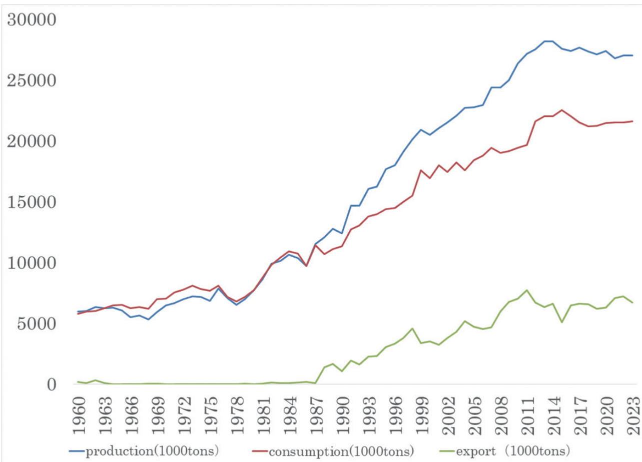

Figure 7.1. Vietnamese Rice Production, Consumption, and Exports
Source: FAOSTAT, 2024

Despite this agricultural success, Vietnam faces a significant challenge: while excelling in rice exports, the country has limited adoption of environmentally friendly farming practices. The Vietnamese government has responded by introducing two key initiatives: the "One Must Do Five Reductions" (1M5R) and "Three Gains Three Reductions" (3G3R) programs. The 3G3R program specifically targets three areas: optimizing seed density, decreasing chemical fertilizer usage, and minimizing pesticide application (Huelgas et al. 2008). The 1M5R initiative is an extension of 3G3R, providing a framework focusing on controlled seed density, reduced chemical fertilizer usage, minimal pesticide application, reducing post-harvest losses, and saving water resources.

These government initiatives, however, have faced obstacles in gaining widespread adoption. The concept of sustainable agriculture is relatively easy to understand but difficult to define and apply in practice. Current statistics paint a concerning picture: only 63,536 hectares — just 0.5% of total agricultural land — have implemented environmentally friendly farming practices, with only 17,174 farmers adopting these sustainable methods. Farmers hesitate to embrace these practices without government certification systems and subsidies to demonstrate concrete benefits. While agricultural cooperatives could spread knowledge and best practices, farmer participation in these groups remains low. This study therefore aims to understand the benefits of sustainable rice farming for productivity and the factors influencing farmers' choices regarding sustainable rice farming in the Mekong Delta, particularly in Long An province.

2. Data Collection and Methodology

(1) Study Site and Data Collection

The research was conducted in Long An Province, in the Mekong Delta region of southern Vietnam. This area holds particular significance as Vietnam's third-largest rice-producing region, according to recent government statistics (GSO 2022). To gather data, we employed a field survey methodology, conducting detailed face-to-face interviews with local farmers during November 2022.

The study focused on two strategically selected districts — Duc Hue and Tan Hung — to ensure representation of different agricultural conditions within the province. Initially, the research team interviewed 163 farmers across these districts. Following a thorough data validation process to ensure response quality and completeness, the final analysis incorporated data from 152 farmers, representing a robust 93% retention rate of the original sample.

Figure 7.2. Face-to-face Interviews with Local Farmers in Long An Province in November 2022
Source: Author's survey

(2) Methodology

First, the Cobb-Douglas production function is used to determine important inputs and the role of SAPs on rice productivity. The formula is:

$$Y = \beta_0 Seed^{\beta_1} Chem^{\beta_2} Pest\_cost^{\beta_3} Irri^{\beta_4} Labor\_cost^{\beta_5} SAPs^{\beta_6} \varepsilon$$

Or,

$$lnY = \beta_0 + \beta_1 lnSeed + \beta_2 lnChem + \beta_3 lnPest_{cost} + \beta_4 lnIrri$$
$$+\beta_5 lnLabor\_cost + \beta_6 lnSAPs + \varepsilon$$

Where, Y: Rice productivity (kg/ha), Seed: Amount of seed used (kg/ha), Chemical: Amount of chemical fertilizer (kg/ha), Pesticides cost: Total chemical pesticides and insecticides cost (VND/ha), Irrigation cost: Total irrigation cost (VND/ha), Labor cost: Total hired labor cost (VND/ha), SAPs: Adoption of sustainable rice farming (Dummy variable, 1 = adoption of sustainable rice farming, 0 = otherwise).

Then, a logit regression model is used to determine the influencing factors on the farmers' choice of SAPs

$$Y = \frac{1}{1+e^{-(\alpha_0+\alpha_i X_i)}}$$

Where, Y: Adoption of sustainable rice farming, X_1: Education (years), X_2: Knowledge 1 (1-Strongly disagree to 5-Strongly agree to the statement "Environmental pollution can be caused by agrochemicals"), X_3: Knowledge 2 (1-Strongly disagree to 5-Strongly agree to the statement "Sustainable agriculture prevents air and water pollution and the destruction of nature"), X_4: Knowledge 3 (1-Strongly disagree to 5-Strongly agree to the statement "Sustainable agriculture reduces carbon emission from crop production"), X_5: Knowledge 4 (1-Strongly disagree to 5-Strongly agree to the statement "The healthier the soil, the more rice productivity"), X_6: Knowledge 5 (1-Strongly disagree to 5-Strongly agree to the statement "Chemical residues on rice pose a significant health threat to the consumer."), X_7: Farming experience (years), X_8: Participation in social group (Dummy variable, 1 = farmer participates in social group, 0 = otherwise), X_9: Geographical location (Dummy variable, 1 = locate near Ho Chi Minh City, 0 = otherwise),

X_{10}: Distance from farm to the nearest water sources (meter), X_{11}: Number of household member (people), X_{12}: Income from off-farm activity (Dummy variable, 1 = Yes, 0 = No), X_{13}: Small-scale farming (Dummy variable, 1 = Small scale, 0 = Otherwise), X_{14}: Medium-scale farming (Dummy variable, 1 = Medium scale, 0 = Otherwise).

3. Results and Discussion

In rice farming in Long An Province of Vietnam, chemical fertilizer costs comprise a substantial 40% of total rice production expenses, while hired labor represents another significant 30% of the total costs, making these two factors the predominant economic considerations in rice cultivation. By implementing sustainable rice farming practices such as 3G3R or 1M5R, farmers can achieve notable reductions in various input costs (Table 7.1). These practices specifically target and minimize expenditures related to seeds and seedlings, chemical fertilizers, and agricultural chemicals when compared to conventional farming methods. The adoption of sustainable rice farming practices presents promising potential for enhanced economic returns, as the reduction in input costs combined with maintained yield levels can result in improved overall profitability compared to traditional conventional farming approaches.

Table 7.1. Cost and Benefit of Rice Farmers in Long An Province

Item	SAPs (n=104)	Conventional rice (n=48)	Difference test (t_test)
Average yield (kg/ha)	7,058.31	6,870.78	-0.951
Selling price (VND/kg)***	5,938	5,566	-4.047***
Total income (VND/ha)	**41,915,529**	**38,240,157**	
Seeds and seedlings cost (VND/ha)*	1,796,169	1,975,770	1.735*

Fertilizer cost (VND/ha)*	6,000,361	6,543,130	1.950*
Agricultural chemical cost (VND/ha)*	1,133,453	1,353,985	1.799*
Irrigation cost (VND/ha)	843,952	1,030,693	1.455
Hired labor cost (VND/ha)	4,990,232	5,624,678	1.333
Total cost (VND/ha)	**14,764,167**	**16,528,256**	
Profitability (VND/ha)	**27,151,363**	**21,711,901**	

Note: *** p<0.01, ** p<0.05, * p <0.1. Source: Author's calculations

Analysis using the Cobb-Douglas production function reveals significant relationships between agricultural inputs and rice productivity (Table 7.2). Specifically, the research demonstrates that increasing the seed rate leads to enhanced rice productivity through improved plant density and resource utilization. Conversely, higher irrigation costs were found to negatively impact rice productivity, likely due to increased operational expenses and potential water management inefficiencies. Furthermore, the study highlights the advantages of sustainable farming practices, showing that farms implementing sustainable rice cultivation methods achieved approximately 5% higher productivity levels when compared to those using conventional farming techniques. This improvement in productivity under sustainable practices suggests the potential long-term benefits of environmentally conscious farming methods.

Table 7.2. Important Inputs in Rice Productivity in Vietnam

Variables	**Coefficient**	**S.E.**	**P_value**
lnSeed	0.129**	0.064	0.046
lnChemical	-0.038	0.029	0.206
lnPesticide cost	-0.0217	0.022	0.329
lnIrrigation cost	-0.044**	0.017	0.015
lnLabor cost	-0.004	0.029	0.902

SAPs	0.056*	0.032	0.087
Constant	9.356***	0.617	0.000
R-squared	0.100		
Prob > F	0.030		
Number of observations	137		

Note: *** p<0.01, ** p<0.05, * p <0.1. Source: Author's calculations

The findings from Table 7.3 indicate that consumer awareness regarding the health implications of chemical residues from conventional rice production methods can serve as a powerful motivator in their decision to support and choose sustainably farmed rice. This awareness creates a ripple effect that encourages farmers to adopt more sustainable farming practices. The study also reveals that active participation in community organizations, particularly farmer associations, plays a crucial role in influencing agricultural decisions and promoting sustainable farming methods. Furthermore, the research demonstrates that farmers in rural areas show a higher propensity for implementing sustainable rice farming practices, possibly due to stronger community ties and greater awareness of traditional farming methods. These rural farmers often have deeper connections to their land and more direct exposure to the environmental impacts of different farming approaches.

Table 7.3. Influencing Factors on Farmers' Choice of Sustainable Rice Farming

Variables	**Coefficient**	**S.E.**	**P_value**
Education	0.036	0.079	0.651
Knowledge1	0.010	0.296	0.974
Knowledge2	-0.043	0.332	0.896
Knowledge3	-0.206	0.291	0.479
Knowledge4	0.017	0.483	0.972

Knowledge5	0.716**	0.294	0.015
Social group	1.869***	0.628	0.003
Location	-2.509***	0.619	0.000
Irrigation distance	-0.001	0.001	0.406
Farming experience	-0.003	0.019	0.870
Household size	-0.065	0.136	0.632
Off_farm income	-0.130	0.544	0.811
Small-scale farming	0.341	0.646	0.598
Medium-scale farming	-0.144	0.635	0.821
Constant	-0.396	2.598	0.879

Note: *** p<0.01, ** p<0.05, * p <0.1. Source: Author's calculations

4. Conclusions and Policy Implication

Seed rate and irrigation costs are critical factors that significantly influence rice productivity in agricultural systems. The implementation of sustainable rice farming practices has been shown to substantially reduce various input costs, including not only seeds and irrigation requirements, but also the expensive chemical fertilizers that traditional farming methods heavily rely upon. This innovative approach has demonstrated remarkable results, generating higher profits for farmers while simultaneously improving overall productivity by approximately 5% when compared to conventional farming methods.

Multiple factors shape farmers' decisions to adopt sustainable rice farming practices, including their existing agricultural knowledge base, their level of engagement in social groups and community networks, and their specific geographical location, which affects the local growing conditions. To facilitate and support this important transition towards more sustainable practices, it is essential to strengthen rural organizations such as agricultural cooperatives, farmer groups, and women's unions that serve as vital knowledge-sharing networks. This strategic enhancement of social capital within farming communities will ultimately empower farmers to make more informed and effective decisions about their agricultural practices, leading to improved outcomes for both individual farmers and the broader agricultural system.

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Chapter 8
Ca^{2+-} Sensitive and Non-selective Na^{+}/K^{+} Channel Activity of a Barley Aquaporin HvPIP2;8 under Saline Conditions

Thi Huong Sen TRAN

Summary: HvPIP2;8 transcript abundance increased in barley shoot tissues following salt treatments in a salt-tolerant cultivar, Haruna-Nijo, but not in salt-sensitive I743. Here we report that one of the 12 barley PIPs (PIP1 and PIP2) tested, HvPIP2;8, facilitated cation transport when expressed in Xenopus laevis oocytes. HvPIP2;8-associated ion currents were detected with Na^{+} and K^{+}, but not Cs^{+}, Rb^{+}, or Li^{+}, and were inhibited by Ba^{2+}, Ca^{2+}, Cd^{2+} and, to a lesser extent, Mg^{2+}, which also interacted with Ca^{2+}. Currents were reduced in the presence of K^{+}, Cs^{+}, Rb+, or Li^{+} relative to Na^{+} alone. Co-expression of HvPIP2;8 with HvPIP1s, barley aquaporins in the PIP1 subfamily, significantly abolished the ions permeability of HvPIP2;8, but not water permeability. There is potential for HvPIP2;8 to be involved in barley salt-stress responses, and HvPIP2;8 could facilitate both water and Na^{+}/K^{+} transport activity, depending on the phosphorylation status. Future research will uncover the molecular and structural mechanisms that control the dual permeability of aquaporins for ion and water, and more testing of the physiological role of HvPIP2;8 in planta.

1. Introduction

Salt stress encompasses two primary components that affect plant physiology and growth: ionic stress, which results from the accumulation of toxic ions within plant tissues, and osmotic stress, which is caused by the reduction in water potential in the soil solution that limits water uptake by plant roots (Figure 8.1).

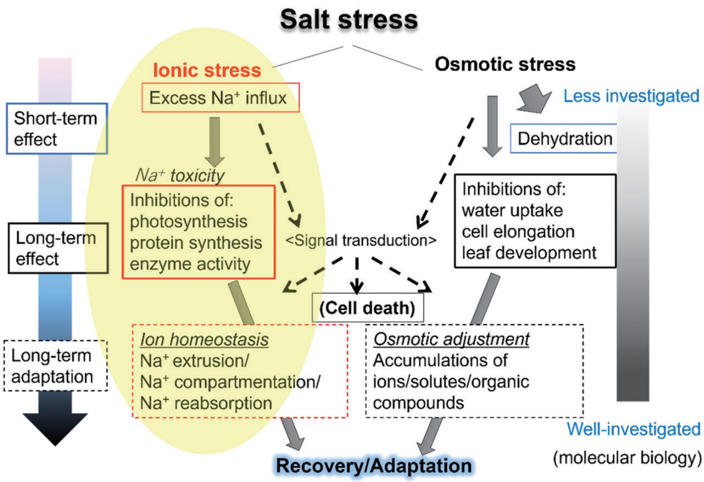

Figure 8.1. Mechanism of Salt Stress
Source: (Horie et al. 2012)

Plant aquaporins are specialized membrane proteins that function primarily as channels responsible for the transportation of water molecules and various neutral solutes across cellular membranes. These integral membrane proteins play a crucial role in maintaining cellular water homeostasis and facilitating the movement of specific molecules. In recent scientific investigations, researchers have discovered that certain aquaporins possess dual functionality, exhibiting the capability to transport both water and ions simultaneously. This remarkable dual permeability has significant implications for understanding plant physiology and cellular transport mechanisms. Despite these advancements in knowledge, there remains a substantial gap in our understanding regarding the precise mechanisms by which plasma membrane intrinsic proteins (PIPs), a subfamily of aquaporins (Katsuhara and Shibasaka 2007), facilitate ion influxes across the plasma membrane in various plant species. This area of research requires further investigation to fully elucidate the functional diversity and physiological significance of these transport proteins in different plant contexts.

Salinity (NaCl) affects PIP2 aquaporin expression in a time- and isoform-dependent manner. This regulation is noteworthy as studies show that the abundant AtPIP2;1 protein relocates from the plasma membrane to an internal position in *Arabidopsis* roots under saline conditions, potentially explaining reduced root hydraulic conductance (Katsuhara et al. 2003; McGaughey et al. 2018).

Barley (*Hordeum vulgare*) is an important grain crop worldwide and is relatively salt-tolerant compared to other crops (Ismail et al. 2017).

Therefore, this research aims to identify ion-conducting PIP aquaporins in barley and clarify the mechanisms of ion transport activity by PIP aquaporins (HvPIP2;8) and their regulation under salinity stress in barley.

2. Materials and Methods

This research used electrophysiological measurement techniques to investigate membrane transport phenomena at the cellular level. These sophisticated methodologies allowed for precise quantification of ion fluxes (i.e., two electrode voltage clamp) across plant cell membranes under controlled experimental conditions (Figure 8.2). Then, the data were analyzed using SPSS statistics software (version 20). All data are means ± standard error (SE).

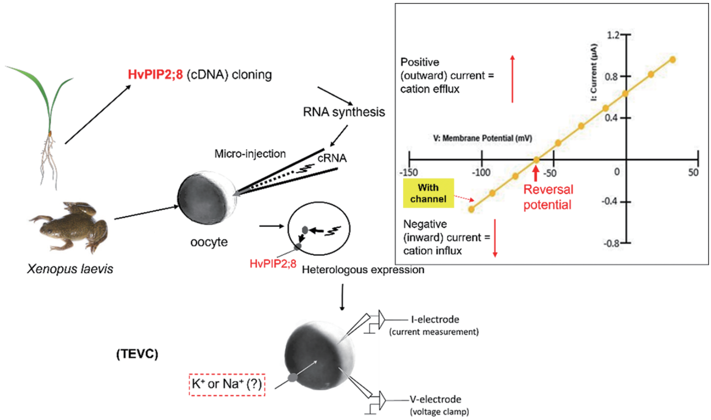

Figure 8.2. A Mechanism of Electrophysiological Measurement Techniques
Source: Author

3. Results

(1) Expression of HvPIP2;8 in Barley

The research found that only HvPIP2;8 could move ions in both directions across cell membranes under specific test conditions (Figures 8.3 and 8.4).

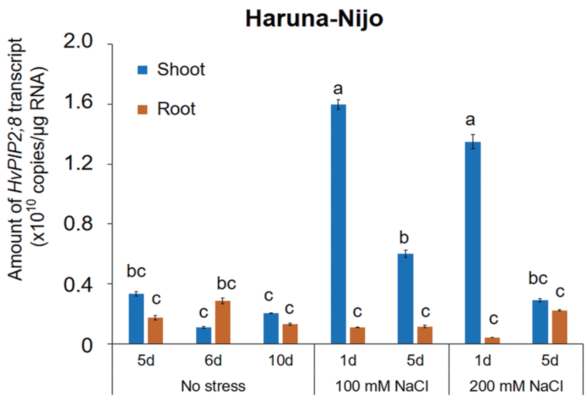

Figure 8.3. HvPIP2;8 Expression in Haruna-Nijo Barley
Note: d means day after exposed to salt. Source: Author

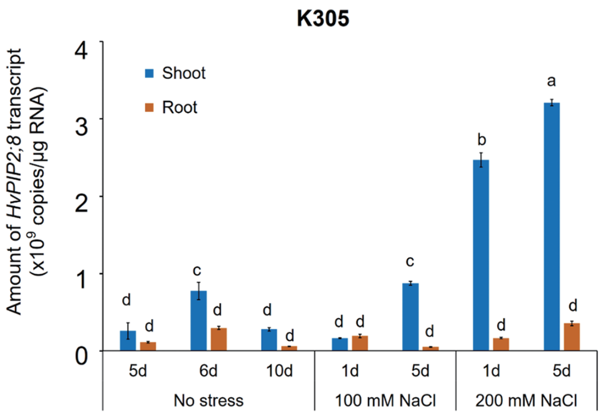

Figure 8.4. HvPIP2;8 Expression in K305 Barley
Note: d means day after exposed to salt. Source: Author

(2) HvPIP2;8 in Barley Can Transport Ions

The study found that only HvPIP2;8 could move ions in both directions across cell membranes under specific test conditions (Figure 8.5).

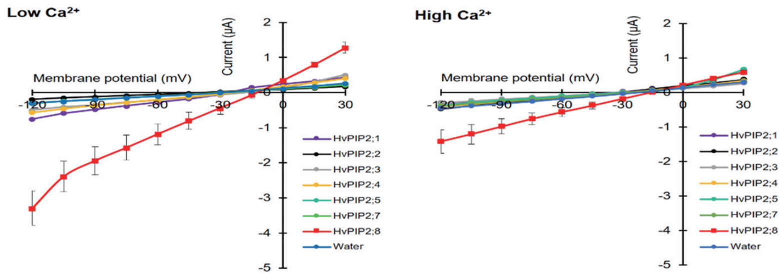

Figure 8.5. HvPIP Ion Transport Activity
Source: (Tran et al. 2020)

The ionic conductance was strongly inhibited in accordance with increases in the external free Ca^{2+} concentration (Figure 8.6). It reveals that its ionic conductance characteristics exhibit sophisticated patterns of differential sensitivity when exposed to various divalent cations in the external environment. Specifically, the presence of external calcium, cadmium, and barium ions results in pronounced inhibitory effects on the channel's conductance capabilities, whereas magnesium ions, despite their divalent nature, demonstrate a markedly reduced capacity to inhibit the channel's conductance properties.

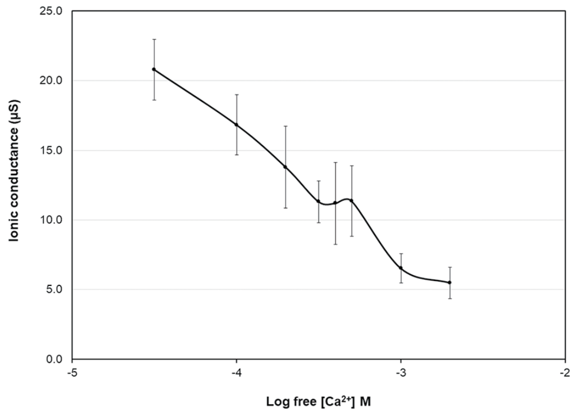

Figure 8.6. Relationships between the External Free Ca^{2+} Concentration and HvPIP2;8

Source: (Tran et al. 2020)

(3) Identification of HvPIP2;8 as a Na^+/K^+ Channel

HvPIP2;8 is a specialized protein channel in cell membranes that can transport both sodium (Na^+) and potassium (K^+) ions. When potassium ions are present in the environment, they block the channel's ability to transport sodium, but chloride ions don't have this blocking effect (Figure 8.7).

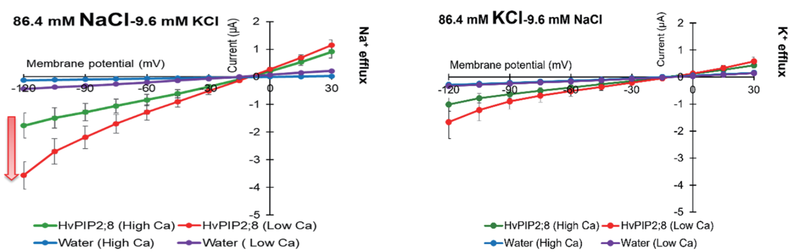

Figure 8.7. Identification of HvPIP2;8 as a Na^+/K^+ Channel

Source: Tran et al. 2020

(4) HvPIP2;8 Monovalent Alkaline Cation Selectivity

The investigation of HvPIP2;8's monovalent selectivity sequence has unveiled a particularly distinctive hierarchical pattern in ion permeability: the channel displays comparable levels of permeability for both sodium and potassium ions, with sodium showing marginally higher or equal permeability compared to potassium ($Na^+ \geq K^+$). Moving down the periodic table, rubidium ions demonstrate notably restricted permeability through the channel, while both cesium and lithium ions are completely excluded from passage through the HvPIP2;8 transport pathway.

The Na^+ permeability of HvPIP2;8 demonstrates a strong and significant dependence on the concentration of external K^+ ions, suggesting a complex interplay between these two ionic species in the transport mechanism. This relationship appears to be a key factor in determining the overall conductance properties of the protein channel.

(5) Co-expression of HvPIP2;8 with HvPIP1s

A particularly intriguing aspect of HvPIP2;8's behavior emerges during co-expression studies with HvPIP1s: this experimental scenario reveals a complex functional interaction whereby the HvPIP2;8-dependent ionic conductance undergoes substantial reduction, yet remarkably, the channel's capacity for water permeability remains completely unaltered by this co-expression arrangement, suggesting distinct regulatory mechanisms for ion and water transport pathways (Figure 8.8).

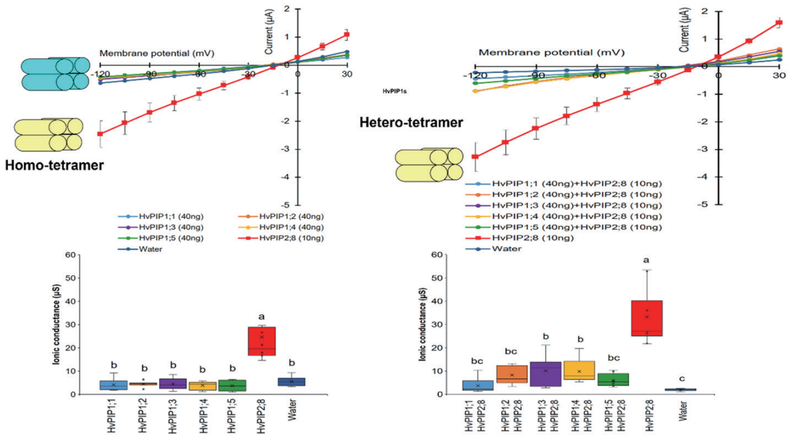

Figure 8.8. Co-expression of HvPIP2;8 with HvPIP1s Reduced HvPIP2;8 Ion Transport Activity

Source: Author

4. Conclusion

Our research on barley proteins shows that HvPIP2;8 can move specific ions (sodium and potassium) across cell membranes, but this ability depends on calcium levels outside the cell. When we combined HvPIP2;8 with related proteins (HvPIP1s), its ability to transport ions was significantly reduced. We also found that changes in protein phosphorylation suggest that HvPIP2;8 is controlled through a complex system involving both protein interactions and chemical modifications. These discoveries help us better understand how plants deal with salt stress. This research opens new paths for studying how these proteins can transport both ions and water, and for investigating the specific role of HvPIP2;8 in living barley plants.

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Chapter 9
The Effect of High Temperature on Vietnamese Rice Cultivars and Rice Cultivation Strategy to Cope with High Temperature

Loc Thuy TRAN

Summary: Vietnam is one of the most vulnerable countries to extreme weather caused by climate change, such as high temperature and flooding. High temperature is the major factor affecting the rice grain yield and quality, especially during the flowering stage. In our experimental field, the grain yield of Vietnamese rice cultivars fell to 81.5% and 79.4% of normal when the highest daytime temperature remained above 36°C. The variable with the greatest impact on grain yield was spikelet sterility induced by high temperature. A low seed set was recorded in some popular Vietnamese rice cultivars, such as "OM4900" and "OM18" under high-temperature conditions. The pollen viability and germination of the Vietnamese rice cultivar decrease when the highest daytime temperature remains above 36°C. In addition, the chalkiness rate of Vietnamese rice cultivars increased under high temperature. Thus, understanding the potential impacts of high temperature is necessary for scientists and local authorities in designing mitigation and adaptation plans. Our research investigates the effect of heat stress on the flowering stage and management options for Mekong Delta, Vietnam, which include using (i) heat-tolerant cultivars, (ii) early morning flowering trait to avoid the heat in the noon, (iii) rice cropping adjustment, and (iv) crop management.

1. Introduction

Vietnam is one of the world's leading rice producers and exporters, thanks to its extensive network of fertile river deltas, favorable climate conditions, and centuries-old agricultural expertise. The Red River Delta region accounts for 18% of Vietnam's total rice production according to the General Statistics Office of Vietnam (GSO 2020). This area is characterized predominantly by alluvial soil types, which provide excellent growing conditions. The temperature ranges from 22–27°C throughout the year, creating an ideal climate for rice cultivation. Farmers in this northern region maintain two distinct crop seasons: the Spring season from January to May, and the Autumn season, from June to November.

The Mekong Delta is Vietnam's primary rice-producing region, contributing a substantial 52% of the country's total rice production (GSO 2020). This region benefits from highly fertile alluvial soils and maintains slightly warmer temperatures, averaging between 25 and 27°C. The favorable climate allows for a more intensive cultivation schedule, with farmers able to manage either two or three crop seasons annually: the Summer–Autumn season (April–July), the Autumn–Winter season (July–October), and the Winter–Spring season (November–February).

Global air temperatures rose by approximately 0.5°C during the 20th century, as documented by the Intergovernmental Panel on Climate Change (IPCC 2001). This warming trend is expected to accelerate, with temperatures projected to increase between 2.0°C and 4.5°C by the end of the 21st century, according to more recent IPCC assessments (2007). The IPCC's 2007 report projects a steady warming rate of about 0.2°C per decade over the next several decades. This ongoing temperature rise poses significant concerns, as heat stress can severely impact agricultural productivity and reduce the nutritional quality of food crops

— particularly rice — potentially threatening global food security.

Therefore, this study aims to explore the potential impacts of high temperature on rice, which is critically necessary for scientists and local authorities in their efforts to design and implement effective mitigation and adaptation measures in both the short and long term.

2. Temperature and Rice Production

Rice plants thrive in a specific temperature range between 27°C and 32°C, which provides optimal conditions for growth and grain development. When temperatures exceed this ideal range, the plants experience physiological stress that negatively impacts their productivity and grain formation. Even brief periods of exposure to temperatures surpassing 35°C can cause significant damage to the rice plants' cellular structures and metabolic processes, ultimately leading to reduced grain filling and diminished harvest yields. The sensitivity to high temperatures makes rice particularly vulnerable to thermal stress during critical growth stages, especially during flowering and grain development periods. Figure 9.1 shows the impacts of temperature on the growth stage of rice production.

Growth stage	Seedling	Tillering	Booting	Anthesis	Flowering	Grain formation	Grain ripening
Threshold temperature (°C)	35	32		33.7	35	34	29-30
Symptoms	Poor growth of seedling	Reduced tillering and height	Decreased number of pollen grains	Poor anther dehiscence and sterility	Floret sterility	Yield reduction	Reduced grain filling
Source	Yoshida, 1981	Yoshida, 1977	Tinarle et al., 1989	Kobayashi et al., 2011	Jagadish et al., 2007	Morita et al., 2005	Yoshida, 1981

Figure 9.1. Threshold Temperatures at Rice Growth Stages
Source: Author's Review

This study attempts to (1) examine how Vietnamese rice (*Oryza sativa* L.) cultivars respond to high temperatures during grain filling under field conditions and (2) identify heat-tolerant breeding materials to develop new cultivars better suited for Vietnam's future climate.

3. Material and Method

In this study, field experiments were conducted in 2015 and 2016 in the paddy field of Okayama University, Okayama, Japan (Faculty of Agriculture 34°40'N, 133°55'E) (Figure 9.2). The field experiments involve the following steps:

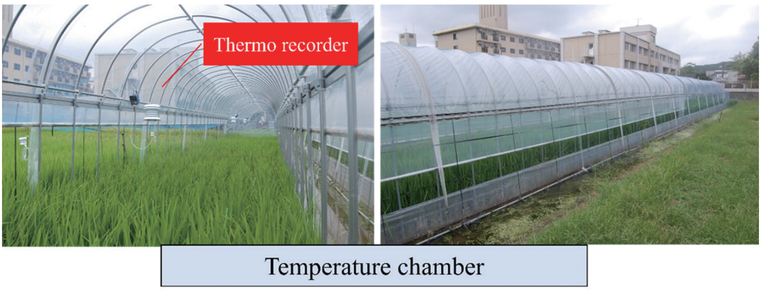


Figure 9.2. Field Experiment
Source: Author's experiment

1. Rice cultivation: Fourteen rice cultivars commonly grown in Vietnam's Mekong Delta were used in this experiment. The Cuu Long Delta Rice Research Institute in Can Tho, Vietnam, provided the cultivars.
2. Temperature treatment: The side-opened plastic chamber was covered with transparent plastic film. A transparent divider split the chamber into two equal sections at the center. One half

served as the control plot (CT), as its air temperature matched the outside temperature.

3. Measurement of air temperature: Air temperature was recorded at 10-minute intervals throughout the growing period.
4. Yield and yield component: For sterility analysis, three replications (20–30 g) of spikelets were collected from 20 hills. To determine the percentage of sterile spikelets, panicles were threshed, and the spikelets were separated by submerging them in a specific gravity solution. Spikelets were classified based on their specific gravity: filled grains (≥1.06 g cm−3), partially filled grains (≥1.0 g cm−3), and sterile spikelets (<1.0 g cm−3).
5. Grain appearance quality: Grains with white parts covering more than 20% of their total surface area — such as a white belly, white center, or white back — were recorded as chalky grains.
6. Fertility and pollen viability

4. Results and Discussion

(1) The Impacts of Temperature on Sterile Grain

The result from Figure 9.3 shows that high temperatures increased spikelet sterility across cultivars. OM6161 and OM4900 showed the highest sensitivity, with sterility increases of 22.3% (2015) and 25.7% (2016), respectively. Several other cultivars showed significant increases, while OM8923 remained most resilient with minimal changes (2.9% in 2015, 1.1% in 2016).

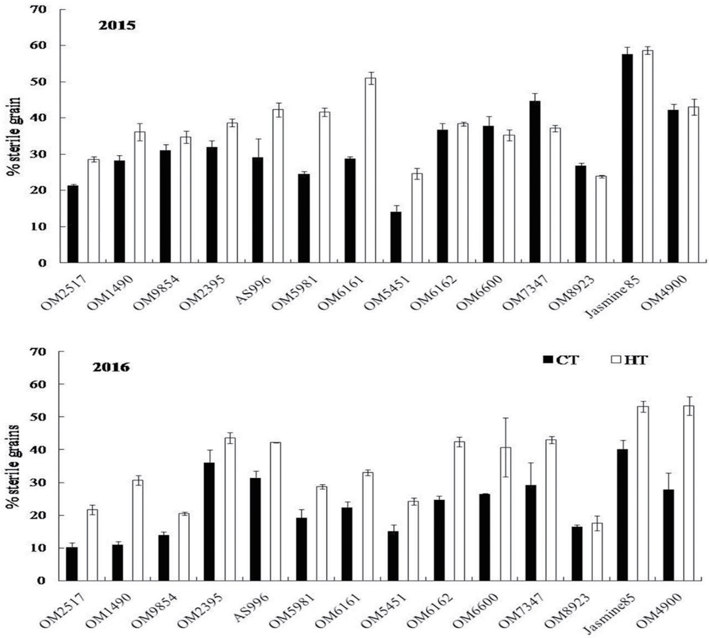


Figure 9.3. The Impacts of Temperature on the Percentage of Sterile Grain in 2015 and 2016
Note: CT — Control Temperature Group and HT — High Temperature Treatment Group. Source: Author's calculation

(2) The Impacts of Temperature on Grain Yield

Grain yields differed significantly between CT and HT treatments in both years (Table 9.1 and 9.2). CT yields averaged 568 and 636 g m^{-2} in 2015 and 2016, while HT yields were lower at 463 and 505 g m^{-2}, representing decreases of 105 and 131 g m^{-2} respectively. High temperatures reduced spikelets per panicle by 4.1–4.5% and increased sterility. Jasmine85 showed the lowest HT yields, while OM6161, OM6162, Jasmine85, and OM4900 all experienced yield reductions exceeding 30% under HT conditions.

Table 9.1. Yield and Yield Components of 14 Vietnamese Cultivars in Control and High Temperature Treatment in 2015

Cultivar	Treatment	No. of panicle/m^2	No. of spikelets/ panicle	% ripened grain	1000-grains weight(g)	Grain yield(gm^{-2})
OM2517	CT	288	108	75.9	25.2	596.1
	HT	285	110	68.2	25.3	539.1
OM1490	CT	341	111	69.4	23.2	609.6
	HT	306	127	60.5	22.4	534.0
OM9854	CT	307	113	65.0	23.9	535.1
	HT	271	113	59.1	23.9	434.2
OM2395	CT	300	120	64.0	27.1	628.1
	HT	240	121	56.5	27.4	450.7
AS996	CT	245	129	66.4	26.8	561.9
	HT	278	124	54.0	26.8	499.9
OM5981	CT	327	105	72.7	25.6	637.9
	HT	294	107	56.1	25.2	443.7
OM6161	CT	299	108	70.5	25.2	571.3
	HT	257	103	47.6	25.5	318.9
OM5451	CT	286	101	80.8	24.7	574.3
	HT	271	98	71.3	24.7	465.6
OM6162	CT	209	147	60.2	24.5	452.9
	HT	228	135	59.4	17.4	317.2
OM6600	CT	219	152	58.5	24.5	478.4
	HT	207	144	62.3	25.0	463.0
OM7347	CT	216	138	61.3	25.5	465.0
	HT	233	147	51.5	25.2	442.7
OM8923	CT	318	118	70.3	25.5	670.0
	HT	269	105	72.0	25.1	511.5
Jasmine85	CT	237	128	39.4	25.7	307.0
	HT	192	112	38.2	26.2	215.5
OM4900	CT	250	146	54.3	25.1	497.1
	HT	191	131	53.2	25.3	337.0
	Cultivar	**	**	**	**	**
	Treatment	**	NS	*	NS	**

Source: Author’s calculation

Table 9.2. Yield and Yield Components of 14 Vietnamese Cultivars in Control and High Temperature Treatment in 2016

Cultivar	**Treatment**	**No. of panicle m^{-2}**	**No. of spikelets/ panicle**	**% of ripened grain**	**1000 grains weight (g)**	**Grain yield (g m^{-2})**
OM2517	CT	228	119	87.1	26.6	692
	HT	220	120	75.0	26.2	572
OM1490	CT	211	139	87.3	24.1	677
	HT	236	142	66.1	23.9	583
OM9854	CT	209	129	81.7	24.7	598
	HT	220	137	70.5	23.9	559
OM2395	CT	193	140	59.9	26.6	474
	HT	207	141	52.9	27.3	464
AS996	CT	227	133	65.4	25.7	558
	HT	226	127	54.6	26.9	463
OM5981	CT	219	135	76.2	24.7	611
	HT	237	134	65.0	25.6	579
OM6161	CT	260	141	76.5	25.2	778
	HT	216	136	64.4	25.1	521
OM5451	CT	233	127	81.4	24.7	652
	HT	223	137	71.8	23.8	574
OM6162	CT	174	210	72.4	23.7	691
	HT	162	182	55.4	23.5	422
OM6600	CT	192	202	70.5	23.8	715
	HT	199	188	57.3	22.7	529
OM7347	CT	163	202	68.8	24.7	613
	HT	164	182	54.9	24.4	440
OM8923	CT	251	138	81.6	25.2	783
	HT	259	131	79.2	24.4	723
Jasmine85	CT	151	168	55.8	24.5	380
	HT	140	149	44.6	24.4	249
OM4900	CT	191	185	70.4	24.6	673
	HT	199	168	45.3	24.4	404
	Cultivar	**	**	**	**	**
	Treatment	NS	*	**	NS	**

Source: Author's calculation

(3) The Impacts of Temperature on Grain Chalkiness

High temperatures significantly increased grain chalkiness across cultivars (Figure 9.4). Chalkiness differences between the control (CT) and high-temperature (HT) treatments ranged from 0.72–10.1% in 2015 and 0.1–10.8% in 2016. OM8923 (2015) and OM5981 (2016) showed the highest increases at 10.1% and 10.8% respectively, while OM2517, AS996, and OM6161 also showed notable increases. According to Wang et al. (2007), high temperatures during the ripening stage cause chalky grain by creating an imbalance in carbohydrate metabolism between sink and source. Figure 9.5 depicts the heading stage in the net house (control) and the temperature control chamber (treatment).

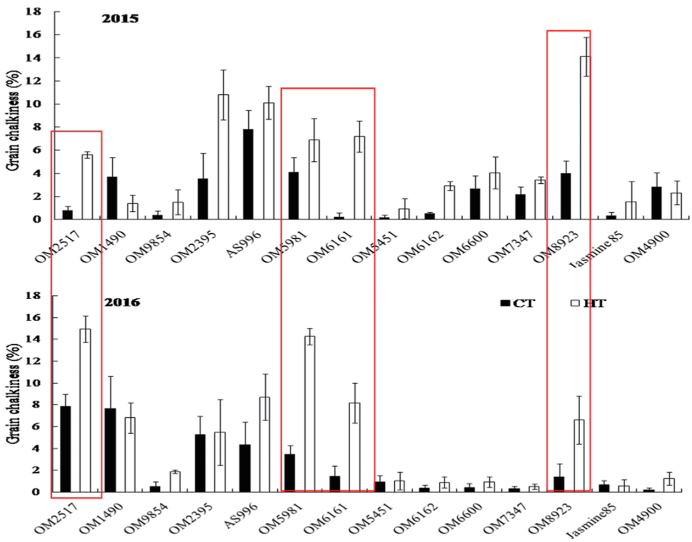
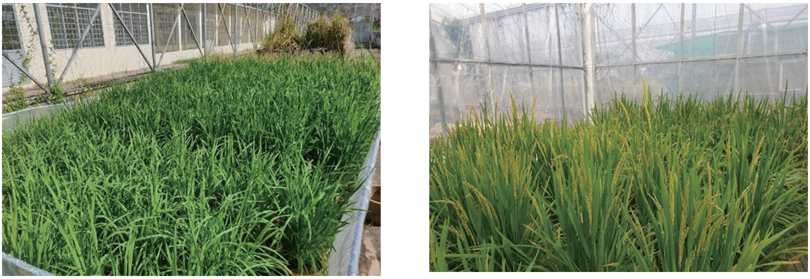


Figure 9.4. Effect of High Temperature on Percentage of Chalky Grains in Vietnamese Cultivars (vertical bar indicate SD of means (n=3))
Source: Author’s calculation



(a) (b)

Figure 9.5. The Heading Stage in (a) Net house (Natural condition) and (b) Temperature chamber (High temperature treatment)
Source: Author's experiment

(4) The Impacts of Temperature on Pollen Viability

Figure 9.6 depicts the relationship between temperature and pollen viability, showing the pollen viability percentage (A) and observed pollen viability by microscope in cultivar "OM5451" (B) according to different regimes at the flowering stage. Different letters indicate significant differences at $p \leq 0.05$.

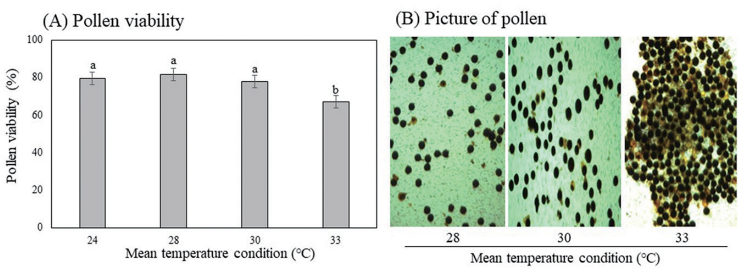


Figure 9.6. Temperature and Pollen Viability in Rice
Source: Author

Figure 9.7 depicts the pollen germination percentage (A) and observed pollen germination by microscope in cultivar "OM5451" (B) according to different regimes at the flowering stage. Different letters indicate significant differences at $p \leq 0.05$.

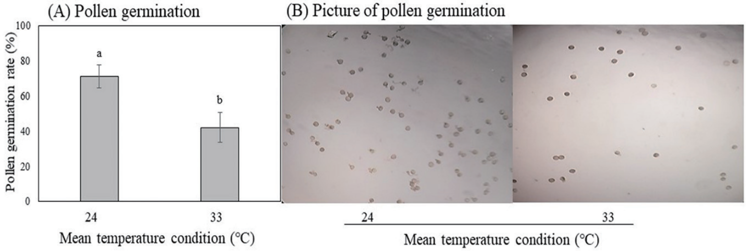


Figure 9.7. Temperature and Pollen Germination in Cultivar OM5451
Source: Author

Figure 9.8 shows the correlation between mean temperature and fertility rate (A), pollen viability (B). The correlation between the percentage of fertility rate and pollen viability (C).

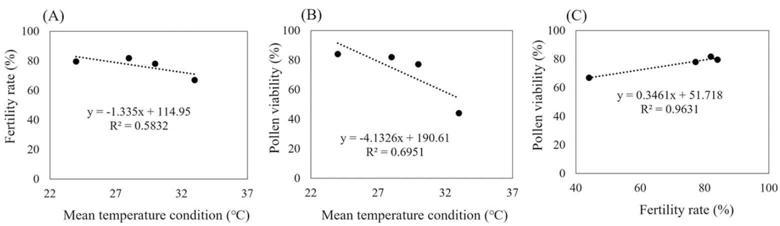


Figure 9.8. Relationship between Temperature and Fertility Rate and Pollen Viability, between Fertility Rate and Pollen Viability
Source: Author

(5) Rice Cultivation Strategy to Cope with High Temperature

1) Heat Tolerance Cultivars (HTC)

In tolerant genotypes, the large amount of pollen on the stigma appeared to compensate for reduced pollen growth under high temperature during the flowering stage (Mackill et al. 1982). Other varieties of high-temperature-tolerant cultivars dehisce more easily than those of susceptible cultivars and contribute to pollination under high-temperature conditions (Satake and Yoshida 1978 and Mackill et al. 1982). The anther locule walls in HTC were thicker and better developed, which promoted pollen grain swelling by retaining water in the locules (Matsui et al. 2001). Some cultivars of the International Rice Research Institute (IRRI) showed adaptive ability to high temperature at the anthesis stage. Cultivar: IR86991-146-2-1-1 was found to be more tolerant to heat stress at the flowering stage with higher yield and pollen viability (80-100%) (Masuduzza et al. 2016).

2) Early Morning Flowering Trait

The timing of flowering during the day is important because spikelet sterility is induced by high temperatures during or 1–3 hours after anthesis in rice (Satake and Yoshida 1978). Some wild-type flowers are as early as 0600h (*Oryza officinalis*) or as late as 1700h (*Oryza australiensis*), with a few flowers during the night (Jagadish et al. 2015). In general, indica rice flowering peaks before 1200h and japonica rice flowering peaks after 1200h (Wang et al. 2019). In the report of Raju et al. (2017), a near-isogenic of early morning flowering line (IR64+ qEMF3) effectively minimized spikelet sterility by 71% during the dry season under field conditions, compared to tropical and subtropical cultivars.

3) Crop Management

To reduce the canopy temperature during the flowering stage, adjusting the rice planting and the microclimate in the field can also alleviate heat damage. Increasing the row spacing between rice plants is beneficial for air circulation in paddy fields, leading to a decrease in the canopy temperature (Wang et al. 2019). Moreover, some previous studies show that applying fertilizer management also mitigates the effects of high temperature during the flowering stage (Wang et al. 2019; Wu et al. 2013). Applied biochar and phosphorus fertilizer before transplantation alleviated the damaging effects of high temperature on pollen germination, another dehiscence, and greater pollen retention and germination (Shah et al. 2015). Micronutrient fertilizers (Silicon, KH_2PO_4, $ZnSO_4$, Na_2SeO_3) and natural abscisic acid can increase the capacity for spikelet fertilization under heat-stress conditions (Wang et al. 2019; Wu et al. 2013).

5. Conclusion

Our study found significant differences in grain yield between control (CT) and high temperature (HT) conditions. Under HT, we observed decreased panicles per m^{-2}, spikelets per panicle, and increased sterility in 2015–2016. Spikelet sterility was the primary factor reducing yield. OM1490, OM4900, OM5981, AS996, OM6162, and OM6161 showed high sterility sensitivity, while OM8923 and OM2517 demonstrated tolerance. HT also increased grain chalkiness in several cultivars, including OM8923, OM5981, OM2517, AS996, and OM6161. With Vietnam projected to see a 2.3°C temperature rise by 2100 and 10–20 more days above 35°C annually, these findings provide crucial insights for breeding heat-tolerant rice cultivars.

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Chapter 10
Using SOFIX Analysis for Soil Fertility Evaluation in Japan

Quoc Thinh TRAN, Tomoya ONISHI, Motoki KUBO

Summary: Modern agriculture faces significant challenges due to agrochemical farming methods. While conventional farming relies on synthetic chemicals to boost yields, these practices harm soil microbes and organic matter, ultimately degrading soil health. Though organic farming improves soil fertility without chemicals, it typically produces lower yields. These tradeoffs have led to new approaches that aim to balance soil health with crop productivity. This study examines how SOFIX analysis is being applied in Japanese agriculture, demonstrating how organic fertilizer use can improve both short-term soil quality and long-term agricultural sustainability. The findings offer practical guidance for farmers shifting toward more environmentally sustainable farming practices.

1. Introduction

Throughout history before the twentieth century, agriculture deeply relied on traditional organic practices. Farmers refined their growing methods through careful observation and practical experience, creating farming systems that worked in harmony with nature's cycles and local environments. The agricultural landscape underwent a revolutionary transformation in the twentieth century, driven by the emergence and widespread adoption of chemical-based farming methods. Farmers started using more chemical fertilizers and pesticides during this time because they promised better harvests and made farming easier to manage. However, agrochemical farming approaches are now confronting numerous significant challenges:

- Pesticide residues and chemical fertilizers contaminate soil and water, endangering human health and biodiversity
- Rising costs of agricultural chemicals create financial strain on farmers who depend on these inputs
- Chemical exposure poses health risks to agricultural workers through long-term contact with harmful substances
- Weakening of crops' natural disease resistance, leading to greater susceptibility to pests and diseases, while also reducing the nutritional value of harvested crops

On the other hand, while organic farming represents an environmentally conscious approach to agriculture, it continues to face several significant operational challenges:

- Complex organic farming methods require extensive expertise, creating barriers to entry for newcomers to the farming sector
- Long waiting periods are needed for soil to naturally regenerate and establish sustainable cycles
- Lower crop yields compared to chemical farming methods, reducing production efficiency
- Limited scaling potential due to labor requirements and natural growth constraints

In examining the broader agricultural landscape, several critical challenges emerge:

- Heavy use of chemicals in farming has made it hard to find safe food products that consumers can trust
- Consumers have lost confidence in farm products because there is not enough transparency and reliable quality

checking in food production
- Farmers are struggling financially because rising production costs are cutting into their profits
- Current farming methods are not sustainable and make it hard for Japanese agriculture to compete in international markets

Like many nations, Japan relies heavily on imported raw materials for chemical fertilizers in its agricultural practices. This dependency has become particularly problematic due to the global surge in fertilizer prices, a direct consequence of the Russia-Ukraine War (Ben Hassen and El Bilali 2022). In response to these challenges, there is growing recognition that transitioning to organic fertilizers could significantly enhance both the environmental sustainability and economic viability of Japan's rice cultivation practices. The Japanese government has shown a long-standing commitment to sustainable agriculture, beginning with the implementation of the "Law for promoting the introduction of sustainable agricultural production practices" in 1999. Building upon this foundation, the more recent MIDORI program was enacted in July 2022 to further accelerate the development and adoption of organic farming practices throughout Japan. However, the transition to organic farming methods presents significant challenges, particularly in terms of organic fertilizer application. Farmers, having extensive experience with chemical fertilizers, often struggle with determining appropriate application rates and selecting the most suitable organic alternatives. This transition is further complicated by the fact that improper implementation of organic management practices can potentially compromise both soil fertility and rice yield outcomes.

Soil fertility is extremely important for plant growth. While conventional farming uses synthetic chemicals to increase yields, this reduces soil health by harming microbes and organic matter. Organic farming offers a chemical-free alternative that improves soil fertility, though with lower yields. This has prompted new farming approaches focused on balancing soil fertility and improving yield.

A research group led by Professor Motoki Kubo at the College of Life Sciences, Ritsumeikan University, developed the Soil Fertility Index (SOFIX) based on the assessment of soil biological characteristics, announcing their breakthrough on December 10, 2012. This pioneering development marked the world's first soil fertility index based on microbial health. SOFIX methods assess soil fertility by measuring biological, chemical, and physical factors (Adhikari et al. 2014; Aoshima et al. 2006). Our research shows SOFIX's effectiveness for soil analysis in Japanese organic farming (Pholkaw et al. 2019; Tran et al. 2021). Our research attempts to introduce the necessity of soil analysis, SOFIX analysis, and SOFIX applications in Japan.

2. SOFIX Analysis and Its Applications

(1) Necessity of Soil Analysis

To effectively assess and quantify the presence, persistence, and environmental impact of pesticides and chemical fertilizers in agricultural soils, we must implement a thorough and methodical microorganism evaluation process. This evaluation requires multiple carefully coordinated analytical steps that examine both direct chemical impacts and broader ecological effects through:

Microorganism Quantification and Community Analysis: through eDNA isolation from soil samples (Figure 10.1)

- Detailed bacterial communities' assessment through genomic sequencing

- Comprehensive measurement of microorganism populations and diversity

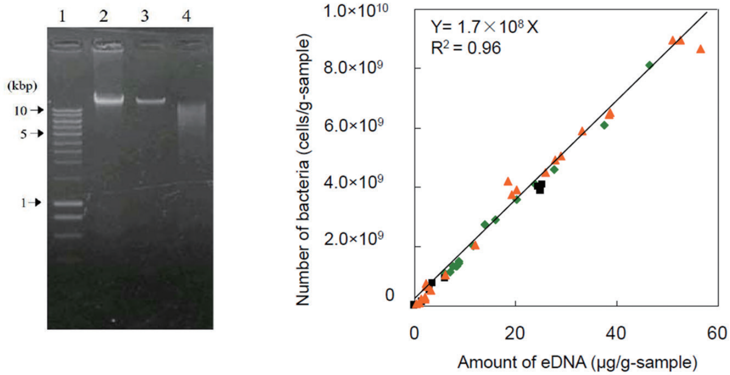

Fig. Agarose gel electrophoresis of eDNA extracted from soil in an agricultural field using various eDNA extraction methods.
Lane 1 Smart Ladder (mass marker)
Lane 2 slow stirring method
Lane 3 heat treatment method
Lane 4 the bead method

Fig. Relationship between the bacterial number obtained using DAPI staining and the amount of eDNA in 57 soils.
■; the amount of eDNA in an agricultural field
◆; oil-polluted field
▲; non-agricultural field.

Figure 10.1. Evaluation of Bacterial Communities in Soil
Source: (Aoshima et al. 2006)

Microbial Activity Assessment

- In-depth analysis of nitrogen metabolism pathways and rates (Figure 10.2-10.4)

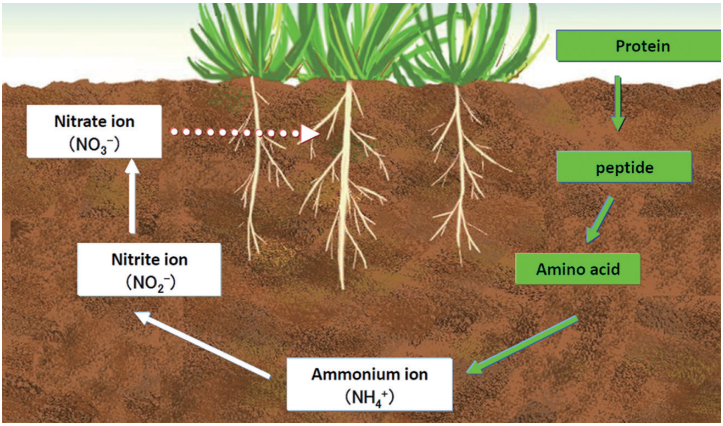

Figure 10.2. Nitrogen Transformation in Soil
Source: Author

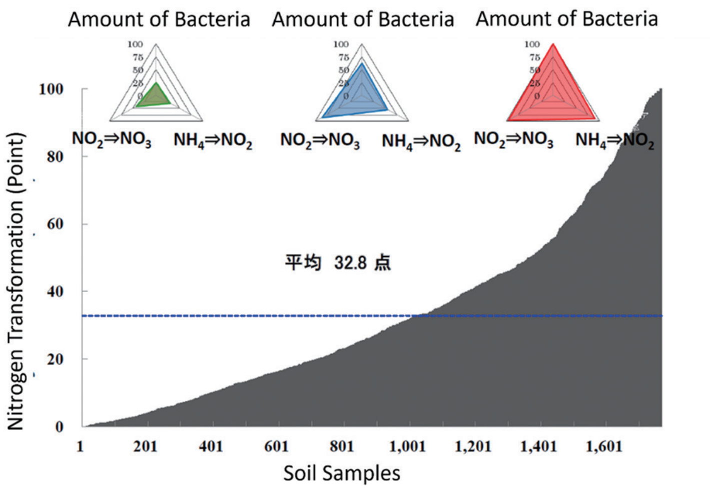

Figure 10.3. Agricultural Soil Nitrogen Transformation Database
Source: Author

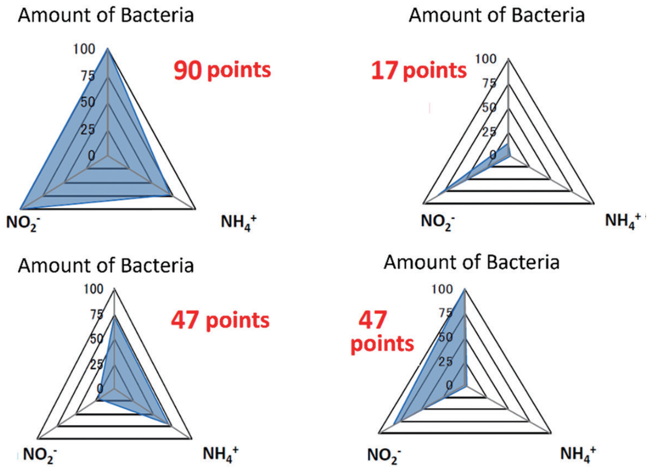

Figure 10.4. Nitrogen and Amount of Bacteria
Source: Author

- Detailed examination of phosphorus metabolism and cycling (Figure 10.5)

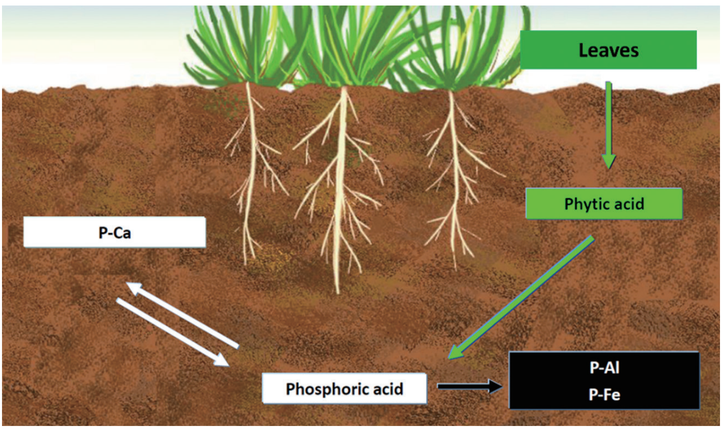

Figure 10.5. Phosphorus Transformation in Soil
Source: Author

- Evaluation of overall soil microbial health and function (Figure 10.6)

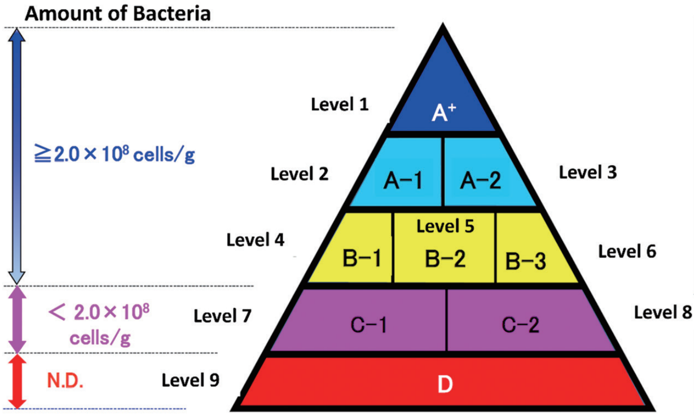

Figure 10.6. Soil Classification
Source: Author.

(2) Soil Diagnosis in SOFIX Analysis

In the SOFIX analysis, several techniques are used to analyze soil biological properties:

- Analysis of bacterial biomass: The bacterial biomass in the soil samples was measured by quantifying the environmental DNA (eDNA)
- Analysis of nitrogen (N) circulation activity: Nitrogen (N) circulation activity was analyzed based on bacterial biomass, ammonium oxidation rate, and nitrite oxidation rate in the soil
- Analysis of phosphorus (P) circulation activity: Phytate (the most dominant form of soil organic P) is used as a substrate in this method

- Analysis of chemical properties: total carbon (TC), total nitrogen (TN), total phosphorus (TP), total potassium (TK), C:N ratio, C:P ratio

Figure 10.7 shows results from soil samples using the SOFIX analysis, which provides detailed insights into soil composition, microbial activity, and nutrient availability through systematic laboratory testing and evaluation.

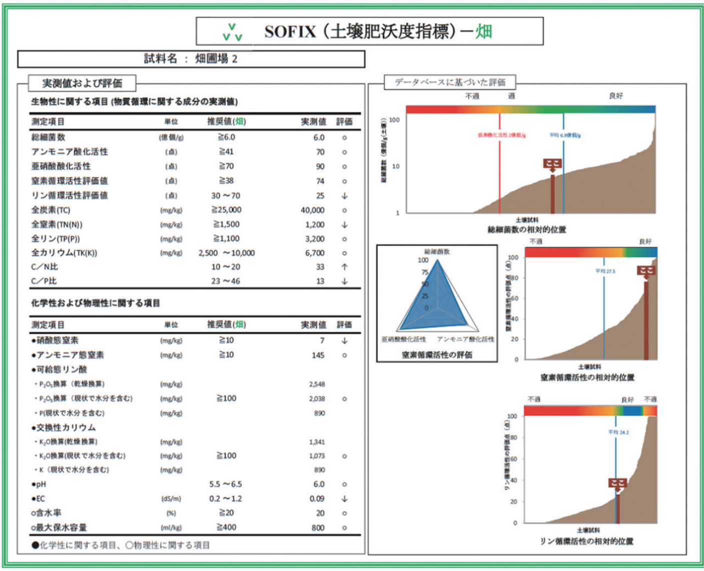

Figure 10.7. A Sample of SOFIX Analysis Result
Source: Author

(3) Impacts of Organic Agriculture on Soil Fertility

According to Tran et al. (2021), the soil type does not determine soil fertility in upland soils. The large variations in bacterial biomass, TC, and TN in all soil types are probably explained by agricultural practices (i.e., chemical or organic farming).

Soils amended with organic fertilizer (SOFIX) and chemical fertilizers showed different tendencies of soil fertility, especially biological properties. Providing organic fertilizers supplies carbon sources for microorganism development in soil. According to Islam et al. (2024), the application of organic fertilizers increased soil bacterial biomass and bacterial community compared to chemical fertilizers (Table 10.1). In addition, SOFIX analysis showed the increase of nitrogen and phosphorus circulation activities in organic fertilizer-amended soils (Pholkaw et al. 2019).

Table 10.1. Difference between Chemical Soil and Organic Soil Regarding TC, TN, and Bacteria

Soil Types	TC (mg/kg)	TN (mg/kg)	Bacteria (x108 cells/g)
Chemical soil	13,600	700	N.D.
Organic soil	41,800	1,300	3.5

Source: (Islam et al. 2024)

Plants cultivated in organic soils demonstrate significantly enhanced growth rates compared to those grown in chemically treated soils (Figure 10.8). The natural composition and biological diversity of organic soil significantly strengthens plants' natural defense mechanisms, resulting in markedly improved resistance to various diseases and environmental stresses (Figure 10.9). Based on comprehensive SOFIX analysis and evaluation metrics, specific soil conditions can be recommended to optimize plant health and productivity while maintaining sustainable agricultural practices.

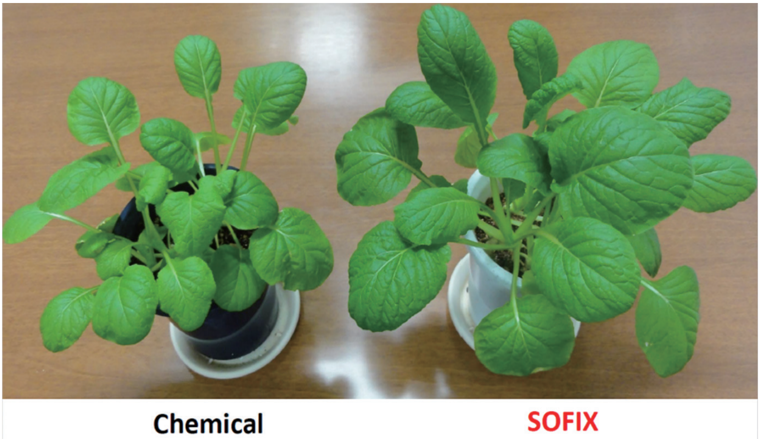

Figure 10.8. Lab Experiments on Komatsuna Plant between Chemical Farming and SOFIX Farming
Source: Author

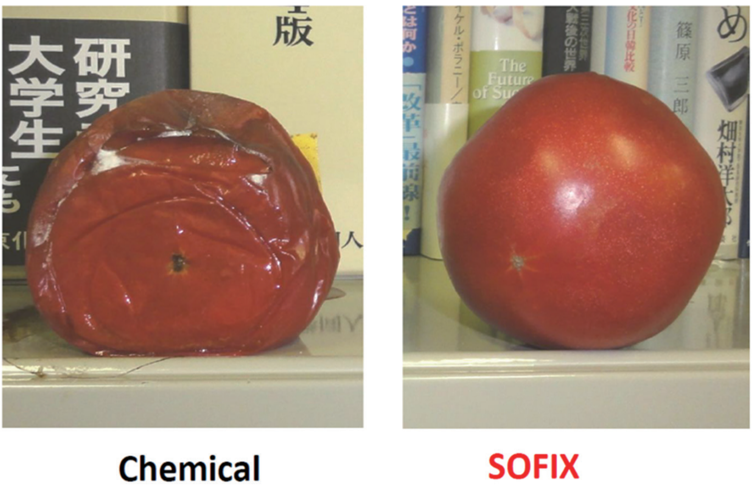

Figure 10.9. Shape Change of Tomatoes at Room Temperature for One Month
Source: Author

(4) SOFIX Applications for Agricultural Development

SOFIX is an innovative soil enhancement system designed to systematically improve soil fertility and boost agricultural productivity. Through a carefully developed process, SOFIX transforms low-quality Type C soil into premium Type A+ soil, implementing specific interventions at each stage of improvement. Figure 10.10 illustrates this transformation pathway, demonstrating how the SOFIX methodically enhances soil quality through multiple stages to achieve optimal fertility levels.

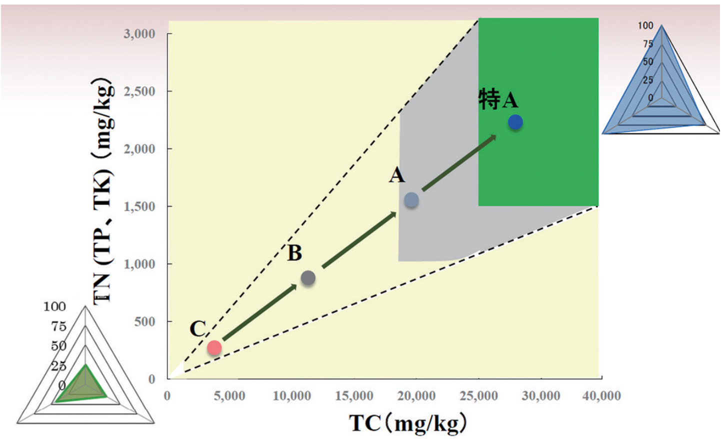

Figure 10.10. Soil Improvement Using SOFIX Techniques
Source: Author

SOFIX is being increasingly adopted throughout Japan's agricultural sector as farmers seek to enhance their organic production capabilities. This innovative approach has gained significant traction among producers who aim to transition from conventional to organic farming methods while maintaining soil health and crop productivity (Figure 10.11).

(1) (2) (3)

Figure 10.11. (1) Organic Rice with SOFIX Application, Shiga Prefecture, (2) Organic Pumkin with SOFIX Application, Nara Prefecture, (3) Juice Product with SOFIX Application

Source: Author

3. Conclusion

This study introduces the efficacy and real-world applications of SOFIX analysis within the context of Japanese agricultural practices. Through detailed examination of soil composition and nutrient profiles, the study demonstrated that the strategic application of organic fertilizers leads to measurable improvements in soil fertility parameters. The findings from case studies suggest that this SOFIX approach represents a particularly promising avenue for developing sustainable agricultural systems that can maintain their productivity over extended periods. The study also highlights how organic fertilizer integration can enhance both immediate soil health metrics and long-term agricultural sustainability, providing valuable insights for farmers transitioning to more environmentally conscious farming methods.

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